

Systems Development and Integration – Scale-Up Portfolio

April 3, 2023

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Introductions – BETO Systems Development and Integration



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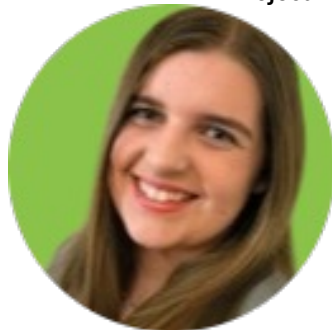
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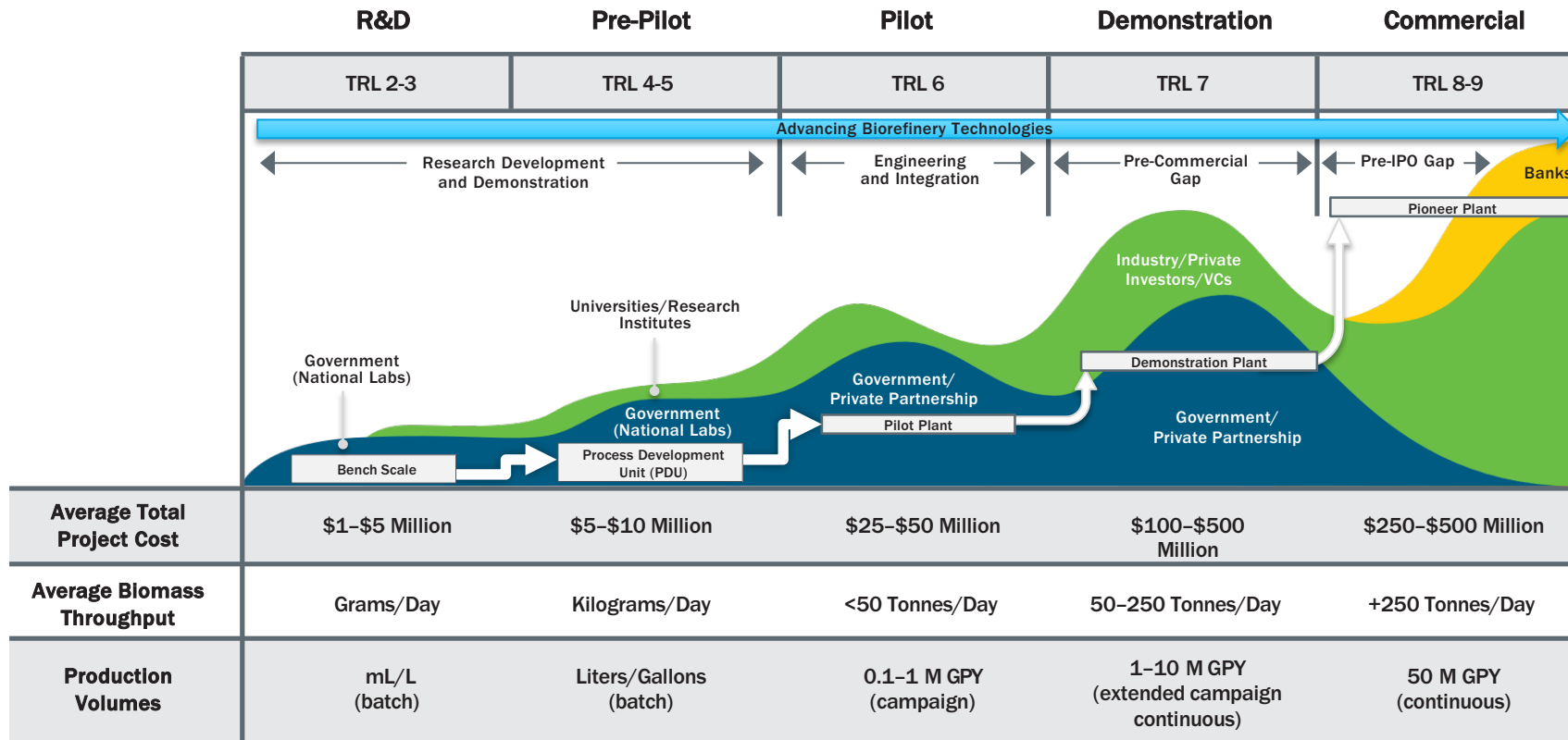


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BETO Strategy from R&D through Pioneer Refinery to Commercialization



● Government ● Project Recipients and Partners ● Banks/Bonds/Institutional Investors

SDI Strategy – Goals and Targets

- SDI directly supports BETO's strategic goal to decarbonize the transportation sector through R,D, &D to produce cost-effective, sustainable aviation and other strategic fuels
 - By 2030, SDI aims to support scale-up of multiple biofuel production pathways with a focus on sustainable aviation fuels capable of >70% GHG reduction by enabling the construction and operation of at least 4 demonstration-scale integrated biorefineries

At least 4 demo-scale IBRs producing SAF and other strategic fuels

SDI Strategy

Strategic Goal: *Enable the construction and operation of at least 4 demonstration-scale integrated biorefineries producing SAF and other hard-to-decarbonize transportation fuels (marine, rail) at >70% GHG reduction*

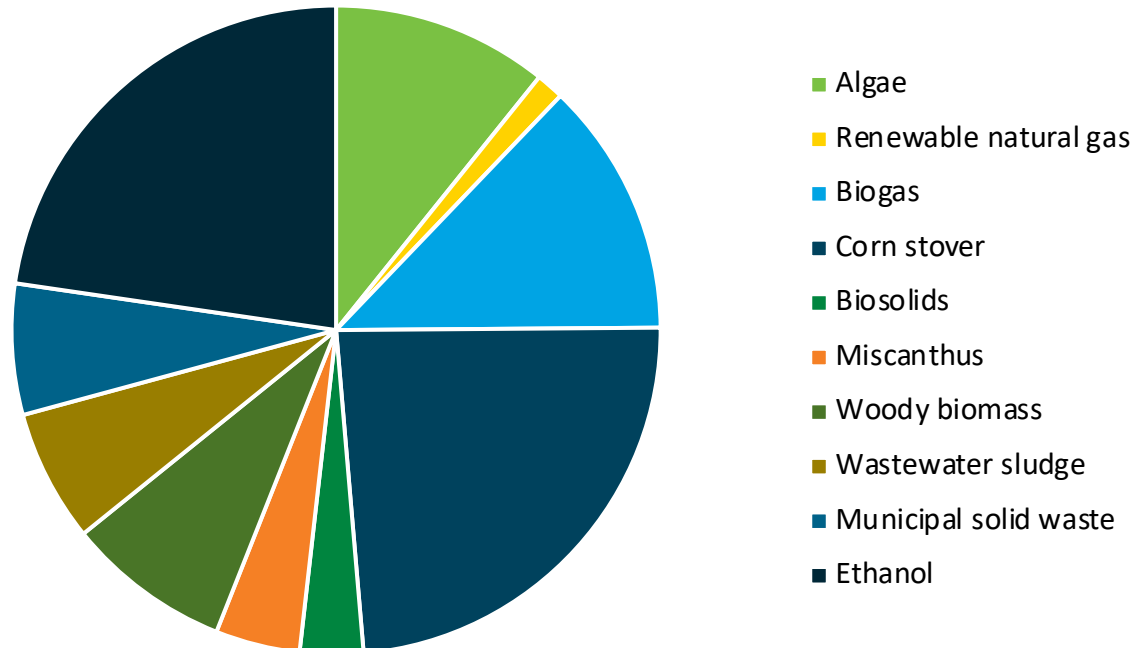
Approaches:

- Selecting **“pre-pilot” scale projects that focus on critical unit operation priorities** brought forth by industry partners, National Labs, or other BETO subprograms
- Encouraging use of **modeling, of unit operations or key integrations**
- Providing **feedback loops to BETO’s other R&D subprograms**
- Conducting feasibility studies and demonstrating technologies to significantly **reduce GHG emissions from first generation ethanol facilities**
- Prioritizing investments to demonstrate production using the 7 ASTM **approved SAF pathways** and **enabling ASTM approval** of new SAF routes in development
- Supporting R&D into **possible fuel improvements for SAF** such as molecules that reduce contrail formation, reduce emissions, or deliver higher energy densities
- Collaborating with interagency and international partners to investigate fuels for **maritime sector**
- Conducting technoeconomic feasibility studies on liquid biofuels for U.S. **freight rail**
- Engaging with **policymakers and industry stakeholders** to facilitate joint planning and investment in biofuel production and supporting infrastructure

SDI Strategy – Approach

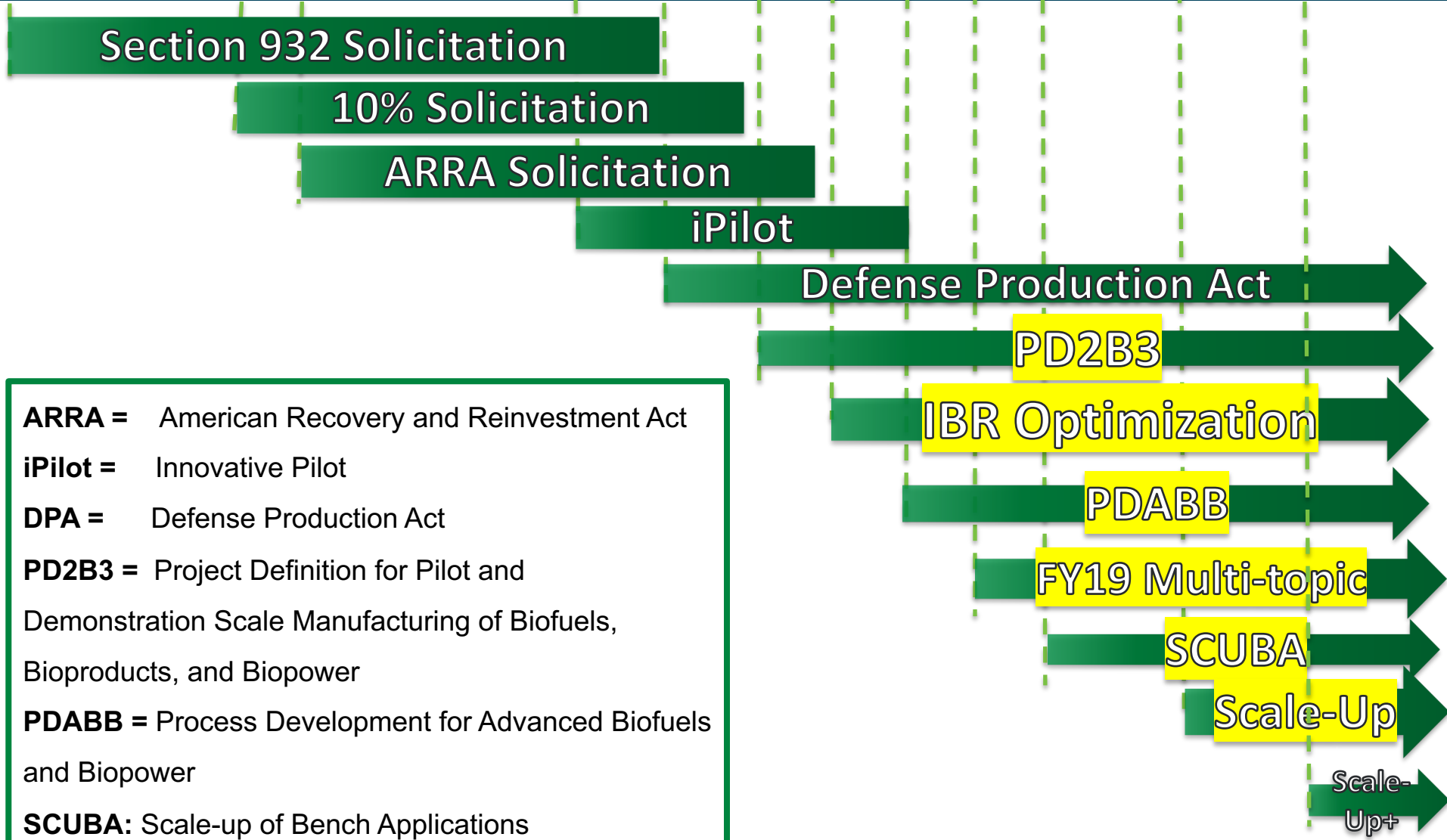
- \$95 million Federal funding will be presented in SDI-SUP
 - Majority of funding is tech using corn stover or ethanol

Federal budget, SDI projects presenting in SDI-SUP



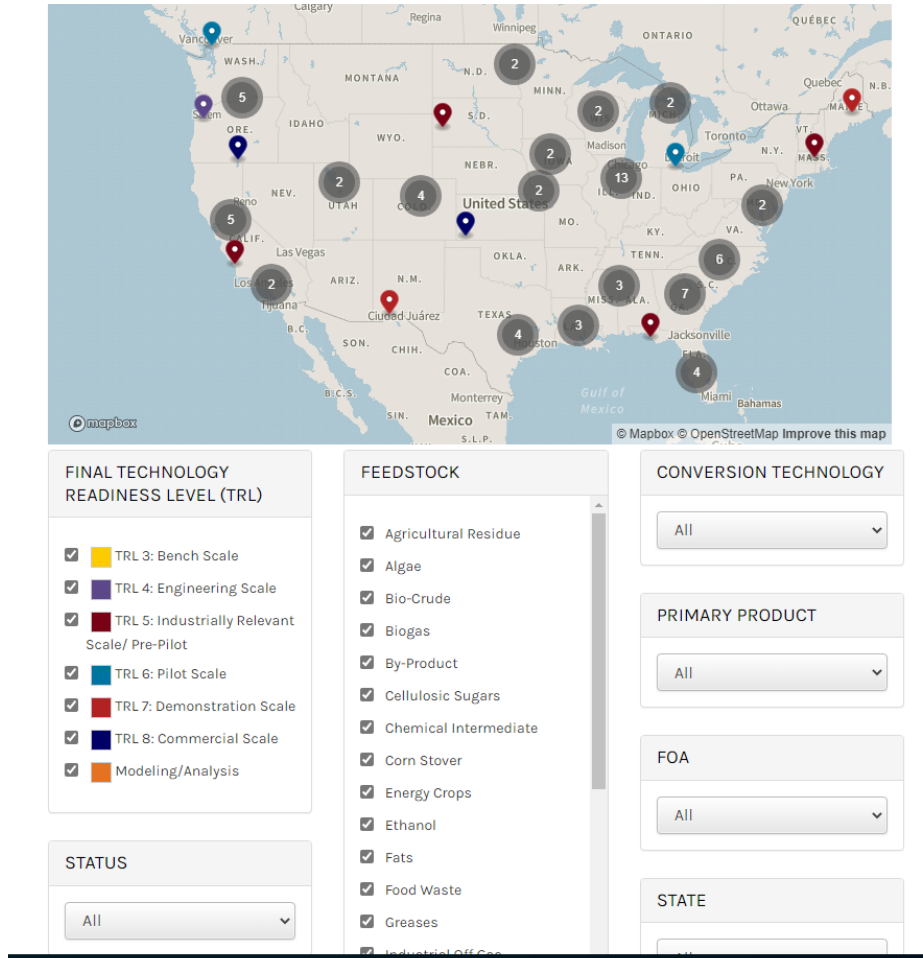
SDI Program FOA History

2006 2008 2010 2012 2014 2016 2018 2020 2021 2022



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
SCUBA: Scale-up of Bench Applications

SDI Program FOA History

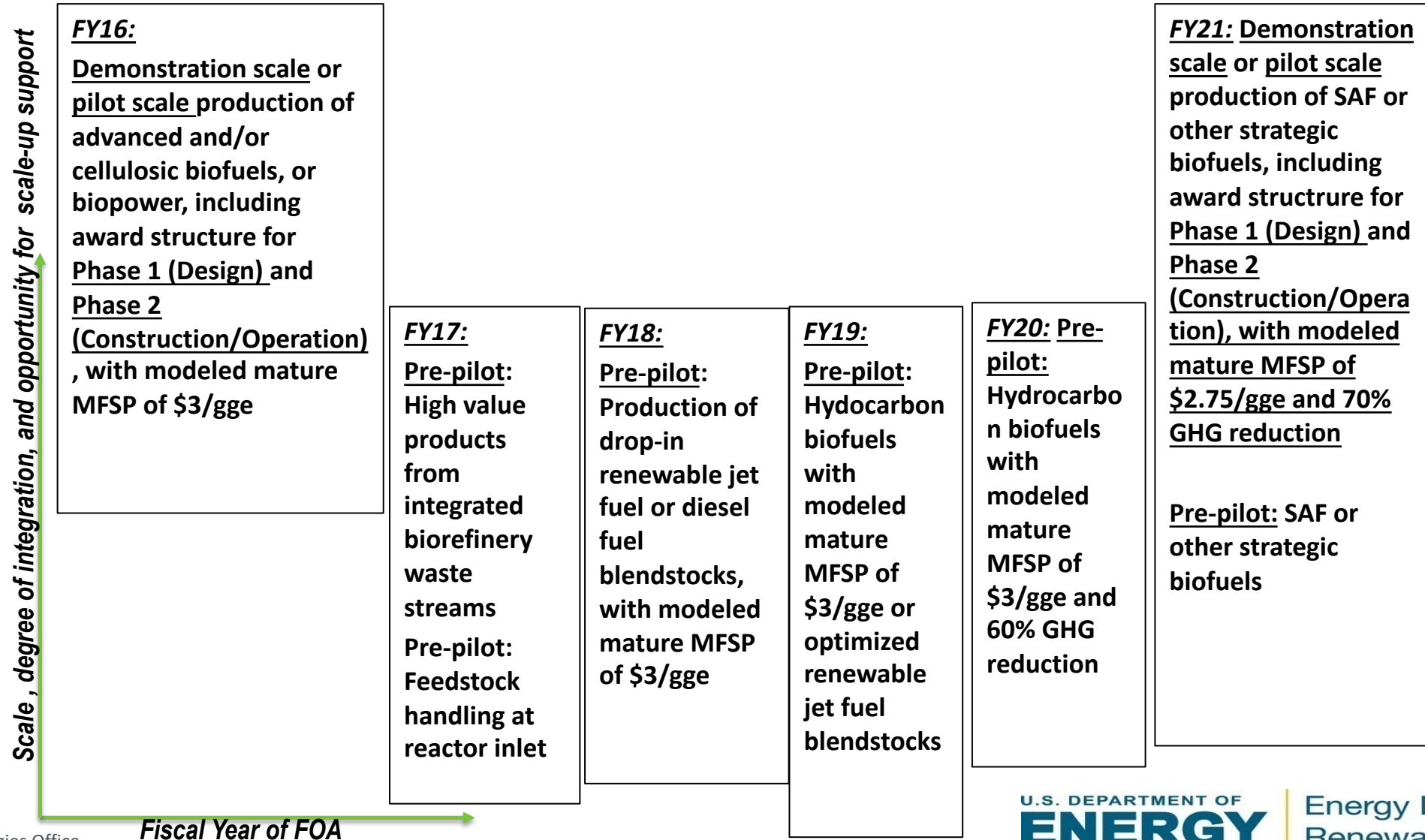


Final
Technical
Reports



<https://www.energy.gov/eere/bioenergy/integrated-biorefineries>

SDI Strategy - FOA approach of projects at Peer Review



- FY16 – Project Development for Pilot and Demonstration Scale Manufacturing of Biofuels, Bioproducts, and Biopower (PD2B3): DE-FOA-0001232
 - Topic Area 1: **Pilot** scale production of biofuels from high impact cellulosic, algal, or biogas feedstocks. Minimum feedstock throughput must be **1 dry metric ton per day** or equivalent.
 - Topic Area 2: **Demonstration** scale production of biofuels from high impact cellulosic, algal, or biogas feedstocks. Minimum feedstock throughput must be **50 dry metric tons per day** or equivalent.
 - Topic Area 3: Production of either biopower or biofuels from biosolids and other allowable wet waste feedstock streams. Minimum feedstock throughput must be 1 dry metric ton per day.

- FY17 – Integrated Biorefinery Optimization: DE-FOA-0001689
 - Topic Area 2: High value products from waste or other undervalued streams in an integrated biorefinery New analytical and characterization methods to analyze waste streams in integrated biorefineries
 - Sensitivity analyses to address the variability of the waste streams
 - Monetization of components contained in the waste by creating high value co-products to improve the overall profitability of IBRs
 - More efficient methods for utilizing residual carbon in IBRs

- FY18 – Process Development for Advanced Biofuels and Biopower (PDABB): DE-FOA-0001926
 - Topic Area 1: Drop-In Renewable Jet Fuel Blendstocks Minimum of **1 dry metric ton per day (pilot-scale)**
 - Development of drop-in renewable jet blendstocks with high specific energy, price competitiveness, and acceptability by certification organizations such as ASTM
 - Must produce and test at least 100 gallons of renewable jet fuel
 - Topic Area 2: Drop-In Renewable Diesel Fuel Blendstocks Minimum of **1 dry metric ton per day (pilot-scale)**
 - Must produce at least 100 gallons of fuel for testing

- FY19 – BETO Multi-Topic FOA: DE-FOA-0002029
 - AOI 4: Systems Research of Hydrocarbon Biofuel Technologies Verify innovative technologies at engineering-scale to enable cost-competitive integrated biofuels technology pathways
 - Likely to achieve \$2.50/GGE with a maximum reduction in emissions relative to petroleum-derived fuels by 2030
 - 500 hours cumulative time on stream, 100 hours continuous, 100 gallons biofuel product accumulated

- FY20 BETO Multi-Topic FOA: DE-FOA-0002203
 - Topic Area 1: Scale-Up of Bench Applications (SCUBA)
 - Engineering solutions for key high-risk process step(s), to reduce risk of eventual fully integrated engineering- or pilot-scale facility
 - Minimum 0.5 dry tonnes per day biomass
 - 500 hours cumulative time on stream, 100 hours continuous
 - Minimum \$3/gge fuel selling price; \$2.50/gge stretch target
 - 60% reduction in emissions relative to petroleum fuels

- FY21 Scale-up and Conversion FOA
 - Topic Area 1: Scale-Up of Biotechnologies
 - Subtopic Area 1a: Pre-Pilot for Biofuels and Bioproducts
 - 0.5 dry tons per day; not fully integrated; single phase
 - Minimum 70% GHG reduction; \$2.75/GGE fuel selling price
 - 500 hours cumulative time on stream; 100 hours continuous
 - Subtopic Area 1b: Pilot Scale for Biofuels and Bioproducts 20,000 gallons per year (~1 ton per day); fully integrated; two phases for Verification & Design (12 months) and Design, Construction, and Operation (~4 years)
 - Minimum 70% GHG reduction; \$2.75/GGE fuel selling price
 - 1,000 hours cumulative time on stream, 500 hours continuous
 - Subtopic Area 1c: Demonstration Scale for Biofuels and Bioproducts 1 MGY (~50 tons per day); fully integrated; two phases for Verification & Design (12 months) and Design, Construction, and Operation (~4 years)
 - Minimum 70% GHG reduction; \$2.75/GGE fuel selling price
 - 1,000 hours cumulative time on stream, 500 hours continuous

Agenda Overview – SUP Monday afternoon

- *Pilot- and demo-scale Phase 1's: some new, some sunseting. Mostly Gas-To-Liquids*

Start Time	End Time	WBS #	Title	Organization	Speaker	FOA
1:30 PM	2:00 PM	3.2.4.001	Risk Management Program for BETO Scale-Up Projects	PNNL	Hannah Rabinowitz	AOP
2:00 PM	2:30 PM	3.5.3.107	Landfill Off-gas To Ultra-low carbon intensity SAF	SkyNRG Americas	Brian James	FY21 Demo, Phase 1
2:30 PM	3:00 PM	3.5.3.103	Production of Sustainable Aviation Fuels from Corn Stover via NREL's Deacetylation and Mechanical Refining Technology (SAFFiRE)	D3MAX	Mark Yancey	FY21 Pilot, Phase 1
3:00 PM	3:20 PM		<i>Break</i>	<i>All</i>		
3:20 PM	3:50 PM	3.5.1.201	TRIFTS Catalytic Conversion of Biogas to Drop-in Renewable Diesel Fuel	T2C Energy	Devin Walker	FY21 Demo, Phase 1
3:50 PM	4:20 PM	3.5.3.105	Demonstration Scale-up: TRIFTS Biogas to Renewable Fuel	T2C Energy	Devin Walker	FY19 Pre-pilot – Systems Research for Hydrocarbon Biofuels
4:20 PM	4:50 PM	3.5.2.405	Advance Biofuels and Bioproducts with AVAP	AVAPCO	Ryan Zebroski	FY16 Demo, Phase 1
4:50 PM	5:30 PM		<i>Closed Door Comment Review Session</i>	<i>Reviewers</i>		

Agenda Overview – SUP Tuesday morning

- *Pre-pilots, and some sunseting pilot and demo projects. Mostly Gas-To-Liquids*

Start Time	End Time	WBS #	Title	Organization	Speaker	FOA
8:00 AM	8:30 AM		<i>Registration, Breakfast</i>	<i>All</i>		
8:30 AM	8:45 AM		Technology Area Daily Intro	BETO		
8:45 AM	9:15 AM	3.5.1.203	Production of Liquid Hydrocarbons from Anaerobic Digester Gas	OxEon Energy	Jessica Elwell	FY19 Pre-pilot: Systems Research for Hydrocarbon Biofuels
9:15 AM	9:45 AM	3.4.3.603	Field-to-Fuel Production of Carbon-Negative Sustainable Aviation Fuel from Regenerative Agriculture Biomass	Alder Energy	Derek Vardon	FY21 Pre-pilot
9:45 AM	10:15 AM	3.5.2.403	Low Carbon Hydrocarbon Fuels From Industrial Off Gas	LanzaTech	Laurel Harmon	FY16 Demo, Phases 1-2
10:15 AM	10:30 AM		<i>Break</i>	<i>All</i>		
10:30 AM	11:00 AM	3.5.1.406	Ultra-low Sulfur Winterized Diesel	LanzaTech	Rick Rosin	FY18 Pre-pilot – drop-in diesel fuel
11:00 AM	11:30 AM		<i>Break</i>	<i>SDI-SUP only</i>		
11:30 AM	12:00 PM	3.5.2.601	Rialto Advanced Pyrolysis Integrated Biorefinery	Rialto	Andrew Dale	FY16 Pilot, Topic 3: Biosolids

Agenda Overview – SUP Tuesday afternoon

- *Pre-pilots. Mostly Gas-To-Liquids*

12:00 PM	1:00 PM		Lunch	All		
1:00 PM	1:30 PM	3.5.2.701	Novel Electric Reformer for Drop in Fuels from Biogas or Waste CO2	Gas Technology Institute	Terry Marker	FY21 Pre-pilot
1:30 PM	2:00 PM	3.5.3.101	R-GAS™ Advanced Gasification Pre-Pilot Demonstration for Biofuels (BioR-GAS)	Gas Technology Institute	Zach El Zahab	FY21 Pre-pilot
2:00 PM	2:30 PM		Break	SDI-SUP only		
2:30 PM	3:00 PM	3.5.1.405	Cool GTL® for the Production of Jet Fuel from Biogas	Gas Technology Institute	Terry Marker	FY18 Pre-pilot – drop-in jet fuel
3:00 PM	3:20 PM		Break	All		
3:20 PM	3:50 PM	3.4.2.101	Scale-up of Novel Algae Drying and Extraction Unit Operations	Global Algae Innovations	Dave Hazlebeck	FY20 Pre-pilot - ScUBA
3:50 PM	4:20 PM	3.5.1.101	Integration of IH2 with the Cool Reformer for the Conversion of Cellulosic Biomass to Drop-In Fuels	Gas Technology Institute	Terry Marker	FY19 Pre-pilot – Systems Research for Hydrocarbon Biofuels
4:20 PM	5:00 PM		Closed Door Comment Review Session	Reviewers		

Agenda Overview – SUP Wednesday morning

- *National Lab Process Development Units, and algae*

Start Time	End Time	WBS #	Title	Organization	Speaker	FOA
8:00 AM	8:30 AM		<i>Registration, Breakfast</i>	<i>All</i>		
8:30 AM	8:45 AM		Technology Area Daily Intro	BETO		
8:45 AM	9:15 AM	3.4.1.202	Biomass - Feedstock User Facility	INL	Neal Yancey	AOP - PDU
9:15 AM	9:45 AM	3.4.2.301	PNNL Hydrothermal PDUs	PNNL	Dan Anderson	AOP - PDU
9:45 AM	10:15 AM	3.4.2.302	TCPDU - Catalytic Carbon Conversion Center of Piloting and Excellence (C4PE)	NREL	David Robichaud	AOP - PDU
10:15 AM	10:30 AM		<i>Break</i>	<i>All</i>		
10:30 AM	11:00 AM	3.4.2.201	Biochemical Pilot Scale Support and Process Integrations	NREL	Dan Schell	AOP - PDU
11:00 AM	11:30 AM	3.5.2.702	Direct Air Capture Algae Cultivation	Global Algae Innovations	Dave Hazlebeck	FY21 Pre-pilot
11:30 AM	12:00 PM	3.5.2.201	Pilot-Scale Algal Oil Production	Global Algae Innovations	Dave Hazlebeck	FY16 Pilot: Phase 1
12:00 PM	1:00 PM		<i>Lunch</i>	<i>All</i>		

Agenda Overview – SUP Wednesday afternoon

- *Deacetylation and Mechanical Refining of corn stover to cellulosic sugars and lignin*

1:00 PM	1:30 PM	3.5.1.502	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	Rajesh Shende	FY17 Pre-pilot – IBR co-products
1:30 PM	2:00 PM	3.1.1.012	Modeling Flow Behavior in a Disc-Refiner for DMR process	NREL	Xiaowen Chen	AOP - DMR pretreatment
2:00 PM	2:30 PM	3.3.4.601	Solid Lignin Recovery	NREL	Dan Schell	AOP - DMR pretreatment
2:30 PM	3:00 PM	3.4.3.501	Scale-up of the Primary Conversion Reactor to Generate a Lignin-Derived Cyclohexane Jet Fuel	University of North Dakota	Wayne Seames	FY20 Pre-pilot - DMR pretreatment
3:00 PM	3:20 PM		<i>Break</i>	<i>All</i>		
3:20 PM	3:50 PM	3.4.2.203	Innovation and optimization of the Szego Mill for reliable, efficient, and successful up-scaling of the deacetylation and mechanical refining process for biofuel production	University of Alabama	Luke Brewer	FY20 Pre-pilot - DMR pretreatment
3:50 PM	4:20 PM	3.4.2.501	Conversion of 2,3-Butanediol to Biojet Fuel: Scale-up and Techno-economic Analysis of Energy-Efficient Separations and Fermentative Diol Production	Georgia Institute of Technology	Sankar Nair	FY20 Pre-pilot - DMR pretreatment
4:20 PM	5:00 PM		<i>Closed Door Comment Review Session</i>	<i>Reviewers</i>		

SDI Strategy – Active Management of Pilots and Demos

Phases	Budget Periods	Scope
Phase 1: Verification & Design Basis Definition (12-18 months) Up to \$2 million Federal, plus matching cost share	BP1	Verification of baseline data presented in application <i>with Independent Engineer</i>
	Go/No-Go Review of Verification outcome	
	BP2	Design Basis Definition
Down-select (CD-2): Approve project scope and begin design (Subject to future appropriations)		
Phase 2: Final Design, Construction, Operation (42-48 months) Up to \$100 million Federal, plus matching cost share	BP3	Project Definition – preliminary planning and design
	Go/No-Go (CD-3): Review to approve start of construction	
	BP4	Project Execution: complete final design and construction
	Go/No-Go (CD-4): Performance test to verify readiness to begin operations	
	BP5	Operations

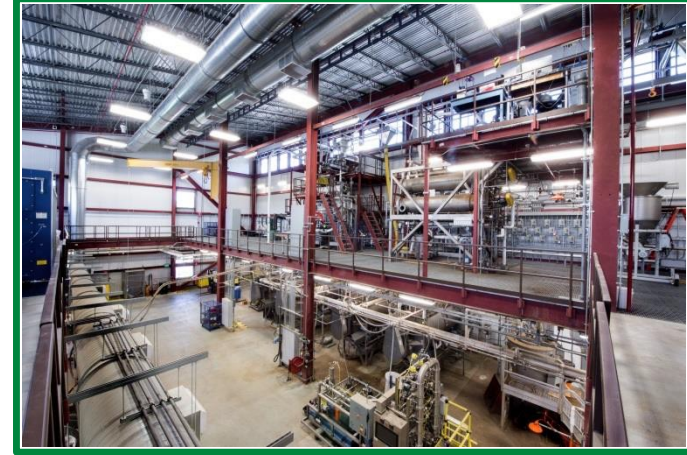
National Laboratories Process Development Units



Advanced Biofuels and
Bioproducts PDU LBNL



Biomass Feedstock PDU
INL



Integrated Biorefinery PDU
NREL

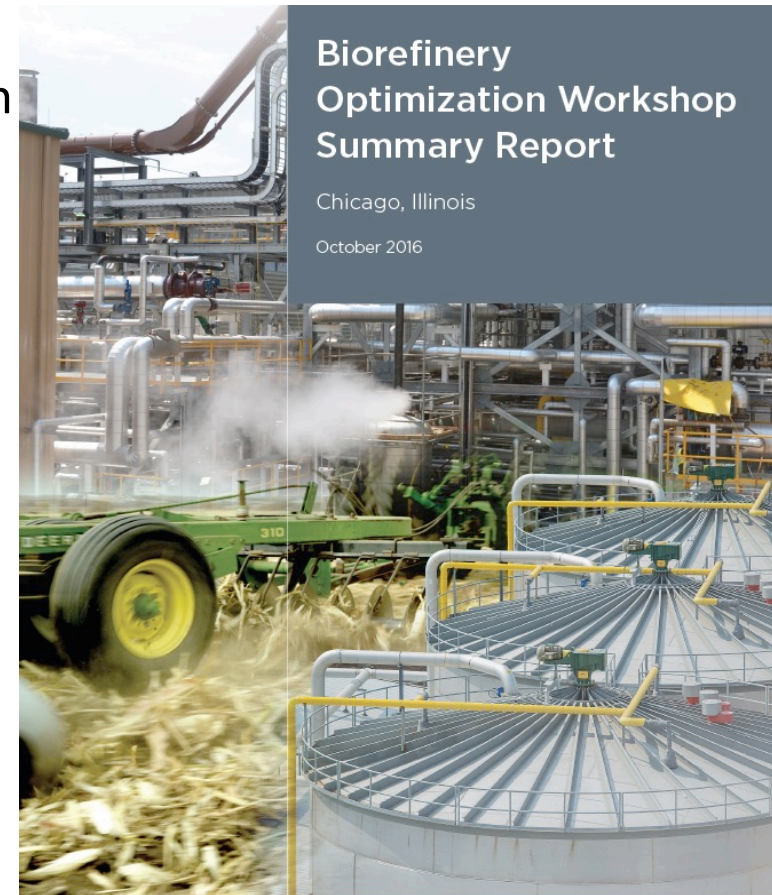
Thermal and
Catalytic PDU
NREL



Hydrothermal
&
Hydrotreating
PDU
PNNL

SDI Strategy – Engagement through Workshops

- SDI-SUP will hear from 1 project (South Dakota School of Mines and Technology) from the FY17 FOA, which was designed with input from a 2016 workshop
 - Feedstock and solid materials handling
 - Co-product and waste stream monetization



SDI Strategy – Engagement through RFIs





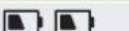



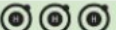




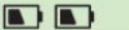




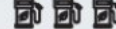




- SDI-SUP will hear several projects from an organization (Gas Technology Institute) that responded to the FY16 RFI on Biofuels and Bioproducts Process Pilot Verification Capabilities



<https://www.energy.gov/eere/bioenergy/articles/biofuels-and-bioproducts-process-pilot-verification-capabilities-rfi>

SDI Progress in addressing Transportation Decarbonization

- The multi-agency U.S. National Blueprint for Transportation Decarbonization clearly scoped the best long-term opportunities for biofuels

	 BATTERY/ELECTRIC	 HYDROGEN	 SUSTAINABLE LIQUID FUELS
Light Duty Vehicles (49%)*		—	TBD
Medium, Short-Haul Heavy Trucks & Buses (~14%)			
Long-Haul Heavy Trucks (~7%)			
Off-road (10%)			
Rail (2%)			
Maritime (3%)		 *	
Aviation (11%)			
Pipelines (4%)		TBD	TBD
Additional Opportunities	<ul style="list-style-type: none"> Stationary battery use Grid support (managed EV charging) 	<ul style="list-style-type: none"> Heavy industries Grid support Feedstock for chemicals and fuels 	<ul style="list-style-type: none"> Decarbonize plastics/chemicals Bio-products
RD&D Priorities	<ul style="list-style-type: none"> National battery strategy Charging infrastructure Grid integration Battery recycling 	<ul style="list-style-type: none"> Electrolyzer costs Fuel cell durability and cost Clean hydrogen infrastructure 	<ul style="list-style-type: none"> Multiple cost-effective drop-in sustainable fuels Reduce ethanol carbon intensity Bioenergy scale-up

* All emissions shares are for 2019

* Includes hydrogen for ammonia and methanol

Figure B. Summary of vehicle improvement strategies and technology solutions for different travel modes that are needed to reach a net-zero economy in 2050 (more details provided in Section 5).

<https://www.energy.gov/eere/us-national-blueprint-transportation-decarbonization-joint-strategy-transform-transportation>

SDI Strategy – SAF

- Sustainable Aviation Fuel (SAF) Grand Challenge
 - Government-wide effort for enabling SAF

2030: 3 billion gallons per year SAF
2050: ~35 billion gallons per year SAF



<https://www.energy.gov/eere/bioenergy/articles/sustainable-aviation-fuel-grand-challenge-roadmap-flight-plan-sustainable>

SDI Progress - Maritime Fuels

- Maritime transport is 1% of U.S. GHG emissions and rising globally
- Hard to electrify **>8 billion GGE fuels used in the U.S. maritime sector**
- Tuesday afternoon in the SDI-EAST session - AOP “Advancing the Development of Biofuels for the Maritime Sector – ORNL, NREL, PNNL, ANL”



- BETO participating in Mission Innovation: Zero-Emissions Shipping
 - Goal: at least 5% of the global deep-sea fleet capable of running on zero-emission fuels by 2030
- FY22 Scale-Up+ FOA selections included maritime biofuels project

SDI Progress – Freight Rail

- Renewable diesel and biodiesel considered near-term solutions for decarbonizing freight rail
- SDI started funding a new AOP “Rail Feasibility Study – ANL, ORNL, PNNL”
 - The outcome of the project will be a report assessing different biofuels types as near-term bioenergy solutions for freight rail
- SDI discussions with rail agency
- SDI interfacing with VTO’s new Decarbonization of Off-road, Rail, Marine, and Aviation program
- 4 billion GGE diesel fuel used in rail transportation in the U.S.
 - <https://afdc.energy.gov/data/10661>

Legacy locomotive diesel in the freight rail fleet will remain for decades

SDI Progress - Descoping Biofuels R&D for Cars and Trucks

- In light of shifts in market, policy, and funding, DOE ended the Co-Optimization of Fuels & Engines (Co-Optima) after 6 years of support from Vehicle Technologies Office and BETO

Major Foundational Discoveries and Impacts of Co-Optima

Established central engine and fuel hypotheses to guide research activity

Developed engine efficiency merit function for turbocharge Spark Ignition combustion

Evaluated thousands of molecules and mixtures through tiered screening to identify 10-15 most promising blendstocks each for diesel and gasoline fuels

Advanced understanding of chemical kinetics, particular their effects on autoignition and soot formation

Uncovered new insights into fuel molecular structure-property relationships to predict fuel properties and identify new blendstock candidates

Assessed interplay of candidate blendstocks with multiple combustion approaches

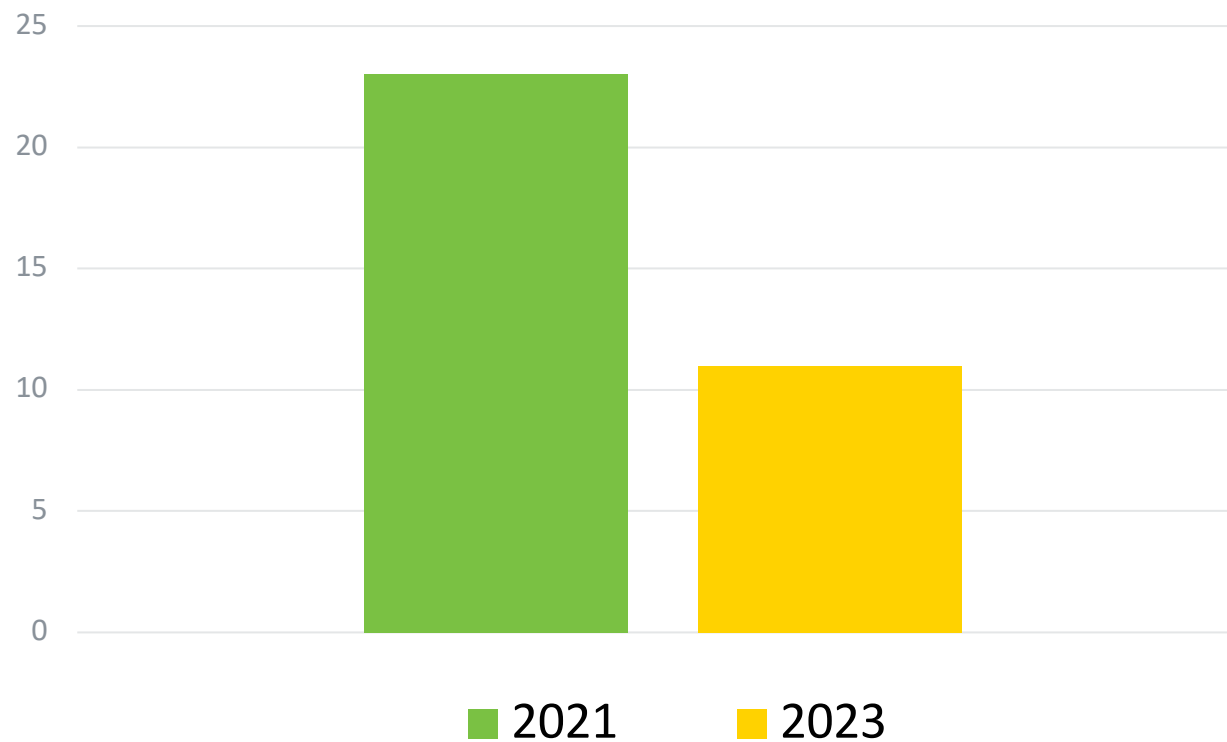
SDI Progress – Scaling up and Integrating New Pretreatment Methods for Corn Stover

- Corn stover IBRs in the 2010's mostly used dilute acid pretreatment, some relatively expensive alkaline pretreatment, or steam explosion
 - Unexpectedly higher reactor severity was required to sufficiently break down biomass to get flowing xylose liquor;
 - Higher severity led to inhibitors that reduced ethanol yields
 - Separators and screens plugged and required difficult repairs
 - Plastic in feed stream plugged systems
- BETO's Conversion program supported alternative technologies utilizing alkaline and mechanical pretreatment methods
 - Wednesday afternoon 1:30-4:20 in the SDI-SUP session, 5 FY20 projects scaling up DMR (deacetylation and mechanical refining) present
 - DMR also is a key component of the Monday afternoon SDI-SUP presentation from D3Max and the Tuesday morning SDI-EAST NREL presentation on "Virtual engineering for low temperature conversion"

SDI Progress - Active Management

- SDI's FOA/AOP funding proportion has shifted more and more to FOAs
- FOAs use language encouraging cooperation with National Labs

Number of National Lab AOPs in SDI portfolio



Former Conversion FOA projects, with their tech now in SDI FOA projects presenting this week

2011

2013

2015

2017

2019

2021

FY11 Conversion FOA “Catalytic Upgrading of Thermochemical Intermediates”
-Virent
-Research Triangle Institute
-LanzaTech

FY12 Conversion FOA “Innovative Biosynthetic Pathways to Advance Biofuels”
-Novozymes
-Texas A&M University

FY12 Conversion FOA “Bio-oil Stabilization and Commoditization”
-Gas Technology Institute

FY14 Conversion FOA “Biological and Chemical Upgrading for Advanced Biofuels and Products”
-Vertimass
-Texas A&M University
-American Process Inc.

FY18, FY19, FY20 SDI: Research Triangle Institute

FY16, FY18 SDI: LanzaTech

FY19 SDI: University of Colorado (w/ Virent)

FY21 SDI: D3Max (w/ Novozymes)

FY17 SDI: Texas A&M AgriLife Research

FY19 SDI: Gas Technology Institute

FY19 SDI: Vertimass

FY16 SDI: AVAPCO

SDI Progress – Recent Success

- Monday afternoon in the SDI-SUP session, you will hear from the sunseting Phase 1 demo project from AVAPCO, which was an FY16 award of \$4.6 million federal and matching cost share, to
 - Validate integrated pilot scale production of SAF from woodchips
 - Continuous pilot scale production of nanocellulose
 - Complete demo-scale basic engineering package and commercialization business plan
 - Conduct LCA showing up to 93% GHG reduction

4:20 PM	4:50 PM	30	3.5.2.405	Advance Biofuels and Bioproducts with AVAP	AVAPCO	Ryan Zebroski	FY16 Demo
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- And in January 2023, AVAPCO was awarded a Phase 2 for \$80 million federal and matching cost share, to
 - Construct and operate a 1.2 million gallon per year equivalent fully integrated biomass to cellulosic SAF and renewable diesel demo plant

Room Rules

- 20-minute presentations
- 10 minutes Q&A
 - Lead Reviewer first, then open to all of Review panel, then open to general audience
- We must stay on time