DOE Bioenergy Technologies Office (BETO)
2021 Project Peer Review

Ultra-Low Sulfur Winterized Diesel

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Systems Development and Integration

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Project Overview

FOA Objectives

DE-FOA-0001926: Process Development for Advanced Biofuels and Biopower (PDABB)
Topic Area 2: Drop-in Renewable Diesel Fuel Blendstocks

Specific FOA Objectives

- Product drop-in Renewable Diesel Fuel compatible with current infrastructure and vehicles
- Product qualifying as Advanced or Cellulosic Biofuel under Renewable Fuel Standard
- Primary product stream containing at least 50% biogenic carbon
- Modeled mature price of ≤ $3/Gallon of Gasoline Equivalent (GGE) of Advanced Biofuel

Required Outcomes

- 100 to 1,000 gallons of Renewable Diesel for testing and evaluation
- Basic Engineering Package for next-scale implementation at a minimum throughput of 1 DTPD biomass or 16,000 Mbtu/day industrial flue gas

Project Goal

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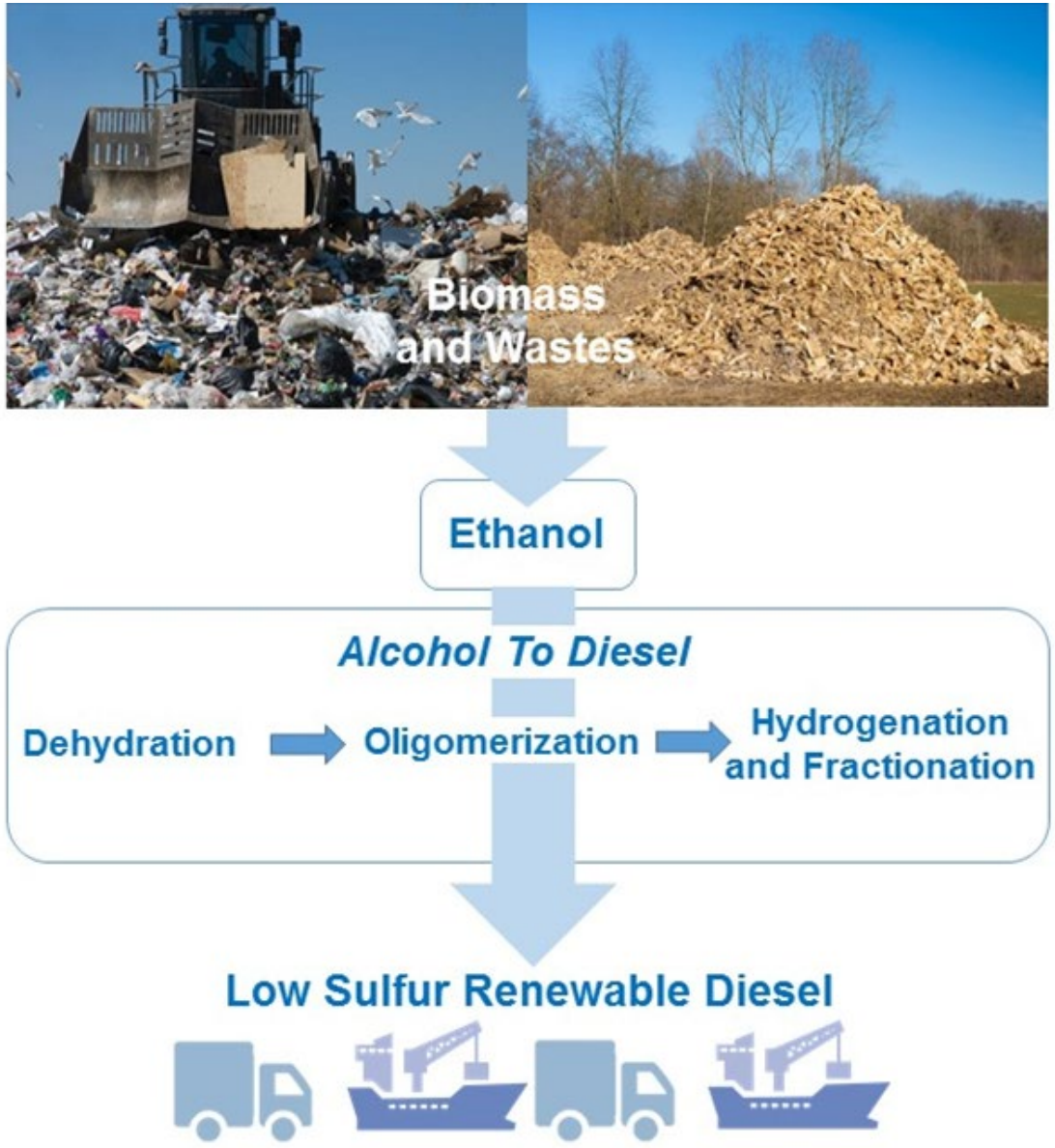
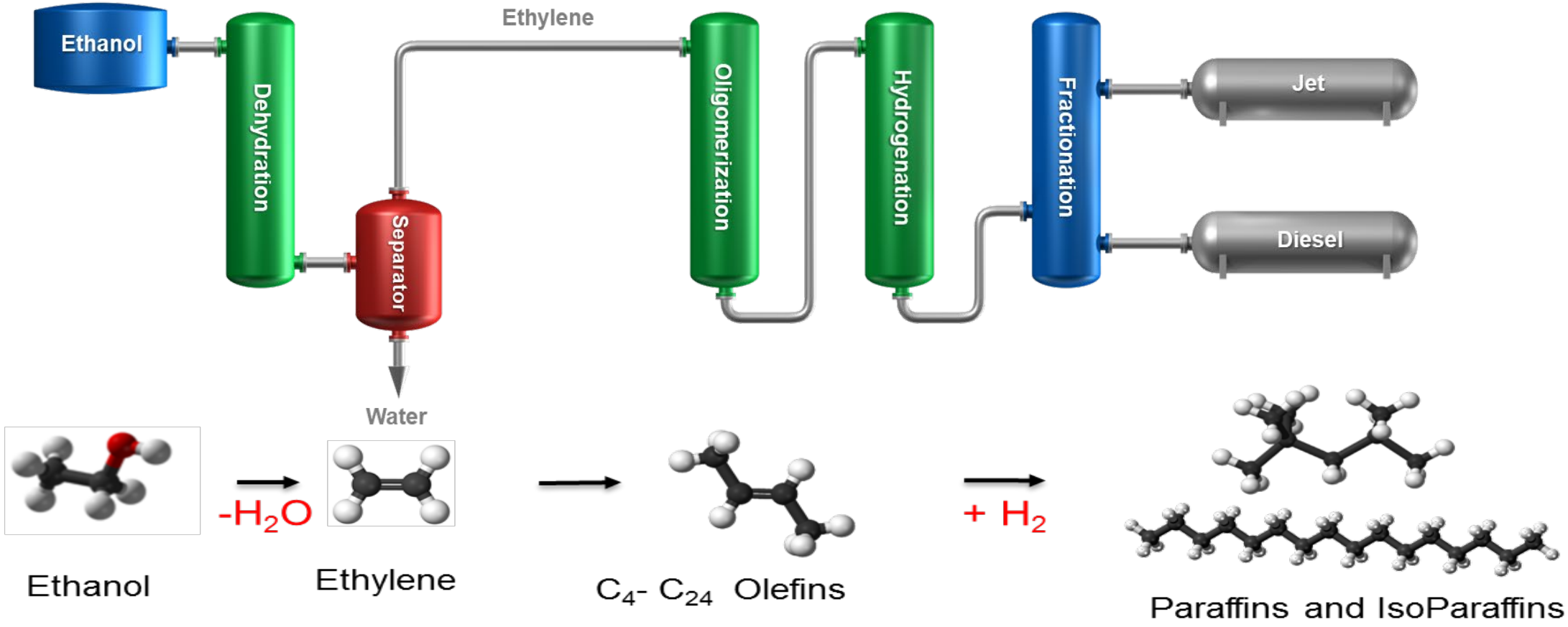
Develop and validate a robust, flexible Alcohol-to-Diesel (ATD) process for producing drop-in, renewable, diesel fuel blend-stocks from biomass-derived ethanol

Project objectives:

- Adaptation of Alcohol-to-Jet process for maximum synthetic paraffinic diesel (SPD) production
- Process protocols for producing synthetic paraffinic diesel suitable for select applications
- Optimized catalysts and commercially-relevant catalyst preparation methods
- Alcohol-to-Diesel Production Unit (ATDPU) to produce 500 gallons of ATD-SPD
- Basic Engineering Package for the next-scale implementation of the ATD process



Alcohol-to-Diesel Process



Jet range hydrocarbons (C_8 to C_{16}) selectively built

LanzaTech Jet and Diesel Production at Freedom Pines Biorefinery

Increased Run Time and Production Rate → Improved Product Yield → Reduced Operating Cost → Lower Cost Commercial Product

LanzaTech Produced

✓4000 gallons Jet

✓**600 gallons Diesel**

- **Demonstrated feedstock flexibility**
  - **Waste Gas Ethanol (Lanzanol)**
  - **Grain Ethanol**
- **Waste gas ethanol (Lanzanol) produced in an RSB-certified demonstration facility**
  - **Shougang-LanzaTech 100,000 gal/yr China demonstration plant**
  - **Site of SGLT Commercial Plant**

Background

- FAME (Fatty Acid Methyl Ester) biodiesel is a staple of road transport but blending levels are constrained by properties (oxygenate)
- HEFA (Hydroprocessed Esters and Fatty Acids) processes make renewable diesel as Synthetic Paraffinic Diesel, which is a drop-in fuel meeting ASTM D975.
- FAME and HEFA processes rely on lipid feedstocks whose supplies are limited in the long run, even as demand increases
- FAME and HEFA product yields and properties are determined largely by chemistry and feedstock
- Maximum theoretical diesel yield from HEFA is ~75%
- Optimization of HEFA yield for one product impacts overall yield

Alcohol-to-Diesel

- Alcohol-to-Diesel (ATD) produces a drop-in renewable diesel fuel meeting ASTM D975
- ATD can use ethanol from any source, expanding feedstock supply and long-term production potential
- ATD product properties are controlled by processing conditions as long-chain hydrocarbons are built up from C2 starting point
- Current Alcohol-to-Jet process can achieve 75% diesel product, equivalent to HEFA maximum theoretical yield
- ATJ and ATD product slate can be varied with no loss of overall product yield

Project will increase yield of renewable diesel from abundant, low-cost feedstocks, and provide process and protocols to serve multiple diesel applications on demand

1 - Management

Management

Management Approach

Project builds on prior LanzaTech-PNNL collaborations combined with experience and data from developing the Alcohol-to-Jet process.

LanzaTech (prime)

- Scale up catalysts for sample production
- Adapt and augment existing process equipment to build an ATD Production Unit (ATDPU)
- Install and shake down ATDPU at LanzaTech Freedom Pines Biorefinery in Soperton, Georgia
- Produce 500+ gallons of diesel from ethanol for multiple diesel applications

PNNL (CRADA partner)

- Experimentally study effects of catalyst and process parameters on diesel properties
- Optimize catalyst and process at lab scale
- Produce gallon quantities of fuel
- Coordinate engine testing

Other Stakeholders

- Project will leverage infrastructure and O&M staff of Freedom Pines Biorefinery and Freedom Pines Fuels

Risk Assessment and Mitigation

Risk Area	Level	Mitigation
Ethanol feedstock quality	Low	• LanzaTech and PNNL have both produced ethylene from multiple sources of ethanol. • Ethanol clean-up is part of commercial ethanol dehydration technology
Catalyst performance and robustness	Low	• Will perform parametric evaluations of a number of variables on diesel production, identifying key variables to optimize performance
Engine performance	Low	• Product samples generated using the ATD process have shown excellent properties
Process performance	Low	• Incorporated select optimization activities into project plan • All process steps have been operated successfully at prior scale
Process scale up	Low	• Project will leverage the results of ongoing projects using related process technology • All process steps have been operated successfully for the jet application
Catalyst scale up	Low	• LanzaTech has relationships with commercial-scale catalyst producers who have experience producing similar types of catalysts
Execution risk	Low	• LanzaTech and PNNL have a history of successful collaborations
Market risk	Low	• Regulations continue to push for low-sulfur, low-carbon fuels

2 - Approach

Overview of Approach

- Use existing Alcohol-to-Jet process as baseline, originally designed to maximize jet range hydrocarbons (synthetic paraffinic kerosene or SPK)
- Develop Alcohol-to-Diesel process capable of 90% yield of diesel range hydrocarbons
- Develop protocols to produce ATD-SPD meeting requirements of different diesel applications
- Validate Alcohol-to-Diesel process at 5,000 gallon per year scale (ATDPU)
- Develop Basic Engineering Package for next scale Alcohol-to-Diesel unit
- Verify progress toward BETO's $3/gge target using TEA and LCA

Technical Approach – Process and Catalyst

- Analyze literature data and prior results from operation from lab to field pilot scale
- Determine optimum conditions to increase degree of oligomerization
- Systematically vary process conditions to develop correlations between process and product properties such as cloud point and cold filter plugging point
- Perform catalyst optimization studies
- Determine minimum hydrogen requirements for hydrogenation of olefins
- Scale up catalyst and develop protocol for future commercial production

Technical Approach – ATD Production and Testing

- Produce and characterize lab-scale samples to verify ATD yield
- Develop diesel application-specific protocols for operating ATD process and verify at lab scale
- Implement ATD at bench-scale and produce 1 gallon SPD sample
- Characterize SPD fuel and perform engine testing in third-party laboratory
- Implement ATD in ATD Production Unit (ATDPU) at LanzaTech Freedom Pines
- Operate ATDPU to produce a total of 500 gallons of SPD, with portions tailored to different applications
- Provide SPD from the ATDPU for detailed engine and emissions testing in third-party laboratory

Summary of Tasks – BP1 and BP2

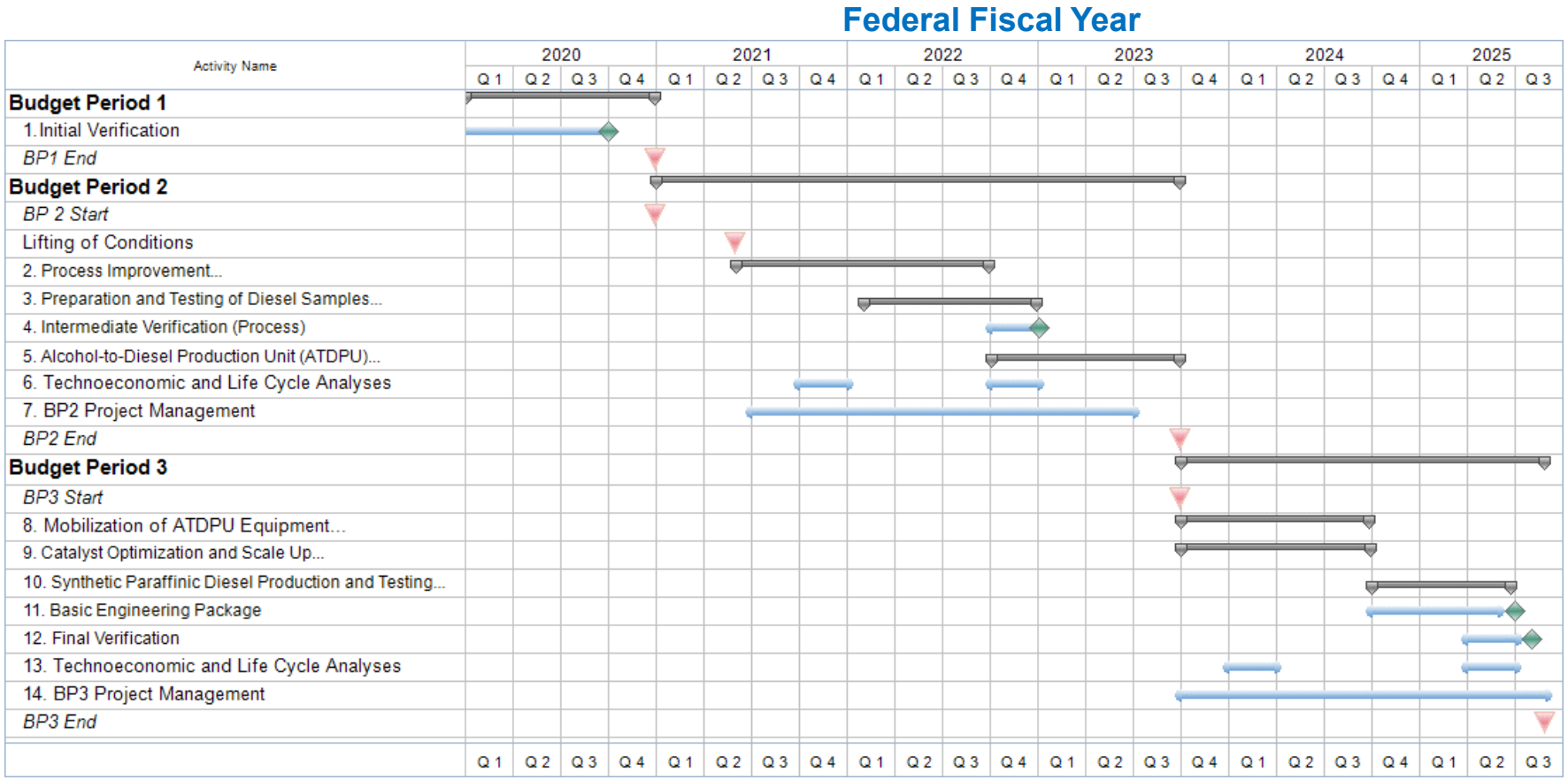
Budget Period	Task	Title	Summary
BP1	1	Initial Verification	Develop test plan for approval by IE. Reproduce baseline performance of unit operations in the laboratory and deliver data package to IE.
BP2	2	Process Improvement	Maximize yield of diesel range product. Conduct parametric study of process variables and product properties. Optimize catalysts. Establish minimum hydrogen requirements. Leverage results from literature and prior operations.
	3	Preparation and Testing of Diesel Samples	Produce SPD samples for testing at bench scale under conditions established at lab scale. Produce over 1 gallon SPD and supply to external testing laboratory for detailed characterization and engine testing.
	4	Intermediate Verification	IE verification in laboratory that process and catalyst from Task 2 produce 85% SPD product with target properties.
	5	Alcohol-to-Diesel Production Unit	Develop ATDPU engineering package including equipment specifications and integration with existing assets. HAZOP review to include IE.
	6	Technoeconomic and Life Cycle Analyses	Interim TEA and LCA using data from interim verification.
	7	BP2 Project Management	On-going project management and reporting.

Summary of Tasks – BP3

Budget Period	Task	Title	Summary
BP3	8	Mobilization of ATDPU Equipment	Procure, install, and integrate ATDPU equipment. Commission ATDPU
	9	Catalyst Optimization and Scale Up	Scale up catalyst from Task 2 and procure quantities needed for ATDPU operation. Establish robust catalyst production protocols for future commercial production.
	10	Synthetic Paraffinic Diesel Production and Testing	Produce at least 500 gallons of SPD in ATDPU, demonstrating 90% SPD in products. Supply SPD to external testing laboratory for characterization and combustion studies of neat SPD and blends, including emission reports.
	11	Basic Engineering Package	Develop Basic Engineering Package for next-scale unit, as basis for future detail design and construction by EPC firm.
	12	Final Verification	IE observation of ATDPU operation to verify SPD yield and suitability for different diesel applications, based on properties of samples prepared under different conditions.
	13	Technoeconomic and Life Cycle Analyses	Final TEA and LCA using data from final verification.
	14	BP3 Project Management	On-going project management and reporting.

Schedule

Schedule extended to reflect contracting timeline and slowdown due to impacts of pandemic



Primary Challenges

- Potential catalyst performance challenges
  - Addressed by parametric studies that identify critical variables to optimize diesel yield
- Process scale up challenges
  - Mitigated by experience scaling up related ATJ technology
- Possible market challenges from uncertainty in renewable fuel mandates
  - Mitigated by increasingly stringent regulations on sulfur and growth in carbon-based regulations like the California Low Carbon Fuel Standard

Metrics for Success

Critical Success Factors

- Demonstrate diesel yield increase to 90% with economic benefits verified by TEA
- Demonstrate ability to tune diesel properties for target applications

Go/No-Go	Description
G1	**Baseline Verification**. Independent Engineer verification of baseline ATD process in PNNL laboratory Verification report accepted by DOE
G2	**Intermediate Verification** Independent Engineer verification of improved ATD process in PNNL laboratory Independent Engineer verification of ATDPU design package Verification reports accepted by DOE
Final	Production of 500 gallons SPD meeting specifications TEA demonstrates support for BETO $3/gge goal **Final Verification** Independent Engineer verification of ATDPU operation

3 - Impact

Relevance to BETO objectives

- Low sulfur, low temperature drop-in renewable diesel fuel with > 60% GHG reductions, using low-cost feedstocks
- Fully compatible with existing fueling infrastructure and engines at any blend level
- Flexible tuning of diesel properties to meet specifications for any diesel application
- Addresses limitations in lipid feedstocks for FAME, HEFA and expands renewable diesel supply potential by extending to any ethanol feedstock or ethanol production technology
- Optimizes economics via feedstock flexibility that allows a commercial ATD refinery to use the lowest-cost feedstock acceptable for each market or customer
- 66 B gallon per year production potential from domestic biomass sources

4 – Progress and Outcomes

BP1 Baseline Verification

Scope of Verification

- Ethylene through final diesel product
- Ethylene feed supplied from commercial cylinders because of prior E2E validation
- Each unit operation observed running in PNNL laboratory
- Key performance metrics compared against baseline from Application and proposed Design Basis

Results

- Performance met or exceeded baseline and proposed Design Basis

Summary of Planned Activities

Budget Period 1

✓ Conduct initial verification

✓ Lift conditions to proceed into Budget Period 2

Budget Period 2

- Design and execute laboratory experiments to optimize process parameters and catalyst
- Prepare lab- and bench-scale samples for analysis and testing
- Design ATD Production Unit
- Conduct intermediate verification

Budget Period 3

- Procure equipment and integrate ATD Production Unit
- Optimize and scale up catalyst for production
- Produce at least 500 gallons of SPD for analysis and engine testing
- Diesel engine testing
- Develop Basic Engineering Package for next-scale implementation of SPD process

Quad Chart Overview

Timeline*

- Budget Period 1: 10/01/2019 to 09/30/2020
- Budget Period 2: 10/01/2020 to 09/30/2022
- Budget Period 3: 10/01/2022 to 07/31/2025

	FY20 Costed	Total Award
DOE Funding	$75,000 (BP1)	$2,500,000
Project Cost Share	$18,750 (BP1)	$630,327

Project Partners

- Zeton
- PNNL (+ engine testing facility)**

**Revised dates due to contracting and pandemic delays.*

***Contracted to PNNL*

Project Goal

Develop and validate a robust, flexible Alcohol-to-Diesel (ATD) process for producing drop-in, renewable, diesel fuel blend-stocks from biomass-derived ethanol

End of Project Milestone

500 gallons of Synthetic Paraffinic Diesel produced, demonstrating 90% of product in diesel range; Basic Engineering package for next-scale implementation complete.

Funding Mechanism

DE-FOA-0001926: Process Development for Advanced Biofuels and Biopower (PDABB)
Topic Area 2: Drop-in Renewable Diesel Fuel Blendstocks

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Summary

Summary

- ATD offers a unique opportunity for producing renewable diesel from abundant feedstocks to meet long-term diesel demand in medium and heavy-duty market
- ATD offers a unique ability to tune diesel properties for different applications, including cold-weather uses
- Experienced team is positioned for success based on prior collaboration in development and scale up of baseline ATJ process
- Project has completed initial verification and is now starting Budget Period 2
- Schedule has been extended to accommodated coronavirus-related restrictions on laboratory R&D
- No other constraints or concerns are anticipated in project execution

Additional Slides (N/A)