DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review

# Low Carbon Hydrocarbon Fuels From Industrial Off Gas

April 4, 2023

Systems Development and Integration Session B

Dr. Laurel Harmon
LanzaTech, Inc.

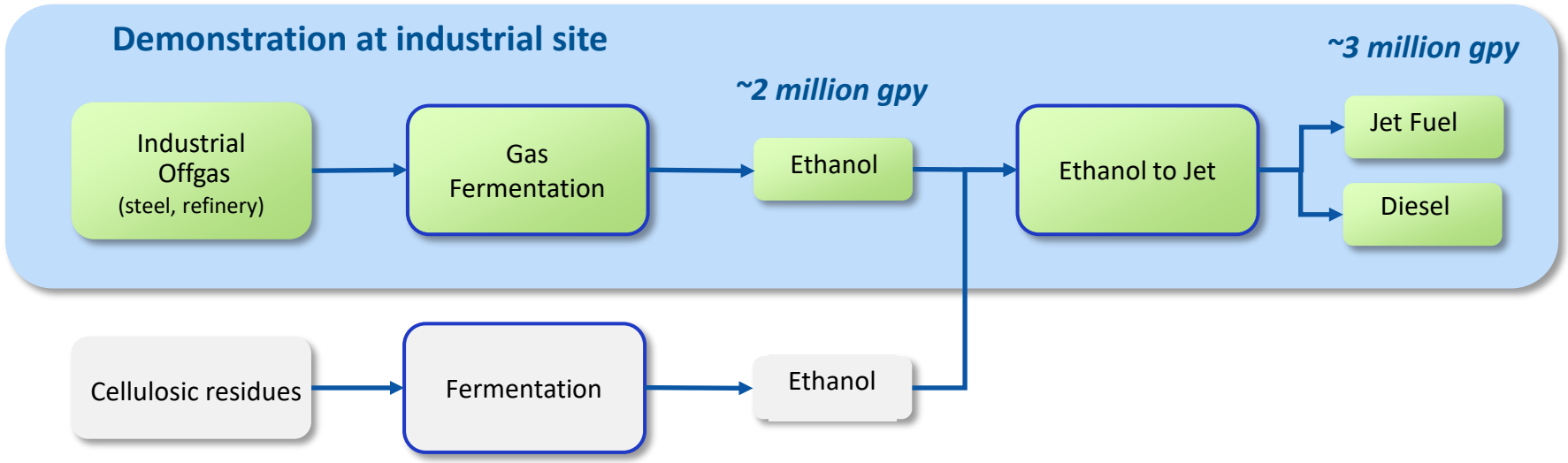
LanzaTech


This presentation does not contain any proprietary, confidential, or otherwise restricted information

# Project Overview

# Original Project Goal and Scope

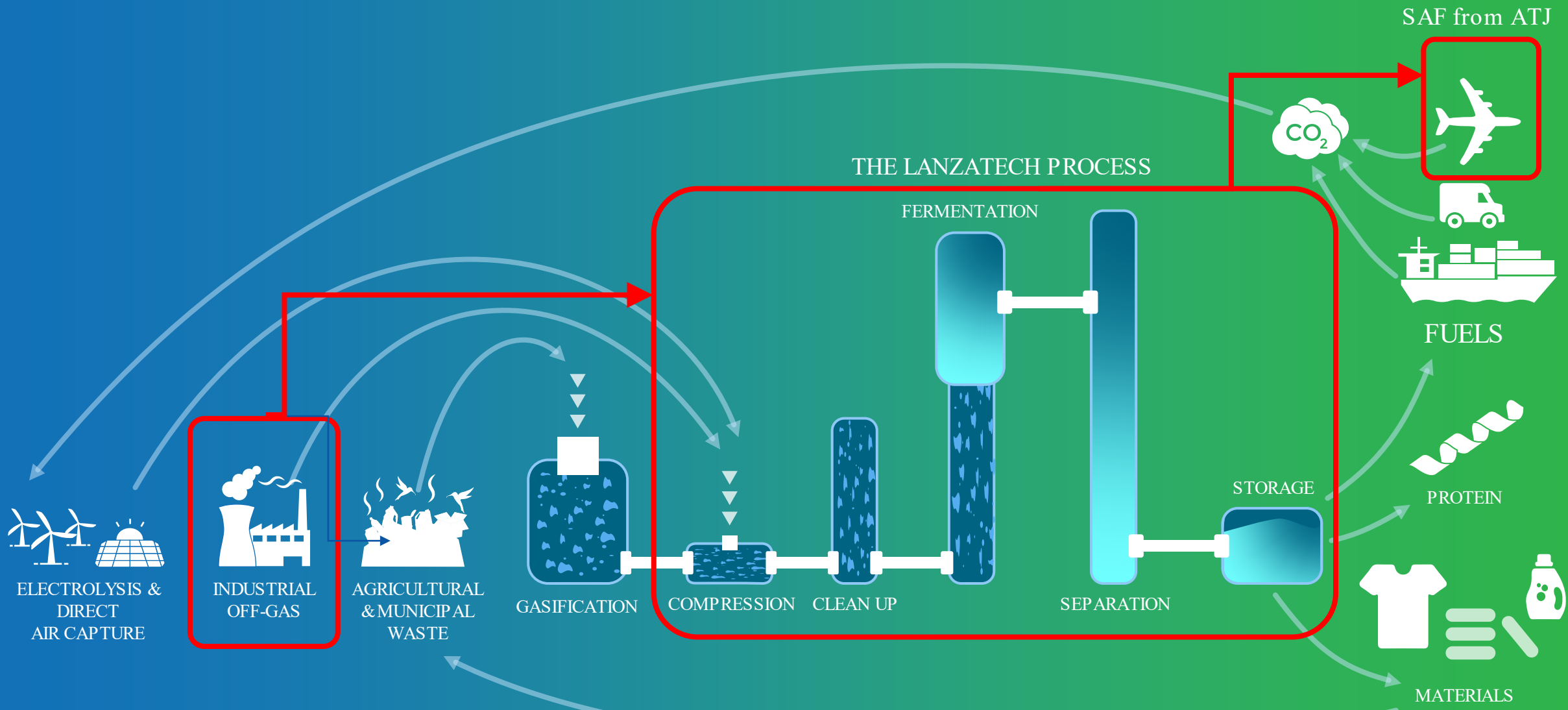
FOA Objectives
- ✓ Produce hydrocarbon fuels from qualifying feedstocks
- ✓ At a rate equal to or greater than 50 DMT/day cellulosic feedstock equivalent
- ✓ Where the majority of the product is a biofuel
- ✓ And that products qualify as advanced or cellulosic under the RFS




**Original Project Goal**

***Demonstrate production of jet and diesel from industrial waste gases via gas fermentation to ethanol intermediate followed by conversion of ethanol to jet***

# The LanzaTech Process



# Gas fermentation became commercial

Laboratory
2005

Pilot
2008

Demonstration
2012

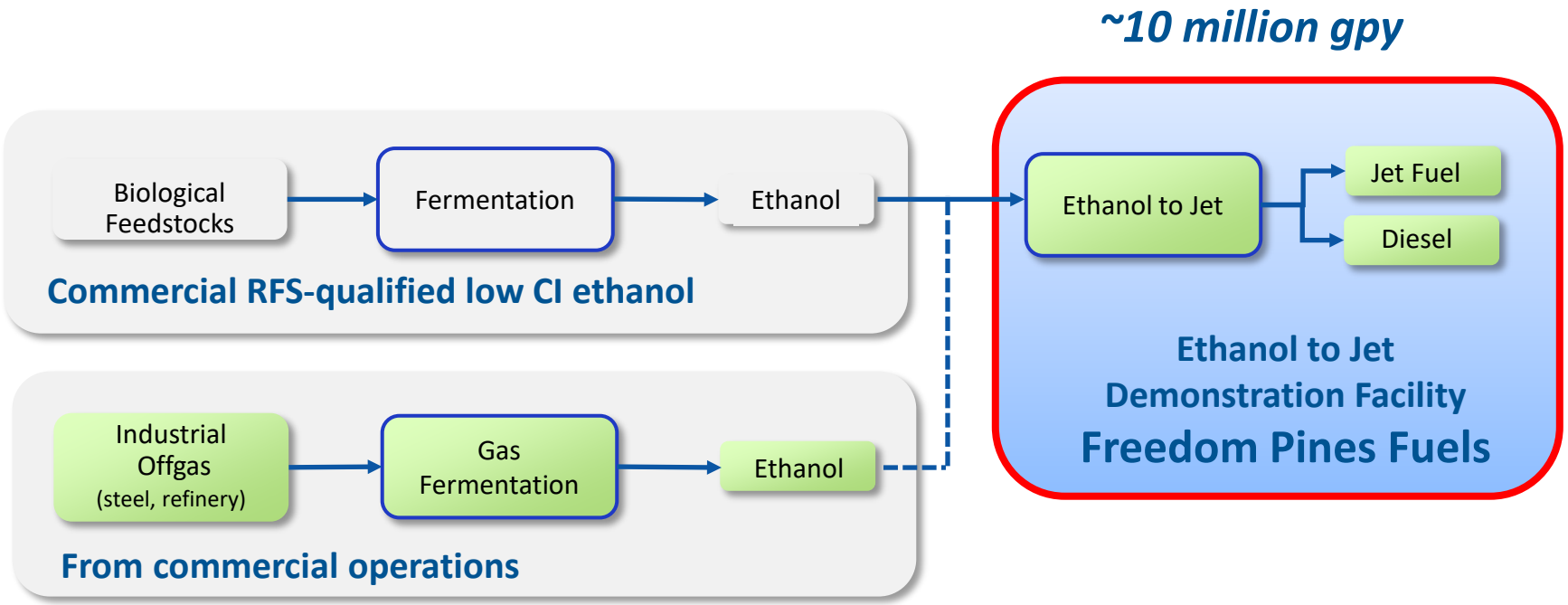
- ✓ Industrial emissions to ethanol
- ✓ Three commercial plants operating

## Commercial Scale 2018

RSB

## >200,000 tonnes of carbon dioxide avoided

# Revised Goal and Scope




**Revised Project Goal**

***Accelerate commercialization of ethanol-to-jet technology by building a standalone Alcohol-to-Jet pre-commercial demonstration facility to produce sustainable aviation fuel (SAF) and diesel***

# Revised Project Objectives: Freedom Pines Fuels

## Objectives

- Design, build, and operate 10 million gallon per year facility to produce jet and diesel from ethanol intermediates
- Validate technology from waste gas and other ethanol feedstocks and inform next stage of scale up
- Deliver first commercially-relevant quantities of jet and diesel from ethanol

## Key Project Outcomes

- Demonstrate production of jet and diesel qualifying as Advanced Biofuel
- Provide continuous operating data to validate technology and inform commercial design
- Produce first commercially-relevant quantities of jet and diesel from ethanol
- Validate business model, cost model, and distributed supply chain model

# 1 - Approach

# What is the driver?

For Commercial Aviation…

| | US | World |
|---|---|---|
| *Jet Fuel Consumption (Pre-Covid)* | **~21B+** Gallons / year | **~96B+** Gallons / year |
| *Sustainable Aviation Fuel Production (2021)* | **~5M** Gallons / year | **~33M** Gallons / year |

+

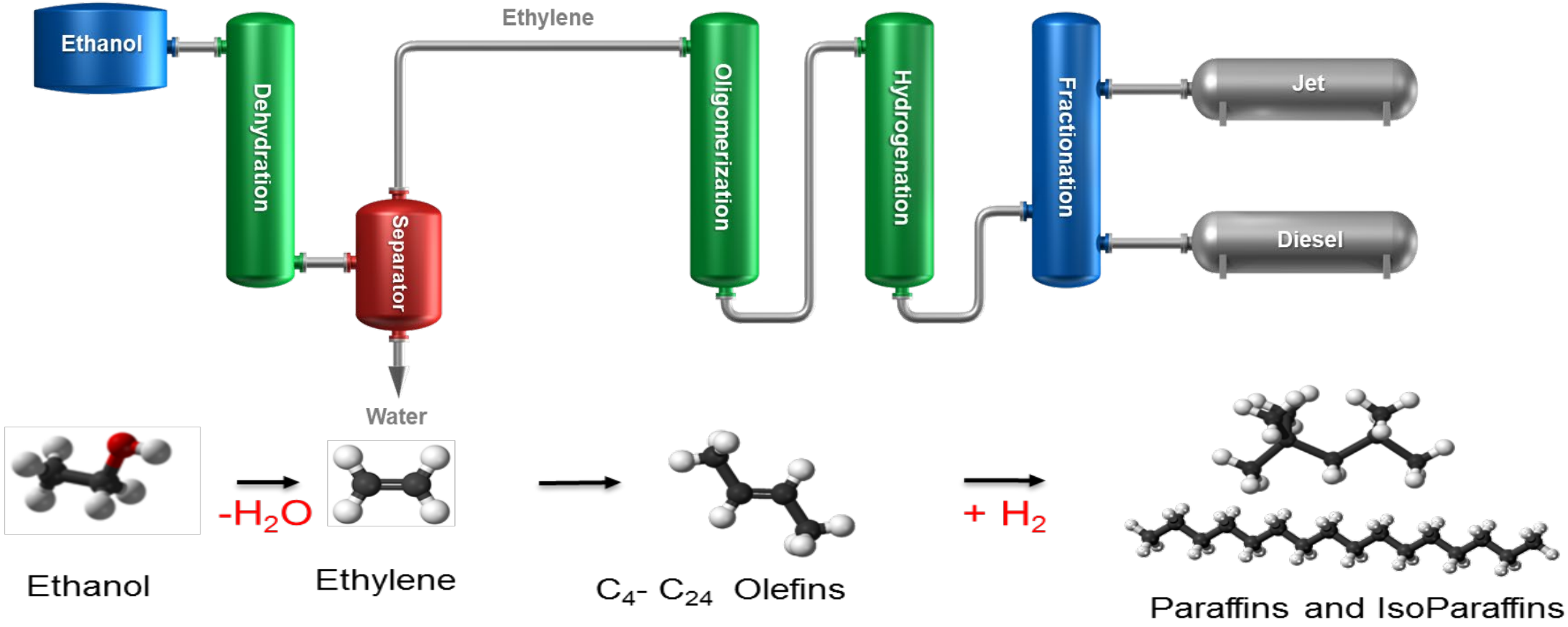
- **New Goals**
- **New Mandates**
- **New Incentives**
- **New Scale in Technology & Production**

**Catalyzing a New Global Market**

Sources: World = IATA, US = Various including Regulatory Incentives

LanzaJet

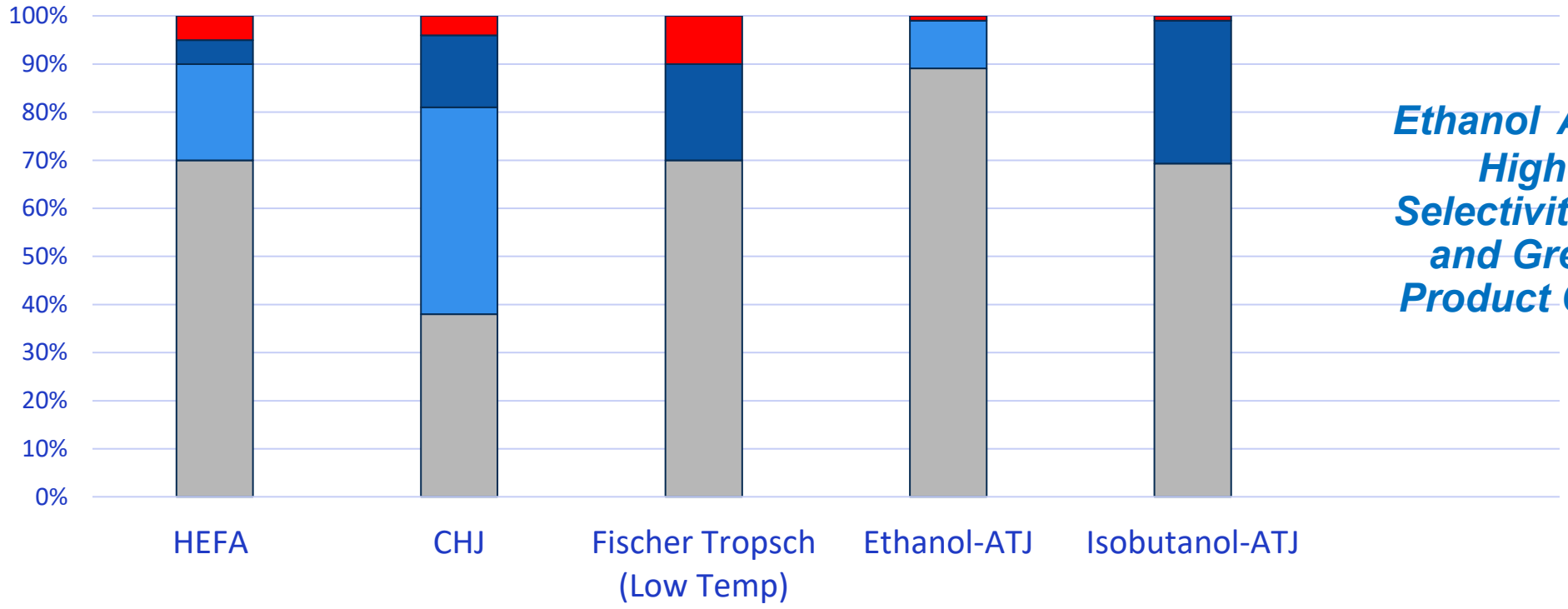
# Why Ethanol-Based Alcohol-to-Jet?




| Ethanol to Jet | Representative |
|---|---|
| Mass Yield (water loss) | 0.6 |
| Carbon Yield to Hydrocarbon | 0.98 |
| Hydrogen/mole of Jet | 1 |

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

# Current Sustainable Aviation Fuel (SAF) alternatives and limitations




***Ethanol ATJ has Highest Selectivity to Jet and Greatest Product Control***

**HEFA (Hydrogenated Esters and Fatty Acids)** is the only commercially-practiced SAF alternative today

- Feedstock supply (fats, oils, and greases) limited relative to global SAF demand

**Fischer-Tropsch (FT)** facilities are in construction to utilize MSW and woody biomass feedstocks

- High capital costs when implemented at the scales of sustainable feedstocks

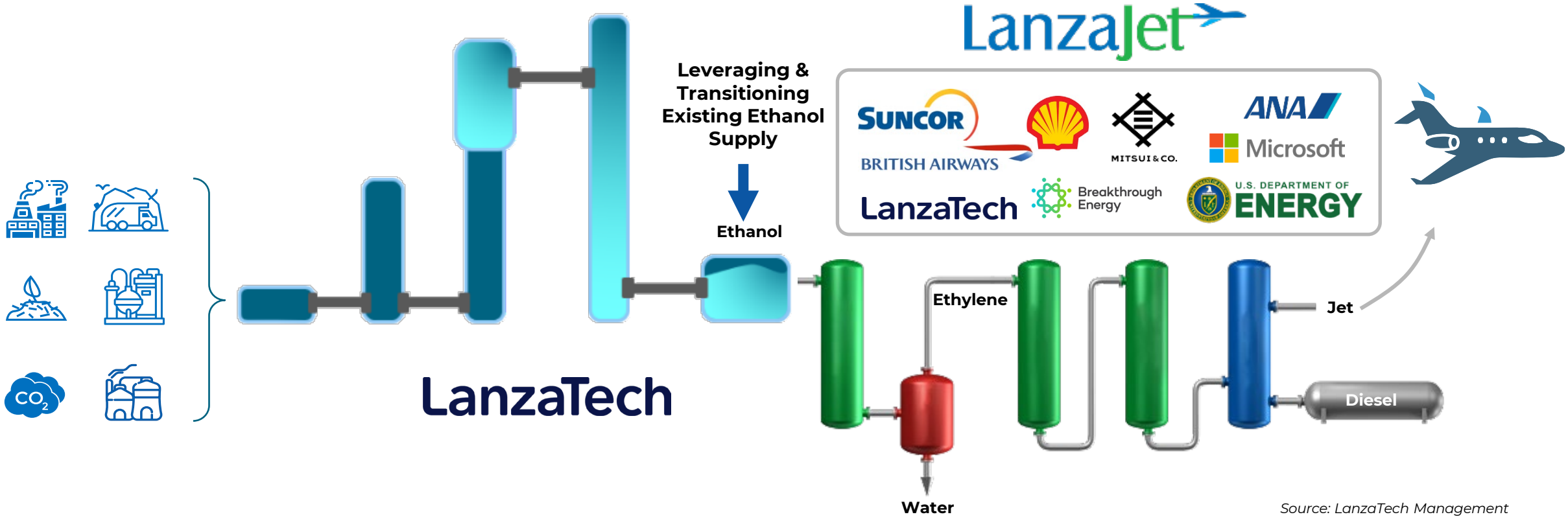
# LanzaTech spun out LanzaJet in 2020

**Abundant, Waste-based Feedstock** + **Low-Cost Process** = Competitive Waste-to-SAF Solution

With opportunity to utilize existing ethanol supply today

Pacific Northwest NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY




*Source: LanzaTech Management*

# Supported by World-class Investors and Funders





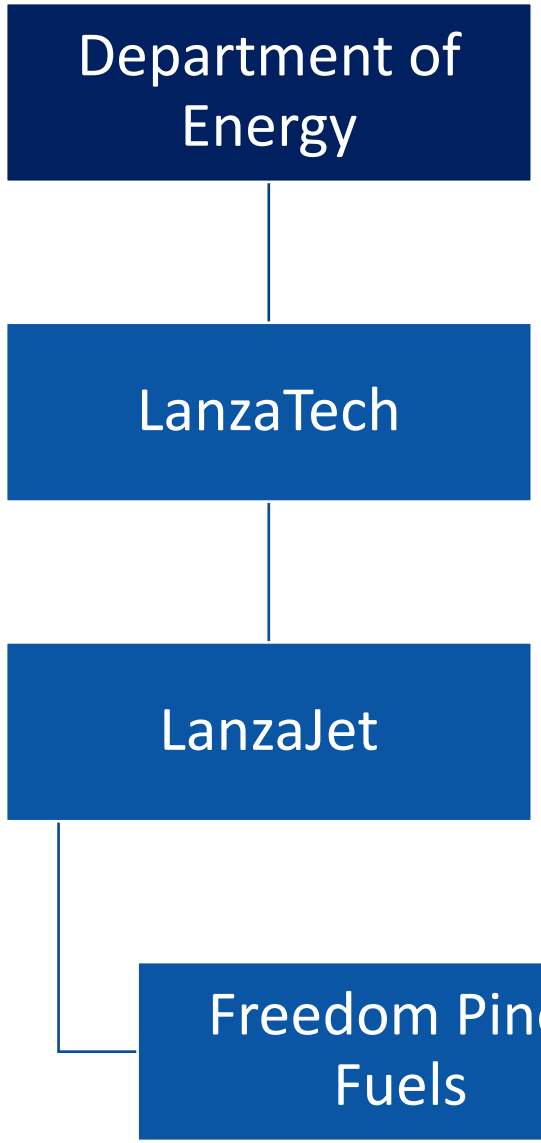




- ✓ Funding commitments
- ✓ Commercial-scale projects commitments
- ✓ Offtake commitments
- ✓ Knowledge, support, and secondees commitments
- ✓ Feedstock supply flexibility commitments
- ✓ Innovation commitments

LanzaJet

# PD2B3 Project Organization




*Key Stakeholders*

| Entity | Role |
|---|---|
| **PNNL** | ATJ licensor and technical support |
| **Zeton** | ISBL - modular design, engineering, fabrication |
| Technip | E2E technology |
| Zachry | OSBL engineering |
| Thompson | Civil and OSBL construction |
| LanzaJet Investors | Investment, offtake |
| **LanzaTech** | Waste gas ethanol |
| Confidential | Other ethanol |

# High-level Project Risks

| Area | Risk | Mitigation |
|---|---|---|
| **Technical** | 1st ethanol to jet at scale | • Technology validated at multiple prior scales<br>• Strong technology partners |
| **Finance** | Unable to raise sufficient capital in uncertain economic environment (pandemic) | • Diversify sources of capital<br>• Diversity funding mechanisms |
| **Feedstock supply** | Unable to negotiate supply agreements required for financing | • Sought supply agreements with 3rd parties with access to multiple sources |
| **Offtake** | Unable to negotiate long-term offtake at required price point | • Strong demand for both SAF and Renewable Diesel<br>• Strategic offtake partners |
| **Supply chain** | Pandemic disrupted supply chains and increased cost for material, equipment, and components | • Identified alternative sources with support from investors, technology partners, suppliers<br>• Secured sufficient capital to cover cost uncertainty |
| **Schedule** | Delays in engineering and/or construction, deliveries, permitting and/or regulatory requirements | • Continuous monitoring and updates to schedule<br>• Early initiation of permit and RFS pathway applications |

# 2 – Progress and Outcomes

# PD2B3 Scope within overall Freedom Pines Fuels Project

**PD2B3**
**(DOE Project)**

**Contributes To:**

Regulatory and permitting, including NEPA

Engineering (ISBL, OSBL)

EPC oversight, HAZOP, FAT (ISBL, OSBL)

O&M training

Demonstration run

**PM & reporting**


**External Funding**
**(outside of PD2B3 Project)**

**Remainder to Achieve Operational Status:**

Capitalized equipment and materials (ISBL, OSBL)

Civil works and utilities

Engineering, Procurement, Construction (EPC)

Start up and operation, exclusive of demonstration

***PD2B3 funding supports a subset of the overall Freedom Pines Fuels Project***

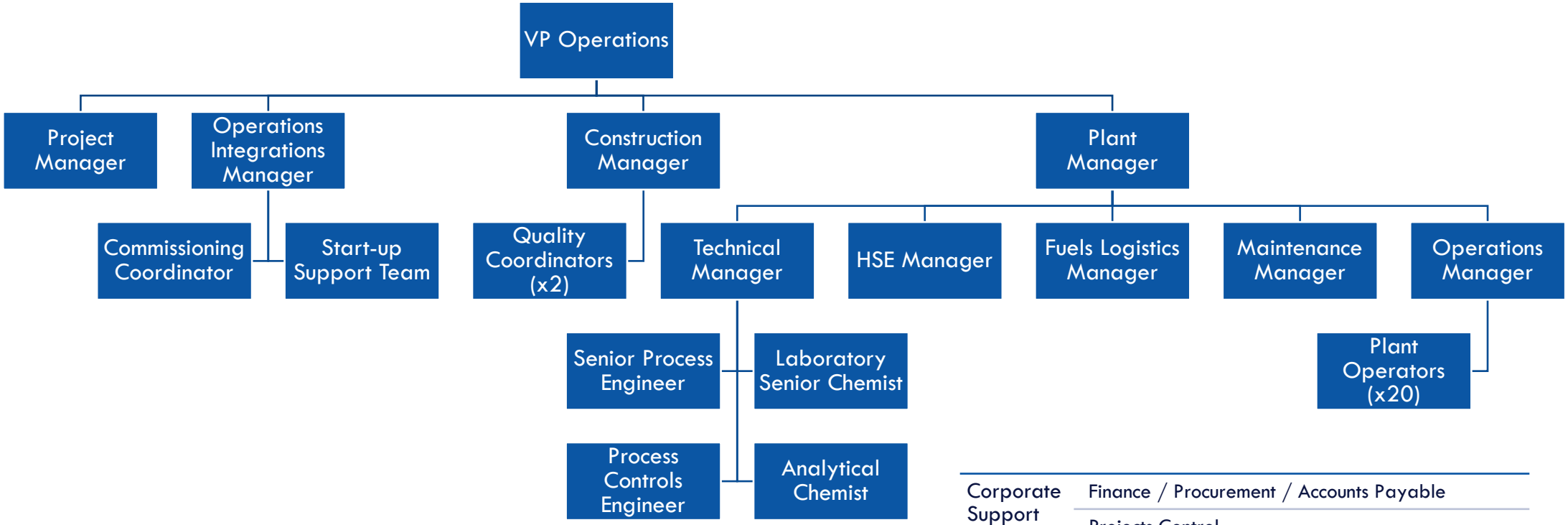
# Scope of Budget Period 3

| Task | Description | Status |
|---|---|---|
| 3.1: Initiate Budget Period 3 | Finalize scope, budget, lift conditions | Complete |
| 3.2: Detail Design of ATJ Modules | Engineering support for detailed design of modules<br>30% and 60% design reviews with DOE Independent Engineer (IE) | Complete |
| 3.3 Final Engineering of Alcohol-to-Jet (ATJ) Modules | Engineering support for: detailed engineering package, selection, and ordering of long-lead items. | Complete |
| 3.4: OSBL Assessment and FEED Study | OSBL requirements and Front End Engineering Design Package; HAZOPs with IE | HAZOP in progress |
| 3.5: Detailed Engineering of Site Upgrades | Detailed engineering of site upgrades and equipment; ordering of long-lead items | In progress |
| 3.6: Site Preparation | Support site upgrades for installing ISBL, OSBL, utility connections | In progress |
| 3.7: Operations and Maintenance Training | Develop training program and Standard Operating Procedures (SOPs | In progress |
| 3.8: Zeton Factory Acceptance Test and Shipment | Factory acceptance test (FAT) for ISBL modules and shipment to site | Complete except for certain external packages |
| 3.9: ATJ Module Receipt, Reassembly, Interconnection, and On-Site Testing | Receive and test ISBL modules at site. Pre-Startup Safety Review with IE. | In progress |
| 3:10 Project Management, Administration, and Compliance | On-going project management activities, permitting, regulatory approvals. | On-going |

# Scope of Budget Period 4

| Task | Description | Status |
|---|---|---|
| 4.1: Commissioning with Feed | Commission plant after introduction of ethanol feed. | Not started |
| 4.2: Initial Jet and Diesel Production Ramp-Up | Ramp up capacity and verify Key Performance Indicators, product quality. | Not started |
| 4.3: Performance Test - Integrated Demonstration of ATJ | Integrated demonstration that plant performance meets FOA requirements (with IE) | Not started |
| 4.4: Technical Support | Support from technology providers during commissioning and demonstration | Not started |
| 4.5: Project Management, Administration, Compliance, Documentation and Reporting | Ongoing project management, LCA and TEA updates, commissioning and demonstration report. | Not started |

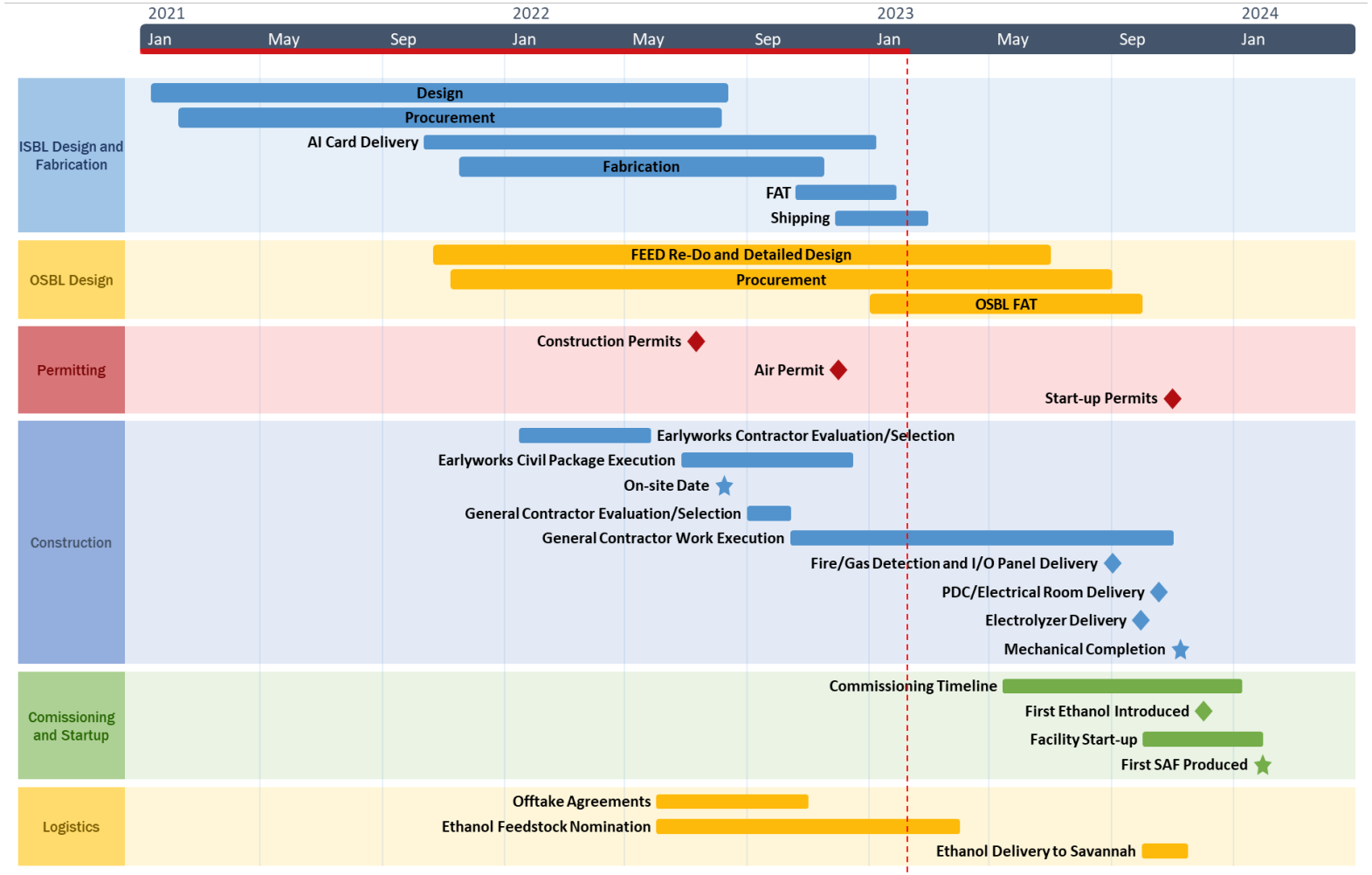
# Freedom Pines Fuels Organization




| | |
|---|---|
| Corporate Support Team | Finance / Procurement / Accounts Payable |
| | Projects Control |
| | People Business Partner |
| | Logistics & Fuels |
| | Commercial |
| | Government Relations |

LanzaJet

# Overall Schedule: Mechanical completion timing holding for Q4 2023; Worked with suppliers to mitigate equipment delay risk




- Supply chain is regularly reviewed and equipment challenges are frequently managed
- Mechanical Completion is still expected Q4 2023
- Supply chain issues leading to potential delays in long-lead items are being mitigated



LanzaJet Freedom Pines Fuels

# Engineering and construction continues to progress as planned

## ISBL Construction

**ISBL module deliveries and erection on site progressed on schedule; Other site prep, foundations, and construction activities also progressing**

## ISBL Modules

**All ISBL modules have been received and are being erected on site**

## OSBL Engineering and Construction

**OSBL procurement of major long-lead items is complete; Zachry working closely with Thompson to optimize release of engineering packages**

### ISBL Scorecard

| | | |
|---|---|---|
| Budget |  | No major change orders for Phase 1; Phase 2 CO's to be controlled |
| Schedule | | Minor impact due to rain |
| Risk | | So far, delays mainly weather related |

### Module Scorecard

| | | |
|---|---|---|
| Budget |  | Change orders at 1.5% of overall budget |
| Schedule |  | Overall module delivery schedule is on target - completed |
| Risk |  | All risks mitigated to medium and below |

### OSBL Scorecard

| | | |
|---|---|---|
| Budget |  | Budget remaining on track with September TIC refresh |
| Schedule |  | Delays from equipment vendors identified and mitigated |
| Risk |  | Equipment deliveries tracked to eliminate schedule risk |



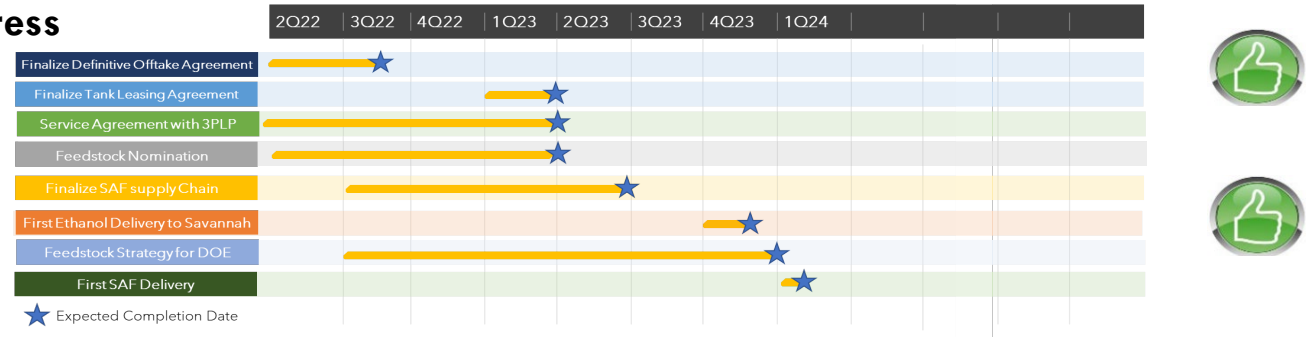
LanzaJet Freedom Pines Fuels

# Supporting programs are also progressing on schedule

## Fuel & Logistics

**Finalizing feedstock supply, chain of custody and title transfer protocols to deliver optimal value to offtakers**

**Progress**




## Regulatory

**FPF continues to achieve regulatory milestones; EPA RFS petition final approval received**

**Progress**

| Environmental Protection Agency (EPA/RFS) | California Air Resource Board (CARB/LCFS) | Round Table on Sustainable Bio (RSB) | Tax and Trade Bureau (TTB) |
|---|---|---|---|
| Initial Engagement | Initial Engagement | Initial Engagement, PO Signed | Counsel retained |
| Petition Submitted | Pathway Submitted | Gap Analysis Completed | Kickoff meeting with TTB held |
| Pathway Approved | Pathway Approved | Audit Completed | NDA executed |
| | | Certification Received | Design meets security requirements |

Green = Milestone Completed
Yellow = Upcoming Milestone



LanzaJet Freedom Pines Fuels

# ISBL modules erected; Compressor foundations, tank foundations, and pipe rack supports progressing

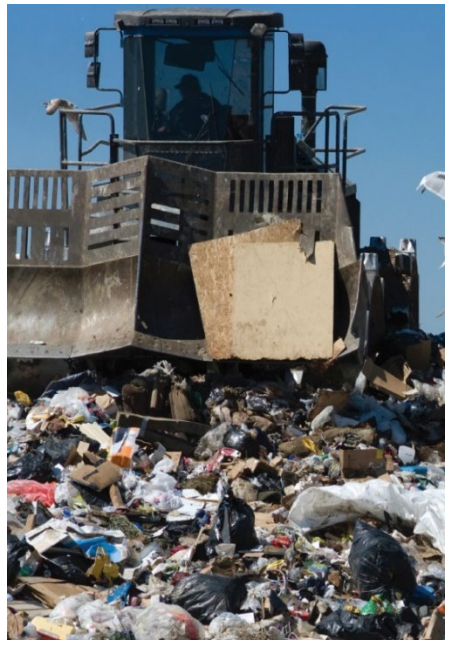


LanzaJet Freedom Pines Fuels

# 3 - Impact

# Ethanol-to-Jet: Foundation for Fully Scalable SAF Industry




**Every Waste Resource Including $CO_2$ Can be Utilized**
**In the Integrated LanzaTech-LanzaJet Solution**

LanzaJet

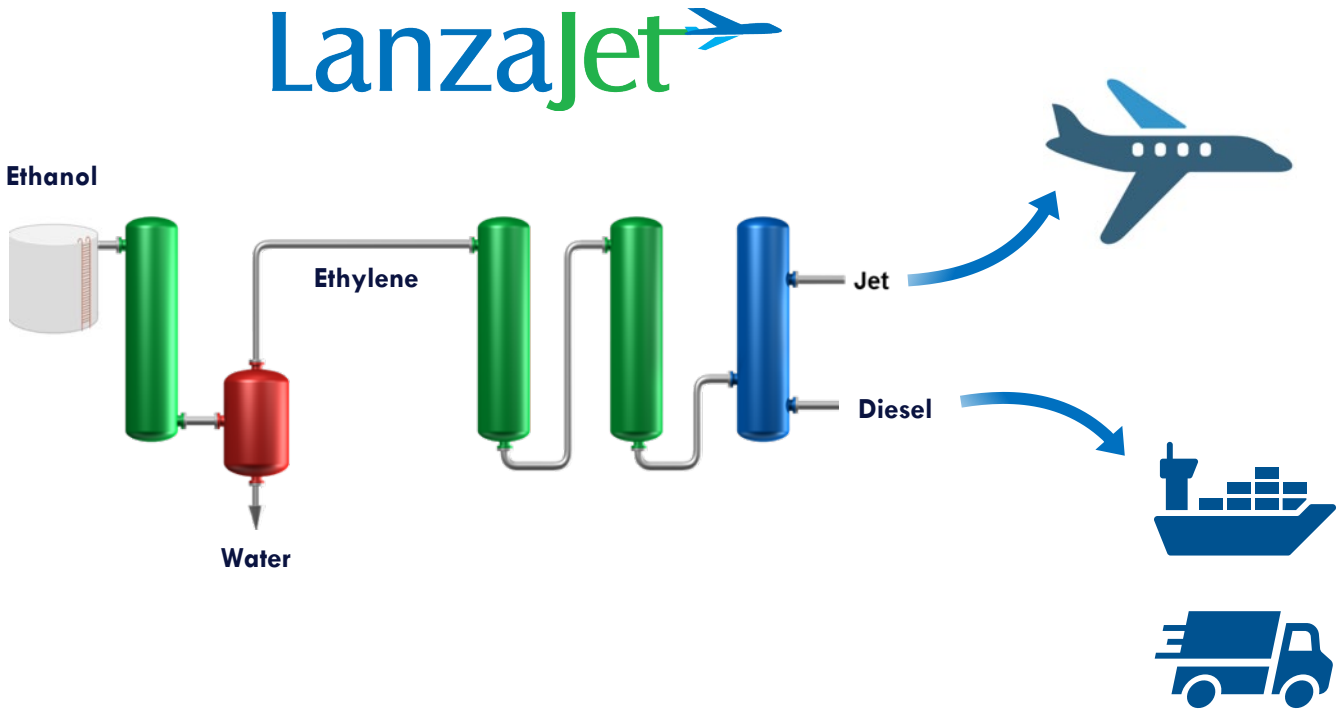
# Existing Ethanol Industry + Developing Waste-based Supply Chain

A **Leveraging & Transitioning Existing Ethanol Supply**

- Existing low-CI ethanol production
- Cellulosic ethanol
- Waste-based ethanol

B **Building New Waste-Based Ethanol Supply**

- Industrial / landfill off-gasses
- Agricultural waste and residues
- Municipal Solid Waste (MSW)
- Corn fiber cellulose / sugarcane bagasse
- Direct Air Capture (DAC) – $CO_2$ + $H_2$




LanzaJet

# Freedom Pines Fuels Sets Standard as First of Many Global Projects

**Pilot Plant**
Georgia, USA

2014 – 2017

10M GPY
(29 KMTA)
(38 M LPY)

**LanzaJet Freedom Pines Fuels**
Georgia, USA

PD2B3 Project

30M – 120M+ GPY Each
(90 – 250+ KMTA)
(113 – 450+ M LPY)

**FLITE**
Central Europe

**Vattenfall, SAS, Shell, and LanzaTech**
Sweden

**#1: Dragon (LT)**
**#2: Speedbird (BA)**

**IOC**
India

**Marquis SAF**
Illinois

**Suncor**

**Mitsui**

**Shell**

**Others**
Various

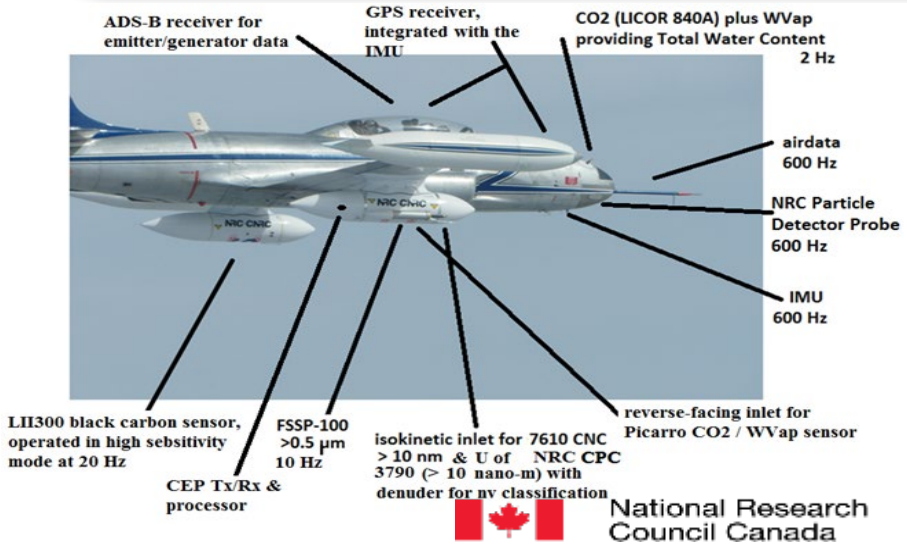
Follow-on Projects

LanzaJet

# Beyond greenhouse gas emissions

## National Research Council Canada (NRC) testing showed >95% reduction in LanzaJet™ SAF emission particles and resulting contrails

NRC
Falcon 20 Jet




NRC CT-133 instrumented

**LanzaJet SPK**
**>95%**
**Lower Contrails and Particles**



Canada

***Comparison of Particle Number Emissions from In-Flight Aircraft Fueled with Jet A1, JP-5 and an Alcohol-to-Jet Fuel Blend***
*Steven Tran, Anthony Brown, and Jason S. Olfert Energy & Fuels 2020 34 (6), 7218-7222; DOI: 10.1021/acs.energyfuels.0c00260*

# Summary

# Summary

1. DOE funding for Phase 2 released
2. Remainder of project financing secured
3. ISBL modules completed, delivered, and are being erected at site
4. OSBL engineering in progress; major long-lead items procured
5. Ethanol sourcing and offtake agreements complete
6. Majority of FPF staffing in place with training underway
7. All required permits obtained to-date; RFS pathway application approved

# Quad Chart Overview

## Timeline

- *Project start date:* 1/15/2017
- *Project end date:* 9/30/2023*

| | FY22 Costed | Total Award |
|---|---|---|
| **DOE Funding** | $2,384,178** | $18,444,107** |
| **Project Cost Share** | $2,423,602 | $20,018,704 |

| | |
|---|---|
| TRL at Project Start: | 6 |
| TRL at Project End: | 7 |

*NCTE will be required

**Excludes PNNL funding

## Project Goal

- Design, build, and operate 10 million gpy facility to produce jet and diesel from ethanol intermediates

## End of Project Milestone

- Demonstrate 500 hours of stable operation producing jet and diesel from qualified ethanol intermediates
- Demonstrate products meet RFS2 requirements for Advanced or Cellulosic biofuels

## Funding Mechanism

- DE-FOA-0001232: Project Development for Pilot and Demonstration Scale Manufacturing of Biofuels, Bioproducts, and Biopower (PD2B3) Topic Area 2

## Project Partners (Phase 2)

- PNNL
- Zeton
- LanzaJet

# Thank you to DOE's BETO and all the stakeholders that have gotten us this far!


LanzaJet

# Thank you!

# Additional Slides


LanzaTech

# Responses to Reviewers Comments

# LanzaTech response to reviewer comments

| Weakness from 2021 DOE Review | LanzaTech Response |
|---|---|
| Advantages of site unclear | Site already developed with significant infrastructure. Site also received prior USDA and DOE FONSIs, facilitating NEPA approval for the project. Project brings jobs to Soperton – a rural area with high minority population and low median incomes. |
| Why use ethylene for SAF instead of chemical markets and conduct an economic study of relative markets? | Using ethanol overcomes feedstock limitations for current commercial SAF because it is an abundant resource. This project is focused on SAF and only concerned with whether the economics in the SAF market are attractive. LanzaTech has extensive experience supplying ethylene supply chains for a number of commercial customers, including L'Oreal, Mibelle, On Running, Lululemon, etc. Please see www.lanzaech.com. |
| Ethanol sourcing - is sustainable ethanol available in the market? Why use multiple sources? What about cellulosic ethanol? | At the time of the previous review, LOIs had been obtained for cellulosic ethanol supply. Since that time, US sources have been reduced. LanzaJet has secured ethanol supply that will enable the SAF/diesel to qualify as Advanced Biofuels, meeting the FOA requirements. Waste gas ethanol will not, at this time, create RINs under RFS, but can still serve aviation markets. Details of corn fiber ethanol requested are no longer relevant.<br><br>Since ethanol dehydration (Ethanol-to-Ethlyene) has been validated on ethanol from a wide variety of sources, we no longer think it is necessary to include such variation in the Freedom Pines Fuels demonstration. |
| Risk assessment – not sufficiently robust<br>Individual concerns addressed in bullets | LanzaTech and LanzaJet have continuously evaluated and mitigated risk.<br>**Technology**: Two DOE IE reports were prepared addressing technology risk, with positive recommendations.<br>Scale up: Review mistakenly though scale up was $10^6$ X, based on description of DOE-funded work. LanzaTech conducted a field demonstration without DOE funding. Actual scale up factor is 200X.<br>**Construction**: Modular design enabled ISBL construction to continue in parallel with OSBL, despite pandemic disruptions.<br>**Permitting**: As noted in original response, permitting risks were reduced by location; since that time, the project has received DOE FONSI and both construction and Air Permits have been issued.<br>**Catalyst**: Commercial catalyst performance has been validated experimentally against demo catalyst |

# Publications, Patents, Presentations, Awards, and Commercialization

# Awards and Publication

**ACS AWARD FOR AFFORDABLE GREEN CHEMISTRY**:
RICHARD T. HALLEN, JOHNATHAN E. HOLLADAY, AND MICHAEL A. LILGA

**Sponsor**: Dow, and endowed by Rohm and Haas
**Citation**: For developing the technology for the first sustainable aviation fuel from recycled carbon, helping to decarbonize a sector that currently has limited options

*Other publications to be added by end of week.*