# DOE Bioenergy Technologies Office (BETO)
# 2021 Project Peer Review

## Low Carbon Hydrocarbon Fuels From Industrial Off Gas

March 25, 2021

Systems Development and Integration

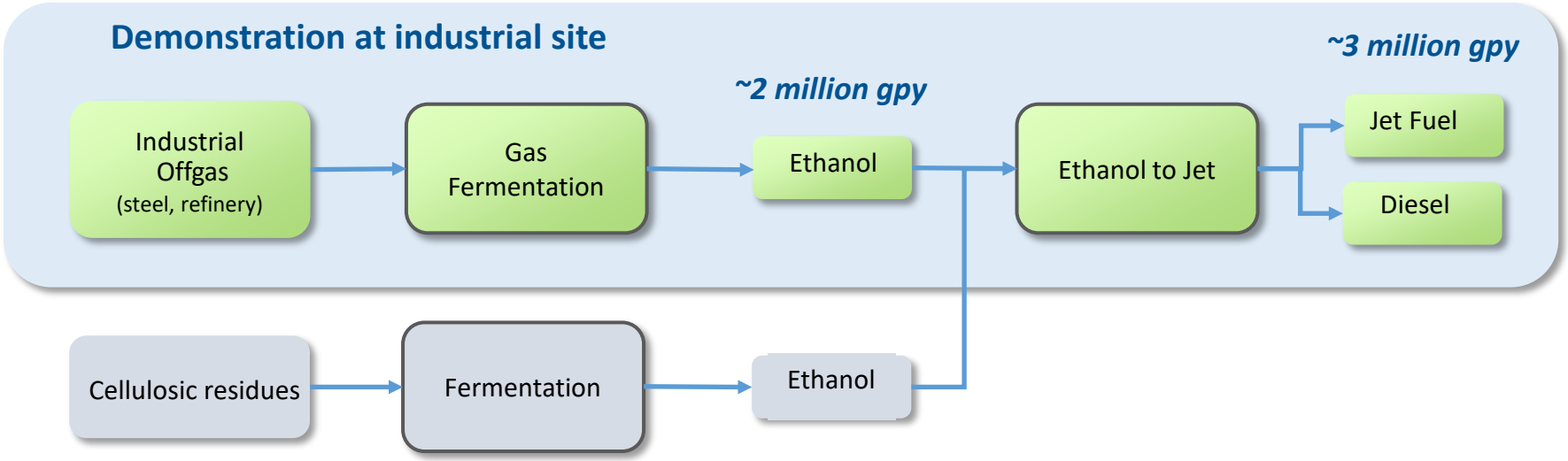
Dr. Laurel Harmon

LanzaTech, Inc.

# 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**

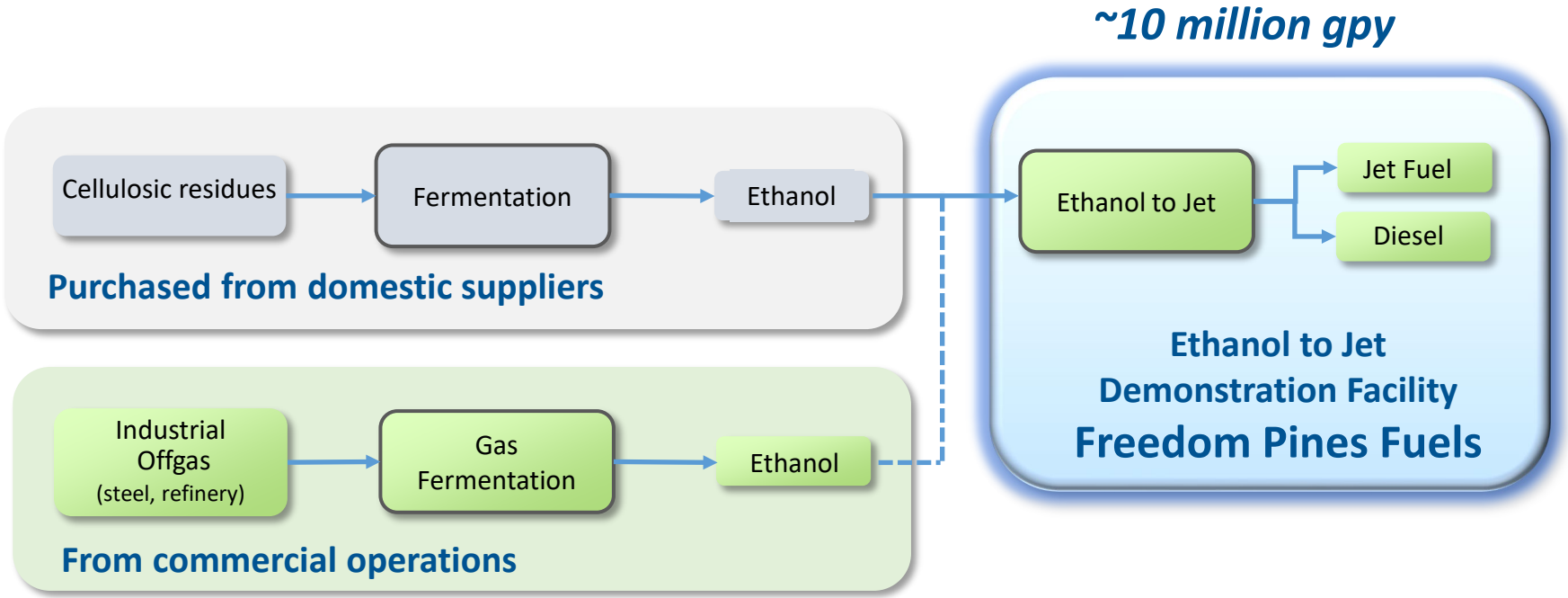
***Demonstrate production of jet and diesel from industrial waste gases via gas fermentation to ethanol intermediate followed by conversion of ethanol to jet***

# Gas Fermentation Operating Commercially

首钢朗泽
Shougang LanzaTech

## >20M Gallons Ethanol Produced
## >100,000 metric tons $CO_2$ 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

## Objectives

- Design, build, and operate 10 million gallon per year facility to produce jet and diesel from ethanol intermediates
- Validate technology from multiple 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

# Why is this important?

Mandated SAF Demand for **$50B+** by 2030

***New technologies and expanded feedstock pool are critical to meet projected SAF demand***

## International Mandates[1]

16B gals by 2030

## National Mandates[2]

| | | |
|---|---|---|
| France | 5% in 2030 | 130m gals |
| Sweden | 30% in 2030 | 100m gals |
| Finland | 30% in 2030 | 90m gals |
| Norway | 30% in 2030 | 90m gals |
| Spain | 2% in 2025 | 50m gals |

1. *Estimated projection based on CORSIA mandates*
2. *Anticipated mandates applied to 2019 jet fuel consumption*

## Industry Commitments

BRITISH AIRWAYS / IAG INTERNATIONAL AIRLINES GROUP

**Net zero** $CO_2$ by 2050

UNITED

**Net zero** $CO_2$ by 2050

DELTA

**$1B** committed to carbon mitigation

KLM Royal Dutch Airlines

**15% reduction** in $CO_2$ footprint by 2030

# 1 - Management

# LanzaTech spun out LanzaJet in 2020


LanzaTech

Gasification and Gas Fermentation → Ethanol

LanzaJet

Ethanol → Sustainable Fuels

# LanzaJet & Freedom Pines Fuels

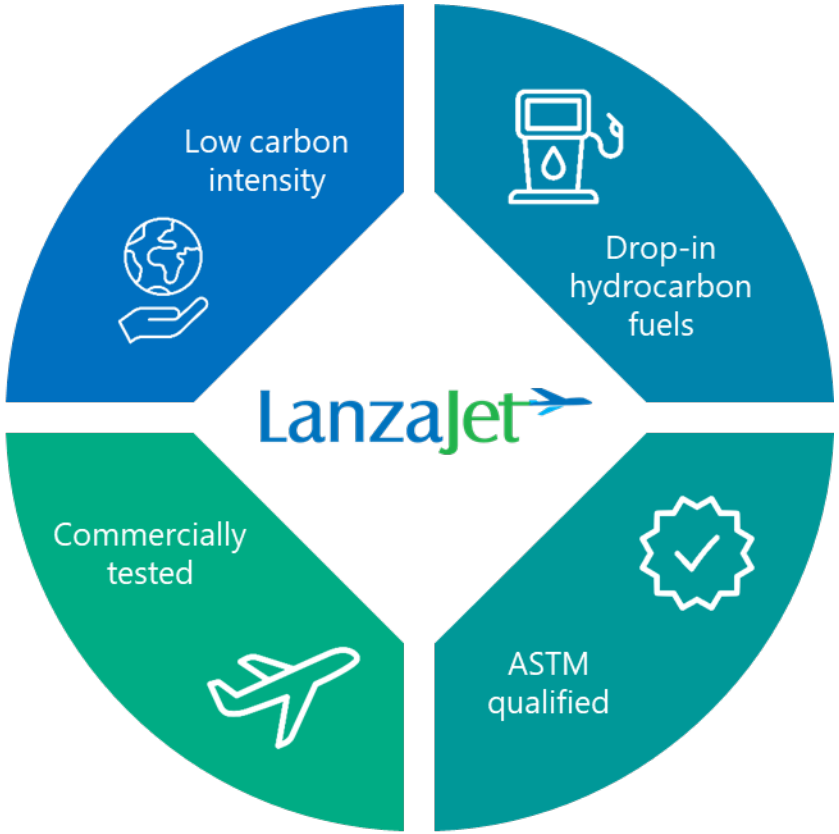
***LanzaJet formed by LanzaTech to commercialize LanzaJet™ Alcohol-to-Jet technology***

LanzaTech — Technology License

SUNCOR, MITSUI & CO., BRITISH AIRWAYS — Capital

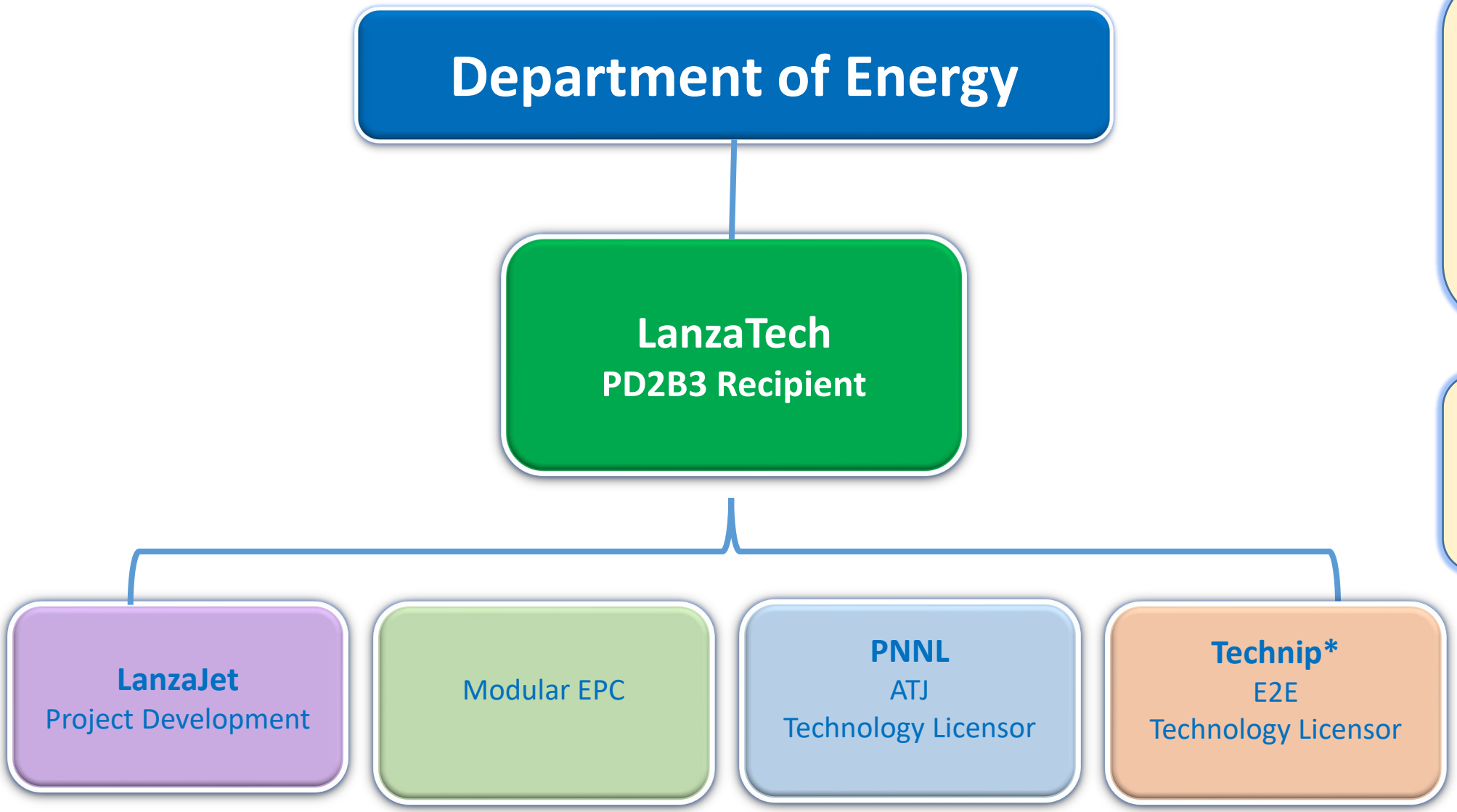
ANA — Pre-Paid Offtake

U.S. DEPARTMENT OF ENERGY — PD2B3 Funding




***Freedom Pines Fuels, a LanzaJet subsidiary, is the special-purpose vehicle for this project***

# Current Project Team




## Feedstock Providers

**Demonstration**
- Domestic corn kernel fiber
- Imported waste gas ethanol

**Production**
- Domestic and imported cellulosic and advanced ethanol

## Product Offtake

- ANA
- British Airways
- Suncor
- Others (confidential)

**Announced July 2020*
*https://www.technipfmc.com/en/media/news/2020/07/technipfmc-s-hummingbird-ethylene-technology-selected-by-lanzatech-for-lanzajet-sustainable-aviation-fuel-biorefinery/*

# Freedom Pines Fuels Organization

**LanzaTech**

DOE Project Liaison
DOE Project Financial Controls
Government Relations

Sr. Technology Specialist

**LanzaJet**

Product Compliance Manager

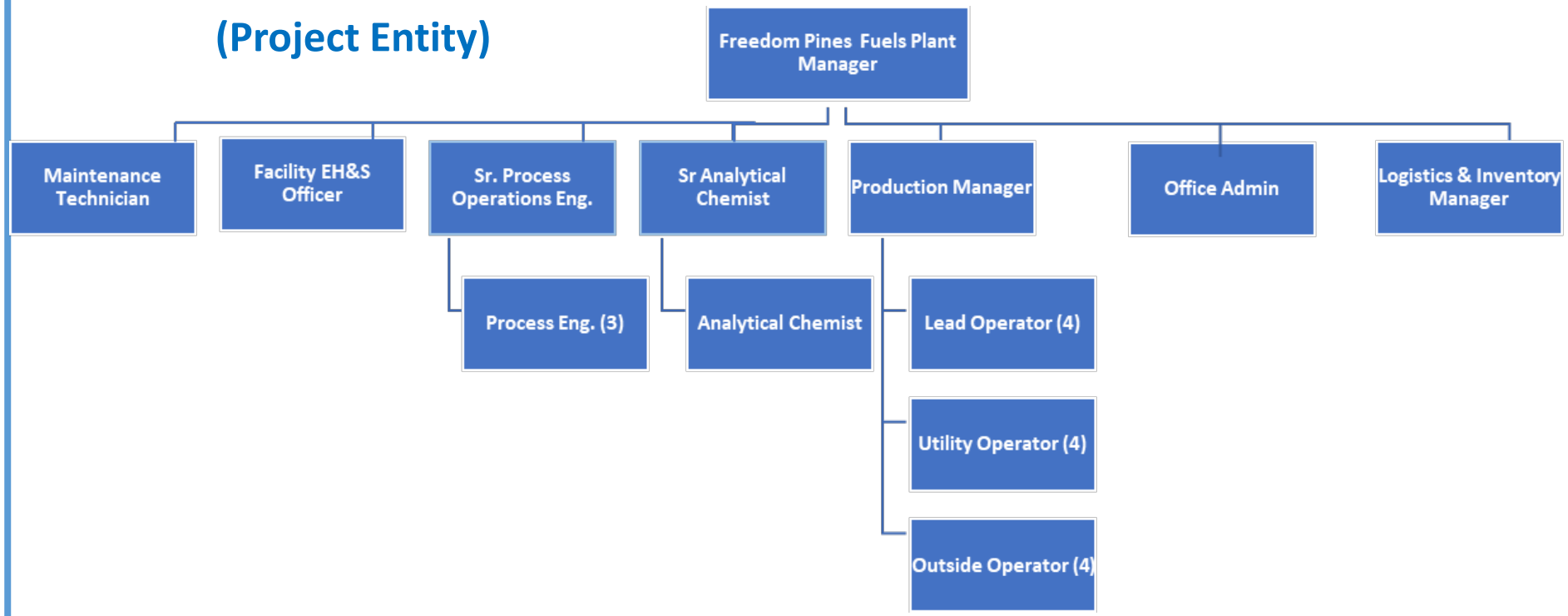
Sr Accountant / HR

**LanzaTech Freedom Pines Biorefinery**

Site Host
Site Security
IT & Instrumentation Support
EH&S Support
Facilities Maintenance Support
Utilities

## Freedom Pines Fuels

### (Project Entity)



# Project Risks

**Risks**

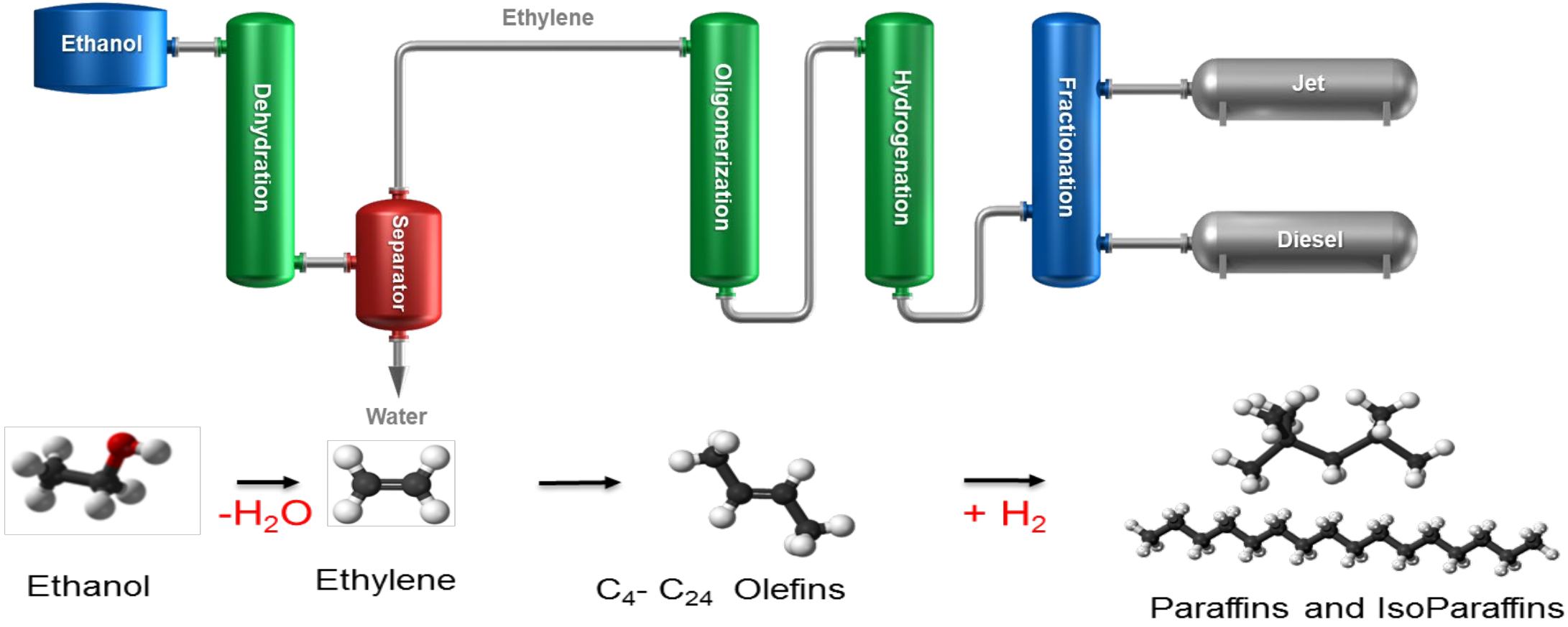
- Technical risk – first-of-a-kind demonstration of ethanol-to-jet technology at this scale
- Financing risk – raising equity and debt in an economic downturn
- Feedstock supply – securing quantities that meet offtaker requirements
- Offtake agreements – given pandemic impact on airlines

**Mitigation**

- Technology validated at multiple prior scales; strong technology partners
- Equity raised in advance; pursuing USDA Loan Guarantee
- Feedstock secured for demonstration; letters of intent with multiple suppliers for production
- Offtake agreements in place

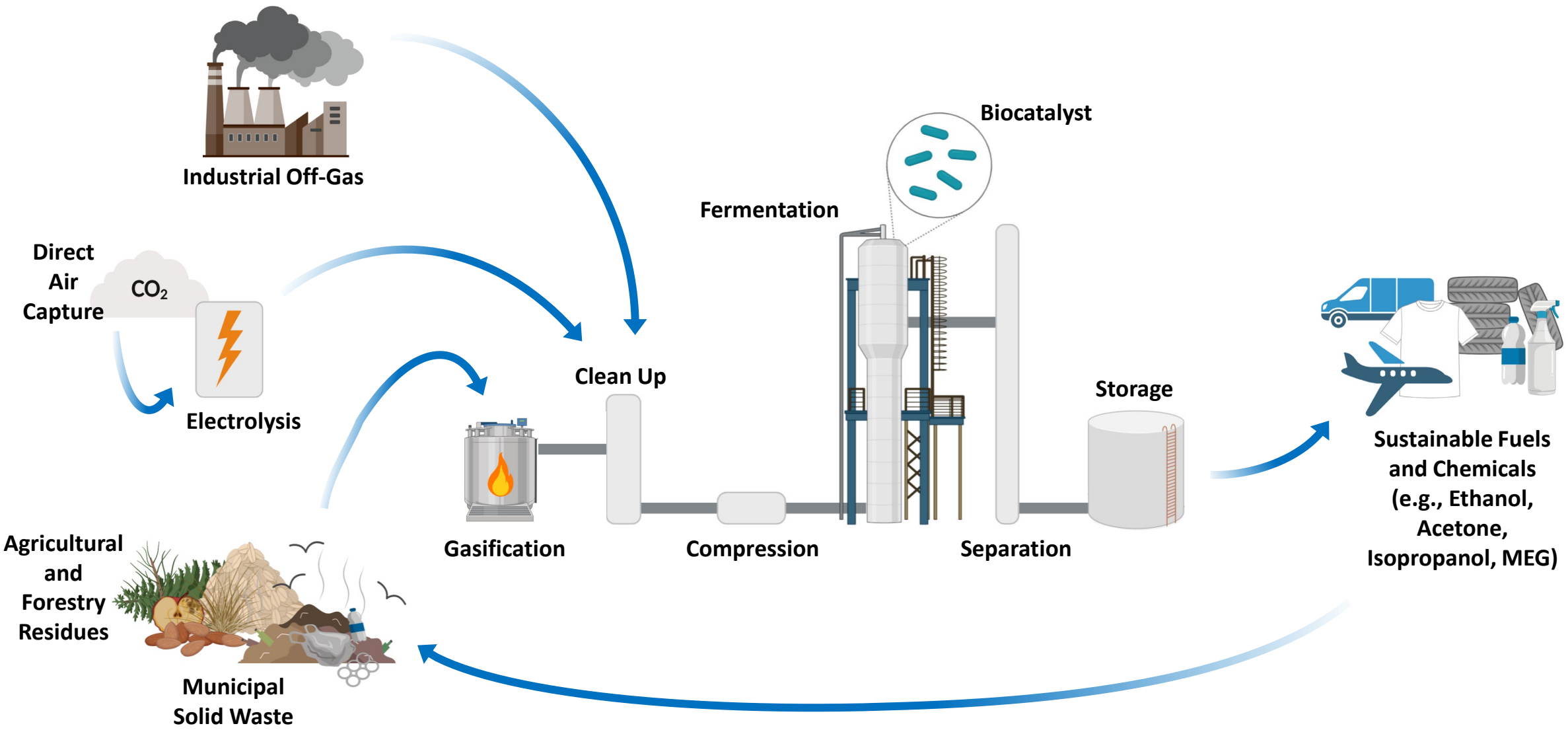
# 2 - Approach

# Why Ethanol-Based Alcohol-to-Jet?




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

# How did we get here - recycling waste carbon to ethanol




**Starting 2005: developed platform for low-cost ethanol and other chemicals**
**>100,000 hours of operation at multiple pilot, demo facilities**

# Global ethanol platform build out

# How did we get here – ethanol to sustainable aviation fuel

***LanzaTech-PNNL Cost-Shared Competitive Awards***

***Cost-shared CRADA***

2010 – 2011

**Ethanol to Jet**

Imperium renewables

Pacific Northwest NATIONAL LABORATORY

1 gal/yr

**Upgrading of TC Intermediates**

2012 – 2016

**Biomass to Jet & Chemicals**


1 to 5 gal/yr

**PD2B3**

2016 – present

**Industrial Gas to Jet**

10M gal/yr

***Commercialization Activities***

**LanzaTech**

- Catalyst scale-up and optimization for manufacturing
- Process scale up and integration of process units
- Field piloting (50,000 gal/yr capacity)
- Fuel production (4000 gal jet, 600 gal diesel)
- Obtained ASTM qualification (led ASTM committee, produced Research Report for OEM review and approval)
- Developed modular engineering strategy and technology partnerships
- Developed commercialization strategy and secured investment
- Selected site and proceeded with environmental and engineering activities

**PNNL**

- Catalyst lifetime studies and initial scale-up
- Samples and testing in support of ASTM qualification (AOP & Lab funding)
- ATJ process intensification (TCF funding)

# Key Challenges

## Technology and Cost Risks

- Technology risks addressed by prior scale data
- Unit operations well-understood from refining and petrochemicals
- Ethanol-to-ethylene partner, Technip, with global experience in commercial ethylene plants
- Cost risk minimized through firm, fixed-price agreement for ISBL

## Business Risks

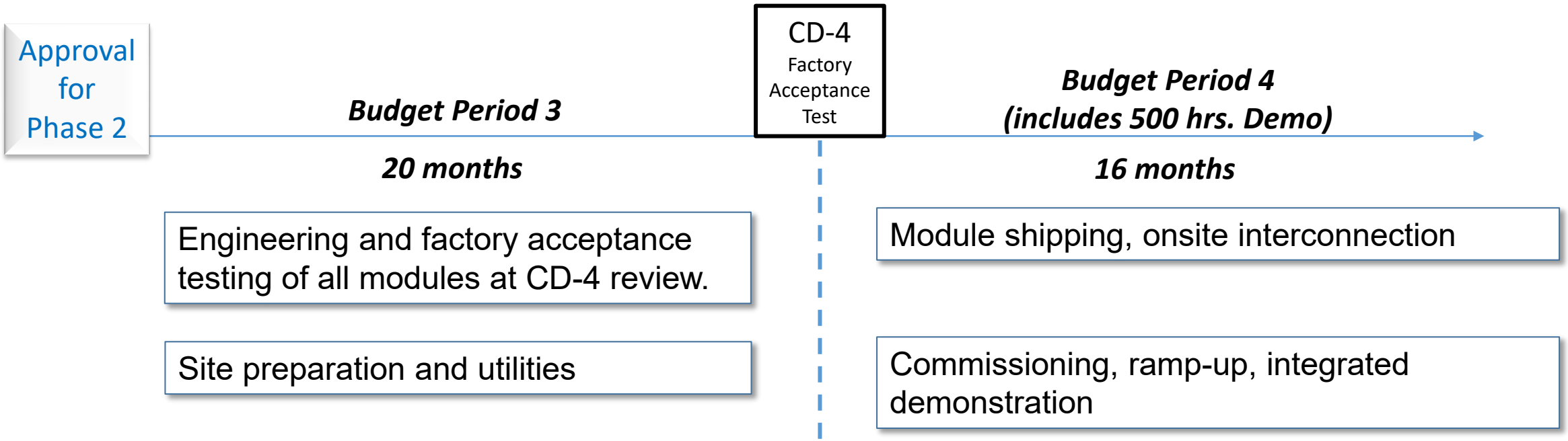
- Feedstock supply and cost depend upon offtaker requirements; suppliers identified
- Offtake risks addressed by existing commitments
- Financing risk reduced by advanced commitment of equity and USDA Loan Guarantee (in process)

## Policy and Regulatory Risks

- Existing policies support SAF and diesel products
- Registration of RFS pathways initiated
- RIN category and LCFS credits dependent on ethanol source

***Risks systematically reduced at each stage of project development***

# High-Level Phase 2 Structure and Go/No-go Points




Phase 2 goal is to demonstrate a fully integrated capability to selectively produce jet fuel and diesel – from a variety of ethanol heritages – at rates above and beyond that required by the PD2B3 FOA

# Scope of Phase 2 tasks within PD2B3

CD-4
Factory Acceptance Test and DOE IE Validation

Inform design and construction of commercial ATJ facilities

## *Budget Period 3*

*20 months*

- Detailed and final engineering for ISBL & OSBL
- ATJ process equipment acceptance*
- OSBL engineering and site prep
- Staffing for operations; operations and maintenance training
- Permitting and regulatory compliance

** Fabrication & assembly are out of DOE scope*

## *Budget Period 4 (includes 500 hrs. Demo)*

*16 months*

- ATJ module shipping, reassembly, interconnection, and pre-commissioning
- Start-up and commissioning
- Fuel production ramp-up
- 500 hour integrated demo
- Updated LCA and TEA
- Final report detailing technical and commercial status

# 3 - Impact

# Ethanol-based ATJ offers a new source for Sustainable Aviation Fuel meeting Renewable Fuel Standard Advanced or Cellulosic Biofuels criteria

## Lifecycle GHG Emissions for LanzaJet™ ATJ

| **Units** (g-$CO_2$e/MJ of ATJ-SPK or ATJ-SPD) | **Corn Starch Ethanol** | **Corn Stover Ethanol** | **Corn Kernel Fiber Ethanol** | **Waste Gas Ethanol (China)** | **Sugarcane Ethanol (Brazil)** |
|---|---|---|---|---|---|
| Ethanol Feedstock<br>Ethanol Transport<br>LanzaJet™ ATJ Process<br>ATJ-SPK/SPD Transport<br>ATJ-SPK/SPD Distribution | **64.7** | **3.5** | **36.1** | **45.2** | **8.3 – 36.9** |
| **Emissions Reduction over Fossil Baseline, %** | **30%** | **96%** | **61%** | **51%** | **61 - 91%** |

## GHG Emissions of LanzaJet™ ATJ

- GHG emissions dominated by ethanol feedstock
- ATJ-SPK from **corn stover** ethanol and **corn kernel fiber** ethanol both qualify as **Cellulosic Biofuels (≥ 60% reduction)**
- ATJ-SPK from **sugarcane ethanol** would qualify as an **Advanced Biofuel (≥50% reduction)**
- ATJ-SPK from corn starch ethanol would qualify as a renewable fuel (≥20% reduction)
- ATJ-SPK from **waste gas** ethanol is not currently accepted under RFS but would qualify as an Advanced Biofuel with a **51% reduction**

## Further Opportunities to Reduce GHG Emissions

- Solar Electricity: Georgia regulations allow use of solar electricity "behind the meter", which satisfies RFS, LCFS requirements;site is well-suited for solar installation.
- Hydrogen produced by electrolysis: small contribution - actual impact depends on how solar energy accounting and delivery are handled
- Biogas: purchase agreement to offset natural gas use during steam generation
- Biogas - largest emissions reduction but solar likely better economics.
- Options continue to be evaluated from LCA and economic perspectives

# Progress has triggered international initiatives

## *UK Department for Transport: Stage 1 Project Development*

News story

**Government funding boost for low carbon fuels development**

First stage winners of the Future Fuels for Flight and Freight Competition announced.

Published 18 June 2018
From: Department for Transport and The Rt Hon Jesse Norman MP

https://www.gov.uk/government/news/government-funding-boost-for-low-carbon-fuels-development

## *Horizon 2020 Grant: Fuel via Low Carbon Integrated Technology from Ethanol (FLITE Consortium)*


**Building Europe's first of its kind Alcohol-to-Jet production plant**

*Sustainable aviation fuel produced from waste-based ethanol resources*

**The FLITE consortium, led by SkyNRG and with LanzaTech as the technology provider, will build the first-of-its-kind LanzaJet™ Alcohol to Jet (AtJ) facility. The facility will convert waste-based ethanol to sustainable aviation fuel (SAF) at a scale of over 30,000 tons/yr. The project received €20 million in grant funding from the EU H2020 programme and is a major milestone on the path to a net-zero emission for the aviation industry.**

https://skynrg.com/press-releases/building-europes-first-of-its-kind-alcohol-to-jet-production-plant/

# LanzaJet business model accelerating commercial deployment

LanzaJet

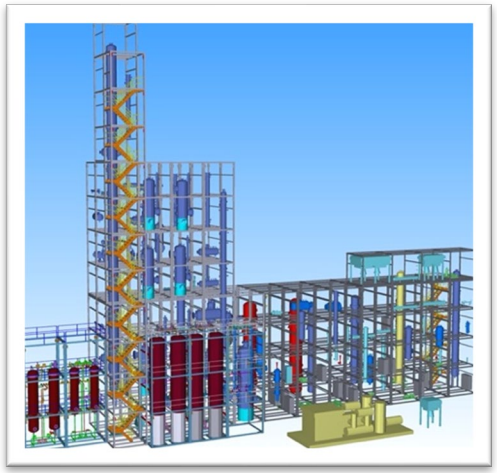
LanzaTech

SUNCOR

MITSUI & CO.

BRITISH AIRWAYS

ANA



**Freedom Pines Biorefinery**
Georgia, USA
**Demo Scale**
2014 - 2016

**Freedom Pines Fuels**
Georgia, USA
**10M GPY (37M LPY)**
2022

**FLITE (LanzaTech)**
Western Europe
**13M GPY (49M LPY)**
2024

**4 Commercial Facilities (Core)**
JA, CA, UK1, UK2
**30M GPY each (113M LPY each)**

**+ Commercial Facilities**
EU, US, …
**30M+ GPY (113M+ LPY) each**

2024+



LanzaJet

# Ethanol-based Alcohol-to-Jet (ATJ): Potential for major global impact



***Diverse Ethanol Technologies***

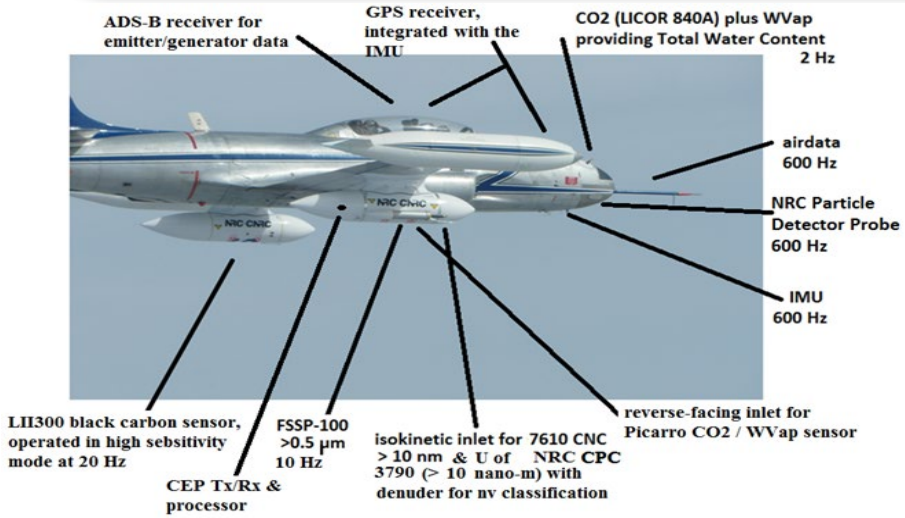
***Abundant, Regionally-Appropriate Resources***

***Ideal Feedstock for Global SAF Production***


# 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 >95% Lower Contrails and Particles**



National Research Council Canada
Conseil national de recherches Canada

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

# 4 – Progress and Outcomes

# Summary of Phase 1 Accomplishments

## Technical

- Implementation site selected
- Existing site services assessed
- FEL-3 (-5/+15%) ISBL and OSBL cost estimates complete.
- E2E technology vendor selected and validated.
- Modular EPC vendor selected.
- Initial data validated by Independent Engineer (IE)
- Two Independent Engineer reviews completed

## Business

- Completed TEA of 10 MGY and 30 MGY facilities, including market and scale-up analyses.
- Freedom to operate and access to all IP secured.
- Ethanol supply agreements for demonstration executed.
- Offtake agreements secured
- Cost share and 25% contingency commitments in place.

## Regulatory

- ATJ-SPK meets ASTM D7566 Annex A5 standard.
- Diesel meets ASTM D975 standard
- LCA validates qualification of fuels under RFS and LCFS.
- Ethanol-based ATJ is recognized under CORSIA.
- Environmental Assessment and Phase 1 Environmental Site Assessments complete
- Permit schedule complete

***CD-3 Review Completed***

# Status of Phase 1 Deliverables from PD2B3 FOA

| Deliverable | LanzaTech Rating |
|---|---|
| FEL-3 Design | Fully Complete |
| Business Plan | Fully Complete |
| Project Management Plan | Fully Complete |
| Risk Management Plan | Fully Complete |
| Regulatory Approval Strategy | Fully Complete |
| Life Cycle Analysis | Fully Complete |
| Technical and Financial Data Sheet | Fully Complete |
| Techno-economic Analysis | Fully Complete |
| Cost Share and Contingency | Fully Complete |
| NEPA Review | Awaiting final FONSI notice |
| Phase 2 Application Documents | In Progress |

# Freedom Pines Fuels: Project Site


*Site previously cleared and leveled – no new land disturbance or wetland impacts*

# Freedom Pines Fuels: Project-Related Staffing

## Freedom Pines Fuels

- Key **project-specific positions** being filled in line with project schedule
- **Plant Manager** – 29 years of industry experience in environmental, chemicals and petroleum refining
- **Project Manager** – 16 years oil and gas company experience
- **Senior Plant Process Engineer** – 25 years of industry experience in high-hazard agricultural chemicals manufacturing
- **Process Engineer** – extensive refinery experience, specializing in Process Safety

## LanzaTech/LanzaJet

- LanzaTech PD2B3 Project team
- LanzaJet CEO, executive, and administrative team hired
- Expanded process engineering and operations staff (LanzaTech, LanzaJet)
- Hired dedicated business development leads (LanzaTech, LanzaJet)
- **Director, Process Engineering (LanzaJet)** – 20+ years of engineering experience in process engineering, design engineering, technology and capital projects execution

# Freedom Pines Fuels: Environmental Status

## Environmental Assessment
## Phase 1 Environment Site Assessment

- Environmental Assessment completed and approved by DOE and USDA NEPA Specialists
- Notice published and public comment period ended Feb
- Finding of No Significant Impact (FONSI) completed by USDA, being finalized by DOE
- Phase 1 Environmental Site Assessment (ESA) conducted to assess prior environmental impacts and potential costs for remediation
- Phase 1 ESA concluded no *Recognized Environmental Concerns* at the site and therefore no Phase 2 ESA is required

## Environmental Permitting

- Site originally permitted for Range Fuels
- Range Fuels' permitted limits exceed needs of FPF
- Permit consultants selected; initiating work in March
- Weighing pros and cons of amending current permit vs. acquiring new permit
- Includes air, water, and Spill Prevention, Control, and Countermeasure (SPCC)
- No critical path impacts

# Freedom Pines Fuels: Engineering Status

## Inside Battery Limits (ISBL)

- ISBL engineering continuing
- HAZOP in process (March 22 - April 16)
- Initiating
  - Frame Fabrication Design
  - Isometrics
  - Control Design
- Ongoing schedule recovery options

## Outside Battery Limits (OSBL)

- Detailed utilities calculations enable OSBL work to begin
- Front-End Engineering Design (FEED) contractor selection complete
- Evaluating contracting strategy (EPC or EPCM)
- Target execution of FEED cost-reimbursable contract end March
- In parallel, developing design basis documents for OSBL systems

# Summary

# Summary

1. **Environmental reviews complete** and FONSI in process
2. **Funding advanced** with equity secured and late stages of Phase 2 USDA Loan Guarantee
3. **DOE Phase 2 negotiation** for $14M investment in progress
4. **ISBL agreement executed** and work kicked-off in January
5. **OSBL FEED** contractor evaluation complete, initiate work in April
6. **Ethanol sourcing and fuel registration** ongoing in conjunction with offtake agreements
7. **Staffing underway** to meet project timeline

# Quad Chart Overview

## Timeline

- 1/15/2017
- 12/31/2020 (pending Phase 2 approval)

| | FY20 Costed | Total Award |
|---|---|---|
| **DOE Funding** | $404,441 | $4,994,107* |
| **Project Cost Share** | $453,655 | $5,266,115 |

## 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

## Project Partners

- LanzaJet
- PNNL, Technip (Michigan Tech)
- Zeton, EPC

## Funding Mechanism

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

*Includes $1,000,000 added to Phase 1 award

# Additional Slides

# Responses to Reviewers Comments

# LanzaTech response to reviewer comments – Technical

| Weakness from 2019 DOE Review | LanzaTech Response |
|---|---|
| $H_2$ requirement & Carbon intensity:<br>• Concern that diversion of current hydrogen use within refineries would impact fossil operations<br>• Most current $H_2$ sources are from fossil operations | • Project cost includes $H_2$<br>• Only 1 $H_2$ per molecule hydrocarbon (mono olefins) - 1/3 to 1/6 of the $H_2$ required by HEFA or FT<br>• Minor LCA impact; all LCA to-date assume $H_2$ from SMR. Green $H_2$ will further reduce carbon intensity |
| Carbon conversion efficiency:<br>• Lacking a discussion of overall carbon conversion efficiency<br>• Lacking LCA discussion over the total process; ie, not certain what a 75% in GHG refers to | • Overall carbon efficiency is 98%.<br>• Since LT ATJ uses ethanol as feedstock, the reduction in carbon intensity of the final SPK SAF is largely determined by ethanol feedstock<br>• 75% was for ethanol and ATJ production exclusive of transportation; results presented here include transportation of feedstock and product |
| Go/No-go:<br>• Go/no-go decision still pending<br>• No cost extension pending | • The project has successfully passed two Go/No-go decisions (Validation and CD-3 review)<br>• The project received a no-cost extension to 12/31/2020; next extension will be based on approval for Phase 2. |

# LanzaTech response to reviewer comments – Economic

| Weakness from 2019 DOE Review | LanzaTech Response |
|---|---|
| Ethanol supply:<br>• Concerns on identifying sources for sufficient quantities of ethanol<br>• Reliance on cellulosic ethanol feedstock will limit initial adoption | • Ethanol for demonstration secured from domestic corn-kernel fiber producers and LT China plant<br>• LanzaJet is in negotiations with multiple suppliers for cellulosic and low-CI ethanol for mid-term operations<br>• LanzaTech is engaged with others to develop cellulosic ethanol projects based on gasification & fermentation<br>• Multiple global ethanol traders are bidding to be ethanol supplier |
| Offtake:<br>• May be underestimating time and complexity for completing agreements | • All offtake has been spoken for as noted in slides<br>• Additional offtakers are negotiating for a share of offtake from current commitments<br>• Specifics of offtake agreements are confidential. |
| RIN, LCFS credit requirement:<br>• Did not address cost point for commercialization in terms of meeting $/<br>• Need RINs and LCFS to be successful | • “Credits” from low-carbon ethanol are included in ethanol feedstock price; The fully-loaded cost is below $3/gge, net of incentives<br>• Pricing model has been accepted by off-takers |

# Publications, Patents, Presentations, Awards, and Commercialization

# Awards and Publication

**PNNL and LanzaTech**

- 2019 “Excellence in Technology Transfer Award” from Federal Laboratories Consortium for Technology Transfer (FLC)

**PNNL and LanzaTech**

- 2020 Innovation Research Interchange (IRI) Achievement Award

**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