# DOE Bioenergy Technologies Office (BETO) 2022 Project Peer Review

# Novel Method for Biomass Conversion to Renewable Jet Fuel Blend

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System Development and Integration

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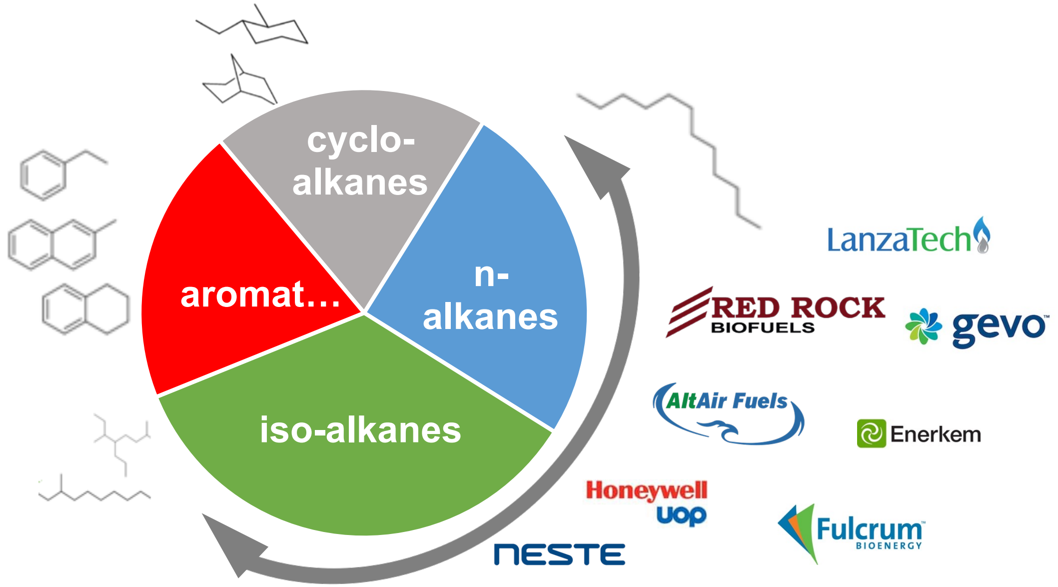
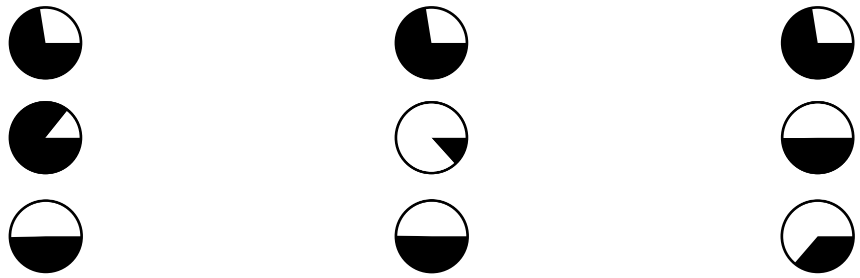
# Project Overview

- *Higher Energy Density drop-in renewable jet fuel blendstock*
- *Project goal: Develop the process to produce renewable superior jet fuel blend*
- ***Project Description***
  - *Commercialize renewable jet fuel*
  - *Current Alternatives: Petroleum derived jet and Hydrotreated renewable (F-T fuels) or hydrotreated esters and fatty acids (HEFA)*
  - *Important to demonstrate superior jet fuel from biomass*
  - *Risks: First of a kind plant capital, competition with petroleum jet*

# The Problem: SAF Technical Attributes



| | HEFA | FT-SPK | ATJ |
|---|---|---|---|
| Energy Density (MJ/L) | | | |
| Biogenic Carbon Yield (%) | | | |
| % of Blend SAF | | | |
| Aromatics Needed? | Yes | Yes | Yes |
| Current Players | NESTE, AltAir Fuels, Honeywell UOP | RED ROCK BIOFUELS, Fulcrum BIOENERGY, Enerkem | gevo, LanzaTech |

### Key Issues in Aviation:

- Aviation is the hardest sector to decarbonize and represents ~1 gigaton [(1)] of annual $CO_2$ emissions (12% of total transport $CO_2$ emissions)
- Current aviation fuel demand is ~360BN liters, and demand is projected to be ~800BN liters by 2050

### Key Issues with Current SAF Processes:

**Current SAF processes are based on modifications of established procedures, like FT-SPK and ATJ, and produce n-alkanes and iso-alkanes that have:**

- Lower energy density than permitted standards
- O-ring swelling considerations
- Substandard and limited economical viability
- Need for petroleum-based additives
- Requires use of aromatics, which have issues with contrails

(1) 2019 figure sourced from June 2020 IEA report

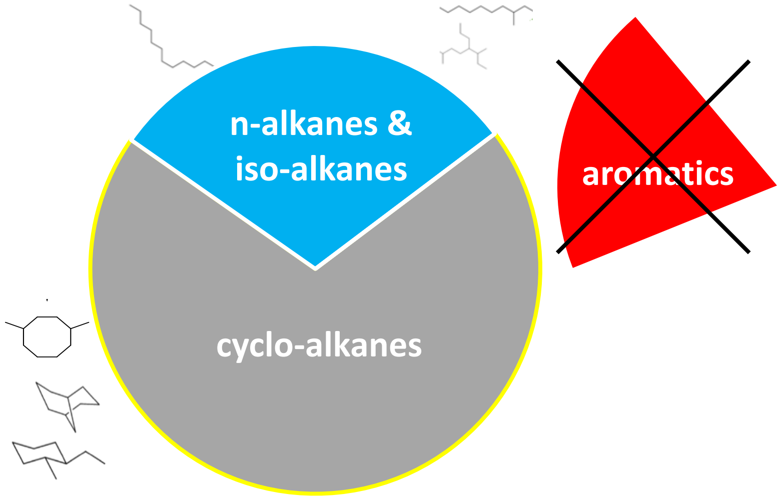
Source: EIA, Statista

# Fundamental Redesign of Superior SAF

| | |
|---|---|
| Process | CJ CycloSAF |
| Product | SAF |
| Key Takeaways | Superior energy density; no aromatics; petroleum-free 100% “drop-in” |
| Energy Density (MJ/L) | [redacted] |
| Biogenic Carbon Yield (%) | [redacted] |
| % of Blend SAF | [redacted] |
| Aromatics Needed? | No aromatics needed |

**CleanJoule SAF…**

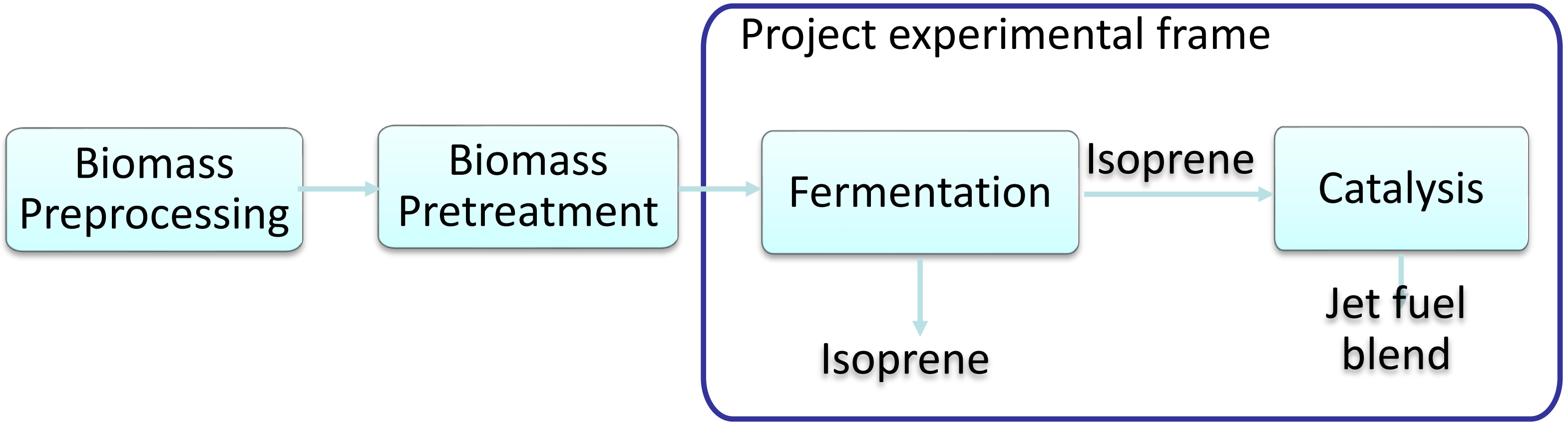
- *More Sustainable*
- *Longer Range*
- *High Quality*
- *More Efficient*
- *No Blend Needed*

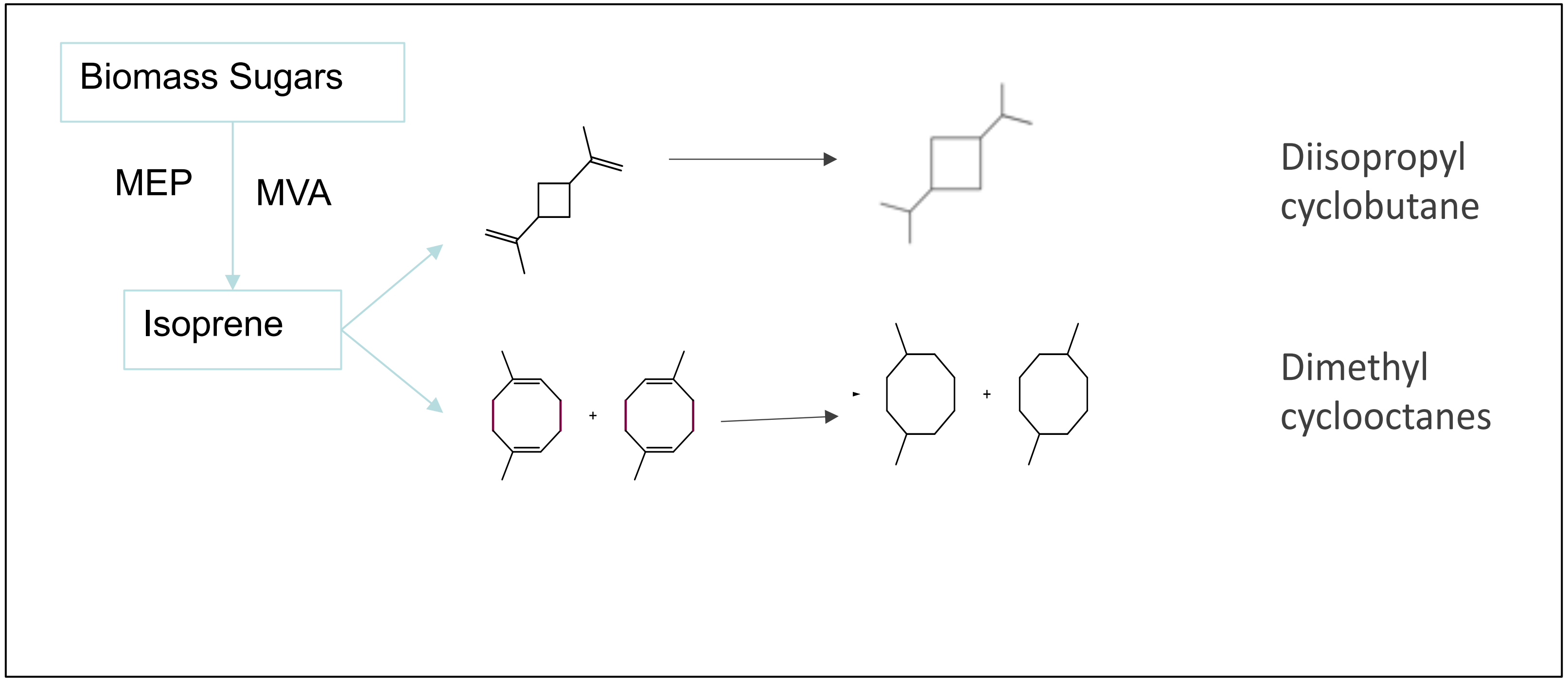



Market size for CycloSAF: 70 Billion Gallons

- ✓ Has Higher Energy Density
- ✓ Has Higher Biogenic Carbon Yield
- ✓ Produces SAF at Low Temp and Low Pressure
- ✓ Is Aromatics Free
- ✓ Fits in Existing Infrastructure
- ✓ Makes Full SAF Tank (100% Drop-in SAF)
- ✓ Highly sustainable (Carbon neutral to negative)

# 1 – Approach




- *Optimize and scale-up isoprene production using biomass hydrolysate*
- *Optimize the catalytic conversion of isoprene to drop-in jet fuel blend to produce higher specific energy jet fuel*
- *Process integration*
- *Deliver 100 gallons of fuel blend for characterization*
- *Develop overall process system, LCA and TEA models*

# 2 – Progress and Outcomes

- ✓ BP1 (verification) Go/No-Go (task 1)
- ✓ Successful chromosomal integration (2.1)
- ✓ Performed directed evolution using biomass hydrolysate (Milestone 2.2)
- ✓ Master cell banking (Milestone 2.3)
- ✓ Bioreactor parametric optimization (3.1) - 2X improvement in titer of isoprene compared to verification period (in progress)
- ✓ Catalyst optimization for DIPCB (4.1)
- ✓ Catalyst/Activator Optimization for Hydrogenation Protocols (4.2)
- ✓ Integrated cyclodimerization and hydrogenation (4.3)
- ✓ Produced 4 Liter DMCO for detailed characterization as a blend with HEFA and jet A (6.1)
- ✓ Pilot plant design in progress (Task 7)

# 3 – Impact
# ASTM D7566 Table 1

| Property | DMCO / HEFA Blend | ASTM D7566 / ASTM D1655 |
|---|---|---|
| Density (g/mL) | 0.780 | > 0.775 |
| η(-20 °C) [$mm^2 s^{-1}$] | 5.03 | < 8.0 |
| η(-40 °C) [$mm^2 s^{-1}$] | 10.54 | < 12 |
| NHOC (MJ $kg^{-1}$) | 43.76 | > 42.8 |
| Flash Point (°C) | 51 | > 38 |
| Corrosion (No.) | 1A | 1 |
| Smoke Point (mm) | 49.4 | > 25 |
| Conductivity (pS/m) | STADIS | STADIS 50-600 (Jet-A) |
| Simulated Dist. (T50-T10) | 28.5 | > 15 |
| Simulated Dist. (T90-T10) | 104 | > 40 |
| Exist. Gum (mg/100 mL) | 4 | < 7 |
| Lubricity (mm) | 0.734 | < 0.85 |
| Thermal Stability | Code: 1; pressure drop (0 mmHg); deposits (7.050 nm) | Code (<3); pressure drop (<25 mmHg); deposits (<85 nm) |
| Acidity (mg KOH/g) | 0.001 | < 0.10 |
| Derived Cetane No. | 44.1 | > 30 |

*TSI of DMCO is 10.8 compared to jet fuel at 15-29*

**D7566 Requires:**

DMCO: Dimethyl cyclooctane
HEFA: Hydrogenated esters and fatty acids

**Aromatic content of 8-25% (O-ring swelling properties of DMCO will be sufficient for operability)**

Zero-aromatic SAF will reduce coking, emissions and potentially reduce maintenance requirements

**Mercaptan mass percent of less than 0.003% (Not measured since feedstock contains no mercaptans)**

**Maximum sulfur content 0.3% (zero to trace sulfur in the SAF, lubricity requirements met)**

**Freezing point of <-40 °C (DMCO freezing point <-78 °C. HEFA – not measured, however a viscosity value at -40 °C suggests lower freezing point)**

***DMCO eliminates the need for blending with petroleum***

# 3 - Impact
# 10:90 Blend Test Results

| Property | 10:90 DMCO:Jet-A | ASTM D7566 |
|---|---|---|
| Density (g/mL) | 0.808 | > 0.775 |
| η(-20 °C) [$mm^2s^{-1}$] | 4.10 | < 8.0 |
| η(-40 °C) [$mm^2s^{-1}$] | 8.03 | < 12 |
| NHOC (MJ $kg^{-1}$) | pending | > 42.8 |
| Flash Point | pending | > 38 |
| Corrosion (No.) | 1A | 1 |
| Smoke Point (mm) | pending | > 25 |
| Conductivity (pS/m) | 255 | 50-600 (Jet-A) |
| Simulated Dist. (T50-T10) | 34.3 | > 15 |
| Simulated Dist. (T90-T10) | 102.6 | > 40 |
| Exist. Gum (mg/100 mL) | pending | < 7 |
| Lubricity (mm) | 0.590 | < 0.85 |
| Thermal Stability | Code: 1; pressure drop (13 mmHg); deposits (10.8 nm) | Code (<3); pressure drop (<25 mmHg); deposits (<85 nm) |
| Acidity (mg KOH/g) | 0.013 | < 0.10 |
| Derived Cetane No. | 43 | > 30 |

***D7566 Table 1 properties met with 10:90 DMCO and Jet A blend***

# 3 – Impact

- *Feasible to replace aromatics (ring swelling issue addressed)*
- *In-service Engine maintenance addressed*
- *Co-product (intermediate) isoprene as a feedstock to chemical industry*
- *In discussions with one Aircraft manufacturer and two Oil and Gas Companies*
- *Interest from Air Force Research Laboratory for defense applications*
- *Interest from various segments of the US Navy*

# Path to ASTM Certification

Tier 1 Spec Tests: upto 10 Gallons
Tier 2 FFP: 10 – 100 gallon
Tier 3:
Component and Rig Tests: 250 -10,000 gallons
Engine Tests: upto 225,000 gallons

- **Phase I (Initial screening)** → Tier 1 (Specification Properties) → Tier 2 (Fit for purpose properties)
- **Phase II (Follow-on Testing)** → Tier 3 (Component Rig Testing) → Tier 4 (Engine / APU Testing)
- **Balloting and Approval** → FAA Review → ASTM balloting → ASTM Specifications

# Summary

- Meets ASTM D7566 Table 1 requirement as a blend with jet A as well as HEFA
- Higher energy content (2.4% higher gravimetric and 4.5% volumetric)
- Promising renewable jet fuel blend
- Valuable intermediate / co-product
- High level of industrial and DOD interest
- Highly favorable full spectrum characterization for blending
- Potential to replace aromatics
- Potentially reduced engine maintenance

# Quad Chart Overview

## Timeline
- 10/01/2018
- 03/31/2023

| | FY22 Costed | Total Award |
|---|---|---|
| **DOE Funding** | $607668.69 | $2,499,999 |
| **Project Cost Share** | $147,870.69 | $625,001 |

TRL at Project Start: 3
TRL at Project End: 4

## Project Goal
Demonstrate techno-economic feasibility of producing high energy density renewable jet fuel blend

## End of Project Milestone
1. Production of 10 gallon finished fuel blend
2. complete a non-location specific basic engineering package (BEP) for the renewable jet fuel engineering scale (1 dry metric tonne per day biomass feedstock) process
3. Detailed fuel characterization profile

Funding Mechanism
FOA: DE-FOA-0001926
Topic Area 1: Drop-in renewable jet fuel blendstocks, FOA year: 2018

## Project Partners
- Princeton University
- Naval Airfare Warfare Center, Weapons Division