DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Enhancing Yields of Renewable Cycloalkanes from Ethanol for Blending with Jet Fuel

April 3, 2023
Session A: Systems Development and Integration
Denver, Colorado

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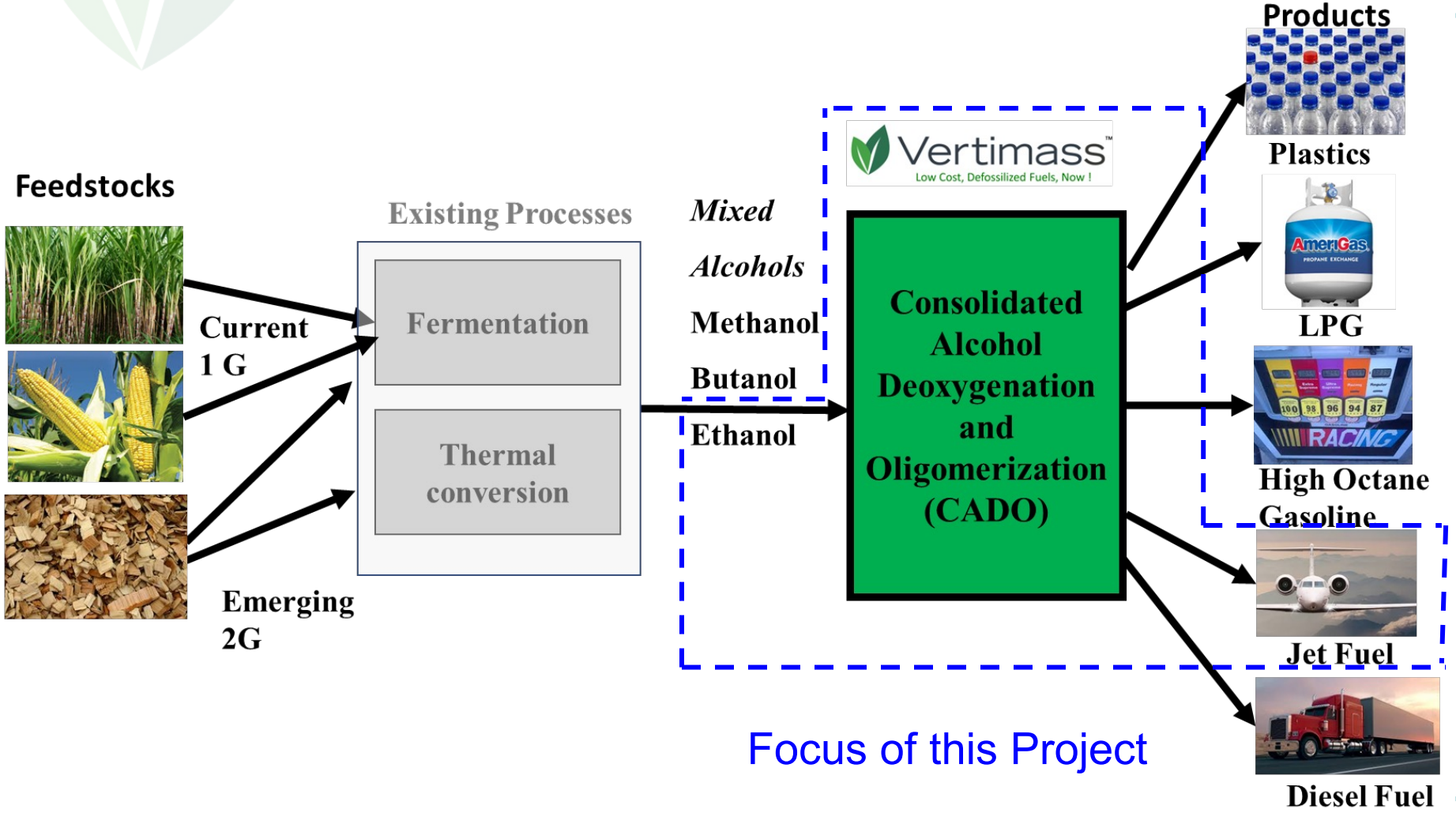
Vertimass™
Low Cost, Defossilized Fuels, Now !

Project Overview (Context): Breakthrough Transforms Alcohols from Biomass into Range of Low-Carbon Hydrocarbon Fuels and Chemicals

Diverse feedstocks support long term business growth

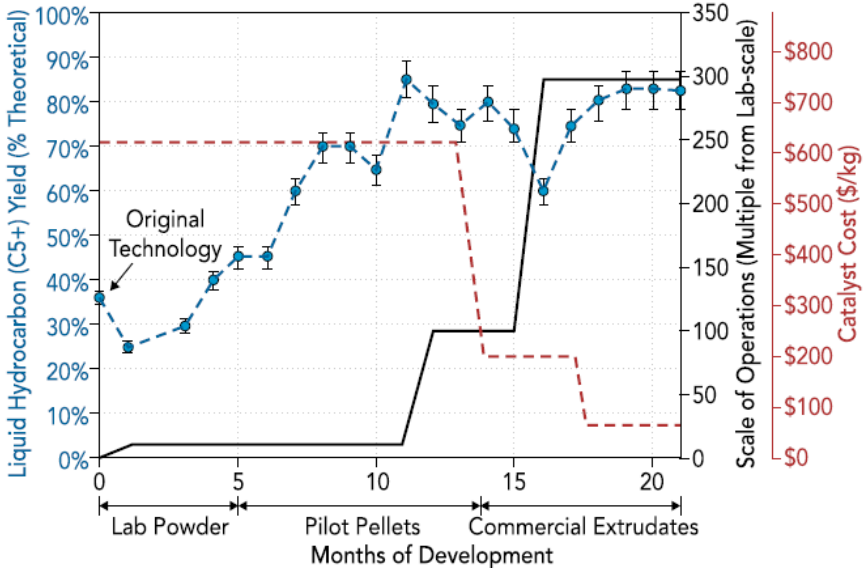


Multiple products provide market flexibility

Project Overview (History & Goals)

Project History:

1) Previous DOE BETO funding advanced the Oak Ridge National Laboratories (ORNL) technology from lab to pilot (TRL 3 to TRL 5) to produce high octane gasoline and building block chemicals BTEX (Benzene, Toluene, Ethyl Benzene and Toluene). Overall Liquid Yields increased from 36% to 82%, Catalyst from powder to low cost commercial extrudates, and 300x scale-up.
2) Publication in *Proceedings of the National Academy of Sciences* (PNAS)by 19 experts from 12 industrial, academic, and national laboratory organizations highlighted these advances (Hannon et al 2019).



Project Goals:

1) Scale-up (pilot to Demo): Technip Energies to obtain engineering data for commercialization. TRL 5 to TRL 7.
2) Shift to SAF products: Shift carbon number range from current C4-C12 to 75% as C7-C17 (jet fuel range).
3) Reduce aromatics: Drop from ~50% to <20% %wt while increasing cycloalkanes to max 30% wt.
4) Target: Increase energy density and minimize emissions

Project Outcomes:

1) One-step Conversion: Minimizes capital investment and operating costs versus conventional ATJ (4-6 step approaches).
2) Dramatic change in biofuels landscape: Opens up hydrocarbon market to ethanol.
3) Ethanol Producer or Stand-Alone Biorefinery: Ability to make high-octane gasoline to eliminate the ethanol “blend wall”, SAF blendstocks that expand ethanol markets, and chemical coproducts (BTEX) and liquified petroleum gases (LPG).
4) Blends of Blends for 100% SAF: High aromatic and cycloalkanes compliment paraffinic products from other SAF routes

1- Approach (Management)

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CLARIANT

T.EN TECHNIP ENERGIES

University of Dayton Research Institute

- Project Structure
  - **Vertimass:** Overall management of the project activities, schedule, and budget to achieve technical goals. Establish Vertimass Laboratory, Lab to enhance SAF, TechnoEconomic Analysis (TEA) lead.
  - **Technip Energies:** Demo scale-up operations provide technical data, scale-up expertise, and hydrogenation and commercialization packages as needed to achieve technical goals.
  - **UDRI:** Initial Product guidance and testing, SAF Fast Track qualification.
  - **Clariant:** Commercial Vertimass catalyst, identify and provide catalysts for alkylation and possible hydrogenation.
- Management Approach
  - Bi-Weekly coordination meetings with Technip Energies (E. Weymouth MA Demo).
  - Quarterly video and in-person meetings with Clariant, Technip Energies, and Vertimass.
  - Planned quarterly meetings with UDRI in BP 3.
  - Monthly conference video updates with DOE BETO and quarterly reports on progress and budgets.

1- Approach (Technical)

- Technical Approach
  - **Scale-up Experts:** Capitalizing on Technip Energies' 40+ years experience, 20+ commercialization successes in scale-up from our Demo scale (E. Weymouth, MA) to commercial operations.
  - **Commercial Catalyst Experts:** Utilizing Clariant's expertise to define most effective catalyst supports.
  - **Parametric Examination:** Optimizing temperature, pressure, space velocity, and catalyst formulations to maximize yields of SAF hydrocarbon blendstocks from ethanol at Demo scale.
  - **SAF Modeling:** Leveraging UDRI expertise on predicting hydrocarbon distributions.
  - **Other SAF Modeling:** Connecting with labs with capabilities to predict SAF properties (Sandia, WSU).
  - **TechnoEconomic Model:** Defining technical opportunities to enhance economics.
  - :**Laboratory Development:** Defining catalyst and operating condition advances at Vertimass Laboratory.
- Top 3 challenges to technical approach (mitigation plans)
  - Ensuring scale-up success through Demo operations (Isothermal, adiabatic, and fluidized bed reactors).
  - Maximizing the shift from gasoline to SAF with commercial catalyst formulations (Clariant catalysts).
  - Qualifying product suitable for jet fuel blending with HEFA, FT, other ATJ SAF, or kerosene.
- Go / NoGo Decision Points (notes)
  - **Go/No Go 1:** Complete initial validation (documenting product yields, product compositional analysis, carbon distribution, energy content, flow rates (scale)) with current catalyst. (passed Mar 2022)
  - **Go/NoGo 2:** Increase average MW of liquid (at room temperature and pressure) hydrocarbon product from current 100% C4-C12 to 75% as C7-C17 (jet fuel range) on ethanol feedstock. (targeting June 2023)

2- Progress and Outcomes

- Technical Progress

  Go/NoGo 1: Passed in March 2022.

  Demonstration Unit: Successfully designed, constructed, and operated Demonstration Reactor unit at Technip Energies.

  Demo Operation: Technip Energies successfully running single step ethanol conversion into hydrocarbons for 6 months now. Technip Energies confirmed they can scale to commercial (up to 1,000,000x scale up, larger than any ethanol facility in the world)!

  Extended Catalyst life: Longer times between regenerations versus daily in pilot unit.

  Vertimass Lab Pilot System: Allows Vertimass to quickly evaluate catalysts from Clariant to accomplish project goals.

  Vertimass Analytical: Allows Vertimass to measure product distributions immediately.

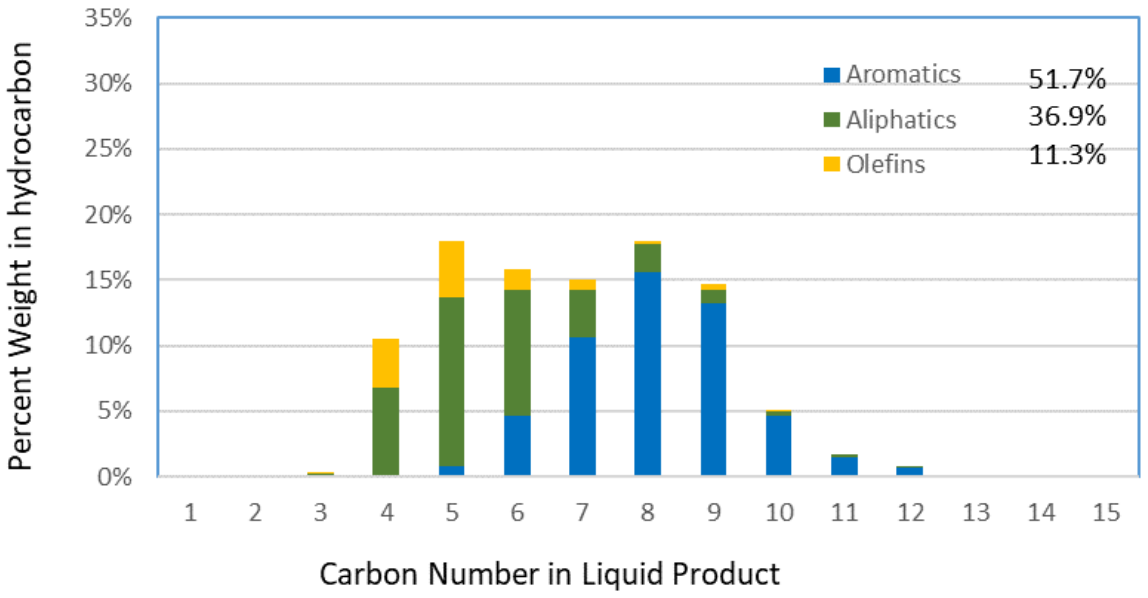
Figures: Clockwise from top left (Demo reactor System, volumes of hydrocarbon product produced daily, Vertimass new lab analytical, Vertimass pilot reactor system

2- Progress and Outcomes

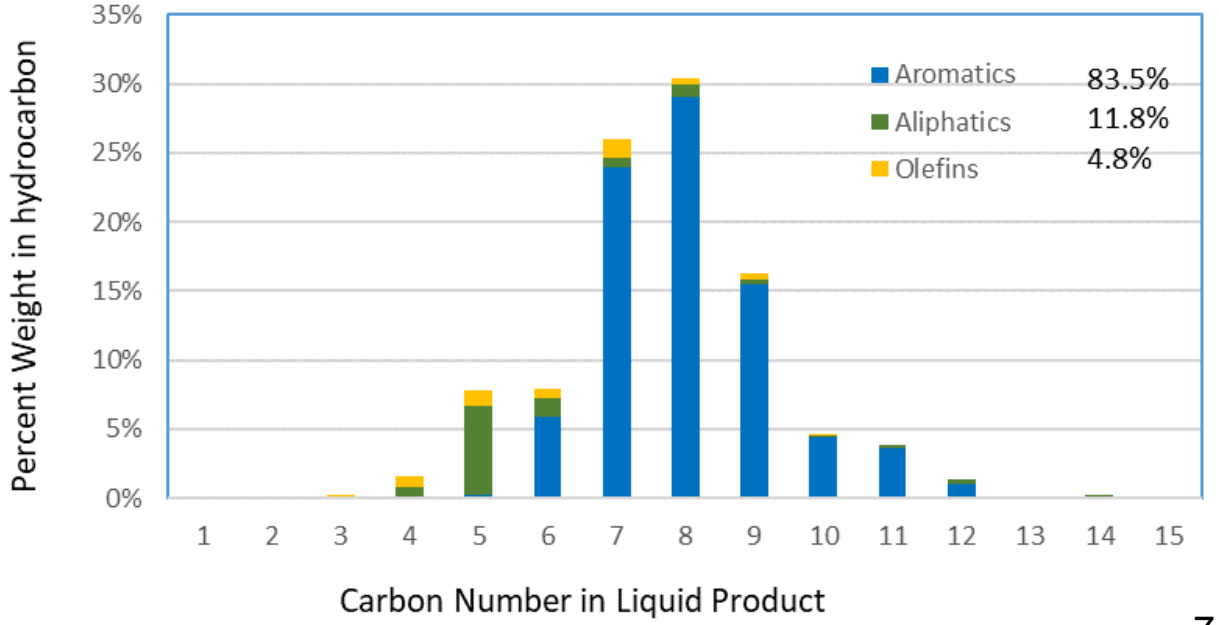
- Technical Progress

Progress on Go/NoGo 2: Increased average liquid hydrocarbon MW from previous 100% C4-C12 to 75% as C7-C17 (jet fuel range) on ethanol feedstock.

Initital Technip Demo Product Distribution
(C7+ 55.3% hydrocarbons)



In Progress Vertimass Pilot Product Distribution
(C7+ 82.5% hydrocarbons)



3- Impact

Technology Impacts:

1) Vertimass Consolidated Deoxygenation and Oligomerization (CADO): Offers novel route for 100% conversion of ethanol and other alcohols into hydrocarbons using single step, low pressure, low temperature process without need for hydrogen versus conventional ATJ (4-6 steps).
2) Drastically Changes Biofuels Landscape: Opens ethanol to hydrocarbon markets.
3) Ethanol Producer or Stand-alone Biorefinery: Producers could make high-octane gasoline to eliminate the ethanol “blend wall,” SAF blendstocks to enhance ethanol markets, and chemical coproducts (BTEX) and liquified petroleum gases (LPG) to further diversify market opportunities.
4) Blends of Blends for 100% SAF: High aromatic and cycloalkanes compliment paraffinic products.

Wider adoption:

1) New partnership and investment (2022) from UGI to produce SAF and LPG (20 plants over 15 years).
2) New partnership (2022) with World Energy to compliment their fuels and chemicals.
3) New partnership (2022) with European Energy to convert methanol from CO_2 into SAFs

Summary

- Vertimass CADO provides a novel route to low-cost, low-carbon fuels and chemicals.
- The wide range of CADO products potentially offers a true biorefinery to maximize profits.
- Vertimass made excellent progress through prior DOE BETO award to advance CADO technology from laboratory to pilot scale (highlighted in *Hannon et al 2019*).
- Vertimass and Technip Energies transition from pilot to Demo operations shows product distribution tunability and extending catalyst life.
- Technip could now scale up to 1,000,000 times larger commercial scale-up plants.
- Vertimass Laboratory has developed approaches to increase molecular weight distribution that are being transferred to Technip and continues to optimize molecular weight distribution.
- Work is in progress to hydrogenate to cycloalkanes and perform fast track qualification with UDRI.
- Vertimass and Technip have initiated engineering of commercial CADO plants.
- Vertimass formed 3 partnership and strategic investments with companies for production of rLPG, high octane gasoline, BTEX, and SAF.

Quad Chart Overview

Timeline

- *March 2022 (Initial Validation)*
- *September 2024*

	FY22 Costed	Total Award
DOE Funding	$123,401	$1,434,738
Project Cost Share *	$44,931	$358,685

Project Goal

Construct and operate a commercially scalable Demonstration reactor to convert ethanol into Sustainable Aviation Fuels focusing on converting SAF aromatics into cycloalkanes, increasing energy density and minimizing particulate emissions.

End of Project Milestone

Qualify Vertimass Jet fuel for minimum10% blend.

Funding Mechanism

DE-FOA-0002029

TRL at Project Start: 5
TRL at Project End: 7

Project Partners*

- Technip Energies
- Clariant
- UDRI

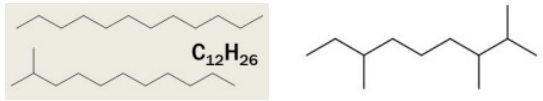
*Only fill out if applicable.

CADO Complimentary to Other SAF Technologies

ATJ / HEFA / FT SAFs

n-alkanes

iso-alkanes



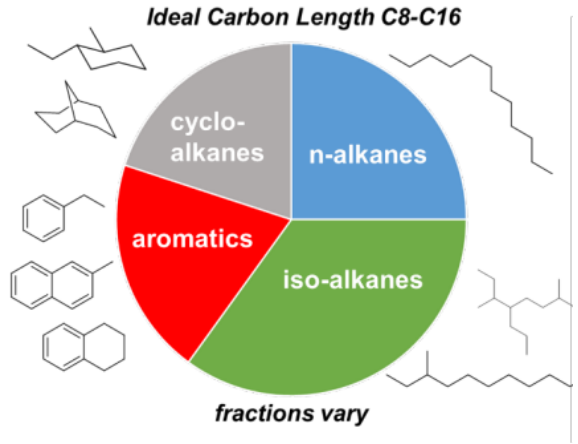
Complementarity enhances blend levels in Jet Fuel

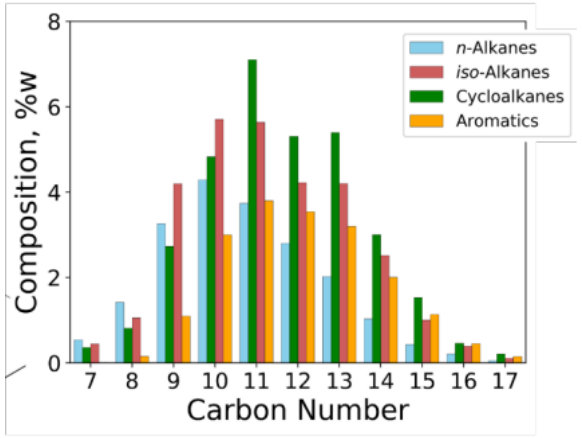
Vertimass SAF

aromatics

cycloalkanes

Ideal Jet Fuel[1]





1. https://www.energy.gov/eere/bioenergy/downloads/sustainable-aviation-fuel-review-technical-pathways-report