2024 Final ESS REPORT (project ongoing)

PROJECT TITLE: Modeling Production of Sustainable Aircraft Fuel from Corn Ethanol and CO2
PROJECT NUMBER: 6129-24DD
REPORTING PERIOD: 4/1/24-3/31/25
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1.) PROJECT ACTIVITIES COMPLETED DURING THE REPORTING PERIOD.

This report provides an interim update on the techno-economic and environmental evaluation of producing Sustainable Aviation Fuels (SAF) through the integration of CO_2 conversion pathways into corn ethanol refinery infrastructure. The study specifically investigates the application of ASTM-approved Fischer-Tropsch (FT), Alcohol-to-Jet (ATJ), and Methanol-to-Jet (MTJ) production pathways, leveraging existing ethanol refinery feedstocks and processes. The following activities have been conducted on this project according to the tasks listed in the work plan for the first year of the project:

This project evaluates the feasibility and benefits of converting CO_2 emissions from ethanol refineries into SAF. The objectives, as outlined in the original proposal, are as follows:

1. **Build a Plant Model**
   Construct a detailed process model for sustainable aviation fuel (SAF) production pathways that align with ASTM standards and are compatible with ethanol refinery feedstocks. This model will focus on Fischer-Tropsch, Alcohol-to-Jet, and Methanol-to-Jet processes, building upon the validated Chippewa Valley Ethanol Company (CVEC) plant model to ensure accuracy and applicability
2. **Conduct Parametric Studies**
   Conduct parametric analyses using the developed model to assess renewable ethanol blends and fuel production potential. Key parameters such as CO_2 flow rates, hydrogen sources, and energy requirements will be evaluated to identify optimal operating conditions and maximize efficiency and sustainability benefits.
3. **Assess Economic Feasibility and ROI**
   Perform a comprehensive cost-benefit analysis to determine the financial viability of implementing a CO_2-to-fuel system at various production scales. This assessment will include operational expenses, hydrogen production costs, CO_2 capture expenditures, and methanol synthesis economics, incorporating tax incentives to evaluate return on investment (ROI).
4. **Refine Reactor Models and Disseminate Findings**
   Modify and optimize reactor models based on insights from simulation results and parametric studies. The final outcomes will be communicated through conference presentations, peer-reviewed journal publications, and direct engagement with ethanol plant operators to promote the adoption of CO_2-to-fuel conversion technologies.

MATERIALS AND METHODS

The methodology employed in this project involves detailed process simulations and comprehensive techno-economic analyses primarily utilizing Aspen Plus software. The Chippewa Valley Ethanol Company (CVEC) plant model, previously validated through empirical data, provides the foundational platform for modeling Sustainable Aviation Fuel (SAF) production pathways and evaluating their feasibility within corn ethanol refinery operations.

Pathway Selection
Based on ASTM D7566 standards, three SAF production pathways compatible with corn ethanol feedstocks and infrastructure were selected for modeling and analysis:

- **Fischer-Tropsch (FT-SPK and FT-SPK/A)**: Pathways approved for up to 50% blending with conventional jet fuels, utilizing syngas derived from CO_2 and hydrogen.
- **Alcohol-to-Jet (ATJ-SPK and ATJ-SKA)**: Pathways utilizing ethanol or mixed C_2–C_5 alcohols as feedstocks, approved for up to 50% blending.
- **Methanol-to-Jet (MTJ)**: Utilizing methanol derived sustainably from renewable natural gas, biomass gasification, or other renewable sources, also suitable for integration with ethanol refinery outputs.

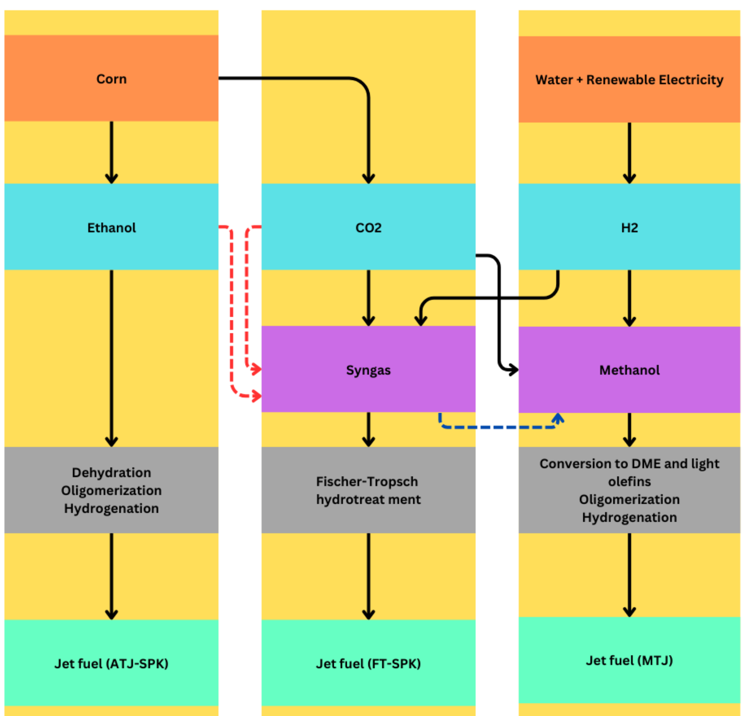

Figure 1 Pathways for conversion of ethanol and Carbon dioxide from ethanol refinery to SAF

Process Modeling
The plant simulation involves defining key unit operations, including reactors, heat exchangers, separators, compressors, and distillation columns. Reaction pathways critical to SAF production were integrated based on validated reaction kinetics and thermodynamic properties:

- **Corn Ethanol Production**:

Saccharification: Polysaccharides to glucose

- **Ethanol Dry Reforming (EDR)** for syngas generation:

$$C_2H_5OH + CO_2 \rightarrow 3CO + 3H_2$$

- **Fischer-Tropsch (FT)** synthesis, producing paraffinic hydrocarbons suitable for aviation fuel:

$$(2n+1)H_2 + nCO \rightarrow C_nH_{2n+2} + nH_2O$$
$$2nH_2 + nCO \rightarrow C_nH_{2n} + nH_2O$$
$$2nH_2 + nCO \rightarrow C_nH_{(2n+1)}OH + (n-1)H_2O$$

  - Hydrogenation:

$$C_nH_{2n} + H_2 \rightarrow C_nH_{2n+2}$$

- **Alcohol-to-Jet (ATJ)** process, involving three steps:

  - Dehydration:

$$C_2H_5OH \rightarrow C_2H_4 + H_2O$$

  - Oligomerization:

$$2C_2H_4 \rightarrow C_4H_8$$
$$nC_2H_4 \rightarrow C_{2n}H_{4n}$$

  - Hydrogenation:

$$C_4H_8 + H_2 \rightarrow C_4H_{10}$$
$$C_nH_{2n} + H_2 \rightarrow C_{2n}H_{2n+2}$$

Overall, assuming that kerosene is $C_{12}H_{26}$:

$$6\ C_2H_5OH + H_2 \rightarrow C_{12}H_{26} + 6\ H_2O$$

- **Methanol-to-Jet (MTJ)** pathways:

Methanol Synthesis:

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$$

Conversion to DME and light olefins:

$$2\ CH_3OH \rightarrow C_2H_4 + C_3H_6 + 2H_2O$$

  - Oligomerization:

$$nC_2H_4 + mC_3H_6 \rightarrow C_{2n+3m}H_{4n+6m}$$

  - Hydrogenation:

$$C_nH_{2n} + H_2 \rightarrow C_nH_{2n+2}$$

Parametric studies are being conducted by systematically varying critical process parameters, including:

- CO_2 feed rates
- Hydrogen source variations (renewable versus non-renewable)
- Energy consumption and efficiency assessments

These parametric analyses help identify optimal conditions that maximize SAF production efficiency and minimize associated costs.

Economic Analysis

Techno-economic evaluation involves estimating capital expenditures (CAPEX) and operating expenses (OPEX). Equipment sizing and costing utilize standard chemical engineering methods (factored equipment cost estimation), incorporating recent literature, industrial cost databases, and published market price projections. Additionally, the economic model incorporates performing sensitivity analyses to evaluate the impacts of key variables like hydrogen costs and CO_2 capture expenses on the Return on Investment (ROI).

Data Sources and Assumptions

Process modeling parameters and economic assumptions are derived from recent literature, publicly available industrial reports, and databases such as DOE reports, IEA studies, and industry benchmarks. Assumptions regarding catalyst performance, conversion rates, energy consumption, market prices, and policy incentives are explicitly detailed to ensure transparency and reproducibility.

2.) IDENTIFY ANY SIGNIFICANT FINDINGS AND RESULTS OF THE PROJECT TO DATE.

Thus far, this project has set up the models necessary to complete the Aspen analysis according to the material shown in Section 1. We are trying to match the distillation curve of SAF in the model to verify that the process is correctly producing the desired product. Once the model is running, we will complete the proposed parametric studies and determine the energy advantages of EDR and CO_2 utilization.

3.) CHALLENGES ENCOUNTERED.

Uncertainty around tax incentives has created uncertainty around the viability of the SAF market. Therefore, this project must ensure that the SAF production pathway from ethanol and CO_2 is economically viable without subsidies created in past years. Without detailed knowledge about capital costs, it will be difficult to fully quantify the true costs of SAF production through the EDR process, but the project will show that it is energetically more favorable than the traditional AtoJ process being considered by most

4.) FINANCIAL INFORMATION

None to report

5.) EDUCATION AND OUTREACH ACTIVITIES.

Thus far, one Ph.D. student has been trained under this project. Based on the analyses completed in this project, she is currently preparing results for dissemination at future conferences.