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Analysis of the bioeconomy for carbon drawdown

Maximizing co-benefits of carbon removal and sustainable aviation fuels production

DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

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Project Overview

- **Scope:** Quantify the technical and economic potential of multiple, diverse bioeconomy pathways that draw down carbon dioxide from the atmosphere. Develop comprehensive integrated lifecycle assessment (LCA) and technoeconomic analysis (TEA) to account for atmospheric, biogenic, and sequestered carbon emissions and the cost investment for negative emission BiCRS pathways.

- **Collaborations:**
  - LLNL (prime)
  - UC Berkeley (subcontract
  - USDRIVE's Net Zero Tech Team (NZTT) with NREL, PNNL and ANL
  - Informal collaboration w U Calgary.

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

Berkeley
UNIVERSITY OF CALIFORNIA

UNIVERSITY OF CALGARY

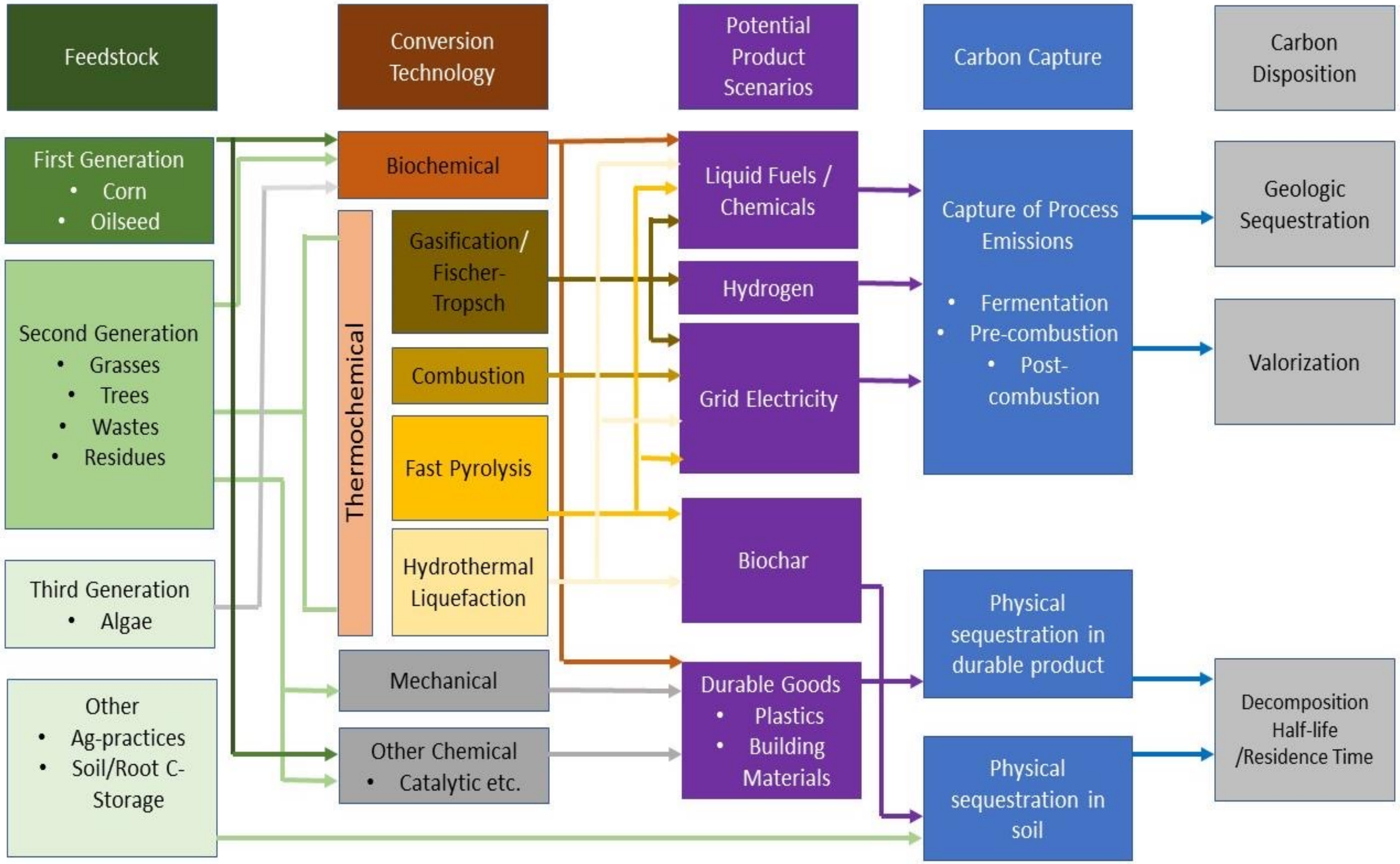
Carbon drawdown is one of the hottest topics in climate technology/policy today.

Approach: integrated process design, TEA and LCA framework

BiCRS Pathways System Analysis	Techno-economic Analysis	Life Cycle Analysis
Select and Innovate BiCRS pathways that permanently immobilize carbon from the air: collaborate and exchange information with the large community of researchers working on BiCRS, CCS, CCU community	Conduct techno-economic analysis on the designed BiCRS system to quantify the costs using discounted cash flow analysis, identify key cost drivers using TEA sensitivity analysis.	Conduct life cycle analysis on the designed BiCRS system to quantify the sustainability and key emission drivers using existing LCA tools. Integrate LCA with TEA using carbon trading system.

Progress and Outcomes: Year 1-2

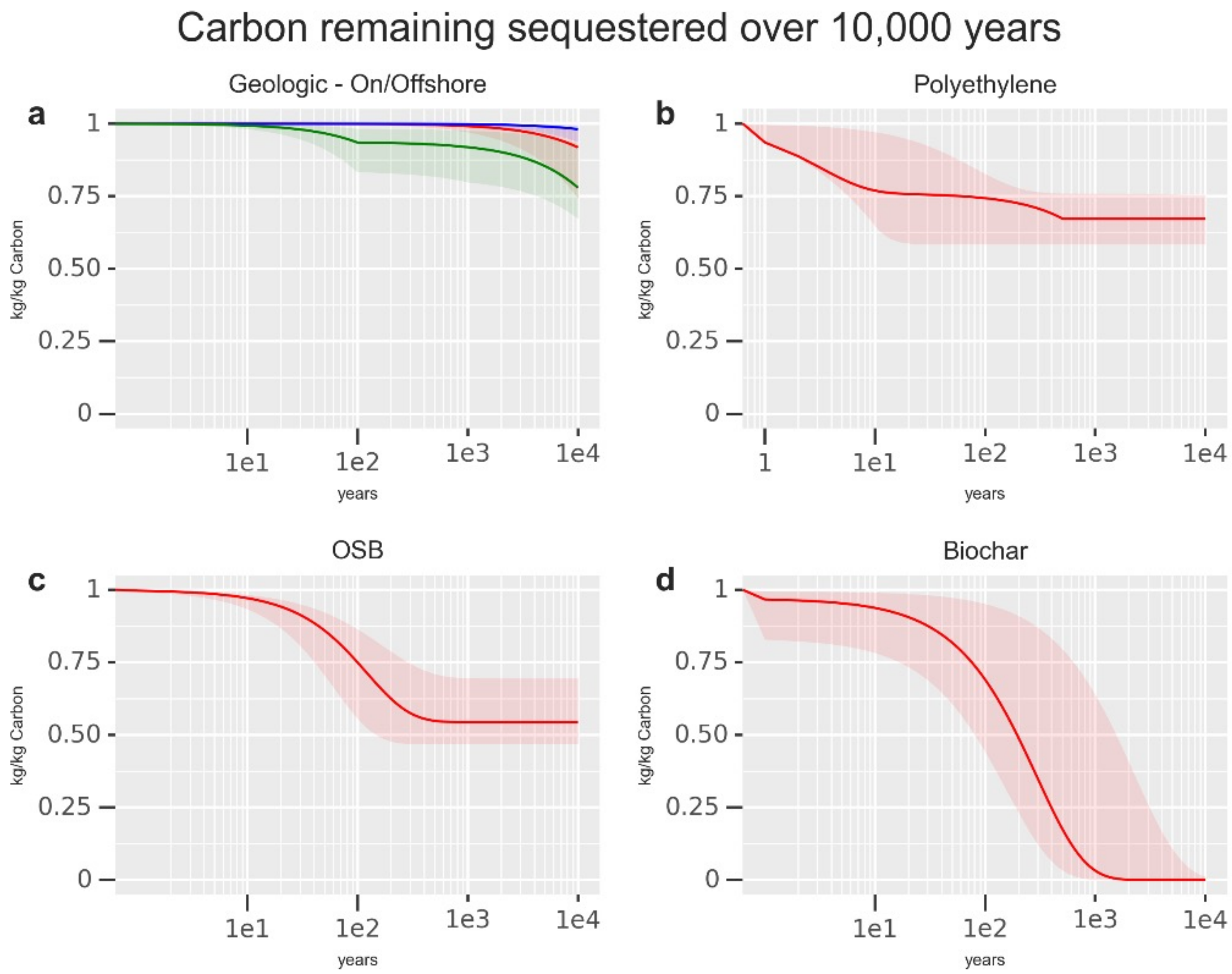
Match different feedstock, conversion technology, product (co-product), carbon sequestration format with high near-term TRL to enumerate the bioeconomy pathways that have drawdown potential.



Progress and Outcomes: Year 1-2

We selected 4 representative BiCRS pathways with different carbon sequestration format.

CO_2, biopolymer, wood products and biochar have different projected end-states and wide bounds of uncertainty.

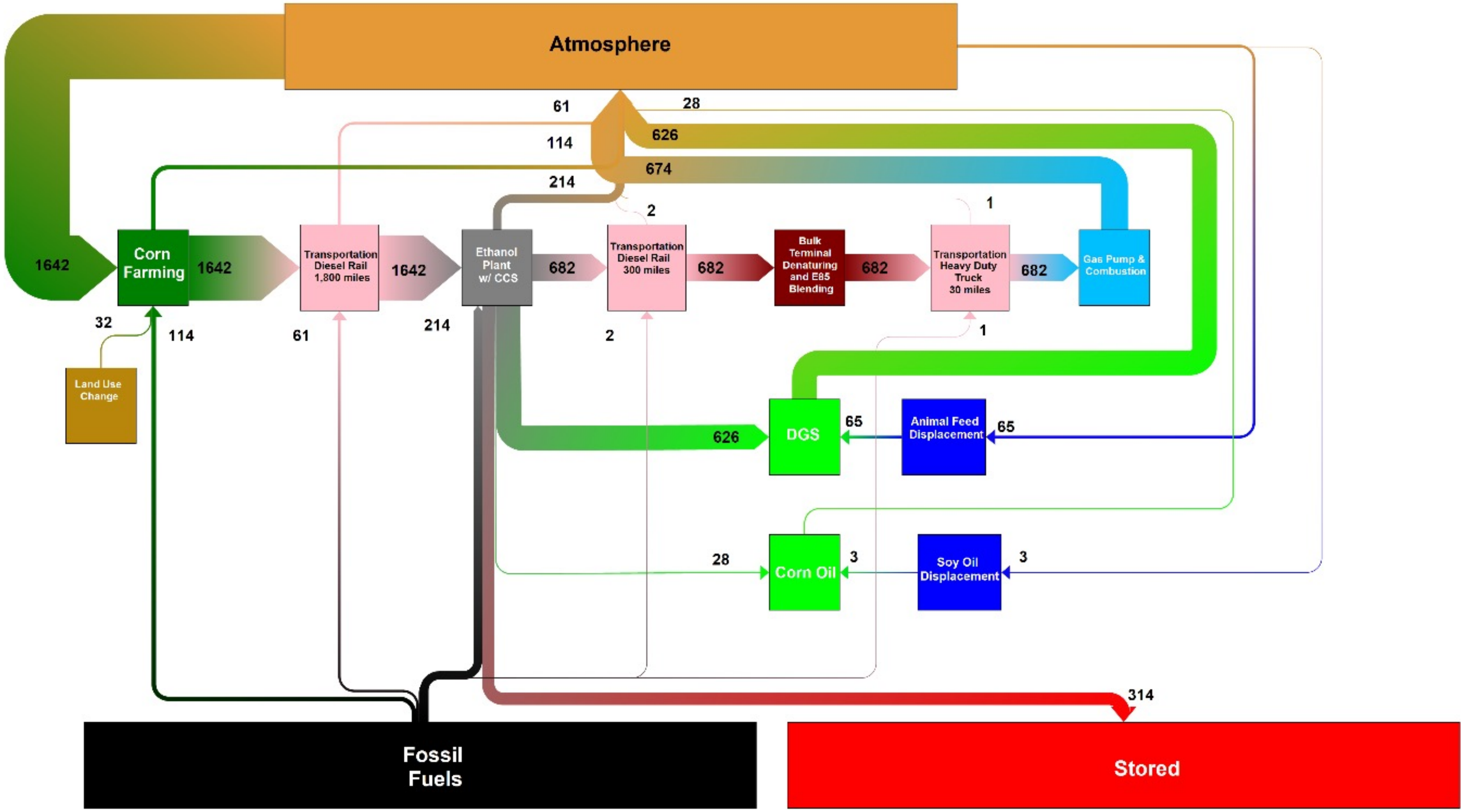


Progress and Outcomes: Year 1-2

Sankey Diagrams illustrate the magnitude of carbon flows, and depict the extent of net carbon emissions.

This diagram depicts CORN STARCH TO ETHANOL WITH CCS. We created similar diagrams for four other pathways.

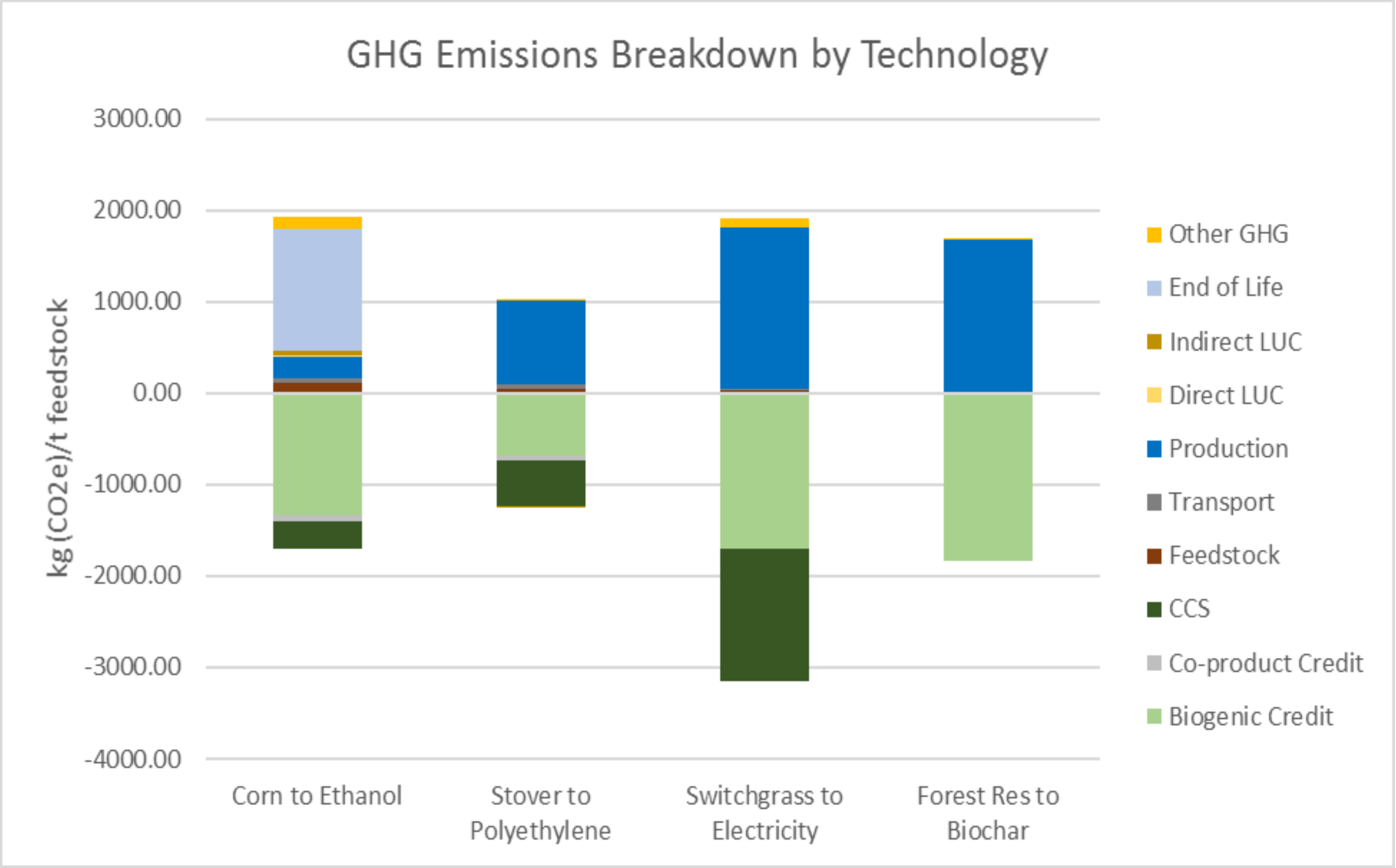
Baseline Ethanol w/ CCS: Carbon Dioxide Flow (kg)



Progress and Outcomes: Year 1-2

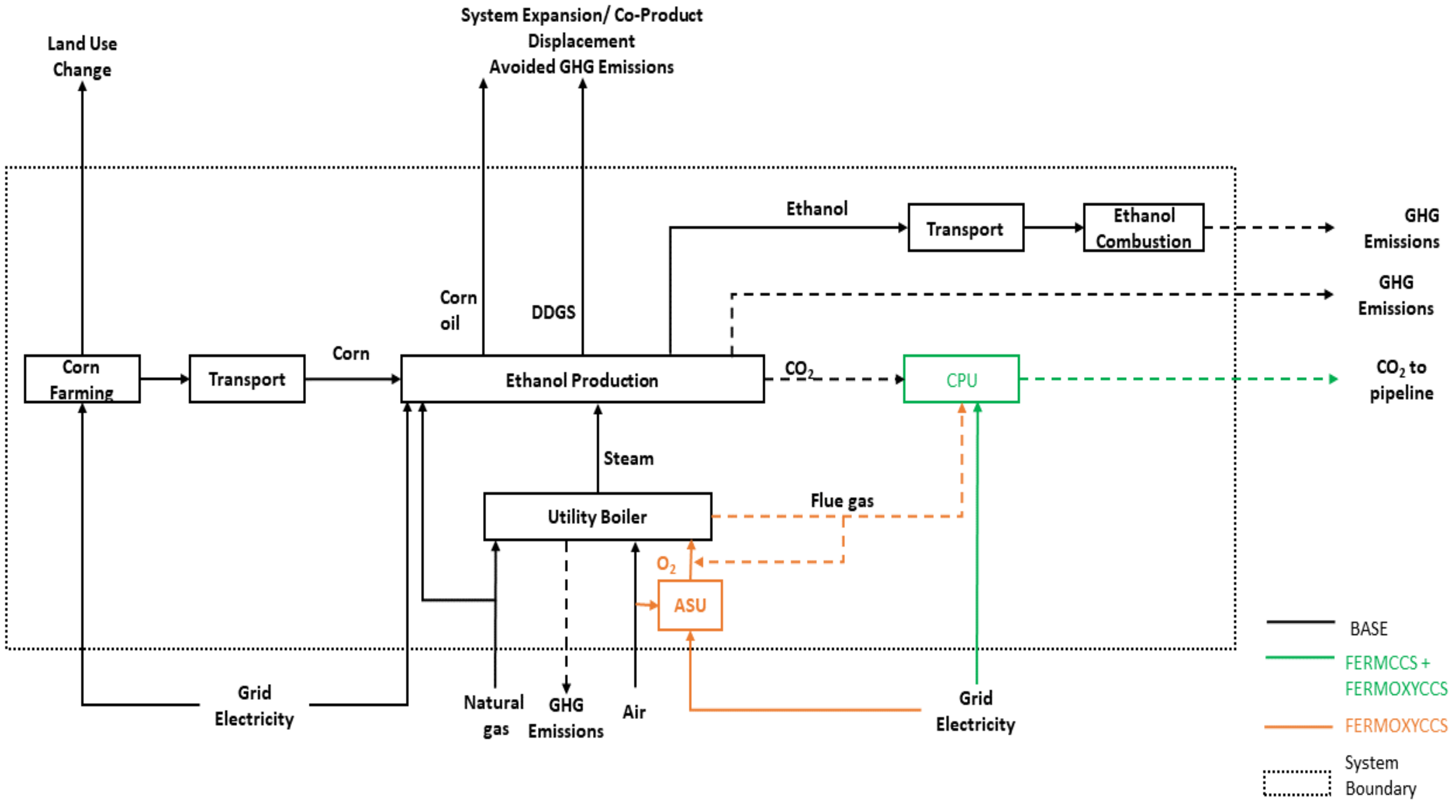
Intercomparison of bioeconomy pathways with diverse products (and co-products).

Bio-electricity with CCS pathways have the most drawdown potential per unit feedstock, but that does not make them the most economical with current technology.



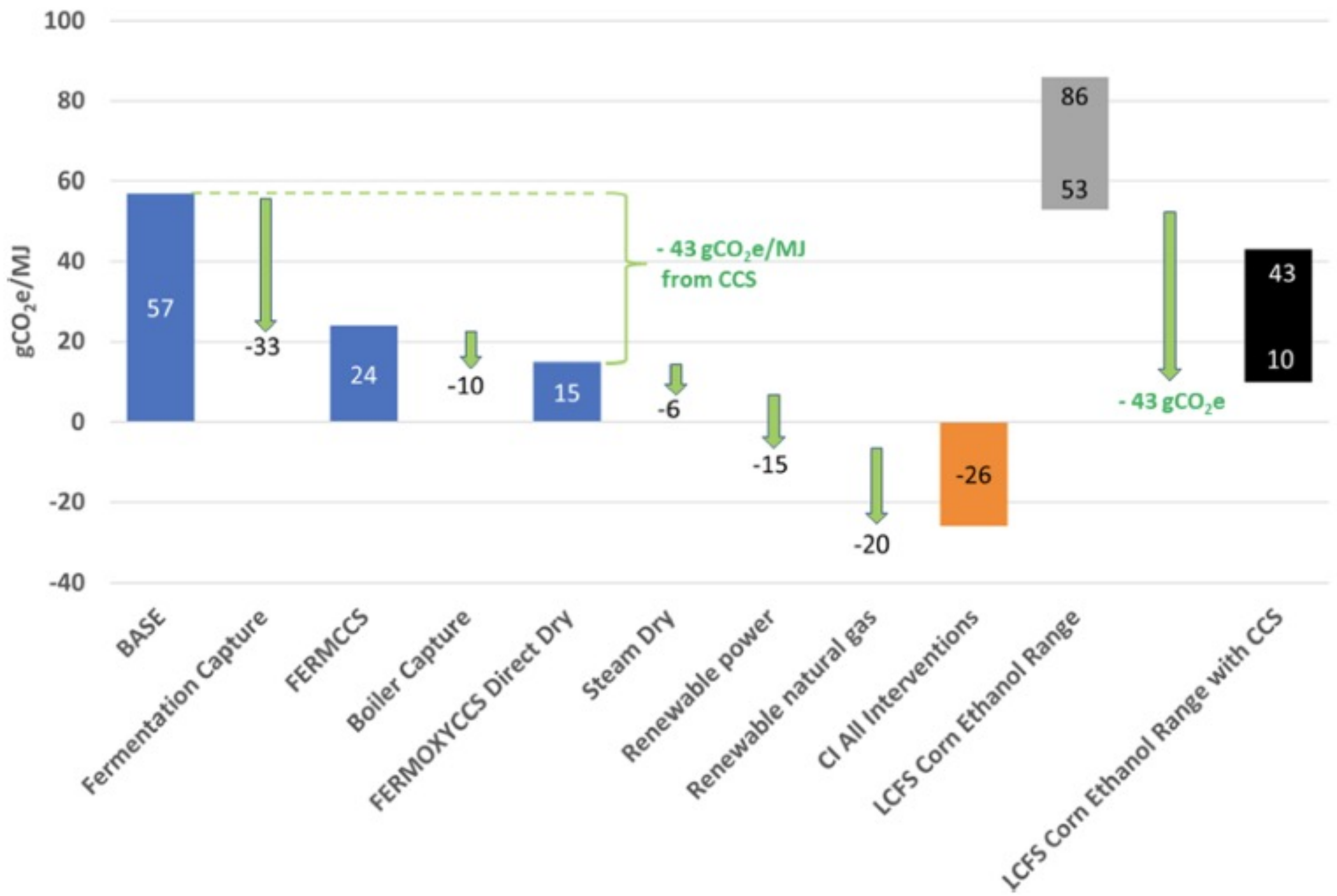
Progress and Outcomes: Year 3

Negative emission ethanol: Designed process configuration for integration of fermentation CCS (FERMCCS) and the oxyfuel boiler (FERMOXYCCS) with the BASE facility.



Progress and Outcomes: Year 3

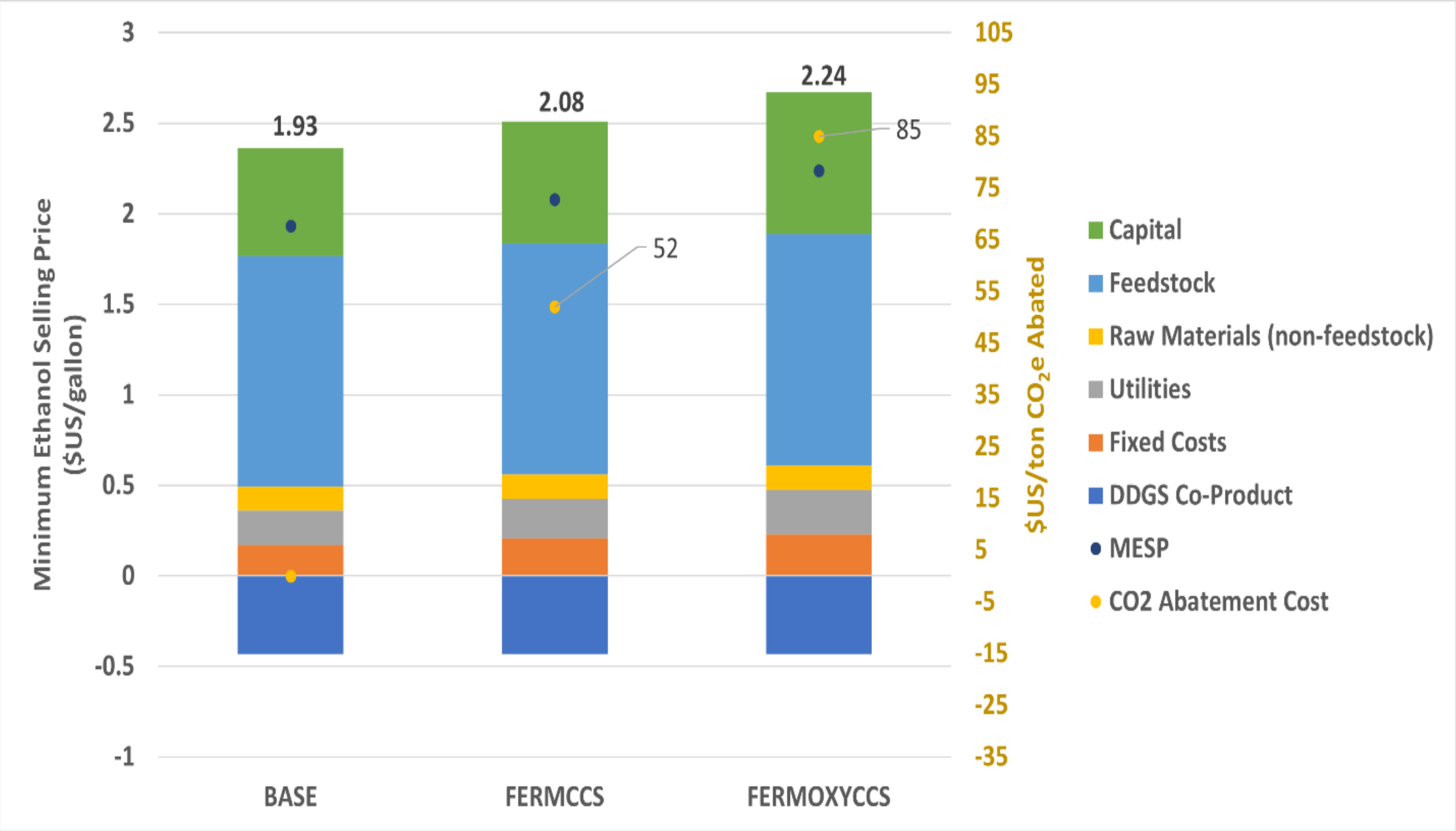
Carbon-negative corn ethanol can be possibly achieved assuming all interventions.



Progress and Outcomes: Year 3

Comparative minimum ethanol selling price and abatement cost among conventional and innovative ethanol production facilities.

- BASE = Baseline facility with direct drying of DDGS
- FERMCCS = CCS on fermentation gas only
- FERMOXYCCS = Oxyfuel boiler added with CCS on both fermentation and boiler flue gas streams

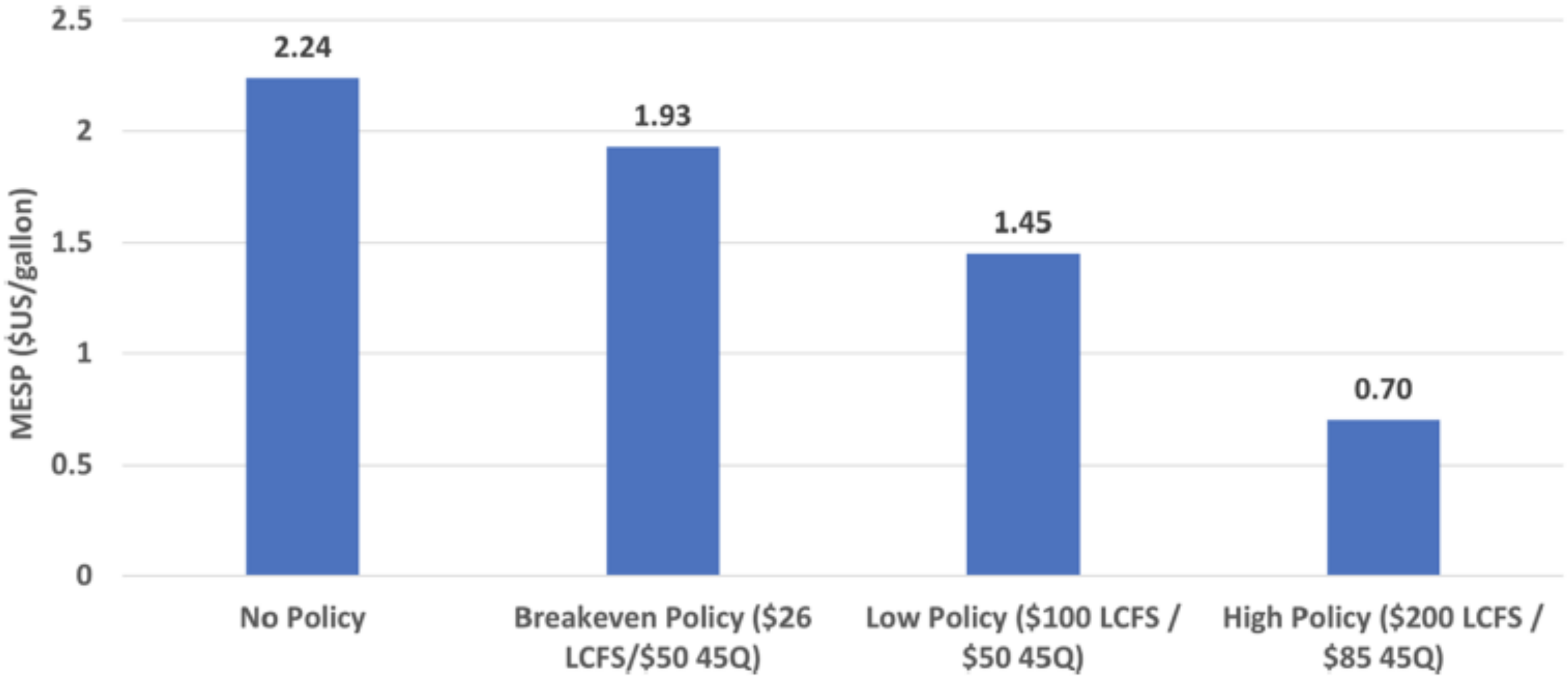


Progress and Outcomes: Year 3

Sensitivity of minimal ethanol selling price to policy support.

LCFS = California Low-carbon Fuel Standard

45Q = U.S. 45Q Tax Credit.



Progress and Outcomes: Future work of a new project

What we learnt from previous project:

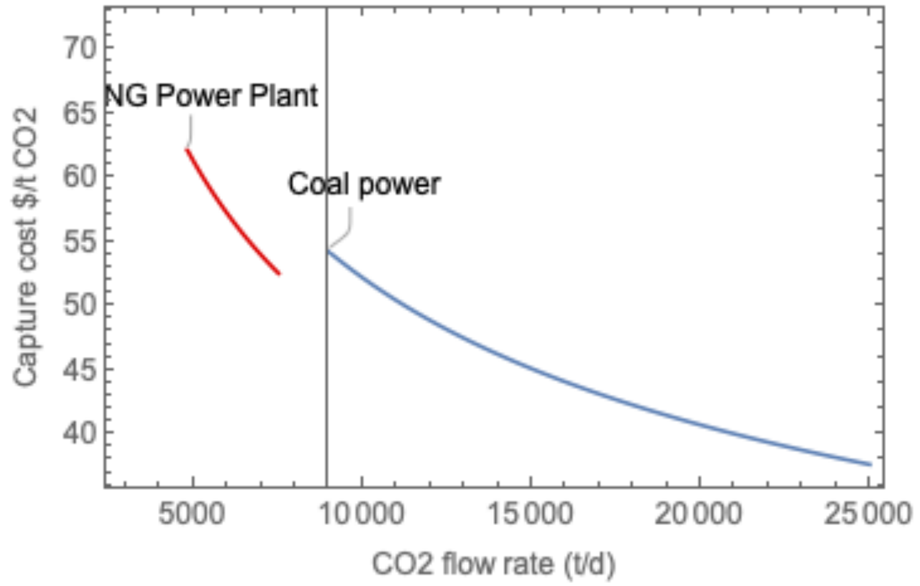
CCS on BiCRS is essential to produce net-zero or negative emission liquid fuels.

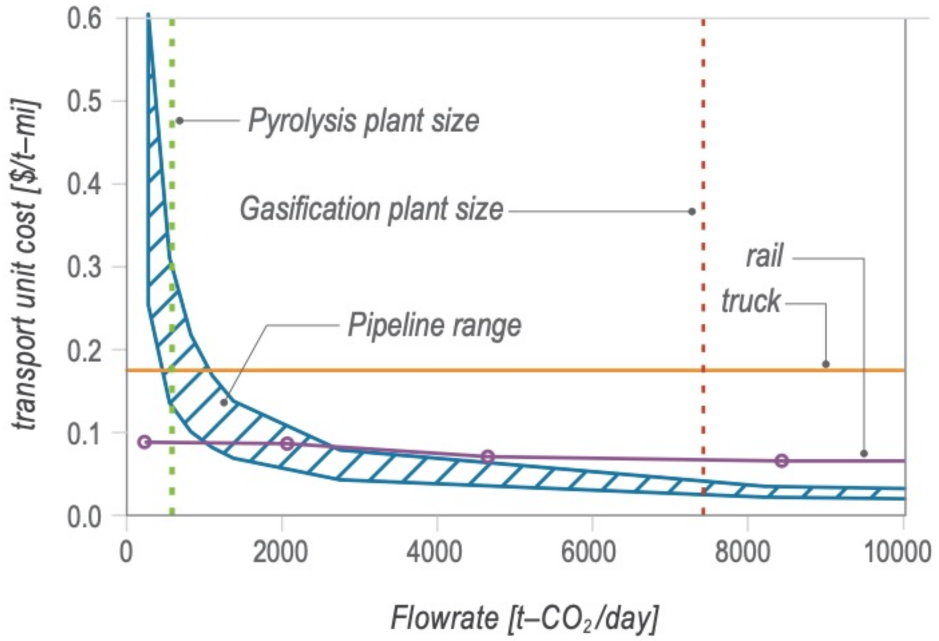
What we need to learn more:

Integration of suitable designed CO_2 capture, conditioning, and transportation system on *small scale* biorefinery is not well studied.

New project:

"Maximizing co-benefits of carbon removal and sustainable aviation fuels production: process design, techno-economic and life cycle analysis"



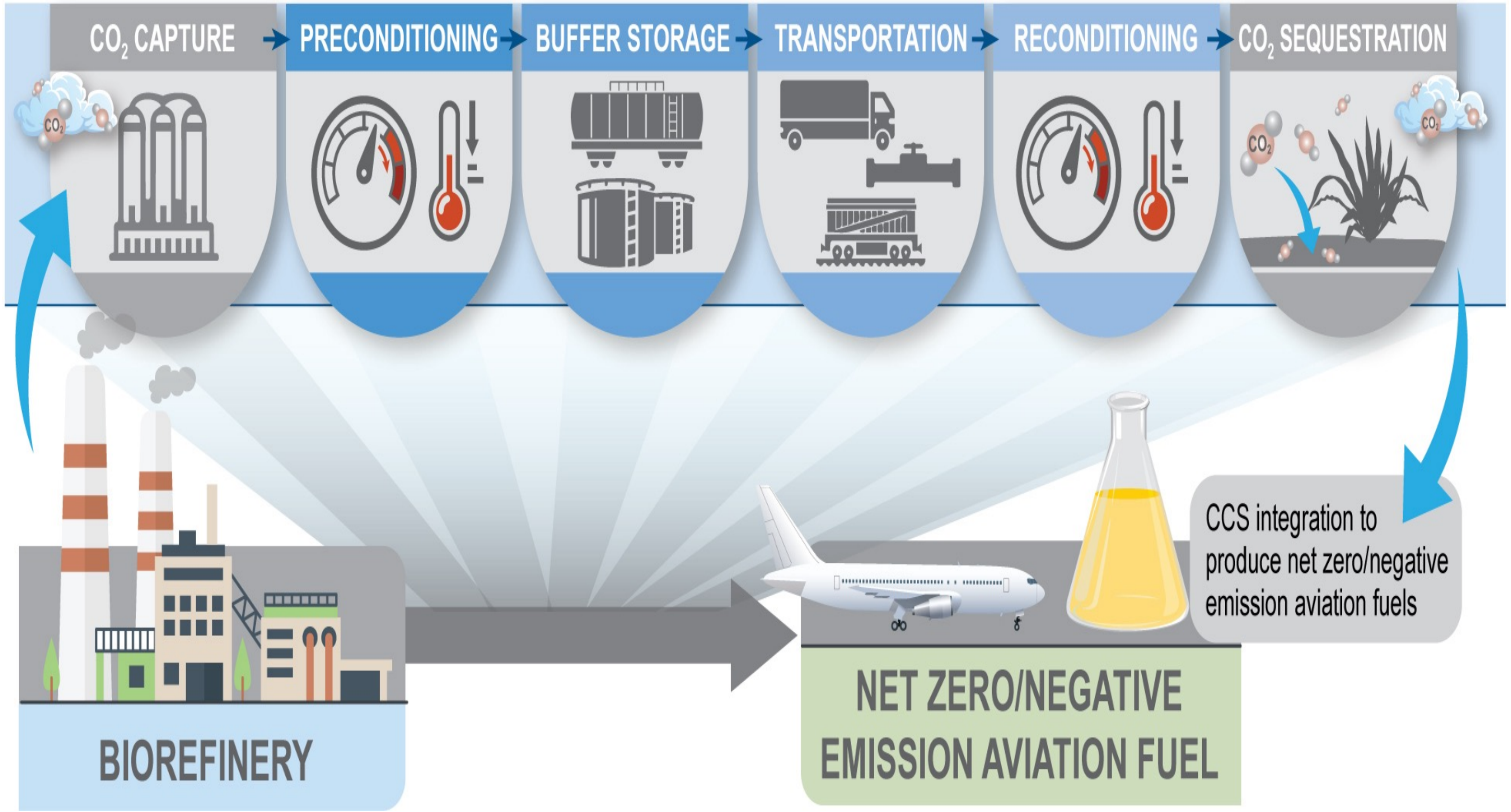


Reference: CA Get to Neutral 2020

Project Overview: New project

Project Goal:

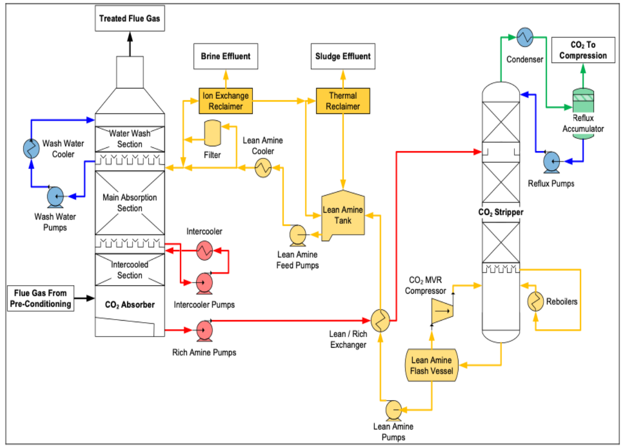
This project will design a small scale biorefinery-based CCS system (including CO_2 capture, preconditioning/reconditioning, transportation, sequestration) and investigate the economic and environmental trade-offs of integrating suitable designed CCS system with small scale gasification to aviation fuel plant.



Maximizing co-benefits of carbon removal and sustainable aviation fuels production: process design, techno-economic and life cycle analysis

Approach: New project

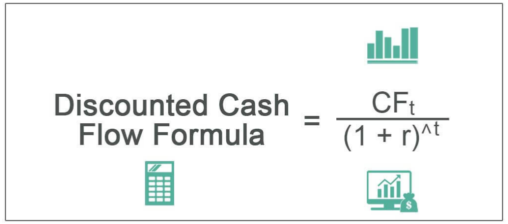
Process Design and Modeling



Design and model CO_2 capture, preconditioning, reconditioning system on 500 – 1000 tpd gasification-to-aviation fuel plant in Aspen Plus.

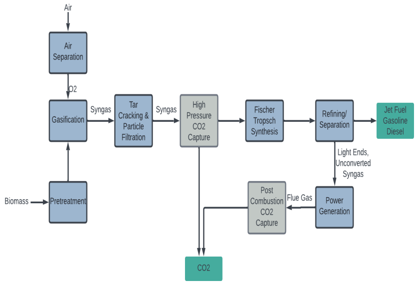
Techno-economic Analysis

aspentech



Evaluate the economic impacts of suitable designed CCS system, using Aspen Plus Economic Analyzer and discounted cash flow rate of return method.

Life Cycle Analysis



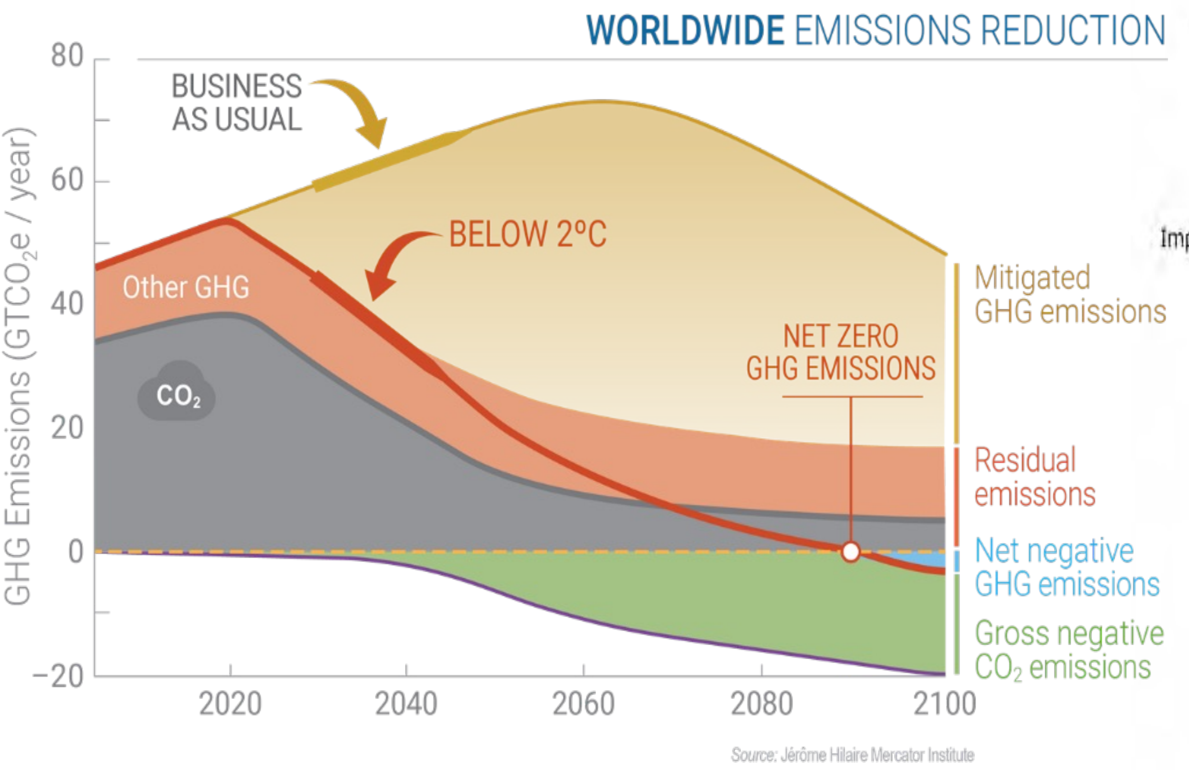
Argonne GREET LIFE-CYCLE MODEL

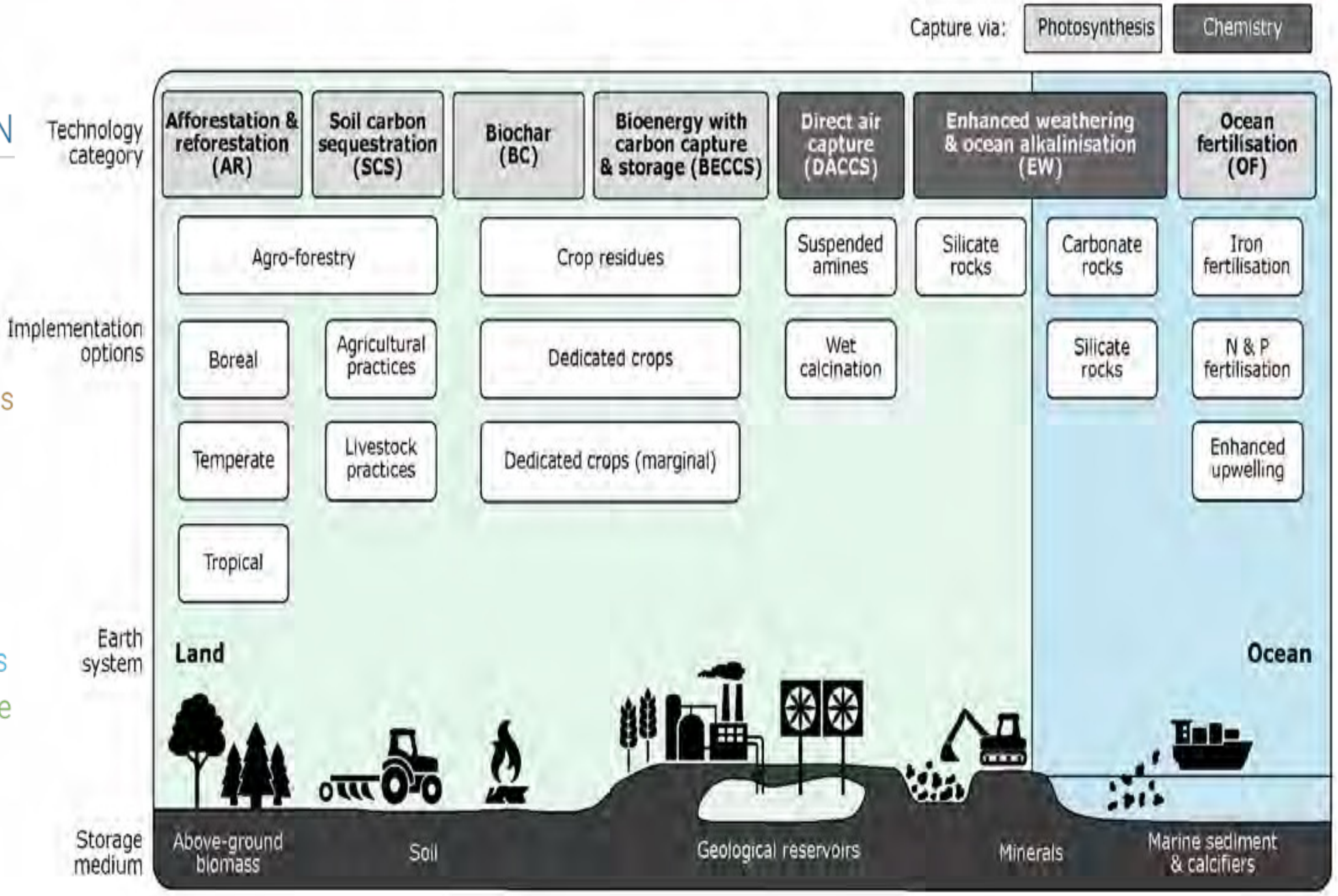
Quantify the emission reduction of integrating suitable designed CCS system on aviation fuel plant, using mass and energy balance from process model and emission factors from GREET.

Impact: Alignment with BETO's Mission

- BETO Goal (1): Develop low-cost, reliable feedstock supply from the entire range of biomass waste.
- BETO Goal (2): Develop carbon management strategies including soil carbon storage and carbon drawdown.
- BETO Goal (3): Develop waste management and environmental remediation strategies.

Impact: BiCRS are a critical component of the Negative Emissions Technology (NET) portfolio

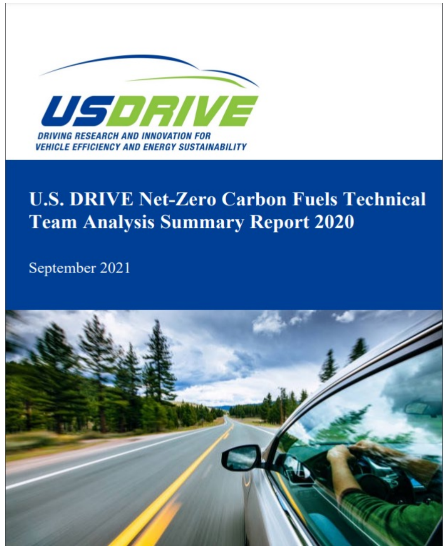


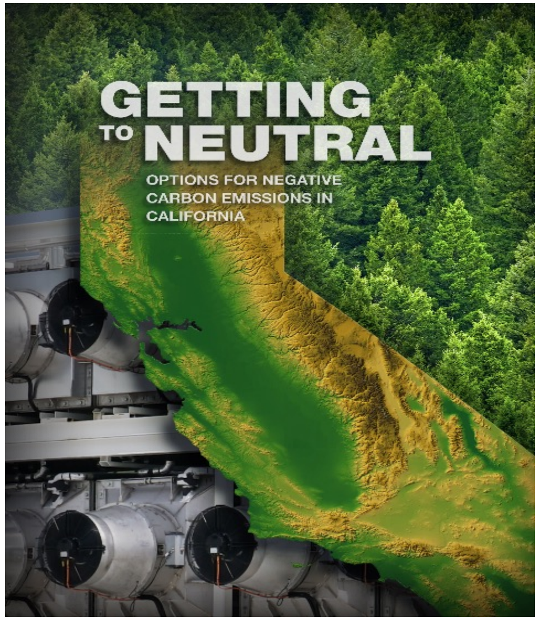


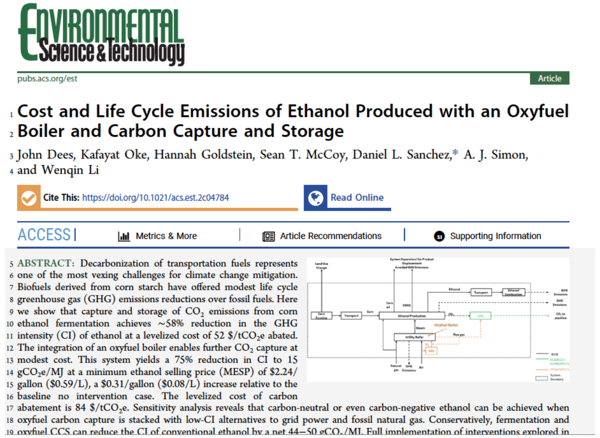
Minx et al. 2018

Impact: Engagement with Negative Emissions Community via Publication and Collaboration

- Journal Publications
  - 1 paper got accepted to Environmental Science & Technology: “Cost and life cycle emissions of ethanol produced with an oxyfuel boiler and carbon capture and storage”
  - 1 paper submitted to Environmental Science & Technology: “Leveraging the bioeconomy for carbon drawdown”
- Joint Reporting: NZTT
  - Published 2 Net-Zero Carbon Fuel report
  - LCA/TEA community: NREL, PNNL, ANL
  - Industry guidance, review & engagement
- LLNL Leadership
  - California “Getting to Neutral” National “Roads to Removal”






Environmental Science & Technology

pubs.acs.org/est Article

Cost and Life Cycle Emissions of Ethanol Produced with an Oxyfuel Boiler and Carbon Capture and Storage

John Dees, Kafayat Oke, Hannah Goldstein, Sean T. McCoy, Daniel L. Sanchez,* A. J. Simon, and Wenqin Li

Cite This: https://doi.org/10.1021/acs.est.2c04784 Read Online

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ABSTRACT: Decarbonization of transportation fuels represents one of the most vexing challenges for climate change mitigation. Biofuels derived from corn starch have offered modest life cycle greenhouse gas (GHG) emissions reductions over fossil fuels. Here we show that capture and storage of CO_2 emissions from corn ethanol fermentation achieves ~58% reduction in the GHG intensity (CI) of ethanol at a levelized cost of 52 $/t$CO_2$e abated. The integration of an oxyfuel boiler enables further CO_2 capture at modest cost. This system yields a 75% reduction in CI to 15 gCO_2e/MJ at a minimum ethanol selling price (MESP) of $2.24/gallon ($0.59/L), a $0.31/gallon ($0.08/L) increase relative to the baseline no intervention case. The levelized cost of carbon abatement is 84 $/t$CO_2$e. Sensitivity analysis reveals that carbon-neutral or even carbon-negative ethanol can be achieved when oxyfuel carbon capture is stacked with low-CI alternatives to grid power and fossil natural gas. Conservatively, fermentation and oxyfuel CCS can reduce the CI of conventional ethanol by a net 44−50 gCO_2/MJ. Full implementation of interventions explored in

Quad Chart Overview

Project Timeline:

Project 1: *"Analysis of the Bioeconomy for Carbon Drawdown"*: Oct 1, 2019 - Sept. 30, 2022

Project 2: *"Maximizing co-benefits of carbon removal and sustainable aviation fuels production"* (this new project was recompeted in 2022):Oct 1, 2023 - Sept. 30, 2025

	Project	FY22	Total awards
DOE Funding	2		$450k

Project Partners

- Project 1: **UC Berkeley** (Dr. Dan Sanchez)

Project 1 Goal

The goal of this project is to quantify the technical and economic potential of multiple, diverse bioeconomy pathways that ***draw down carbon dioxide*** from the atmosphere.

End of Project Milestone

By the end of this project, our team will publish results from several geospatially explicit bioeconomy-enabled carbon drawdown pathways. We will post the data to the bioenergy knowledge discovery framework, submit multiple journal articles, and contribute to DOE reports on net-zero (and net-negative) fuel pathways.

Project 2 Goal

This project will design a small scale biorefinery-based carbon capture, transportation, and sequestration (CCS) system and investigate the economic and environmental trade-offs of integrating that designed suitable CCS system with small scale gasification to aviation fuel production.

End of Project Milestone

By the end of this project, our team will summarize and publish results for techno-economic and life cycle analysis of integrating designed suitable CCS system with small scale gasification to aviation fuel production. We will share our knowledge, data and learnings to the renewable fuel production field about the true costs and benefits of integration of CCS with biorefinery.

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