Refinery Integration Analysis: Pathways, Challenges, and Opportunities

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Why Integrate?

- **Hypothetical:** What if an existing refinery already had all required equipment?

- **Value Propositions:**
  - Reduced production costs
  - Integration with existing distribution infrastructure
  - Leverage experienced workforce and R&D capabilities
  - Reduce sulfur intake, etc.

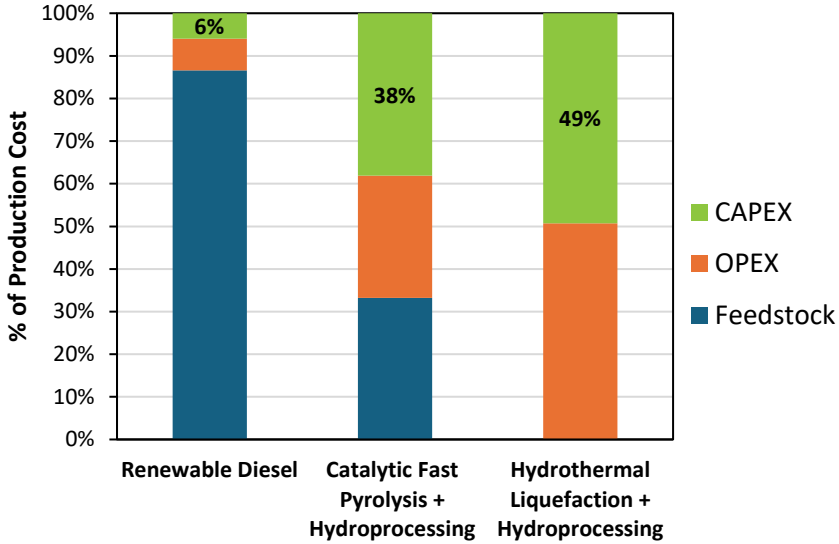
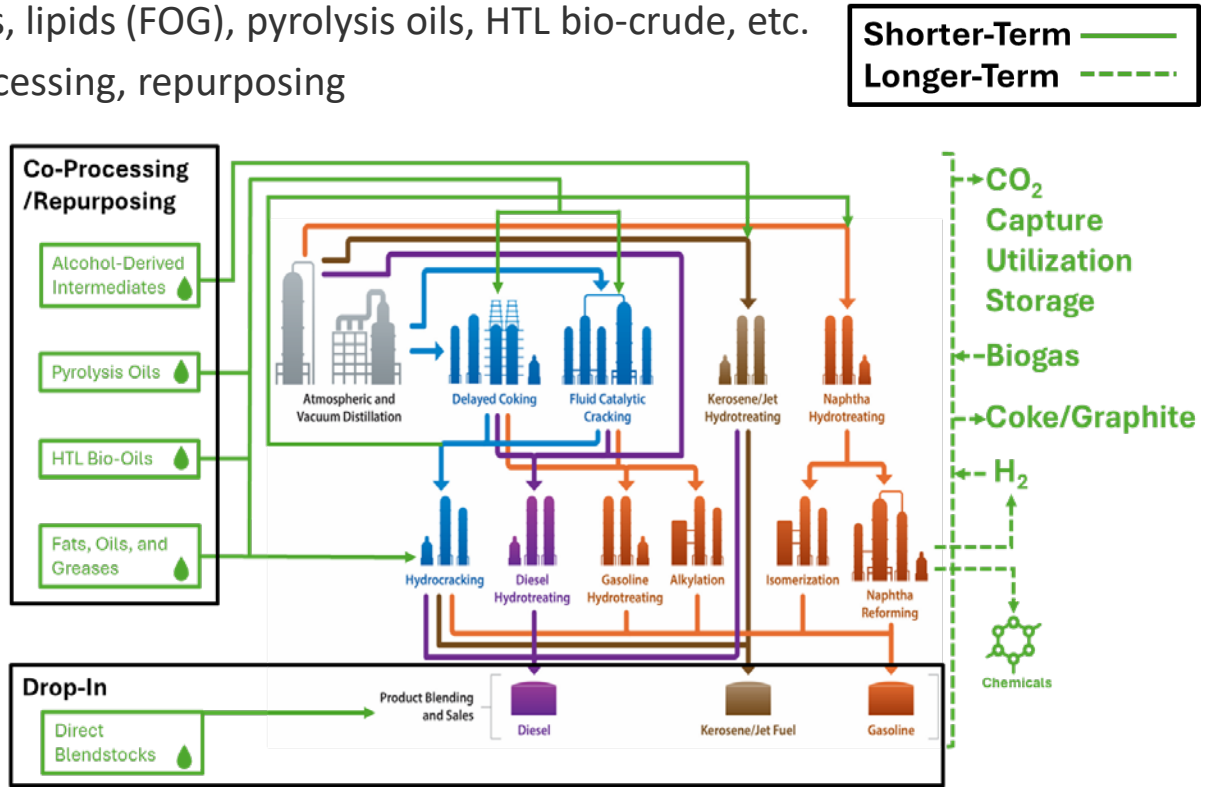


Figure: *Production cost breakdowns for renewable diesel (Xu et al. 2022), catalytic fast pyrolysis (Dutta et al. 2021) and hydrothermal liquefaction with hydroprocessing (Snowden-Swan et al. 2022).*

Integration Strategies Overview

- **Feedstocks:** oxygenated blendstocks, lipids (FOG), pyrolysis oils, HTL bio-crude, etc.
- **Strategies:** drop-in blending, co-processing, repurposing
- **Primary Unit Operations:**
  - **Fluidized Catalytic Cracking**
    - Robust catalyst regeneration
    - Rejection of oxygen as CO2
  - **Hydroprocessing**
    - **Hydrotreating:** remove O
    - **Hydrocracking:** crack to fuel range hydrocarbons
    - Better carbon efficiency
    - More operational concerts
- **Long term:** clean hydrogen, chemicals, CCUS, graphite, etc.



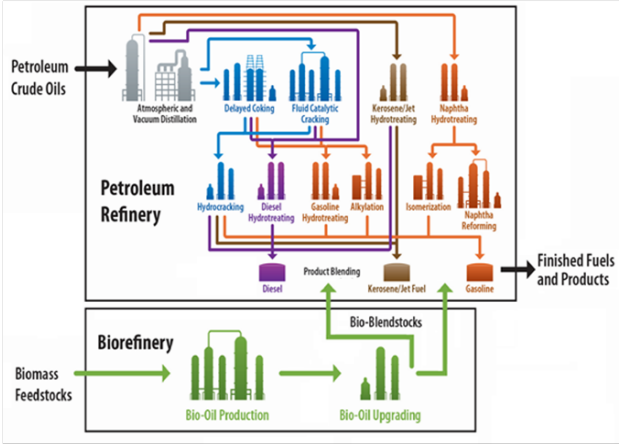
LP Modeling Framework

Peripheral Data/Models

- Refinery configuration and unit capacity basis from EIA.
- Bio-blendstock blending properties.
- ASTM finished fuel specifications are consistent with industry.
- Crude and product pricing data from WTI correlations.
- Fuel market projections from EIA and OPIS.

LP Model

Aspen PIMS
By AspenTech



- **So many options…**
- **Enter optimization modeling:**
  - Linear programming [LP]
  - Heavily utilized in industry
  - Planning & optimization
- **Model enables:**
  - Break-even analysis
  - Debottlenecking studies
  - Pathway down selection
  - Property assessments and valuations

- **Objective function:** maximize daily profitability
- **Constraints:** feedstock purchasing limits, unit constraints, product blending specifications
- **Solution Space:** crude purchases and intermediate stream distributions across units

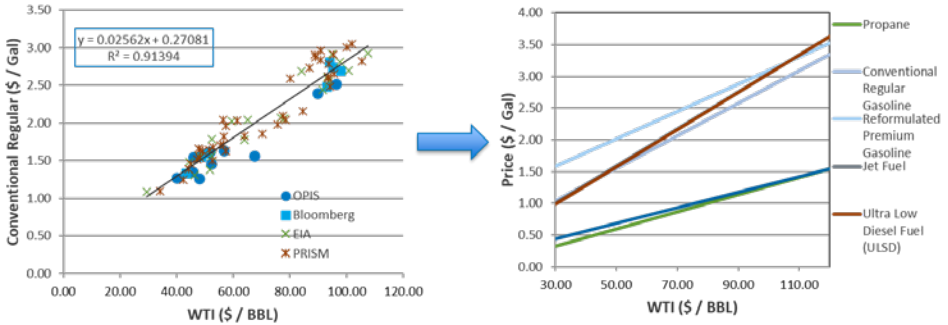
Peripheral Models: Scenarios

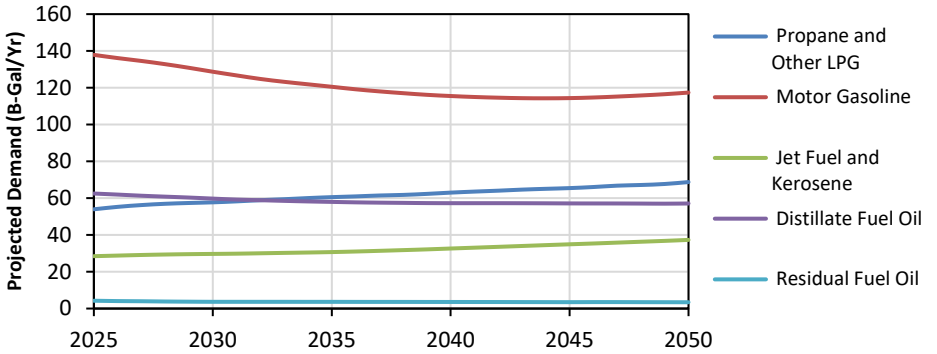
- **Use peripheral models to develop rich case matrix**

- **Feedstock/Product Pricing Models:**
  - Database of historical crude and product prices
  - Correlated to one benchmark crude price (WTI)
  - Gives economic context with one parameter

- **Demand Projections:**
  - Source various product demand projections
  - Index projection by year (i.e. 2030 – 2050)
  - Sets production targets / limits

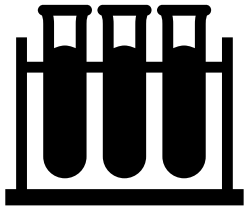
- **Provides economic and market context**





Source: Energy Information Administration (EIA) Annual Energy Outlook 2023.

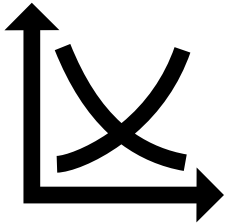
Co-Processing Sub Models



Experimental Data

Co-Processing & Standalone Upgrading

- Hydroprocessing
- Fluid Catalytic Cracking
- Bio-Carbon Tracking



Aspen PIMS Unit Sub models

with Bio-Intermediates

and Bio-Blendstocks

- Reaction drivers: oxygen
- Yield Shifts

FCC

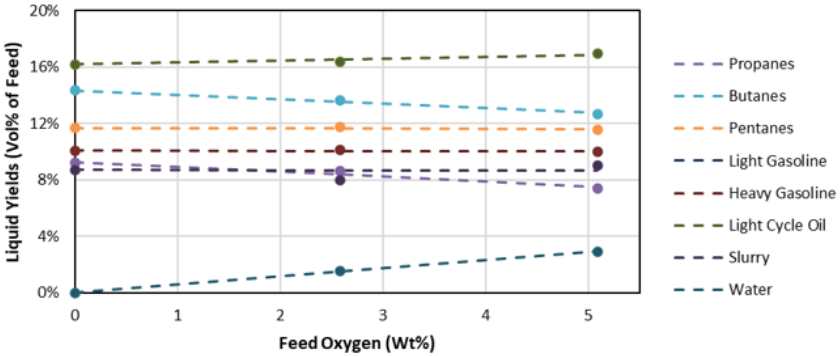


Figure: *Linearized FCC product yields shifts with increasing feed oxygen content from bio-oil co-feeding (Kinchin et al. 2021).*

Hydrotreater

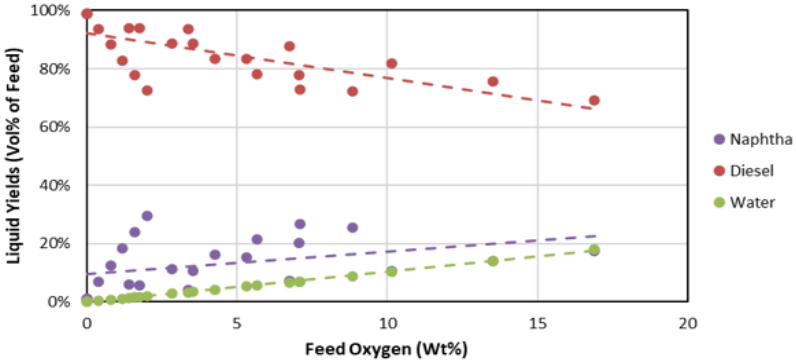


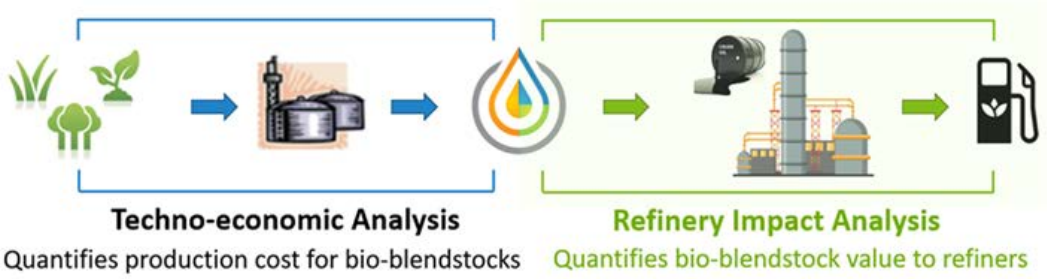
Figure: *Linearized diesel hydrotreater product yields shifts with increasing feed oxygen content from bio-oil co-feeding (Iisa et al. 2018).*

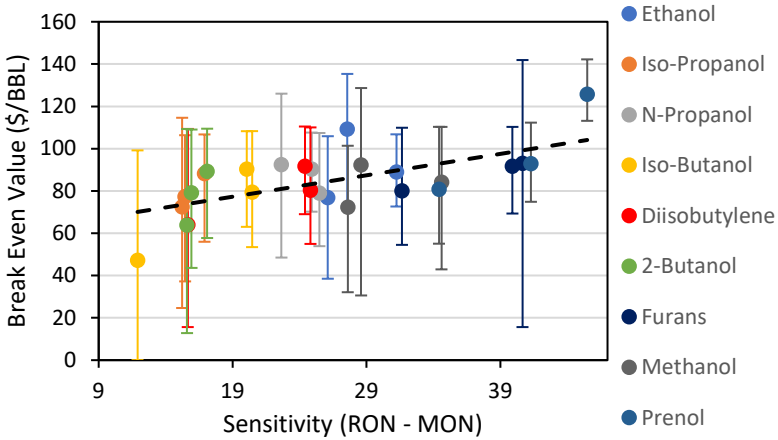
Key Results & Insights

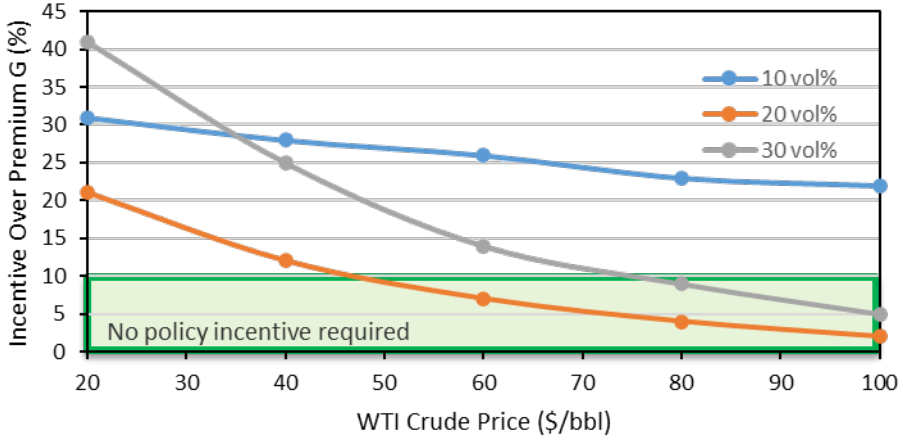
Results: Co-Optima Blendstocks

A Comprehensive Assessment of the Marginal Abatement Costs of CO_2 of Co-Optima Multi-Mode Vehicles Nicholas A. Carlson, Michael S. Talmadge, George G. Zaimes, Troy R. Hawkins, and Yuan Jiang *Energy & Fuels* **2025** *39* (1), 444-453 DOI: 10.1021/acs.energyfuels.4c03451

- **Break even value analysis was conducted to complement TEA for various gasoline blendstocks**
- **Results:**
  - Hyper octane boosting from select oxygenated blendstocks is valuable
  - New properties (i.e. Sensitivity = RON – MON) can add value proposition to gasoline pool





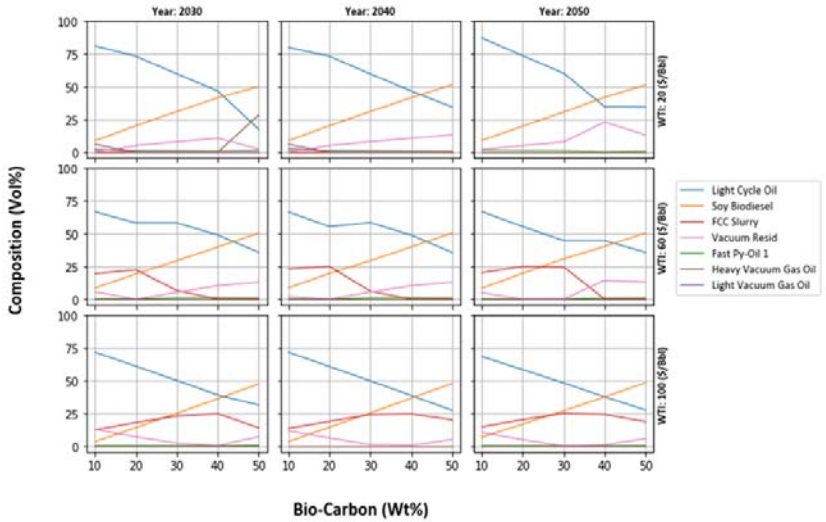


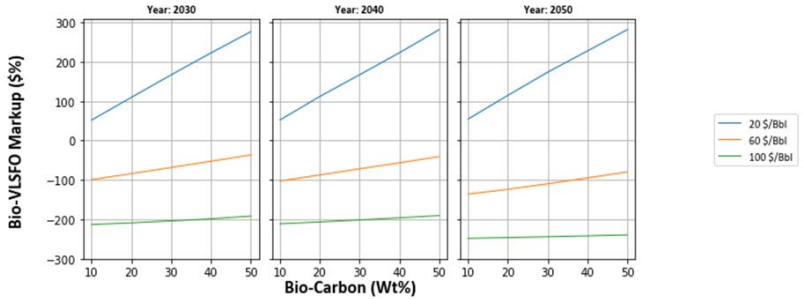
Results: Marine Biofuels

Refinery Perspective on Decarbonizing with Marine Biofuels Nicholas A. Carlson, Michael S. Talmadge, Eric C. D. Tan, Emily K. Newes, and Robert L. McCormick Energy & Fuels 2023 37 (19), 14411-14420 DOI: 10.1021/acs.energyfuels.3c02460

- **Configured refinery model to produce marine biofuel**
  - **Pathways:** catalytically upgraded pyrolysis oils, FCC co-processing, diesel blending
  - Imposed biogenic fraction spec on marine product: 10 – 50 wt%

- **Results**
  - FCC light cycle oil (LCO) after co-processing identified as promising marine blendstock
  - Above benchmark crude price of 60 $/Bbl, strategy appears to be viable
    - Less restrictive product specifications
    - Low-quality blendstocks enriched with diesel substitutes

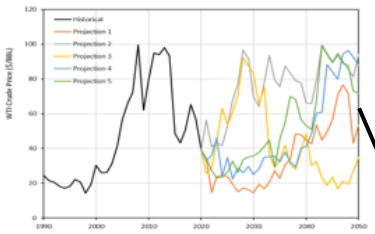




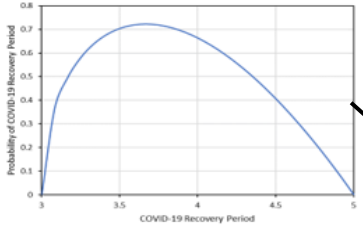
Results: SAF Monte-Carlo Analysis

Stochastic Models

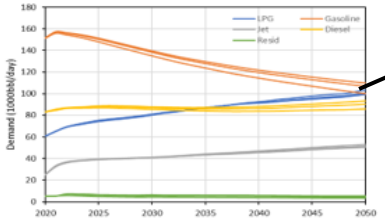
Benchmark WTI Crude Price



Covid-19 Recovery Period



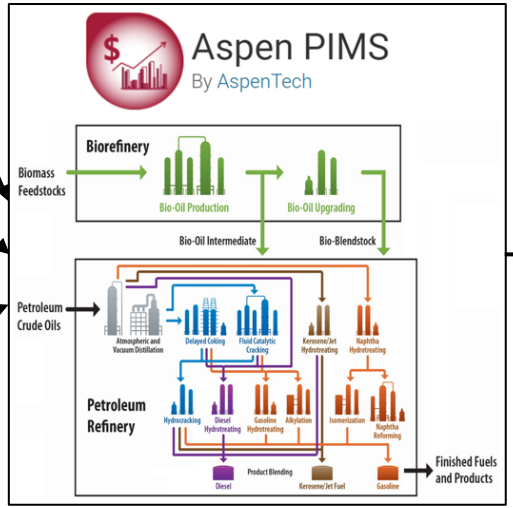
Refinery Product Demands



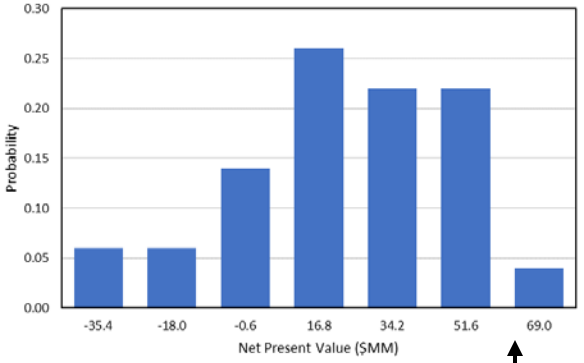
Monte-Carlo Analysis enables:

1) Risk adjusted performance comparisons between different refinery strategies
2) Scenario reduction

Refinery Optimization Model



Cash flow



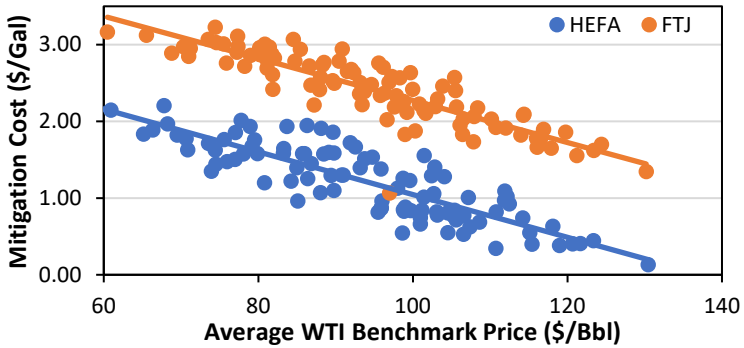
Discounted Cash Flow Table

Year	2020	2021
Fixed Capital Investment	$ -	$ -
Working Capital	$ -	$ -
Depreciation	$ -	$ -
Loan Payment	$ -	$ -
Loan Interest Payment	$ -	$ -
Loan Principal	$ -	$ -
Product Sales ($/yr)	$ (21,281,275)	$ 6,091,227
SAF Blendstock Volume (bbl/yr)	2,269,766	2,269,766
Cost Share ($/yr)	$ -	$ -
New Product Sales ($/yr)	$ (21,281,275)	$ 6,091,227
Feedstock Costs ($/yr)	$ (45,742,248)	$ (19,311,926)
Utility Costs ($/yr)	$ (740,976)	$ 1,379,176
Total ($/yr)	$ (46,483,224)	$ (17,932,750)
Net Revenue	$25,201,949	$24,023,977
Losses Forward		$0
Taxable Income	$25,201,949	$24,023,977
Income Tax	$8,820,682	$8,408,392
Annual Cash Income	$16,381,267	$15,615,585
Discount Factor	1.000	0.909
Annual Present Value	$16,381,267	$14,195,986
Total Capital Investment + Interest	$0	$0
Net Present Worth	$99,391,962	

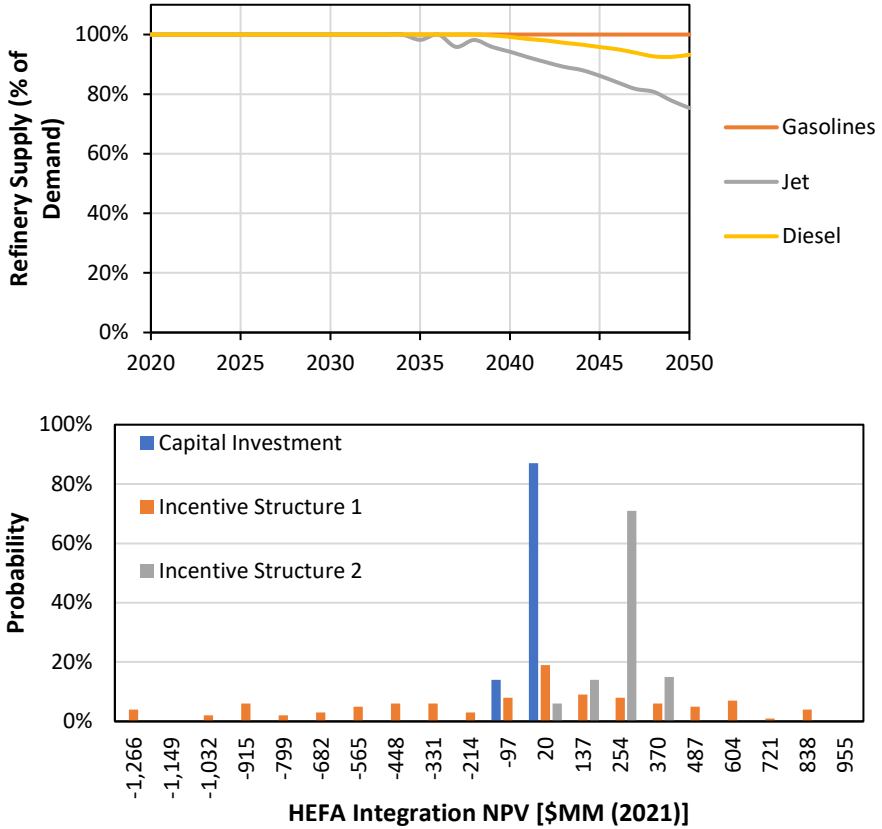
Results: SAF Monte-Carlo Analysis

Economic impact and risk analysis of integrating sustainable aviation fuels into refineries Nicholas A. Carlson, Michael S. Talmadge, Avantika Singh, Ling Tao, and Ryan Davis Front. Energy Res., 04 September 2023 (11), DOI: 10.3389/fenrg.2023.1223874

- **Conducted debottlenecking study given projected increases in jet demand**
- **Developed a crude price sensitive incentive structure**



- **Compared net-present values of capital project and SAF purchases with fixed/variable incentives**



Challenges

- **Operability:** Reactor plugging, catalyst deactivation, etc.
- **Metallurgical compatibility:** many biogenic feedstocks are acid
- **Yield mismatch:**
  - Co-processing implies one feed (fossil or bio-oil) is not optimized
  - Bottlenecks can develop with new yield structures (requires capital projects)
- **Hydroprocessing specific:**
  - Increased hydrogen requirement
  - Exotherm management (hydrodeoxygenation)
- **Bio-Carbon tracking**
- **New critical material attributes / consequences**

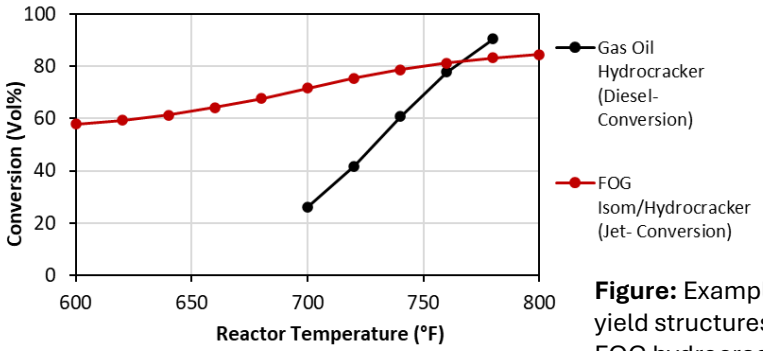


Figure: Example of different yield structures for gas-oil / FOG hydrocracking.

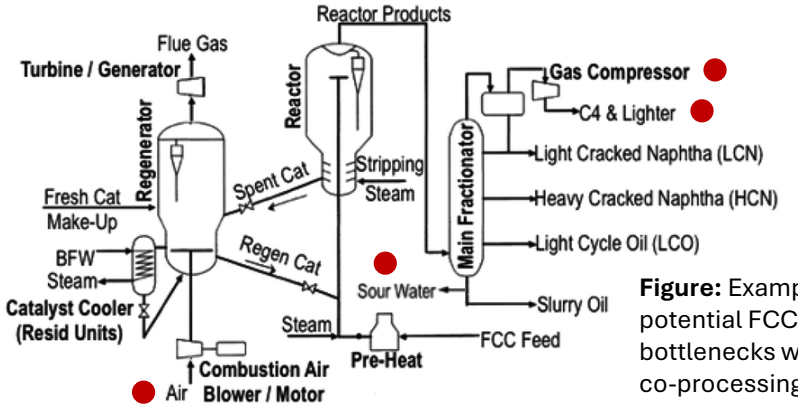
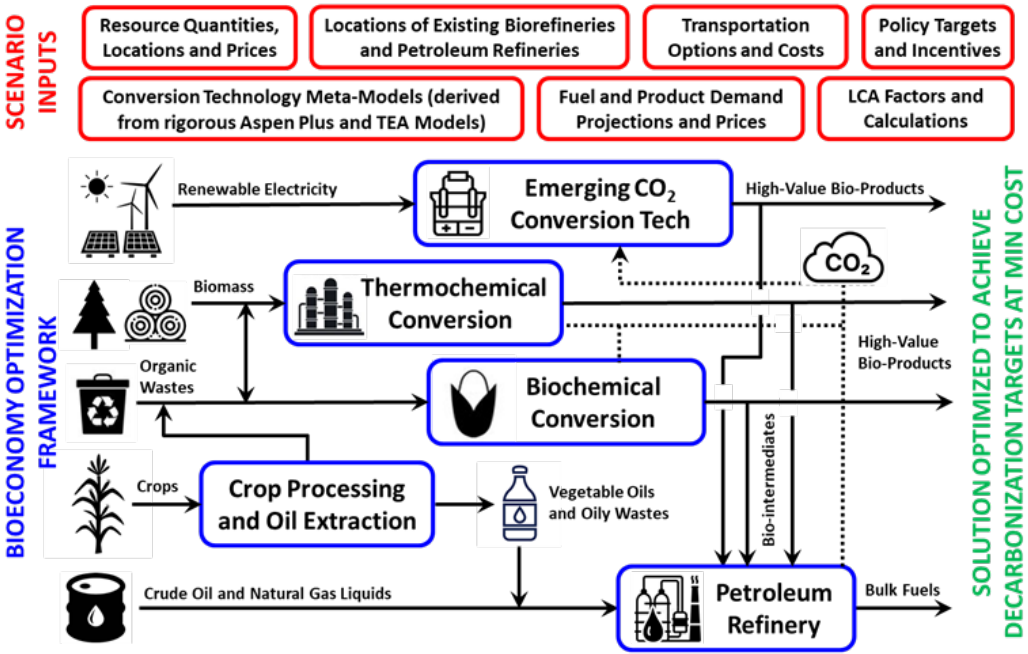


Figure: Example of potential FCC bottlenecks when co-processing.

Bio-Economy Optimization

How can existing biomass resources, conversion capacity ***(refineries),*** *and biofuel technologies be optimally leveraged to achieve various decarbonization objectives?*

BiOpt: A network model developed in Python designed to connect rigorous TEA models from ESMA group together, with market projections, and DOE decarbonization objectives



Working concept diagram of complete bio-economy optimization framework (not representation of current capabilities).

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