

BETO 2021 Peer Review: Strategic Analysis Support WBS 4.1.1.30

Ling Tao, Eric Tan, Yimin Zhang and
Avantika Singh
National Renewable Energy Laboratory
Data, Model and Analysis
March 9, 2021

Project Overview

Objective: Develop and apply an array of analysis tools to support the strategic direction of BETO

Goal and Context:

- **Evaluate emerging areas of interest** (USDRIVE tech team, jet fuel, WTE, lower cost targets, bio-based chemical market assessment).
- **Utilize analyses beyond traditional** biorefinery focused **TEA/LCAs** to identify both technical (sustainable design) and non-technical barriers (value proposition) and outline mitigation strategies and R&D needs.



Project Overview

Objective: Provide strategic support to BETO, coordinate analytical efforts across EERE offices, inform external and internal collaborations

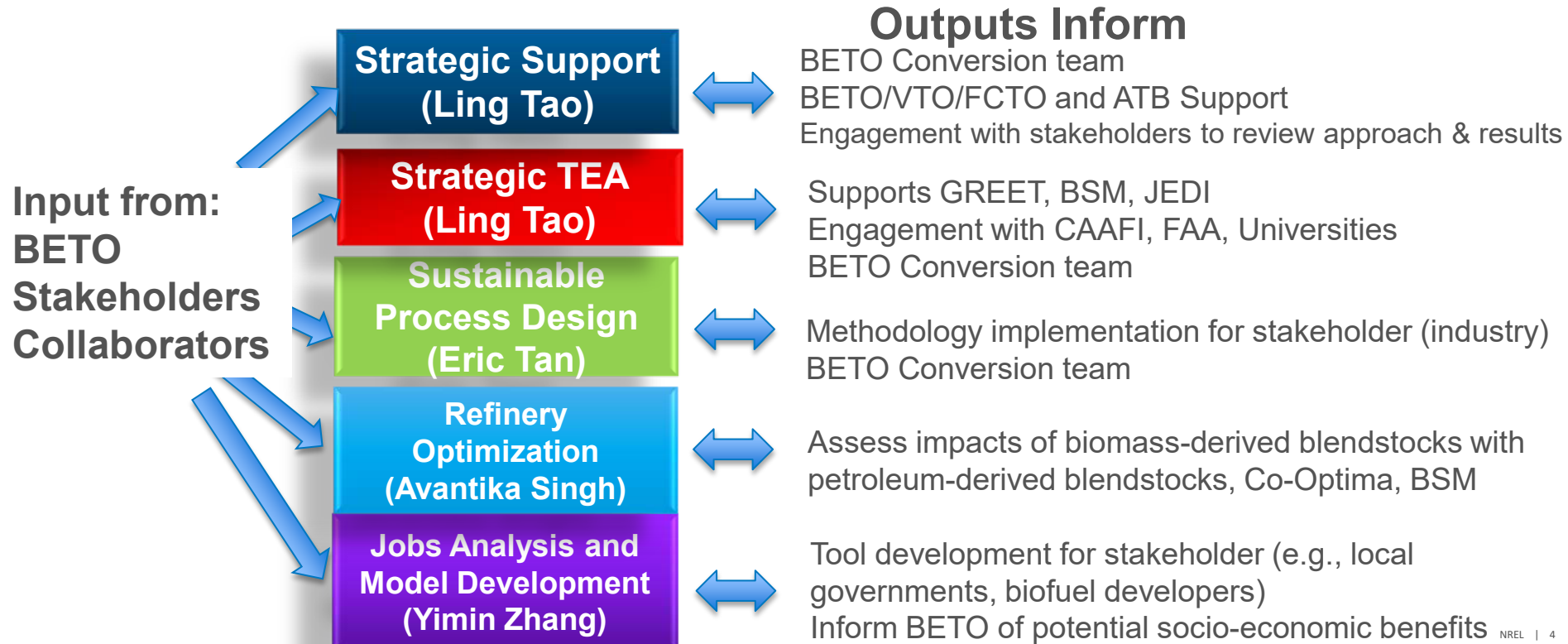
Goal and Context:

- **Estimate social-economic effects on bioeconomy** (number of jobs) for biorefinery deployment.
- **Develop defensible methodologies, analyses, and tools** to understand the impact of expanding the bioeconomy (economy analysis tools including **refinery blending tools**).



1. Management: Task Structure

Integrate multiple dimensions of strategic support for BETO and for external and internal stakeholders



1. Management: Team and Risk Mitigation

Strategic Support

Strategic TEA
(Ling Tao)

Sustainable
Process Design
(Eric Tan)

Refinery
Optimization
(Avantika Singh)

Jobs Analysis and
Model Development
(Yimin Zhang)

Risk

Project recommendations
cannot keep up with rapid
changing externalities

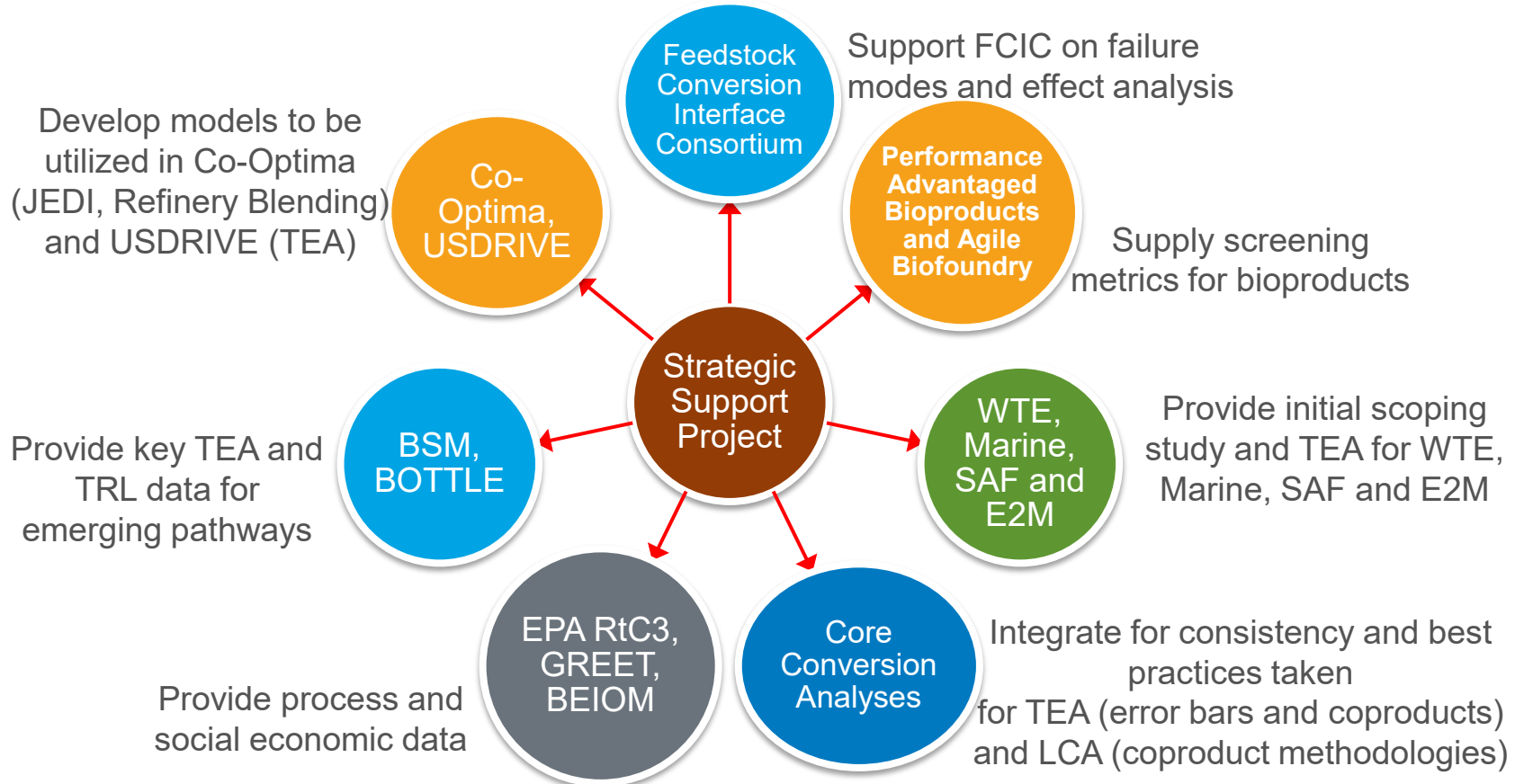


Mitigation Strategies

- Team stays current on technical literature and advancements of biofuel industry.
- Assumptions and tools used in the analysis are consistent with state-of-market and state-of-art.
- Frequent collaboration and check-ins with other offices and industrial experts to ensure **integration and alignment with BETO's mission and priority.**

1. Management

Outcomes Support and Bridge a Range of DOE BETO Projects and Beyond



2. Approach

Develop Models and Conduct Analysis to Support Strategic Decisions

Strategic Support (Ling Tao)

Provide analyses of emerging strategies

Strategic TEA (Ling Tao)

Identify drivers, barriers, and R&D needs

Sustainable Process Design (Eric Tan)

Support informed process designs

Refinery Optimization (Avantika Singh)

Assess refinery integration opportunities

Jobs Analysis and Model Development (Yimin Zhang)

Estimate jobs for a growing bioeconomy

Common approach:

- Models are **transparent** and rigorous with a **consistent set of assumptions** that allows for direct comparison.
- Each task is closely **integrated with four other tasks** to provide holistic output for strategy development.
- Analysis results and approaches are **verified by stakeholders**.

2. Approach

Critical Success Factors	Challenges	Approach to overcome
Model results are accurate and recommendations from the models are relevant.	<ul style="list-style-type: none">• Availability and quality of input data.• Model is not representative.	<ul style="list-style-type: none">• Consult subject matter experts globally to get the best and most accurate data.• Perform sensitivity analysis to understand impact of assumptions and uncertainty in data.• Engage third party reviewers to build transparent models.
Apply the appropriate method/tool to address questions.	A wide range of analysis approaches can be employed.	<ul style="list-style-type: none">• Coordinate across analysis projects to identify appropriate tools to address questions.• Engage with industry and science experts to review and verify approach.
Clearly define critical questions to address.	Scope shift.	<ul style="list-style-type: none">• Work closely with stakeholders to define needs and key questions.

2. Approach

Strategic Support
(Ling Tao)

Strategic TEA
(Ling Tao)

Sustainable
Process Design
(Eric Tan)

Refinery Optimization
(Avantika Singh)

Jobs Analysis and
Model Development
(Yimin Zhang)

Communication/Outreach Strategy

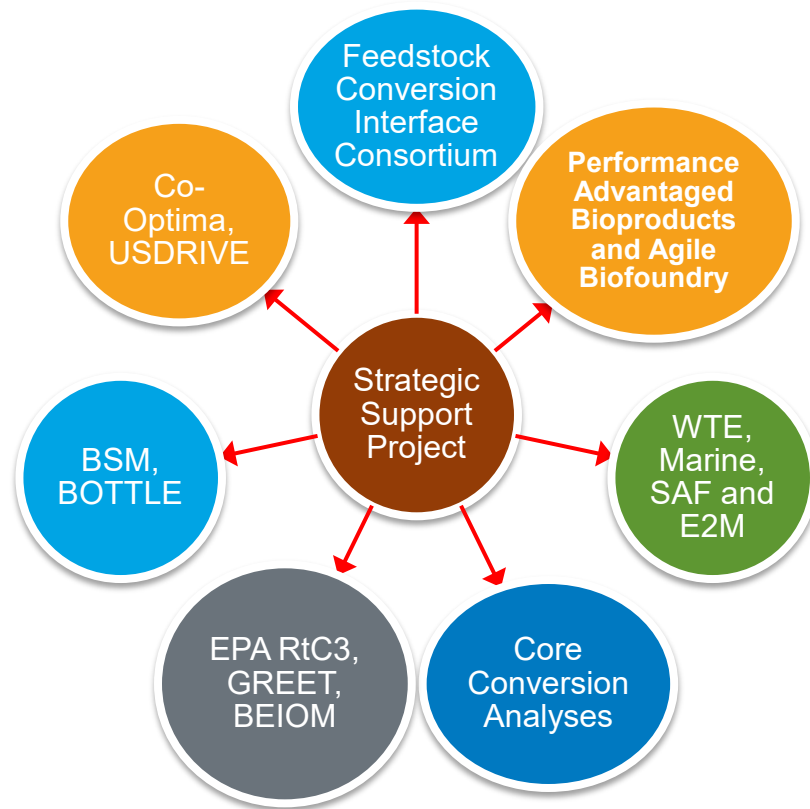
- **Quarterly check-ins** on work progress and report outcomes for meeting AOP defined QPMs/milestones.
- For projects directly supporting requests of A&S and BETO, we hold check-in on a **more frequent basis** (such as biweekly USDRIVE analysis PI calls).
- Participate in **monthly A&S platform calls** as well as bi-annual modeling workshop to ensure **coordination and collaboration** across the portfolio.
- Results and tool availability are communicated to stakeholders through peer-reviewed publications, presentations, web-based tools, and technical reports.

3. Impact

Outcomes Support and Bridge a Range of DOE BETO Projects and Beyond

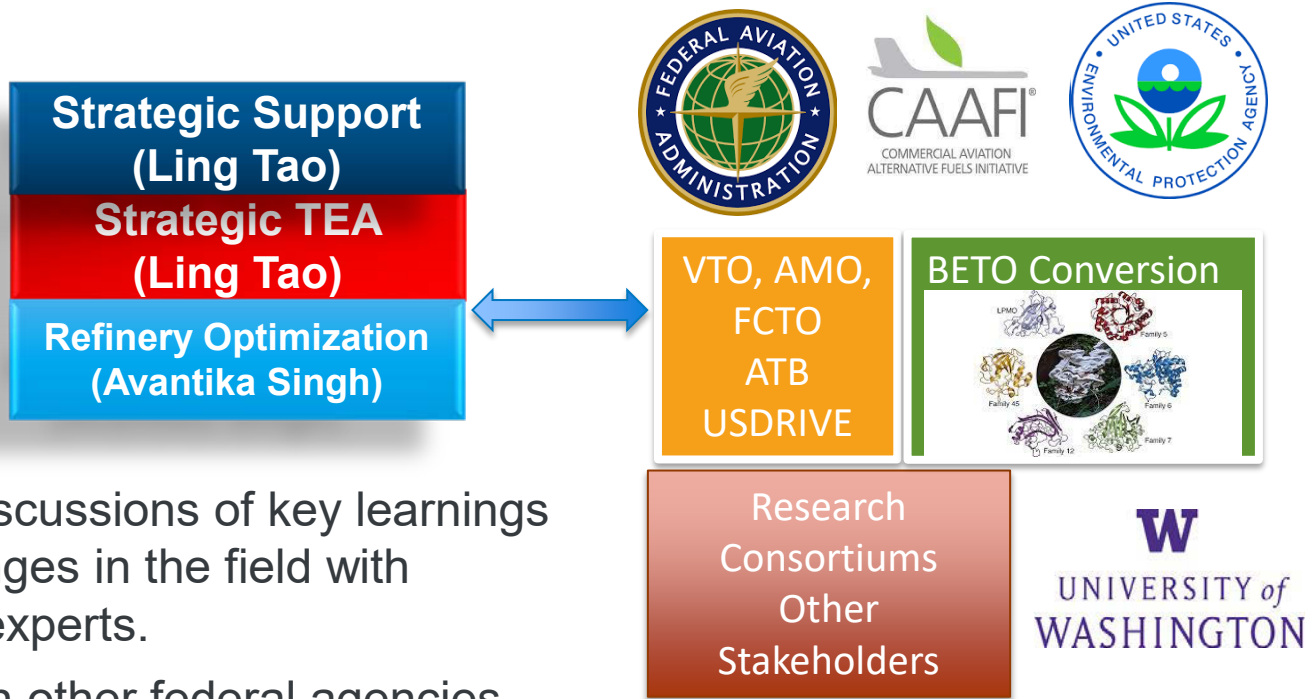
Selected examples of impact:

- Waste-to-SAF can be cost competitive in existing market.
- Opportunities for bioproducts with oxygenated molecules conferring performance benefits.
- Biofuel pathways have the potential to get to near net zero carbon emission.



3. Impact

Provide strategic information to agencies outside of BETO



- Promote discussions of key learnings and challenges in the field with academia experts.
- Partner with other federal agencies.
- 12 peer-reviewed papers and book chapters, >7 conference talks.

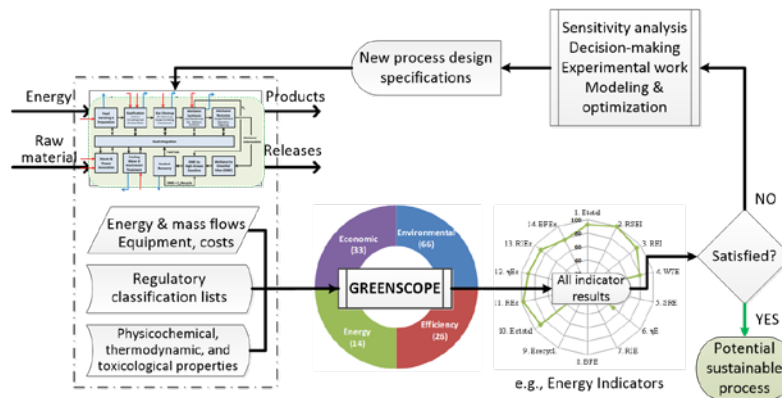
3. Impact

This project provides strategic information to agencies outside of BETO

Sustainable Process Design (Eric Tan)

Decision made by the interest parties

- Researchers
- Process designers
- Funding agency (BETO)
- Other stakeholders.



Jobs Analysis and Model Development (Yimin Zhang)

- Primarily state government
- Biofuel developers
- Social justice



4. Progress and Outcomes: Strategic Support Task

**Strategic Support
(Ling Tao)**

**Strategic TEA
(Ling Tao)**

**Sustainable
Process Design
(Eric Tan)**

**Refinery Optimization
(Avantika Singh)**

**Jobs Analysis and
Model Development
(Yimin Zhang)**

Strategic Goal:

- Support BETO's strategic mission and analysis needs.
- Utilize a range of approaches, work collaboratively with partner labs and agencies, to investigate critical questions.
- Handoff results and outcomes of analyses to support core BETO projects.

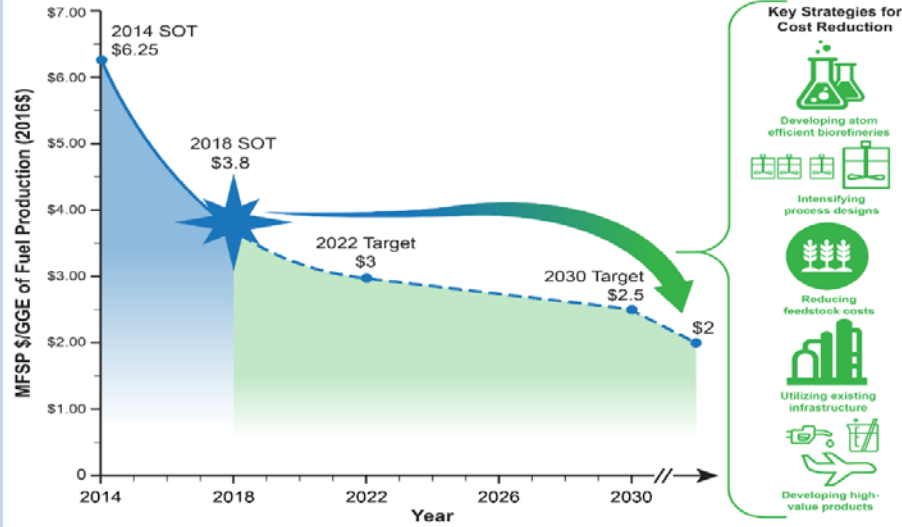
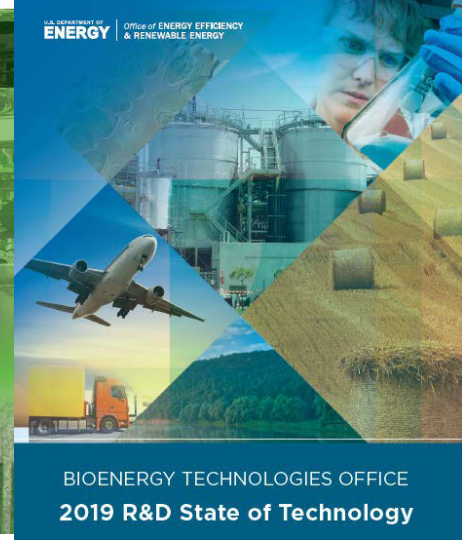
Integrated Strategies to Enable Lower-Cost Biofuels

MOTIVATION: Address BETO strategies on producing biofuels at $\leq \$2.5/\text{GGE}$.

GOAL: Identify strategies and R&D opportunities for meeting a cost goal.

OUTCOMES:

- Interlaboratory collaborative efforts by NREL, PNNL, ANL, INL, ORNL.
- Provides a high-level overview of strategies for meeting cost goal of an integrated supply chain approach.
- Review work underdevelopment by both R&D and analysis.
- Provide initial, high-level estimates on potential cost savings.



Public DOE BETO Biofuels TEA Database

MOTIVATION: Support transparency of and ease of access to DOE BETO supported public techno-economic analysis data.

GOAL: Develop and publicly release a biofuels cost data base that summarizes key inputs utilized in conversion TEAs.

OUTCOMES:

- 50+ DOE BETO funded TEA studies, including design reports, SOT reports and publications.
- Reviewed by lead analysts to ensure consistency.
- Provide annual update with new TEAs.



BETO Biofuels TEA Database

Purpose of Repository Database

The goal of this repository is to promote transparency and ease-of-access to DOE BETO supported public studies involving techno-economic analysis. As such, this database summarizes the economic and technical parameters associated with the modeled biorefinery processes for the production of biofuels and bioproducts, as presented in a range of published reports and papers. The database serves as a quick reference tool by documenting and referencing the results of techno-economic analyses from the national laboratories and in peer-reviewed journals.

The analyses presented in this database may be distinguished in several regards, such as cost year, feedstock cost, and financial assumptions (tax rate, percent equity, project lifetime, etc.), and reflect details as they were provided in the original studies. Accordingly, the intent of this database is not to directly compare one technology pathway against another, and caution should be taken in interpreting the outputs as such.

Funding Acknowledgement

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Bioenergy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Attachment

[BETO Biofuels TEA Database 2020.xlsx](#)

Publication Year

2020

Bioenergy Category

[Biofuel Production](#)

Keywords

[BETO Biofuels TEA Datab](#)

[biofuels](#)

[TEA](#)

[database](#)

Contact Person

Christopher Kinchin

Contact Organization

Bioenergy Technologies O

National Renewable Ener

Laboratory

Phone

303-384-7709

Email

christopher.kinchin@nrel

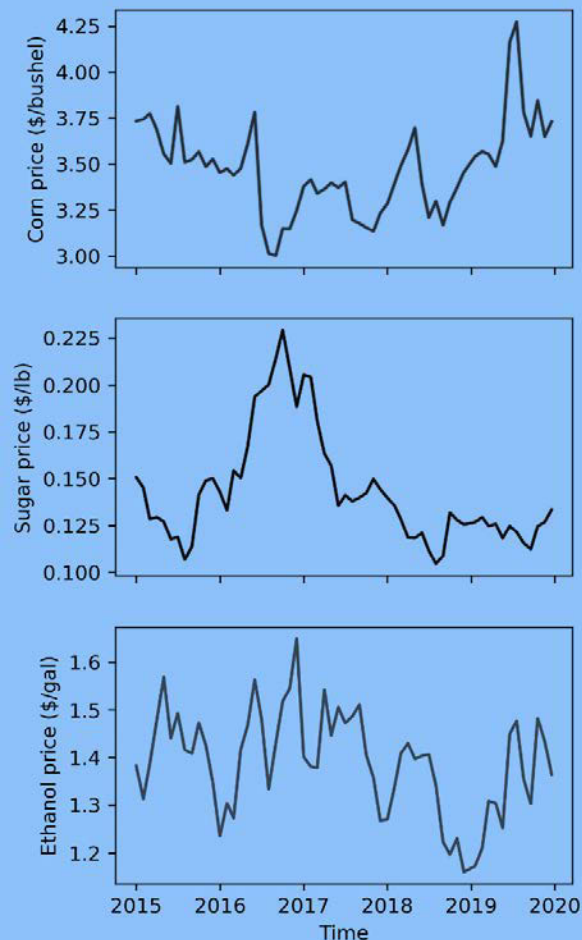
Lab

NREL

Organization

Available for download on the Biomass KDF:
<https://bioenergykdf.net/content/beto-biofuels-tea-database>

Estimate Uncertainty in Predictions



MOTIVATION

- Estimate error bars for MFSP with partner labs and agencies, investigate critical questions.
- Increase confidence in meeting a \$2.5/GGE cost goal with bioproduct cost analysis.

KEY QUESTIONS BEING EXPLORED

- **What is the pioneer plant cost?**
- What is the level of confidence in the MFSP values? What is the level of MFSP uncertainty over a range of user-defined values or distributions?

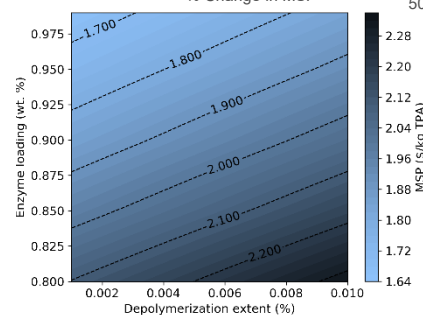
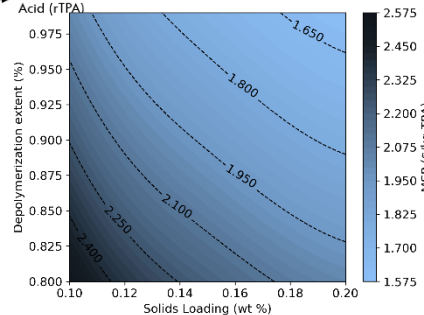
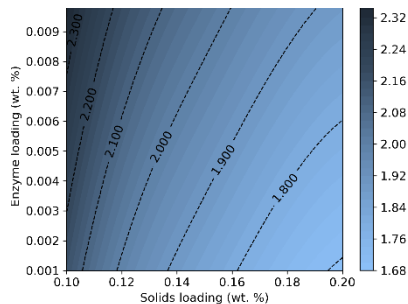
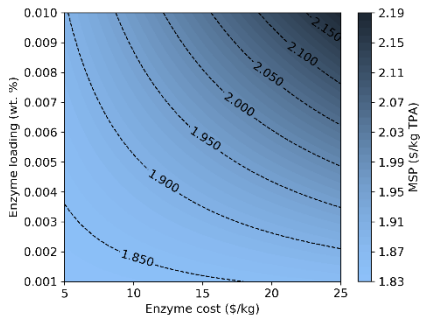
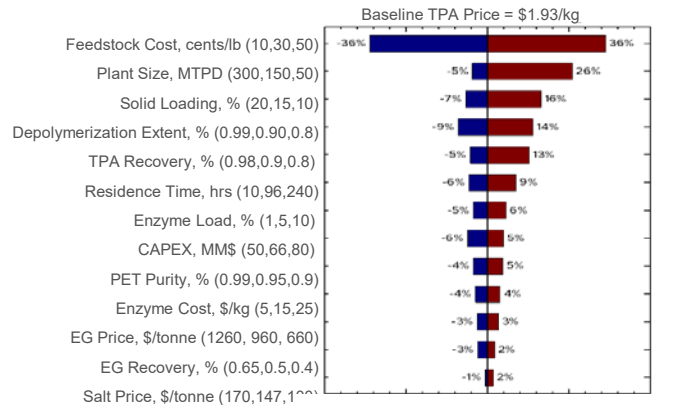
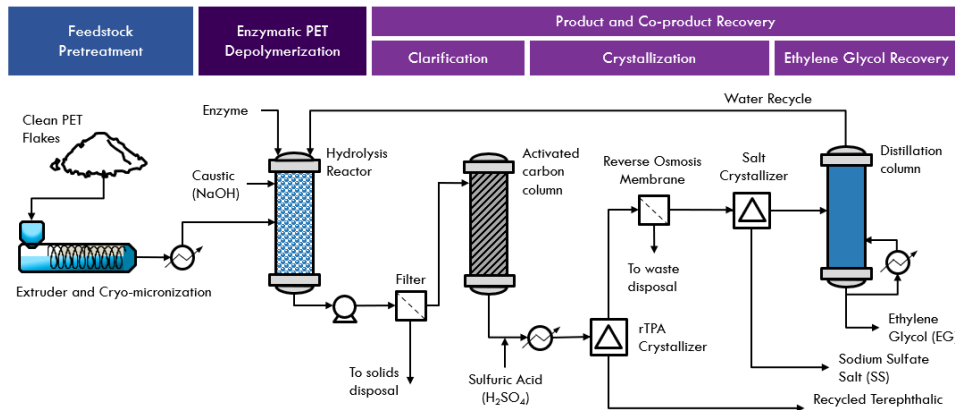
OUTCOMES:

- Relate error bars to level of maturity of design.
- Prepare an analytical capability for quantifying risks associated with technology development and technology transfer to market.

Multivariate Sensitivity Analysis



Multivariate sensitivity analysis is used to understand perturbation from varying 2+ inputs simultaneously



PET bales to terephthalic acid (TPA) including feedstock pretreatment, depolymerization, downstream separation, TPA crystallization and EG recovery (Courtesy of Avantika).

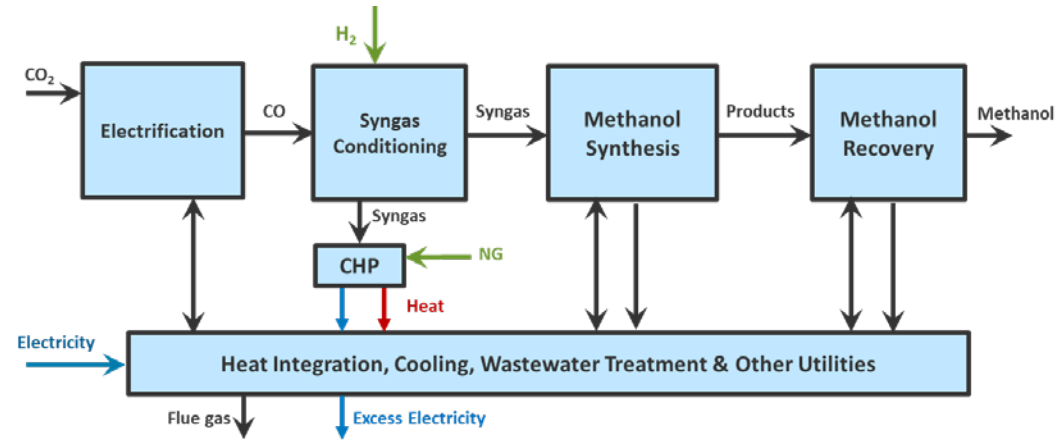
USDRIVE Net Zero Carbon Fuel Tech Team



MISSION: Drive research, development, and demonstration of renewable energy solutions for the transportation sector through an assessment of the carbon intensity, technoeconomic readiness, and challenges for volume implementation of net-zero carbon fuel pathways.

USDRIVE NZTT:

- Fuels Industry
- US Department of Energy
- Electric Utilities
- Automotive Industry
- Associate members
- Analysis task by the four participating National Labs (NREL, PNNL, ANL and LLNL)



OUTCOMES: Completed initial TEA/LCA to understand the potential of 4 illustrative near-term pathways for generating net-zero carbon fuels.

4. Progress and Outcomes: Strategic TEA

Strategic Support
(Ling Tao)

Strategic TEA
(Ling Tao)

Sustainable
Process Design
(Eric Tan)

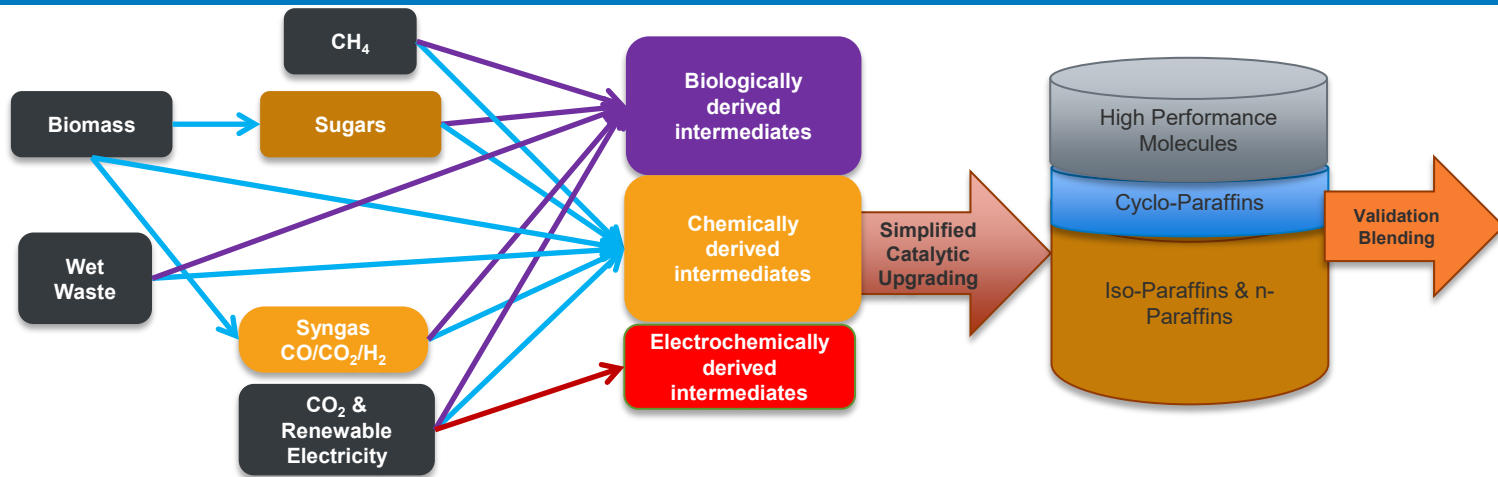
Refinery Optimization
(Avantika Singh)

Jobs Analysis and
Model Development
(Yimin Zhang)

Strategic Goal:

- Perform TEA to highlight R&D needs for emerging strategies.
- Supply key data for GREET, BSM analysis, and JEDI tools.
- Provide critical inputs to inform BETO.

Strategic TEA: SAF TEA Overview



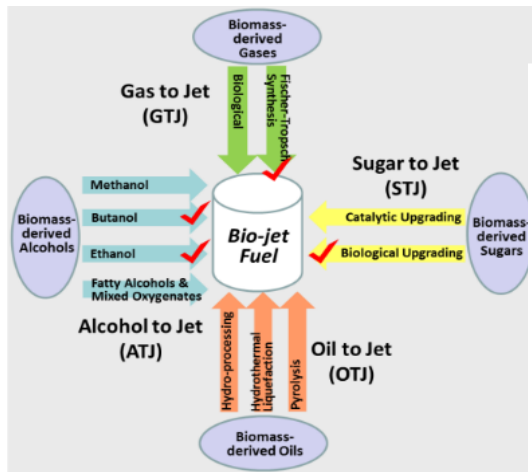
Frame with TEA and LCA

- Report key cost drivers and key cost related strategies for a path forward to approach \$2.5/GGE to R&D, stakeholders.
- Consider cost impacts from process integration, hybrid/synthesis process design; regional, scales, 1st of kind.
- Consider cost impact from blending of various feedstocks to blending intermediates

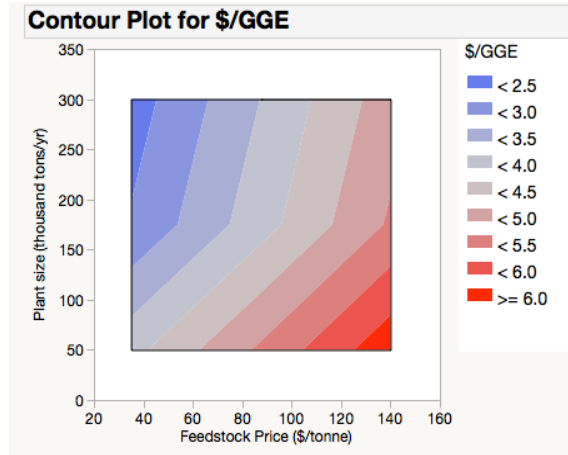
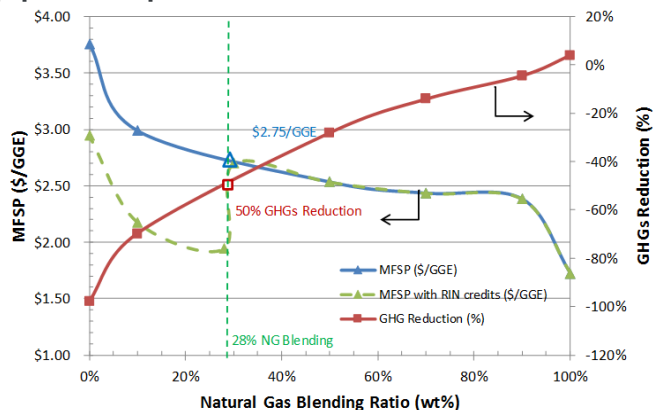
OUTCOMES: SAF costs from \$3.5-6/GGE for selected pathways; ≤ \$2.5/GGE needs.

SAF TEA: Progress and Outcomes

Established a Library of TEA Models for Biomass-Derived SAF



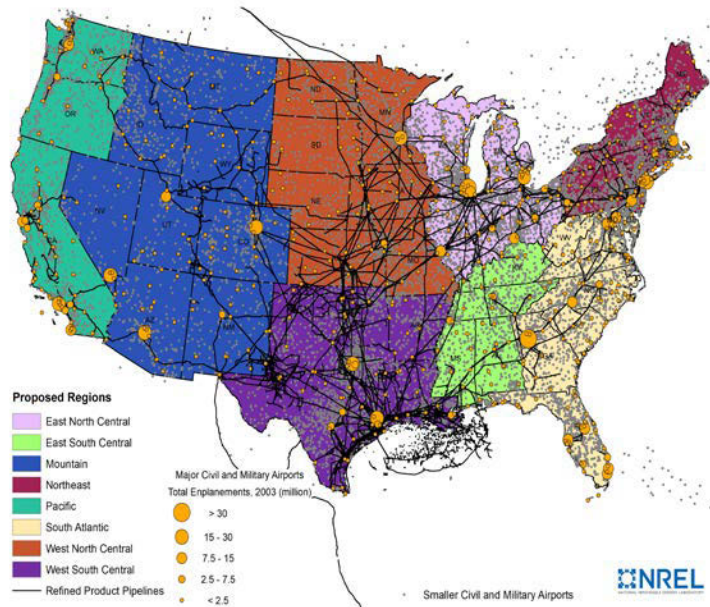
Blending fossil and renewable feeds can provide optimal balance between GHG and cost



Key Takeaways to \$2.50/GGE study: A combination of strategies required such as: 1) low-cost feedstocks, 2) high process yields, 3) larger scales, 4) coproducts, 5) renewable/cheap H₂ sources and 6) RIN/LCFS credits.

SAF TEA: Progress and Outcomes

Outline barriers, challenges, R&D needs to meet projected SAF in specific US regions and review how/why there are any region-specific needs



Rank	Airport	Code (IATA/ICAO)	Region	2017 Total Passengers
1	Hartsfield–Jackson Atlanta International Airport	ATL/KATL	South Atlantic	103,902,992
2	Los Angeles International Airport	LAX/KLAX	Pacific	84,557,968
3	O'Hare International Airport	ORD/KORD	East North Central	79,828,183
4	Dallas/Fort Worth International Airport	DFW/KDFW	West South Central	67,092,194
5	Denver International Airport	DEN/KDEN	Mountain	61,379,396

OUTCOMES:

- Consider top 5 busiest airports in US.
- Estimate SAF production potentials and percentage of conventional jet fuel that could be displaced.
- Estimate conversion costs for SAF.

4. Progress and Outcomes: Sustainable Process Design

Strategic Support
(Ling Tao)

Strategic TEA
(Ling Tao)

Sustainable
Process Design
(Eric Tan)

Refinery Optimization
(Avantika Singh)

Jobs Analysis and
Model Development
(Yimin Zhang)

Strategic Goal:

Further incorporate and integrate sustainability into conversion process design.

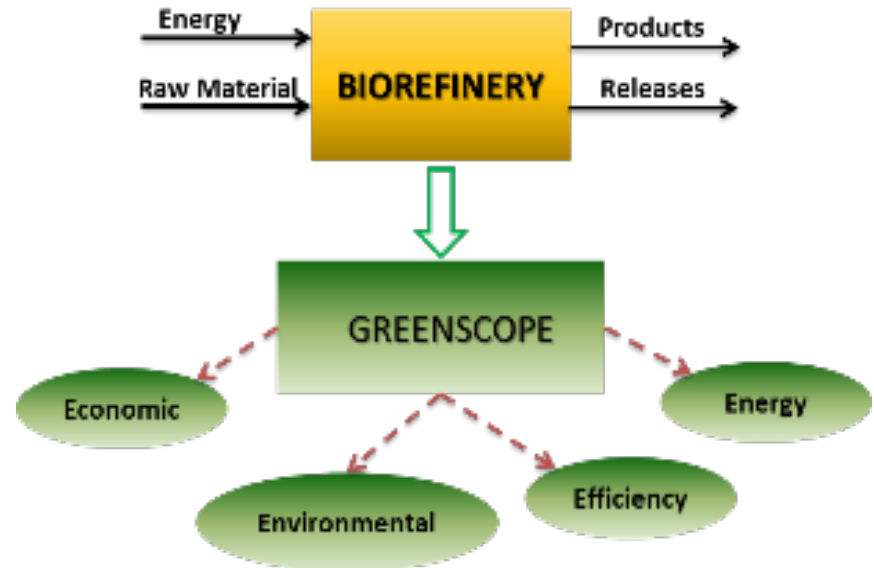
Sustainable Process Design

APPROACH: Implementing **GREENSCOPE** methodology for sustainability performance assessment of biomass-to-fuel conversion processes.

- A holistic sustainability analysis where the designers and decision-makers can implement changes to the process design and understand impacts at the unit-operations level.

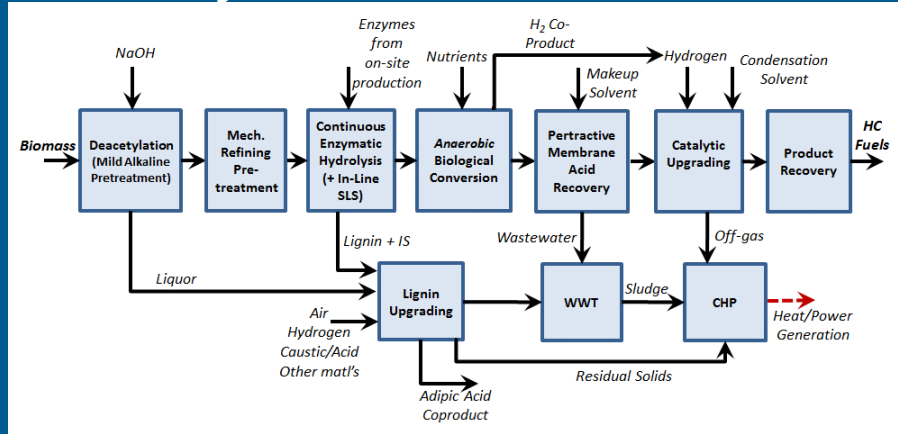
MODEL CAPABILITIES:

- Wide range of sustainability metrics.
- Four performance areas: Environment, Energy, Economics, and Efficiency.
- Integrated framework.



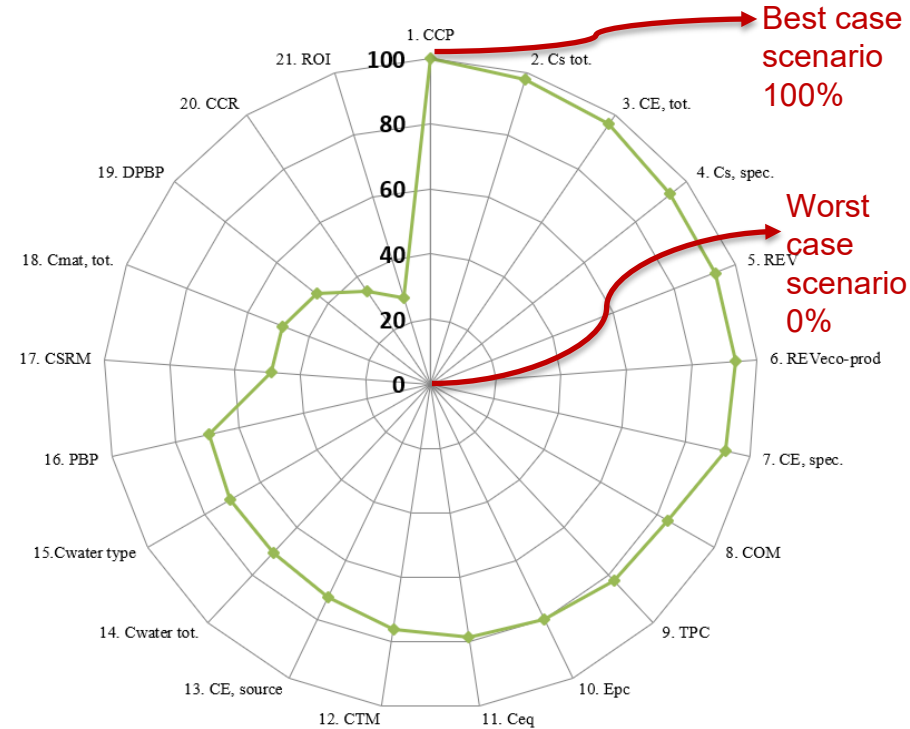
Integrate Sustainability in Biorefinery Design

Case Study



6 out of 21 economic indicators exhibit sustainability scores < 50%:

- Specific raw material cost (17. *CSRM*).
- Total material cost (18. *Cmat,tot*).
- Discounted payback period (19. *DPBP*).
- Cumulative cash ratio (20. *CCR*).
- Rate of return on investment (21. *ROI*).

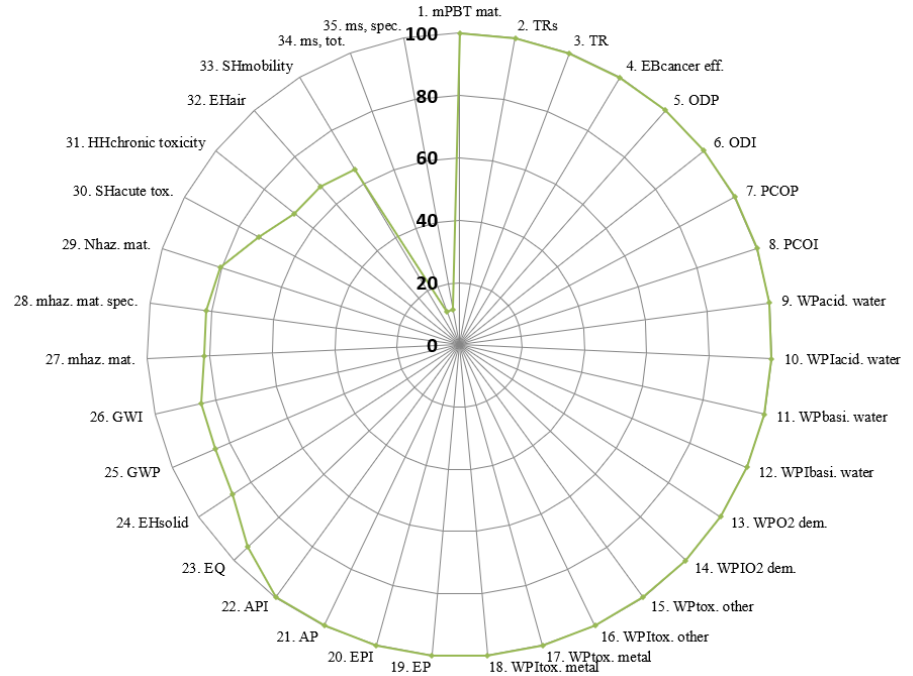


21 Economic Indicators

Integrate Sustainability in Biorefinery Design

Example of analysis outcome to inform R&D strategy

- Most of the environmental indicators exhibit a relatively high level of sustainability (i.e., > 50%).
- Indicative of good process performance for many environmental aspects.
- Critical aspect: total solid waste (ash, gypsum, lime, 34, 35).

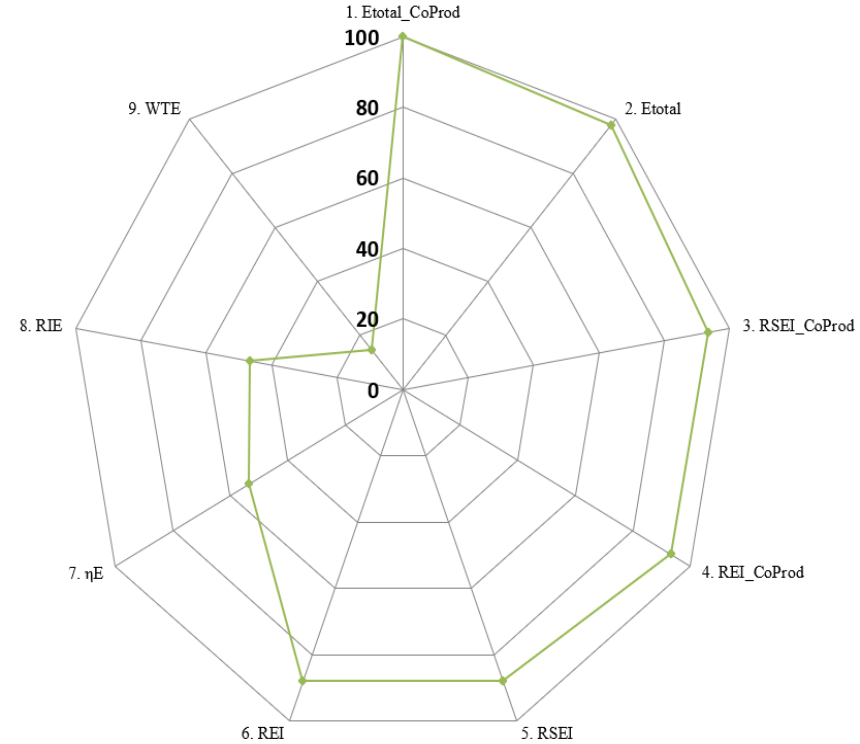


Integrate Sustainability in Biorefinery Design

Example of analysis outcome to inform R&D strategy

- Waste treatment energy indication (9. WTE) displays a low sustainability score.
- Low renewability-energy index (8. RIE), the ratio of the consumption of renewable energy to the total quantity of energy supplied to the process.

OUTCOMES: Identify the “hot spots” and opportunities for improving the sustainability of the biorefinery.



9 Energy Indicators

4. Progress and Outcomes: Refinery Optimization

Strategic Support
(Ling Tao)

Strategic TEA
(Ling Tao)

Sustainable
Process Design
(Eric Tan)

Refinery Optimization
(Avantika Singh)

Jobs Analysis and
Model Development
(Yimin Zhang)

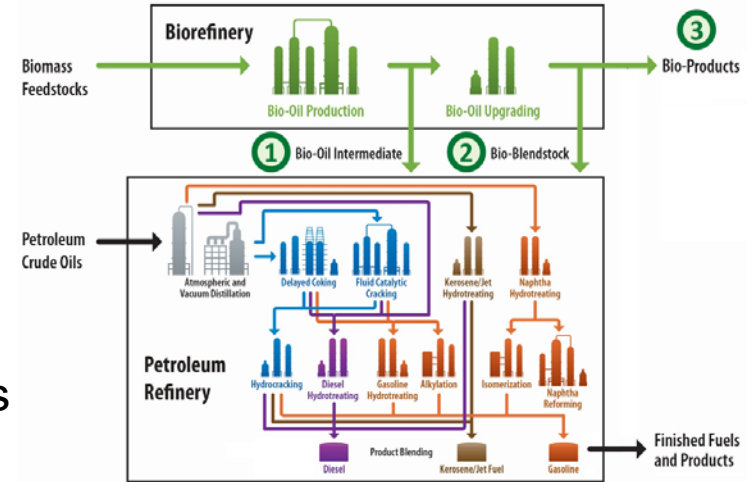
Strategic Goal:

Seek opportunities for biofuels in the context of petroleum refineries.

Petroleum Refinery Optimization

Opportunities for inserting bio-derived intermediates in refinery operations

- ① Minimize cost of commodity bio-fuels through refinery integration.
- ② Produce high-quality, high-value fuel blendstocks for emerging engine technologies.
- ③ Produce high-value bio-chemicals and other value streams.



OBJECTIVE:

- Develop and **leverage modeling innovations from other DOE-funded projects** (Co-Optima, SCR, TC Analysis) to inform petroleum refinery integration strategies.
- Identify primary finished fuel **challenges** and valuable **fuel properties**.
- Calculate the **value of bio-intermediates** and blendstocks through integration modeling to compliment cost analysis (TEA).

Petroleum Refinery Optimization: Marine Fuels

OBJECTIVE: Reduce sulfur (to 0.5%) in current heavy fuel oil in compliance with IMO rules. Marine vessels move over 80% of global trade volume (70% of trade value) and account for 4% of global oil demand.

APPROACH:

- Develop a preliminary minimum selling price that biofuel blendstocks must achieve to be comparable to the projected cost of low-sulfur marine fossil fuels.
- Evaluate the refinery impact if these bio-blendstocks were available for blending to produce low sulfur marine fuels.

OUTCOME: The relative economic benefit to a refiner depends on the biofuel pricing and properties, as well as the refinery configuration.

Publication:

ORNL/TM-2018/1080

Understanding the Opportunities of Biofuels for Marine Shipping



Approved for public release.
Distribution is unlimited.

Mike Kass¹
Zia Abdullah²
Mary Biddy²
Corinne Drennan³
Troy Hawkins⁴
Susanne Jones³
Johnathan Holladay³
Doug Longman⁴
Emily Newes³
Tim Theiss¹
Tom Thompson⁵
Michael Wang⁴

¹Oak Ridge National Laboratory
²National Renewable Energy
Laboratory
³Pacific Northwest National
Laboratory
⁴Argonne National Laboratory
⁵US Maritime Administration

December 2018

Several national laboratories collaborated to publish a joint report that examined the economic potential to utilize bio-derived fuels in marine applications as well as outlined further research and development needs and uncertainties associated with the integration of bio-blendstocks.

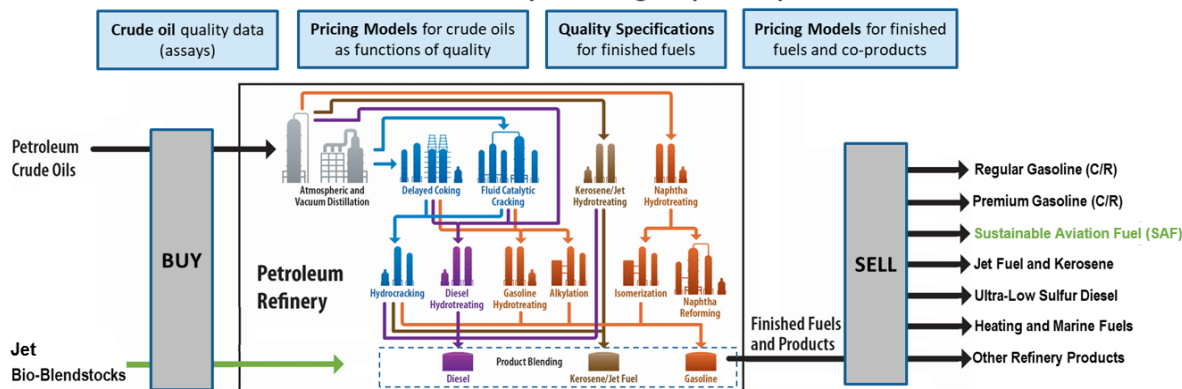
Petroleum Refinery Optimization: Jet Fuels



OBJECTIVE: Evaluate jet decarbonization methods with changing jet fuel demand between 2020-2050 and the propose carbon offsetting and reduction scheme as imposed by CORSIA initiative.

APPROACH: Used linear programming for (1) assessing the baseline refinery product slate, particularly jet fuel range, as it evolves from 2020-2050 (2) analyzing opportunities for refiners by incorporating capital expansion cost estimates and jet fuel pricing dynamics for optimal decisions between CAPEX and OPEX.

Overview of Commercial Refinery Modeling Scope in Aspen PIMS



OUTCOMES: Refinery profitability is most impacted by smoke point and sulfur content. Bio-blendstocks allow smaller refineries transitioning from selling off-spec distillate to producing SAF.

4. Progress and Outcomes: Job Analysis

Strategic Support
(Ling Tao)

Strategic TEA
(Ling Tao)

Sustainable
Process Design
(Eric Tan)

Refinery Optimization
(Avantika Singh)

Jobs Analysis and
Model Development
(Yimin Zhang)

Strategic Goal:

Understand the potential of job creation and economic benefits resulting from the build-out of new biorefineries.

Jobs Analysis for Bio-Derived Fuels

RELEVANCE: Publicly available tool for estimating the economic impacts of potential bioenergy technologies on local jobs.

PROBLEM: Lack of tools for evaluating the broad socioeconomic impact of bioenergy technologies.

APPROACH: Input-output model for estimating economic impacts for wet waste (sludge, in particular)-to-biofuel blendstocks.

OUTCOMES: Developed a **J**obs and **E**conomic **D**evelopment **I**mpact model to estimate the jobs impact of producing biofuels.

Project Descriptive Data - Sludge Hydrothermal Liquefaction and Biocrude	
Project Location	Texas
Year Construction Starts	2018
Construction Period (Duration in months)	36
HTL Plant Feedstock	Sludge from Waste Water
Baseline Feedstock Rate (US dry tons/day)	110
Feedstock Rate Adjustment (percent change)	10%
Total Feedstock Utilized (US dry tons/year)	36,300
Fuel Produced	Renewable Diesel Blendstock and Naphtha
Total Renewable Fuel Production (Mil. gge/Year)	4.26
HTL Plant Share of Upgrading Plant Capacity	11%
Distance from HTL Plant to Upgrading Plant (miles one way)	100
Transportation Cost Per Mile (\$/mile)	\$1.54
Money Value (Dollar Year)	2014

[Go To Summary Impacts](#) [Review/Edit HTL Plant Cost Data](#)

<https://www.nrel.gov/analysis/jedi/>



Jobs Analysis for Gen 1.5 Technology

RELEVANCE: Potential job growth opportunities from bolt-on Gen 1.5 technologies to produce additional ethanol in dry mills in Midwest.

OBJECTIVE: How do bolt-on Gen 1.5 compare to stand-alone cellulosic ethanol biorefinery in terms of job creation?

APPROACH: LeveragE TEA for an economic input-output analysis to quantify state-level job potential of adopting Gen 1.5 bolt-on technologies.

OUTCOMES:

- Between 0.89 and 1.27 annual jobs could be supported by each million gallons of Gen 1.5 ethanol produced.
- In comparison, a stand-alone biorefinery is expected to support 0.98 annual jobs per million gallons of ethanol production.



Quad Chart Overview

Timeline

- Project start date: FY2011
- Merit review cycle: FY2019-2021, 80% complete

	FY21	Total Planned (FY19-FY21)
DOE Funding	\$450K	\$1,350K

Project Partners*

- National laboratories: ANL, INL, LLNL, ORNL, PNNL
- NREL—core platform analysis; NREL—Market and Policy Impact Analysis Group; NREL—SI, NREL—VT,
- Industry: Exxon-Mobil, ICM, USDRIVE
- Government agencies: CAAFI, DOE-AMO, DOE-FCTO, DOE-VTO, DOD, DOT, EPA
- Academia: MIT, University of Chicago

Barriers addressed

At-A. Analysis to Inform Strategic Direction

At-D. Identifying New Market Opportunities for Bioenergy and Bioproducts

At-E. Quantification of Economic, Environmental, and Other Benefits and Costs

Project Goal

- Provide sound, unbiased, and consistent analyses to inform BETO strategic direction.
- Comparative analyses of biomass conversion processes to evaluate emerging areas of interest.
- Model and tool development to support BETO and to understand the impact of expanding bioeconomy.

End of Project Milestone

- Develop a standard methodology to estimate the prices of the chemical coproducts.
- Solidify strategy around alternative jet fuel production and guide R&D strategies on both TEA/LCA and non-technical barriers.

Future Works:

- Improve analysis rigor to meet any cost objective.
- Inform on-going **strategic goals** for **renewable jet fuel**.
- Evaluate **emerging technology pathways** to ensure both economic viability and sustainable design creditability.
- Develop JEDI for emerging technology pathways.

Summary

Management

- Five tasks directly relevant to BETO's mission and MYPP.
- Integrate multiple dimension strategic supports for BETO, external/internal stakeholders.
- Stay current on bioeconomy advancements and state-of-art tools to mitigate risk of rapid changing externality

Approach

- Transparent, rigorous models with a consistent set of assumptions.
- Integrated task structure to provide holistic output for strategy development.
- Consult experts globally to get the best data; work closely with stakeholders to define needs and key questions.

Impact

- Support and bridge a range of DOE BETO projects.
- Provide strategic and critical information to industry and agencies outside of BETO.
- Disseminate technical results to web-based tools and in high impact publications.

Progress & Outcomes

- Developed strategies to meet a <\$2.5/GGE cost goal for hydrocarbon fuels and SAF.
- Supported USDRIVE on net zero carbon fuels strategies.
- Identified opportunities for improving the sustainability of the biorefinery.
- Developed Gen 1.5-focused JEDI model for employment potentials.

Acknowledgements



NREL: Zia Abdullah, Adam Bratis, Nick Carlson, Ryan Davis, Abhijit Dutta, Gary Grim, Kylee Harris, Jenny Huang, Daniel Inman, Chris Kinchin, Anelia Milbrandt, Michael Talmadge, Eric Tan, Matt Wiatrowski, Yimin Zhang, Helena Chum, Mark Davis, Rick Elander, Tom Foust, and NREL technology platform researchers

PNNL: Lesley Snowden-Swan, Aye Meyer, Corinne Drennan, Yunhua Zhu, Steve Phillips

ANL: Michael Wang, Uisung Lee, Troy Hawkins, Eunji Yoo

LLNL: A.J. Simon, Hannah Goldstein, Daniel Sanchez (Berkeley)

INL: Damon Hartley

Other industrial and academic collaborators



BIOENERGY TECHNOLOGIES OFFICE

Bioenergy Technologies Office (BETO): Alicia Lindauer, Zia Haq, Ian Rowe, Andrea Bailey, Beau Hoffman, Nichole Fitzgerald, Kevin Craig, Jay Fitzgerald, Liz Moore

Thank you!

www.nrel.gov

NREL/PR-5100-79272

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Bioenergy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.




Additional Slides


3. Impact: Contribute Directly to BETO Goals & MYPP

BETO Goal	Project Contributions
<p>“Develop and maintain analytical tools, models, methods, and datasets to advance the understanding of bioenergy and its related impacts.” (A&S Performance Goal) [2-130]</p>	<p>Developed a suite of tools and models that are publicly available, including JEDI and the Biofuels Database. Both tools work to ensure transparency in modeling approaches and are user-friendly tools to support stakeholder outreach.</p>
<p>“The Office supports the development and deployment of new analytical tools and methods and guides the selection of assumptions and methodologies to be used for all analyses to ensure consistency, transparency, and comparability of results.” [2-134]</p>	<p>Strategic Support future work is focused on improving the rigor associated with the analysis to meet any cost objective as well as improving methodologies for incorporating the cost of coproducts in TEA. Additionally, in FY19/20 worked with ANL and core conversion project on coproduct considerations in LCA of biorefinery analyses and published the joint BETO reports.</p>
<p>Support efforts to “provide an analytical basis for BETO planning and assessment of progress.” [2-129]</p>	<p>Strategic Support collaborative analysis for \$2/GGE. Strategic TEA results have supported the initial analyses and transition to strategic areas for WTE.</p>
<p>Develop analyses to “quantify the environmental and socio-economic effects of bioenergy production, assess opportunities for improvement, disseminate technical information..” [2-121]</p>	<p>JEDI tools help to understand bioenergy’s impact and potential benefits on creating and supporting domestic job growth. Work over last years has focused on expansion to align with core BETO funded strategies</p>
<p>Technology-specific analyses explore sensitivities and identify areas where investment may lead to the greatest impacts. [2-129]</p>	<p>Project has long history in supporting this goal. Strategic TEA models identify key cost drivers for jet fuel and new emerging technologies, as well as develop pioneer plant costs for near-term deployment.</p>


Market Trends

Product


 Gasoline/ethanol demand decreasing, diesel demand steady

 Increasing demand for aviation and marine fuel


 Demand for higher-performance products

 Increasing demand for renewable/recyclable materials


Feedstock

 Sustained low oil prices

 Decreasing cost of renewable electricity


 Sustainable waste management


 Expanding availability of green H₂

 Closing the carbon cycle

Capital


 Risk of greenfield investments


 Challenges and costs of biorefinery start-up

 Availability of depreciated and underutilized capital equipment

Social Responsibility

 Carbon intensity reduction

 Access to clean air and water

 Environmental equity

NREL's Bioenergy Program Is Enabling a Sustainable Energy Future by Responding to Key Market Needs

Value Proposition

- An array of analysis tools to support BETO strategic direction
- Assess impacts and potential for emerging technologies and outline R&D needs/barriers for further development
- Outreach to bioenergy community to support impacts on the bioeconomy.
- Strategic support efforts have maintained external collaborations with EPA, DOE FCTO/VTO, USDRIVE to provide key biofuel production metrics.
- Evaluation of the emerging pathways of interest of BETO by 1) exploring the emerging strategies and ensuring no unintended consequences resulting from focusing on lower cost costs, 2) highlighting key sustainability and 3) working with R&D teams and BETO to review and propose alternative opportunities to improve sustainability designs and economic viability

Key Differentiators

- Consider a wider range of metrics (costs, GHGs, sustainability indicator, jobs, refinery integration) that allow for more comprehensive direct comparison bioeconomy alternatives.
- Bridge analysis with R&D, conversion platform, national labs, federal agency, industrial and academia

Abbreviations and Acronyms

A&S: Analysis and Sustainability
AMO: DOE Advance Manufacturing Office
ANL: Argonne National Laboratory
AOP: Annual operating plan
BETO: Bioenergy Technologies Office
CAAFI: Commercial Aviation Alternative Fuels Initiative
CARB: California Air Resources Board
DOD: Department of Defense
EPA: US Environmental Protection Agency
FOA: Funding Opportunity Announcement
GGE: Gasoline gallon equivalent
INL: Idaho National Laboratory
IRR: Internal Rate of Return
ISU: Iowa State University
JEDI: Jobs and Economic Development Impact
LCA: Life-cycle analysis
LCFS: Low Carbon Fuel Standard
MFSP: Minimum fuel selling price
MYPP: Multi-year program plan
NREL: National Renewable Energy Laboratory
NZTT: Net Zero Tech Team

ORNL: Oakridge National Laboratory
PNNL: Pacific Northwest National Laboratory
RIN: Renewable Indication Number
TEA: Techno-Economic Analysis
WTE: Waste To Energy
VTO: Vehicles Technology Office

Publications and Technical Reports

1. Zhang Y, Sahir AH, Tan EC, Talmadge MS, Davis R, Bidy MJ, Tao L. Economic and environmental potentials for natural gas to enhance biomass-to-liquid fuels technologies. *Green Chemistry*. 2018;20(23):5358-73.
<https://pubs.rsc.org/en/content/articlehtml/2018/gc/c8gc01257a>
2. Dunn, J.B., Neues, E., Cai, H., Zhang, Y., Brooker, A., Ou, L., Mundt, N., Bhatt, A., Peterson, S. and Bidy, M., 2020. Energy, economic, and environmental benefits assessment of co-optimized engines and bio-blendstocks. *Energy & Environmental Science*.
3. Fei, Q., Liang, B., Tao, L., Tan, E.C., Gonzalez, R., Henard, C. and Guarnieri, M., 2020. Biological valorization of natural gas for the production of lactic acid: techno-economic analysis and life cycle assessment. *Biochemical Engineering Journal*, p.107500. "Applying Environmental Release Inventories and Indicators to the Evaluation of Chemical Manufacturing Processes in Early-Stage Development," *ACS Sustainable Chemistry & Engineering*, 7, 10937-10950 (2019).
4. Adhikari, S.P., Zhang, J., Guo, Q., Unocic, K.A., Tao, L. and Li, Z., 2020. A hybrid pathway to biojet fuel via 2, 3-butanediol. *Sustainable Energy & Fuels*. "An Integrated Sustainability Evaluation of High-Octane Gasoline Production from Lignocellulosic Biomass," *Biofuels, Bioproducts and Biorefining*, 13, 1439-1453 (2019).
5. Tan, E.C.D., "Sustainable Biomass Conversion Process Assessment," in *Recent Advances in Process Intensification and Integration for Sustainable Design*, ed. Wiley VCH (May 20, 2020) ISBN-13: 978-3527345472 .
6. Joint contributions from 2.1.0.100 (Biochemical Platform Analysis), 2.1.0.302 (Thermochemical Platform Analysis), 4.1.1.30 (Strategic Support), and collaborations with other partners from ANL, INL, PNNL, ORNL: "Integrated Strategies to Enable Lower-Cost Biofuels." DOE Technical Report, July 2020: <https://www.energy.gov/sites/prod/files/2020/07/f76/beto-integrated-strategies-to-enable-low-cost-biofuels-july-2020.pdf>

Publications and Technical Reports

7. Tan, E.C., Ruddy, D., Nash, C.P., Dupuis, D.P., Dutta, A., Hartley, D. and Cai, H., 2020. High-Octane Gasoline from Lignocellulosic Biomass via Syngas and Methanol/Dimethyl Ether Intermediates: 2020 State of Technology and Future Research (No. NREL/TP-5100-76619). National Renewable Energy Lab.(NREL), Golden, CO (United States). <https://www.nrel.gov/docs/fy20osti/76619.pdf>
8. Tan, E.C. and Tao., L., 2020. Biomass-Derived Liquid Fuels Via Fischer-Tropsch Process As a Potential Replacement for Marine Fuels (No. NREL/PR-5100-75504). National Renewable Energy Lab.(NREL), Golden, CO (United States).
9. Shen R, Tao L, Yang B. Techno-economic analysis of jet-fuel production from biorefinery waste lignin. *Biofuels, Bioproducts and Biorefining*. 2019 May;13(3):486-501. <https://onlinelibrary.wiley.com/doi/pdf/10.1002/bbb.1952>
10. Cai H, Benavides T, Lee U, Wang M, Tan E, Davis R, Dutta A, Bidy M, Clippinger J, Grundl N, Tao L. Supply Chain Sustainability Analysis of Renewable Hydrocarbon Fuels via Indirect Liquefaction, Ex Situ Catalytic Fast Pyrolysis, Hydrothermal Liquefaction, Combined Algal Processing, and Biochemical Conversion: Update of the 2018 State-of-Technology Cases and Design Cases. Argonne National Laboratory, Argonne, IL (United States); 2018 Dec 1. <https://publications.anl.gov/anlpubs/2019/01/149543.pdf>
11. Mann MK, Bidy MJ, Augustine CR, Nguyen Q, Hu H, Ebadian M, Webb E. Evaluation of Agricultural Equipment Manufacturing for a Bio-Based Economy. National Renewable Energy Laboratory, Golden, CO (United States); 2019 Jun 26. <https://www.nrel.gov/docs/fy19osti/71570.pdf>
12. Sahir AH, Zhang Y, Tan EC, Tao L. Understanding the role of Fischer–Tropsch reaction kinetics in techno-economic analysis for co-conversion of natural gas and biomass to liquid transportation fuels. *Biofuels, Bioproducts and Biorefining*. 2019 Jul. <https://onlinelibrary.wiley.com/doi/pdf/10.1002/bbb.2035>

Conference Papers

1. “Techno-Economic Analysis and Life-Cycle Assessment for Gas Phase Catalytic Oxidation of Lignin to Produce Phenolic Compounds, National Renewable Energy Laboratory Presentation”. 2018 AIChE Annual Meeting, Pittsburgh, PA, 2018 Oct. <https://www.osti.gov/biblio/1482502>
2. “Evaluating Indicators and Life Cycle Inventories for Processes in Early Stages of Technical Readiness,” 2017 AIChE Annual Meeting, Minneapolis, MN, October 29 – November 3, 2017.
3. “An Integrated Sustainability Evaluation of Indirect Liquefaction of Biomass to Liquid Fuels,” 7th International Congress on Sustainability Science & Engineering, Cincinnati, OH, August 12-15, 2018.
4. “Sustainable Process Design for Biofuel Production via Syngas Conversion Pathway,” 8th International Congress on Sustainability Science & Engineering, Kuala Lumpur, Malaysia, July 1-3, 2019.
5. “Estimating Chemical Releases and Evaluating Indicators for Manufacturing Processes: Biorefinery Case Studies,” 2020 AIChE Annual Meeting, Virtual, November 15-20, 2020.
6. “Sustainable Process Design for Biofuel Production Via Syngas Conversion Pathway”. 8th International Congress on Sustainability Science & Engineering (ICOSSE '19: Industry, Innovation and Sustainability), Kuala Lumpur, Malaysia 2019 <https://www.osti.gov/biblio/1542267>
7. “The Technical and Economic Feasibility of CO2 Reduction Using Low-Cost Electrons”. USCAR/BETO Joint Workshop, USCAR offices, Detroit, MI. 2019 Jul.

Responses to Previous Reviewers' Comments

- **Reviewer comment:** This team provided excellent work results. This type of analysis in industry is routine and often starts early in large projects. The value of such analysis work at early, middle and late-stage projects is critical to BETO programs. These analyses increase dramatically the speed of development providing where to focus future efforts to drive down cost or where to stop working since further refinement is not impactful. Only question is can BETO provide some level of techno-economics to even smaller start projects to make sure that the original strategy has right to succeed. Only other comment is funding for plant capital for new technologies typically, from my experience, is not 20 years payout but more like 10 years, thus only true for nth plant. Also never know a plant to come in on original capital cost estimates. Some confidence info on calculations i.e., $\pm x\%$ would be helpful as well for reviewers.
- **Response:** We thank the reviewers for their helpful feedback and comments. Going forward, we will work to adopt suggestions from the panel to estimate cost ranges and to consider more near-term cost estimation (pre-Nth plant evaluations) for these new and novel technologies. We will also consider payback period potential for these new technologies as replacement for incumbent baseline technologies and further expand our sustainability analysis to consider a wider range of metrics.