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

- **Strategic Support** (Ling Tao)
- **Strategic TEA** (Ling Tao)
- **Sustainable Process Design** (Eric Tan)
- **Refinery Optimization** (Avantika Singh)
- **Jobs Analysis and Model Development** (Yimin Zhang)

**Outputs Inform**

- BETO Conversion team
- BETO/VTO/FCTO and ATB Support
  - Engagement with stakeholders to review approach & results
- Supports GREET, BSM, JEDI
  - Engagement with CAAFI, FAA, Universities
- BETO Conversion team
  - Methodology implementation for stakeholder (industry)
- BETO Conversion team
  - Assess impacts of biomass-derived blendstocks with petroleum-derived blendstocks, Co-Optima, BSM
- Tool development for stakeholder (e.g., local governments, biofuel developers)
  - Inform BETO of potential socio-economic benefits

**Input from:**

- BETO Stakeholders Collaborators
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)**

**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.

**Risk**

Project recommendations cannot keep up with rapid changing externalities.
1. Management

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

- **Co-Optima, USDRIVE**
  - Develop models to be utilized in Co-Optima (JEDI, Refinery Blending) and USDRIVE (TEA)

- **Strategic Support Project**
  - Support FCIC on failure modes and effect analysis

- **Feedstock Conversion Interface Consortium**
  - Provide process and social economic data

- **Performance Advantaged Bioproducts and Agile Biofoundry**
  - Supply screening metrics for bioproducts

- **WTE, Marine, SAF and E2M**
  - Integrate for consistency and best practices taken for TEA (error bars and coproducts) and LCA (coproduct methodologies)

- **BSM, BOTTLE**
  - Provide key TEA and TRL data for emerging pathways

- **EPA RtC3, GREET, BEIOM**
  - Provide process and social economic data

Integrate for consistency and best practices taken for TEA (error bars and coproducts) and LCA (coproduct methodologies)
2. Approach

Develop Models and Conduct Analysis to Support Strategic Decisions

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

<table>
<thead>
<tr>
<th>Critical Success Factors</th>
<th>Challenges</th>
<th>Approach to overcome</th>
</tr>
</thead>
</table>
| Model results are accurate and recommendations from the models are relevant. | • Availability and quality of input data.  
• Model is not representative. | • 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. | • 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. | • Work closely with stakeholders to define needs and key questions. |
2. Approach

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.

Strategic Support (Ling Tao)
Strategic TEA (Ling Tao)
Refinery Optimization (Avantika Singh)

VTO, AMO, FCTO
ATB
USDRIVE

BETO Conversion

Research Consortiums
Other Stakeholders
3. Impact

This project provides strategic information to agencies outside of BETO

**Sustainable Process Design** (Eric Tan)
- Researchers
- Process designers
- Funding agency (BETO)
- Other stakeholders.

**Jobs Analysis and Model Development** (Yimin Zhang)
- Primarily state governments
- Biofuel developers
- Social justice

Decision made by the interest parties
4. Progress and Outcomes: Strategic Support Task

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.

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).

Feedstock Cost, cents/lb (10,30,50)
Plant Size, MTPD (300,150,50)
Solid Loading, % (20,15,10)
Depolymerization Extent, % (0.99,0.90,0.8)
TPA Recovery, % (0.98,0.9,0.8)
Residence Time, hrs (10,96,240)
Enzyme Load, % (1,5,10)
CAPEX, MMS (50,66,80)
PET Purity, % (0.99,0.95,0.9)
Enzyme Cost, $/kg (5,15,25)
EG Price, $/tonne (1260, 960, 660)
EG Recovery, % (0.65,0.5,0.4)
Salt Price, $/tonne (170,147,100)

% Change in MSP
Baseline TPA Price = $1.93/kg
-5% 5% 10% 15% 20% 25% 30%

NREL | 17
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.
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

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

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

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 Goal:

Further incorporate and integrate sustainability into conversion process design.
Sustainable Process Design


- 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).
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).

35 Environmental Indicators

NREL | 26
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.
4. Progress and Outcomes: Refinery Optimization

Strategic Goal:
Seek opportunities for biofuels in the context of petroleum refineries.
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).
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.

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.
**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 programing 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.

**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 Goal:

Understand the potential of job creation and economic benefits resulting from the build-out of new biorefineries.
**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 Jobs and Economic Development Impact model to estimate the jobs impact of producing biofuels.
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 quality 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.

*Gen 1.5 uses feedstock fiber already on-site to produce cellulosic ethanol.
Quad Chart Overview

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

<table>
<thead>
<tr>
<th>DOE Funding</th>
<th>FY21</th>
<th>Total Planned (FY19-FY21)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$450K</td>
<td>$1,350K</td>
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</tbody>
</table>

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.

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
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
<table>
<thead>
<tr>
<th>BETO Goal</th>
<th>Project Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Develop and maintain analytical tools, models, methods, and datasets to advance the understanding of bioenergy and its related impacts.” (A&amp;S Performance Goal ) [2-130]</td>
<td>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.</td>
</tr>
<tr>
<td>“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]</td>
<td><strong>Strategic Support</strong> 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.</td>
</tr>
<tr>
<td>Support efforts to “provide an analytical basis for BETO planning and assessment of progress.” [2-129]</td>
<td><strong>Strategic Support collaborative</strong> analysis for $2/GGE. <strong>Strategic TEA</strong> results have supported the initial analyses and transition to strategic areas for WTE.</td>
</tr>
<tr>
<td>Develop analyses to “quantify the environmental and socio-economic effects of bioenergy production, assess opportunities for improvement, disseminate technical information..” [2-121]</td>
<td>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</td>
</tr>
<tr>
<td>Technology-specific analyses explore sensitivities and identify areas where investment may lead to the greatest impacts. [2-129]</td>
<td>Project has long history in supporting this goal. <strong>Strategic TEA</strong> models identify key cost drivers for jet fuel and new emerging technologies, as well as develop pioneer plant costs for near-term deployment.</td>
</tr>
</tbody>
</table>
**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 for 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

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**Market Trends**

- 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
- Sustained low oil prices
- Decreasing cost of renewable electricity
- Sustainable waste management
- Expanding availability of green H₂
- Closing the carbon cycle
- Risk of greenfield investments
- Challenges and costs of biorefinery start-up
- Availability of depreciated and underutilized capital equipment
- Carbon intensity reduction
- Access to clean air and water
- Environmental equity
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


• **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. +/- 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.