Strategic Analysis Support

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National Renewable Energy Laboratory (NREL)

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Analysis and Sustainability Peer Review
2017 U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO) Project Peer Review
Goal Statement

**Goal:** Develop tools and perform analyses to address key questions in support of the strategic direction of the DOE Bioenergy Technologies Office.

**Outcomes:**

- Assess the current and future market drivers for the production of biomass-derived chemicals.
- Provide comparative economic analyses for jet fuel production pathways.
- Evaluate alternative waste feed streams for the production of fuels and chemicals.
- Investigate the economics of biofuel quality in blending.
- Estimate the number of jobs that will be created in the United States with biorefinery deployment.

**Relevance:** Assess impacts of the emerging bio-economy and outline R&D needs/barriers for further development by BETO and industry.
Quad Chart Overview

### Timeline
Start Date: October 2015
End Date: Expected to undergo merit review in FY18
Percent Completion: 50%

### Barriers
**At-A:** Comparable, transparent, and reproducible analyses
**At-B:** Analytical tools and capabilities for system-level analysis
**At-C:** Data availability across the supply chain

### Budget

<table>
<thead>
<tr>
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<th>DOE Funded</th>
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<tr>
<td>FY12–FY14 (Total)</td>
<td>$2.0M</td>
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<tr>
<td>FY15</td>
<td>$600k</td>
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<tr>
<td>FY16</td>
<td>$650k</td>
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<tr>
<td>(FY17–Project End Date) Total Planned Funding</td>
<td>$1.3M</td>
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### Interactions/Collaborations
- National laboratories: 
  ANL, INL, NREL—core platform analysis; NREL—Market and Policy Impact Analysis Group; NREL—SI, NREL—VT, ORNL, PNNL
- Industry: 
  Celanese, Exxon-Mobil, U.S. DRIVE
- Government agencies: 
  CAAFI, DOE-BETO DMT, DOE-VTO, DOD, EPA
- Academia: 
  CU, ISU, MIT
• **Comparative analyses of biomass conversion processes to evaluate emerging areas of interest for BETO and Bioindustry.**
  - COP/ISU/NREL collaboration focused on techno-economic analysis (TEA) of biofuels (FY11).
  - NREL/PNNL hydrocarbon technology pathways (FY12/13).
  - Jet fuel economics and chemicals market assessment.
  - Provide quick turnaround analyses to support BETO and EERE.

• **Model and tool development to support BETO and to understand the impact of expanding the biomass economy.**
  - Estimate job growth potential for the developing bioeconomy.
  - Investigate the optimal biorefinery economics.
  - Develop economic analysis tools.
Project Overview: Objective

Develop and utilize an array of analysis tools to support the strategic direction of BETO and understand the development of a biomass economy:

- **Analysis** to identify the market drivers and uncertainties in the deployment of chemicals production from biomass.
- **Integrated biorefinery optimization** to guide BETO on the development of biofuels and bioproducts.
- **Techno-economic analysis** in support of the expansion of strategic programmatic technologies to jet fuel production.
- Estimates of **job growth** and the broader impacts of emerging industries.

Provide credible results to assist decision making in bioenergy investment by applying appropriate analyses and models.
Project Management Approach

• **Critical success factors:**
  - On-time and on-budget delivery of results.
    - Track progress through quarterly reports/updates.
    - Set intermediate goals to show continuous progress and received feedback from DOE on direction of analysis to project objectives.
    - Clearly defined objectives and milestones of the project.
Project Technical Approach

Develop Models and Conduct Analysis to Support Strategic Decisions

- Common approach for all projects:
  - Models are transparent and rigorous with a consistent set of assumptions that allows for direct comparison.
  - Analysis results and approaches are vetted by stakeholders.
  - Results and tool availability is communicated to stakeholders through peer-reviewed publications, presentations, and technical reports.

- Critical success factors: Availability and quality of data. Work with BETO to identify relevant stakeholders and collaborators for vetting and for data sources.
Strategic Support Task

**Strategic Goal:** Support BETO’s strategic mission and analysis needs by utilizing a range of methodologies and tools to investigate critical questions. Handoff results and outcomes of analyses to support core projects in BETO.
Market analysis report for the production of bio-derived chemicals based on public information.

- Initially identified **27 biomass-derived products**.
- Down-selected to **12 products** based on market potential.
- Report reviewed by over 15 experts from academia, national laboratories, and industry.

**Expanded report in FY15** to include additional products and information based on reviewer feedback.

### Criteria used to evaluate the market potential of biomass-derived products

<table>
<thead>
<tr>
<th>High Volume/Value</th>
<th>Market maturity</th>
<th>High growth (domestic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High growth (global)</td>
<td>Feedstock flexibility</td>
<td>Platform chemical</td>
</tr>
<tr>
<td>DOE interest/funding</td>
<td>Integrated with conversion pathways</td>
<td>Avoids competition with natural gas</td>
</tr>
<tr>
<td>Market pull</td>
<td>End-user specifications</td>
<td>Bioprocess advantage</td>
</tr>
<tr>
<td>Current scale</td>
<td>Favorable life cycle</td>
<td>Near-term deployment (high technology readiness level [TRL])</td>
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Significance and Impact

• Focus of report is on products that will have **near-term market impact**.

• Reviews current projects and planned efforts for bio-derived chemicals.

• **Identifies major drivers** for moving biomass-derived products to market and current market champions.

• Assesses ways in which chemicals production can be **leveraged to expand and accelerate the growth of biofuels**.

• Report published in FY16 and presented at three different conferences including Bioenergy 2016.

www.nrel.gov/docs/fy16osti/65509.pdf
<table>
<thead>
<tr>
<th>Chemical</th>
<th>Type</th>
<th>Conversion Pathway</th>
<th>TRL based on commodity feedstocks</th>
<th>Research &amp; development (R&amp;D) ongoing for lignocellulosic feedstocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butadiene (1,3-)</td>
<td>Drop-in</td>
<td>BC—Biological</td>
<td>6</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TC/BC—Gasification/Fermentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butanediol (1,4-)</td>
<td>Drop-in</td>
<td>BC—Biological</td>
<td>8</td>
<td>Y</td>
</tr>
<tr>
<td>Ethyl Lactate</td>
<td>Functional</td>
<td>BC—Biological</td>
<td>9</td>
<td>Y</td>
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<tr>
<td>Fatty Alcohols</td>
<td>Drop-in</td>
<td>TC—Gasification, BC—Biological, Algae</td>
<td>9</td>
<td>Y</td>
</tr>
<tr>
<td>Furfural</td>
<td>Functional</td>
<td>TC—Pyrolysis, BC—Catalytic</td>
<td>9</td>
<td>Y</td>
</tr>
<tr>
<td>Glycerol</td>
<td>Functional</td>
<td>Algae</td>
<td>9</td>
<td>Y</td>
</tr>
<tr>
<td>Isoprene</td>
<td>Drop-in</td>
<td>BC—Biological</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Lactic Acid</td>
<td>Functional</td>
<td>BC—Biological</td>
<td></td>
<td></td>
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<tr>
<td>Propanediol (1,3-)</td>
<td>Functional</td>
<td>BC—Biological</td>
<td></td>
<td></td>
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<tr>
<td>Propylene Glycol</td>
<td>Functional</td>
<td>BC—Biological</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Succinic Acid</td>
<td>Functional</td>
<td>BC—Biological</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xylene (para)</td>
<td>Drop-in</td>
<td>BC—Catalytic</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TC—Pyrolysis</td>
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• Selection of products based on a number of metrics (e.g., market considerations, TRLs, and life cycle analyses [LCA]).

• Range of drivers for bio-derived products:
  - Supply/demand and market need (fossil replacements).
  - Consumer demand.
  - Superior properties and potential lower costs.

• Majority of scaled processes are focused on commodity feedstocks; however, there is growth in lignocellulosic feedstocks.

• Expansion and utilization of data/study in a number of other projects:
  - [CEMAC] www.manufacturingcleanenergy.org
  - AGILE BioFoundry http://agilebio.lbl.gov/
  - Strategic Analysis Bioproduct Transition System Dynamics Model
Strategic Support: Analysis Results

- Support BETO and provide TEA for U.S. Drive C2G team.
- Describes approaches to handling co-products and impact of assumptions.
- Reviewed by 10 external reviewers.
- Work ongoing to finalize and publish in FY17.

https://greet.es.anl.gov/publication-c2g-2016-report

The Impact that Coproduct Valuations have on the Economics of an Integrated Biorefinery

Mary J. Biddy
National Renewable Energy Laboratory
Supported the development and organization of the 2016 Alternative Aviation Fuel Workshop (with PNNL):

- Over 100 stakeholders took part in 2-day meeting.
- Organized location and logistics of meeting.
- Supported development of think tank questions presented during meeting.
- Helped to develop final workshop report/aviation biofuels white paper (to be published in 2017).
Strategic Goal: Perform techno-economic analyses to understand potential costs, outline barriers, and highlight R&D needs for emerging conversion strategies. Provide critical input to inform BETO supported models.
Provide comparative economic analyses for biomass conversion technologies.

- Identify R&D data needs for emerging pathways.
- Supply key process data for expansion of GREET LCA pathways, BSM analysis and JEDI tools.
Modeling is rigorous and detailed with transparent assumptions. Baseline assumes nth-plant equipment costs. Perform pioneer plant evaluations to understand the near-term cost of jet fuel production pathways. Quantify the underlying uncertainties through sensitivity analysis. Prioritize TEAs based on programmatic requests and data availability.
Established a library of TEA models for biomass-derived sustainable alternative jet fuel.

TEA provides critical input for a range of models to address BETO strategic goals.

- Provided TEA data for GREET expansion (Han et al. 2017)
- Provided key input and data for NREL BSM study and Biojet White Paper: *Assessment on displacement of 30% of aviation fuels with low carbon alternative bio-derived jet fuels by 2030*
Opportunities to reduce cost by co-production with fossil feedstocks.

Natural gas and biomass-derived syngas are blended for Fischer-Tropsch synthesis to consider a range of conversion facility sizes.
Understanding economic and sustainability tradeoffs could influence investment decisions.

Co-processing natural gas enables the economic feasibility of converting biomass to the liquid fuel but at the expense of the environmental sustainability.
Evaluating opportunities and risk for conversion of waste streams to value-added co-products.

- Analysis of alternative waste stream feedstocks (methane and CO₂) to fuels and chemicals using biological, thermochemical, or hybrid concepts.
- Initial study focused on:
  - Availability of waste feedstocks considering impurity.
  - Potential pathways for upgrading with current SOT and R&D needs.
Biofuels Blending Model

Strategic Goal: Understand how fuel quality will impact blending economics and evaluate potential for biofuels market growth.
Biofuels blending model: Overview

**Approach:** Incorporate **actual process data** from 15 U.S. refineries.
- Varying complexity of refineries that span all 5 U.S. PADDs.
- Data includes overall capacity, unit capacity, and blend stream qualities.
- Bio-derived data from public sources and collaborative partners.

**Model Capabilities:**
- Estimate the **value of a bio-blendstock** to a refiner/fuel blender based on quality.
- Identify **blending limits and constraining properties**.
- Pursue analyses for all hydrocarbon pathways under development by BETO core platform R&D.
- Have key stakeholders continuously vet tools and results.
Biofuels blending model: Approach

Leveraging process simulation capabilities to validate biofuels blending model

Additionally, worked with AspenTech and stakeholders for initial review.
Biofuels blending model: Accomplishments

Support Core Conversion / Algae Project R&D decisions:
- TEA calculates the cost of adding hydroisomerization process to the pathway.
- The Biofuels Blending Model is utilized to assess the increase in value and blendability.

Key Results
- Blendstock Value: Base + $0.25 / Gallon
- Blended Volume: <10%
- Isomerized Diesel Blendstock with Improved Cold-Flow Properties: >90%
Biofuels blending model: Accomplishments

Support Core Conversion and Co-OPTIMA R&D efforts:
• Overall goal is to expand analysis capabilities beyond hydrocarbon blending (near-zero oxygen blendstocks and products) to benefit emerging fuel analysis and tool development.

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Demonstrating capabilities for modeling emerging fuels in engines. Example shows dew point estimates using ASPEN PLUS to assess predictions relative to literature.

Exploiting the impact of high-ethanol contents (10%–40%) on predictability of finished blending properties using the Biofuels Blending Model and process modeling tools.
Developing Public Tool for Blending of Bio-Derived Hydrocarbons

- NREL has completed beta versions of simplified gasoline and diesel blending models for review by BETO and other stakeholders. **Plan to publish in FY17.**
Jobs analysis and model development for bio-derived fuels

**Strategic Goal:** Understand the potential for job creation and economic benefits in the emerging bio-economy.
Development of a suite of Jobs and Economic Development Impact (JEDI) models.

- Publicly available tools found at www.nrel.gov/analysis/jedi/

The model represents the entire economy as a system of linkages between subsectors of the economy.

- The linkages are represented by multipliers (derived from IMPLAN, 2014) that determine the impact of construction and operation of a new project on employment, earnings, and output in other sectors.
- Uses input-output analysis to capture impacts throughout the supply chain.
Publicly available, user-friendly, Excel-based models.

Each JEDI model has a user guide that summarizes input requirements, interpretation of results, and limitations of the tool.

Recently developed JEDI tools are based on hydrocarbon design reports and the latest design of biomass logistics systems.

Models are reviewed and vetted by PIs (INL, NREL, PNNL) prior to release.

Validated model with cellulosic ethanol industry estimates (FY15).

Validation is continuous as job estimates become available.
Overview:

• Identify key factors that contribute to job growth resulting from biorefinery construction and operation
• Gain a better understanding of which sectors will benefit from new biofuel production.
Understanding job development – direct versus indirect jobs

Case 1: cellulosic ethanol biorefinery in Iowa
Case 2: renewable diesel biorefinery in Georgia
Case 3: renewable diesel and gasoline biorefinery in Mississippi

DMT/day = dry metric tons per day, FTE = full-time equivalent
Jobs analysis for bio-derived fuels: Accomplishments

- Understanding which sectors benefit from biorefinery operation

Case 1: cellulosic ethanol biorefinery in Iowa
Case 2: renewable diesel biorefinery in Georgia
Case 3: renewable diesel and gasoline biorefinery in Mississippi

$\text{DMT/day} = \text{dry metric tons per day}, \text{FTE} = \text{full-time equivalent}$
Outreach to bioenergy community to support impacts on the bioeconomy.

Engage and communicate results of analyses to stakeholders:

- **JEDI models** (biofuels, biopower, and petroleum fuels) are widely used and are publicly available (via the NREL website and the Bioenergy KDF) with over 1,500 downloads in the last 2 years.

- **Strategic TEA** on jet fuel pathways are utilized to expand the conversion processes in GREET and support collaborative relationships with CAAFI, DOD, EPA, and MIT.

- Strategic support efforts have maintained external collaborations with DOE VTO, U.S. DRIVE, and USCAR teams to provide cost numbers and key biofuel production metrics.

- **Published eight peer-reviewed papers and technical publications** with six more drafts in preparation for peer-reviewed journals; gave more than 10 presentations.
Project directly contributes to BETO goals per 2016 Multi-Year Program Plan:

<table>
<thead>
<tr>
<th>BETO Goal</th>
<th>Project Contributions</th>
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<tbody>
<tr>
<td>Develop models and methodologies to advance the understanding of the impacts and socio-economic benefits in the United States due to the growth of the bioeconomy.</td>
<td><strong>JEDI tools</strong> help to understand bioenergy’s impact on creating and supporting domestic jobs.</td>
</tr>
<tr>
<td>Provide analyses that “help the Office focus its technology development priorities and identify key drivers and hurdles for industry growth”.</td>
<td><strong>Chemicals market report</strong> focused on understanding potential commercial success, market uncertainties, and financial backing.</td>
</tr>
<tr>
<td>Provide an analytical basis for BETO planning and assessment of progress.</td>
<td><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>
<tr>
<td>Apply these models to conduct systems-level analyses that support decision-making at different levels (e.g., policy, industry, and bioenergy projects).</td>
<td>The <strong>biofuels blending model</strong> estimates the value of a bio-blendstocks to a petroleum refiner.</td>
</tr>
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</table>
Project directly contributes to BETO goals per 2016 Strategic Plan:

**Strategy:** Conduct analysis to inform R&D and programmatic priorities

**Substrategy:** Provide an analytical framework for bioproducts research

**Substrategy:** Better understand the benefits of bioenergy to rural communities

**Substrategy:** Analyze the environmental and social sustainability of bioenergy

Chemicals market report discusses the market pull and value proposition that are enabling the scale-up of chemicals from biomass.

On-going studies for JEDI to consider the effect of income distribution due to the scaling up of the biofuels industry.

Analysis of a range of metrics including jobs development, technical and economic evaluations, and market assessments.
Chemicals market report focused on how lessons learned from the production of chemicals can be leveraged to accelerate production of biofuels.

On-going work in Strategic Support to evaluate scalability and modularity of hydrocarbon pathways.

On-going work in Strategic TEA to evaluate potential for the use of waste streams to a range of chemicals and fuels.

Substrategy: Develop robust technologies to convert waste streams to fuels and chemicals

Substrategy: Reduce capital costs through process intensification and modularization

Substrategy: Develop bioproducts that enable biofuels

Project directly contributes to BETO goals per 2016 Strategic Plan:

Strategy: Reduce cost and improve performance

Substrategy:
- Develop robust technologies to convert waste streams to fuels and chemicals
- Reduce capital costs through process intensification and modularization
- Develop bioproducts that enable biofuels

Project directly contributes to BETO goals per 2016 Strategic Plan:

- Substrategy: Develop robust technologies to convert waste streams to fuels and chemicals
  - On-going work in Strategic TEA to evaluate potential for the use of waste streams to a range of chemicals and fuels.

- Substrategy: Reduce capital costs through process intensification and modularization
  - On-going work in Strategic Support to evaluate scalability and modularity of hydrocarbon pathways.

- Substrategy: Develop bioproducts that enable biofuels
  - Chemicals market report focused on how lessons learned from the production of chemicals can be leveraged to accelerate production of biofuels.
Future Work

Strategic support

Aim 1: Determine whether the hydrocarbon design cases are representative of the near-term business case for each pathway.
- Perform comparative study of biofuel hydrocarbon pathways from a venture capitalist perspective (FY17).

Aim 2: Given the commodity nature of the chemicals industry, understand if co-products always improve the economic viability of a biorefinery.
- Quantify the impact of co-product cost assumptions for the economic viability through case studies on oil-price-dependent scenarios (FY18).
- Develop alternative strategies to estimate chemical coproduct prices.

Strategic TEA

Aim 1: Understand the potential costs and R&D needs for the production of fuels and chemicals from waste streams (FY17/18).

Aim 2: Provide tools to the stakeholder community for developing conceptual process designs.
- Develop tools that support both economic and sustainability considerations for conceptual process designs (via engagement with EPA) (FY17/FY18).
**Future Work**

**Biofuels blending model**

**Aim 1:** Examine the impacts to petroleum refinery economics due to biofuels blending stream displacement (in support of the FY18 A&S platform milestone) (FY17 go/no-go/FY18).

**Aim 2:** Understand impact of refinery integration in the blending value chain economics (FY17/FY18).

**Jobs analysis for bio-derived fuels**

**Aim 1:** In-depth analysis on the benefits of bioenergy to rural communities.
- Examine case studies with JEDI to consider the effect of income distribution (e.g., rural vs. urban households) due to the scaling up of a biofuel industry (FY17).

**Aim 2:** Incorporate strategies for feedstock logistics.
Future Work

• **Support/collaborate with other BETO projects:**
  - Leverage existing tools for **Co-OPTIMA** evaluations—biofuels blending model (BLEND) and JEDI
  - Utilize biofuels blending model to further analyze **conversion platform** hydrocarbon pathways
  - Bioproduct market evaluation supports initial studies in **CEMAC, Agile Biorefinery project, and strategic analysis Bioproduct Transition System Dynamics Model**
  - Work with **GREET team** to consistently evaluate both economics and sustainability the impact of functional deviates in a biorefinery.

• **Planned peer reviewed journal articles and public milestone reports by the end of FY17 / early FY18.**
  - Journal article on blending model methodologies and capabilities and release public version of tool.

• **Continue to vet models and analyses through stakeholder engagement and collaboration.**
• Develop tools and perform analyses to address key questions in support of the BETO strategic direction.

• Progress over past 2 years includes:
  - Market report analysis and publication on bioproducts to enable biofuels.
  - Development of TEAs for understanding jet fuel production.
  - Support for conversion R&D strategies to understand fuel quality valuation.
  - JEDI case studies to identify key factors that contribute to job growth.

• Future deliverables include:
  - Case studies with JEDI to consider the effect on income distribution.
  - Comparison of biofuel hydrocarbon pathways for near-term scale-up.
  - Development of TEAs for understanding waste stream upgrading.
  - Assessment of refinery economics due to biofuels blending stream displacement.

• Provide credible results to assist decision making in bioenergy investment by applying appropriate analyses and models.
  - Document sources of data, understand uncertainties, vet analysis approach and results, and quantify impact of uncertainties.
Thank you to...

Bioenergy Technologies Office:
• Alicia Lindauer, Kristen Johnson, Zia Haq (Strategic Analysis and Sustainability Platform)
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PNNL collaborators:
• Sue Jones, Aye Meyer, Corinne Drennan, Yunhua Zhu

National Laboratory Partners (PNNL, INL, ORNL)

Industrial and Academic Partners
The JEDI model offers an opportunity for stakeholders to estimate the employment impacts of a given bioenergy system. The tool is limited in its ability to evaluate indirect impacts or endogenous response, but the direct impacts offered are still of value and clearly in demand given the number of public downloads the tool has had in recent years.

- The JEDI models built on economic input-output approach, apply historical relationships between demand (i.e., specific expenditures within a given industrial sector) and the resulting economic activity to estimate how new expenditures will affect economic development metrics including jobs. The accuracy of these inter-industry relationships (i.e., input-output coefficients or multipliers) is dependent on parameters including the date of the multipliers reflecting the relationships, how well the defined industrial sectors reflect the particular inputs and outputs of the technology project being studied, and how well the multipliers reflect the geography of where the technology project is located. The JEDI models do include supply chain related indirect impacts. However, like all input-output models, JEDI models have limitations. JEDI models are static models, which do not take into account some endogenous variables such as how changes in demand for certain inputs might affect the price of the inputs. We do update the multipliers every two years for all JEDI models to ensure we use the best information to reflect the most up-to-date inter industry relationships.
The refinery and blending optimization work is also important, but its value is hard to judge based on what has been presented thus far.

- Work that has been developed over the past several years has focused on utilizing these tools to consider cost from a refiner’s perspective and value the fuel streams being considered based on quality and properties relative to petroleum equivalent streams. This talk outlines recent work to demonstrate the impact that this analysis has had on conversion platform and algal platform efforts. Further, we outlined on-going efforts to utilize this tool in the Co-Optima project.
Abbreviations and Acronyms

A&S: Analysis and Sustainability
ANL: Argonne National Laboratory
AOP: Annual operating plan
BETO: Bioenergy Technologies Office
CAAFI: Commercial Aviation Alternative Fuels Initiative
COP: ConocoPhillips
CU: University of Colorado
DOD: Department of Defense
EPA: US Environmental Protection Agency
GGE: Gasoline gallon equivalent
JEDI: Jobs and Economic Development Impact
INL: Idaho National Laboratory
ISU: Iowa State University
LCA: Life-cycle analysis
MFSP: Minimum fuel selling price
MYPP: Multi-year program plan
NREL: National Renewable Energy Laboratory
ORNL: Oakridge National Laboratory
PNNL: Pacific Northwest National Laboratory
VTO: Vehicles Technology Office
Publications


- J. Han, L. Tao and M. Wang, “Well-To-Wake Analysis of Ethanol-To-Jet and Sugar-To-Jet Pathways”, Accepted by Biotechnology for Biofuels, December 2016


Presentations