Strategic Support
WBS (4.1.1.30)

Mary J. Biddy, Christopher Kinchin, Ling Tao, Eric Tan, Yimin Zhang

National Renewable Energy Laboratory (NREL)

Strategic Analysis and Sustainability Platform

DOE Bioenergy Technologies Office (BETO)
2019 Project Peer Review

March 4, 2019

Goal Statement

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

Outcomes:

- **Evaluate emerging areas of interest** (jet fuel, WTE, lower cost targets) to provide a sound analysis platform in supporting new strategies, collaborations, and R&D direction.
- **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.
- **Estimate the number of jobs** that can be created in the United States with biorefinery deployment.
- **Developing defensible methodologies, analyses, and tools** that are publicly available to support stakeholders and bioeconomy growth.

Relevance: Assess impacts and potentials for emerging technologies and outline R&D needs/barriers for further development by BETO and industry.

Quad Chart Overview

Timeline

- Start: FY2011
- Merit review cycle: FY2019-2021
- 20% complete of review cycle

	Total Costs Pre FY17**	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded	$3.2MM	$650k	$525k	$1.6MM

Key collaborators

- National laboratories:
  ANL, INL, NREL—core platform analysis; NREL—Market and Policy Impact Analysis Group; NREL—SI, NREL—VT, ORNL, PNNL
- Industry: *Exxon-Mobil, ICM, U.S. DRIVE*
- Government agencies:
  CAAFI, DOE-BETO DMT, 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

Objective

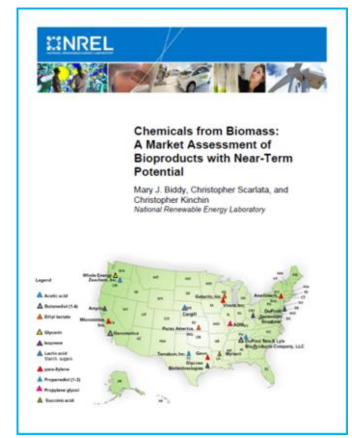
Provide sound, unbiased, and consistent analyses to inform the strategic direction of the DOE BETO efforts.

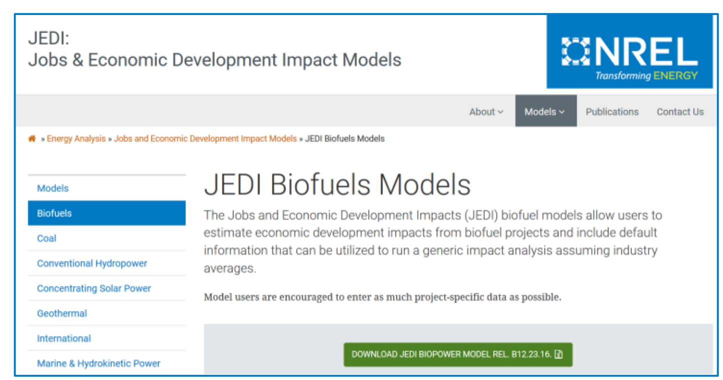
End of Project Goal

- Develop a standard methodology to estimate the price of the chemical coproduct that should be integrated in the economic evaluation.
- Solidify strategy around alternative jet fuel production. Final results will help guide R&D strategies that are informed by not only TEA/LCA but also non-technical drivers and barriers for renewable jet fuel production.

Project Overview: History

- **Comparative analyses of biomass conversion processes to evaluate emerging areas of interest for BETO and Bioindustry.**
    - COP/ISU/NREL collaboration of techno-economic analysis (TEA) of biofuel strategies (FY11).
    - Ahead of new design reports, NREL/PNNL transition to hydrocarbon technology pathway analysis (FY12/13).
    - Bio-based chemicals market assessment (FY15/16).
    - Provide quick turnaround analyses to support BETO and EERE requests.
- **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.
    - Develop economic analysis tools including refinery blending tools





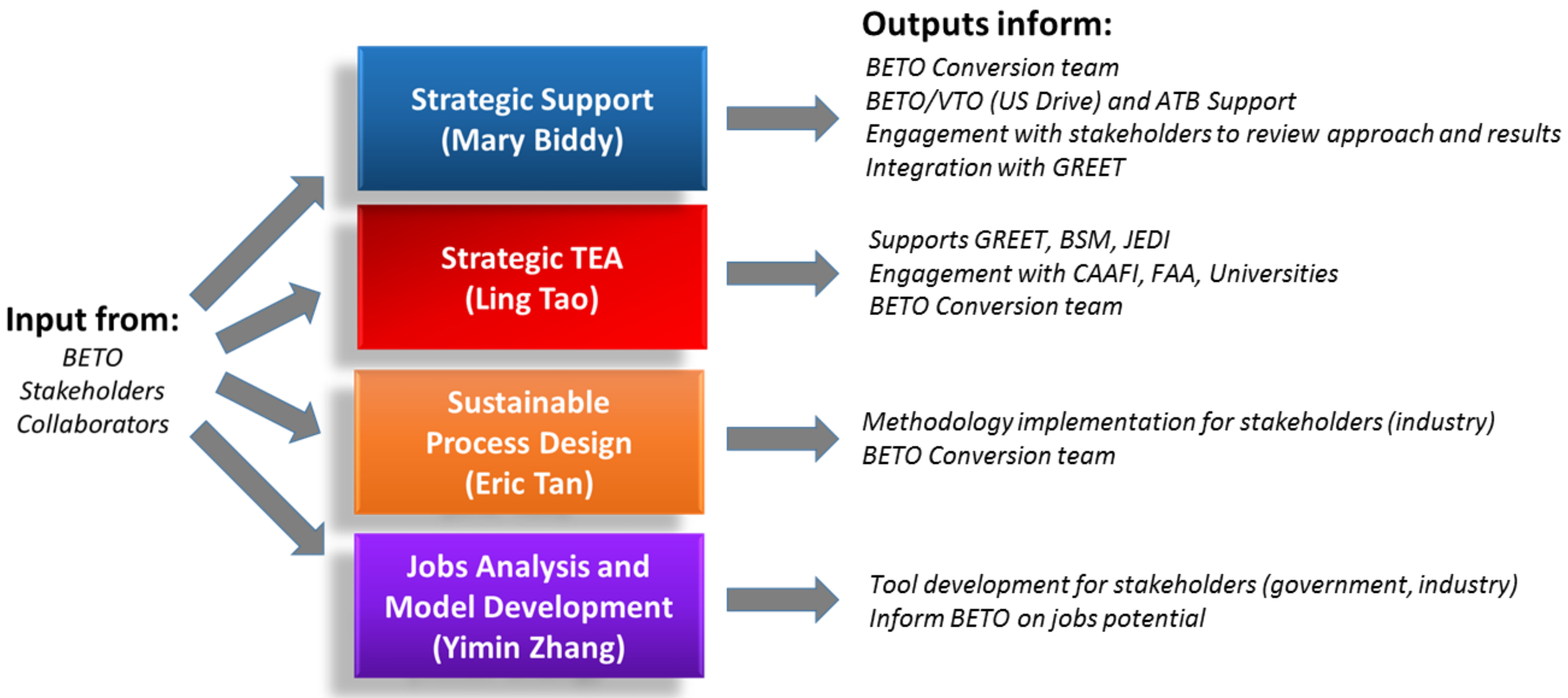
Project Overview: Objectives

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

- **Evaluate emerging areas of interest** (jet fuel, WTE, lower cost targets) to provide a sound analysis platform in supporting new strategies, collaborations, and R&D direction.
- **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.
- **Estimate the number of jobs** that can be created in the United States with biorefinery deployment.
- **Developing defensible methodologies, analyses, and tools** that are publicly available to support stakeholders and bioeconomy growth.

Approach - Management

To ensure the success of and provide value from this project, work is highly integrated and informed by BETO to support analysis needs.



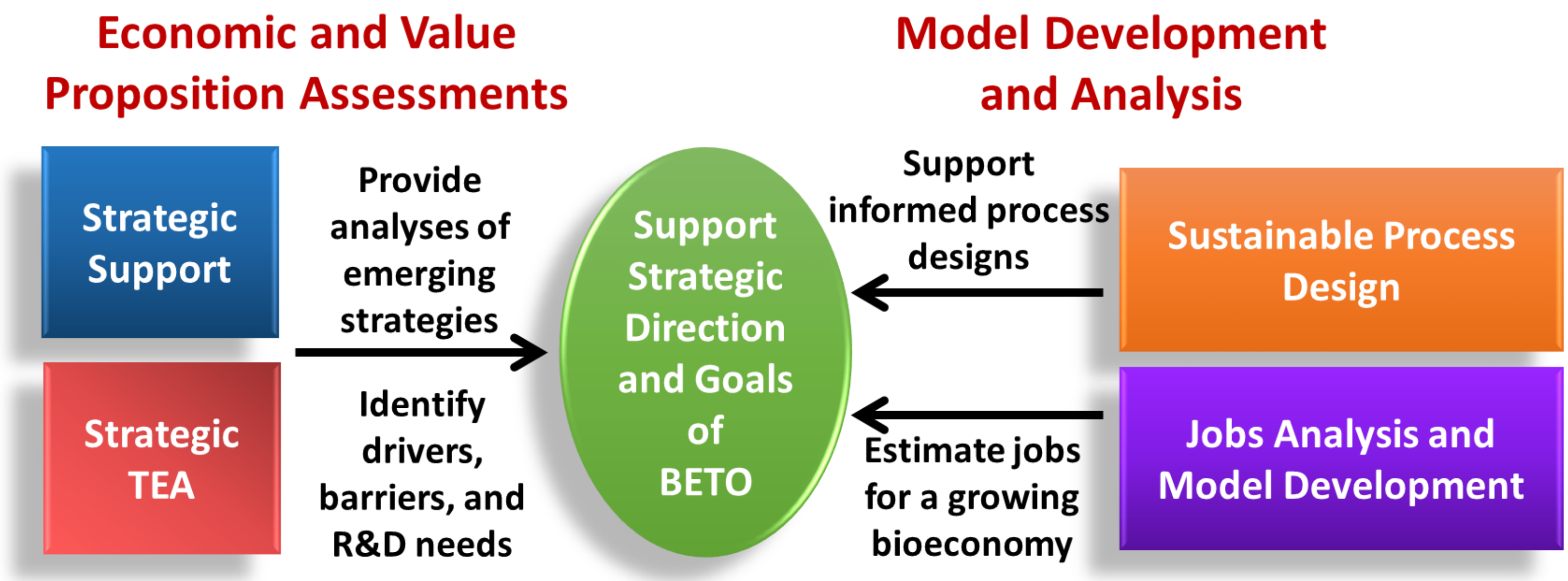
Approach - Management

Work plans and prioritization are based on discussions with and reviews by BETO and active project management continues throughout the project:

- **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**.
- Check-ins also **review approach and methods** to ensure project is progressing towards desired outcomes.
  - What are the analysis questions we are trying to answer?
  - Who is the target audience?
  - Do we have the data we need to address these questions?
  - Are we applying the appropriate tools/methods to address these questions?
- To **support integration**, check-ins are often **cross-platform discussions** and include technology managers from other BETO areas (like conversion, ADO, or WTE).
- Participate in **monthly A&S platform calls** as well as bi-annual modeling workshop to ensure **coordination and collaboration** across the portfolio.

Approach - Technical

Develop Models and Conduct Analysis to Support Strategic Decisions



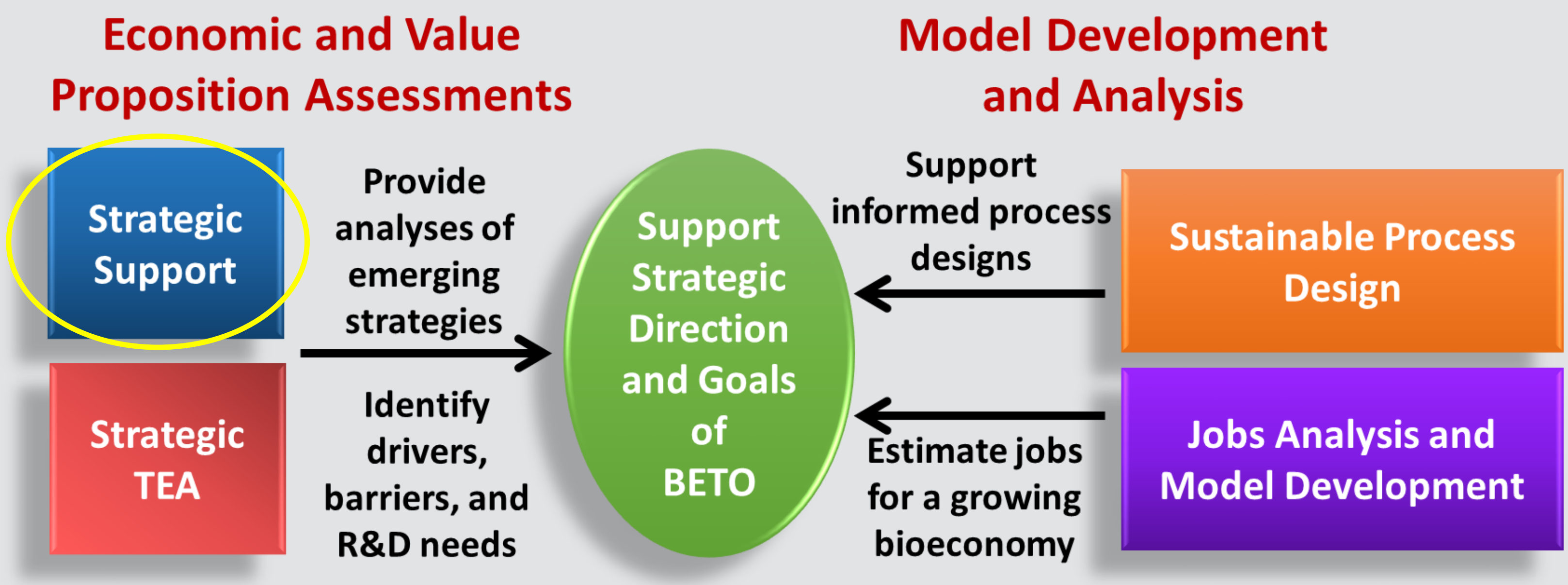
Common approach for all projects:

- **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 are communicated** to stakeholders through peer-reviewed publications, presentations, and technical reports.

Approach - Technical

Critical Success Factors	Challenges	Approach to overcome
Develop sound modeling approaches and reliable results.	Availability and quality of data.	• Work with BETO and stakeholders to provide missing information. • Perform sensitivity analysis to understand impact of assumptions. • Engage stakeholder to review results and approach.
Ensure emerging technology analysis is comparable to other BETO pathways.	Consistency of analyses.	• Collaborate with core analysis projects to ensure consistency in approach and assumptions. • Perform sensitivity analysis to understand impact of assumptions.
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 BETO/stakeholder to review and vet approach.
Clearly define critical questions to address.	Scope shift.	• Work closely with stakeholders (BETO) to define needs and key questions. • Outline plan to address questions in AOP and active project management/regular check-ins to keep project inline with goals.

Strategic Support Task



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

$2/GGE Gap Analysis: Approach

MOTIVATION: Address questions from BETO on strategies to produce hydrocarbon biofuels at less than $2.5/GGE.

GOAL: Identify strategies and R&D opportunities for meeting a $2/GGE cost goal.

APPROACH:

- Interlaboratory collaborative review developed by analysists at NREL, PNNL, ANL, INL, and ORNL.
- Provides a high-level overview of strategies for meeting the $2/GGE cost goal of an integrated supply chain approach.
- Review work underdevelopment by both R&D and analysis efforts.
- Provide initial, high-level estimates on potential cost savings.


Integrated strategies to produce $2/GGE lignocellulosic biofuels

NREL: Mary J. Biddy, Ryan Davis, Abhijit Dutta, Ling Tao, Eric C.D. Tan
PNNL: Susanne B. Jones, James R. Collett, Lesley J. Snowden-Swan
ORNL: Erin Webb, Michael Kass, Matthew Langholtz
ANL: Jennifer Dunn, Cristina Negri
INL: David N. Thompson, Amber Hoover, Damon S. Hartley, Jaya Tumuluru, Jeffrey A. Lacey, Kevin L. Kenney, Leslie Ovard, Lloyd M. Griffel, Mohammad S Roni, Neal A. Yancey, Rachel M. Emerson, Shyam K. Nair, William A. Smith, Allison Ray, Jason K. Hansen, Luke Williams, Magdalena Ramirez-Corredores, Patrick N. Bonebright, Quang A. Nguyen, Tyler Westover, Vicki S. Thompson, Lynn Wendt, Patrick Lamers

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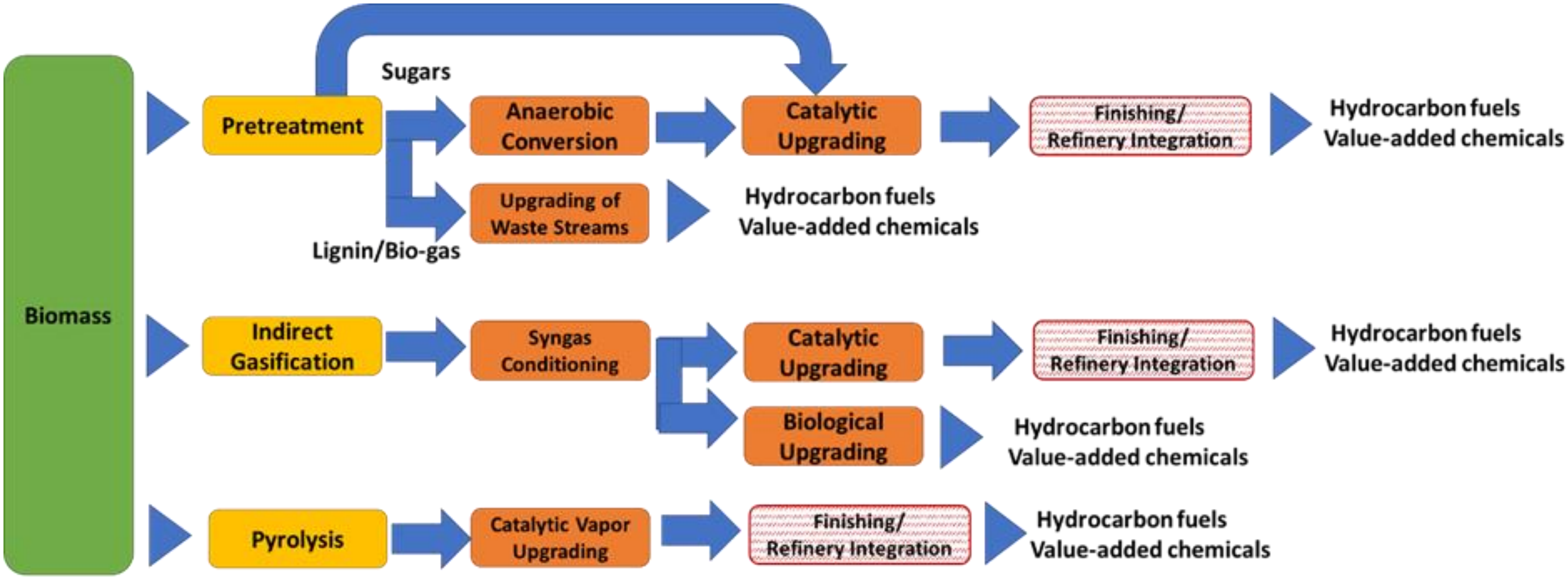
$2/GGE Gap Analysis: Accomplishments



Highlights five main areas for cost reductions:

- Developing atom efficient biorefineries.
- Intensifying process designs.
- Utilizing existing infrastructure.
- Reducing feedstock costs.
- Developing products from biomass with near-term market impact.

Under review at DOE BETO

Public DOE BETO Biofuels TEA Database: Approach

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.

APPROACH:

- Currently contains over 40 DOE BETO funded conversion TEA studies, including design reports and publications.
- Reviewed by lead analysts to ensure consistency as well as modify format per suggestions (NREL/PNNL).
- Available for download on the Biomass KDF: https://bioenergykdf.net/content/beto-biofuels-tea-database
- Will be updated yearly with new BETO funded TEAs.

Public DOE BETO Biofuels TEA Database: Approach

Background information:

- Title page overview (with contact e-mail address)
- Key definitions
- Summary of cases
- Supporting calculations

For each TEA:

- Direct and indirect installed capital costs.
  - Includes the formulas and performs calculations in excel
- Fixed and variable operating costs.
- Financial assumptions, such as plant life, depreciation period, startup time, IRR, income tax rate, etc.
- Summary of results, such as minimum fuel selling price ($/gge), total energy price ($/MMBtu), energy production rate (MMBtu/yr), etc.

DOE BETO Biofuels TEA Database: Accomplishments

Biofuels TEA Database

Definitions

Supporting Calculations

Comparative techno-economic analysis and process design for indirect liquefaction pathways to distillate-range fuels via biomass-derived oxygenated intermediates upgrading

Eric C. D. Tan, Lesley J. Snowden-Swan, Michael Talmadge, Abhijit Dutta, Susanne Jones, Karthikeyan K. Ramasamy, Michel Gray, Robert Dagle, Asanga Padmaperuma, Mark Gerber, Asad H. Sahir, Ling Tao, Yanan Zhang

2016

https://onlinelibrary.wiley.com/doi/abs/10.1002/bbb.1710

Biofuels, Bioproducts, and Biorefining
Biofuel, Bioprod. Bioref. 11:41–66 (2017)

	Pathway 1A	Pathway 1B
Total Fuel yield (MM GGE/yr)	41.1	44.8
Total Fuel yield (GGE/yr)	41,100,000	44,800,000
Lower Heating Value, Btu/gal	116,090	116,090
Lower Heating Value, MMBtu/gal	0.1161	0.1161
Energy Production Rate (MM Btu/yr)	4,771,299	5,200,832
Minimum Fuel Selling Price ($/GGE)	$4.89	$3.40
LHV of gasoline, Btu/gal	116,090	116,090
Total Energy Price ($/MMBtu)	$42.12	$29.29

DOE BETO Biofuels TEA Database: Accomplishments

Gasification, IDL

Report | Author | Publica | url | Publica | Case/S

Summary of Process and Results

Final Pr | Feedsto | Feedsto | Namep | Days or | Percent | Product | Cost Ye | Minimu

Capital

Feed | Gasi | Syng | Tar | Alco | Com | FT S | Alco | MTG | Mix | DME and H | Hydrocrack | Separation | Air Separat

PSA Unit

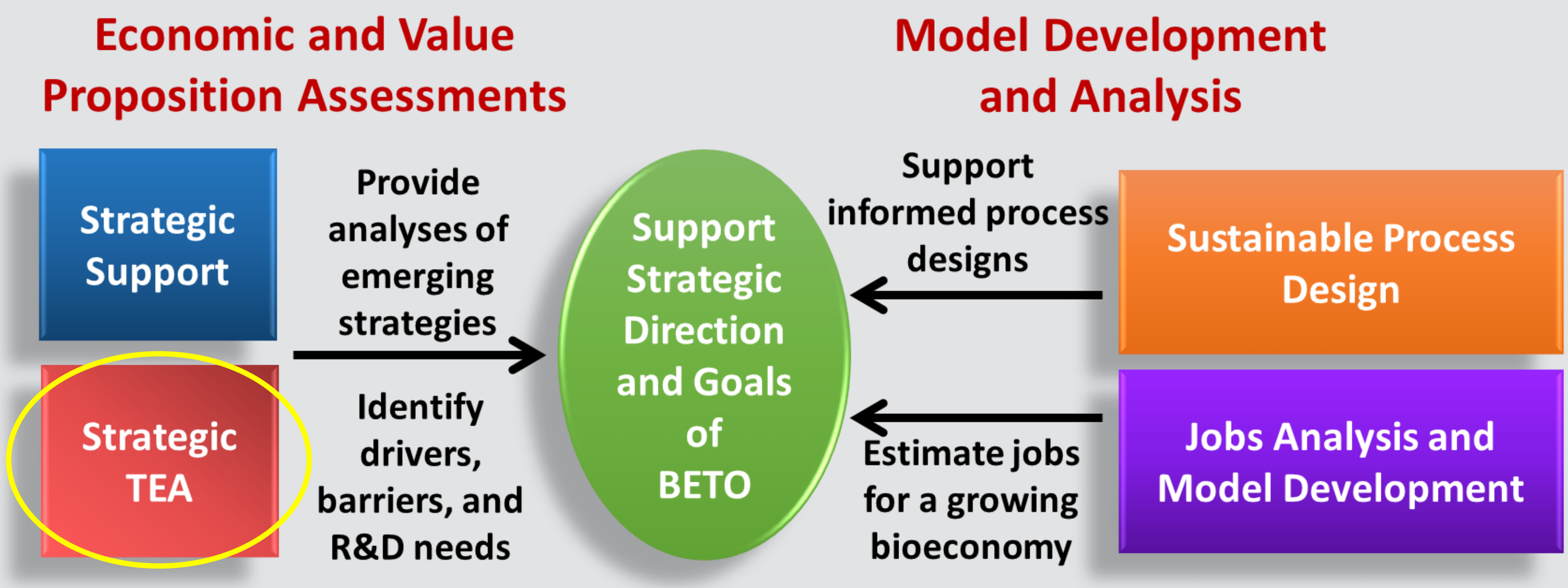
Ste | Co | Re | **Tot** | **Other** | Bui | Site | Ad | **Tot** | **Indire** | Eng | Ho | Leg | Fie | Prc | Oth | **Tot** | **Fix** | Lar | Wc | **Tot**

Operating Costs (per year at 100% time on stream)

Variable | Feed | Stea | Natu | Cata | Olivi | Tar | Hydr | Coo | BFW | Othe | M | E | C | A | N | L | D | D | N | Was | Was | Elec | Cop | E | V

DCFROR Data	
Fixed Capital Investment (FCI)	$376,425,(
Equity	4
Loan Interest	
Loan Term, years	
Annual Loan Payment	$33,659,(
Working Capital (% of FCI)	5.0
Plant Life, yrs	
Salvage Value	
General Plant	
Steam Plant	
Type of Depreciation	MAC
General Plant depreciation percent of straight-line	
Steam Plant depreciation percent of straight-line	
Depreciation Period, years	
General Plant	
Steam Plant	
Construction time, years	
% Spent in Year -3	
% Spent in Year -2	6
% Spent in Year -1	3
Start-up Time (Years)	
Revenues (% of Normal)	5
Variable Costs (% of Normal)	7
Fixed Cost (% of Normal)	10
Internal Rate of Return	10.0
Income Tax Rate	21.0

Strategic Techno-Economic Analysis

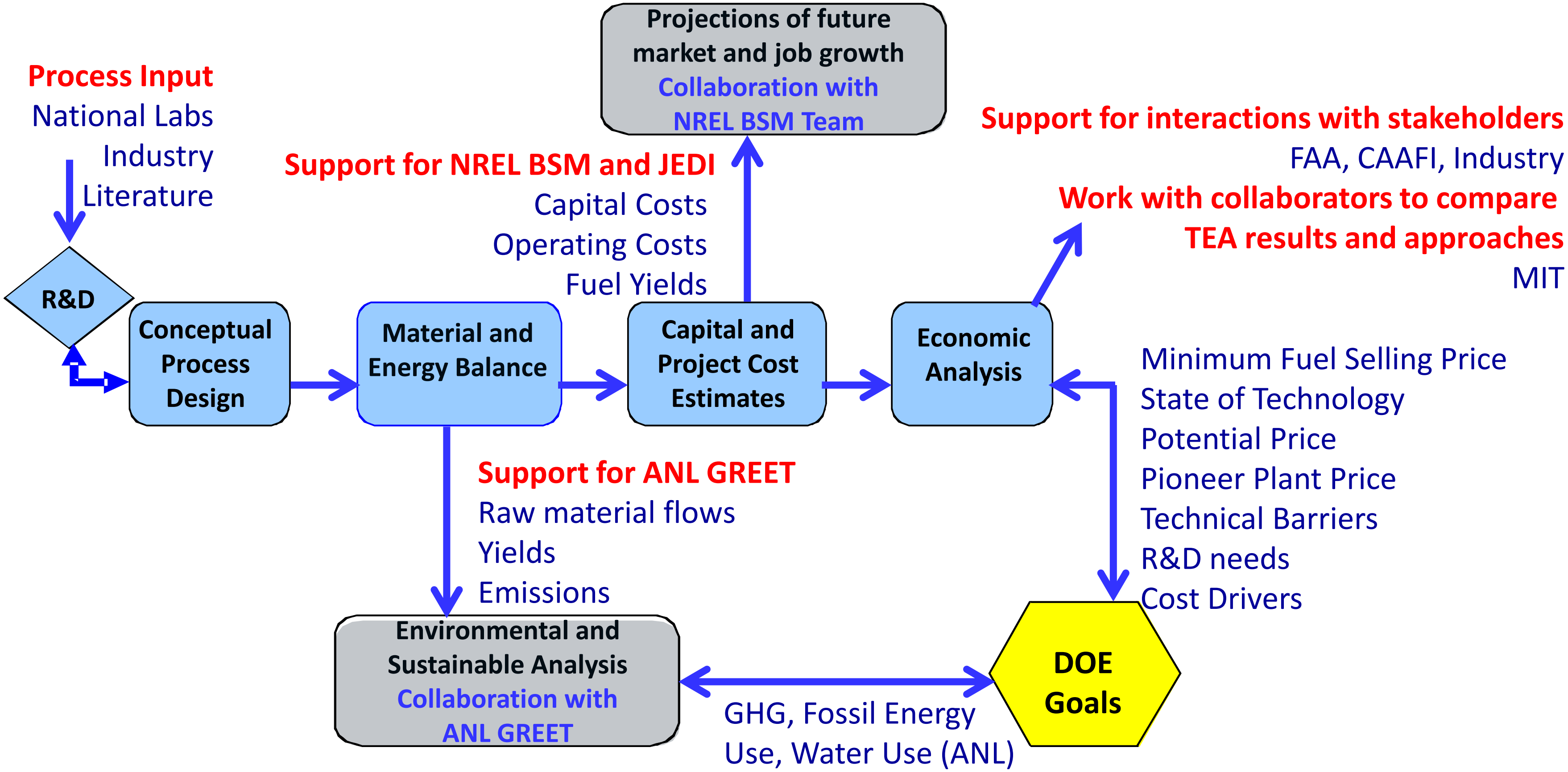


Strategic Goal: Perform techno-economic analyses to understand potential costs, outline barriers, and highlight R&D needs for emerging strategies including jet fuel pathways and WTE. Provide critical input to inform BETO supported models.

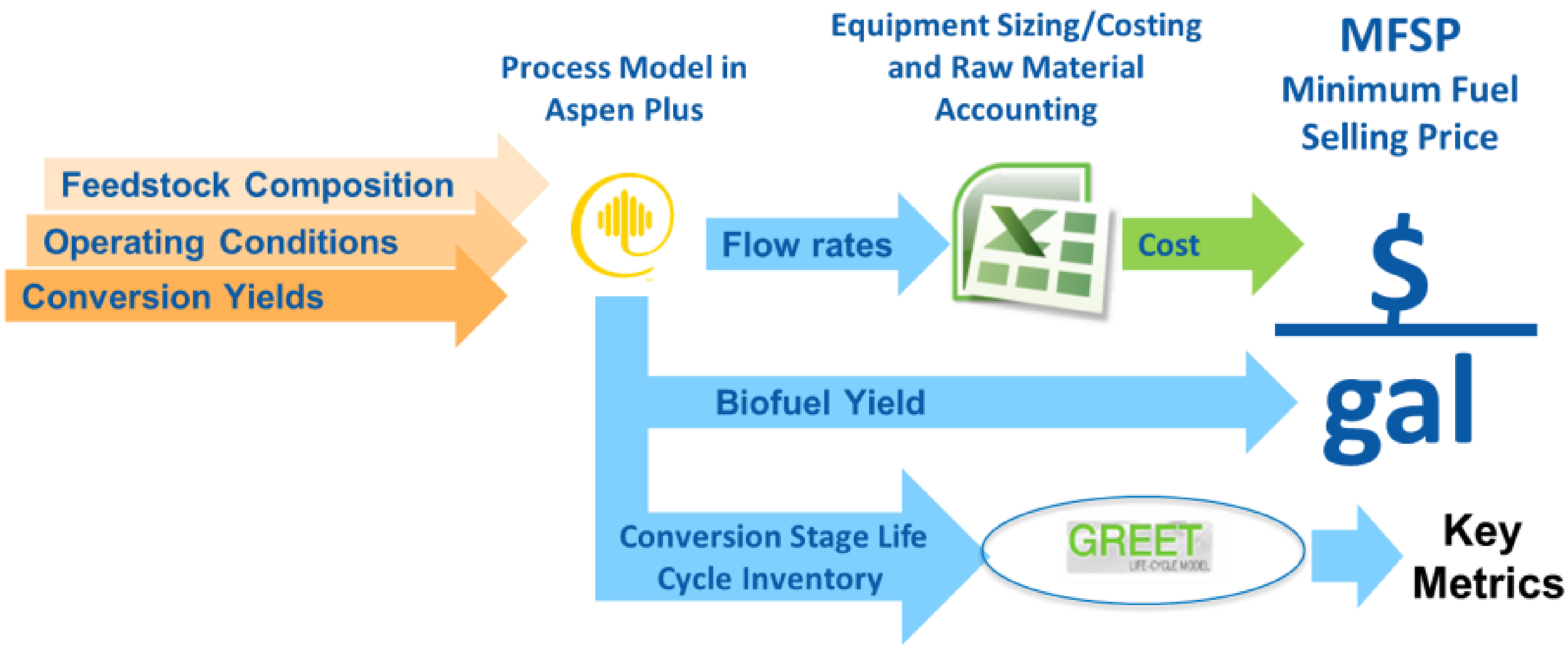
Strategic TEA: Overview

Provide comparative economic analyses for biomass conversion technologies.

- Identify R&D data needs for emerging pathways including jet fuel and WTE.
- Supply key process data for expansion of GREET LCA pathways, BSM analysis, and JEDI tools.



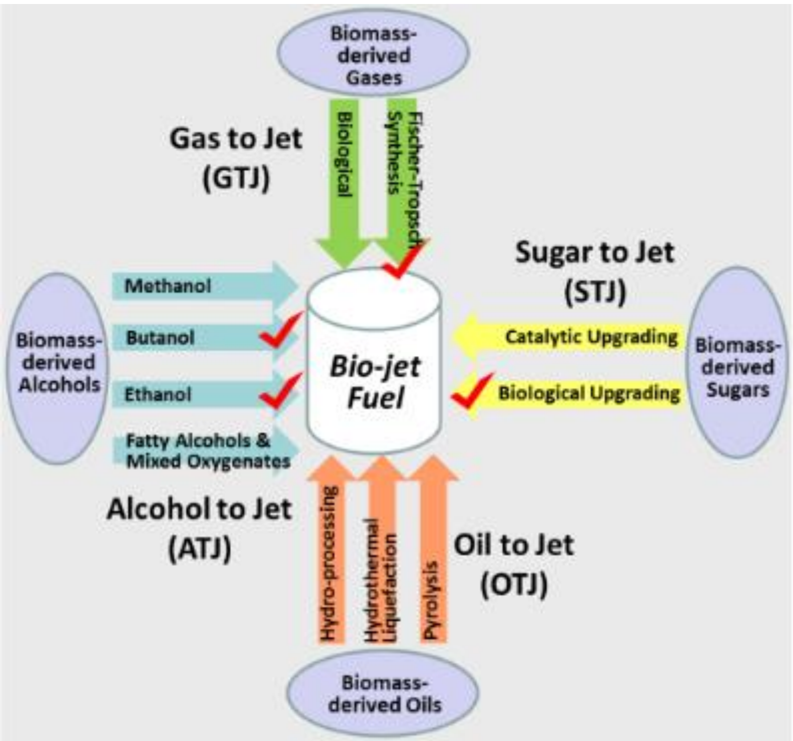
Strategic TEA: Approach

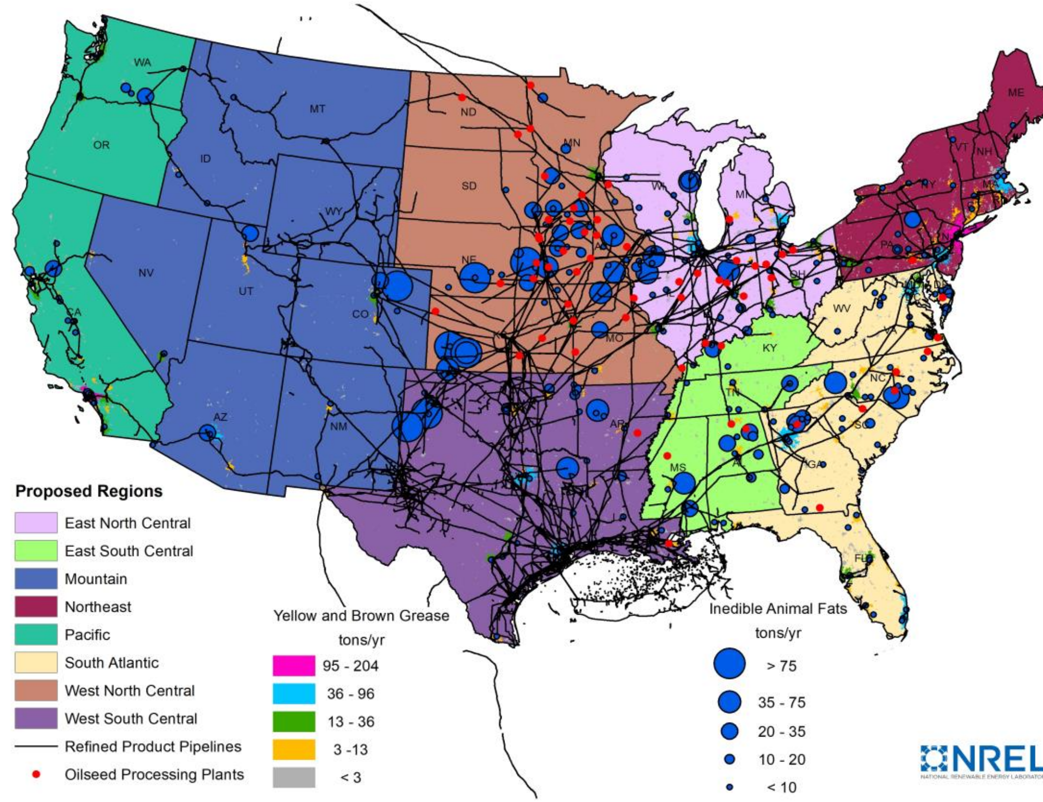


- Modeling is rigorous and detailed with **transparent assumptions**.
- Baseline assumes nth-plant equipment costs.
- Perform **pioneer plant** evaluations to understand the near-term cost of jet fuel production pathways.
- Quantify the underlying uncertainties through **sensitivity analysis**.
- Prioritize TEAs based on programmatic requests and data availability.

Strategic TEA: Results

Established a library of TEA models for biomass-derived sustainable alternative jet fuel.





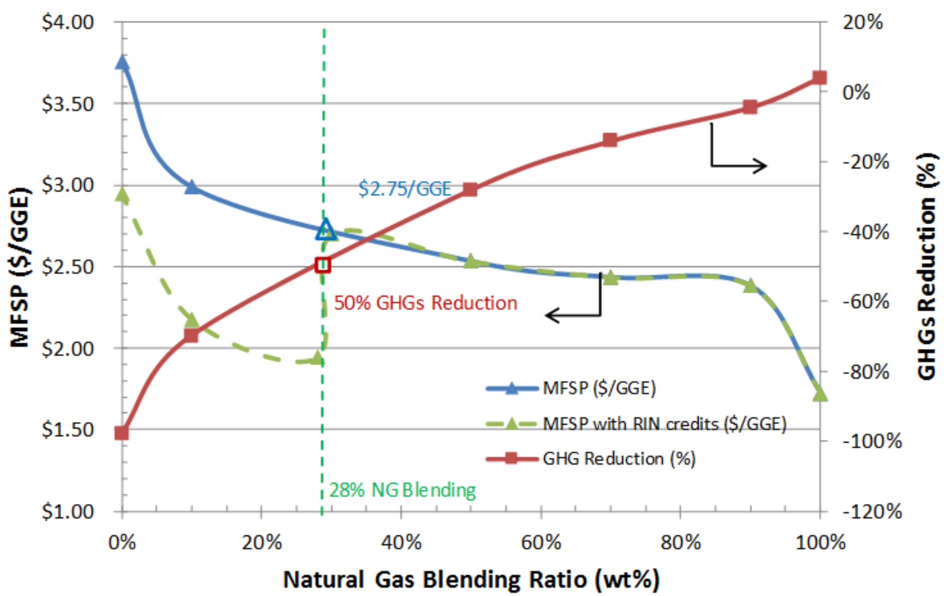
TEA data presented to multiple audiences including supporting discussions at the DOE BETO Trilateral Jet Fuel workshop (May 15-16, 2018).

More information from: http://www.nrel.gov/docs/fy16osti/66291.pdf

Strategic TEA: Results

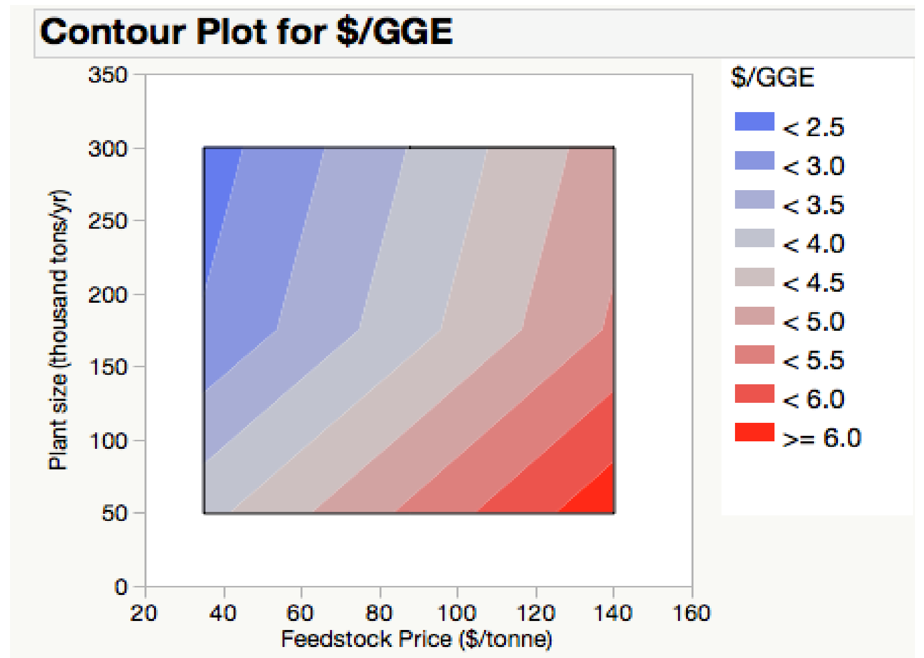
Explored strategies to meet a $2.50/GGE cost target for jet fuel pathways

An example for achieving $2.50/GGE via Fischer-Tropsch as a function of natural gas to biomass ratio



Not shown in figure but included in analysis is impacts of RIN credits

An example contour map for achieving $2.5/GGE for HEFA-SPK pathway

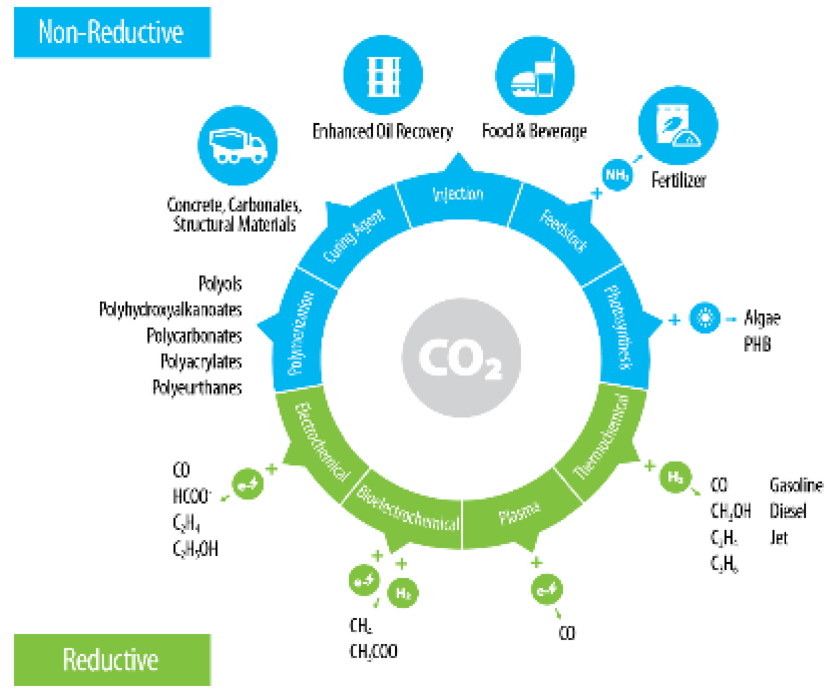


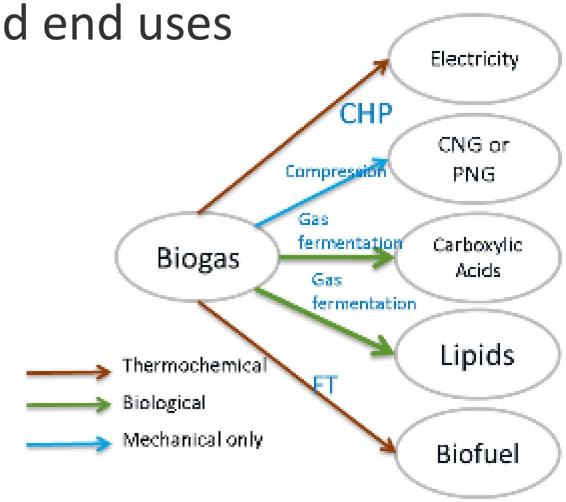
Key Takeaways to $2.50/GGE study: A combination of strategies required such as: 1) low cost feedstocks (such as waste feeds – WTE strategies), 2) high process yields (conversion needs), 3) larger scales (ADO strategies), 4) coproducts (conversion strategies), 5) renewable/cheap H_2 sources (AMO) and 6) RIN/LCFS credits (on-going discussions CARB).

Strategic TEA: Results

Identify promising research routes from C1 feedstocks (methane, methanol and waste CO_2) to both fuels and chemicals

- Evaluate opportunities and risk for conversion of waste streams to value-added co-products with current SOT and R&D needs
- Criteria includes TRL, market size, research challenges, process complexity, SOT cost, favorable life cycle inventory, industrial interests and end uses

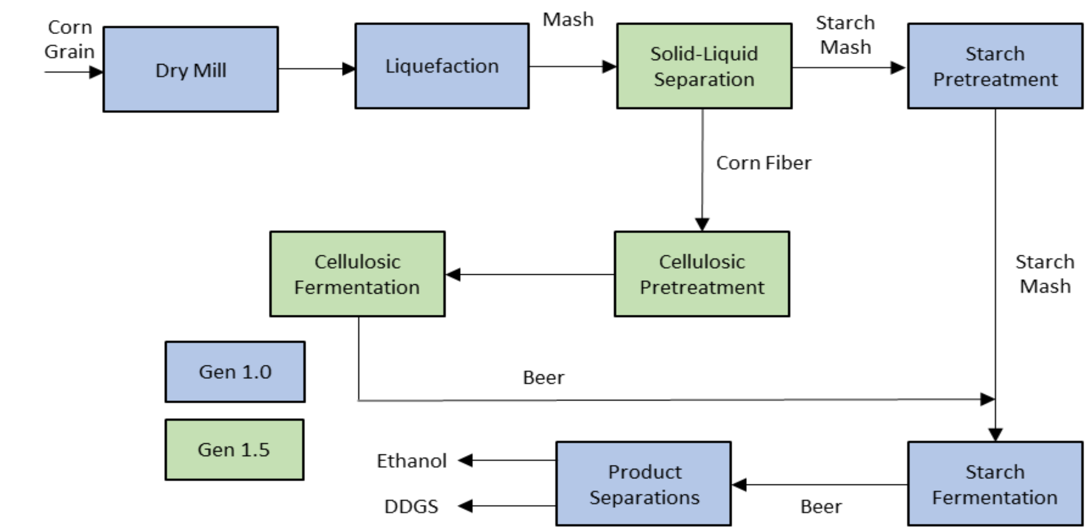


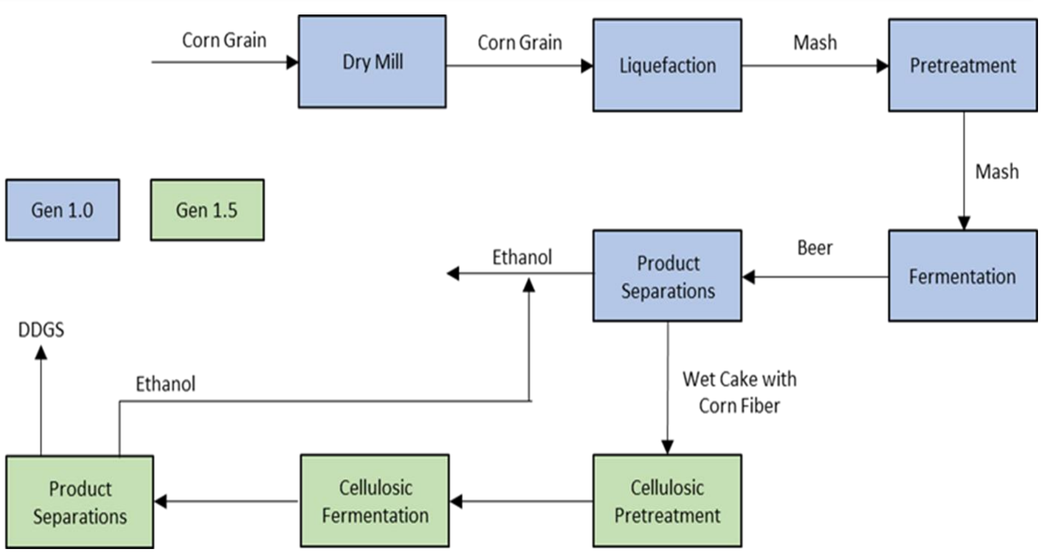


- **Expanded key analysis results, data and tools to CO_2 upgrading feasibility studies**
- **Analyses help to inform and support the new efforts under WTE platform (transitioned initial work to WTE)**

Strategic TEA: Progress/Results

Perform analysis for corn fiber ethanol (Gen 1.5)





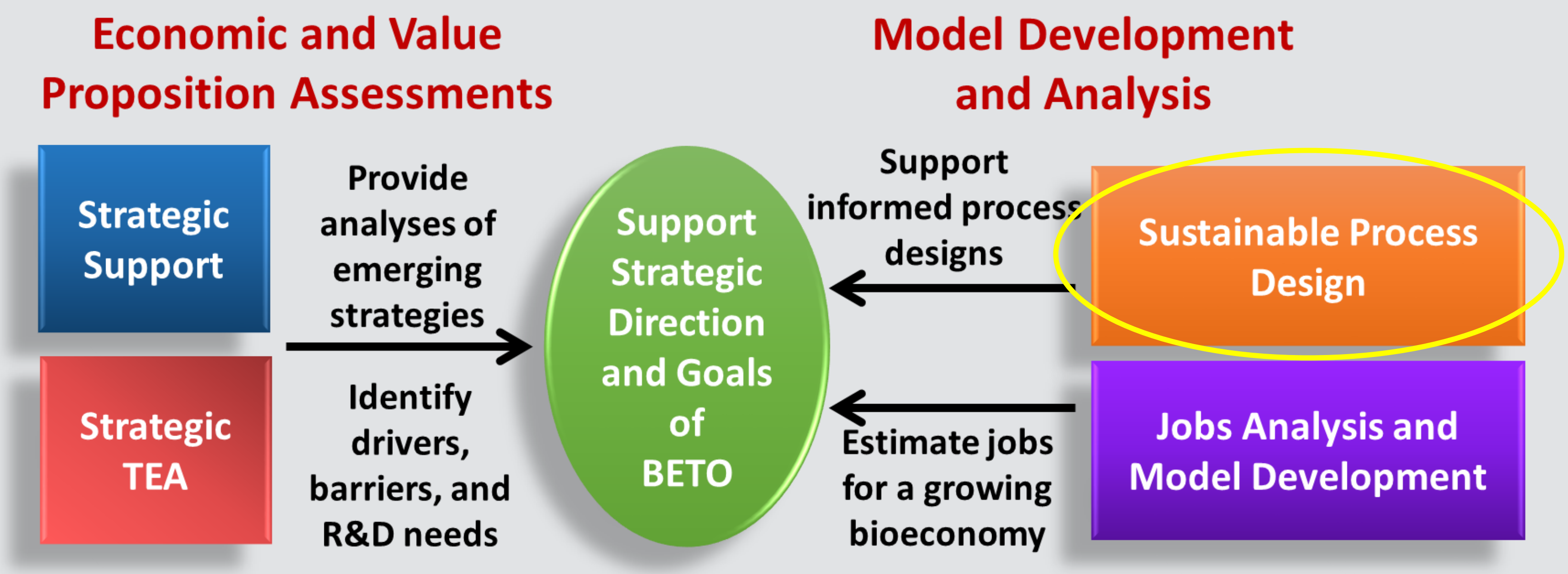
Developed TEAs for a range of generation 1.5 ethanol strategies.

Provided economic data for BSM studies for bolt-on technology and synergistic impact studies.

Provided key data to help inform on-going ASTM discussions for approach on cellulosic ethanol certification.

Manuscript in preparation.

Sustainable Process Design



Strategic Goal: Further incorporate and integrate sustainability into conversion process design.

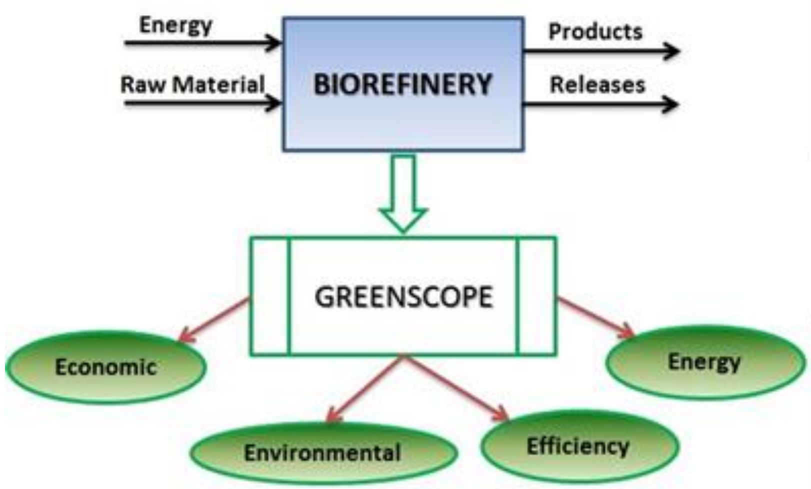
Integrating Sustainability in Biorefinery Design: Overview/Approach

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
- Working with EPA for implementation and evaluation of DOE BETO design cases.

Model Capabilities:

- Consider a wider range of sustainability metrics for more comprehensive direct comparison when evaluating process design modifications and alternatives.
- Convert the conceptual principles into a quantitative and realistic design tool by evaluating processes in four performance areas: Environment, Energy, Economics, and Efficiency.
- Integrate a systematic framework in biorefinery process design
- Capture the multi-dimensional aspect of process design and operation.

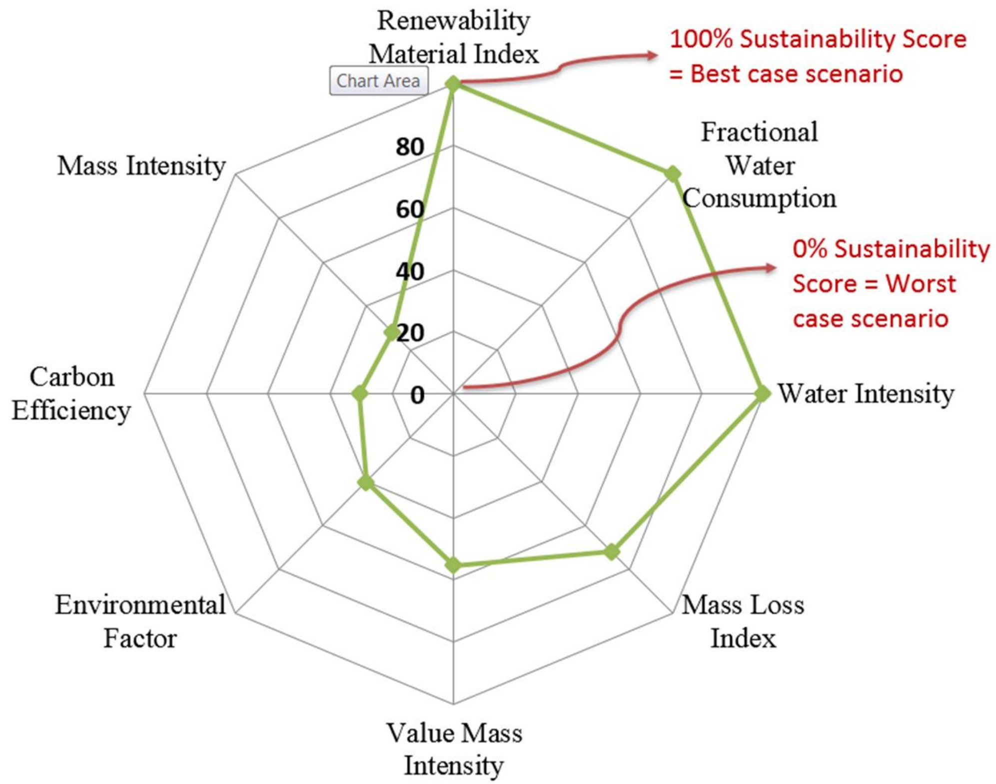


Integrating Sustainability in Biorefinery Design: Accomplishments

NREL has demonstrated the successful implementation of GREENSCOPE for a sustainability performance assessment for the production of high-octane gasoline from biomass design case.

Results from the GREENSCOPE sustainability evaluation help answer the following questions:

- What process areas/unit operations are in need of sustainability improvement?
- What are the challenges and opportunities for achieving the best possible sustainability targets?
- Where to allocate research and resources to improve sustainability in process design?

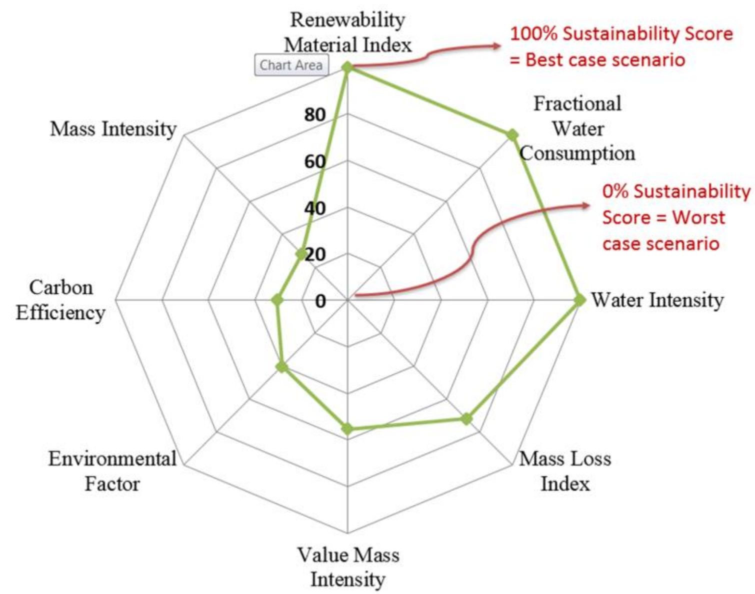


Material Efficiency Indicators

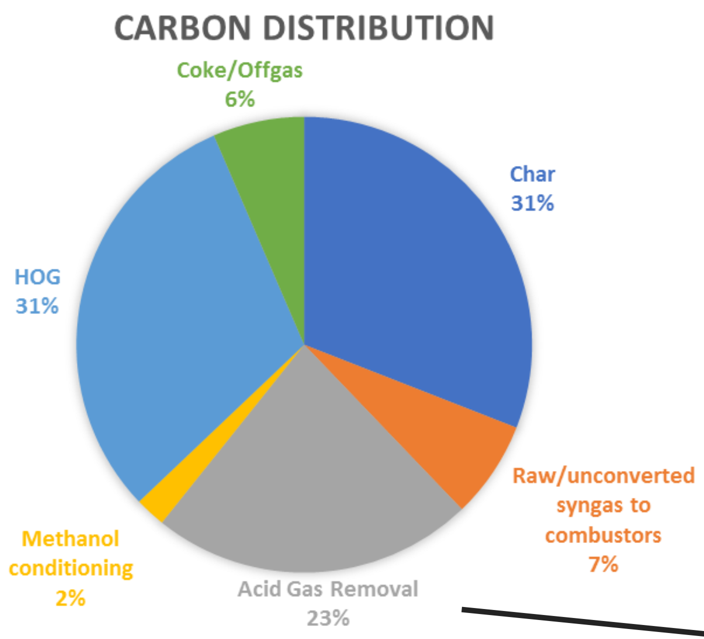
Integrating Sustainability in Biorefinery Design: Accomplishments

Example of analysis outcome to inform R&D strategy

Carbon efficiency in need of sustainability improvement



Material Efficiency Indicators



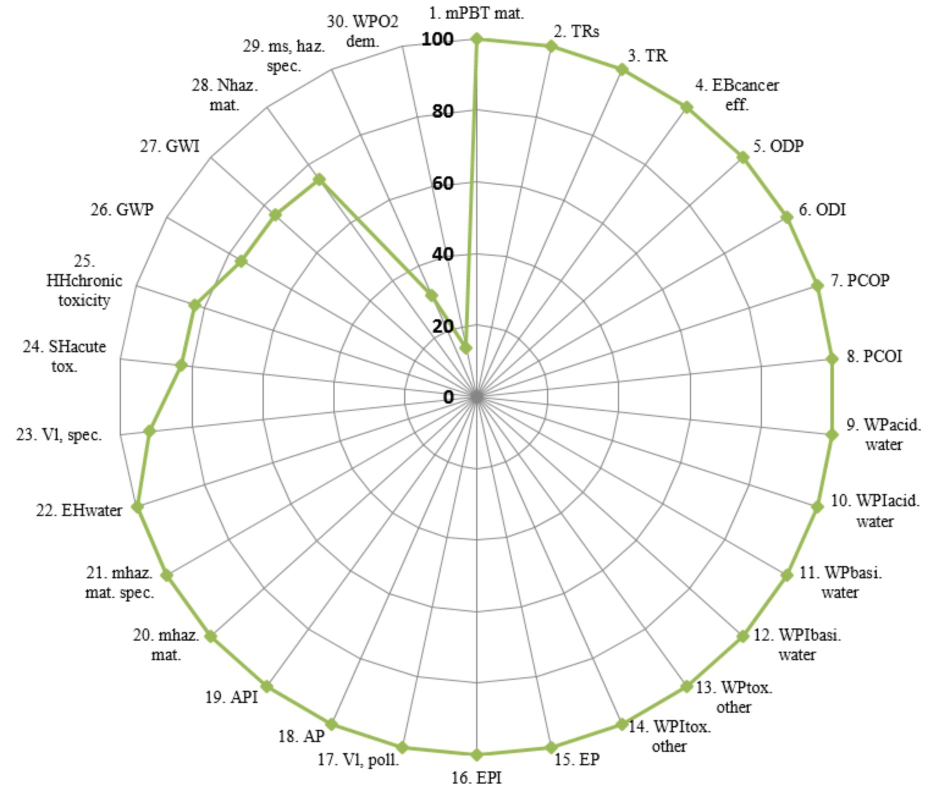
Inform R&D strategy to improve performance:

- Recover CO_2 from AGR to reformer for dry reforming
- Reactivate CO_2 from AGR in HC synthesis reactor

Integrating Sustainability in Biorefinery Design: Accomplishments

Indicator	Description	Sustainability % Score
1. $m_{\text{PBT mat.}}$	Total mass of persistent, bio-accumulative and toxic chemicals used	100
2. TR_s	Specific toxic release	100
3. TR	Toxic release intensity	100
4. $EB_{\text{cancer eff.}}$	Human health burden, cancer effects	100
5. ODP	Stratospheric ozone-depletion potential	100
6. ODI	Stratospheric ozone-depletion intensity	100
7. PCOP	Photochemical oxidation (smog) potential	100
8. PCOI	Photochemical oxidation (smog) intensity	100
9. $WP_{\text{acid. water}}$	Aquatic acidification potential	100
10. $WPI_{\text{acid. water}}$	Aquatic acidification intensity	100
11. $WP_{\text{basi. water}}$	Aquatic basification potential	100
12. $WPI_{\text{basi. water}}$	Aquatic basification intensity	100
13. $WP_{\text{tox. other}}$	Ecotoxicity to aquatic life potential	100
14. $WPI_{\text{tox. other}}$	Ecotoxicity to aquatic life intensity	100
15. EP	Eutrophication potential	100
16. EPI	Eutrophication potential intensity	100
17. $V_{\text{l, poll.}}$	Polluted liquid waste volume	100
18. AP	Atmospheric acidification potential	99.98
19. API	Atmospheric acidification intensity	99.98
20. $m_{\text{haz. mat.}}$	Mass of hazardous materials input	99.96
21. $m_{\text{haz. mat. spec.}}$	Specific hazardous raw materials input	99.96
22. EH_{water}	Environmental hazard, water hazard	99.8
23. $V_{\text{l, spec.}}$	Specific liquid waste volume	91.8
24. $SH_{\text{acute tox.}}$	Safety hazard, acute toxicity	83.1
25. $HH_{\text{chronic toxicity}}$	Health hazard, chronic toxicity factor	82.9
26. GWP	Global warming potential	75.8
27. GWI	Global warming intensity	75.8
28. $N_{\text{haz. mat.}}$	Number of hazardous materials input	75.0
29. $m_{\text{s, haz. spec.}}$	Specific hazardous solid waste	31.07
30. $WP_{\text{O2 dem.}}$	Aquatic oxygen demand potential	13.92

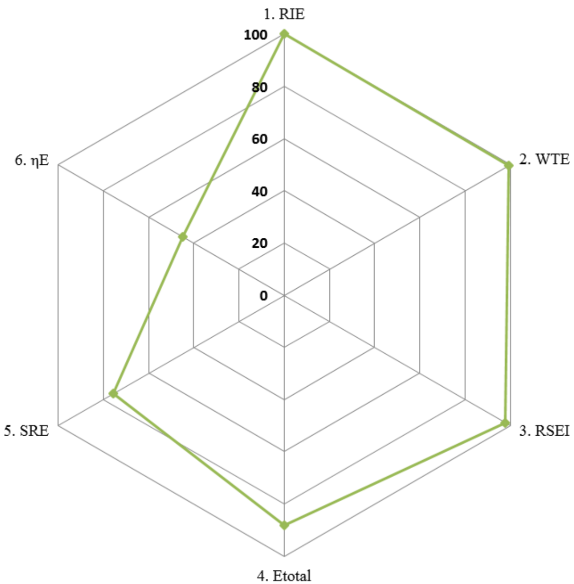
Environmental Indicators



Integrating Sustainability in Biorefinery Design: Accomplishments

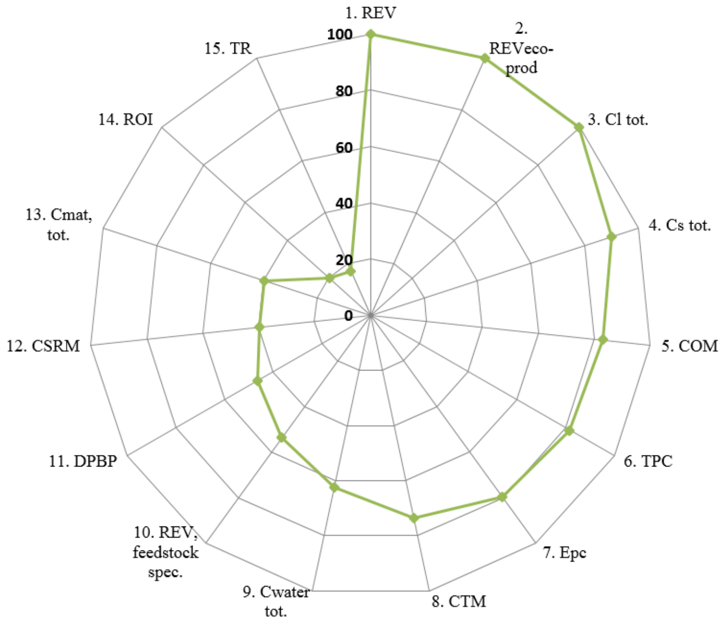
Energy Indicators

Indicator	Description	Sustainability % Score
1. RIE	Renewability-energy index	100
2. WTE	Waste treatment energy	99.2
3. RSEI	Specific energy intensity	97.9
4. Etotal	Total energy consumption	88.1
5. SRE	Solvent recovery energy	75.6
6. ηE	Resource-energy efficiency	45.0



Economic Indicators

Indicator	Description	Sustainability % Score
1. REV	Revenues from eco-products	100
2. REVeco-prod	Revenue fraction of eco-products	100
3. Cl tot.	Total liquid waste cost	99.7
4. Cs tot.	Total solid waste cost	90.2
5. COM	Manufacturing cost	83.2
6. TPC	Total product cost	81.8
7. Epc	Production cost	79.6
8. CTM	Capital cost	73.7
9. Cwater tot.	Total water cost	62.6
10. REV, feedstock spec.	Specific feedstock revenue	53.8
11. DPBP	Discounted payback period	46.5
12. CSRM	Specific raw material cost	39.7
13. Cmat, tot.	Total material cost	39.7
14. ROI	Rate of return on investment	19.9
15. TR	Turnover ratio	17.3



Integrating Sustainability in Biorefinery Design: Accomplishments

- The successful implementation and use of GREENSCOPE for a sustainability performance assessment for the production of high-octane gasoline from biomass has been demonstrated.

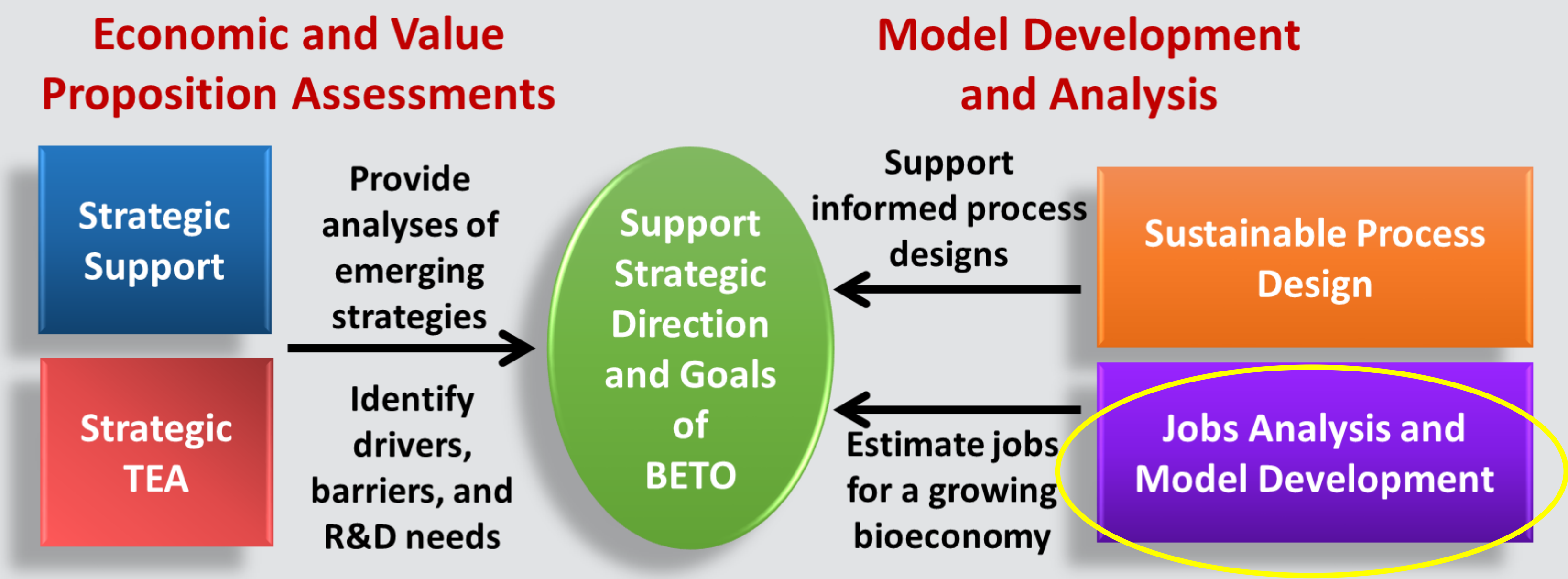
- Integrating sustainability in process design should be considered a worthy practice in biorefinery design. It should also be done in the early stages of development and not something to wait to do until the end.

- Considering multiple metrics for evaluation when comparing technologies and design modifications can help make more informed decisions by looking at the design more holistically.

- GREENSCOPE can be an effective tool for biomass-to-fuels/chemicals process sustainability evaluation and design.

- Conference presentation:
  - E.C.D. Tan and M. Biddy. "An Integrated Sustainability Evaluation of Indirect Liquefaction of Biomass to Liquid Fuels", 7th International Congress on Sustainability Science & Engineering (ICOSSE '18: Industry, Innovation and Sustainability), Cincinnati, OH, August 12-15, 2018.

Jobs analysis and model development for bio-derived fuels



Strategic Goal: Understand the potential for job creation and economic benefits in the emerging bioeconomy.

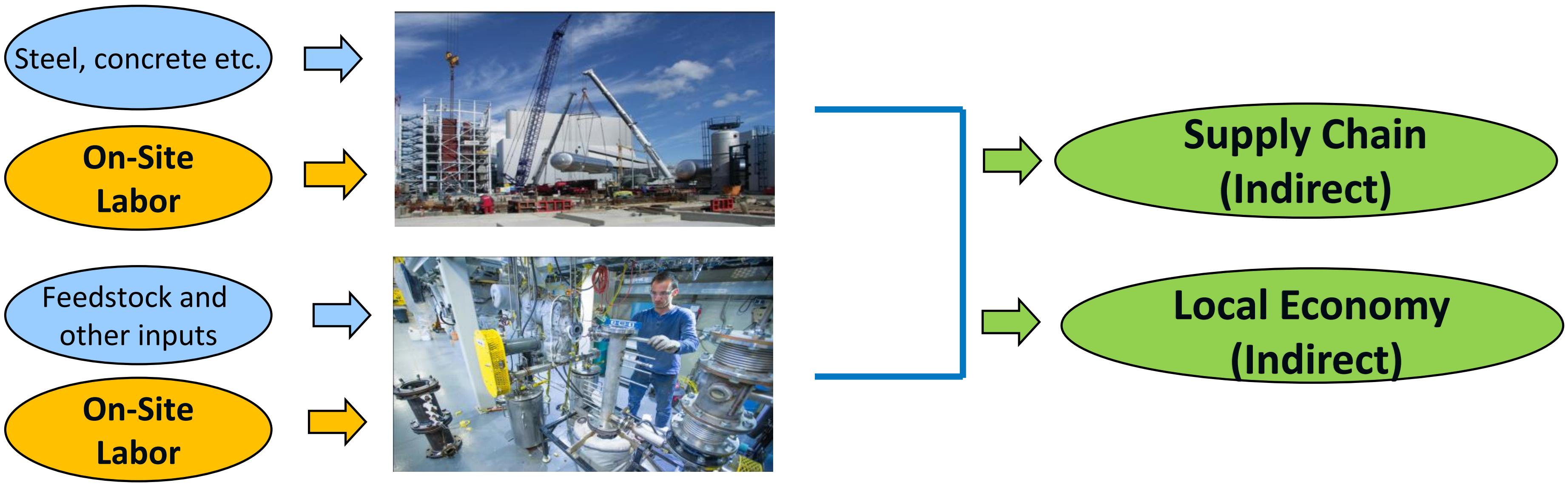
Jobs analysis for bio-derived fuels: Methodology

Development of a suite of Jobs and Economic Development Impact (JEDI) models.

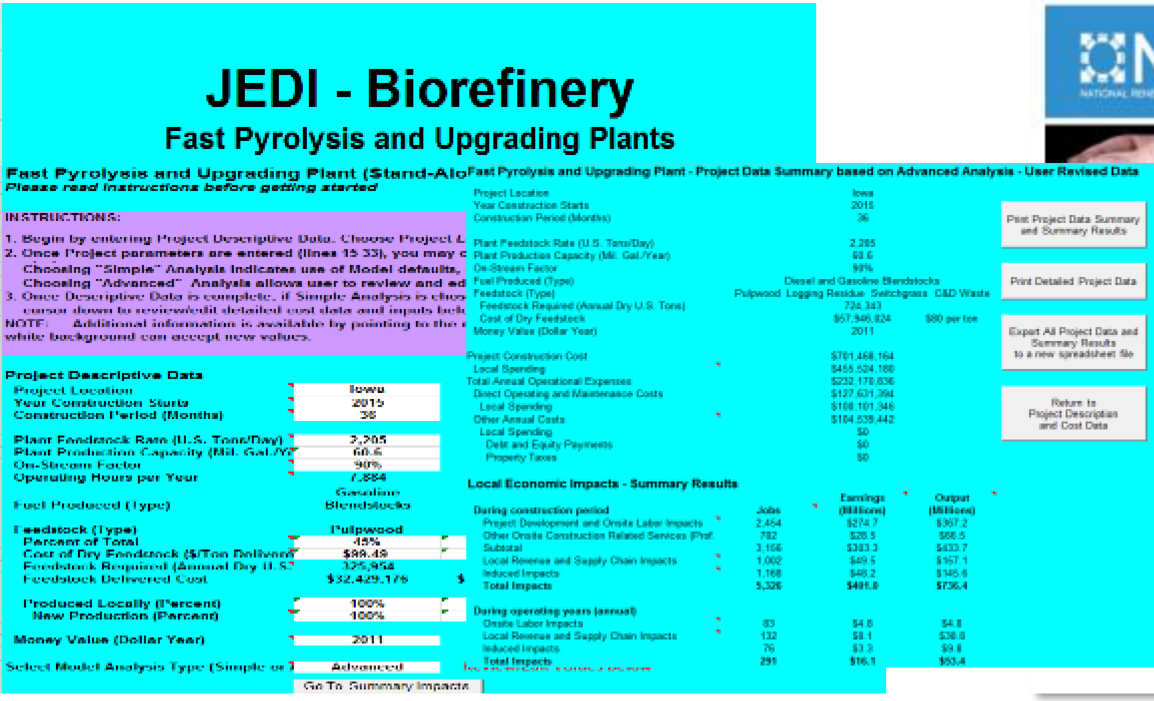
- Publicly available tools found at www.nrel.gov/analysis/jedi/ and KDF.

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, 2016) 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.



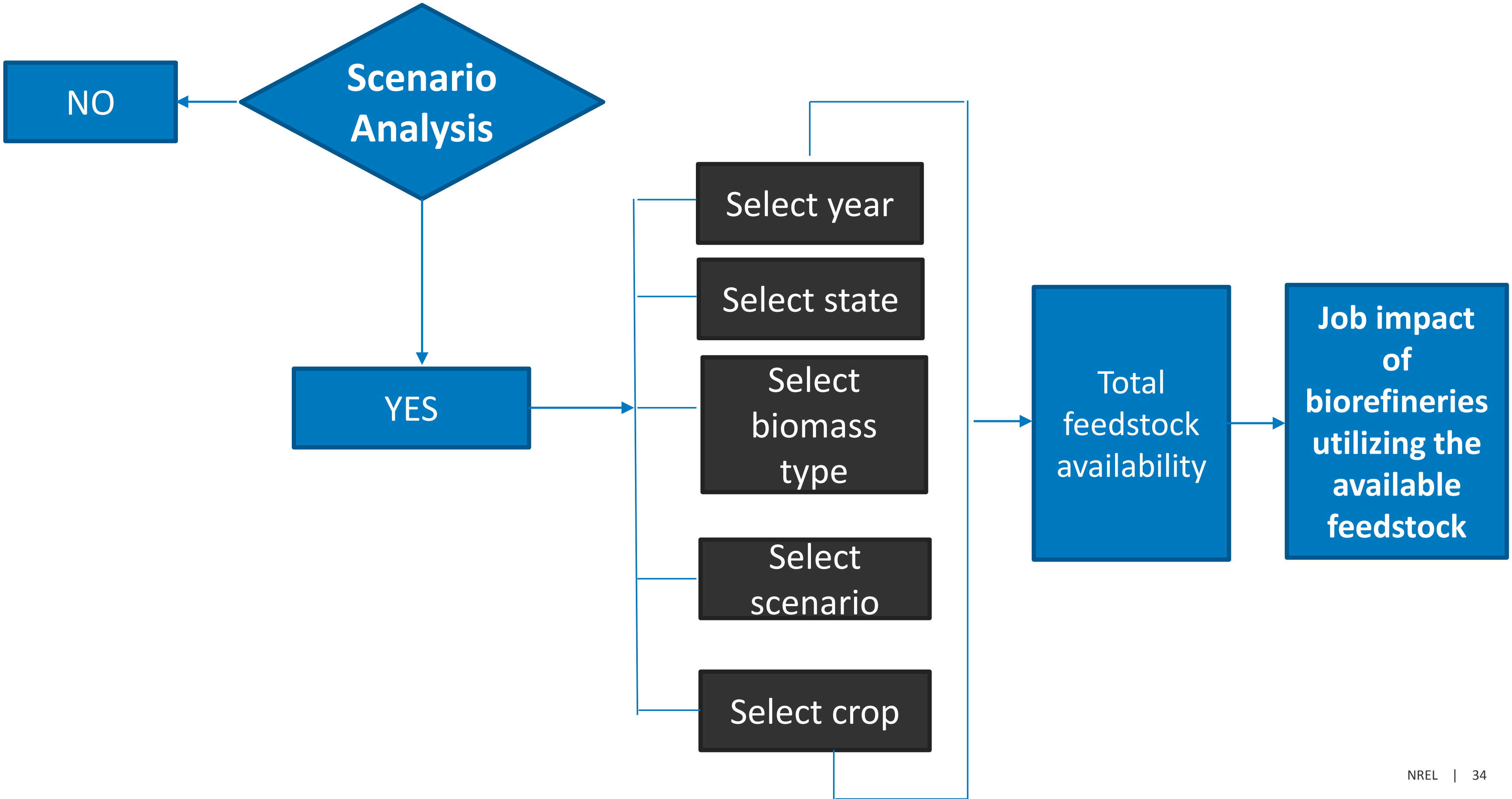
Jobs analysis for bio-derived fuels: Overview



- 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.
- Connected JEDI models with feedstock availability (BT16) to allow for scenario analysis (FY17).
- Validated models with hydrocarbon biofuel industry estimates and survey data (FY18).
- **Validation is continuous** as job estimates become available.

Scenario analysis within JEDI: Accomplishments

Connected JEDI models with feedstock availability (BT16) to allow for scenario analysis



Jobs analysis for bio-derived fuels: Accomplishments

Understanding job development for algal biomass and biofuel production

Algal Biomass and Biofuel Production Project Data
Please read instructions before getting started

INSTRUCTIONS:

1. Begin by entering Project Descriptive Data. Choose Project *Location* (from pull-down list) and other parameters relevant to your project. After inputting each parameter press enter (or cursor to the next cell) to continue.

2. Once the base project parameters are entered (lines 13-15), click on the button corresponding to the Algal Biomass Production Process choosen (cell B15) to review/edit the algae production system data and choose a Biofuel Production Process (if desired)..

NOTE: Additional information is available by pointing to the red triangles located in cell corners. Only those cells with a white background can accept new values.

Project Descriptive Data

Project Location	Arizona
Year Construction Starts	2018
Algal Biomass Production Process (choose one)	Open Pond

Review/edit Open Pond Data

Review/Edit Open Pond System Data and choose Biofuel Production Process

Review/Edit Enclosed Photobioreactor Microalgae System Data and choose Biofuel Production Process

Project Descriptive Data - Open Pond Algae Production

Project Location	Arizona
Construction Period (Duration in months)	36
Individual Pond Size (Average Acres)	2.0
Module Size (Acres)	100
Algae Cultivation Area (Acres)	5,000
Algae Average Productivity (g/m²/day)	25
Biomass Baseline Productivity Rate (Million tons/year)	0.188
Biomass Productivity Adjustment (percent change)	0%
Money Value (Dollar Year)	2011

Project Descriptive Data - Algal Biomass Fractionation Biofuels Production

Project Location	Arizona
Algal Feedstock Rate (US dry tons/day)	568
Process Feedstock Rate Adjustment (percent change)	0%
Fuel Produced	Biodiesel
Renewable Diesel Production (Mil. Gal./Year)	21.9
Money Value (Dollar Year)	2011

	Jobs
During construction period	
Project Development and Onsite Labor Impacts	494
Local Revenue and Supply Chain Impacts	276
Induced Impacts	321
Total Impacts	**1,091**
During operating years (annual)	
Onsite Labor Impacts	27
Local Revenue and Supply Chain Impacts	44
Induced Impacts	19
Total Impacts	**91**

Summary of Key Milestones/QPMs – All Met On Time

Milestone/QPM	Due Date	Progress
(Strategic TEA) Perform a comparative TEA to study the production of a single fuel or chemical from biomass using at least 3 different starting carbon sources (sugar, methane, syngas, or CO2). Report findings in a brief to BETO. This analysis will review the advantages as well as technical and economic trade-offs when considering a range of feedstocks for a target product. The goal of this study is to outline conclusions which could support the office when considering the range of waste feedstocks (in comparison with cellulosic feedstocks) for upgrading opportunities in this newly emerging field.	9/30/2017	Met on-time ✓
(Support) Deliver a report reviewing the comparison of at least 4 hydrocarbon design cases which will detail TRL, scale-up considerations (including modularity, process throughput considerations, and financing availability) as well as technical uncertainties/gaps/barriers. This report will also detail the results from the application of multi-objective process evaluation for at least 1 process hydrocarbon design. Successful completion of this analysis will support the utilization of tools to evaluate a range of metrics outside of MFSP and GHGs in the area of economics, efficiency, energy, and environment/societal impacts on a comparative basis. These tools can be applied to additional design cases and/or incorporated into core conversion platform TEAs as design reports are updated and improved.	9/30/2017	Met on-time ✓
(JEDI) A milestone report to document the methods, data sources, results and findings from the case study for the two selected states or regions. The milestone will demonstrate who, where and which sectors will benefit from the increased biomass and biofuel production in terms jobs, income (earnings) and output.	9/30/2017	Met on-time ✓
(Support) Provide BETO with draft outline and current information available for $2/gge report.	12/31/2017	Met on-time ✓
(Strategic TEA) Outline pathways for cellulosic ethanol production from corn fiber. Brief BETO on technology pathways, current deployment, and technology pathways.	12/31/2017	Met on-time ✓
(Support) Provide BETO with draft report documenting pathways for meeting $2/gge for at least 3 conversion strategies. Describe key R&D and data needs to support these strategies. Pending BETO review and approval, submit for final publication in early Q3.	3/31/2018	Met on-time ✓
(Strategic TEA) Detailed TEA studies on two ASTM approved jet fuel pathways, including key cost drivers and strategies to get to $2/GGE.	6/30/2018	Met on-time ✓

Relevance

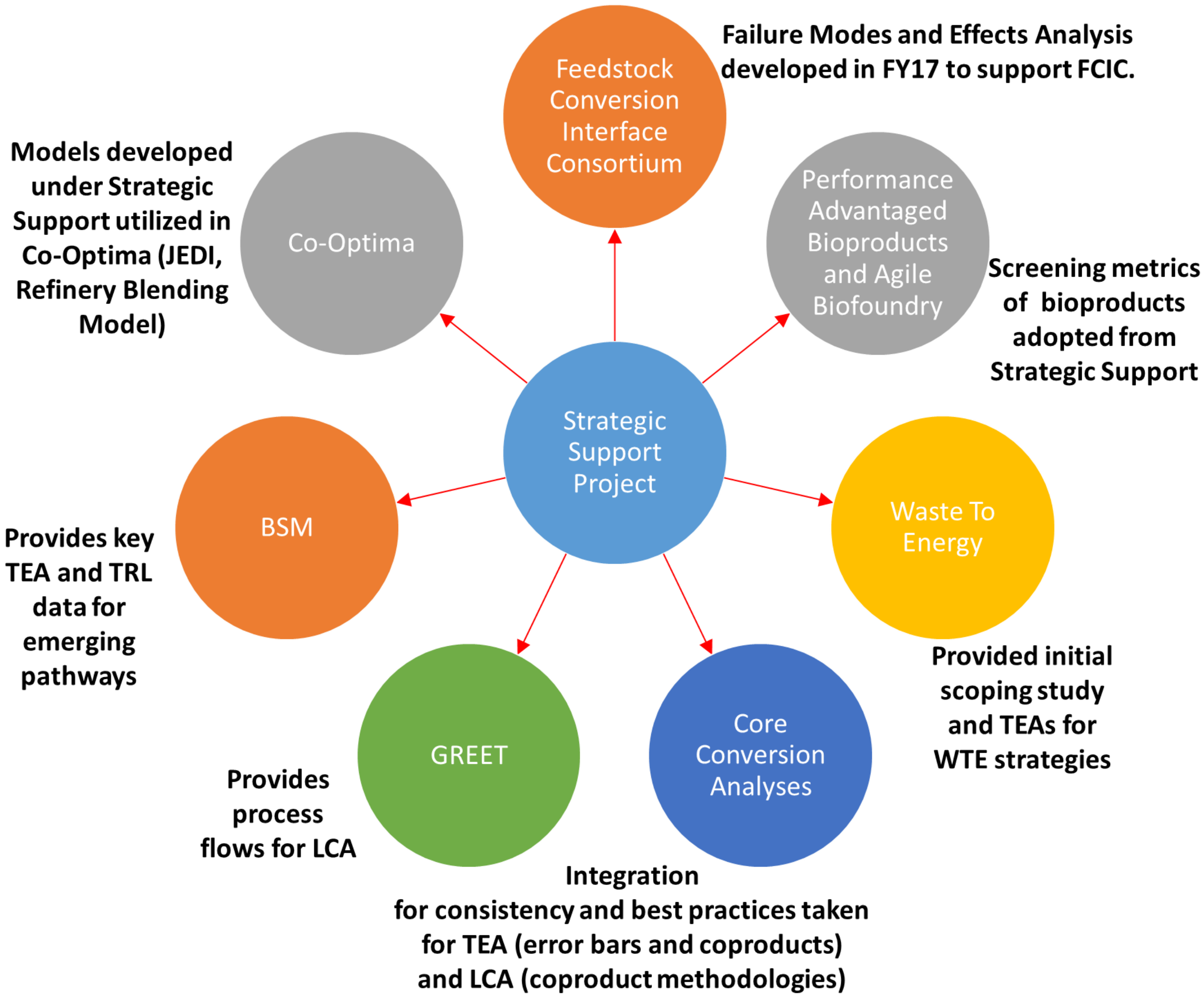
Outreach to bioenergy community to support impacts on the bioeconomy.

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).
- **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 ten peer-reviewed papers and book chapters** with three more drafts in preparation for peer-reviewed journals; gave more than 8 presentations.
- **Supported outreach activities** including co-leading a workshop on TEA/LCA approaches at the 40th Symposium on Biotechnology for Fuels and Chemicals and serving as an industrial advisory for senior engineering students design class.

Relevance

Output supports a range of DOE BETO projects



Relevance

Project directly contributes to BETO goals per 2016 MYPP:

BETO Goal	Project Contributions
"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]	**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.
"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]	**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 FY17/18 worked with ANL and core conversion project on coproduct considerations in LCA of biorefinery analyses and published a joint peer reviewed publication.
Support efforts to "provide an analytical basis for BETO planning and assessment of progress." [2-129]	**Strategic Support collaborative** analysis for $2/GGE options. **Strategic TEA** results have supported the initial analyses and transition to strategic areas for WTE.

Relevance

Project directly contributes to BETO goals per 2016 MYPP:

BETO Goal	Project Contributions
Develop analyses to "quantify the environmental and socio-economic effects of bioenergy production, assess opportunities for improvement, disseminate technical information.." [2-121]	**JEDI tools** help to understand bioenergy's **impact and potential benefits on creating and supporting domestic job development.** Work over last years has focused on expansion to align with core BETO funded strategies (BT16).
Technology-specific analyses explore sensitivities and identify areas where investment may lead to the greatest impacts. [2-129]	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. JEDI tools and sustainable process design working to understand potential benefits, as well as R&D needs, of emerging WTE focused areas.

Future Work

Strategic support

Improve the rigor associated with the analysis to meet any cost objective

- Address questions commonly raised about the minimum fuel selling price (MFSP) estimates, namely: 1) what is the actual range of this value and 2) what is the associated error bars of these values

Methodology to best represent co-product value in TEAs

- 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
- Methodologies will be reviewed as part of an 2020 Go/No-Go

Strategic TEA

Inform BETO on-going strategic goals for jet fuel by evaluating the region-specific needs for renewable jet fuel

- Understand the costs associated with the logistical aspects of the production and delivery of renewable jet fuel
- Consider the potential scale, demand, and location of production
- Methodologies will be reviewed as part of an 2020 Go/No-Go

Future Work

Sustainable Process Design

Evaluate DOE BETO emerging technology pathways

- New design modifications being proposed to move to lower cost targets
- Strategic pathways such as waste-to-energy designs, biopower strategies, and the CO_2 upgrading (chosen by Go/No-Go)
- Ensure moving in a direction that not only supports economic viability, but also sustainable design creditability

Jobs analysis for bio-derived fuels

Develop JEDI tools for DOE BETO emerging technology pathways

- Waste-to-energy technologies (such as recently published sludge HTL strategy)
- Biopower strategies (align with recent FOA supported studies under A&S)
- Provide critical information to understand the economic impacts of the technology and variances due to geographic locations/energy demand

Future Work

- **Support/collaborate with other BETO projects:**
  - Continue to leverage existing tools for **Co-OPTIMA** evaluations—biofuels blending model (BLEND) and JEDI.
  - Work with **GREET team** to consistently evaluate both economics and sustainability for a biorefinery.
  - Work closely with core conversion analysis teams to share tools and methodologies for coproduct costing and cost range of selling price estimates.
  - Support on-going discussions for the Annual Technology Baseline (ATB).
- **Planned peer reviewed journal articles and public milestone reports.**
  - Publish $2/GGE white paper, pending BETO approval.
- **Continue to vet models and analyses through stakeholder engagement and collaboration.**

Summary

Overview: Provide credible, unbiased, and consistent analyses to inform the strategic direction of the DOE BETO office efforts

Approach:

- Analysis **results** and approaches are **vetted by stakeholders**
- Results and tool availability are **communicated to stakeholders**
- Work plans and prioritization are based on discussions with BETO with **active project management** throughout the project

Technical Progress:

- Led **inter-laboratory screening study** to develop strategies to meet a <$2.5/GGE cost goal
- Developed a **public database** summarizing key TEA data from BETO-funded studies
- Outlined strategies to meet $2.5/GGE for **jet fuel pathways**
- Developed initial **scoping studies for WTE** strategies and helped inform platform development
- Applied GREENSCOPE on BETO support design cases to **integrate sustainability in process design**
- Developed algal-focused JEDI model and incorporated **BT16 results into JEDI models**

Relevance: Project aligns with a range of BETO MYPP goals and supports stakeholder outreach. Output supports a range of DOE BETO projects with clear handoffs to other projects.

Future Work:

- Improve the rigor associated with the analysis to meet any cost objective
- Inform BETO on-going **strategic goals** by evaluating the region-specific needs for **renewable jet fuel**
- Evaluate DOE BETO **emerging technology pathways** to ensure moving in a direction that not only supports economic viability, but also sustainable design creditability
- Develop JEDI tools for DOE BETO emerging technology pathways

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Thank You

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Additional Slides

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
COP: ConocoPhillips
CU: University of Colorado
DOD: Department of Defense
EPA: US Environmental Protection Agency
FOA: Funding Opportunity Announcement
GGE: Gasoline gallon equivalent
HTL: Hydrothermal Liquefaction
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
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

- Zhang, Yanan, Asad H. Sahir, Eric CD Tan, Michael S. Talmadge, Ryan Davis, Mary J. Biddy, and Ling Tao. "Economic and environmental potentials for natural gas to enhance biomass-to-liquid fuels technologies." Green Chemistry 2018.
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- Schaidle, Joshua A., Michael S. Talmadge, Mary J. Biddy, Mark R. Nimlos, and Adam D. Bratis. Chemicals Derived from Biomass Thermolysis and Gasification. No. NREL/CH-5100-67480. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2017.

Presentations

- E. Tan, “Overview on Evaluation of Sustainable Biofuel Conversion Processes,” 2016 AIChE Annual Meeting, San Francisco, CA, November 13-18, 2016. (Poster)
- R.L. Smith and E. C. D. Tan, “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.
- M. J. Biddy and L. Tao, “A review of opportunities for lignocellulosic biorefineries: Maximizing value by minimizing waste” Bioenergy 2017, Washington DC June 2017.
- M. Biddy and Ling Tao “Economic Drivers and R&D Needs for Renewable Jet Fuel Pathways” DOE BETO Trilateral Jet Fuel workshop, Pasco, WA May 15-16, 2018.
- M. J. Biddy, “Techno-economic analysis: Understanding research drivers to the cost-efficient production of bio-derived fuels and chemicals.” Invited presentation, 2018 ACS Green Chemistry Conference, Portland, OR, June 2018.
- M. J. Biddy and L. Tao (invited talk) “Techno-economic Approach towards Alternative Jet Fuel Conversion Pathways” Alternative Aviation Fuel Workshop, Macon, GA, September 14-15, 2016.
- E.C.D.Tan and M. Biddy, “An Integrated Sustainability Evaluation of Indirect Liquefaction of Biomass to Liquid Fuels,” 7th International Congress on Sustainability Science & Engineering (ICOSSE ’18: Industry, Innovation and Sustainability), Cincinnati, OH, August 12-15, 2018.
- E.C.D.Tan and M. Biddy, “Improving Life Cycle Inventory for Life Cycle Assessment of Bio-based Fuels and Chemical Production,” LCA XVIII, Fort Collins, CO, September 25-28, 2018. (Poster)

2017 Peer Review Feedback

- The goal of the Strategic Analysis Support group is to develop and utilize an array of analysis tools to support the strategic direction of BETO and understand the development of a biomass economy. The types of analyses range from assessing the current and future market drivers for the production of biomass-derived chemicals to providing comparative economic analyses for jet fuel production pathways. This group utilizes a wide variety of tools and expertise. The project is well managed with clearly defined objectives and milestones. The use of go/no-go decisions has proven effective. Communication and collaboration is critical to the successful hand off of the information in support of other BETO projects. The group has made a great deal of progress since the last review. This progress includes a market report analysis and publication on bioproducts to enable biofuels, the development of TEAs for understanding jet fuel production, support for conversion R&D strategies to understand fuel quality valuation, and jobs and economic development impact (JEDI) case studies to identify key factors that contribute to job growth. Each of these projects is significant by themselves. Together they represent an enormous amount of work which helps to highlight the impacts of the emerging bioeconomy and outline specific hurdles or gaps for further development by BETO and industry. One good example of this is the market analysis report for the production of bio-derived chemicals. This report identified 27 biomass-derived products which were down-selected to 12 products based on market potential. The emerging area of biobased chemicals and bioproducts has the potential to produce some short-term wins that could spill over to the broader biofuels market. This report was a great example bioenergy space by applying appropriate analyses and models. The group provides a go to group for BETO whenever the need arises. The work is often started here and then passed off to others. They have proven they have the ability to provide a quick turnaround on BETO requests. I see this group as being a key enabler of the Co-Optima initiative, and a close collaboration between the two groups is important. Future work includes case studies with JEDI to consider the effect on income distribution, the comparison of biofuel hydrocarbon pathways for near-term scale-up, the development of TEAs for understanding waste stream upgrading, and the assessment of refinery economics due to biofuels blending stream displacement. Given the current interest in job creation, further refinement of the JEDI model to include an analysis of job “shifting” and job loss would give a more complete picture and strengthen the validity of the model.

2017 Peer Review Feedback

- This project has yielded obvious accomplishments, but it is unclear how the project strategically aligns with other BETO-funded efforts and whether the project is uniquely qualified to tackle the specific future analyses identified. Perhaps this was a function of the presentation and materials provided to the reviewers, as responses to questions asked by the Review Panel helped address this important issue somewhat.

- This project provides a comprehensive analysis of the economic viability of biofuel and product development. My sense is that the treatment of the demand side of prospective markets is more qualitative than that of the supply side, but this seems appropriate given what are probably the greater uncertainties in the development of potential product markets. The supply side analysis largely takes an "engineering" approach, but again, this is reasonable given the lack of data on the development of required technologies. Employment analysis is always problematic, as one should consider not only the number of people employed in a new industry, but also the numbers displaced in old ones which the project considers in its future plans.

2017 Peer Review Feedback

- Overall, this project seems to have delivered valuable quick-turnaround analytic and modeling capacity to BETO. The project seems well integrated to feed into other BETO projects, including GREET and Co-Optima. Showing the data interconnections among projects would help demonstrate value. Also, it would be valuable to ensure analyses and tools are disseminated on platforms such as the Bioenergy KDF and BIC.
- This is an exemplary project. It is asking the right questions, engaging a broad set of stakeholders, managing the project confidently and collaboratively, working closely with other DOE laboratories, and clearly planning next steps based on critical gaps in understanding. Moving forward, this project should continue to engage stakeholders, looking for additional stakeholders to further strengthen the analysis and expand the broader impacts, and to identify the next key knowledge gaps to inform decision making for policy, investment, and other strategic purposes.

2017 Peer Review
PI Response to Reviewer Comments

- We thank the reviewers for their helpful feedback and suggestions. We will continue to work to ensure the analyses and tools developed under this project are disseminated. To start, these project outcomes and models will be posted on the Bioenergy KDF and BIC websites. Moreover, this project strives to provide BETO with critical information and tools to address key questions in support of the strategic direction of the office. This project supports informational needs for a range of BETO-supported projects including GREET and BSM. It is our goal to continue to support our strong collaborations both within the national laboratories (with GREET and BSM) and externally through collaborations with industry and other government agencies. We also plan to integrate details of our bioproducts analyses into the Bioenergy Market Report supported by the A&S Technology Area. Additionally, through our integration with the Co-Optima initiative, there are ongoing efforts to develop methods to estimate 'net' jobs analyses which will be incorporated into this project in the future.