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DOE Bioenergy Technologies Office (BETO)
2019 Project Peer Review

Analysis & Sustainability Interface
2.1.0.301

March 4, 2019

WTE Review

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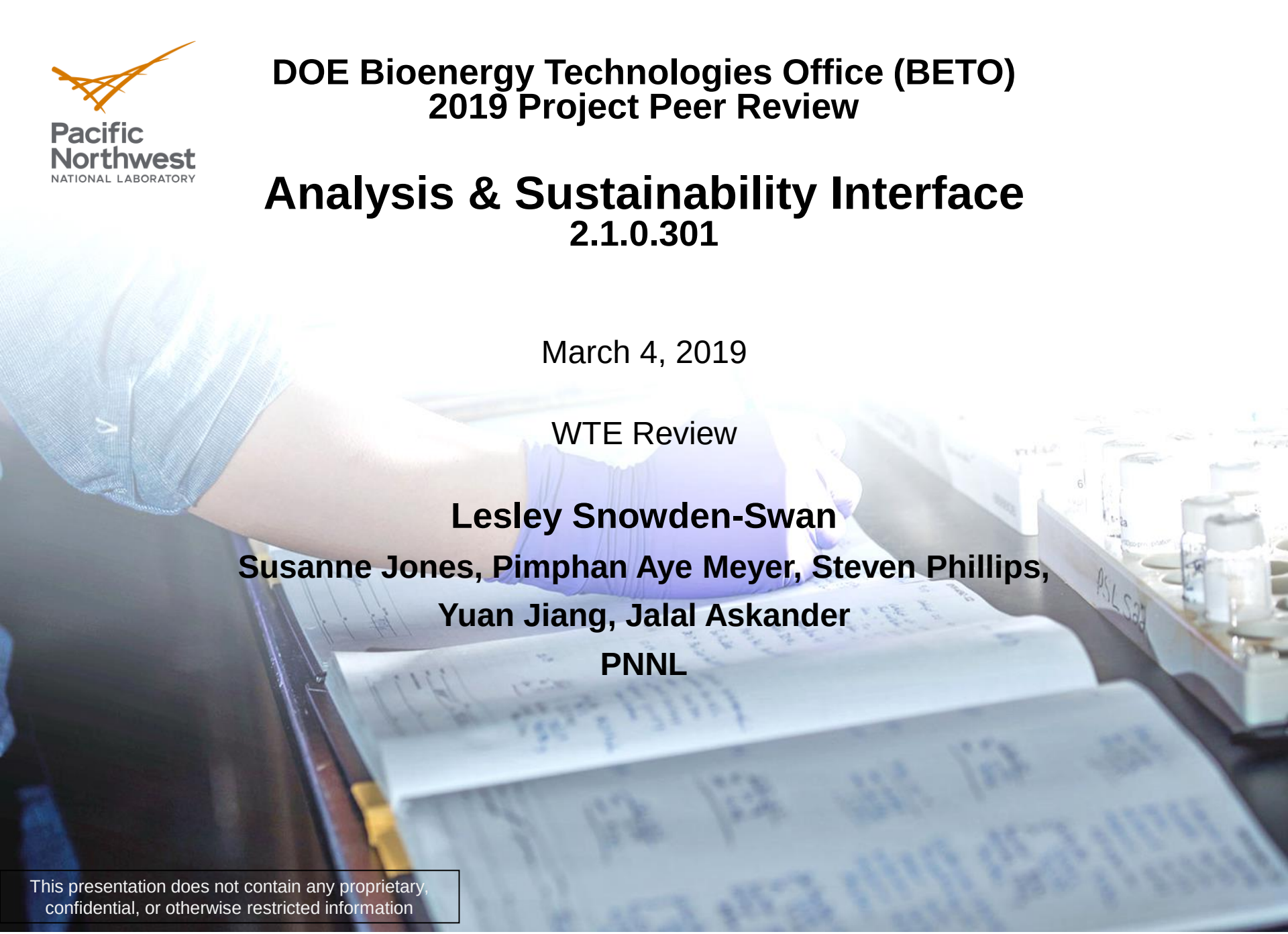
PNNL

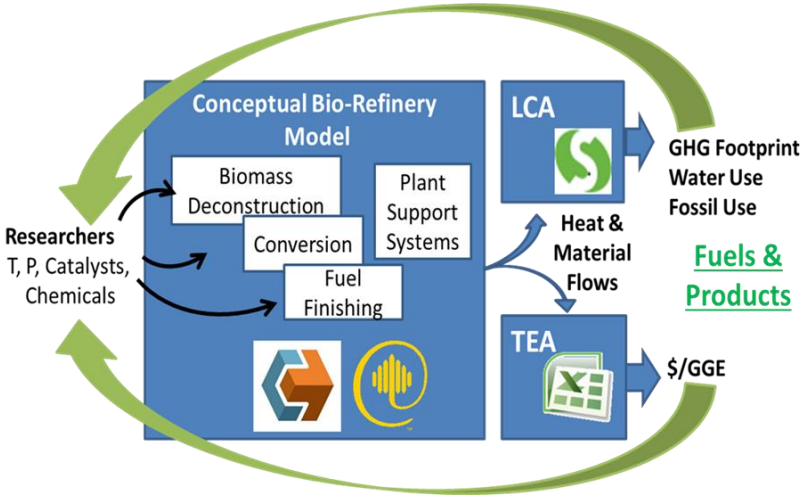


Goal Statement

Producing Cost Effective Biofuels is Challenging

GOAL: Develop research-driven process models and perform techno-economic analysis to inform biomass conversion research for fuels and chemicals

- *Guide research*
- *Track progress*
- *Reduce costs*



Quad Chart Overview

Timeline
- Project start date: October 1, 2017
- Project end date: September 30, 2019
- Percent complete: 80%

Barriers addressed

At-E Quantification of Economic, Environmental and other Benefits and Costs

	Total Costs Pre FY17 (FY14-16)	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY19)
DOE Funded	$2,115	$771k	$499k	$721k
Project Cost Share	$0k	$0k	$0k	$0k

Partners: Collaborators/Interactions
- **National Lab Interactions**
  - **ANL: life-cycle analysis**
  - **INL: feedstocks**
  - **NREL: techno-economics & wet feeds**
  - **ORNL: experimentalists**
  - **PNNL: experimentalists & analysis**
- **LanzaTech: experimentalists/analysts**

Objective: Develop process and cost models to inform research goals and to track research progress and publish results

End of Project Goal: Summarize learnings from past 3 years of project and publish for stakeholder use.

The annual milestone reads: “TEA Manuscript - Identifying and disseminating data regarding viable routes to economic production of biofuels and chemicals is needed to advance the bio-economy. We will complete a TE and sustainability analysis draft manuscript summarizing the conversion costs for at least 3 pathways developed under this project for submission to a peer reviewed journal.”

1 - Project Overview

History: Merit reviewed project for FY17-19, combining several separate but related analysis projects from prior years

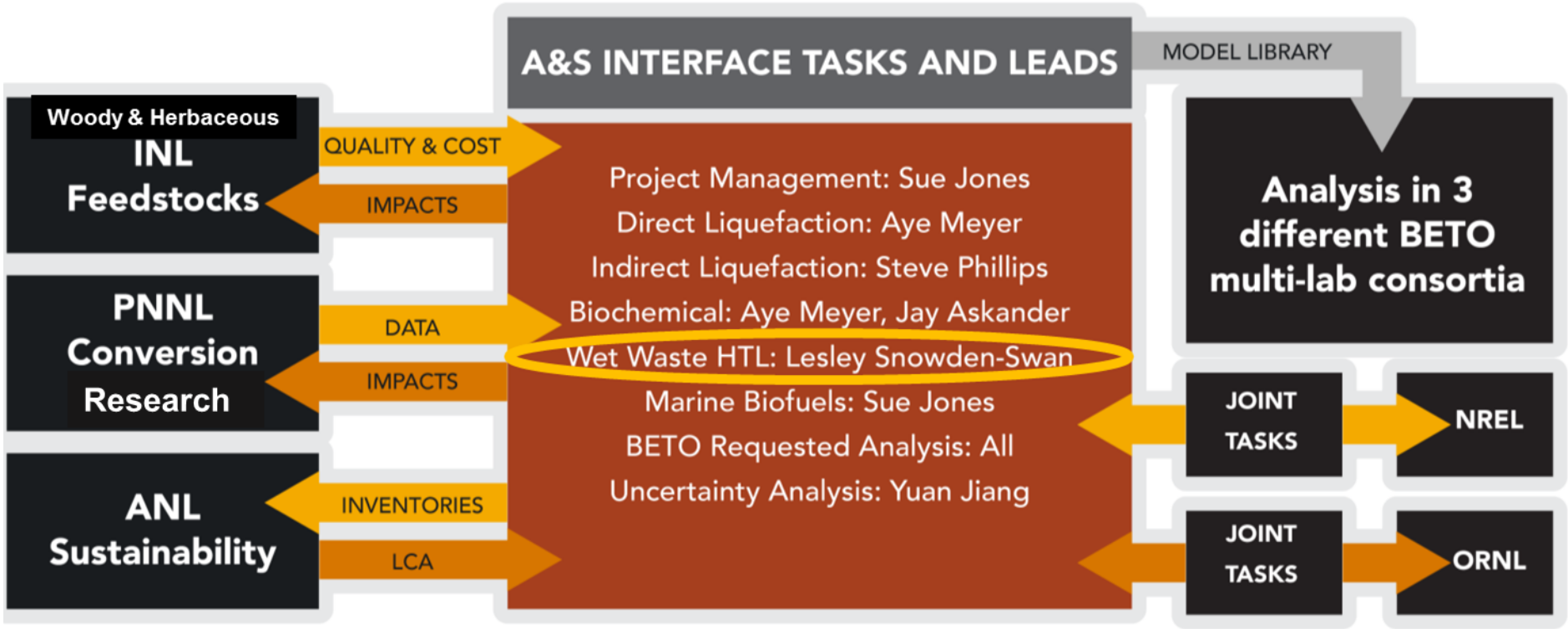
Goals: analysis enables R&D toward sustainable economic biomass conversion to liquid fuels and chemicals

- Identify barriers and cost reduction strategies
- Assess sustainability impacts
- Set technical & cost targets
- Track R&D progress

Value:

- Assists researchers to make best use of limited funds
- Allows cross-cutting analysis over various research efforts, e.g., enabling hybrid thermochemical/ biochemical combined approaches
- Drive processes towards BETO's outyear goal of < $3/gge

2 – Approach (Management)



This project supports research activities in <u>several areas</u> including WTE. Given the constraints on time and subject matter, this presentation will focus primarily on <u>WET WASTE HTL</u>.

2 – Approach (Management)

Approach Structure

- Annual Operating Plans (AOP) with quarterly progress measures and deliverables
- Quarterly reporting to BETO
- **Merit reviewed** in FY16 for the FY17-19 time period
- Mid-FY18 **Go/No-Go**: “Develop TEA for at least one pathway via BC, TC or hybrid processing that reduces the MFSP at or below $2.50/gge
  - **Criteria met**
  - Details shown in back-up slides
- Planned publications and presentations for use by stakeholders

2 – Approach (Technical)

Technical Approach

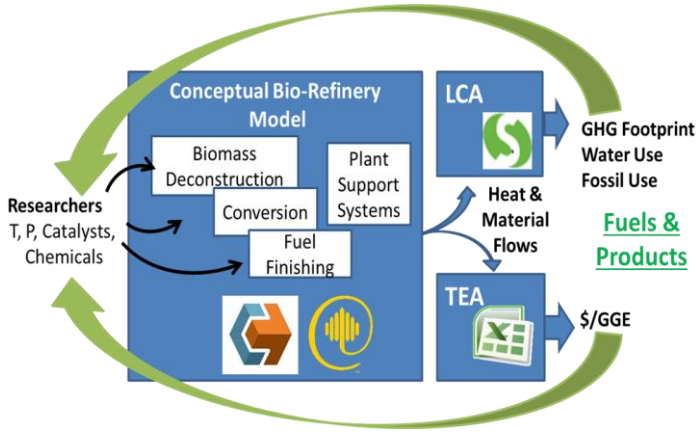
- Develop data-driven process (Chemcad and AspenPlus) and cost models (Excel)
- Work closely with researchers to convey impacts, identify data gaps (frequently scheduled meetings)
- Use well-defined basis for economic analysis as described in the BETO MYP
- Consider combinations of effects vs. one variable at a time

Challenges – Data Limitations

- Develop flexible models for quick scenario assessments
- Quantify sustainability impacts concurrently with TEA
- Seek review and input from experts external to PNNL

Critical Success Factors

- Identify gaps and opportunities: where is research needed? What research has the greatest impact?
- Make results available for public use



Guide Research
Track Progress
Reduce Costs

3 – Technical Accomplishments/Progress/Results

All milestones met on time, on budget

(see backup slides for details)

Overview of Highlights from:

- **HTL of Wet Wastes**
- **Predictive Modeling**

HTL of Wet Wastes to Fuels

FY17: subtask under the experimental wet waste HTL project

- Detailed process and cost models developed

FY18: combined with the algae HTL modeling project

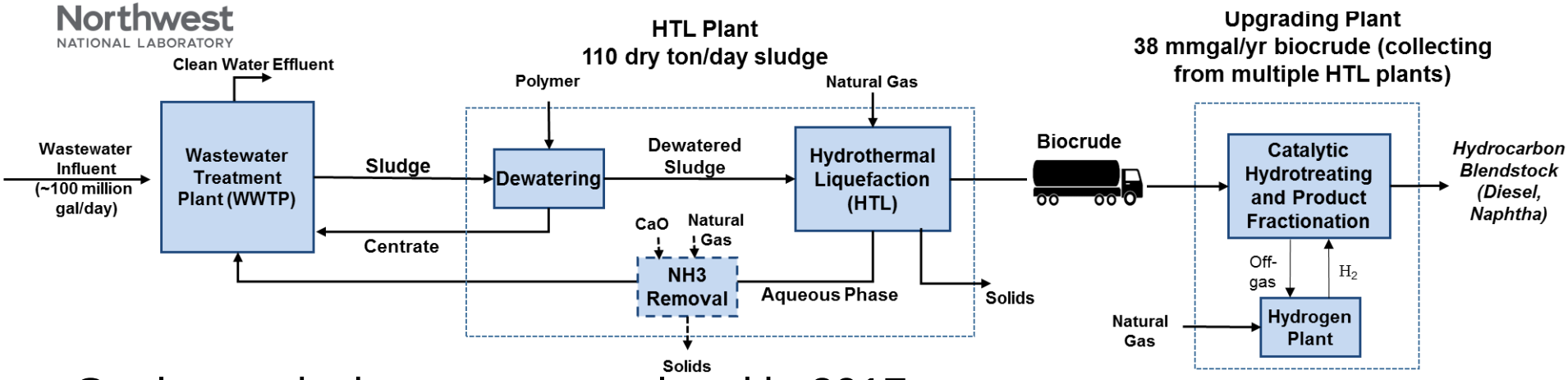
- Goal design case published in Q1 targeting 2022
- Baseline State of Technology (SOT) completed for inclusion in the BETO MYP

FY19: merged into Analysis & Sustainability Interface project to better highlight its place in the BETO portfolio

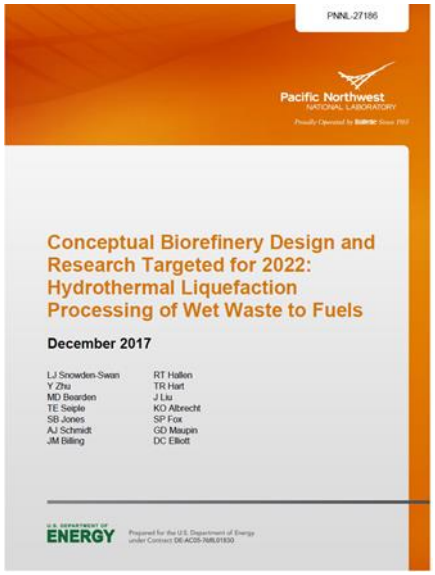
BETO Strategic Goal: "enable use of America's abundant biomass and **waste resources** for advance biofuels"

3 – Technical Accomplishments/Progress/Results

Wet Wastes to Fuels



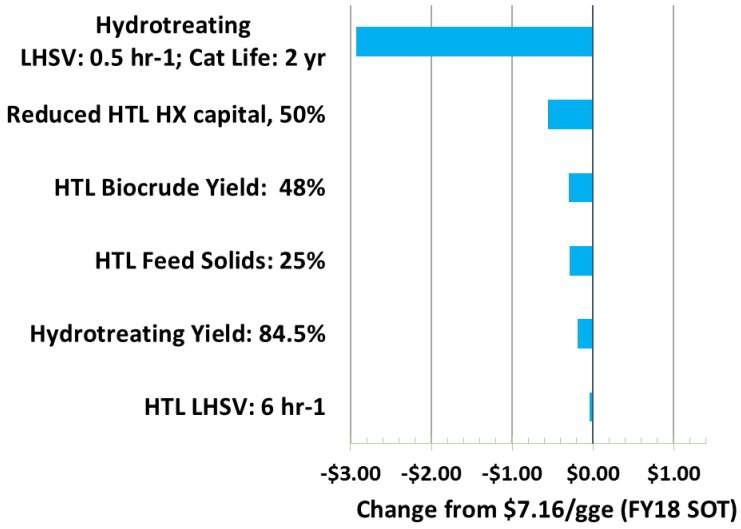
- Goal case design report completed in 2017
- Base case state of research technology (SOT) completed in FY18
  - Uses standard BETO economic assumptions to allow comparison across different conversion options
  - Provides basis to measure HTL and upgrading research improvements moving towards the goal case.
  - Assessed with and without ammonia removal to address potential impact on WWTP operations & regulatory limits
  - Provides life-cycle inventory to ANL for their LCA
- Sharing learnings with related projects helping to define additional cost metrics most useful to industry



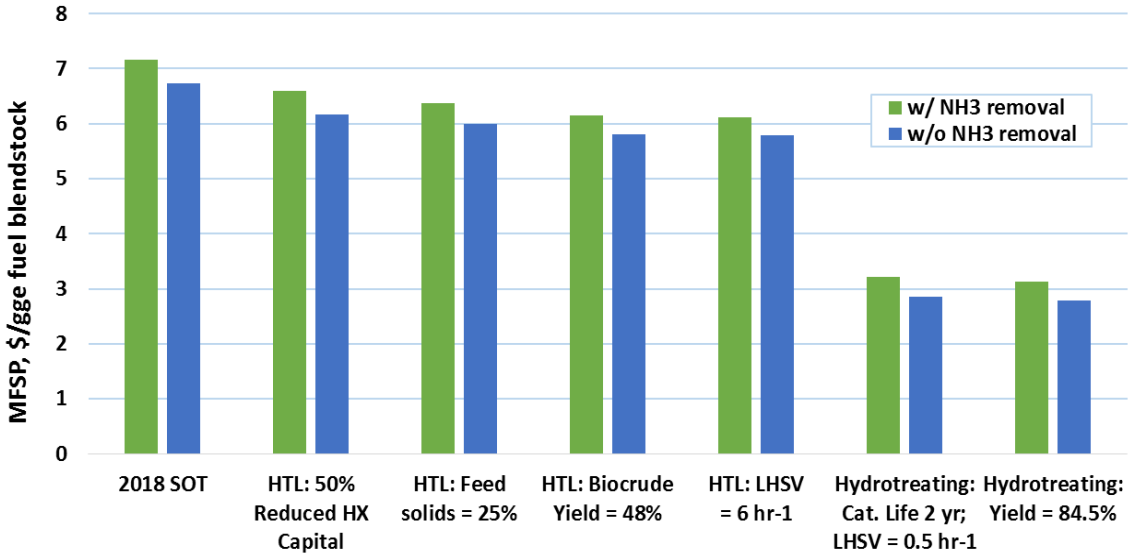
3 – Technical Accomplishments/Progress/Results

Scenario Analysis Identifies Key Cost Drivers

Individual Improvements



Aggregated Improvements

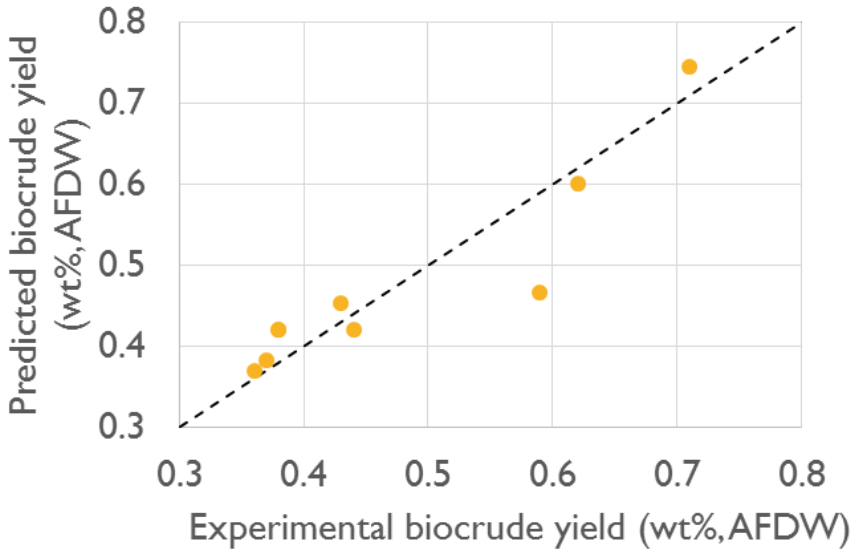


- First hydrotreating run with sludge biocrude used a **large bed** size and **slow throughput**: much improvement possible!
- HTL experimental systems in laminar flow regime limiting efficiency: design optimized for scale-up could improve heat rate, cost.

Enhancing Analysis Capabilities for Improved Estimations: Predictive Modeling

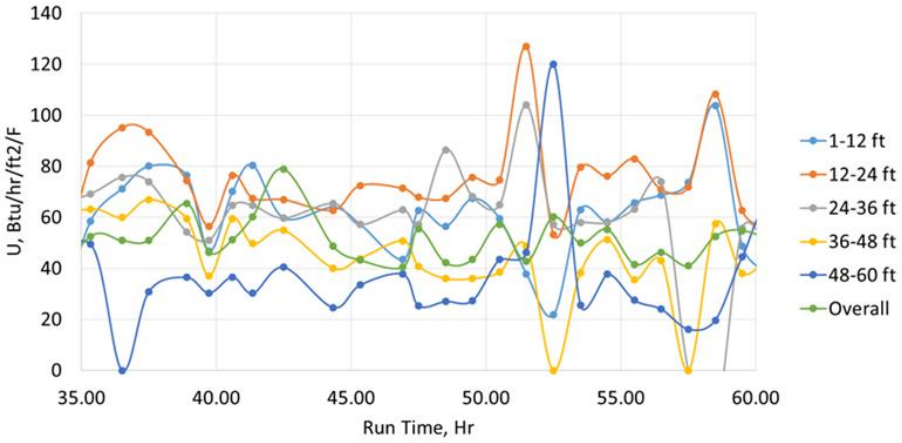
HTL Reactor

- Correlated feed composition (carbohydrates, protein, lipids) to HTL yield (developed jointly with the HTL Model Development project)
- Programmed into process model to predict all phases
- Data from large set of runs over a range of feedstock compositions (algal feedstocks but applicable to wet wastes)



HTL Heat Integration

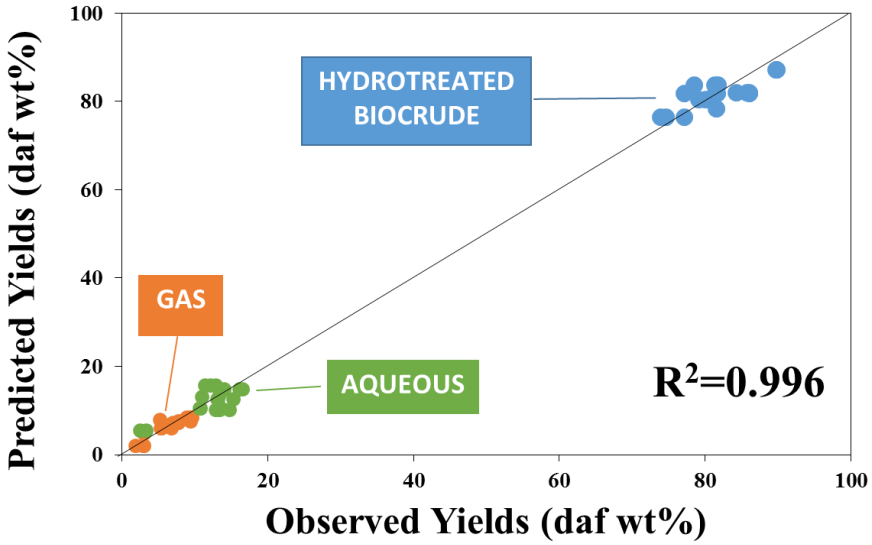
- Data collected from the HTL PDU used to predict heat transfer coefficient
- Explore alternative configurations for reducing costs for scale-up



Enhancing Analysis Capabilities for Improved Estimations: Predictive Modeling

Hydrotreating Reactor

- Correlated biocrude elements
- Predicts hydrotreating yields for gas, hydrocarbon and aqueous products



Impact

- Process models are increasingly predictive, no longer static
- Estimated heat transfer coefficient for engineering scale system (PDU) will be used to design more cost-effective configurations
- Predictive models provide more flexible and efficient method of estimating process performance as a function of feedstock variability

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4 – Relevance

Project Goal: Develop Cost and Performance Models to Guide Research, Track Progress, Reduce costs

Why this project is important (for all tasks including wet waste HTL)

- Develops experimentally based modeled production costs indicating high impact research areas for conversion,
- Assists researchers in defining targeted research,
- Makes best use of limited funding,
- This project also has a specific task to support other BETO needs as they arise, such as goal setting:
  - Contributed to NREL lead white paper on options for reducing fuel production costs to <$3/gge (internal to BETO) including **waste feedstocks**
  - Contributed to BETO lead multi-lab effort identifying and assessing BETO goal options beyond 2022

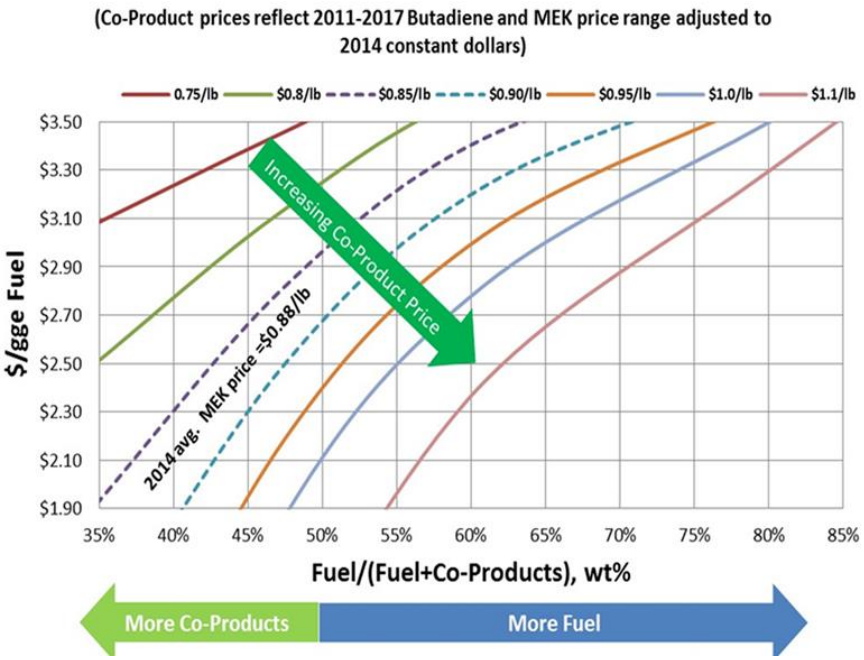
4 – Relevance

Supporting BETO Performance Goals

Direct support for meeting the FY17 Milestone through analysis of the BETO funded LanzaTech/PNNL process

- TEA for multiple scenarios involving distillate fuel and co-product chemicals
- Life-cycle inventories for ANL's LCA
- Feedstock cost and quality from INL

Most of the work to date in this project was for non-WTE pathways, but this serves as an example of how this project has helped BETO develop cost and performance models to track projects

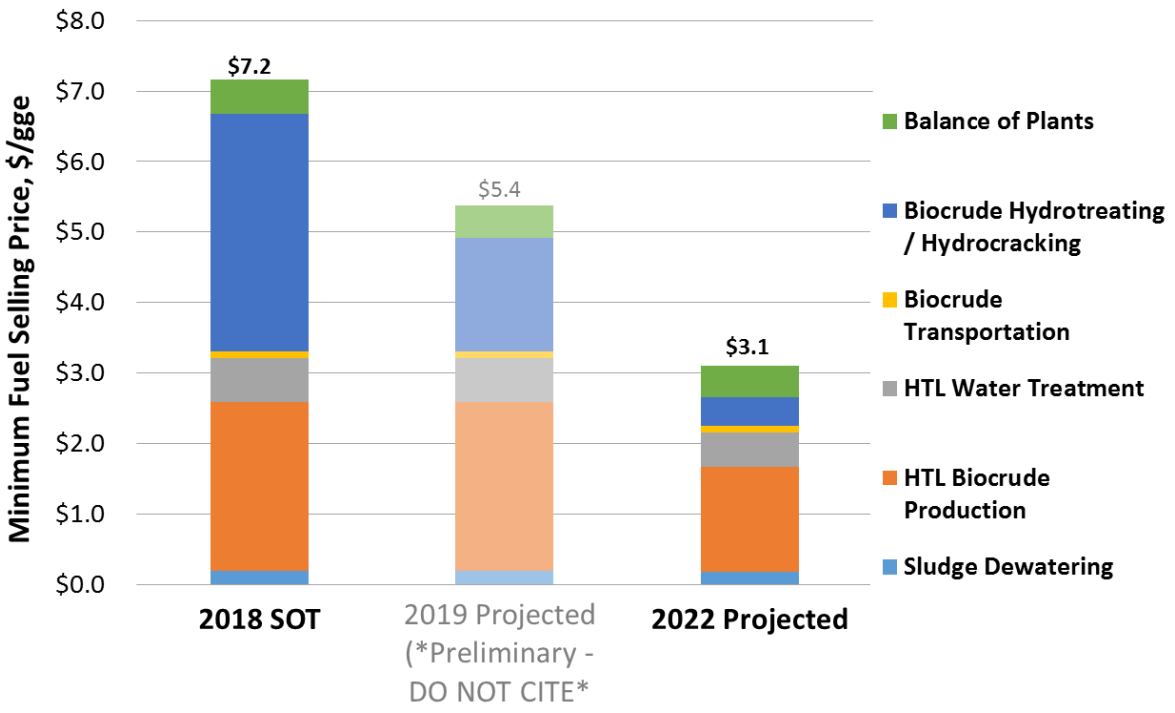


BETO Target: "**By 2017**, validate at a pilot scale at least one technology pathway for hydrocarbon biofuel production at a **mature modeled price of $3/GGE with GHG emissions reduction of 50%** or more compared to petroleum fuel" (2016 MYPP)

Advancing the State of Research Technology

Wet Waste HTL: decreasing biofuel cost through conversion of waste feedstocks

- Metrics and technical targets are TEA driven
- Enables focused HTL and biocrude upgrading research to
  - **increase fuel yields**
  - **prolong catalyst life**
- **This work directly supports meeting the BETO 2022 milestone**



BETO Target: "By 2022, verify integrated systems research at engineering scale for hydrocarbon biofuel technologies that achieve a mature modeled MFSP of $3/GGE with a minimum 50% reduction in emissions relative to petroleum-derived fuels."

4 – Relevance
Working with and Informing Stakeholders

Relevance to Industry – Solving an industry problem while making fuel

- **Increasing interest from WWTPs** (Detroit MI, Austin TX, Water Research Foundation, HYPOWERs) – need cost-effective solutions that meet regulations
- Responding to **information requests** from industry and universities
- **Data Dissemination**: (for total project including wet waste HTL) 7 publications (plus 3 more submitted), 13 presentations (8 analysis only, 5 supporting experimental work); additional details in backup slides

Collaboration with BETO projects at PNNL & other labs

- **Waste-to-Energy Cost-Benefit Analyses** – NREL & PNNL
- **GREET Model and Supply Chain Sustainability Analysis** – ANL
- **Separations Consortium** – ANL, ORNL, PNNL (HTL aqueous NH_3 and sulfur removal; biocrude conditioning)
- **Process Development Unit** (PDU) – (HTL, biocrude upgrading, CHG)
- **Refinery Co-Processing Strategies** – NREL & PNNL
- **HTL Algae** – Sharing applicable learnings and modeling techniques
- **Hybrid Biochemical/HTL** – Bioreactor broth mixed with waste lignin

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4 – Future work

Scenario Analysis: Annual State of Technology Assessments

Wet Waste HTL cost reduction strategies

Assess Scenarios for Potential Wet Waste HTL Cost Reduction Strategies

- Apply predictive modeling to wet waste HTL
- Continue heat integration design optimization using PDU data
- Consider impact of co-processing sludge and greases
- Exchange learnings with other HTL related projects

Work with researchers towards FY19 SOT

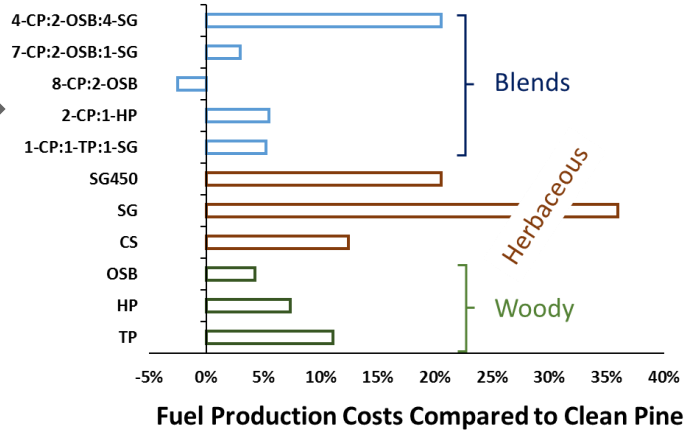
- Share wet screening scenarios for cost reduction (including biocrude upgrading) with researchers – what makes sense and what doesn't
- Complete FY19 SOT and combined research and analysis report to BETO
- Present results at the January BETO quarterly and publish in the BETO MYP

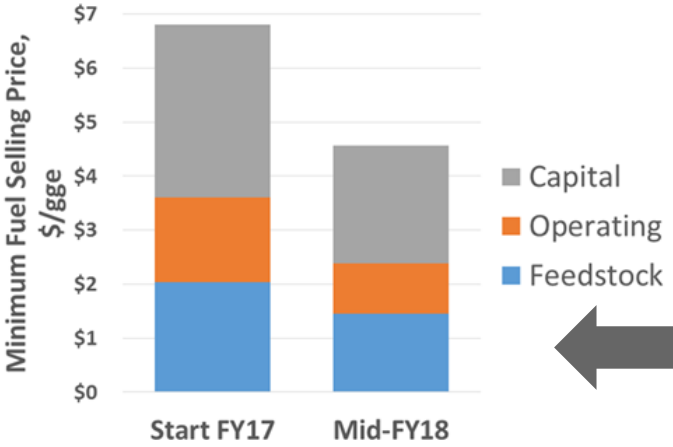
Work with WWTP industry to understand and address their needs while meeting BETO goals

5 – Future Work

Non-WTE Portions of the Project

Publish (with INL) analysis of feedstock effects on fast pyrolysis and upgrading via hydrotreating (submit Q2)

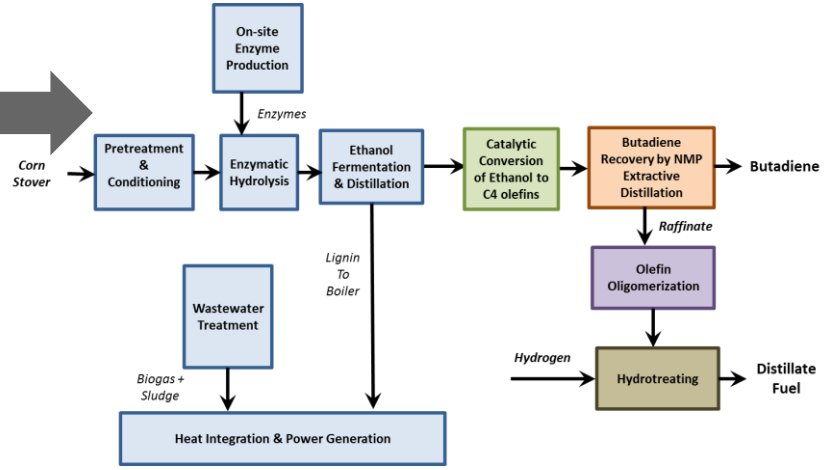




Present TEA of catalyst development for upgrading oxygenated intermediates to fuels and chemicals (AIChE, Q3) & contribute to joint manuscript with researchers

Complete project annual milestone: draft manuscript detailing opportunities for fuels and chemicals from catalytic upgrading of oxygenated intermediates (Q4 FY19)

Provide TEA for the multi-lab Marine Biofuel opportunity assessment



Project Transition: Current merit review period ends 9/30/19

Propose continuation of analysis project for merit review that supports and informs research directed towards BETO's 2022 and 2030 conversion related goals, for example and not limited to:

- Continued analysis support for wet waste HTL
- Cost reduction strategies for current waste problems, such as manure (e.g. wet waste alone or combined with MSW)
- Consideration of regulatory issues, such as how aqueous nitrogen should best be handled in a WWTP
- Scale up implications
- Enhance modeling through further development and use of predictive reaction models
- Seek synergies with related subjects (e.g. Wet Waste HTL, hybrid biochem/thermochem HTL processing, biocrude co-processing in petroleum refineries)

Summary

Guide Research - Track Progress - Reduce Costs

- **Overview:** Cost and performance model development to inform economic and sustainable biofuel production
- **Approach:** closely coupled analysis and research
- **Technical Accomplishments/Progress/Results:**
  - All progress measures and milestones met on time and on budget
  - Identified sustainable cost reduction strategies
  - Enabled impactful, focused research
  - Published results for use by others
  - Analysis covers several conversion methods; presentation focuses on the Wet Waste HTL portion
- **Relevance:** directly supported meeting the BETO 2017 GPRA milestone (LanzaTech/PNNL process) and working towards the 2022 GPRA goal (Wet Waste HTL)
- **Future work:**
  - Prepare merit review proposal to BETO to continue existing work (e.g. wet waste HTL SOT) and enhanced analysis
  - Complete/contribute to 3 journal manuscripts

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Thank you

Acknowledgements

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  - Dr. Yuan Jiang
  - Steven Phillips
  - Dr. Jay Askander
- Experimental Leads
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  - Justin Billing
  - Daniel Anderson
  - Andrew Schmidt
  - Dr. Jon Magnuson
  - Dr. James Collett
  - Alan Zacher
  - Dr. Huamin Wang
  - Robert Dagle

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Additional Slides

- Milestones and Quarterly Progress Measures
- Response to comments from 2017 Review
- Publications and Presentations
- List of Abbreviations
- Non-WTE Analysis Accomplishments/Results

Milestones since FY17 Review

Milestone Name/Description	End Date	Type	On Time?
Complete baseline TEA and projected improvements for conversion of ethanol to C4 linear olefins using a one step process, review results with the researchers for use in the experimental project 2.3.1.304/2.3.1.305 Q2 milestone and summarize in a brief to BETO.	3/31/2017	Quarterly Progress Measure (Regular)	yes
Complete updated fungal biochemical conversion model with the most recent experimental data, including co-product opportunities, review results with researcher and summarize in a draft to BETO that can be submitted to a peer reviewed journal.	6/30/2017	Quarterly Progress Measure (Regular)	yes
Complete (1) draft manuscript of economic and sustainability and sensitivity impacts from fast pyrolysis and upgrading of blended feedstocks for submission to a peer reviewed journal.	6/30/2017	Quarterly Progress Measure (Stretch)	yes
Evaluation of the 2017 LanzaTech demonstration: Produce the SOT for the conversion of syngas fermentation ethanol to jet fuel and 2,3-butanediol to butadiene , based on the experimental data from the demonstration, towards the goal of $3/gge, and the associated GHG reduction. This will be delivered to BETO in the form of a summary report.	9/30/2017	Annual Milestone (Regular)	yes
Task 1: Complete TE analysis of in situ catalytic pyrolysis experimental improvements achieved in FY17 and summarize in a draft to BETO.	12/31/2017	Quarterly Progress Measure (Stretch)	yes
Task 2: Complete analysis in support of determining conversion pathways for experimental project 2.3.1.304 (Liquid Fuels via Upgrading of Indirect Liquefaction Intermediates) that compete favorably against MOGD.	3/31/2018	Quarterly Progress Measure (Regular)	yes
Task 4: Working with NREL, INL and ORNL, complete a tech memo identifying the gaps and opportunities related to meeting a $2/gge fuel cost target.	6/30/2018	Quarterly Progress Measure (Regular)	yes
Task 5: Understanding the economic drivers and potential value propositions for biomass-derived, low sulfur blendstocks will be critical to understand the potential for marine fuel adoption. This techno-economic analysis will work to understand the minimum fuel selling price as well as the cost of end-use of at least 2 biomass-derived blendstocks. The analysis will focus on pathways which show promise to being cost competitive and target pathways of <$2/gge. Additionally, the TEA will outline key cost drivers and uncertainties as well as explore the potential for co-production of renewable fuels with blends of fossil and bio-derived feedstocks.	6/30/2018	Quarterly Progress Measure (Regular)	yes
Task 3: Complete TE analysis showing the impact of research improvements related to yield for L. starkeyi grown on the most current NREL deacetylated hydrolysate and use of HTL and biocrude upgrading to fuels and compare to previous results for clean sugar and “dirty” hydrolysate. Deliver analysis results in a report to BETO that can also serve as a peer reviewed journal draft.	9/30/2018	Annual Milestone (Regular)	yes
Understanding the effects of feedstock composition is necessary towards developing realistic trade-offs with regard to hybrid processing. We will collect and assess available data to allow extending the predictive HTL model to the hybrid routes developed by the bioconversion team, with focus on biocrude quality and upgrading. The intent is to integrate results into existing TEA HTL model for Task 3 to better inform the end of project milestone. The outcomes will be summarized in a brief, including data gaps that might be filled by future research. [Task 4]	12/31/2018	Quarterly Progress Measure (Stretch)	yes
Working with the catalysis research team [2.3.1.304], we will update the oxygenated intermediate models to incorporate current results to help researchers weigh cost tradeoffs between C4 routes to hydrocarbon fuels, with or without co-products. This analysis will assist experimentalists in determining a path forward for this research after their project concludes at the end of FY19. Summarize in a brief, including data gaps and potential opportunities. [Task 2]	3/31/2019	Quarterly Progress Measure (Regular)	
1. For Hybrid Processing, the balance between just enough preprocessing to mono-sugars for fermentation purposes and too much pre-processing that reduces HTL biocrude production must be better understood. Working with the fungal research team [2.3.2.103], and the new seed project “Hybrid Conversion” [2.2.2.501] we will update the biochemical conversion models to incorporate new learnings to assess opportunities for the variations on hybrid processing and summarize in a brief. The intent is to use the most current sugar-based fungal processing data, then look at cost tradeoffs for the extent of pretreatment for sugar production versus feed to HTL. [Task 3]	6/30/2019	Quarterly Progress Measure (Regular)	
2. Clearly defining the economic drivers and potential value propositions for biomass-derived, low sulfur blendstocks will be critical to understand the potential for marine fuel adoption. NREL and PNNL will continue to explore the economic potential of bio-derived marine fuels by updating economic evaluations developed in FY18 as well as developing TEA for at least 2 additional identified biomass-derived marine blendstocks pathway. We will outline key cost drivers and uncertainties as well as explore the potential for co-production of renewable fuels with blends of fossil and bio-derived feedstocks. Deliverable – Q3. [Task 5]			
Tracking progress towards out-year goals is a key analysis outcome for this task. The wet waste HTL SOT annual update will be completed using FY19 data from the PNNL Hydrothermal PDU project (WBS TBD). The annual SOT analysis is BETO’s primary tool with which the experimental and analysis teams work side-by-side to define the target-enabling research and to drive progress towards that target. A life cycle inventory from the SOT analysis will be sent to ANL for their SCSA to determine GHG emissions and water consumption metrics for the pathway. A summary report in the form of a publication draft describing the experimental basis for the SOT and the resultant analysis will be sent to BETO for inclusion in the MYPP. [Task 6]	6/30/2019	Annual Milestone (Regular)	
Identifying and disseminating data regarding viable routes to economic production of biofuels and chemicals is needed to advance the bioeconomy. We will complete a TE and sustainability analysis draft manuscript summarizing the conversion costs for at least 3 pathways developed under this project for submission to a peer reviewed journal. The focus will be on upgrading oxygenated intermediates from biochemical and thermochemical conversion pathways to chemicals and fuels that could lead to production costs < $3/gge and will serve as a summary comparison of TEA related to BETO supported conversion work associated with BC and TC pathways. Publication is targeted for FY20. [Task 2 and 3, End of year]	9/30/2019	Annual Milestone (Regular)	

Response to Previous Reviewers' Comments

Feedback:

- ..team demonstrated solid organization both at working and management levels…no indication of weakness…well-oiled machine.
- Overall strong project with very positive impact for the biofuel community…concerned that results may be taken too literally…allowing public access to spreadsheets would be a great addition.
- ..excellent project that is/will…provide guidance for overcoming cost barriers
- Well planned and executed project. Key challenge is ensuring models are used consistently to guide decision making in support of technical project and DOE objectives.

Response: We agree that although nth plant analysis assists research focus at the laboratories, the commercial maturity level can be misunderstood. While this is addressed in the design reports and emphasized in presentations, the need to understand the cost implications for 1st of a kind plants should be clarified and perhaps could best be handled through public-private presentations. While model maintenance for public use in not funded within this project, we do share information with stakeholders when appropriate.

Publications (since FY17 Review)

1. A Hybrid Catalytic Route to Fuels from Biomass Syngas" LanzaTech DE-EE0005356. https://www.osti.gov/servlets/purl/1423741
2. Butcher M.G., P.A. Meyer, R.T. Hallen, K.O. Albrecht, C.K. Clayton, E. Polikarpov, and K.G. Rappe, et al. 2018. "Fungal Metabolites as Precursors to Renewable Transportation Fuels." *Fuel* 215. PNNL-SA-126614. doi:10.1016/j.fuel.2017.10.052
3. James R. Collett, Justin Billing, Pimphan Meyer, Andrew Schmidt, Brook Remington, Erik Hawley, Beth Hofstad, Ellen Panisko, Ziyu Dai, Todd Hart, Daniel Santosa, Jon Magnuson, Richard Hallen, Susanne Jones. 2019. "Carbon Efficient Renewable Diesel via Combined Liquefaction of Lignin and Oleaginous Yeast: Experimental and Techno-Economic Assessment" *Applied Energy* 233-234: 840-853
4. Kass, M., A. Abdullah, M. Biddy, C. Drennan, T. Hawkins, S. Jones, J. Holladay, D. Longman, E. Newes, T. Theiss, T. Thompson, M. Wang. 2019. "Understanding the Opportunities of Biofuels for Marine Shipping" ORNL/TM-2018/1080, PNNL-28336
5. Supply Chain Sustainability Analysis of Renewable Hydrocarbon Fuels via Indirect Liquefaction, Fast Pyrolysis, and Hydrothermal Liquefaction: Update of the 2016 State-of-Technology Cases and Design Cases, February 2017. https://www.osti.gov/src/biblio/1346567/?title=supply%20chain%20sustainability%20analysis&page=5
6. Supply Chain Sustainability Analysis of Renewable Hydrocarbon Fuels via Indirect Liquefaction, Ex Situ Catalytic Fast Pyrolysis, Hydrothermal Liquefaction, Combined Algal Processing, and Biochemical Conversion: Update of the 2018 State-of-Technology Cases and Design Cases, draft ANL report.
7. Weber R.S., J.E. Holladay, C. Jenks, E.A. Panisko, L.J. Snowden-Swan, M. Ramirez-Corresdores, B. Baynes, D, Boysen. 2018. "Modularized Production of Value-Added Products and Fuels from Distributed, Waste Carbon-rich feedstocks." Wiley Interdisciplinary Reviews: *Energy and Environment* 7, no. 6:e308. PNNL-SA-131136. doi:10.1002/wene.308
8. Jiang Y., S.B. Jones, Y. Zhu, L.J. Snowden-Swan, A.J. Schmidt, J.M. Billing, and D.B. Anderson. 2018. "Techno-Economic Uncertainty Quantification of Algal-derived Biocrude via Hydrothermal Liquefaction." Algal Research. PNNL-SA-138139. [submitted]
9. Zacher A.H., D.C. Elliott, M.V. Olarte, H. Wang, S.B. Jones, and P.A. Meyer. 2018. "Technology Advancements in Hydroprocessing of Bio-oils." *Biomass & Bioenergy*. PNNL-SA-138596. [submitted]
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Abbreviations and Acronyms

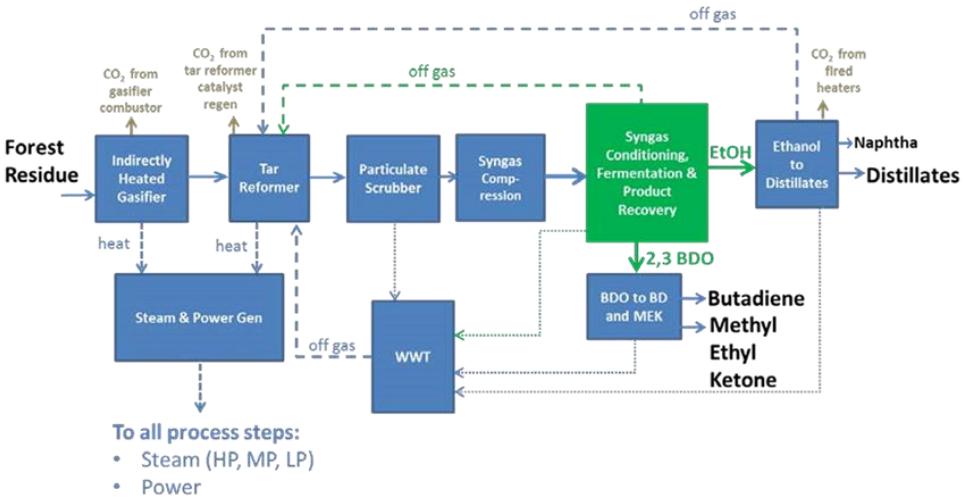
- A&S: Analysis & Sustainability
- ANL Argonne National Laboratory
- AOP: Annual Operating Plan
- BC: Biochemical Conversion
- BETO: Bioenergy Technologies Office
- DMC: Bunker C Fuel
- DMR: Deacetylated and Mechanical Refining
- DPO: Deoxygenated Pyrolysis Oil
- FPO: Fast Pyrolysis Oil
- GGE: Gasoline Gallon Equivalent
- GPRA: Government Project Reporting Act
- HTL: Hydrothermal Liquefaction
- INL: Idaho National Laboratory
- LCA: Life-Cycle Analysis
- MARAD: Maritime Administration (Dept. Transportation)
- MEK: Methyl Ethyl Ketone
- MFSP: Minimum Fuel Selling Price
- MYP: Multi-Year Plan (FY19)
- MYPP: Multi-Year Program Plan (prior to FY19)
- NREL: National Renewable Energy Laboratory
- ORNL: Oak Ridge National Laboratory
- PDU: Process Development Unit
- PMP: Project Management Plan
- PNNL: Pacific Northwest National Laboratory
- SCSA: Supply Chain Sustainability Analysis
- SOT: State of Research Technology
- TAN: Total Acid Number
- TC: Thermochemical Conversion
- TEA: Techno-Economic Analysis

3 – Technical Accomplishments/Progress/Results
Task: Indirect Liquefaction

Assessing Fuel/Co-Product trade-offs for a Hybrid Processing Scheme

BASIS: Demonstrated results from BETO funded project**

- **LanzaTech** syngas fermentation to ethanol and 2,3-butanediol (BDO)
- **PNNL** catalytic conversion of ethanol to distillates & BDO to chemicals
- *Modeled in context of waste wood biomass gasification*



Key Analysis Results

- Multiple production combinations allow meeting a mature modeled price of $3/gge (2014 USD cost year)
- Economics strongly dependent on the co-product yield and value
- Multiple co-products allows production flexibility

Jet Fuel made by the LanzaTech/PNNL process from waste gases used in October 2018 Virgin Airlines trans-Atlantic flight

For this jet production run, the waste gas source was waste steel mill off-gas

** A Hybrid Catalytic Route to Fuels from Biomass Syngas" LanzaTech DE-EE0005356. https://www.osti.gov/servlets/purl/1423741

3 – Technical Accomplishments/Progress/Results
Task: Biochemical Conversion

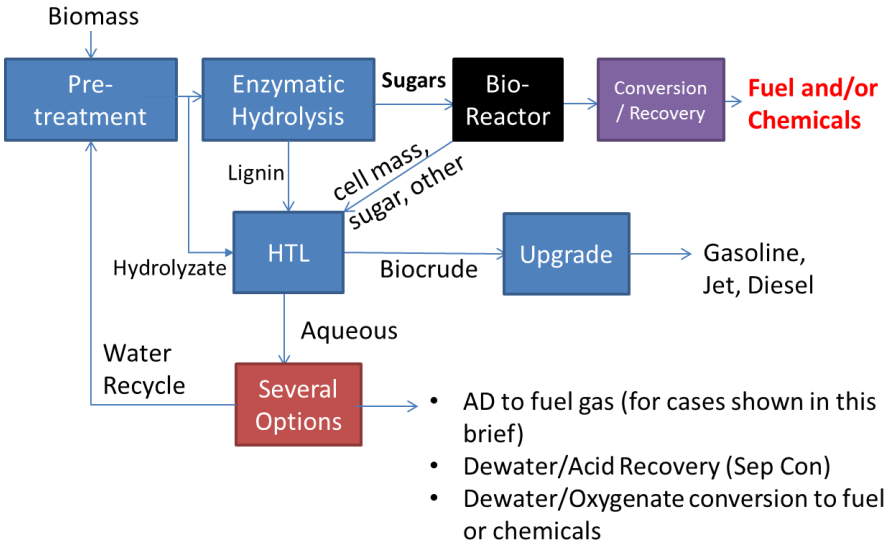
Strategies to address BETO new out-year goals beyond 2022 (Project GO/NO-GO)

Go/No-Go Criteria

"Develop TEA for at least one pathway via BC, TC or hybrid processing that reduces the MFSP at or below $2.50/gge"

Basis

2016 cost year, feedstock at $84/dry ton and 2000 mtpd plant scale)



Hybrid Biological/Thermochemical Route

- HTL reactor converts lignin and bioreactor solids to biocrude that is hydrotreated then distilled into fuel
- The bioreactor produces a C4 organic acid (e.g. maleic, fumaric, succinic) that can serve as a platform chemical for large market C4 chemicals (e.g. butanediol, butadiene, butene)

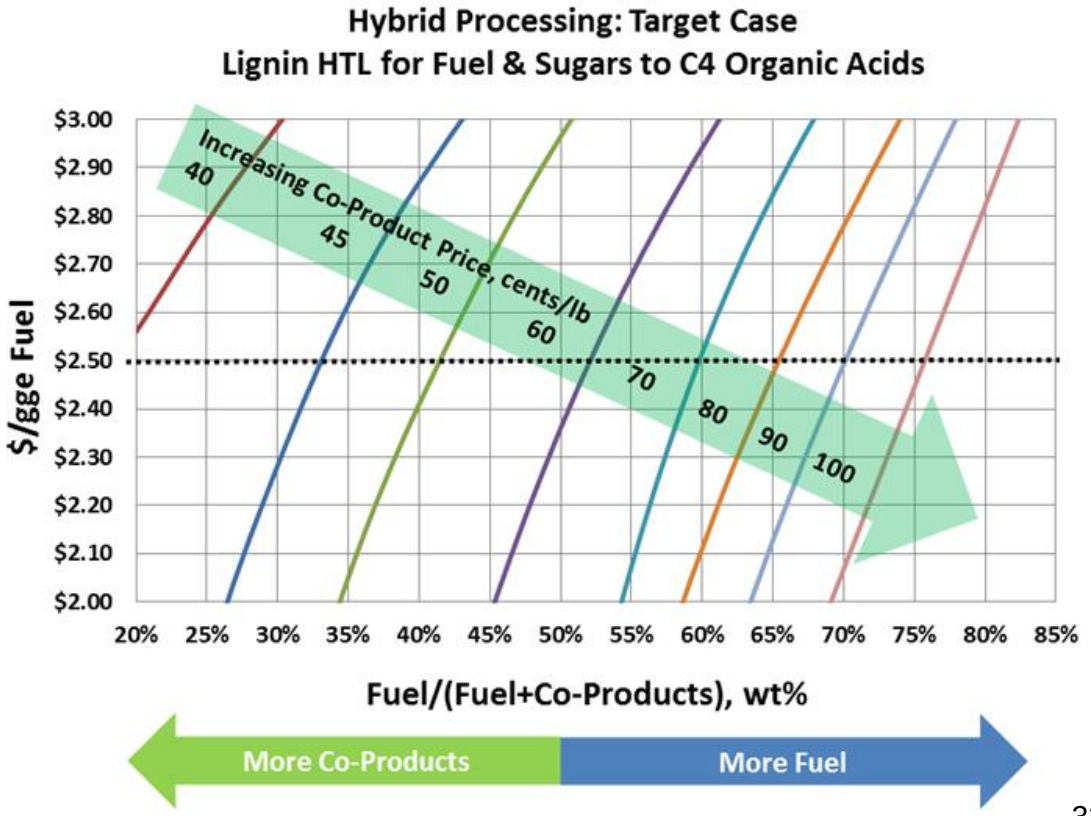
3 – Technical Accomplishments/Progress/Results
Task: Biochemical Conversion

GO/NO-GO, continued

Processing advantage: couples highly selectivity biological processing for chemical production with HTL (highly tolerant to feedstock variability) to produce conventional gasoline and diesel

Key BETO Outcome

- Directly relevant to FY18 multi-lab effort to assist BETO with crafting new BETO targets beyond 2022
- Assists PNNL fungal processing and catalysis teams with research directions and goal setting
- Target case shown at right, conservative case also estimated

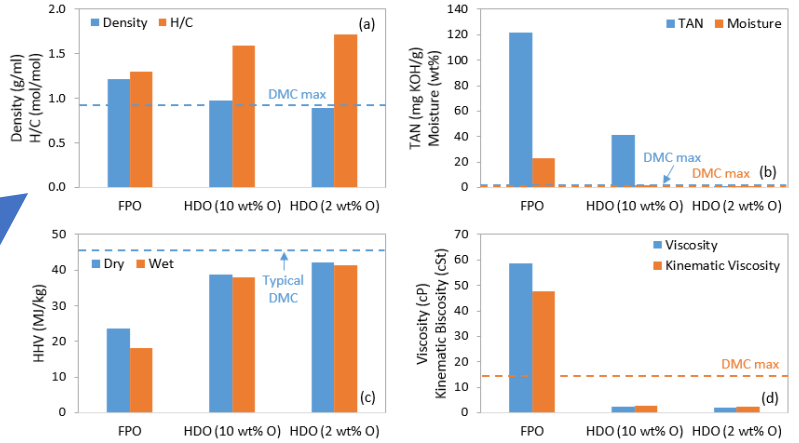


3 – Technical Accomplishments/Progress/Results
Task: Marine Biofuels

Joint Analysis with Other Labs: Low Sulfur Fuel Production for Marine Applications

Goal: assess how biofuels could contribute to meeting low sulfur marine fuel 2020 requirements, and to potential future GHG requirements

- *FY18: Initial joint analysis report to BETO (with NREL and ORNL)*
  - *PNNL assessed pyrolysis bio-oil suitability*
  - *Property comparisons & blend effects*
  - *Preliminary cost estimate*
- FY19 contributed to multi-party white paper BETO, MARAD, ORNL (lead), ANL, NREL, PNNL



Addresses BETO's interest in "identifying new market opportunities:….such as aviation and marine"

3 – Technical Accomplishments/Progress/Results

Enhancing Analysis Capabilities for Improved Estimations - Uncertainty Analysis

Goal: develop methodology to assess impact of analysis uncertainty on the estimated cost of fuel production

Solution:

- Methodology developed in this project
- Used the predictive HTL model based on feedstock characteristics
- Uncertainty method applicable to any model
- HTL predictive model based on algae HTL, and is applicable to wet waste HTL and to hybrid HTL (with the addition of a lignin component)
- Applied so far only to cost of producing biocrude, next need to add upgrading