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DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

1.3.4.101 Thermochemical Interface

March 4, 2019

Technology Session Area Review: Conversion/Waste-to-Energy

Principal Investigator: Dan Anderson

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Goal Statement

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Cost Effective Fuel Production from Algae is Challenging
Fully Integrated Processing is Required

Goal:

Develop fully integrated HTL process for algae conversion to produce fuel blendstocks and co-products that meet BETO's strategic goals and cost targets

Directly supports BETO's mission "By 2030, deliver technologies that can enable the verification of technical performance of algae cultivation, harvesting, and conversion processes at engineering scale capable of converting algal feedstocks to biofuels and bioproducts in support of BETO's goals for mature modeled MFSP of $2.5/GGE for biofuels"

Quad Chart Overview

Timeline
- Project start date: October 1, 2014
- Project end date: September 30, 2020
- Percent complete: 20% FY19

	Total Costs Pre FY17**	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded				
R&D Program	$3,114,496	$1,005,285	$924,765	$1,500,000
Engineering Scale HTL Capability**	$1,158,218	$335,563		
Total	$4,272,741	$1,340,848	$924,765	$1,500,000

** Combined with $1,997,837 Capital Funds from Conversion

Partners: **NA**

Barriers addressed
- Aft-H. Overall Integration and Scale-Up
  - Process integration (HTL, Upgrading, Recycle), TEA; Engr. Scale HTP system being tested
- Aft-J. Resource Recapture and Recycle
  - Aggressively demonstrating reuse of HTL byproduct stream

Objective
Develop processing methods for the algae hydrothermal liquefaction (HTL) pathway including, HTL processing (with feedstock blending and sequential extraction), pretreatment of biocrude and upgrading to fuel blendstocks with water and nutrient recovery/recycle from HTL byproduct streams.

End of Project Goal
Reduce overall conversion cost of algal feedstocks, improve sustainability by reducing green-house-gas emissions to make finished hydrocarbon fuel supporting BETO's strategic goals.

1 - Project Overview

Project History

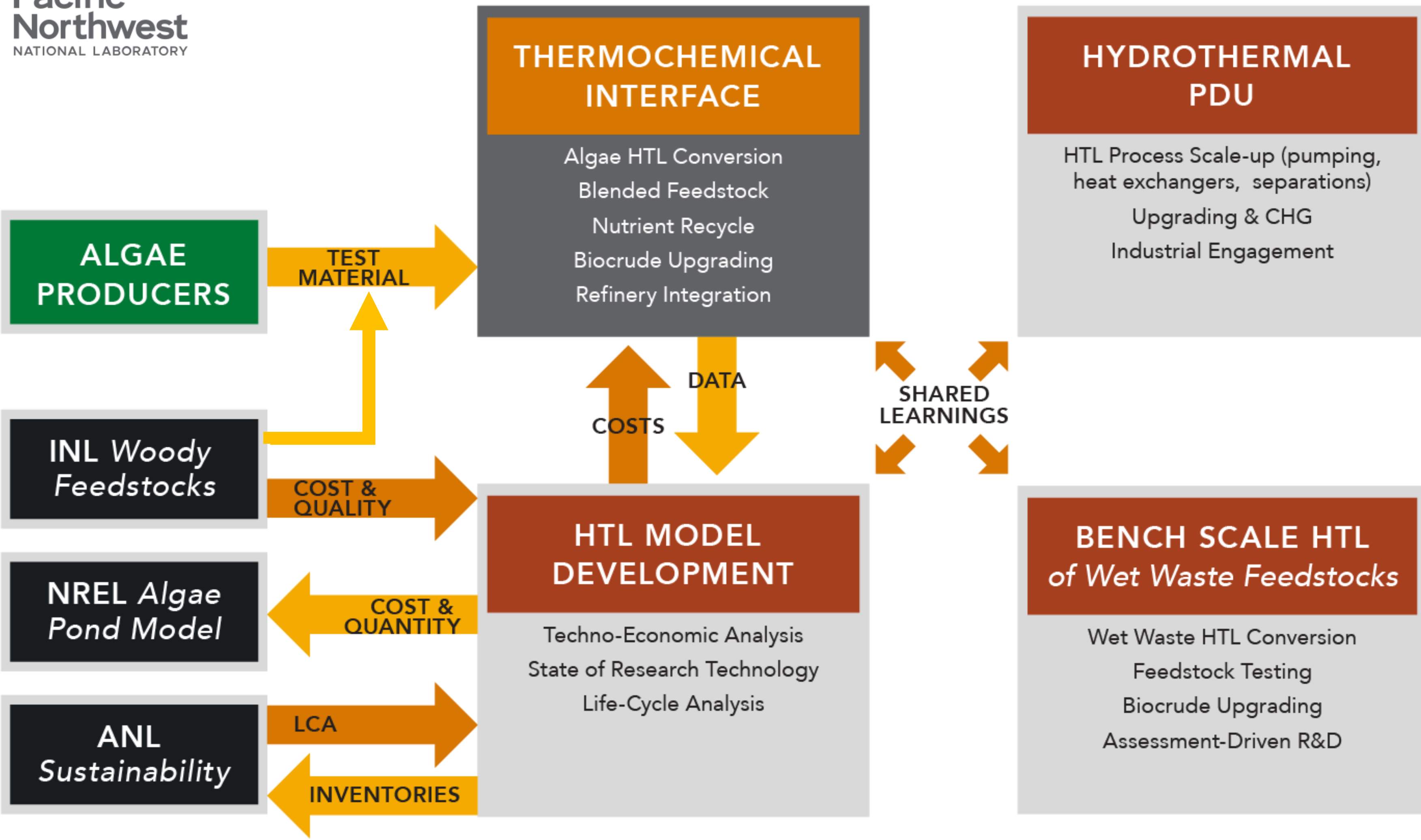
- FY10-13: Algal HTL process first tested as part of the National Alliance of Advanced Biofuels and Bioproducts (NAABB)
  - FY13: Genesis of Thermochemical Interface project was started to wrap up NAABB algae HTL experiments

- FY14-17: Thermochemical Interface project focused on algae HTL pathway
  - Thermochemical Interface Project conducted process R&D and developed HTL pathway *Design Report* published in FY14 that outlined cost reduction targets for the 2022 timeframe
  - SOT was developed and updated to guide R&D efforts to drive down conversion cost
  - Project collaborated with Conversion Program to develop engineering scale HTL capability at PNNL for process scale –up
  - Project passed merit review for the FY17-19 time frame

- FY18: Project budget reduced by ~30%
  - Modeling component Algae HTL Analysis moved in to a separate AOP Project
  - Focused R&D continued for critical elements of algal HTL pathway

- FY19: Updated AOP approved for continuing focused R&D
  - All scale-up work moved to ADO

2 – Approach (Management)



Thermochemical Interface Project Integrated with Modeling and Other Related Projects to Advance Overall HTL Conversion Process

2 – Approach (Technical) FY18-20

Tasks	Challenges	Technical Objectives
HTL Process R&D	Improved HTL Capacity/Capital Cost	Sequential HTL (Higher solids, improved composition, co-product potential
		Evaluate Blended Feedstocks (Cost, scale and capacity)
	Improved Biocrude Yield & Quality	Improve Separations (solids/liquids and liquid/liquid)
		Understanding Conversion Kinetics and Develop Yield Model
		Use of blended feedstocks (wet wastes/lignocellulosics)
Upgrading R&D	Distributed Small–scale Upgrading Process for HTL Biocrude	Preprocessing to Clean-up Biocrude
		Catalyst and Process Development for Biorefinery
		Improved LHSV and Reactor Configuration
	Fuel Production and Testing	Fuel Blendstock Characterization and Engine Testing
		Co-processing Options with Improved Biocrude
Nutrient Recycle	Recycle and Reuse HTL Waste Streams	Direct recycle to Algae Ponds
		HTL filter solids reuse (P and other minerals)
		Complete media and nutrient recycle (Carbon, N, P and Minerals)
Provide Process Data	Process Models, TEA and LCA	Update Process Models, TEA and LCA
		SOT Updates/Pathway Options Analysis
		Adjust R&D Focus

3 – Technical Accomplishments/ Progress/Results
HTL Processing Algae/Wood Blended Feedstocks

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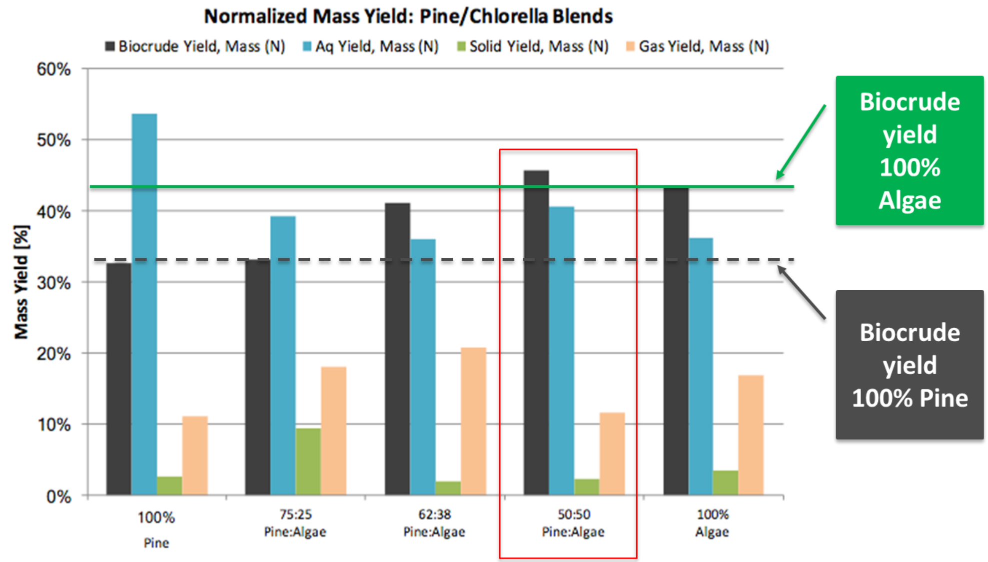
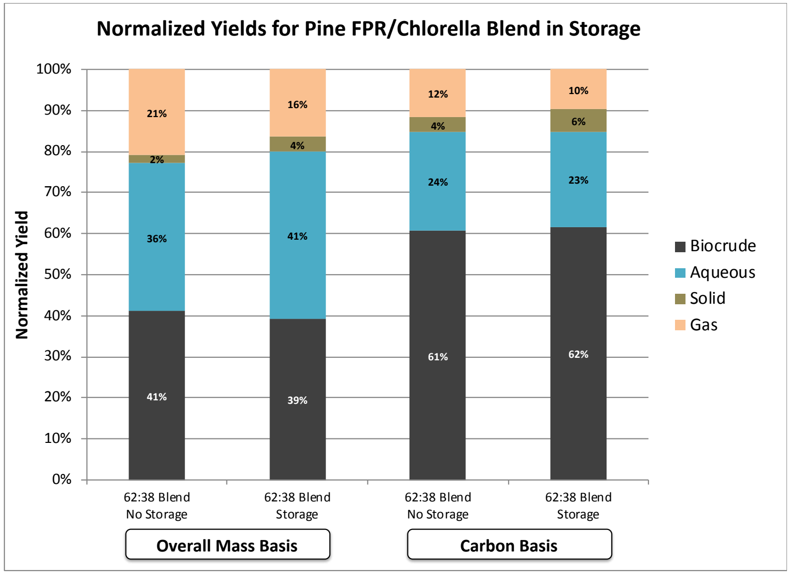
FY18 Milestone

Tested wood: algae storage blend prepared by INL's silage method. Results indicate method does not adversely impact HTL operations

- Feedstock blends can level out seasonal changes in algae productivity
- Algae/wood blends provide synergistic biocrude yield effects
- Biocrude from blended feedstocks were upgraded to fuel blendstocks and used for engine testing

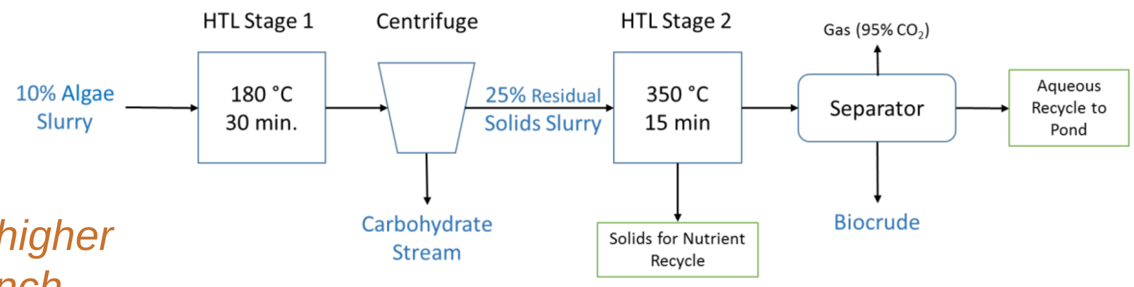


Synergistic Yield with HTL Processing of Algae:Wood Blends



HTL Processing Comparison of Fresh vs. Storage Blend

3 – Technical Accomplishments/ Progress/Results
HTL Processing (Sequential HTL Testing)

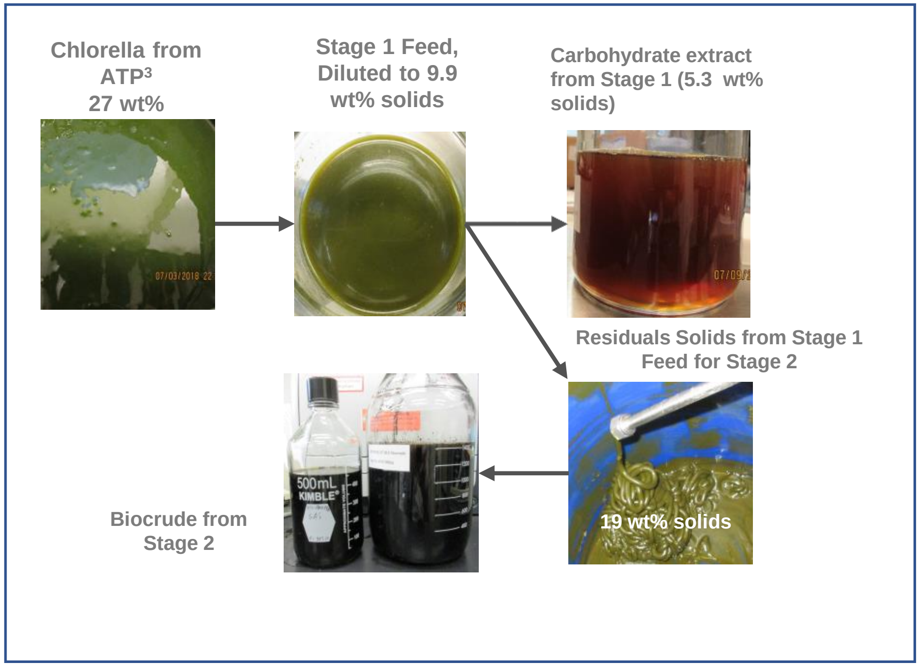


General Process Flow Diagram

FY18 Milestone and Go/No-Go

Demonstrated the potential for 25% higher throughput for HTL conversion at bench scale

- Stage 1 Extraction
  - Yields usable sugars for co-product production
  - Provides improved residual biomass for fuel conversion
- Stage 2 Conversion
  - Results in higher biocrude yields and quality from higher solids feed, lower ash and carbohydrates
- Sequential HTL Processing Progress
  - Technical feasibility proven
  - Modeling underway to determine economic and LCA benefits



Material Flow in Sequential HTL

3 – Technical Accomplishments/ Progress/Results Upgrading to Fuel Blendstocks

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FY18 Milestone

Surpassed 0.45 LHSV using pre-treatment and improved catalyst

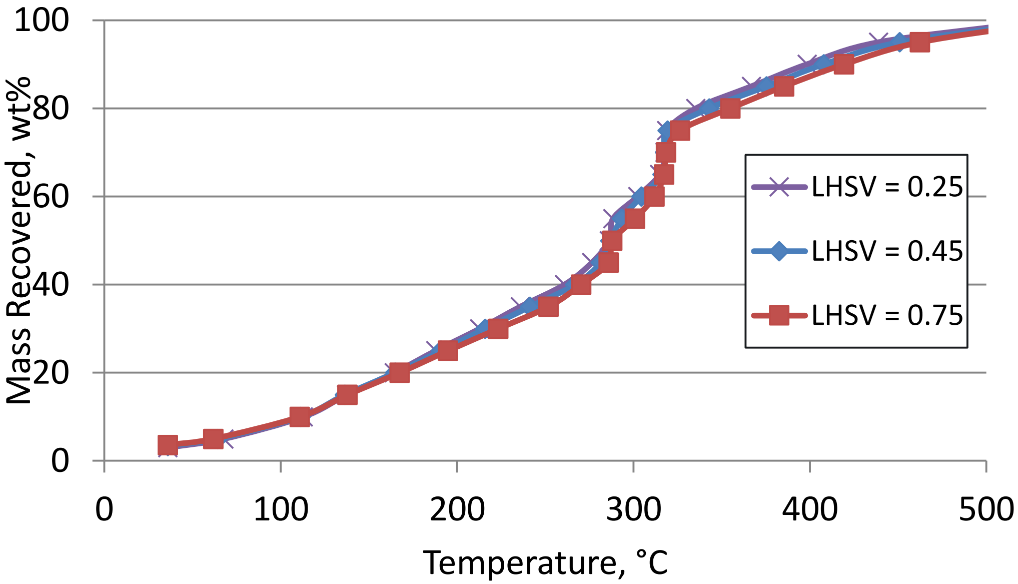
FY18 Go/No-Go

Demonstrated > 200hrs TOS

- Pre-treatment methods developed for iron, silica and water removal
- Demonstrated fuel quality for distillates as function of LHSV
- Completed detailed characterization of diesel fuel blendstocks
- Completed engine testing of 5% blends with diesel meeting all criteria

LHSV (L feed/L catalyst/h)	0.25	0.45	0.75
Density (g/cm3 @20°C)	0.7937	0.7955	0.8007
Viscosity (cSt @20°C)	3.07	3.58	3.54
Total Mass Balance (%)	95.98	98.80	101.09
Yield to Organic (g/g dry biocrude)	**0.87**	**0.89**	**0.90**

Improved NiMo Catalyst for Hydrotreating Pretreated Chlorella (MHTLS-03) Biocrude



Simulated distillation of upgraded Chlorella biocrude as a function of LHSV.

3 – Technical Accomplishments/ Progress/Results
HTL Waste/Nutrient Recycle

FY18 Milestone and Go/No-go

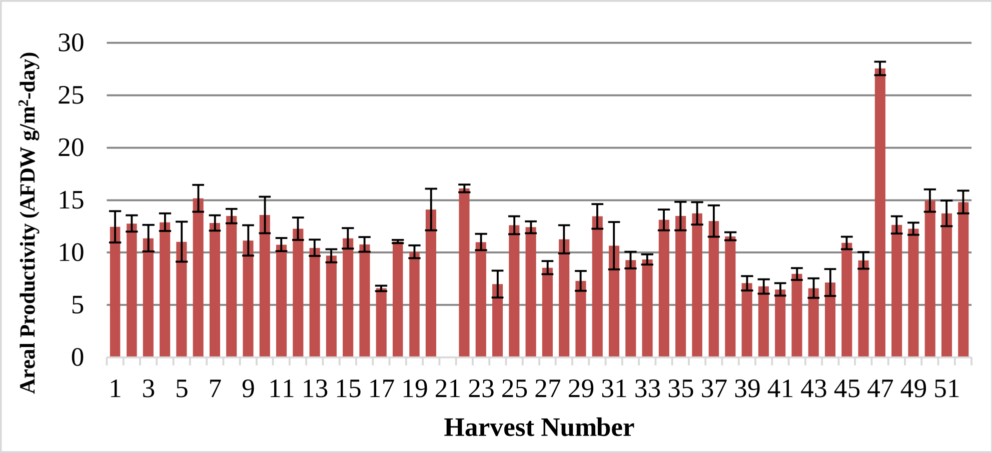
51 cultivation cycles conducted with Chlorella using complete media recycle and HTL derived nutrients

FY19 Milestone

2 additional strains showed exceptional tolerance and high productivity without any adaptation

- Demonstrated algae cultivation on HTL aqueous and filter solids waste stream
  - N, P and organic carbon provide 100% of nutrients for alga cultivation
  - Eliminates need for treatment HTL aqueous phase
- Expanding HTL nutrient recycling to 10 additional algal strains

Complete Media Recycle Using HTL Derived Nutrients



Initial Strain Screening Using HTL Derived Nutrients

Strain (Genus species)	Relative HTL Tolerance
Chlorella sorokiniana DOE1412.HTL	113.0
Nannochloropsis oceanica CCAP849/10	108.5
Tetraselmis sp. (LANL isolate)	87.0
Stichococcus minor CCMP819	41.6
Chlorella vulgaris LRB-AZ1201	27.2
Nannochloris sp. NREL39-A8	20.7
Acutodesmus obliquus UTEX393	17.4
Choelastrella sp. DOE0202	14.9
Scenedesmus sp. NREL46B-D3	3.5
Monoraphidium minutum 26B-AM	3.4
Tisochrysis lutea CCMP1324	2.4

3 – Technical Accomplishments/ Progress/Results
HTL Engineering Scale-up/Verification

FY18 Milestone

Verified engineering scale performance by comparing biocrude yield and process stability metrics

- Commissioned MHTLS
  - System approved for routine R&D operation
- Conducted 3 engineering scale HTL campaigns (2) algae feedstocks and (1) wood: algae blend
  - 130 hours TOS
  - Produced of 120 liters of biocrude
- Product Disposition
  - Biocrude: Upgraded, fractionated, engine testing fuel blendstock
  - Aqueous byproduct: Provided for nutrient recycle, co-product recovery
  - Blowdown solids (mostly ash): Extracted provided (P) for nutrient

Modular Hydrothermal Liquefaction System (MHTLS)

Skid 1 Hockmeyer Wet Mill

3 – Technical Accomplishments/ Progress/Results
HTL Process Model, TEA/LCA, and SOT

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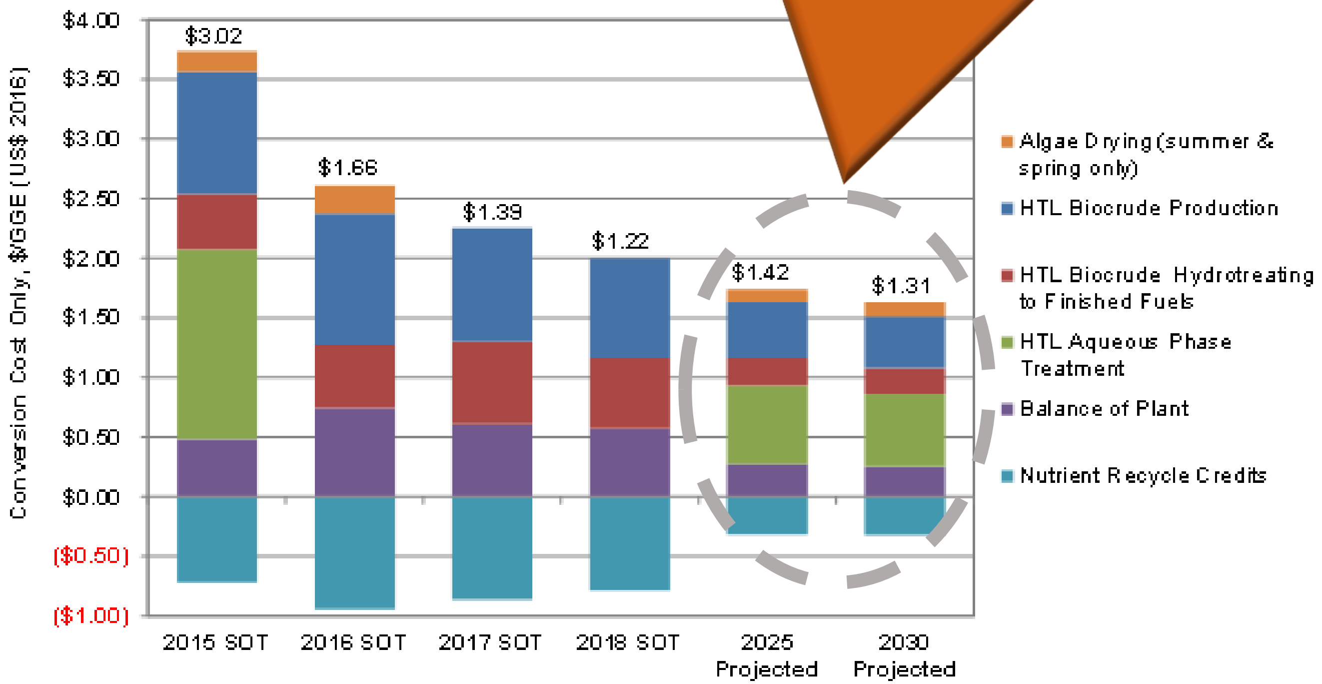
Annual State of Research Technology (SOT)

FY18 Joint Milestone

Updated process models and TEA for algae HTL and upgrading process improvements

- Biomass production costs for algal growth, harvest and dewatering are from the NREL pond model
- Biomass conversion costs are based on this PNNL research into HTL conversion, biocrude upgrading, and HTL aqueous testing

- Out-year cost targets from the HTL Design Case published in 2014 **have already been met**
- A new design case outlining strategies for additional cost reductions slated for FY20 publication

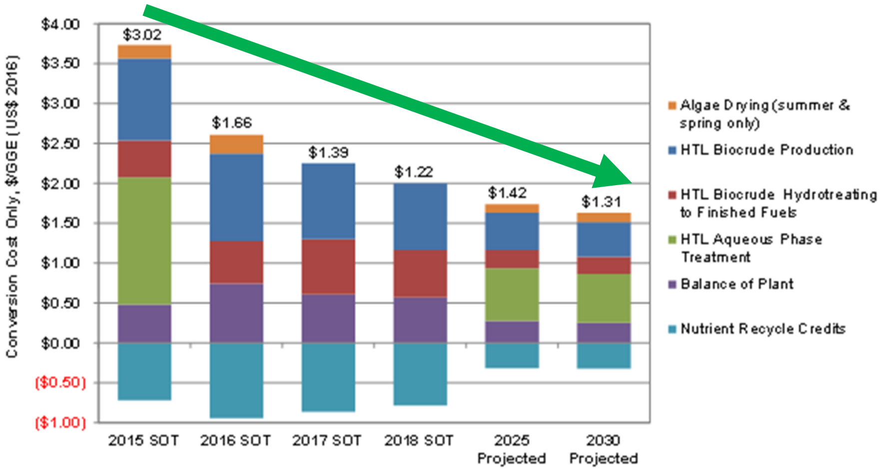


4 – Relevance

Reduce conversion cost, improve sustainability and enable commercialization of algal biofuels

Directly supports BETO's mission "By 2030, deliver technologies that can enable the verification of technical performance of algae cultivation, harvesting, and conversion processes at engineering scale capable of converting algal feedstocks to biofuels and bioproducts in support of BETO's goals for mature modeled MFSP of $2.5/GGE for biofuels"

- HTL pathway R&D focus and cost targets identified and driven by SOT
  - *Developing new enabling technology for critical elements (HTL, Upgrading and HTL waste)*
  - *Project is successfully driving down conversion costs below project targets*



5 – Future Work

WBS/Schedule Aligned with SOT Targets

Tasks	Needs Identification Technical Basis	FY-2018 / FY-2019 / FY-2020
Task 1 **HTL Process R&D**		
Task 1.1 Sequential HTL	**SOT Targets** 25% higher throughput Enable co-product	Optimize Stage 1 Carbohydrate Extraction/Residual Biomass Recovery; Integrated Stage 1 and Stage 2 Conversion Testing
Task 1.2 HTL Kinetic Models	Determine feedstock compositional impacts on conversion	Bench HTL Tests with Spiked Feedstocks for Compositional Impact
Task 1.3 Active Oil/Water Separations	**SOT Targets** 10% higher biocrude recovery	Testing Active Oil/Water Separations
Task 2 Biocrude Upgrading	**SOT Targets** LHSV, Catalyst Life, Smaller Scale HT, Fuel Blendstocks	Biocrude Pretreatment Development and Testing; Biocrude Hydrotreating Development and Testing; Fuel Blendstock Characterization and Engine Testing
Task 3 HTL Aqueous & Nutrient Recycle	**SOT Targets** Complete nutrient and media recycle, applicable to multiple strains	Test HTL Derived Nutrients with Continuous Recycle; Expanded HTL Recycle Testing with DISCOVR Strains
		Go/No Go Meet HTL SOT Conversion Targets (HTL 25% higher throughput, HT LHSV =.45, aqueous nutrient recycle)
Task 4** **HTL Engineering Scale-up/Verification**	Commission MHTLS, Verify Performance at Engineering Scale	Conduct MHTLS Run (Wood/Algae)
		Provide Data to Update Process Models, SOT, TEA and LCA

**** All engineering scale-up activities (Task 4) moved to new PDU AOP in FY19**

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5 – Future Work
FY19 Milestones

Nutrient Recycle

Identify 2 additional HTL-tolerant algae strains from the Algae DISCOVR project. (QPM-R)

HTL Processing

Demonstrate sequential HTL process methods with efficient carbohydrate extraction and residual solids concentrations of 20% for HTL conversion (QPM-R)

Upgrading

Complete >200 hour hydrotreater run of a blended feedstock biocrude produced using recently developed pretreatment processes at a 50% higher space velocity than previous blended feedstock runs. (QPM-R)

Nutrient Recycle

Quantify productivities of one DISCOVR HTL-tolerant strain and compare to Chlorella baseline data. Test 2 new HTL aqueous waste streams. (AM-S)

HTL Processing

Demonstrate an improvement in biocrude recovery via tighter temperature control in the PFR or by employing an active oil/water separation system. (QPM-R)

Modeling/TEA/LCA

Complete updated process models and TEA for Algae HTL and HT process improvements including the MHTLS run data from FY19. Summarize the supporting experimental information and TEA results in a brief. (AM-R)

Q1 | Q2 | Q3 | Q4 | FY20

16

Summary

- **Relevance**: Project directly contributes to meeting the goals and objectives of BETO's Advanced Algal Systems R&D (HTL Pathway)
  - Many shared learnings and capabilities with Waste to Energy
- **Approach**: HTL pathway process development and scale-up base on process modeling and SOT technical and cost targets
- **Technical Accomplishments:** Significant advancements made in HTL processing, nutrient recovery/recycle, upgrading/fuel characterization and process scale-up
- **Future Work:** The project will conduct targeted research in FY19-20 based on SOT targets to continue to reduce HTL conversion cost and enable alga biofuels production
- **Success Factors and Challenges:** The critical success factors and challenges for the project have been identified and are being addressed
- **Technology Transfer:** The project is actively supporting technology transfer to industry through collaborations, IP development and licensing, publications and presentations. Received FLC Award and R&D 100 Award in 2015. Industrial collaborations underway

Thank you

Acknowledgements

- Daniel Fishman - BETO Technology Manager
- Mark Philbrick - Waste-to-Energy Coordinator
- Thermochemical Interface Team
  - Dan Anderson
  - Andy Schmidt
  - Justin Billings
  - Todd Hart
  - Rich Hallen
  - Scott Edmundson
  - Heather Job
  - Sue Jones
  - Yunhua Zhu

Additional Slides

- Spare Information
- Responses to Previous Reviewers' Comments
- Recent Publications
- Past Publications
- Recent Presentations
- past Presentations
- Patents, Awards, and Commercialization

2 – Approach (Management)

- **Critical Success Factors**
  - Process and Project Integration
  - Decreasing HTL Conversion/Upgrading Costs
  - Fuel Blendstock Validation
  - Aqueous & Solids Phase Nutrient Recycle
- **Top Potential Challenges**
  - HTL Capital Costs
  - Biocrude Refining/Refinery Integration
- **PM Approach**
  - Regular Milestones (1/Quarter) and Deliverables, Data Input for Process Model and Validation of SOT Technical Targets
  - Go/No Go Decision Points based SOT
  - Regular Meetings with BETO and TEA Team
  - Management and Integration of Supporting Projects and Partners, including Algae Producers

2 – Approach (Management)

Integration and Leveraging Related Projects

- 1.3.5.202 HTL Model Development
  - (Algal HTL Process Model, TEA, LCA and SOT)
- 1.3.2.501 Algae DISCOVR Project
  - (New Algal Feedstocks/Nutrient recycling)
- 1.3.3.100 Algal Feedstock Logistics
  - (Blended Algae Feedstock/Storage Blends)
- 1.3.5.302 PACE
  - (Sequential Algae HTL Processing)
- 2.1.0.113 Waste-to-Energy: Feedstock Evaluation and Biofuels Production
  - (Targeted Feedstock Blending)
- 2.2.2.301 PNNL Hydrothermal Process Development Units (PDU)
  - (HTL/HT Processing and Scale-up)
- 2.2.2.302 Benchscale HTL of Wet Wastes
  - (HTL/HT Processing)
- 2.3.1.310 Recovering and Upgrading Biogenic Carbon in Biomass-Derived Aqueous Streams
  - (Co-product Potential)
- 2.4.2.302 Strategies for Co-processing in Refineries
  - (Upgrading/Fuel Production)
- 2.1.0.301, Analysis and Sustainability Interface for HTL

4 – Relevance
Enabling Technology Commercialization

- **Project is supporting technology transfer**
  - *Project has resulted new IP*
  - *2015 FLC Award, 2015 R&D100 Award*
  - *Establishment of engineering scale HTL capability*
  - *Multiple collaborations with industrial partners and BETO IBRs*
  - *Extension of technology to other wet wastes and pilot projects (HYPOWERS Sewage Sludge)*
- **Project is leveraging synergies and providing integration and support to other projects**
  - *Algae, Feedstock Logistics, Conversion, Co-processing, Waste to Energy, Industrial collaboration*
- **Project has already contributed to multiple publications and invited presentations**

Responses to Previous Reviewers' Comments
2017 Peer Review Report

Reviewer Comment

I think the TEA of this project would benefit greatly by including a reputable member of industry practiced in upgrading oils to make them suitable as a refinery feedstock. The industry partner should advise on the cost of upgrading (including the removal of metals) the different oils generated by different HTL operating conditions to make them acceptable to a refiner and at what discount the refiner would want in order to take the oils.

PNNL Response

Thank you for your review and insights. This is an excellent suggestion and is the basis for future planned work through a new NREL-PNNL experimental project aimed at understanding the requirements needed for petroleum refinery acceptance. Key to this effort will be assistance from refining experts.

Recent Publications

- Pegallapati, AK, J Dunn, E. Frank, S. Jones, Y Zhu, L Snowden-Swan, R Davis, C Kinchin. April 2015. Supply Chain Sustainability Analysis of Whole Algae Hydrothermal Liquefaction and Upgrading. ANL/ESD—13/8 https://www.osti.gov/src/details.jsp?query_id=1&Page=0&osti_id=1183770
- Davis R., A. Coleman, M.S. Wigmosta, J. Markham, Y. Zhu, S.B. Jones, and J. Han, et al. 2018. *2017 Algae Harmonization Study: Evaluating the Potential for Future Algal Biofuel Costs, Sustainability, and Resource Assessment from Harmonized Modeling*. PNNL-27547. Richland, WA: Pacific Northwest National Laboratory
- Zhu Y., S.B. Jones, and D.B. Anderson. 2018. *Algae Farm Cost Model: Considerations for Photobioreactors*. PNNL-28201. Richland, WA: Pacific Northwest National Laboratory.
- 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]
- Zhu Y., S.B. Jones, A.J. Schmidt, K.O. Albrecht, S.J. Edmundson, and D.B. Anderson. 2018. "Techno-Economic Analysis of Alternative Aqueous Phase Treatment Methods for Microalgae Hydrothermal Liquefaction and Biocrude Upgrading System." *Algal Research*. PNNL-SA-137970. [submitted]
- Jiang Y., S.B. Jones, Y. Zhu, L.J. Snowden-Swan, A.J. Schmidt, J.M. Billing, and D.B. Anderson. 10/29/2018. "Techno-Economic Uncertainty Quantification of Algal-derived Biocrude via Hydrothermal Liquefaction." Pittsburgh, Pennsylvania. PNNL-SA-139100.
- Zhu Y., S.B. Jones, A.J. Schmidt, J.M. Billing, K.O. Albrecht, R.T. Hallen, and D.B. Anderson. 06/12/2018. "Co-feeding of algae/wood blend feedstock for hydrothermal liquefaction (HTL) and upgrading – a techno-economic analysis." Presented by Yunhua Zhu at The 8th International Conference on Algal Biomass, Biofuels and Bioproducts, Seattle, Washington. PNNL-SA-135398.
- Anderson D.B., J.M. Billing, S.J. Edmundson, A.J. Schmidt, and Y. Zhu. 04/29/2019. "Demonstration of the Hydrothermal Liquefaction Pathway for Conversion of Microalgae to Biofuels with Integrated Recycle of Nutrients." Abstract submitted to Biofuels and Bioenergy Conferences, San Francisco, California. PNNL-SA-139499

Recent Publications Continued

- “Performance of a Compression Ignition Engine Fueled with Renewable Diesel Blends Produced from Hydrothermal Liquefaction, Fast Pyrolysis, and Conversion of Ethanol to Diesel.” Jessica Tryner, Karl Albrecht, Justin Billing, Richard T. Hallen, and Anthony J. Marchese. Paper accepted for presentation and publication in Conference Proceedings of the Western States Section of the Combustion Institute Meeting at the University of Wyoming, October 3, 2017
- Edmundson S.J., M. Huesemann, R. Kruk, A. Schmidt, T. Lemmon, J. Billing, and D. Anderson. Phosphorus and Nitrogen Recycle Following Algal Bio-crude Production via Continuous Hydrothermal Liquefaction, *Algal Research*, 26, 415-421. https://doi.org/10.1016/j.algal.2017.07.016
- Edmundson S.J., R. Kruk, K. Pittman, M. Huesemann, A. Schmidt, T. Lemmon, and D. Anderson. Water and Nutrient Recycling in Algal Biomass Production. Nature Scientific Reports, In preparation.
- Edmundson S.J., M. Huesemann, R. Kruk, A. Schmidt, T. Lemmon, J. Billing, and D. Anderson. Phosphorus and Nitrogen Recycle Following Algal Bio-crude Production via Continuous Hydrothermal Liquefaction, *Algal Research*, 26, 415-421. https://doi.org/10.1016/j.algal.2017.07.016
- “FT-ICR MS analysis of blended pine-microalgae feedstock HTL biocrudes.” Jacqueline M Jarvis; Justin M Billing; Yuri E Corilo; Andrew J Schmidt; Richard T Hallen; Tanner Schaub, Ph.D. **Fuel**, Volume 216, 15March 2018, Pages 341-348. (https://doi.org/10.1016/j.fuel.2017.12.016)
- Edmundson S.J., R. Kruk, K. Pittman, M. Huesemann, A. Schmidt, T. Lemmon, N. Schlafer, J. Wood, and D. Anderson. Water and Nutrient Recycling in Algal Biomass Production. In preparation

Past Publications

- Edmundson S.J., M. Huesemann, R. Kruk, A. Schmidt, T. Lemmon, J. Billing, and D. Anderson. Phosphorus and Nitrogen Recycle Following Algal Bio-crude Production via Continuous Hydrothermal Liquefaction, Algal Research, in progress
- Karl O. Albrecht, Daniel B. Anderson, Justin M. Billing, Douglas C. Elliott, Richard T. Hallen, Todd R. Hart, and Andrew J. Schmidt. Progress in Hydrothermal Liquefaction of a Variety of Species of Microalgae, Algal Research, in progress
- Jarvis JM, N Sudasinghe, KO Albrecht, AJ Schmidt, RT Hallen, DB Anderson, JM Billing, and T Schaub. 2016. "Impact of Iron Porphyrin Complexes when Hydroprocessing Algal HTL Biocrude." Fuel 182:411-418. doi:10.1016/j.fuel.2016.05.107
- He Y, X Li, X Xue, MS Swita, AJ Schmidt, and B Yang. 2017. "Biological Conversion of the Aqueous Wastes from Hydrothermal Liquefaction of Algae and Pine Wood by Rhodococci." Bioresource Technology 224:457-464. doi:10.1016/j.biortech.2016.10.059
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- Albrecht, K.O. 2016 “Impact of Heterotrophically Stressed Algae for Biofuel Production via Hydrothermal Liquefaction and Catalytic Hydrotreating in Continuous-Flow Reactors” Algal Research 14, 17-27, web published: January 8, 2016, DOI: 10.1016/j.algal.2015.12.008
- Frank E, AK Pegallapati, R Davis, J Makrham, A Coleman, SB Jones, MS Wigmosta, and Y Zhu. 2016. LIfe-cycle analysis of energy use, greenhouse gas emission, and water consumption in the 2016 MYPP algal biofuel scenarios. https://www.osti.gov/src/details.jsp?query_id=3&Page=0&osti_id=1281137 .
- Maddi, B.; Panisko, E.; Wietsma, T.; Lemmon, T.; Swita, M.; Albrecht, K.; Howe, D., Quantitative characterization of the aqueous fraction from hydrothermal liquefaction of algae. Biomass and Bioenergy 2016, 93, 122-130.
- Pegallapati, AK, J Dunn, E. Frank, S. Jones, Y Zhu, L Snowden-Swan, R Davis, C Kinchin. April 2015. Supply Chain Sustainability Analysis of Whole Algae Hydrothermal Liquefaction and Upgrading. ANL/ESD—13/8 https://www.osti.gov/src/details.jsp?query_id=1&Page=0&osti_id=1183770

Recent Presentations

- An oral presentation entitled “Complete NPK Recycle following Algal Bio-crude Production via Hydrothermal Liquefaction” was presented by Scott Edmundson at the 7th International Conference on Agal Biomass, Biofuels, and Bioproducts in Miami, FL on June 21st, 2017.
- A poster entitled “Climate simulated biomass productivities of *Chlorella sorokiniana* DOE 1412 using recycled nutrients derived from hydrothermal liquefaction processing” was presented by Robert Kruk at the 7th International Conference on Agal Biomass, Biofuels, and Bioproducts in Miami, FL on June 19th, 2017
- “Performance of a Compression Ignition Engine Fueled with Renewable Diesel Blends Produced from Hydrothermal Liquefaction, Fast Pyrolysis, and Conversion of Ethanol to Diesel.” Jessica Tryner, Karl Albrecht, Justin Billing, Richard T. Hallen, and Anthony J. Marchese. Paper presented and publication in Conference Proceedings of the Western States Section of the Combustion Institute Meeting at the University of Wyoming, October 3, 2017.
- “Characterization of Fuel Properties and Engine Performance of Renewable Diesel Produced from Hydrothermal Liquefaction of Microalgae and Wood Feedstocks.” Jessica Tryner, Karl Albrecht, Justin Billing, Richard T. Hallen, and Anthony J. Marchese. Algal Biomass Summit, Salt Lake City UT, October 30, 2017. PNNL-SA-126131.
- Edmundson S.J., R. Kruk, K. Pittman, M. Huesemann, A. Schmidt, and D. Anderson. Sustained Algal Biomass Productivities in Continuously Reused Cultivation Water with Nutrients Derived from the Waste Products of Algal Biocrude Production by Hydrothermal Liquefaction. Presentation at the 2018 International Conference on Algae Biomass, Biofuels, and Bioproducts. Seattle, WA.
- Edmundson S.J., R. Kruk, K. Pittman, M. Huesemann, A. Schmidt, T. Lemmon, N. Schlafer, J. Wood, and D. Anderson (2018) Water and Nutrient Recycling in Algal Biomass Production for Biofuels. Presentation at the 2018 Algal Biomass Summit Houston, TX.
- Kruk R, SJ Edmundson, and MH Huesemann. 2017. "Climate simulated biomass productivities of Chlorella sorokiniana DOE 1412 using recycled nutrients derived from hydrothermal liquefaction processing." Presented by Robert Kruk at The 7th International Conference on Algal Biomass, Biofuels and Bioproducts, MIAMI, FL on June 19, 2017. PNNL-SA-126819.
- Edmundson SJ, R Kruk, MH Huesemann, TL Lemmon, JM Billing, AJ Schmidt, and DB Anderson. 2017. "Complete NPK recycle in algal cultivation after hydrothermal liquefaction of algal biomass." Presented by Scott J Edmundson at 7th International Conference on Algal Biomass, Biofuels, & Bioproducts, Miami, Florida, FL on June 21, 2017. PNNL-SA-126818.

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Past Presentations

- Robert Kruk. “Completing the Nutrient Cycle in Algae Biomass Production” at the 28th Northwest Algae and Seagrass Symposium, on Whidbey Island, WA, May 8th, 2016.
- Scott Edmundson. “Phosphorus Recycle following Algal Biocrude Production via Hydrothermal Liquefaction” at the 6th International Conference on Algal Biomass, Biofuels and Bioproducts in San Diego, California, June 27th, 2016.
- Albrecht KO, RT Hallen, AJ Schmidt, JM Billing, MA Lilga, AR Cooper, JE Holladay, and DB Anderson. 2016. "Waste Streams as Economic Feedstocks for the Production of Sustainable Liquid Fuels." Presented by Karl O Albrecht at 2nd CRC Advanced Fuel and Engine Efficiency Workshop, Livermore, CA on November 2, 2016.
- Billing JM, AJ Schmidt, TR Hart, GD Maupin, KO Albrecht, H Wang, DB Anderson, RT Hallen, and DC Elliott. 2015. "Continuous Flow Hydrothermal Liquefaction of Biomass Feedstock." Presented by Justin Billing at tcbiomass 2015, Chicago, IL on November 4, 2015.
- Billing JM, DB Anderson, RT Hallen, TR Hart, GD Maupin, AJ Schmidt, and DC Elliott. 2016. "Design, Fabrication, and Testing of the Modular Hydrothermal Liquefaction System (MHTLS)." Presented by Justin M Billing at TCS 2016, Chapel Hill, NC on November 3, 2016.
- Elliott DC, DB Anderson, RT Hallen, AJ Schmidt, and JM Billing. 2016. "Recent Developments in Hydrothermal Processing of Wet Biomass." Presented by Douglas C. Elliott (Invited Speaker) at South Dakota School of Mines and Technology, Rapid City, SD on March 22, 2016.
- Drennan C. 2016. "Hydrothermal Liquefaction - a new paradigm for sustainable bioenergy." Presented by Corinne Drennan at Bioenery Australia 2016, Brisbane, Australia on November 14, 2016.
- Jones SB, Y Zhu, LJ Snowden-Swan, and DB Anderson. 2015. "HTL Model Development." Presented by Susanne B. Jones (Invited Speaker) at DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review, Washington DC, DC on March 24, 2015. PNNL-SA-108674.
- Zhu Y, SB Jones, DB Anderson, RT Hallen, AJ Schmidt, KO Albrecht, and DC Elliott. 2015. "Techno-Economic Analysis of Whole Algae Hydrothermal Liquefaction (HTL) and Upgrading System." Presented by Zhu, Yunhua (Invited Speaker) at Algae Biomass Summit, Washington, D.C., DC on October 2, 2015. PNNL-SA-112790.

Patents, Awards, and Commercialization

Awards

- 2015 FLC technology transfer excellence award
- 2015 R&D 100 Award “Hydrothermal Processing to Convert Wet Biomass into Biofuels”

Patents

- Elliott, D.C.; Oyler, J.R. "Methods for Sulfate Removal in Liquid-Phase Catalytic Hydrothermal Gasification of Biomass." U.S. Patent #8,877,098, issued on November 4, 2014.