1.3.4.101

Hydrothermal Processing for Algal Based Biofuels and Co-Products

DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review
Advanced Algal Systems Program

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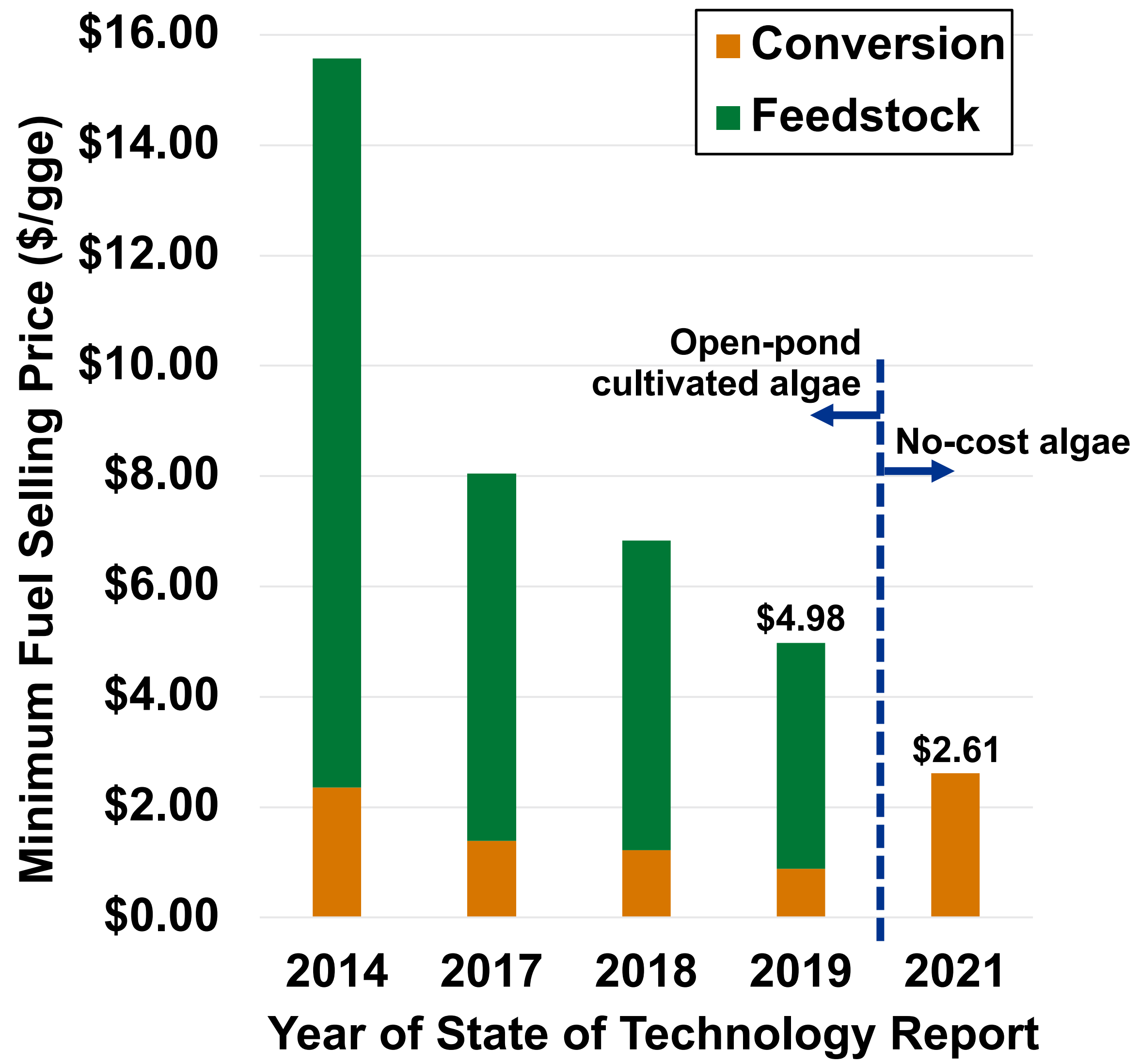
Project Overview

Estimated Minimum Fuel Selling Price (MFSP) for hydrothermally processed algae fuels



MFSP data from Zhu et al. (2022): doi.org/10.2172/1855835
gge: gasoline gallon equivalent

Low- or no-cost algal feedstocks combined with hydrothermal liquefaction (HTL) can enable economically viable fuels and co-products.

Refocused efforts to address new challenges using cost-advantaged feedstocks.

The objective of this project is to make cost-advantaged algae feedstocks readily processable via HTL.

Project goals:

1. Identify and source cost-advantaged algal feedstocks.
2. Overcome technical challenges associated with cost-advantaged feedstocks (e.g., high ash content, low bioenergy content, high viscosity slurries).
3. Develop co-product pathways to enable algal biorefineries.

Project management plan is provided in the supplemental slides

1. Approach: Technical Objectives

2023 goal: Identify and source available cost-advantaged algal feedstocks.

- Collaborate with strategic partners to acquire feedstocks for experiments:
  - Algae residuals from commercial processes
  - Algae from environmental remediation services
  - Harvested nuisance algae.
- Develop risk assessments and safe handling plans:
  - A safe-handling plan will be developed by each laboratory [Idaho National Laboratory (INL) is a project partner].
- Create customized experimental plans and marketable pathways for each alga.

Strategic partners and customized approaches enable industrially relevant technology development.

Harvested harmful algal bloom material from a Florida lake

1. Approach: Technical Objectives

2023 goal: Overcome technical challenges associated with cost-advantaged feedstocks (partnership with INL).

- Investigate separation technologies (e.g., hydrocyclones) to reduce ash content.
  - Key parameters (e.g., pressure, flow, cone angle) of hydrocyclone operations will be investigated.
- Characterize material attributes (e.g., particle size, zeta potential) that impact rheological properties the most.
  - Flowability assessments at INL will be correlated with process reliability assessments in HTL equipment at Pacific Northwest National Laboratory (PNNL).

Reducing ash content and slurry viscosity will improve the processability of cost-advantaged algae during HTL.

Scanning electron microscope images of hydrocyclone fractionated turf scrubber biomass. Calcium is colored blue-green.

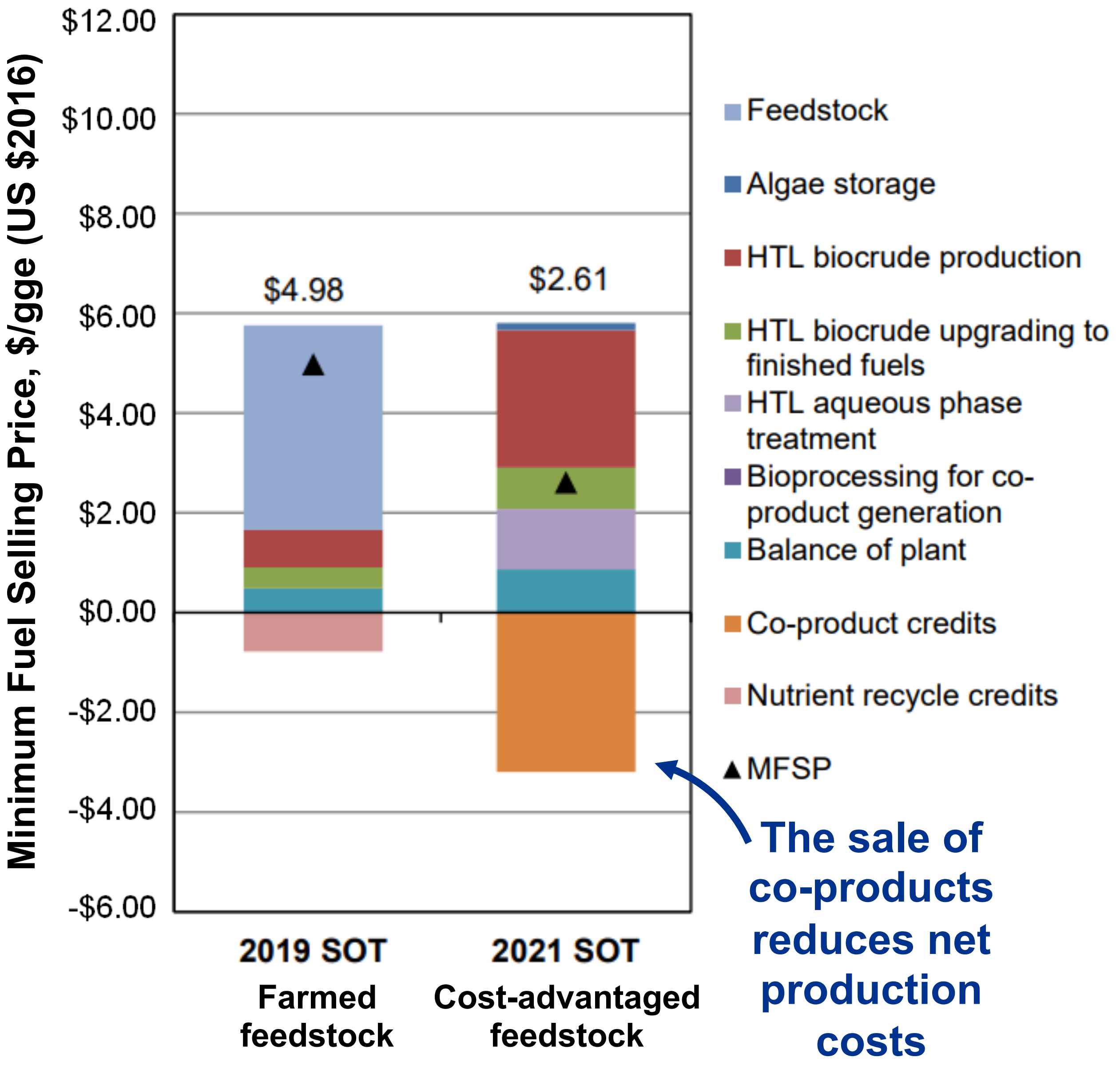
Hydrocyclone test rig

1. Approach: Technical Objectives

2023 goal: Develop co-product pathways to enable algal biorefineries.

- Investigate pre-HTL co-products, leveraging biologically valuable components such as proteins, hydrogels, and lipids.
  - Co-products will be assessed for value along already developed pathways within the Bioenergy Technologies Office (BETO) portfolio (e.g., carbohydrate fermentation or protein processing).
- Investigate post-HTL co-products.
  - Inorganic residues (ash) are potential soil amendments or aggregate fillers for construction materials.
  - Carbon in the post-HTL residues offers additional credits for carbon sequestration.

MFSP from 2021 State of Technology report



Coupling the low cost of cost-advantaged feedstocks with the development of co-product pathways enables economically viable algal biorefineries.

1. Approach: Addressing Risk and Measuring Progress

- Mitigation plans are ready to minimize technical and logistical risks to the project.
  - Mitigation plans allow for shift in approach to overcome potential challenges
  - Note: <u>Risk mitigation plan is in the supplemental slides</u>

- Go/No-go decision at project midpoint (3/31/2024) measures progress against baseline for greenhouse gas (GHG) emissions from petroleum equivalents.

Go/No-Go decision	Criteria
Using knowledge gained in the first year of the project, new methods will be applied to improve the feedstock characteristics and co-product(s) value of a selected cost-advantaged algae. The selected alga will be hydrothermally processed, and the entire conversion pathway will be assessed, with support from the model development project (1.3.5.202) to determine the net reduction in GHG emissions.	Demonstrate a 70% reduction in GHG emissions (compared against petroleum diesel) for an HTL conversion pathway using a cost-advantaged algae as a feedstock with the investigated improvements made via pretreatment and co-product valorization tasks.

1. Approach: Project Integration & Collaboration

The project is integrated with other project teams, national laboratories, and external collaborators to enable shared learning and to leverage a broad and diverse knowledge base

DISCOVR Consortium → Testing Material → **Algae Hydrothermal Processing PNNL & INL**

Algae Producers → Testing Material → **Algae Hydrothermal Processing PNNL & INL**

Algae Hydrothermal Processing
PNNL & INL
- Feedstock sourcing
- Algae HTL conversion
- Ash removal
- Co-product development

Hydrothermal Process Development Unit
PNNL
- HTL process scale-up (pumping, heat transfer, separations)
- Aqueous phase treatment
- Biocrude upgrading
- Industrial engagement

Experimental Data ↓ Cost Results ↑

Shared learning through open inter-team communications

NREL Algae Pond Model ↔ Cost Data ↔ **HTL Model Development PNNL**

ANL Sustainability ← Inventory Data ← **HTL Model Development PNNL**

ANL Sustainability → Life-cycle analysis → **HTL Model Development PNNL**

HTL Model Development
PNNL
- Techno-economic analysis
- Life-cycle inventory
- State-of-technology reports

Bench Scale HTL of Wet Waste Feedstocks
PNNL
- Wet waste HTL conversion
- Feedstock analysis
- Biocrude upgrading
- Assessment driven research & development

1. Approach: Diversity, Equity, and Inclusion

Broad outreach plan to communicate project results and inform about topics related to environmental sustainability.

- Presentation on environmental sustainability with high school students in Kennewick, WA (October 2022).
- Q&A session with middle school students in Platte City, MO in support of their class project to design an off-shore algae farm (January 2023).
- Project mentorship at University of Colorado, Boulder. PNNL will advise chemical engineering seniors for a capstone project on algae cultivation and product manufacturing (In progress).

Platte City middle school project, prototype of an off-shore algae farm. Photo credit: Amy Cordova

The project team coordinates with PNNL's STEM outreach office to establish consistent participation in activities that support PNNL's Laboratory-wide strategy.

2. Progress and Outcomes Since Last Peer Review

Identification and sourcing of cost-advantaged algae biomass

- *Defined cost-advantaged feedstocks:*
  - Biomass that is available now and produced in a way that the biomass is a by-product of another product or service

- *Found cost-advantaged feedstock sources:*
  - Residuals from algal-based products
  - Algae used for remediation services such as wastewater treatment or pollution management
  - Nuisance/harmful algal blooms (micro- and macroalgae) collected and disposed in environmental services

The team identified 11 collaborators and obtained testing-scale quantities of 7 unique types of cost-advantaged biomass

Residuals or Discards

Environmental Services

Nuisance Algae

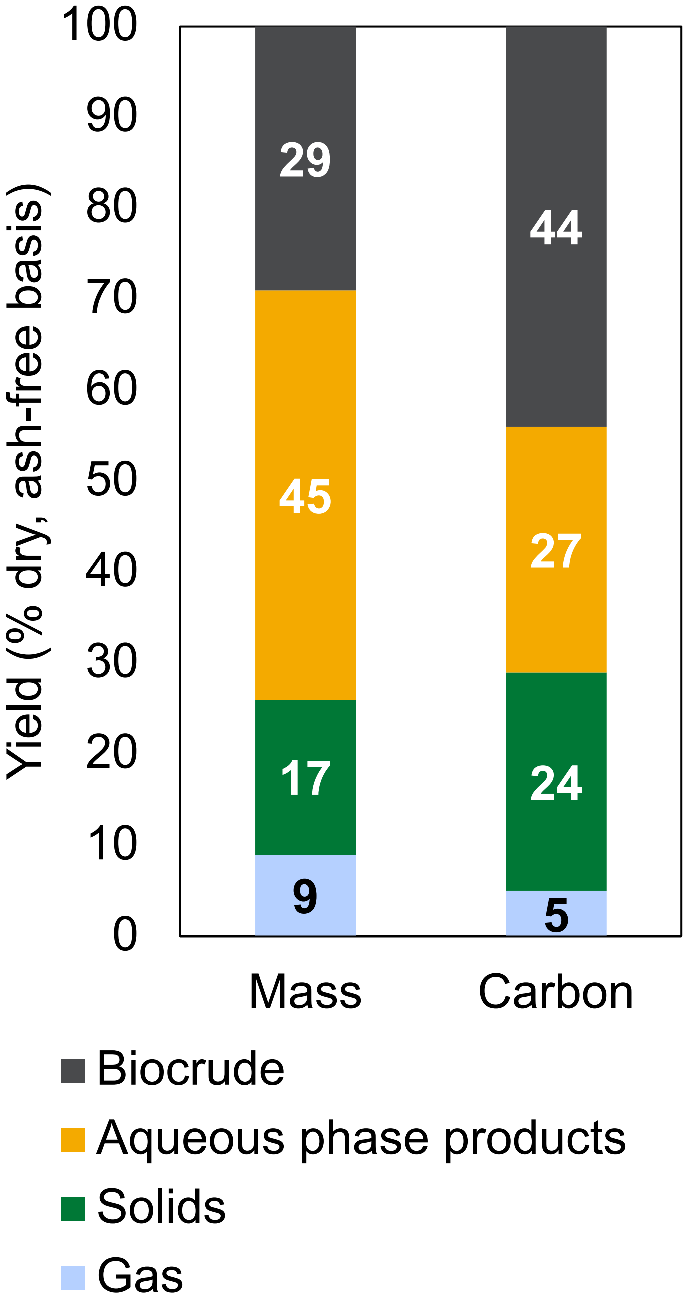
Credit: Benedicte Desrus/ Sipa USA/Newscom

2. Progress and Outcomes Since Last Peer Review

Hydrothermal conversion of cost-advantaged feedstock

- Completed hydrothermal processing of a high-ash (40%) wastewater-grown algae
  - Moderate biocrude yield (29%) compared to typical algal feedstocks (40%)
- Developed struvite (fertilizer) pathway from aqueous and solid by-products
  - Observed 99% removal of ammonia from the aqueous phase

- Experimental results were the basis for analysis in the 2021 State of Technology report resulting in a **proposed minimum fuel selling price of $2.61/gge**.

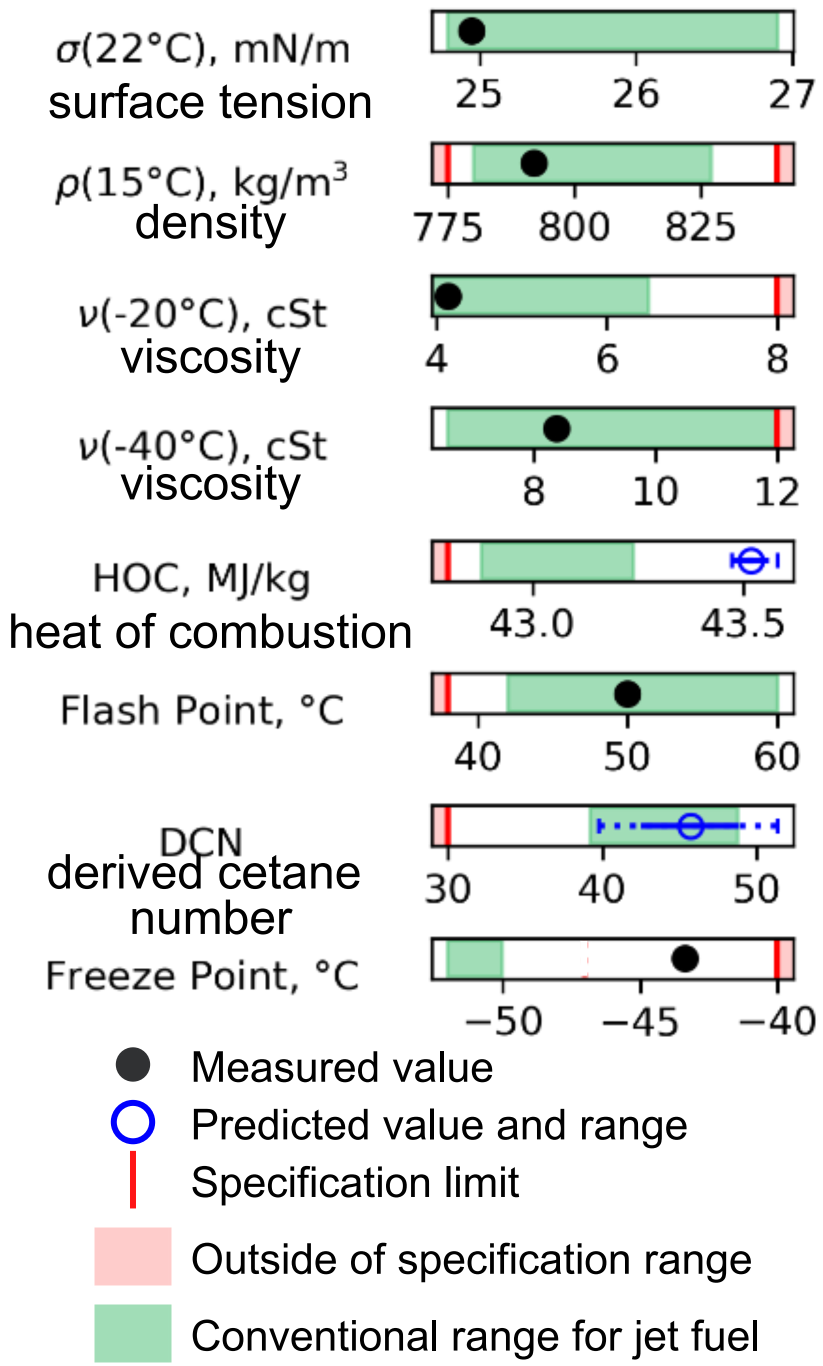


Successful hydrothermal processing and development of a co-product using cost-advantaged algae

2. Progress and Outcomes Since Last Peer Review

Production of sustainable aviation fuel (SAF) from *Picochlorum celeri*

- *P. celeri* was hydrothermally processed, the biocrude was upgraded and distilled (23% was in the jet fuel range)
- The jet fuel range products were assessed using tier α and β testing protocols developed by the University of Dayton for low-volume qualification of SAF
- **All fuel properties were within specification limits and most properties are within range of conventional jet fuel**
- Experimental results were the basis for analysis in the 2022 State of Technology report



Successful demonstration of a direct processing pathway to produce SAF from algal biomass via hydrothermal liquefaction

Note: additional testing results are available in the supplemental slides

2. Current Project Progress

First quarter progress milestones are completed:

- Identify and source feedstocks for 2023 experiments
  - Harmful algal bloom material obtained
  - Wastewater-grown algae obtained
  - Continuing work with previous samples of filamentous algae and macroalgae (*Ulva* sp.)
- Develop safety and experimental plans at each partner laboratory (PNNL & INL)
  - Many cost-advantaged algal sources include chemical and/or biological hazards, e.g., cyanotoxins or pathogens
- Upcoming quarterly project milestones are on track

Project Tasks in 2023

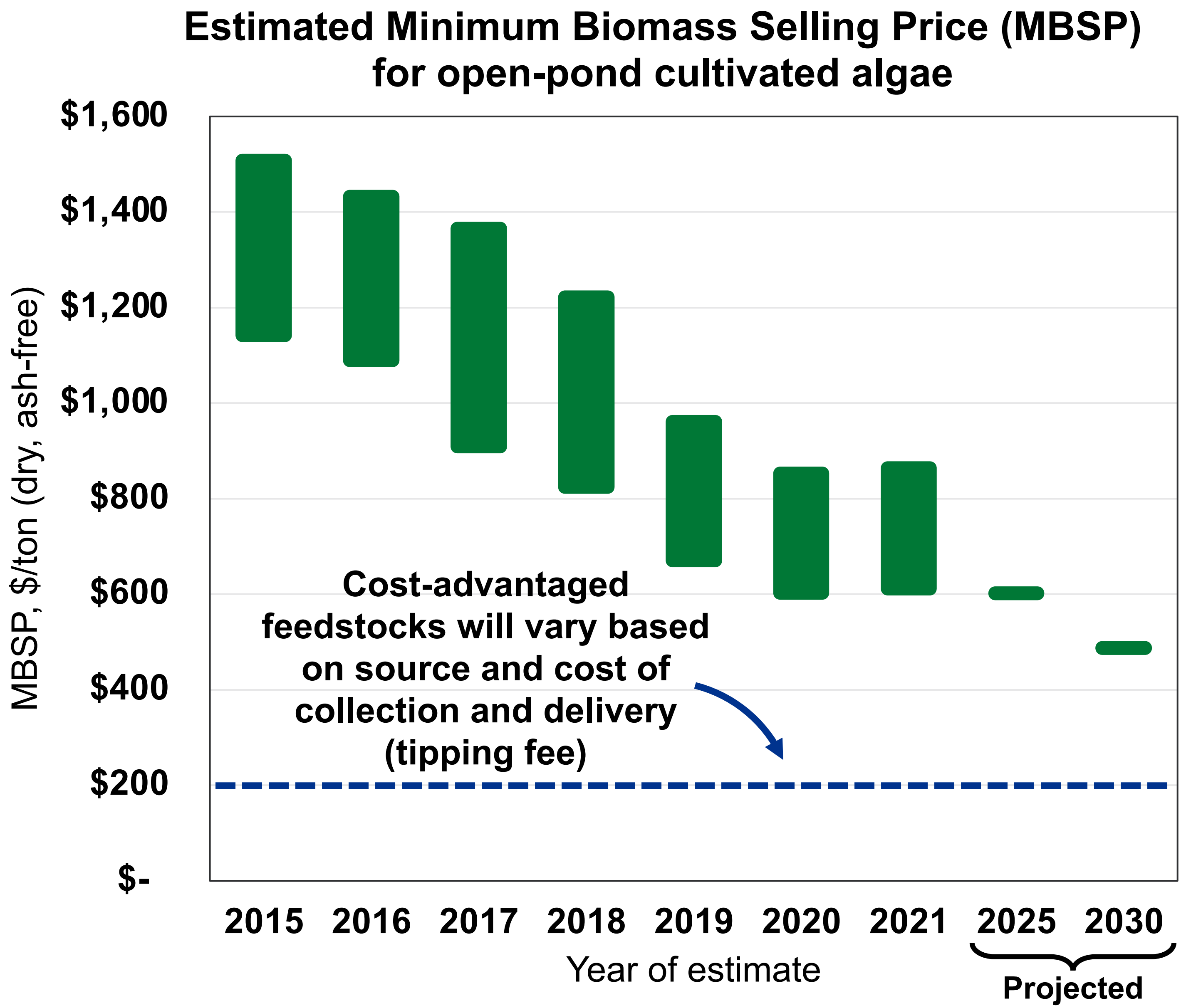
1. Identify and source cost-advantaged algal feedstocks

2. Format and pre-treat feedstocks

3. Run HTL of feedstocks and assess products

4. Develop co-products to add value

3. Impact: Technical Significance



- Cost of cultivated algae contributes the most to the minimum fuel selling price of hydrothermally produced fuels.

Feedstocks that are available now, that would be otherwise discarded, can be utilized while other feedstock sources continue to innovate to reduce costs

- Opportunity to reduce environmental burdens in communities created by:
  - Underutilized biomass materials (landfill-bound)
  - Nuisance algal blooms that recur if not removed
  - Polluted waters or wastewaters sources (algae used in remediation needs a destination)

MBSP data from Klein et al.(2022): doi.org/10.2172/1862662

Pacific Northwest
NATIONAL LABORATORY

3. Impact: Commercial Significance

Collaborators (AECOM, Army Corps of Engineers, Gross-Wen Technologies) envision their algal products as feedstocks for hydrothermal liquefaction.

Demonstration at Lake Harsha in Ohio to harvest and hydrothermally process harmful algal blooms

GWT revolving algal biofilm system for producing wastewater-grown algae

Relevant press releases:

- https://cities-today.com/florida-city-turns-algae-into-fuel/
- https://aecom.com/press-releases/aecom-enters-strategic-partnership-with-genifuel-to-transform-algae-and-wastewater-biosolids-into-sustainable-aviation-fuel/
- https://www.erdc.usace.army.mil/Media/News-Stories/Article/3172838/erdc-rd-underpins-harmful-algal-bloom-removal-technology-at-ohio-demonstration/
- https://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/1920665/harmful-algal-bloom-interception-treatment-and-transformation-system-habitats/

3. Impact: Publicizing Results

Since last peer review, the Hydrothermal Processing for Algal Based Biofuels project has

- presented experimental results at the 2022 American Institute of Chemical Engineers' national meeting in Phoenix, AZ
- provided content for the 2021 and 2022 State of Technology reports

The project provides impact for the Department of Energy, the research community, and commercial partners

Since inception, the Hydrothermal Processing for Algal Based Biofuels project has

- produced **20 publications** and **20 presentations**
- developed **HTL technology** that is being **leveraged** for other **wet waste feedstocks** providing **environmental solutions** in addition to **biofuel and co-products**
- led to several **industrial collaborations** and projects
- supported the development of **several patents** and **licensing of technology** to industry.
- been awarded the **2015 FLC technology transfer excellence award** and the **2015 R&D 100 Award** "Hydrothermal Processing to Convert Wet Biomass into Biofuels"

Summary

1 - Approach

- **Integrated project team** leveraging communications and expertise across national laboratories and external collaborators.
- Developed project plan to address experimental **design**, **safety**, and technical **risks**.

2 - Progress

- Demonstrated HTL process to produce commercially viable fuel and co-products at a minimum fuel selling price of **$2.61/gge**.
- Demonstrated the production of **sustainable aviation fuel** from *P. celeri* via HTL.

3 - Impact

- Demonstrating potential for cost-advantaged algae to produce **fuels and co-products at commercially viable costs**.
- **Gaining Interest from commercial partners** to see the successful implementation of HTL from cost-advantaged algae.
- **Achieving continuous impact** from publications, presentations, awards, and collaborations.

Acknowledgements

Daniel Fishman, BETO Technology Manager
Phillip Lee, BETO Project Monitor

PNNL Project Team

- Peter Valdez
- Andy Schmidt
- Dylan Cronin
- Todd Hart
- Sam Fox
- Uriah Kilgore
- Scott Edmundson
- Marie Swita
- Teresa Lemmon
- Lesley Snowden-Swan
- Yunhua Zhu

INL Project Team

- Brad Wahlen
- Luke Williams

Quad Chart Overview

Timeline
- Project start date: 10/01/2022
- Project end date: 9/30/2025

	FY 22	Total Award
DOE Funding	$600,000	$1,800,000 (negotiated total federal share over active project lifetime)

Related/Leveraged Projects
1.3.5.202 HTL Model Development
1.3.2.501 Algae DISCOVR Project
2.2.2.301 PNNL Hydrothermal Process Development Units

TRL at Project Start: 3
TRL at Project End: 4

Project Goal
Develop hydrothermal process technology to enable the commercialization of algal-based biofuels and co-products from cost-advantaged algae feedstocks.

End of Project Milestone
Demonstrate at the laboratory scale, the feasibility of at least one co-product valorization pathway that reduces net GHG emissions by 100% (compared to petroleum), showing that additional GHG emissions can be achieved through displacement or sequestration of carbon from the co-product.

Funding Mechanism
2023 Lab Call

Project Partners
- Idaho National Laboratory

Thank you

1.3.4.101

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PNNL is operated by Battelle for the U.S. Department of Energy

Supplemental Slides

PNNL is operated by Battelle for the U.S. Department of Energy

Project Tasks and Management Plan

- Project was funded at start of 2023 fiscal year
  - WBS#: 1.3.4.101
- PNNL is the lead organization
  - Responsible for project management
  - Leading tasks 1, 3, and 4
- INL is a project partner
  - Leading task 2

- Monthly team meetings to coordinate and plan activities between task leaders
- Monthly reporting meetings to communicate results and progress to BETO Technology Manager and Project Monitor

Project Tasks in 2023

1. Identify and source cost-advantaged algal feedstocks

↓

2. Format and pre-treat feedstocks

↓

3. Run HTL of feedstocks and assess products

↓

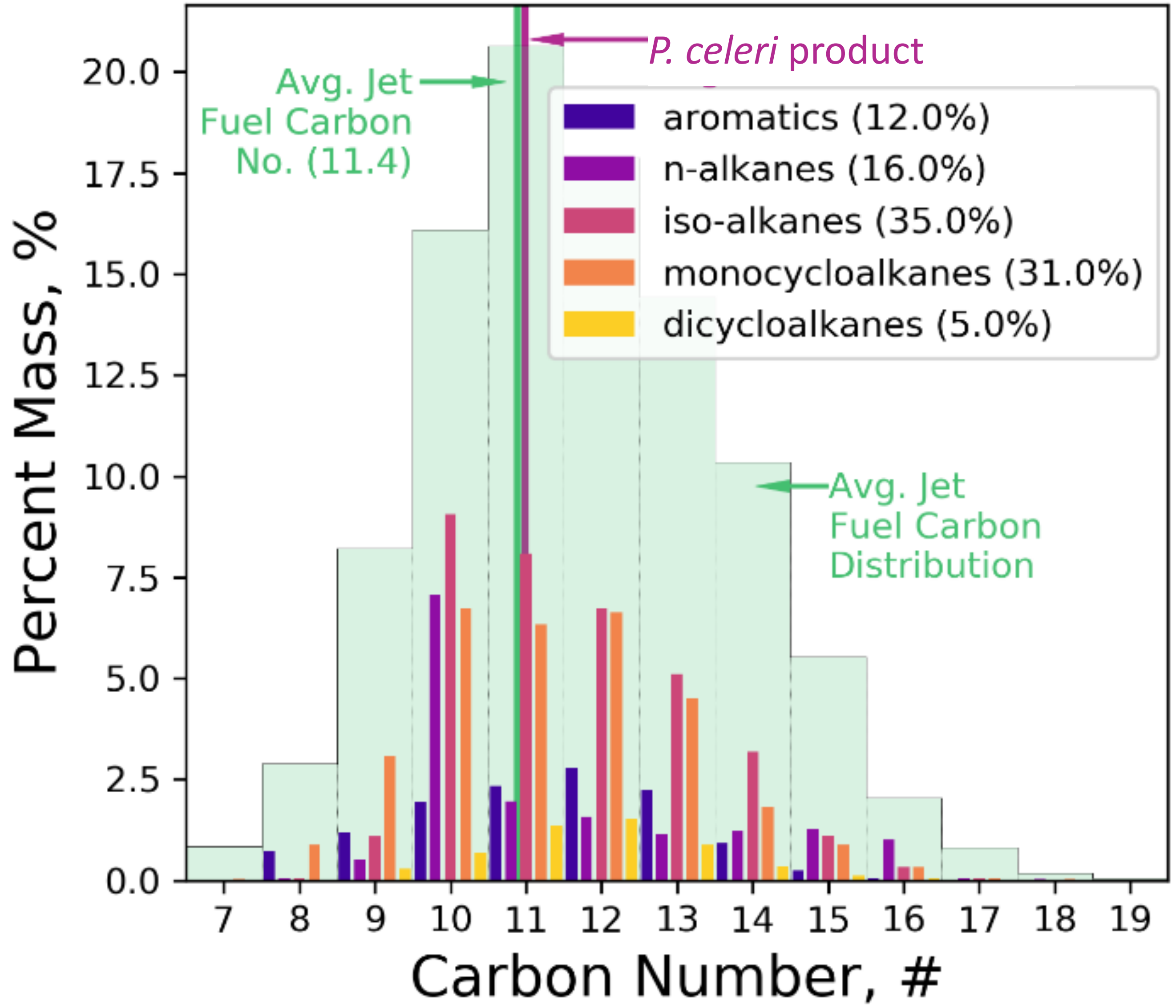
4. Develop co-products to add value

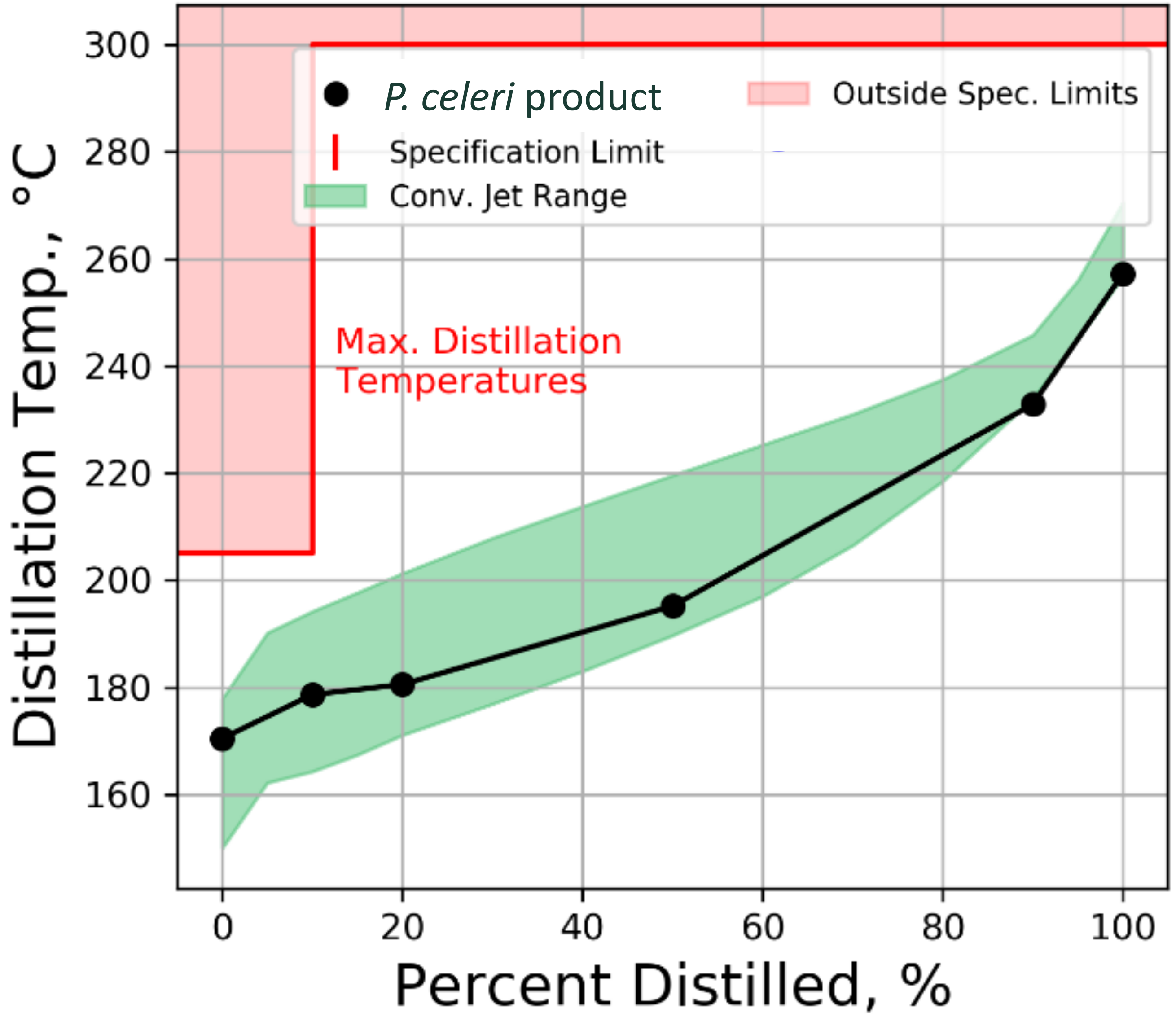
Risk Mitigation Plan

Logistical and technical risks have been identified and a mitigation plan is in place to respond to potential challenges

Project Risks	Mitigation Plan
Lack of algae feedstock availability	Rely on known sources of algae and work with professional networks to find opportunities to work with new feedstocks.
Slurry viscosity prevents feeding algae into HTL equipment	Employ known formatting techniques such as, milling, grinding, blending, or dilution.
Feedstock quality cannot be improved	Investigate methods valorize components of the feedstock
Pre-HTL products cannot be easily recovered from cost-advantaged algae	Shift focus on recovery of co-products from post-HTL

Additional results for assessment of upgraded and distilled biocrude from *P. celeri*





Measured value | Specification limit | Outside of specification range | Conventional range for jet fuel

Responses to Previous Reviewers' Comments

FY21 Peer Review Report for Advanced Algal Systems https://www.energy.gov/sites/default/files/2022-06/beto-02-Advanced-Algal-Systems-2021-peer-review.pdf

Comment 1: *"Additional details on clearer risk management up front and a connection to how this guided the project direction would have been helpful. Technical risks seem to be confused with tasks and as a result risk mitigation seems more like a work breakdown structure than a set of alternatives or parallel paths that could reduce impact of failure at any of the critical path steps."*

Response 1: The project has a more detailed risk mitigation plan that was included in the supplemental slides. We only had time to touch on key risk areas and how those were being addressed in our R&D strategy and associated tasks. Our risk mitigation plan does provide a set of alternatives or parallel pathways to reduce failures with each identified project risk.

Comment 2: *"Real world demonstration of this technology and integration of this data into modeling efforts will be critical for broad adoption of this technology which seems almost certain if proven economically viable."*

Response 2: As presented in the HTL Modeling project review directly following this one, the modeling team is a critical element of the overall R&D team and works side-by-side with the experimental team to integrate all testing data into the conceptual plant model as best as possible to guide the R&D and predict performance and economics at scale. PNNL is highly engaged in demonstrating performance at engineering scale through the PDU and is driving towards real-world demonstration through its collaborative efforts with industrial partners.

Comment 3: *"A model that can predict HTL outputs based on easily translated feed stock composition metrics would be the most impactful work this team could do to make this technology approachable for potential users."*

Response 3: We agree that being able to systematically correlate incoming biomass composition with the upgraded fuel blendstock product properties is of great value. Towards this effort, we have developed reduced order models based on PNNL's extensive library of continuous HTL processing data to predict biocrude yield and quality (Jiang et al. 2019 at https://doi.org/10.1016/j.algal.2019.101450; Li et al. 2021 at https://doi.org/10.1016/j.apenergy.2020.116340). This work was briefly presented in the HTL Modeling project review.

Comment 4: *"The choice of lactic acid as a coproduct seems to lack specific market pull or customer partnership but it does demonstrate the potential for coproduct development, providing needed adaptability for this platform."*

Response 4: As presented in the HTL Modeling project review directly following this one, the modeling team conducted a screening study to identify initial candidates for consideration with the sequential HTL configuration. Using current market size, price, and carbohydrate conversion demonstrated in the literature, lactic acid was identified as just one example, but by no means is the only candidate co-product. Many others are possible and moving forward we will continue to identify and hone the best options considering both co-product market dynamics and overall process economics.

Publications, Patents, Presentations, Awards, and Commercialization since 2021 Peer Review

Publications

20. Zhu, Y., Y. Xu, A. Schmidt, M. Thorson, D. Cronin, D. Santosa, S. Edmundson, S. Li, L. Snowden-Swan, P. Valdez. (2022). “Microalgae hydrothermal liquefaction and biocrude upgrading: 2022 State of Technology.” PNNL-XXXXX. In Progress.

19. Santosa D.M., L. Wendt, B.D. Wahlen, A.J. Schmidt, J.M. Billing, I.V. Kutnyakov, and R.T. Hallen, et al. 2022. "Impact of Storage and Blending of Algae and Forest Product Residue on Fuel Blendstock Production." *Algal Research* 62 (2022) 102622. https://doi.org/10.1016/j.algal.2021.102622

18. Zhu, Y., A. J. Schmidt, P. J. Valdez, L. J. Snowden-Swan and S. J. Edmundson (2022). Hydrothermal Liquefaction and Upgrading of Wastewater-Grown Microalgae: 2021 State of Technology. PNNL-32695. https://doi.org/10.2172/1855835

17. Zhu, Y., S. B. Jones, A. J. Schmidt, H. M. Job, J. M. Billing, J. R. Collett, K. R. Pomraning, S. P. Fox, T. R. Hart, S. J. Edmundson, M. R. Thorson, P. A. Meyer, L. J. Snowden-Swan and D. B. Anderson (2021). “Microalgae Conversion to Biofuels and Biochemical via Sequential Hydrothermal Liquefaction (SEQHTL) and Bioprocessing: 2020 State of Technology.” PNNL-30124. https://doi.org/10.2172/1784347

Presentations

20. Valdez, P., A. Schmidt, S. Edmundson, T. Hart, D. Cronin, S. Fox. 2022. “Overcoming Engineering Challenges for the Hydrothermal Liquefaction of Cost-Advantaged Algal Feedstocks”. AIChE Annual Meeting, Phoenix, AZ.

19. Zhu Y., S.B. Jones, A.J. Schmidt, J.M. Billing, J.R. Collett, L.J. Snowden-Swan, and D.B. Anderson. 2021. "Preliminary Economic Analysis of Microalgae Conversion to Biofuels and Biochemical via Sequential Hydrothermal Liquefaction (SEQHTL) and Bioprocessing." The International Conference on Algal Biomass, Biofuels and Bioproducts, Online Conference.

Past Patents, Awards, and Commercialization Activities

Awards

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

Patents and Patent Applications

- Mike Thorson, Lesley Snowden-Swan, Andy Schmidt, Todd Hart, Justin Billing, Dan Anderson and Rich Hallen. Filed January 2020. “Hydrothermal liquefaction system” U.S. Patent #11,279,882.
- Mike Thorson, Rich Hallen, Justin Billing, Andy Schmidt, Todd Hart, and Teresa Lemmon. Filed December 2019. “MOVING BED PRETREATMENT FOR IRON-CONTAINING BIOCRUDE.” US Pat Appl 31594/ 9760.
- Elliott, D.C.; Oyler, J.R. Issued on November 4, 2014. "Methods for Sulfate Removal in Liquid-Phase Catalytic Hydrothermal Gasification of Biomass." U.S. Patent #8,877,098.

Previous Publications

16. Zhu Y, SB Jones, AJ Schmidt, JM Billing, MR Thorson, DM Santosa, RT Hallen, and DB Anderson. 2020. “Algae/Wood Blends Hydrothermal Liquefaction and Upgrading: 2019 State of Technology.” PNNL-29861. https://doi.org/10.2172/1616287
15. Zhu Y, SB Jones, AJ Schmidt, JM Billing, DM Santosa, and DB Anderson. 2020. “Economic impacts of feeding microalgae/wood blends to hydrothermal liquefaction and upgrading systems.” *Algal Research* 51:102053. https://doi.org/10.1016/j.algal.2020.102053
14. Zhu Y, SB Jones, AJ Schmidt, KO Albrecht, SJ Edmundson, and DB Anderson. 2019. “Techno-economic analysis of alternative aqueous phase treatment methods for microalgae hydrothermal liquefaction and biocrude upgrading system.” *Algal Research* 39:101467. https://doi.org/10.1016/j.algal.2019.101467
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10. Jessica Tryner, Karl Albrecht, Justin Billing, Richard T. Hallen, and Anthony J. Marchese. 2017. “Performance of a Compression Ignition Engine Fueled with Renewable Diesel Blends Produced from Hydrothermal Liquefaction, Fast Pyrolysis, and Conversion of Ethanol to Diesel.”
9. 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

Previous Publications (continued)

8. Jacqueline M Jarvis; Justin M Billing; Yuri E Corilo; Andrew J Schmidt; Richard T Hallen; Tanner Schaub, Ph.D. “FT-ICR MS analysis of blended pine-microalgae feedstock HTL biocrudes.” *Fuel* 216, 341-348. https://doi.org/10.1016/j.fuel.2017.12.016
7. 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." *Fue*l 182:411-418. https://doi.org/10.1016/j.fuel.2016.05.107
6. 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. https://doi.org/10.1016/j.biortech.2016.10.059
5. Elliott, D.C. 2016. “Review of Recent Reports on Process Technology for Thermochemical Conversion of Whole Algae to Liquid Fuels.” *Algal Research* 13, 255-263. https://doi.org/10.1016/j.algal.2015.12.002
4. 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. https://doi.org/10.1016/j.algal.2015.12.008
3. 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/biblio/1352505
2. Maddi, B.; Panisko, E.; Wietsma, T.; Lemmon, T.; Swita, M.; Albrecht, K.; Howe, D. 2016. “Quantitative characterization of the aqueous fraction from hydrothermal liquefaction of algae.” *Biomass and Bioenergy*, 93, 122-130. https://doi.org/10.1016/j.biombioe.2016.07.010
1. 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.” https://www.osti.gov/biblio/1352732

Previous Presentations

18. Anderson D.B., J.M. Billing, S.J. Edmundson, A.J. Schmidt, and Y. Zhu. 2019. "Demonstration of the Hydrothermal Liquefaction Pathway for Conversion of Microalgae to Biofuels with Integrated Recycle of Nutrients." 2019 Biofuels and Bioenergy Conferences, San Francisco, California.
17. Jiang Y., S.B. Jones, Y. Zhu, L.J. Snowden-Swan, A.J. Schmidt, and J.M. Billing. 2018. "Techno-Economic Uncertainty Quantification of Algal-derived Biocrude via Hydrothermal Liquefaction." Pittsburgh, Pennsylvania. 2018 AIChE Annul Meeting, Pittsburgh, PA.
16. Zhu Y., S.B. Jones, A.J. Schmidt, J.M. Billing, K.O. Albrecht, R.T. Hallen, and D.B. Anderson. 2018. "Co-feeding of algae/wood blend feedstock for hydrothermal liquefaction (HTL) and upgrading – a techno-economic analysis." 2018 International Conference on Algal Biomass, Biofuels and Bioproducts, Seattle, Washington. PNNL-SA-135398.
15. Edmundson S.J., R. Kruk, K. Pittman, M. Huesemann, A. Schmidt, and D. Anderson. 2018. “Sustained Algal Biomass Productivities in Continuously Reused Cultivation Water with Nutrients Derived from the Waste Products of Algal Biocrude Production by Hydrothermal Liquefaction.” 2018 International Conference on Algae Biomass, Biofuels, and Bioproducts. Seattle, WA.
14. 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.” 2018 Algal Biomass Summit Houston, TX.
13. Jessica Tryner, Karl Albrecht, Justin Billing, Richard T. Hallen, and Anthony J. Marchese. 2017. “Performance of a Compression Ignition Engine Fueled with Renewable Diesel Blends Produced from Hydrothermal Liquefaction, Fast Pyrolysis, and Conversion of Ethanol to Diesel.” 2017 Western States Section of the Combustion Institute Meeting at the University of Wyoming,
12. Jessica Tryner, Karl Albrecht, Justin Billing, Richard T. Hallen, and Anthony J. Marchese. 2017. “Characterization of Fuel Properties and Engine Performance of Renewable Diesel Produced from Hydrothermal Liquefaction of Microalgae and Wood Feedstocks.” 2017 Algal Biomass Summit, Salt Lake City, UT.
11. 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." 2017 Algal Biomass, Biofuels and Bioproducts, Miami, FL.

Previous Presentations (continued)

10. 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." 2017 Algal Biomass, Biofuels and Bioproducts, Miami, FL.
9. Robert Kruk. 2016. "Completing the Nutrient Cycle in Algae Biomass Production" 2016 Northwest Algae and Seagrass Symposium, Whidbey Island, WA.
8. Scott Edmundson. 2016. "Phosphorus Recycle following Algal Biocrude Production via Hydrothermal Liquefaction" 2016 International Conference on Algal Biomass, Biofuels and Bioproducts, San Diego, CA.
7. 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." 2016 CRC Advanced Fuel and Engine Efficiency Workshop, Livermore, CA.
6. 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)." TCS 2016, Chapel Hill, NC.
5. Elliott DC, DB Anderson, RT Hallen, AJ Schmidt, and JM Billing. 2016. "Recent Developments in Hydrothermal Processing of Wet Biomass." (Invited Speaker) at South Dakota School of Mines and Technology, Rapid City, SD.
4. Drennan C. 2016. "Hydrothermal Liquefaction - a new paradigm for sustainable bioenergy." Bioenery Australia 2016, Brisbane, Australia.
3. Jones SB, Y Zhu, LJ Snowden-Swan, and DB Anderson. 2015. "HTL Model Development." (Invited Talk) DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review, Washington DC.
2. 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." tcbiomass 2015, Chicago, IL.
1. 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." Algae Biomass Summit, Washington, DC.