NREL
Transforming ENERGY

BETO 2021 Peer Review: 1.3.5.200 – Algal Biofuels Techno-Economic Analysis

March 24, 2021
Advanced Algal Systems Session

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National Renewable Energy Laboratory

Project Overview

Goal:

- Provide **process design and economic analysis support** for the algae platform to **guide R&D priorities** to commercialization
  - Translate demonstrated/proposed research advances into economics (quantified as $/ton biomass or $/gal fuels)

Outcomes:

- Benchmark process models and economic analysis tools – used to:
  - Assess cost-competitiveness and **establish process/cost targets** for algal biofuel process scenarios
  - **Track progress** toward goals via state of technology (SOT) updates
  - **Interface** with DISCOVR to support operational baseline TEA beyond n^{th}-plant models, iterate with tech. advisory board
  - Evaluate near-term opportunities for **today's algae industry** on existing resources (protein, wastewater, algal blooms, …)
  - **Disseminate** rigorous, objective modeling and analysis information in a transparent way (the "design report" process)

Context:

- This project provides **direction, focus, and support** for industry and BETO by providing "bottom-up" TEA to show R&D needs for achieving "top-down" BETO cost goals
- One of the longest-serving projects under BETO Algae Platform – 11-year history of impactful, authoritative TEA on algae systems

Market Trends

Product	Anticipated decrease in gasoline/ethanol demand; diesel demand steady
	Increasing demand for aviation and marine fuel
	Demand for higher-performance products
	Increasing demand for renewable/recyclable materials
Feedstock	Sustained low oil prices
	Decreasing cost of renewable electricity
	Sustainable waste management
	Expanding availability of green H_2
	Closing the carbon cycle
Capital	Risk of greenfield investments
	Challenges and costs of biorefinery start-up
	Availability of depreciated and underutilized capital equipment
Social Responsibility	Carbon intensity reduction
	Access to clean air and water
	Environmental equity

NREL's Bioenergy Program Is Enabling a Sustainable Energy Future by Responding to Key Market Needs

Value Proposition

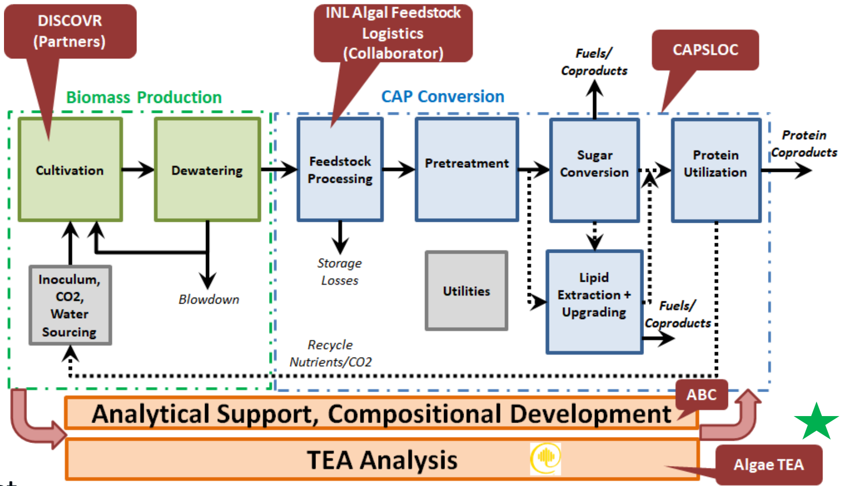
- This project is key to supporting the BETO mission by **highlighting requirements to achieve economic viability**, benchmarking progress towards goals in *$/ton biomass and $/GGE fuels*

Key Differentiators

- Our approach **constantly re-evaluates what is working/not working** in our research portfolio, how to further optimize future R&D to achieve TEA goals
- Success will be driven by acceptance and "cutting loose" underperforming approaches early, **dictated by TEA feedback**

1. Management

- This project is **highly collaborative** with communication/ engagement across numerous active partners:
  - Analysis groups: PNNL, ANL, INL, CSU, SNL
  - FOA partners: TEA support on 6 FOA awards in past 3 years
  - Industry: data sharing (Global Algae Innovations, Algenesis), subcontractor engagement (Nexant, DWH Consulting)
- Risk identification/mitigation:
  1) Research stagnation lacking a clear path to viability
     - Mitigation: **Continuously re-assess** R&D progress vs TEA priorities, feed back recommendations to set new research paths
  2) TEA that misses opportunity to support today's algae industry
     - Mitigation: Include analysis for **today's algae resources**, how best to utilize them (waste/byproduct algae, value-added products); **engage with industry** to identify needs/opportunities for industry to be successful



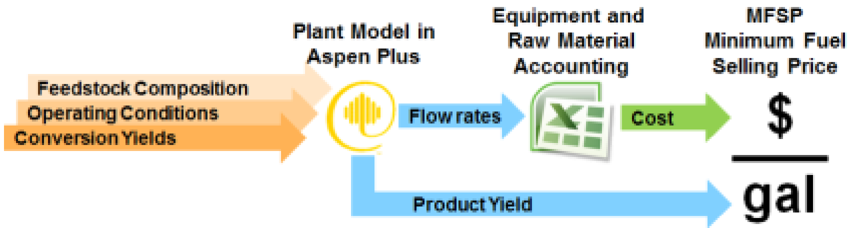
- **Prioritize dissemination** of TEA through reports, conference talks
- Project management tracked via milestones

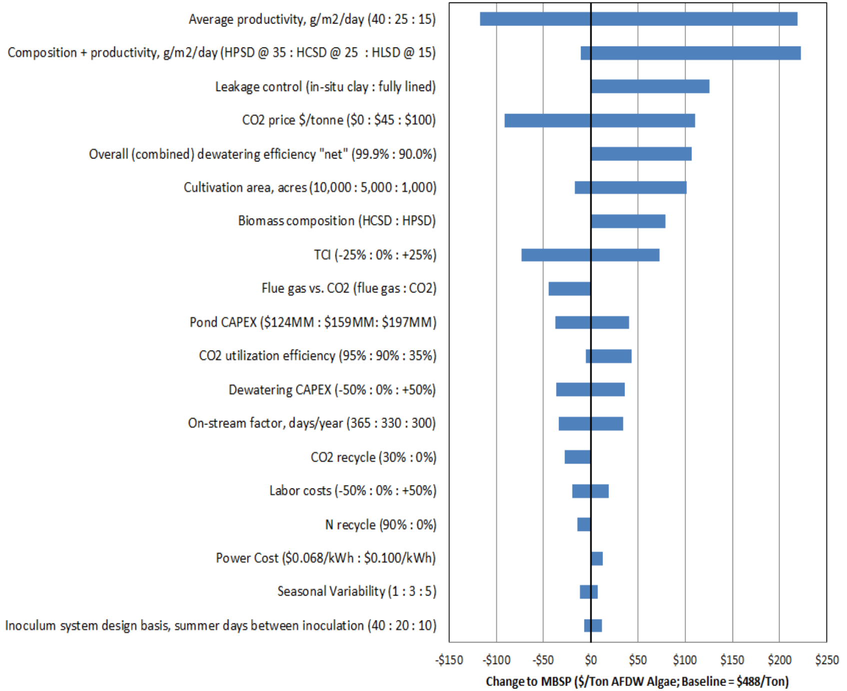
Project Milestones/Activities	FY19 Q1	FY19 Q2	FY19 Q3	FY19 Q4	FY20 Q1	FY20 Q2	FY20 Q3	FY20 Q4	FY21 (planned) Q1	FY21 (planned) Q2	FY21 (planned) Q3	FY21 (planned) Q4
Upstream process focus (biomass production logistics)												
Algae TEA for wastewater remediation	▼										▼	▲
Algal biomass "intrinsic value" modeling		▼							▼	▼		
Opportunities for collection/use of algal bloom biomass						●					▼	▲
SOT benchmarking					▲				▲			
Downstream process focus (biomass conversion to fuels)												
2019 CAP update tech report			▼	▼	▲							
TEA screening for high-protein algae CAP pathway approaches							▼	▼		▼	▼	▲
TEA modeling for non-isocyanate polyurethanes									▼			
SOT benchmarking					▲				▲			

▲ = Milestone ▼ = Quarterly progress measure ● = Go/no-go decision

2. Approach

- Aspen Plus process models reflecting NREL/partner data (preferred), public literature (if necessary)
- Discounted cash-flow calculations determine minimum selling prices (MSPs) at fixed IRR
- TEA modeling for both biomass **production + conversion**
- Measure progress through annual SOTs, prioritize future **R&D "bang for the buck"** through sensitivity analysis





- Challenges:
  - Biomass SOT requires data from long-term growth runs (large-scale, year-round, relevant conditions) – unique challenge for algae SOT vs other platforms
    - Work closely with consortia/FOA partners (DISCOVR, ASU) during experimental planning, **make best use of "one shot" per season**
  - Building credible TEA models without supporting data to investigate new concepts
    - Frequent communication with researchers to set "theoretical potential" limits up front, refine models as data catches up
    - **Stage-gate decision points** to prevent chasing too far down rabbit holes (example: **Go/No-Go** on further pursuit of algal bloom TEA considering status of data availability)

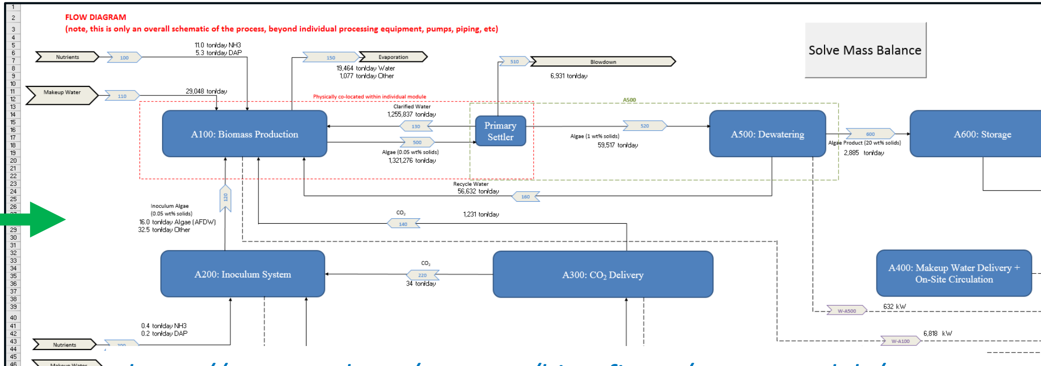
3. Impact

TEA modeling provides high impact:

- **Guides R&D/DOE decisions, sets targets**
  - Technical targets (yields, process performance)
  - Cost targets (basis for BETO MYP goals)
- Identifies key directions (pathways, coproducts, etc.)
  - *Ex: Setting constraints for practical MOT conditions*
- Facilitate interaction between stakeholders in industry, research, DOE
  - *Ex #1: Ongoing interactions with **GAI, MicroBio, Algenol, Algix, AECom, Gross-Wen** to explore TEA*
  - *Ex #2: Algal polyurethane coproduct inclusion in SOTs/targets – supported via inputs from industry on costing (Nexant) + technical (UCSD/Algenesis) info*

SOT Progression: CAP Conversion

- **Foster collaboration** with other modeling groups (ANL, PNNL, ORNL, INL), BETO consortia (ATP3, DISCOVR, Sep-Con)



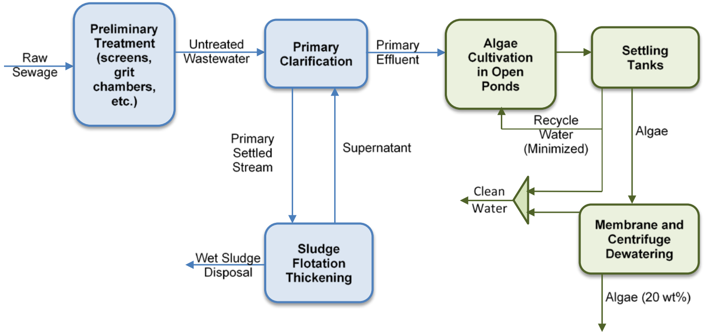
- **Prioritize dissemination** of information: e.g. Excel algae farm TEA tool available publicly:
  - ***~19,000 downloads** of TEA reports **(past 3 years)***

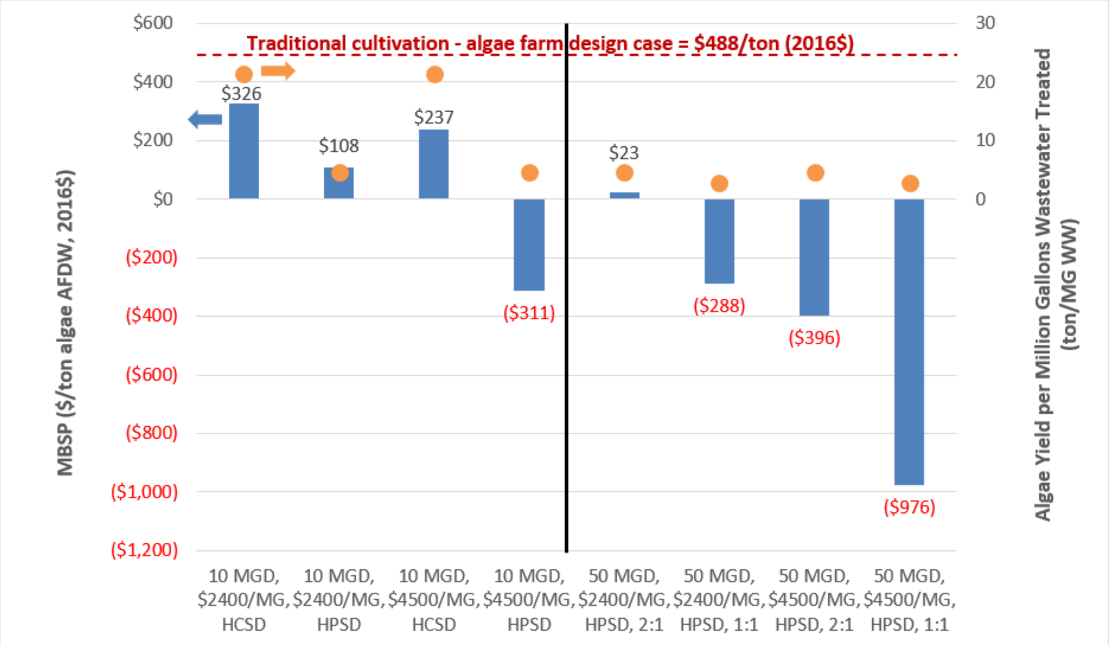
https://www.nrel.gov/extranet/biorefinery/aspen-models/

4. Progress and Outcomes

TEA Screening Identifies Opportunities for Algae WWT

- FY19: feasibility TEA to quantify benefits for valorizing treated wastewater
- Expanded on prior literature studies, supported by inputs from MicroBio
- All scenarios highlighted **lower MBSPs vs traditional cultivation** (many cases near $0 or negative) – opportunities to support higher-cost systems (PBRs)
- Similar results on tertiary treatment for N/P mitigation
- Publication in progress



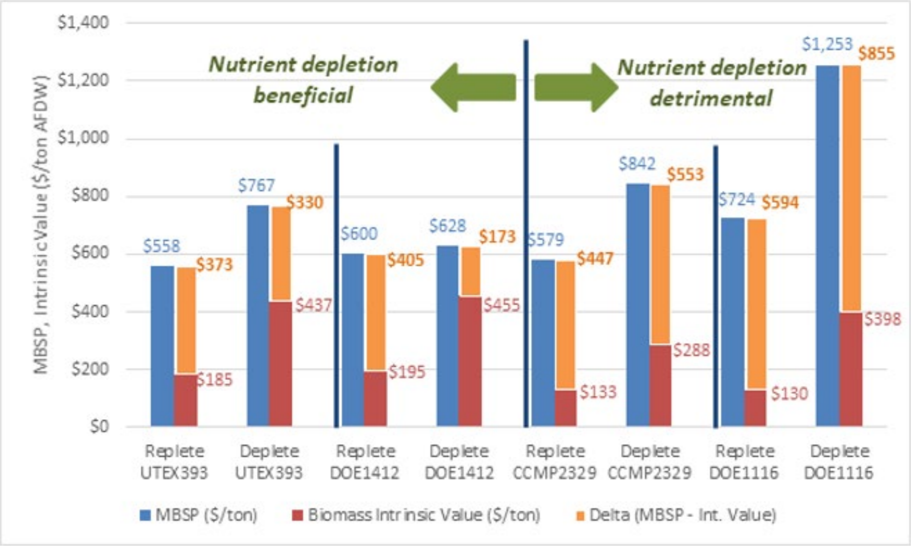


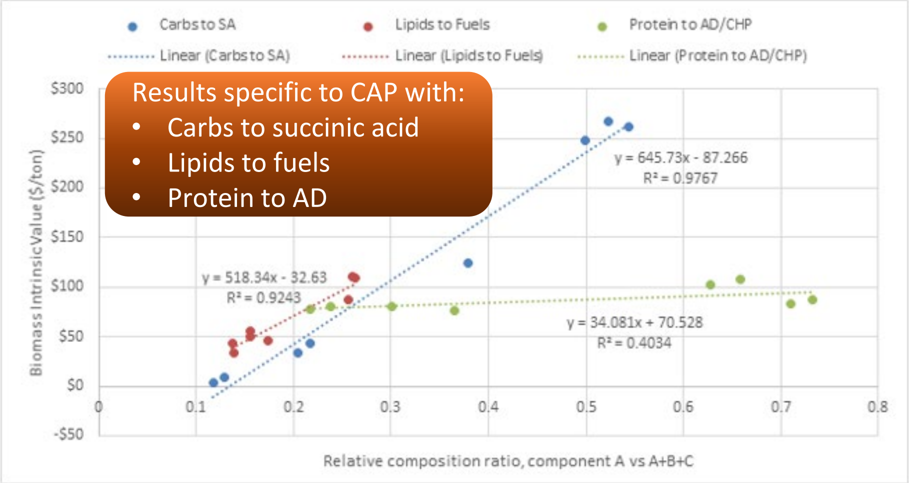
	10 MGD, $2400/MG, HCSD	10 MGD, $2400/MG, HPSD	10 MGD, $4500/MG, HCSD	10 MGD, $4500/MG, HPSD	50 MGD, $2400/MG, HPSD, 2:1	50 MGD, $2400/MG, HPSD, 1:1	50 MGD, $4500/MG, HPSD, 2:1	50 MGD, $4500/MG, HPSD, 1:1
Algal biomass potential, MM ton/yr (base)	29.2	6.2	29.2	6.2	6.2	3.8	6.2	3.8
Algal biofuel potential BGGE/yr (base)	2.5	0.5	2.5	0.5	0.5	0.3	0.5	0.3
Algal biomass potential, MM ton/yr (high)	58.4	12.4	58.4	12.4	12.4	7.5	12.4	7.5
Algal biofuel potential BGGE/yr (high)	4.9	1.0	4.9	1.0	1.0	0.6	1.0	0.6
Algae farm size (acres)	2150	470	2150	470	2353	1473	2353	1473

4. Progress and Outcomes

TEA Modeling Demonstrates New Approaches and User Correlations for Quantifying Algal Biomass Value

- Joint work under NREL's Algae TEA and Algal Biomass Composition projects highlighted a new means of assessing the "value" of algal biomass based on its composition
- Applied to DISCOVR strains run under nutrient replete and deplete harvesting – showed some strains are beneficial, others detrimental to allow shifting to deplete
- Developed **user correlations to quickly estimate biomass "value" contributions** from carbs, lipids, protein fractions independently (specific to one CAP fuel/product configuration)





Biomass value ($/ton AFDW) = A × Fermentable Carbohydrates + B × FAME lipids + C × Protein + X

For this CAP product suite: A = 655; B = 518; C = 34; X = -49

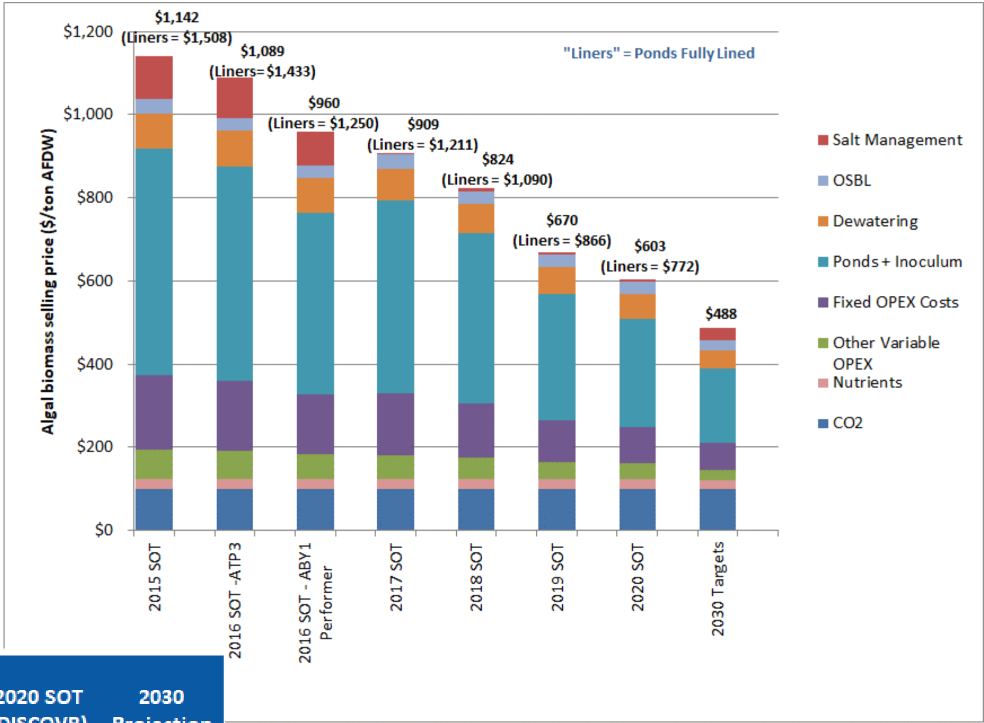
TEA modeling highlights degree of benefit or penalty moving from nutrient replete to deplete harvesting of algal biomass

Cost correlations for algal biomass intrinsic value from carbs, lipids, protein fractions of biomass

4. Progress and Outcomes

NREL TEA Sets SOT Benchmarks

- Incorporated cultivation data from DISCOVR partners to support SOT
- Continued experimental progress demonstrated across FY19-20 trials:
  - Achieved **36% increase in FY19 annual average productivity** vs FY18 (enabled by better contamination control, optimal strains)
  - Exceeded **31 g/m²-day for FY20 summer season** (enabled by switch from *Scenedesmus* UTEX393 to *P. celeri* strain – superior growth and contamination resistance)
  - Achieved **>15% FY20 increase to annual average >18 g/m2-day**



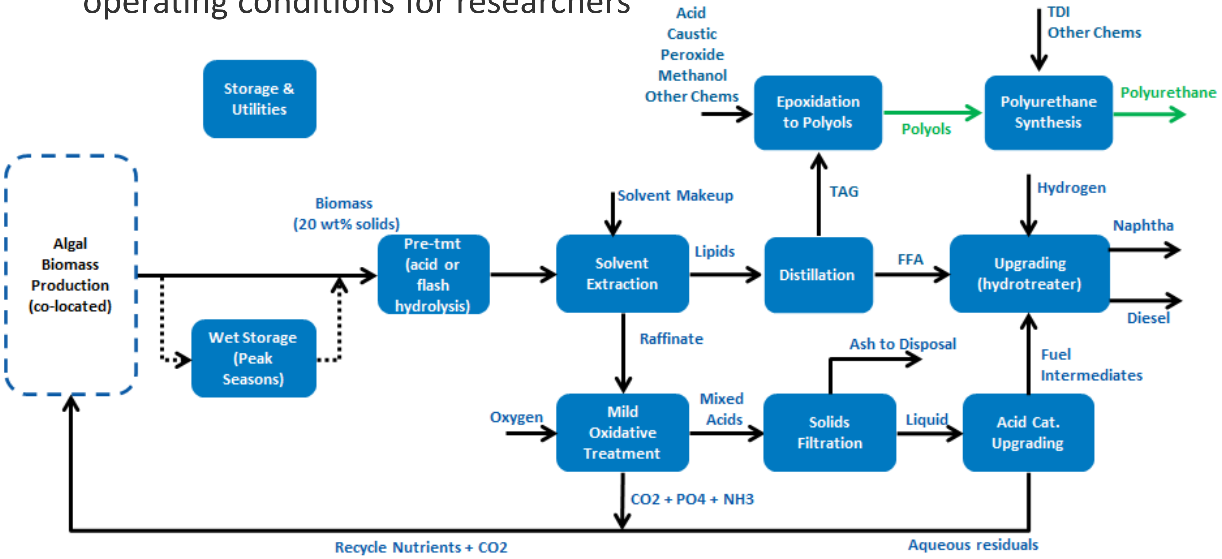
Productivity (g/m²-day)	2015 SOT (ATP³)	2016 SOT (ATP³)	2016 SOT (ABY1 Performer)	2017 SOT (ATP³)	2018 SOT (ATP³/ DISCOVR/ RACER)	2019 SOT (DISCOVR)	2020 SOT (DISCOVR)	2030 Projection
Summer	10.9	13.3	17.5	14.1	15.4	27.1	31.6	35.0
Spring	11.4	11.1	13.0	13.2	15.2	18.6	18.5	28.5
Fall	6.8	7.0	7.8	8.5	8.5	11.4	15.0	24.9
Winter	5.0	5.0	4.8	5.5	7.7	6.4	8.3	11.7
Average	**8.5**	**9.1**	**10.7**	**10.3**	**11.7**	**15.9**	**18.4**	**25**
Max variability	**2.3:1**	**2.7:1**	**3.6:1**	**2.6:1**	**2.0:1**	**4.2:1**	**3.8:1**	**3.0:1**
MBSP ($/ton, 2016$)	**$1,142**	**$1,089**	**$960**	**$909**	**$824**	**$670**	**$603**	**$488**

- *FY20 vs FY19 SOT: 10% MBSP reduction*
- *5-year progression:* ***47% MBSP reduction, 2.2X productivity increase*** *since FY15 basis*

4. Progress and Outcomes

Publication of CAP Conceptual Update Technical Report

- Tech report published Sept 2020 – reflective of newer NREL CAP research on mild oxidative treatment (MOT)
- Schematic focuses on flash hydrolysis, solvent extraction, lipids to fuels + PU, carbs + protein to fuels via MOT and catalytic upgrading
- Envisioned to allow for better feedstock composition flexibility, potential to accommodate higher-protein algae
- Aspirational projections highlight **what would be required to achieve ~$2.5/GGE MFSP** through this new pathway – set constraints on MOT operating conditions for researchers




NREL

Conceptual Basis and Techno-Economic Modeling for Integrated Algal Biorefinery Conversion of Microalgae to Fuels and Products

2019 NREL TEA Update: Highlighting Paths to Future Cost Goals via a New Pathway for Combined Algal Processing

Ryan Davis,[1] Matthew Wiatrowski,[1] Christopher Kinchin,[1] and David Humbird[2]

1 National Renewable Energy Laboratory
2 DWH Process Consulting LLC

NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy Operated by the Alliance for Sustainable Energy, LLC

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Contract No. DE-AC36-08GO28308

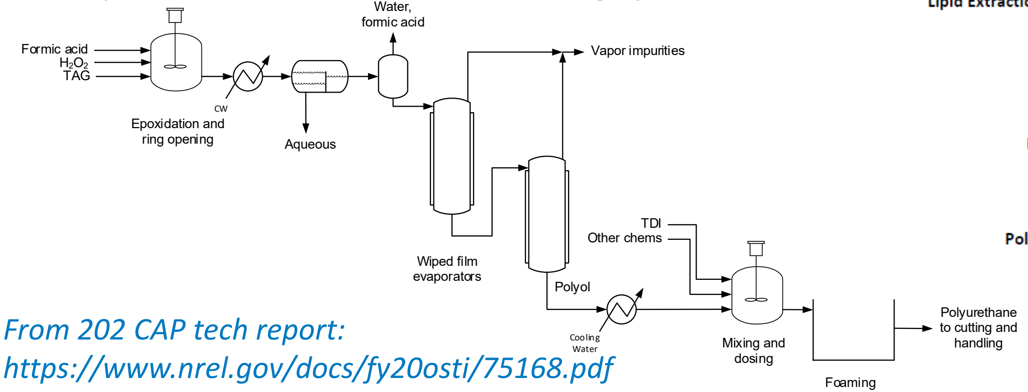
Technical Report
NREL/TP-5100-75168
September 2020

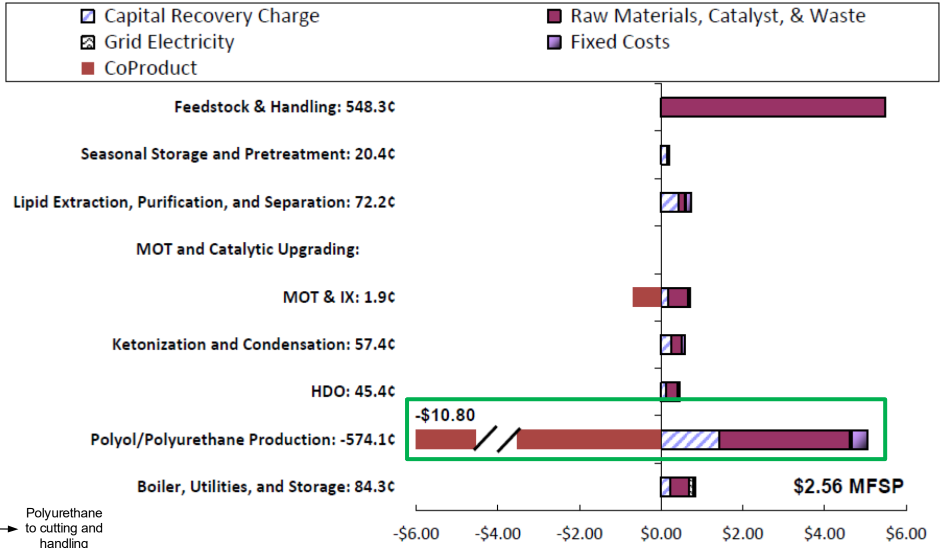
https://www.nrel.gov/docs/fy20osti/75168.pdf

4. Progress and Outcomes

Expanded Focus on Algal Polyurethanes: Opportunities to Enable Algal Biorefineries

- Significant effort has been placed over FY19-21 to understand **technical, market, economic opportunities for PU** as a key value-added coproduct for CAP approaches
- TEA highlights strong sensitivities to both processing costs and market values on overall MFSP
- In light of this, we placed an engineering subcontract with Nexant to refine design/cost details (included in 2020 tech report), and consulted with UCSD/Algenesis to refine process details (included in SOT)
- One example of a unique opportunity with high value and large markets to enable algal biofuels
- New modeling (Q1 FY21) also done to evaluate **non-isocyanate PU (NREL R&D focus)**
- Promising opportunities for NIPU to further reduce costs and improve environmental/safety profile avoiding isocyanates → **~$1/GGE MFSP savings possible**





From 202 CAP tech report: https://www.nrel.gov/docs/fy20osti/75168.pdf

Quad Chart Overview

Timeline
- Project start date: Oct 1, 2010
- Project end date: Sept 30, 2021 (ongoing cycle)

	FY20	Active Project
DOE Funding	$350k (10/01/2019 – 9/30/2020)	$3.0 MM (Total FY11 – FY21)

Project Partners
- No partners with shared funding (but collaborate frequently with other algae analysis projects at ANL, PNNL, ORNL, INL, SNL; also tie-ins with DISCOVR)

Barriers addressed
- AFt-A: Biomass Availability and Cost
  - *This project quantifies biomass + fuel costs*
- AFt-H: Integration
  - *TEA models tie all R&D operations together*

Project Goal
Provide techno-economic modeling and analysis to support algae-related program activities. This is done by creating process/TEA models for production AND conversion of algal biomass to fuels and co-products, in order to relate key process parameters with overall economics and to track progress via SOT benchmarks towards BETO goals.

End of Project Milestone
Submit final draft for publication approval: Near-term opportunities for utilization of algal biomass resources: A CAP biomass utilization report draft will be subjected to an external review process, soliciting inputs from at least 5 reviewers to vet the modeling assumptions documented in the report, and the final draft will be delivered to BETO for subsequent publication approval. The report will demonstrate at least one algal CAP pathway strategy towards achieving economical fuels and products attributed to processing algal biomass that may be collected, in whole or as a residual by-product, from existing activities being pursued in the algae industry.

Funding Mechanism
Direct AOP funding

Summary

Product	Anticipated decrease in gasoline/ethanol demand; diesel demand steady
Product	Increasing demand for aviation and marine fuel
Product	Demand for higher-performance products
Product	Increasing demand for renewable/recyclable materials
Feedstock	Sustained low oil prices
Feedstock	Decreasing cost of renewable electricity
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Social Responsibility	Carbon intensity reduction
Social Responsibility	Access to clean air and water
Social Responsibility	Environmental equity

NREL's Bioenergy Program Is Enabling a Sustainable Energy Future by Responding to Key Market Needs

Summary

- **Management:** Iterate/collaborate with researchers to **maximize efficiency of R&D dollars**
- **Approach: Continuous re-evaluation** for optimal cost impact, vetting TEA details with expert stakeholders
- **Impact:** High impact via **frequent external engagement**, focus on **transparent dissemination** of work
- **Outcomes:** Work is key to supporting BETO mission by **highlighting requirements to achieve economic viability**, benchmarking progress towards goals

Future Work

- Publish *joint manuscript with SNL/Algix* on "CAP processing opportunities for high-protein algae"
- TEA assessment to support "**today's industry opportunities**": collection, processing, conversion costs for *current algae resources* (wastewater, algal blooms, byproduct/residual biomass, etc)
- Further expand on **algal polyurethane/NIPU TEA modeling to support commercial adoption**

Acronyms

- AD = anaerobic digestion
- AFDW = ash free dry weight
- BDO = 2,3-butanediol
- CA = carboxylic acids
- CAP = Combined Algae Processing (biochemical algae conversion process)
- Design case = future technical target projections to achieve TEA cost goals
- GGE = gallon gasoline equivalent
- MBSP = minimum biomass selling price
- MFSP = minimum fuel selling price
- MOT = mild oxidative treatment
- MYP = BETO’s Multi-Year Plan (formerly MYPP = Multi-Year Program Plan)
- NIPU = non-isocyanate polyurethanes
- PU = polyurethanes
- SOT = state-of-technology (annual benchmarking to update TEA based on latest R&D data)
- TEA = techno-economic analysis
- WWT = wastewater treatment

Acknowledgements:

- Matt Wiatrowski
- Bruno Klein
- Chris Kinchin
- Lieve Laurens
- Jake Kruger
- Tao Dong
- Phil Pienkos
- Zia Abdullah
- Dave Humbird, DWH consulting
- Nexant
- DISCOVR consortium

Thank you!
Questions?

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This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, Bioenergy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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Additional Slides

Responses to Previous Reviewers' Comments

- The project team continues to build on their experience strengthening the value of the TEA data to drive the prioritization of R&D activities. There is a now a great opportunity to explore the interactions between cost and value drivers as well as refine areas such as the impact of crop protection in cultivation. It will be great to see further development of the tool as stakeholders begin to use the model and provide feedback.
- We thank the reviewers for their positive feedback in recognizing the utility of this project for BETO and the algae community. We do hope to further develop and refine the newly-published algae farm TEA tool to maximize its utility based on feedback from stakeholders. Since the last peer review, we have continued to expand on the algal biomass cost-versus-value tradeoff considerations, including establishment of a new "intrinsic value" calculation methodology that enables a user to rapidly estimate the value of biomass based on its harvested composition, reflecting one example CAP conversion configuration and product suite. We have also worked to quantify the impact of crop protection on resultant MBSPs, based on data furnished from DISCOVR for the use of fungicide (Fluazinam). Based on the dosage and frequency of fungicide use, its application is not seen to dramatically penalize MBSP. This has also been further explored under our contributions to the TEA subtask of the DISCOVR consortium.

- More work needs to be done on (a) saline water growing systems, (b) cost of CO2 carbon capture vs that of terrestrially deliverable CO2, and (c) incorporating multiple sources on data instead a singular site.
- Over recent years, the focus for algae cultivation (both experimentally and in TEA modeling) has shifted to focus primarily on saline cultivation under NREL/BETO activities. This includes recent harmonization efforts to understand resource scalability projections with saline water sourcing, as well as SOT trials requiring at least 5 ppt salinity tolerance for all strains of focus (most recently, *P. celeri* was cultivated in 50 ppt salinity in support of summer season FY20 SOT data). We continue to investigate TEA implications across a variety of CO2 sourcing scenarios, primarily focused on carbon capture and (under FOA partnerships) direct air capture, though terrestrial CO2 is generally viewed as problematic given it would represent non-biogenic CO2 emissions upon release. We also would welcome the opportunity to incorporate additional data sources/locations in support of SOT inputs, as such data availability would allow.

Publications, Patents, Presentations, Awards, and Commercialization

Publications (since 2019 review):

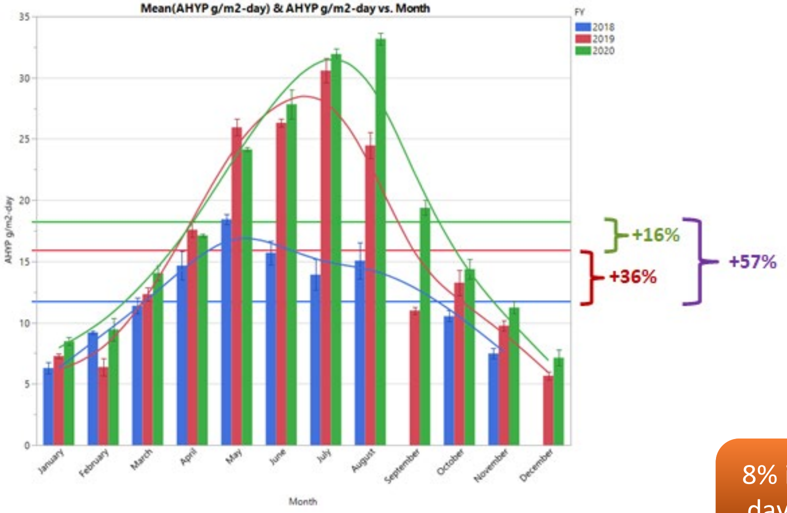
- R. Davis, M. Wiatrowski, C. Kinchin, D. Humbird. "Conceptual basis and techno-economic modeling for integrated algal biorefinery conversion of microalgae to fuels and products. 2019 NREL TEA update: Highlighting paths to future cost goals via a new pathway for Combined Algae Processing." NREL/TP-5100-75168, September 2020: https://www.nrel.gov/docs/fy20osti/75168.pdf.
- R. Davis, L. Laurens. "Algal biomass production via open pond algae farm cultivation: 2019 State of Technology and future research." NREL/TP-5100-76569, April 2020: https://www.nrel.gov/docs/fy20osti/76569.pdf.
- R. Davis, M. Wiatrowski. "Algal biomass conversion to fuels via Combined Algae Processing (CAP): 2019 State of Technology and future research." NREL/TP-5100-76568, April 2020: https://www.nrel.gov/docs/fy20osti/76568.pdf.
- J. Clippinger, R. Davis. "Techno-economic analysis for the production of algal biomass via closed photobioreactors: Future cost potential evaluated across a range of cultivation system designs." NREL/TP-5100-72716, September 2019: https://www.nrel.gov/docs/fy19osti/72716.pdf.
- L.M. Wendt, C. Kinchin, B.D. Wahlen, R. Davis, T.A. Dempster, H. Gerken. "Assessing the stability and techno-economic implications for wet storage of harvested microalgae to manage seasonal variability." *Biotechnology for Biofuels* 2019, 12:80.
- H. Cai, L. Ou, M. Wang, E. Tan, R. Davis, A. Dutta, L. Tao, D. Hartley, M. Roni, D. Thompson, L. Snowden-Swan, Y. Zhu *(report coordinated by ANL)*. "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 2019 State-of-Technology cases." ANL technical report, April 2020. https://greet.es.anl.gov/publication-renewable_hc_2019

Presentations (since 2019 review):

- R. Davis, "Techno-economic analysis for the production of algal biomass: Process, design, and cost considerations for future algae farms." 2019 International Biofuels and Bioenergy Conference, April 29, 2019, San Francisco, CA.

Backup Slides

DISCOVR Cultivation Data: Inputs to SOT



- June/July/August FY20 trials revealed major challenges with new pest for UTEX393 – would lead to summer decline vs 2019
- Frequent crashing due to new (unidentified) bacterial pest, no good contamination control measure found

- Replacing UTEX393 with *P. celeri* values as new FY20 summer strain
  - Exceeded **31 g/m2-day** for the summer season
  - Exceeded the 10% annual improvement target in annual year over year SOT
  - **Achieved >15% increase to an annual average of >18 g/m2-day**

Slide credit: John McGowen, DISCOVR

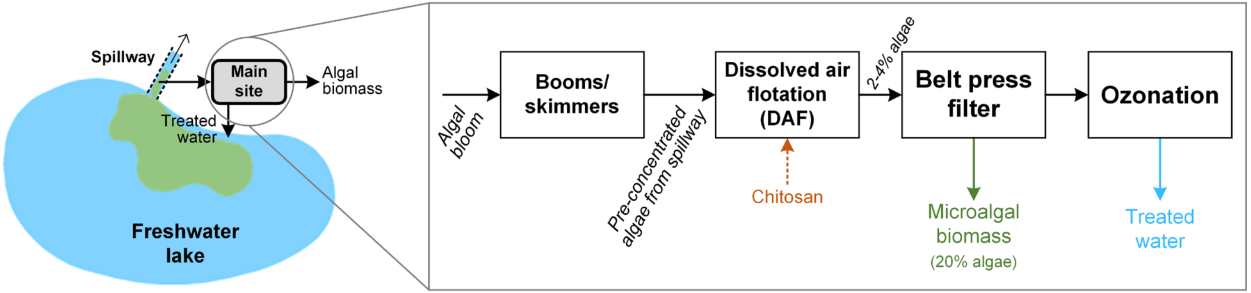
8% increase in total cultivation days (97% - now exceeds 90% SOT basis)

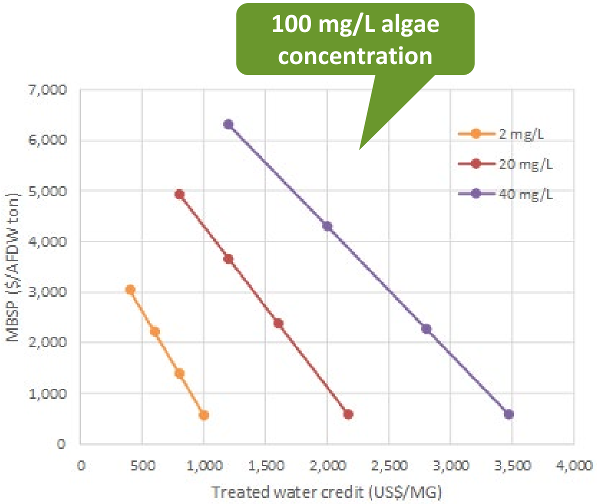
		FY2019 SOT						FY2020 SOT						%
Season	Month	Productivity g/m2-day	AFDW at Harvest g/L	Strain	Days	Ops co	Avg. Stdev	Productivity g/m2-day	Harvest g/L	Strain	Days	Ops cond.	Season Avg. Stdev	Gain/Loss YOY
Fall	September	11.0	0.29	C046	16	20cm/SC	**11.4**	**19.4**	0.35	UTEX393	29	20cm/SC	**15.0**	**32.0%**
	October	13.3	0.38	26BAM	23	20cm/SC	1.8	**14.4**	0.35	26BAM	30	20cm/SC	4.1	
	November	9.8	0.57	26BAM	27	20cm/SC	RSD = 16%	**11.2**	0.36	26BAM	28	20cm/SC	RSD = 27%	
Winter	December	5.7	0.58	26BAM	38	10cm/SC	**6.5**	**7.1**	0.35	26BAM	34	20cm/SC	**8.3**	**28.9%**
	January	7.3	0.52	26BAM	24	10cm/SC	0.8	**8.5**	0.72	26BAM	31	10cm/SC	1.2	
	February	6.4	0.43	26BAM	28	10cm/SC	RSD = 12%	**9.4**	0.60	26BAM	28	10cm/SC	RSD = 14%	
Spring	March	12.3	0.68	26BAM	31	10cm/SC	**18.6**	**14.1**	0.58	26BAM	31	10cm/SC	**18.5**	**-0.9%**
	April	17.6	0.66	26BAM	28	10cm/SC	6.9	**17.1**	0.33	UTEX393	32	20cm/SC	5.2	
	May	26.0	0.46	UTEX393	28	20cm/SC	RSD = 37%	**24.2**	0.33	UTEX393	30	20cm/SC	RSD = 27%	
Summer	June	26.3	0.44	UTEX393	27	20cm/SC	**27.1**	**27.1**	0.40	*P. Celeri*	19	20cm/SC	**31.6**	**16.4%**
	July	30.6	0.48	UTEX393	30	20cm/SC	3.1	**31.9**	0.49	*P. Celeri*	30	20cm/SC	4.4	
	August	24.5	0.37	UTEX393	28	20cm/SC	RSD = 11%	**35.8**	0.56	*P. Celeri*	31	20cm/SC	RSD =	
					328		**15.9**				**353**		**18.4**	**15.4%**

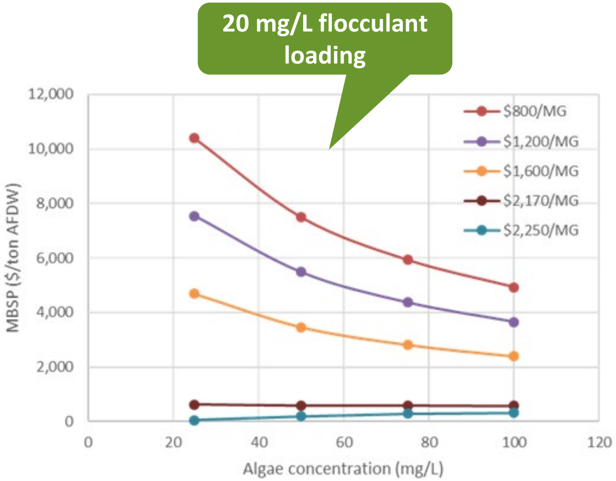
Productivity improvement driven by fall, winter, summer

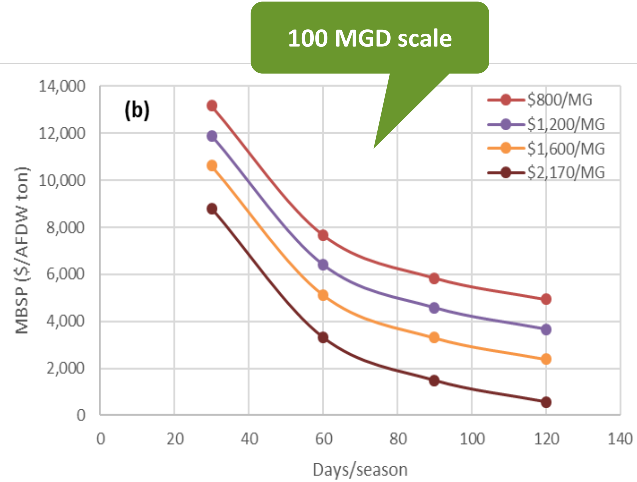
TEA Screening: Costs/Opportunities for Algal Bloom Biomass

- Conducted preliminary screening study on HAB collection/logistics and conversion opportunities based on public info









Algal Bloom Biomass: Preliminary Conclusions

- Opportunities for conversion: HTL (if low carbs), fermentation to products (if high carbs), protein to products (bioplastics), AD
- High-level screening considered AD for biogas

Parameter	Value			
Distance between plants (miles)	0 (co-located)	10	50	100
Total cost with transportation (k$/year)	0	196	263	347
Transportation cost ($/ton)	0	52	70	92
Required treated water credit to reach total biomass price of $45/ton ($/MG)	**2,340**	**2,355**	**2,360**	**2,365**

$45/ton MBSP required to achieve AD biogas cost parity with natural gas ($3.50/MM BTU)

- Go/No-Go: Establish whether sufficient understanding exists to allow for in-depth TEA study on HAB in early FY21 (Go) or must be deferred to collect more info (No-Go)
  - Outcome = NO-GO – not yet sufficient information available, high uncertainties based on limited public data – must first collect more information to reduce uncertainties
- Path forward:
  - Solicit further engagement with industry experts
  - Overall resource availability assessment for HAB scale in U.S.
  - Evaluate other collection/harvesting options, more granularity on energy + flocculent consumption as a function of incoming algae concentration
  - Consideration for HAB collection from open sea