U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

U.S. Department of Energy (DOE)
Bioenergy Technologies Office (BETO)

2019 Project Peer Review

1.3.3.100:
Algal Feedstock Logistics and Handling

This presentation does not contain any proprietary, confidential, or otherwise restricted information

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Advanced Algal Systems

Goal Statement

Utilize feedstock logistics operations to develop process technologies that preserve and even improve quality of algae biomass prior to downstream conversion

Project Outcomes

- Task 1: A process that both preserves harvested microalgae biomass over a six-month period in order to manage seasonal production variation and also enables a biorefinery to run year-round with a consistent feedstock supply

- Task 2: A process to improve the quality of biomass derived from an algal turf scrubber (ATS) through ash reduction that could be applicable to multiple high-ash algae species

Quad Chart Overview

Timeline
- Project start date: 04/01/2015
- Project end date: 9/30/2019
- Percent complete: 75%

	Total Costs (Pre FY17)	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded	$490K	$800K	$800K	$800K

Partners:

NREL: 1.3.4.201 - CAP Process Research; 1.3.1.200 Algal biofuels techno-economic analysis

SNL: 1.3.1.103 - Algae Polyculture Production and Analysis

PNNL: 1.3.4.101 - Thermochemical Interface; 1.3.2.501 - DISCOVR

Arizona State University (AzCATI)

Colorado State University

Barriers addressed
- Aft-F. Algae Storage Systems
- Aft-G. Algal Feedstock Material Properties

Objective
- Use feedstock supply chain logistics to enable cost-effective, consistent, high-quality biomass supply for a biorefinery

End of Project Goals
- Task 1: A 6-month wet stabilization approach that limits losses to 10% for harvested microalgae, reducing costs and energy consumption compared to drying and dry storage
- Task 2: A process that reduces 75% of relevant inorganic species including silicon, chloride, and alkali and alkaline earth metals while retaining 90% of organic material such that downstream conversion costs are reduced

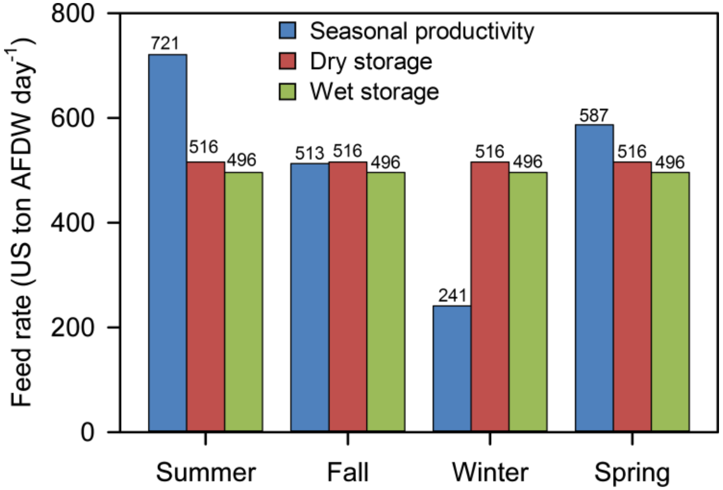
Project Overview: Task 1 Stabilization

Feedstock logistics studies are essential to ensure that the maximum amount of biomass harvested is converted to valuable fuels and co-products

Algae Production	Feedstock Logistics	Conversion
Variable ash, moisture, viscosity	Stabilize feedstock, manage variability	Depends on available, consistent, on-spec & economical feedstock

Managing seasonality through stabilization of harvested algae

- Productivity swings due to seasonal variation necessitate long-term stabilization to maximize conversion efficiency
- Drying is expensive, and dry storage stability is unknown in hot, humid environments
- Near-term approach: Blending with agricultural crops and wet anaerobic storage offers long-term stability and is compatible with existing agricultural practices
- Long-term approach: Microalgae can be stabilized at 20 wt% solids and used in low productivity months



Seasonal productivity of algae growth

Wendt, Kinchin, et al., submitted to Biotechnology for Biofuels, in review

Project Overview: Task 2 Ash Reduction

Feedstock logistics studies are essential to ensure that the maximum amount of biomass harvested is converted to valuable fuels and co-products

Algae Production → **Feedstock Logistics** → **Conversion**

Algae Production	Feedstock Logistics	Conversion
Variable ash, moisture, viscosity	Stabilize feedstock, manage variability	Depends on available, consistent, on-spec & economical feedstock

Improve biomass quality through ash removal

- Ash is undesirable in conversion
  - Abrasive
  - Corrosive
  - Creates void space in conversion reactor, increasing CAPEX
- Algal turf scrubbers are a promising technology, but the biomass can contain 60-65% ash
- The undesirable impacts of ash present in all outdoor growth platforms will become significant as the industry scales up

Algae Type	Ash Content	Reference
Freshwater	4.5%	Dong 2016
Seawater	14%	Dong 2016
Diatom	20%	Cheng 2015
Wastewater	40%	Chen 2017
Turf Scrubber	> 65%	Aston 2018

Dong et al, 2016, *Algal Res.*, 18, 69-77
Cheng et al, 2015, *J. Biosci. Bioeng.*, 120, 161-166
Chen et al, 2017, *Algal Res.*, 25, 297-306
Aston et al, 2018, *Algal Res.*, 35, 370-377

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Management Approach

Engage diverse national laboratory capabilities through collaboration

- Measure cost impacts through TEAs (INL, NREL, CSU) to compare solutions to SOT (State of Technology)
- Measure impacts of storage treatments in multiple conversion approaches through collaboration (e.g. NREL, PNNL)

Quarterly, Annual and Go/No-Go Milestones provide framework for meeting aggressive goals

Interaction with BETO promotes relevance to DOE and industry

- Annual Operating Plans (AOPs) used to define research path and work scope
- Quarterly progress reports and milestones document step-wise progression of research
- Monthly presentations for BETO provide framework for information sharing and feedback
- Participation in biweekly calls with DISCOVR team to discuss outdoor cultivation for SOT reports

Technical Approach – Task 1: Stabilization

Goal: A 6-month wet stabilization approach that limits losses to 5-10%

Background: Wet anaerobic storage is an alternative to drying and dry storage

- Currently available infrastructure for agriculture: >150 million tons forage harvested/year in US
- Dry matter loss in animal feed <5%
- Anaerobic conditions: Air is mechanically excluded
- Lactic acid fermentation stabilizes algae (lowers pH)

Approach: Understand fundamentals at small scale and then demonstrate at large scale with conversion performance

1. Blending with terrestrial feedstock for stabilization:
   - 2015-2016: Research focused on understanding optimal blend ratios and compositional effects of storage
   - 2017-2018: Scale up to 500-mL and 20-L reactors, thermochemical conversion testing with PNNL
2. Stabilization of freshly-harvested microalgae (20 wt% solids):
   - 2017-2019: Optimal storage conditions determined, scale up to 500 mL, biochemical conversion testing with NREL

Technical Approach – Task 2: Ash Removal

Goal: Improve quality of biomass harvested from algal turf scrubber (ATS)

Background: Despite high productivities and water remediation opportunities for ATS systems, ash content for this biomass is consistently > 50 wt%

Approach: Develop methods that can be applied to multiple biomass types and growth platforms

- Understand ash components, most linear with soil inorganic elements
  - Elemental analysis, XRD analysis, SEM imaging, particle size analysis
- Perform ash removal via physical and chemical approaches
  - Water extraction targets soluble components
  - Alkaline extraction targets silica
  - Fractional separation approaches isolate biomass from soil particles
- Use techno-economic analysis to evaluate feasibility and determine boundary conditions for ash removal

Algal Turf Scrubber at Corpus Christi, TX site

Technical Approach

Challenges

Task 1:

- Herbaceous biomass is senesced in storage; algae is metabolically active
- Bacteria in outdoor growth systems can destabilize harvested cultures
- Nutrients in media (e.g. ammonia) can counteract stabilizing acids

Task 2:

- Little is known about impact of ash in algae preprocessing and conversion
- Mechanical approaches are often used for forest residues contaminated with soil, but soil components and algae are a complex mixture, especially when wet
- Ash is highly variable based on location and seasonality
- Biogenic ash in diatom fraction of ATS biomass contains silica in both the cell wall and intracellular silica

Critical Success Factors

- Cost competitiveness
- Sustainable designs to reduce water and energy requirements
- Peer-reviewed publications and conference presentations
- Application of approaches in industrially-relevant species and multiple end-uses

Task 1 Accomplishments – Blend Stabilization

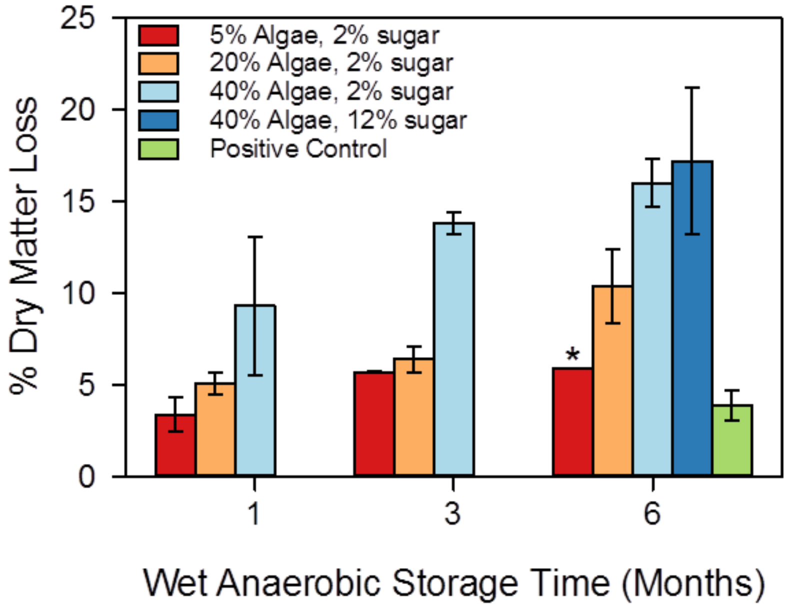
Goal: Determine if wet storage can reduce dry matter loss to less than 30% over 6 months, which is a 50% improvement over wet algae stored aerobically (Go/No-Go Milestone, 3/30/17)

Accomplishment: *Scenedesmus obliquus/*corn stover blends were preserved over 6 months

Observed changes in composition

- Higher Heating Value (HHV) and carbon increase, oxygen decreases
- Carbohydrates are preserved over 6 months or decline proportionally with loss depending on blend ratio
- Protein and lipids are preserved

Impact: Long-term storage of blends containing 5-40% algae is an approach for stabilizing algae so that it can be used in low-productivity months



Wahlen *et al*., submitted to *Algal Research*

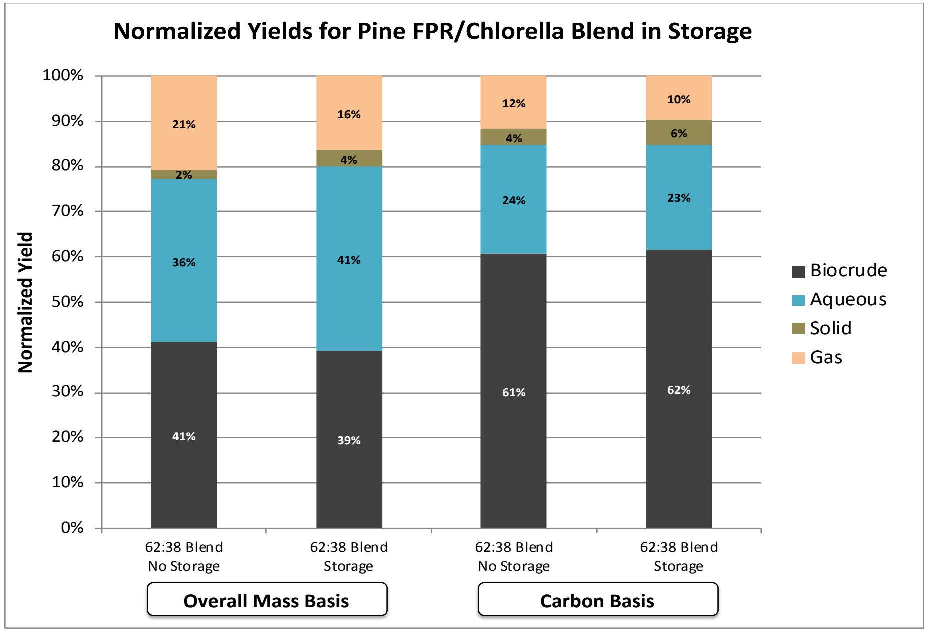
Task 1 Accomplishments – Blend Stabilization Cont.

Goal: Determine impact of stored blends on hydrothermal liquefaction and upgrading to fuel

Accomplishments:

- *Chlorella* blended with loblolly pine forest products residues (FPR) experienced 2.6% ± 1.3% dry matter loss after 123 days
- HTL and upgrading performed in continuous bench-scale unit at PNNL using 40L of slurry at 17.3% solids. Comparison to unstored *Chlorella*:pine blend
- No change observed in biocrude yield or upgraded fuel as a result of storage

Impact: Blending and storage can be used as an approach to manage seasonal variation in algae production



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Task 1 Accomplishments – Microalgae Stabilization

Goal: Optimize microalgae storage conditions

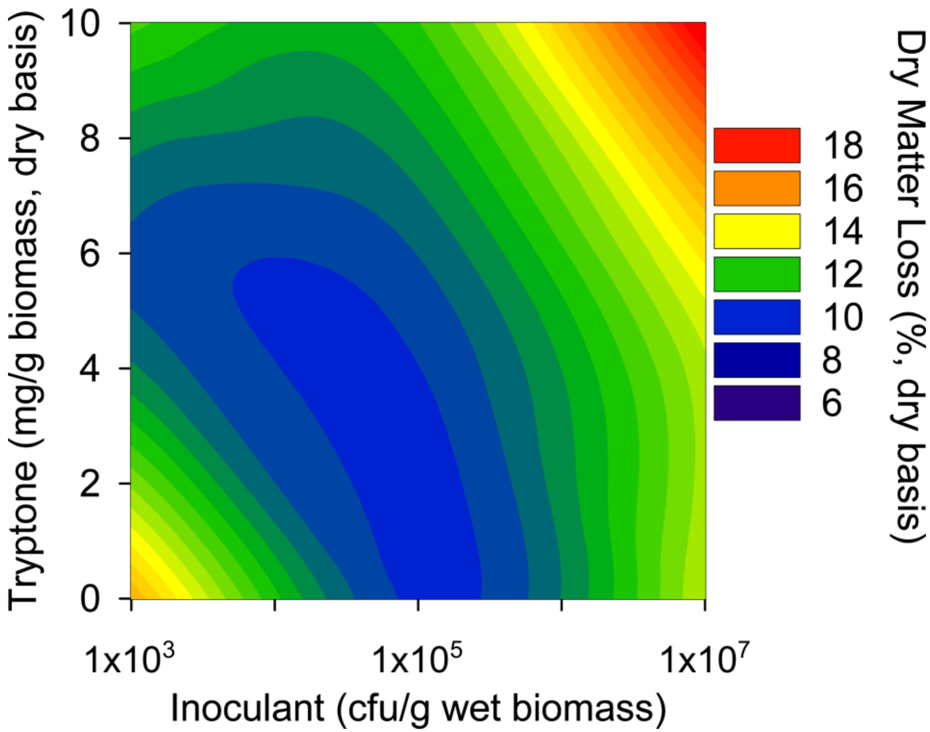
Background: Adding lactic and acetic acids reduced losses in anaerobic storage from 44% to 6% (Wendt et al, 2017, Algal Research) but isn't cost effective

Approach: Box-Behnken Design of Experiment. 7-day screening experiments to identify boundary conditions for preservation by varying the following:

- Sulfuric acid (liberate sugars for conversion, compatible with biochemical conversion)
- *Lactobacillus plantarum* (silage inoculum)
- Tryptone (amino acid source)

Accomplishment: Model was optimized for low DML

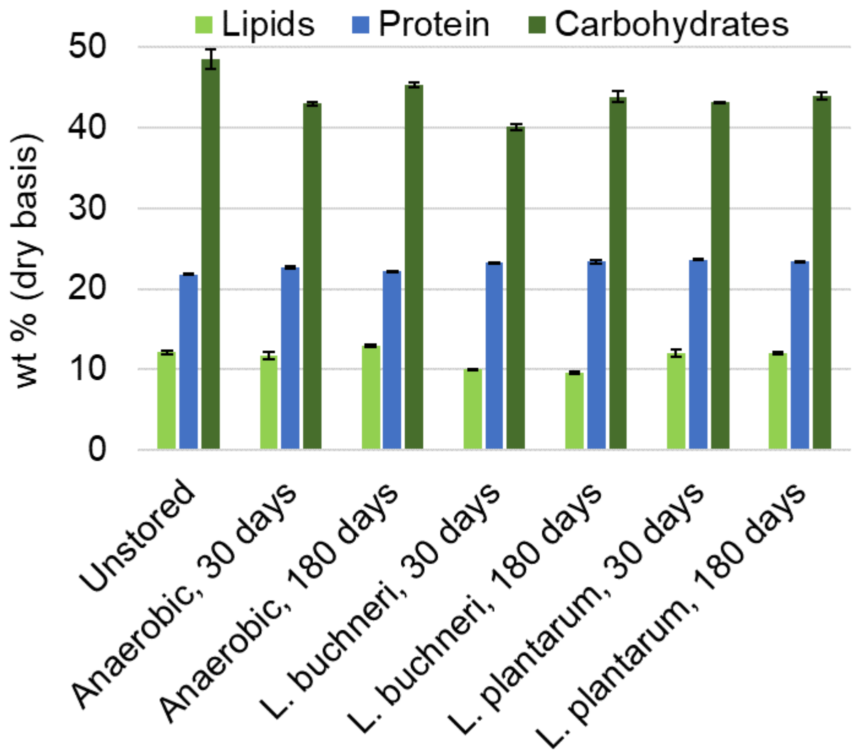
% Dry matter loss as a function of tryptone supplementation and *Lactobacillus plantarum* inoculum rate



Impact: Conditions for optimal anaerobic storage were determined that can be applied to multiple algal species and compositions

Task 1 Accomplishments – Microalgae Stabilization Cont.

Experimental Condition	Storage Duration (Days)	Total Dry Matter Loss (%, db)	Higher Heating Value (MJ/kg)
Unstored	-	-	23.4 ± 0.1
Anaerobic	30	3.3 ± 0.5	23.4 ± 0.3
	180	6.1 ± 0.7	23.0 ± 0.3
L. buchneri, tryptone	30	5.8 ± 0.4	23.6 ± 0.2
	180	8.3 ± 1.2	23.3 ± 0.1
L. plantarum, tryptone	30	5.2 ± 0.2	23.7 ± 0.1
	180	7.9 ± 1.0	23.2 ± 0.0



Goal: Assess long-term performance of *Scenedesmus* at mid-harvest growth conditions using modeled conditions

Accomplishment: 6-month storage resulted in low DML (8% or less) in all scenarios

- Carbohydrates reduced, protein increased, higher heating value (HHV) preserved
- Lipids preserved in anaerobic and *L. plantarum* conditions

Impact: Compositional changes post-storage can predict conversion performance

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Task 2 Accomplishments – Ash Reduction Cont.

Goal: Assess ash content and potential to reduce it through water and alkaline treatments

Approach:

- Biomass obtained from Corpus Christi, TX, site; water source is from estuary
- Biomass comprised of 75 wt% ash
  - Silica content in ash > 50 wt%
  - Saline water source results in ~20 wt% ash (sodium and chloride)
  - Soil components: Silica, aluminum, iron, potassium, magnesium
- Alkaline treatment used to solubilize silica
  - Methods developed for corn stover and pine were modified for algae
  - pH 10.5 required for silica solubilization
  - 4-hr incubation time resulted in reaching solubility limit of silica

Physiological ash

Saltwater ash

Soil ash

	Ash Composition (wt%)
SiO_2	51.0 ± 0.3
CaO	3.5 ± 0.1
SO_3	4.0 ± 0.1
MgO	4.9 ± 0.1
K_2O	2.5 ± 0.1
Na_2O	12.1 ± 0.5
Halides (Cl)	10.9 ± 0.9
Al_2O_3	9.8 ± 0.1
Fe_2O_3	3.5 ± 0.0

Modified from Aston *et al*., 2018, *Algal Research*

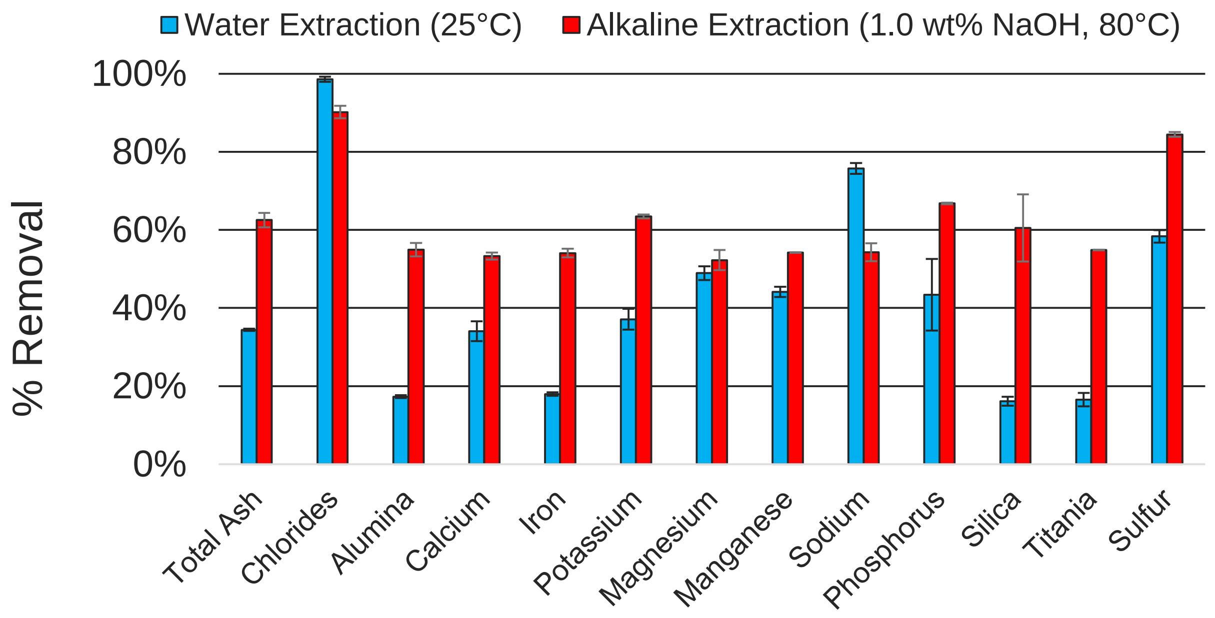
Task 2 Accomplishments – Ash Reduction Cont.

Goal: Assess removal of ash species with water and alkaline extraction

Accomplishments: Only minor temperature effect observed (20-80°C)

- Water washing (25°C) reduced ash to 46% with 99% organic recovery
- Alkaline treatment (1% NaOH at 80°C) reduced ash to 31% with 93% organic recovery. 60.5% of silica removed

Impact: Soluble ash constituents removed with water including sodium, chloride, and sulfur. Alkaline conditions necessary for solubilization of aluminum, iron, silica, and titanium



Modified from Aston *et al.*, 2018, *Algal Research*

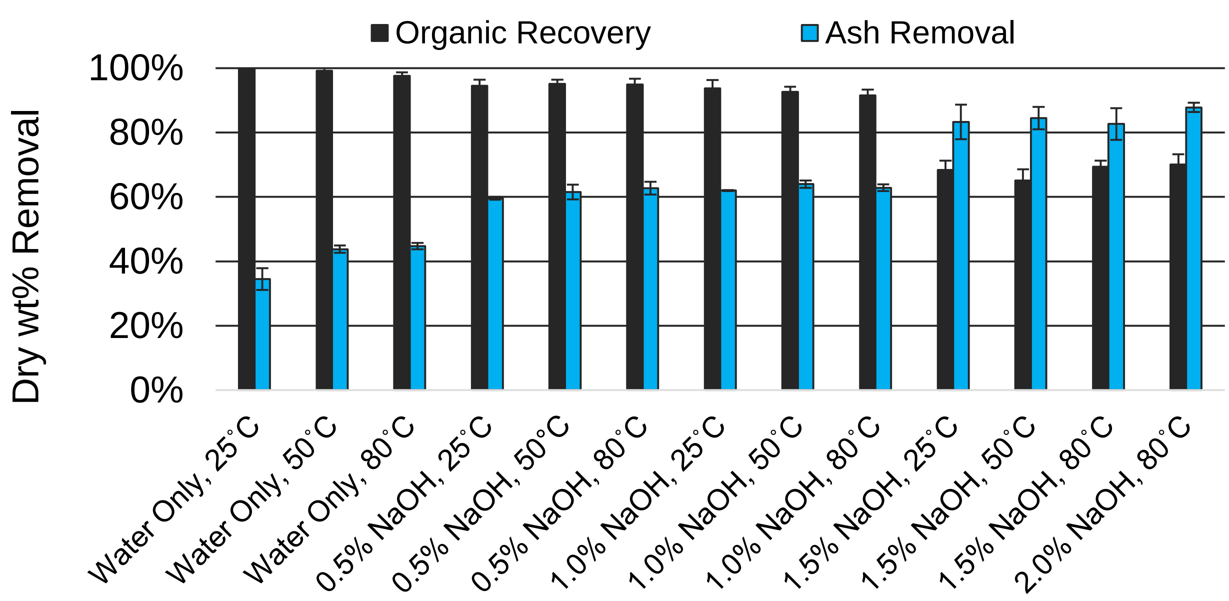
Task 2 Accomplishments – Ash Reduction Cont.

Goal: Determine optimal conditions for water and alkaline extraction by varying temperature and alkali concentration

Accomplishments: Only minor temperature effect observed (20-80°C)

- 0.5% NaOH resulted in similar ash removal to 1% NaOH but higher organic recovery
- 1.5 and 2% NaOH resulted in > 80% ash removal and only 65-70% organic recovery

Impact: Mild conditions (0.5% NaOH and 25°C) produced greatest inorganic removal with lowest loss of organics



Modified from Aston *et al.*, 2018, *Algal Research*

Task 2 Accomplishments – Ash Reduction Cont.

Goal: Understand how ash accumulates in a floway with a freshwater source

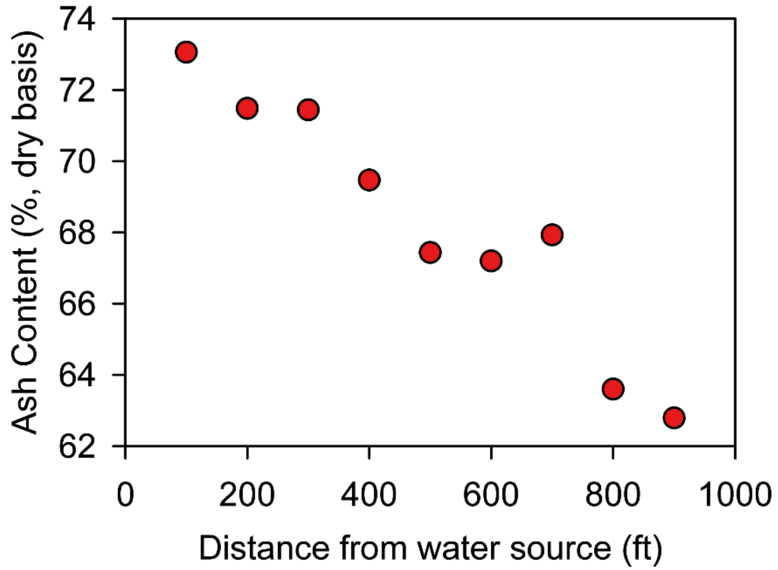
Assess ash content from 900-ft turf scrubber unit installed by SNL in Imperial Valley, CA

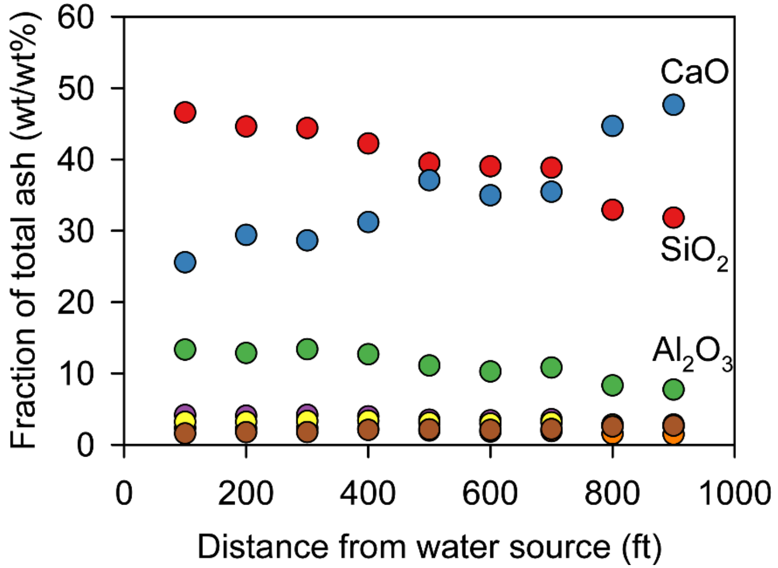
Water source is primarily agricultural runoff: settling pond sourced from Alamo River, tributary to Salton Sea, high in calcium

Accomplishments:

- 60-80 wt% ash along the floway depending on harvest date
- Silica (45-55 wt%) and alumina (13-15 wt%) highest at start of floway
- Calcium concentration high (25 wt%) doubles along floway

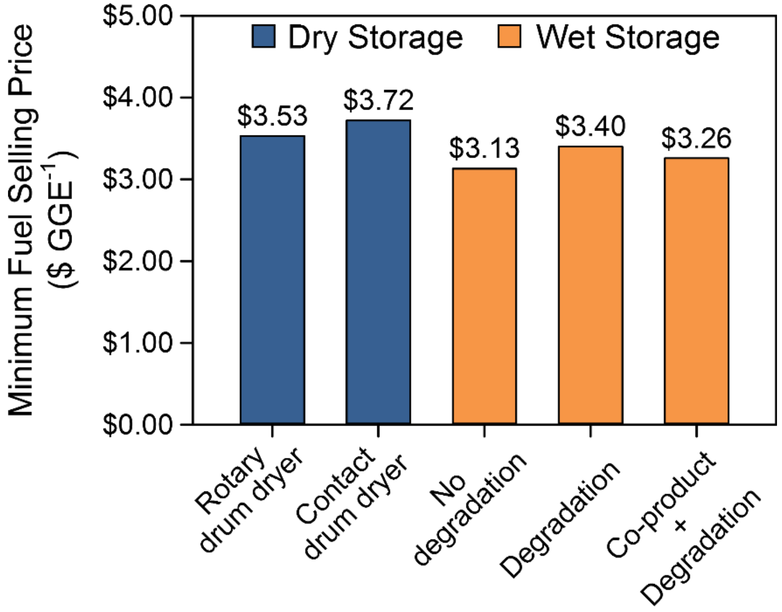
Impact: Ash removal approaches may be source water- and site-specific. Fundamental understanding of inorganic speciation necessary to effectively treat ash





Relevance – Task 1: Stabilization

- Wet storage offers opportunities to lower conversion costs and energy requirements through the elimination of drying in order to manage seasonal variation in production
- Techno-economic analysis performed by NREL based on assumptions in Design Cases
  - Algal Growth Model
  - Biochemical conversion: Succinic acid fermentation and lipid upgrading
- Drying and dry storage costs were higher than wet storage costs in all scenarios modeled
- Cost of degradation loss in wet storage is less than cost of drying and dry storage



Minimum fuel selling price (MFSP) of dry and wet storage scenarios in CAP process

Modified from Wendt, Kinchin, *et al*., submitted to *Biotechnology for Biofuels*, in review

Impact to BETO: Wet storage contributed to decrease in MFSP in FY2017-2018 SOTs

Future Work – Task 1: Stabilization

Goal: Determine impact of storage of 20% solids microalgae on yield in biochemical conversion process

- Stabilization of 20% microalgae represents scale-up of 50x
- Assess conversion potential at NREL through fermentation and lipid extraction
- INL/NREL joint milestone (3/30/19) Conduct pretreatment and subsequent fermentation/lipid extraction process with wet stored biomass.

Anaerobic storage of *S. acutus* in 1-L reactors

Progress: <3% dry matter loss observed over 30 days

- Previous results indicate that sugar monomer yield after storage is reduced, likely due to fermentation of these sugars to organic acids
- Determine opportunities for organic acids produced in storage to be carried through to conversion
- Joint manuscript underway with NREL

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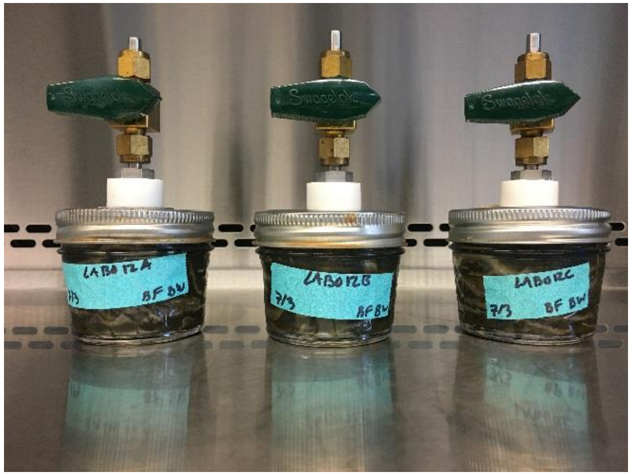
Future Work – Task 1: Stabilization Cont.

Goal: Assess storage performance of promising production strains through BETO's SOT effort on the DISCOVR project

- Outdoor cultivation trials performed seasonally at AzCATI
- 30-day storage treatments at INL identify a range of storage stability profiles and can be used as a screening tool for promising strains
- Results inform future improvements to stabilization efforts as well as strains that are more stable during low productivity months

Progress: Stability data from 2018 harvests are available as a baseline to compare future harvests



Dry matter loss of outdoor harvested microalgae strains stored for 30 days in anaerobic conditions during 2018

Organism	Dry Matter Loss (%, dry basis)
Monoraphidium (H#262)	20.6 ± 0.0
Monoraphidium (H#263)	8.3 ± 2.1
Picochlorum DOE 101	4.9 ± 0.1
Desmodesmus C046	9.7 ± 0.1
Scenedesmus 46BDF3	6.3 ± 3.6

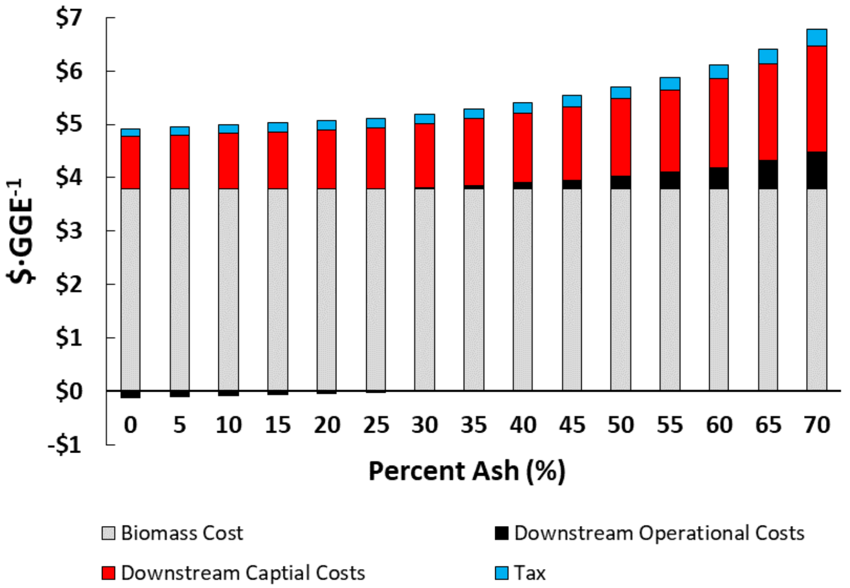
Relevance – Task 2: Ash Reduction

Ash reduction can reduce conversion cost by improving quality

- Techno-economic analysis identified cost drivers for ash removal
- Compared to biomass with 0% ash, 70 wt% ash results in a 42% increase of minimum fuel selling price (MFSP) in HTL conversion and upgrading

Water and alkaline treatments identify opportunities for future development

- Water wash results in lower cost than no ash removal, mild conditions (0.5% NaOH and 25°C promising)
- Two-stage approach shows potential to reduce costs to 20% of no ash removal case and reduce ash content to <30 wt%



Hess et al., submitted to *Biomass and Bioenergy*, in review

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Future Work – Task 2: Ash Reduction

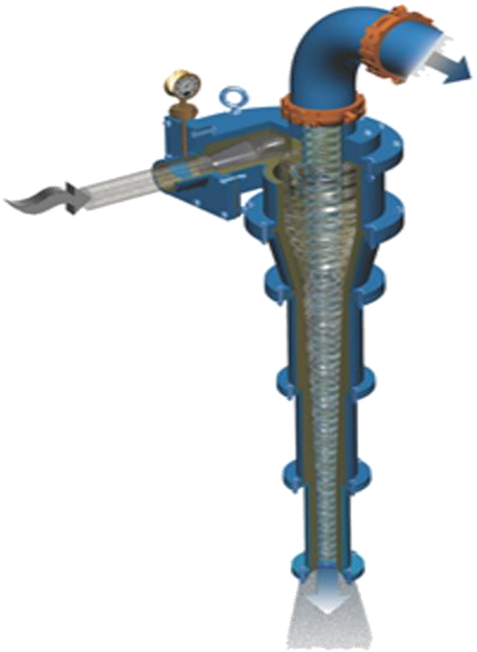
Define a two-step process to reduce ash content while preserving organic material

- Assess treatments to concentrate ash with minimal organics (Lacey et al.) 60% of ash in 10% fraction
- Milestone (6/30/19): Report on ash removal through density-based approaches

Use TEA and LCA to assess the tradeoffs in metrics of sustainability due to ash removal treatment

- Organic recovery
- Tradeoffs: Ash removal vs. $HHV_{biocrude}$
- Tradeoffs: Ash removal vs. $HHV_{algal\ biomass}$

- Coordinate with SNL on upstream removal
- Results will help SNL define a logistics system for biofuel production from ATS biomass



Hydrocyclones are a low-cost option for separating solutions by density. Utilize differences in density between soil and algae biomass to separate soil-fraction

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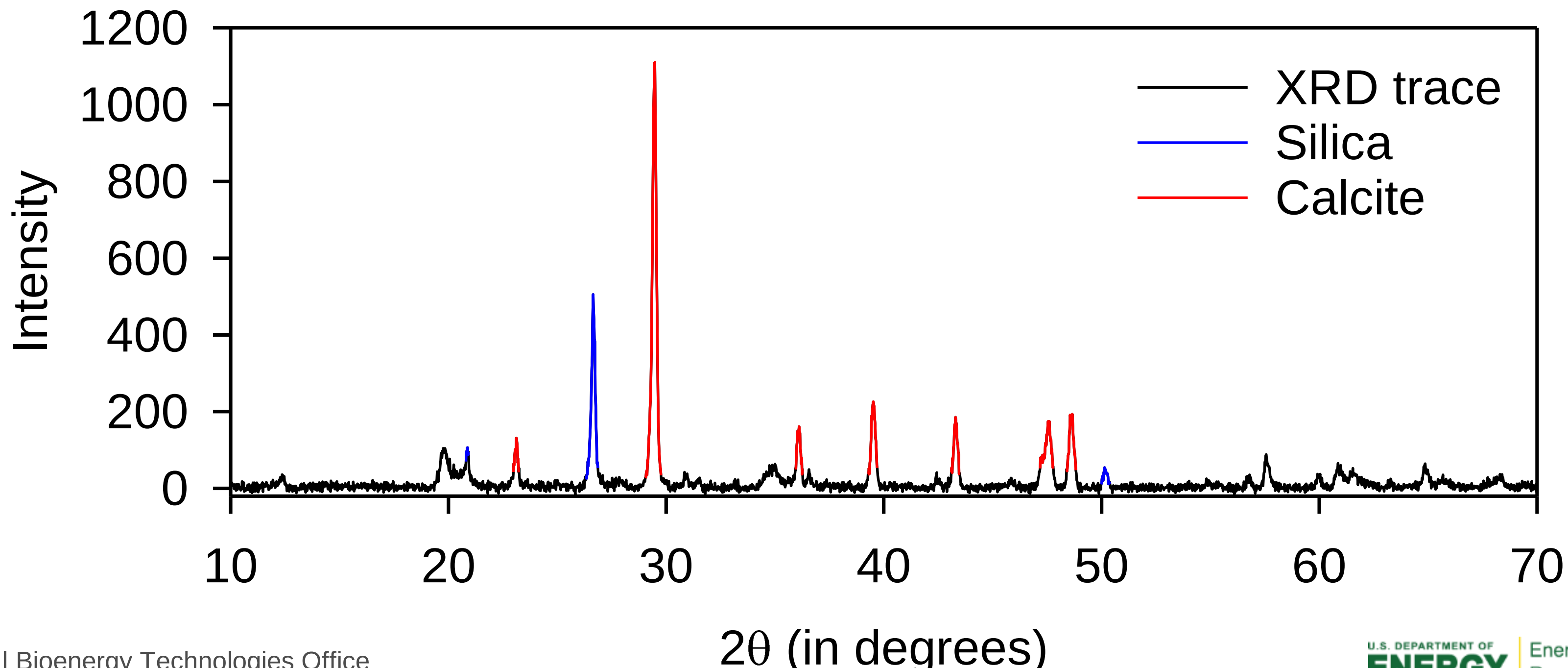
Future Work – Task 2: Ash Reduction Cont.

Goal: Identify prevalent inorganic species in order to understand how they are formed on the turf scrubber matrix

Observation: X-ray diffraction (XRD) indicates calcite is the primary crystalline mineral, some silica present as quartz. Calcite/quartz ratio increases along floway

Future work: Develop fundamental understanding of how water chemistry in turf scrubber systems impact ash content and composition

Develop models of approaches to control ash formation or removal



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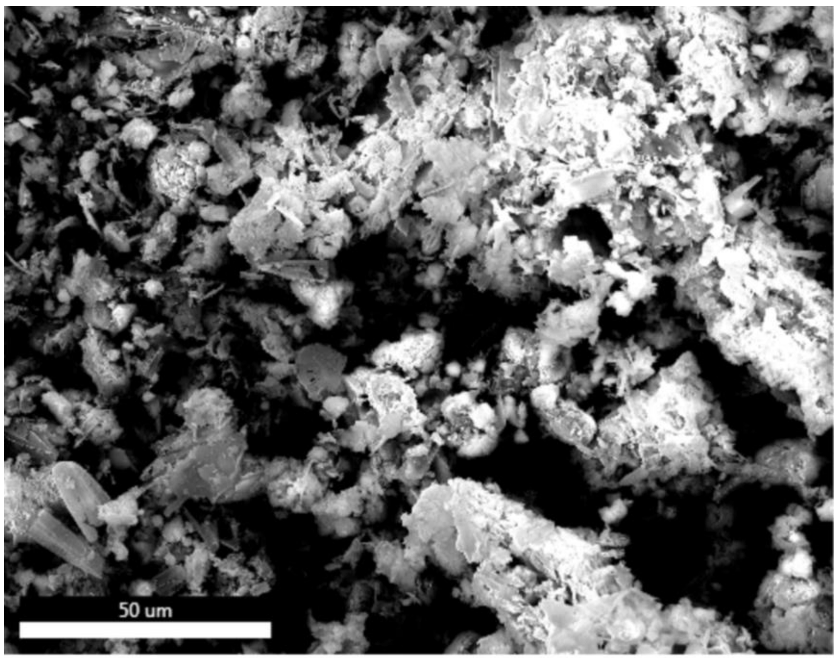
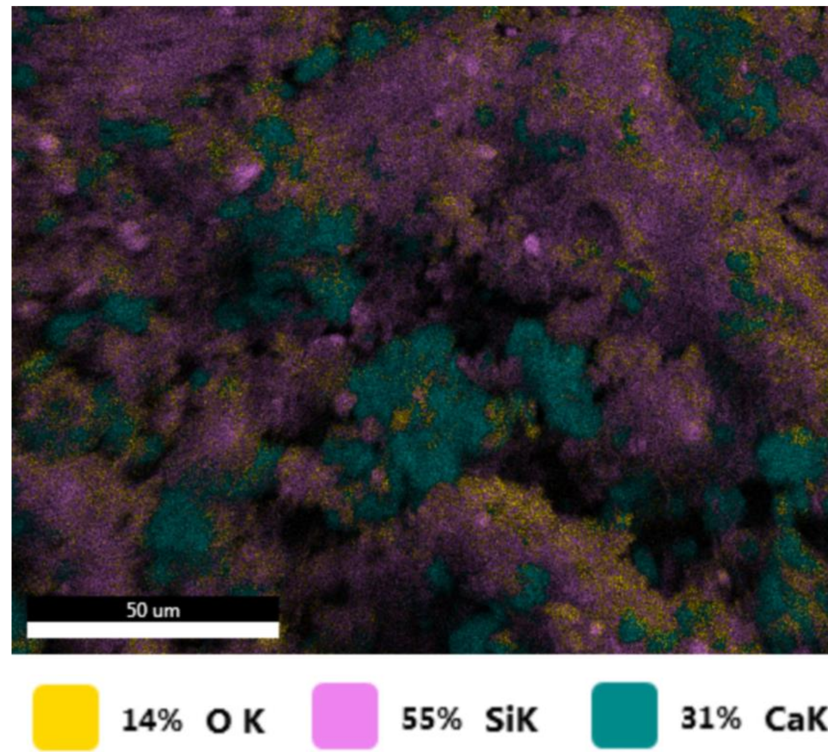
Future Work – Task 2: Ash Reduction

Goal: Use scanning electron microscopy coupled with energy dispersive x-ray spectroscopy (SEM-EDS) to identify spatial location of minerals

Observation: Calcite is distinct from quartz, providing opportunities for physical removal

Future work: Develop physical separation approaches and utilize SEM-EDS to evaluate treatments on individual ash species. Identify opportunities for improvement





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Project Relevance

- Feedstock logistics bridges the gap between production and conversion
  - Seasonal variation in microalgae necessitates long-term storage
  - Wet storage approaches eliminate natural-gas-based drying, reducing costs and greenhouse gas emissions
  - Ash mitigation is a common practice for industries relying on agricultural products (e.g. pulp and paper, biofuel conversion, animal feed) and is a promising process for algae
- Directly supports BETO's mission and addresses BETO targets
  - Supports the 2024 goal in the MYPP: Developing technologies that increase the mature modeled value of cultivated algae biomass by 25% over the 2019 SOT baseline price through incorporation of valuable coproducts and/or services

Relevance for the emerging algal biofuels industry

- Storage reduces risk of feedstock shortages
- Methods applicable to algae biomass with multiple end uses (e.g., nutraceuticals, food additives, protein sources, etc.)
- Integrating feedstock logistics and conversion now will save in the future
- Lack of integration across all operations led to issues for current cellulosic biofuel industry during startup, such as costly repairs/replacement and low fuel yield

Summary

Overview

- Manage seasonal variation of produced algal biomass through high-moisture stabilization to reduce the risk of feedstock loss prior to conversion
- Reduce ash in algae biomass to lower costs through increased conversion yield and improved biomass quality

Relevance

- Optimization in feedstock logistics can assist in meeting or lowering conversion cost targets and help integrate production and conversion

Approach

- Stability research addresses seasonal variation in production and optimization of properties prior to conversion

Progress

- Storage losses in 20% solids microalgae biomass were limited to less than 8% over 180 days, and conversion of stored algae:pine blends showed no change in HTL yield
- Water wash and alkaline extraction removed 40 and 80% ash, respectively. TEA indicates pathway to reduce fuel cost by \$0.58 GGE^{-1}

Future Work

- Determine impact of storage of 20% solids microalgae on yield in conversion processes
- Develop ash reduction strategies based on fundamental understanding of ash compositions and manner of accumulation

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Kimberly Ogden

NREL

Phil Pienkos
Ryan Davis
Nick Nagle
Chris Kinchin
Lieve Laurens

PNNL

Daniel Anderson
Andy Schmidt
Justin Billing

SNL

Ryan W. Davis
Eric Monroe

Publications, Patents, Presentations, Awards, and Commercialization

Publications

Wendt LM, Wahlen BD, Li C, Kachurin G, Ogden KL, Murphy JA. 2017. Evaluation of a high-moisture stabilization strategy for harvested microalgae blended with herbaceous biomass: Part I—Storage performance. *Algal Research.* 25 (Supplement C):567-75.

Wendt LM, Wahlen BD, Li C, Ross JA, Sexton DM, Lukas JC, et al. 2017. Evaluation of a high-moisture stabilization strategy for harvested microalgae blended with herbaceous biomass: Part II — Techno-economic assessment. *Algal Research*; 25 (Supplement C):558-66.

Wahlen BD, Roni MS, Cafferty KG, Wendt LM, Westover TL, Stevens DM, et al. 2017. Managing variability in algal biomass production through drying and stabilization of feedstock blends. *Algal Research*; 24, Part A:9-18.

Aston JE, Wahlen BD, Davis RW, Siccardi AJ, Wendt LM. 2018. Application of aqueous alkaline extraction to remove ash from algae harvested from an algal turf scrubber. *Algal Research*; 35:370-7.

Wendt LM, Kinchin C, Wahlen BD, Davis R, Dempster T, Gerhken H. Assessing the Stability and Techno-Economic Implications for Wet Storage of Harvested Microalgae to Manage Seasonal Variability. In Review, *Biotechnology for Biofuels*

Hess, D, Wendt LM, Wahlen BD, Aston JE, Hu H, Quinn JC. Techno-economic Analysis of Ash Removal in Algal Biomass Harvested from Algal Turf Scrubbers. In Review, *Biomass and Bioenergy.*

Wahlen, BD, Wendt LM, Murphy JA, Seibel F, Ogden KA. Mitigation of algae biomass seasonal productivity through ensiling algae biomass blends and impacts to chemical composition in storage. Submitted to *Algal Research* (Feb 2019).

Presentations

Wendt LM, Wahlen BD, Fornes B, Dempster T, Gerhken H. Ensiling microalgae: compositional changes as a result of long-term storage. The 8th International Conference on Algal Biomass, Biofuels and Bioproducts, Seattle, WA.

Wendt LM, Wahlen BD, Dempster T, Ogden, KA. Fate of total dry matter and composition in long-term storage of microalgae and herbaceous biomass blends. The 7th International Conference on Algal Biomass, Biofuels and Bioproducts, Miami, FL.

Patent

Wendt LM, Wahlen BD, Li C, inventors; Battelle Energy Alliance LLC, assignee. Methods of preserving a microalgae biomass and a preserved microalgae biomass. United States patent application US 15/495,625. 2018 Oct 25.

Previous Peer Reviewer Comments

Reviewer: This project has interesting and innovative ideas. The blending of algal with other types of feedstocks presents an interesting case for the supplementation of material for the larger scale refining process. Ideas for the stabilization of harvested material to reduce the loss of target products could lend to production systems maintaining greater recoverable yields and in turn make the system more profitable. High ash quantities is a serious problem facing the industry so steps to reduce the ash quantities provides a serious benefit to the industry as a whole.

Reviewer: Developing a baseline understanding of the effectiveness of algal biomass stabilization techniques, and optimizing these techniques are essential elements of developing algae as an energy crop. With that in mind, this project represents a valuable step towards industrialization of microalgal biomass. Commendably, this project considers both technical and economic barriers of algal biomass stabilization, but could benefit by a more organized experimental approach to generate more concrete data which would improve the impact of the contribution.

Response: We thank the reviewers for their thoughtful comments and suggestions. We agree that addressing feedstock logistics barriers and proposing solutions for stabilization and maximizing conversion yield will advance the commercialization of algal-based biofuels.

We agree that techno-economic and life cycle assessments (TEA and LCA) should be conducted alongside experimental work such that the full impact of our stabilization approaches can be assessed. We have defined the unit operations and capital and operating costs of a system for stabilization of microalgae through blending and long-term storage and have found it as a cost-competitive approach to drying algae in order to manage seasonal production variation. We will continue to incorporate TEAs, in collaboration with NREL, for the storage of algae alone, and in conjunction with SNL on the impact of ash removal from biomass derived from a turf scrubber.

We have and will continue to incorporate multiple microalgae strains in our experimental plans to ensure that our approaches are applicable to a wide range of industrially relevant strains. We are also working with our partnering national laboratories to understand the impact that wet storage designs have on conversion potential.

Additional slides

Accomplishments – Blend Stabilization

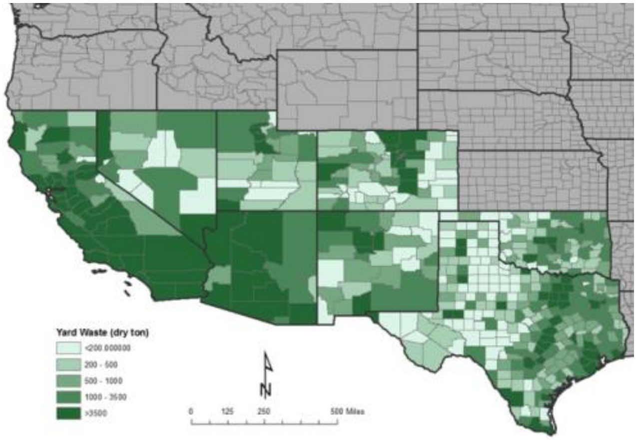
Algae blends (40% algae content)	Dry Matter Loss (%, db)	Final pH
Sweet Sorghum		
Scenedesmus acutus	6.3% ± 3.1%	3.82 ± 0.03
Scenedesmus acutus	10.6% ± 2.5%	3.83 ± 0.09
Chlorella zofingiensis	9.6% ± 2.1%	3.85 ± 0.02
Porphyridium purpureum	9.9% ± 2.4%	3.90 ± 0.06
Grass Clippings		
Scenedesmus acutus	4.8% ± 0.8%	3.98 ± 0.01
Scenedesmus acutus	4.0% ± 0.3%	-
Chlorella zofingiensis	5.6% ± 0.7%	4.09 ± 0.04
Chlorella vulgaris	9.7% ± 0.6%	-
Porphyridium purpureum	6.5% ± 2.6%	-
Nannochloropsis gaditana	16.3% ± 0.9%	-

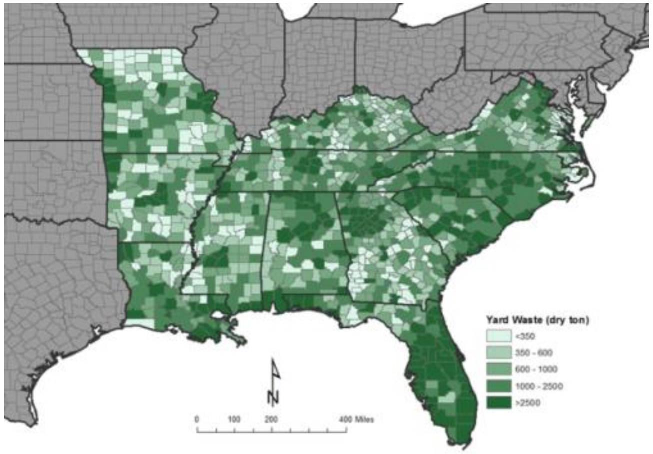
Assessed a number of strains in collaboration with AzCATI to determine range of storage effects

Accomplishments – Blend Stabilization

Resource assessment completed to identify herbaceous biomass available for blending during summer months in Southwest and Southeast US

Feedstock	Annual Inventory, Southeastern U.S. (US ton)	Annual Inventory, Southwestern U.S. (US ton)	Total Annual Inventory (US ton)
Corn stover	27,958,773	11,187,082	39,145,855
Cotton stalks	4,174,541	4,064,226	8,238,767
Peanut hay	4,383,210	462,923	4,846,133
Rice straw	7,157,144	2,756,610	9,913,754
Sorghum	776,201	1,256,652	2,032,853
Haylage	934,803	2,866,954	3,801,757
Distillers grains	2,064,000	2,496,000	4,560,000
Sugar cane/energy cane	27,380,199	1,401,926	28,782,125
MSW Yard waste	2,439,955	2,588,903	5,028,858





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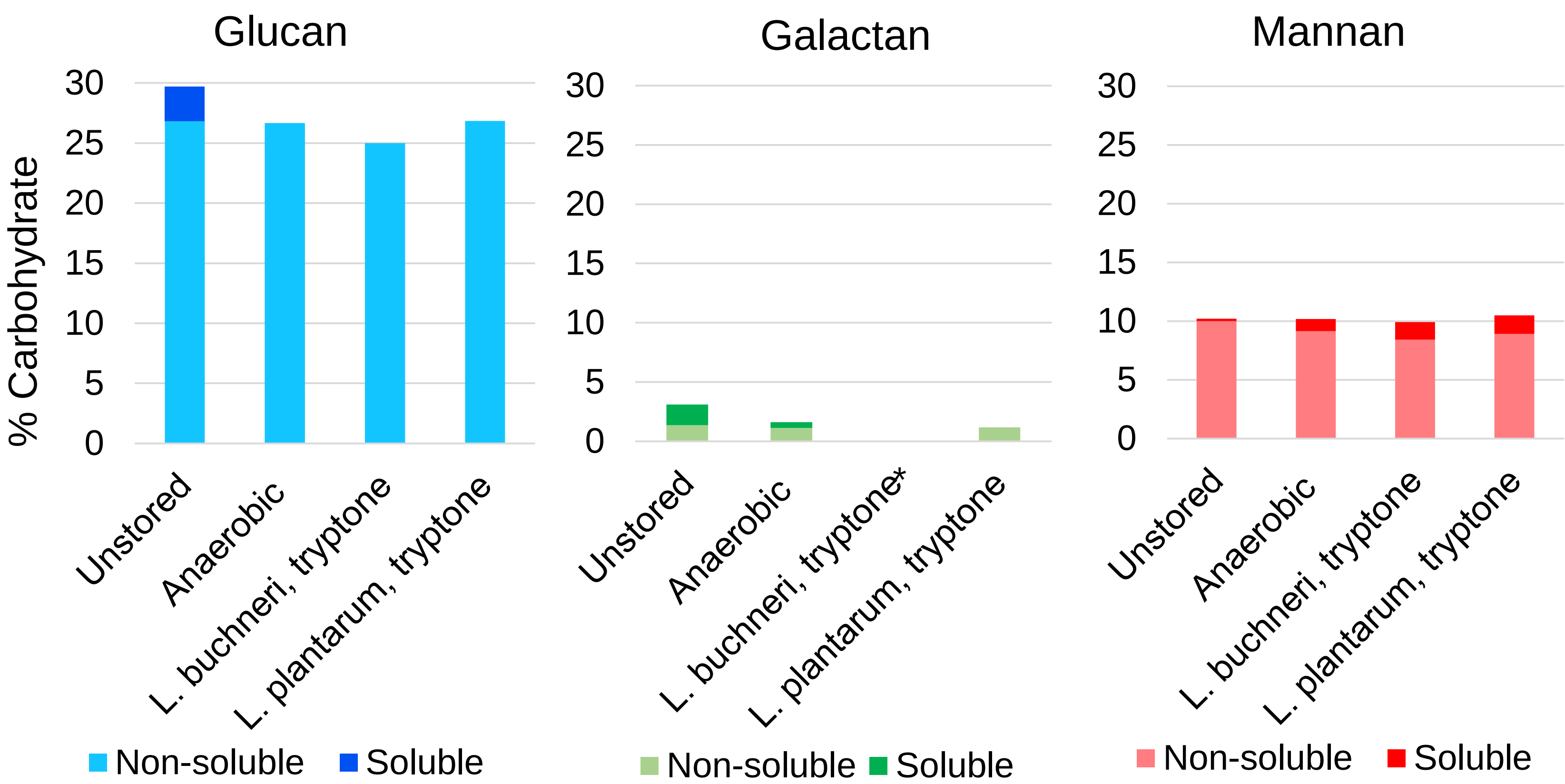
Accomplishments – Microalgae Stabilization

Experimental Condition	Time (Days)	C (%, db)	H (%, db)	N (%, db)	O (%, db)	HHV (BTU/g)
Unstored	0	51.3	7.2	6.7	ND	10,003
Anaerobic	30	51.1	7.3	6.6	ND	10,010
	180	53.1	7.1	6.7	29.3	10,154
Sulfuric Acid (0.5%, db)	30	52.6	7.1	7.0	29.3	10,230
	180	53.2	7.2	7.2	28.2	10,260
Unstored	0	52.5	6.9	6.9	30.0	10,099
Glucose oxidase	30	56.5	7.2	8.0	24.1	11,093
	180	56.9	7.3	8.6	22.7	11,242

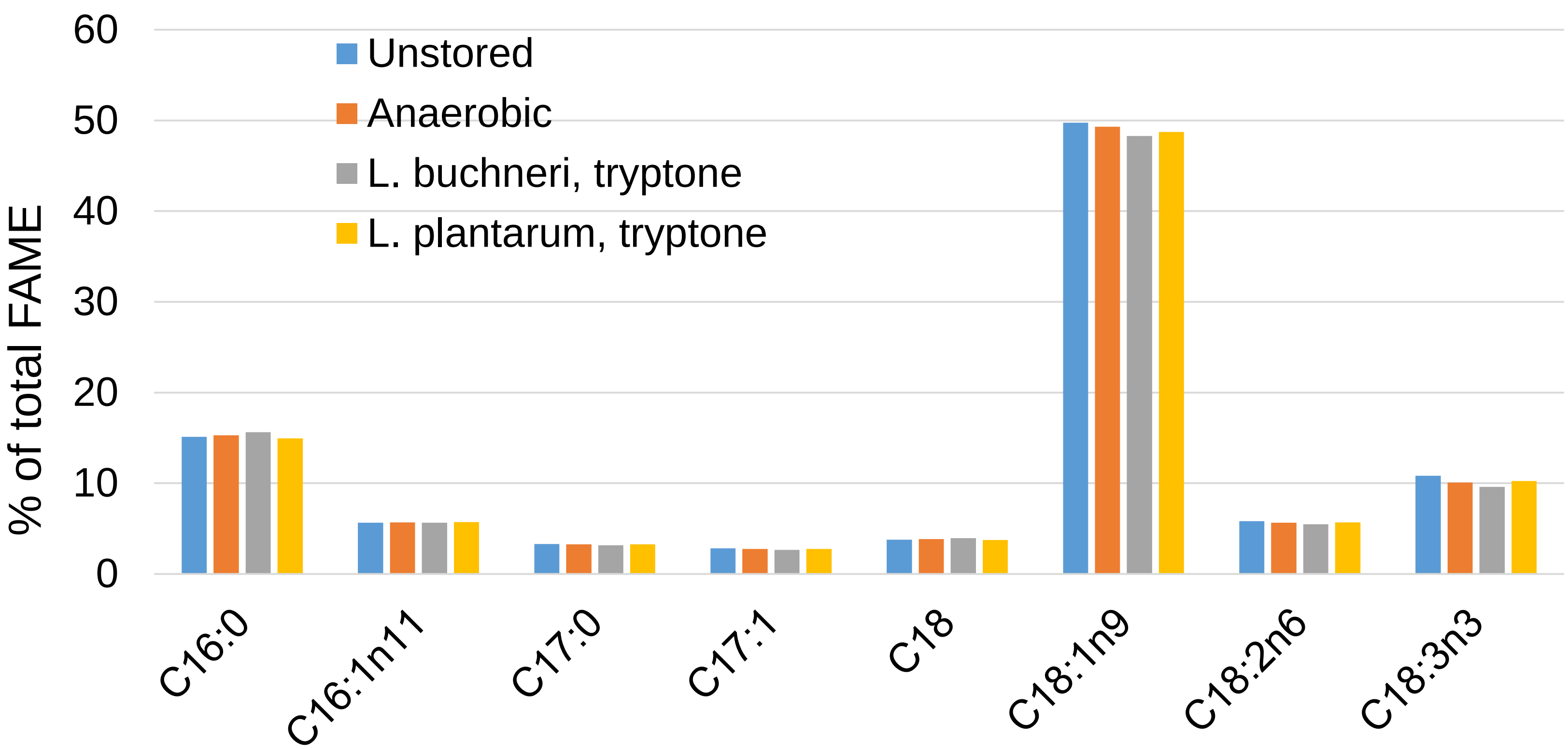
- Carbon increases with time, oxygen decreases
- Higher heating value increases
- Most significant impact is associated with higher degradation condition (glucose oxidase)

Accomplishments – Microalgae Stabilization



- Similar carbohydrate loss in response to storage, total glucan and galactan reduced with mannan stable.
- All soluble glucan and galactan reduced in storage (due to organic acid production), mannan becomes more soluble

Accomplishments – Microalgae Stabilization



- Total FAMES appear to be stable as a result of anaerobic storage
- Only minor changes oleic (C18:1) and linolenic (C18:3) acids