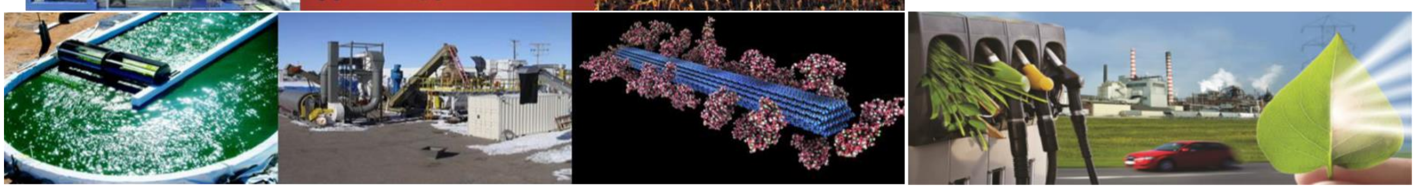
DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

Attached Periphytic Algae Production and Analysis

Sandia National Laboratories



March 6, 2019
Advanced Algae Systems Review

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Goal Statement

- *Goal: Develop cost effective means for cultivating easily harvestable algae biomass using nutrients from compromised surface waters*

- *Expected outcome: Couple remediation of agricultural/storm runoff with biomass production >24 g $m^{-2}day^{-1}$ and ash content <25%*

- *Scale-up of a domestic algae biomass industry requires identification of value propositions including remediation of runoff to achieve production costs that are commensurate with high volume commodities and energy*

- *Provide fieldable algae technology for the agribusiness to produce algae using irrigation ditch infrastructure using fertilizer residuum.*

Quad Chart Overview

Timeline

- Oct 1, 2018
- Sept 20, 2020
- ~15%

	Total Costs Pre FY17**	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded		$750k	$750k	$1.5M
Project Cost Share*		$150k		

•Partners: Wendt (INL), Quinn (CSU), Siccardi (GSU), IVCRC/IID, Fennel (ICL)

Barriers addressed

- AftA: Biomass availability and cost
- AftB: Sustainable algae production
- AftH: Integration

Objective

Provide capability to produce and harvest attached algae biomass using nutrients from runoff without exacerbating evaporation losses; identify amenable biomass utilization or fuels conversion pathways

End of Project Goal

Demonstrate annual production of periphytic algae biomass at >24 g m^{-2} day^{-1} with ash content <25%

1 - Project Overview

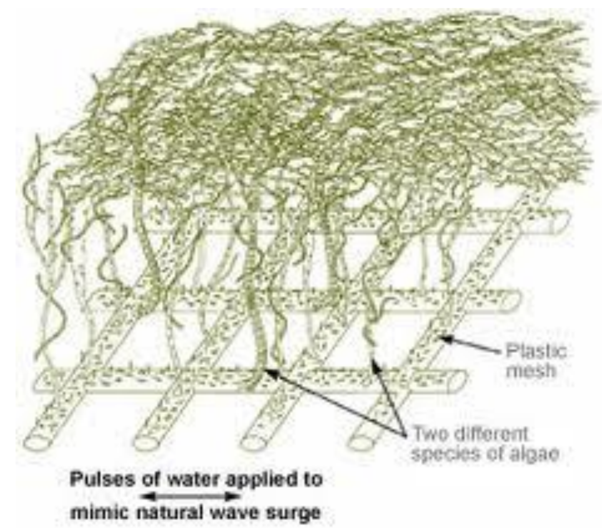
Benthic Algae Turf		***Algae Raceway Pond***
	***VS***	

- Polyculture – resilient and resistant to crashes
- Growth: 5-20+ g/m^2/day (AFDW)*
- **No N/P nutrients or external CO_2 added**
- Harvest & dewatering simple, but ash reduction needed
- Requires energy for water pumping to maintain flow
- Polyculture biomass focus - low neutral lipids & higher ash
- Similarities with open field agriculture

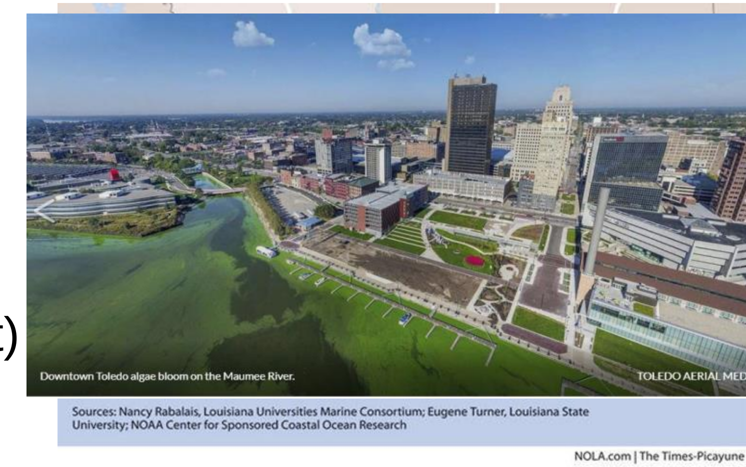
- Monoculture – vulnerable to crashes
- Growth: 5-20+ g/m^2/day(AFDW)*
- Needs fertilizer & CO_2
- Harvest & dewatering more difficult & energy-intensive
- Requires energy for water supply and paddle wheel flow/mixing
- Lipid focus (historical)

Attached periphytic algae cultivation concept

- Provide habitat for natural filamentous algae assemblages to proliferate
- Attached growth allows utilization of dilute nutrients, ie. flow rate can be adjusted based on nutrient concentration variability
- Potential symbiotic mixotrophy benefits from carbon sources in agricultural runoff
- Potential for dramatic decrease in hydrodynamic residence time for water treatment: 35x improvement in L/m^2 versus conventional raceways
- Regular harvesting to maintain log-phase growth



Resource assessment: availability of waste nutrients in the continental U.S.



- N/P equivalents for algae cultivation:
  - 100 MGGE/year from municipal wastewaters
  - >1 **B**GGE/year from agricultural runoff (30% fertilizer runoff, 70% livestock effluent)

- However, once entering river ways, the <u>agricultural runoff N/P concentration is 10-30x more dilute that municipal wastewaters</u>

- Algae-induced aquatic Hypoxia: **"Dead Zones"**
  >600 confirmed algal-bloom induced dead zones world-wide, up ~800% since 70's
  >$4B annual loss in US alone as a result of harmful algae blooms

2 – Approach (Management)

- *Siting and harvesting of biomass at Salton Sea provided through partnership with IID/IVCRC (local agribusiness & water management contractors); System management at Savannah, GA provided through partnership with Prof. Anthony Siccardi (GSU)*

- *Sandia is performing system optimization of 2x 20' environmental simulation floways in the Algae Testbed Facility, biomass characterization from all 3 deployments, microbiome analyses, culture seeding*

- *Partnering with Prof. Jason Quinn (CSU) for independent TEA/LCA of attached algae production and associated conversion pathways*

- *Partnering AOP with Dr. Lynn Wendt (INL) on biomass logistics, storage, and deashing*

- *No-fee collaboration with Prof. Paul Fennel of Imperial College London for evaluation of metals uptake by biomass*

- *No-fee collaboration with Clemson U Biosystems Engineering Dept for Geographic Information Systems Assessment in US SE Region*

2 – Approach (Technical)

- *Modify system parameters, including algae attachment substrate, apply feedback on flowrate through system based on water chemistry changes, use microbiome data to seed cultures with periphyton associated with high productivity and low ash*

- *Challenges: biomass quality, especially with regard to ash – although system has shown >15 g $m^{-2} day^{-1}$ ash content is unacceptably high, routinely >50% and up to 80%; sloughing of biomass off of the floway*

- *Go/No-Go: Demonstrate seeding of marine/estuarine and fresh water cultures in environmental simulation recirculating flow way system with productivities of at least 24 g m^{-2} day^{-1} using the baseline or modified substrate*

3 – Technical Accomplishments/ Progress/Results

- *Salton Sea deployment: complete 2 years of continuous operation at austere site using photovoltaic pumping, completed time-dependent microbiome analysis with associated productivity performance metrics in Q1 of FY19*

- *Savannah GA deployment: completed system setup in Q1 of FY19*

- *Sandia test system: completed system fabrication, seed cultures obtained from culture collection, Corpus Christi and Salton Sea deployments*

SANDIA BIOSCIENCE

Salton Sea Floway

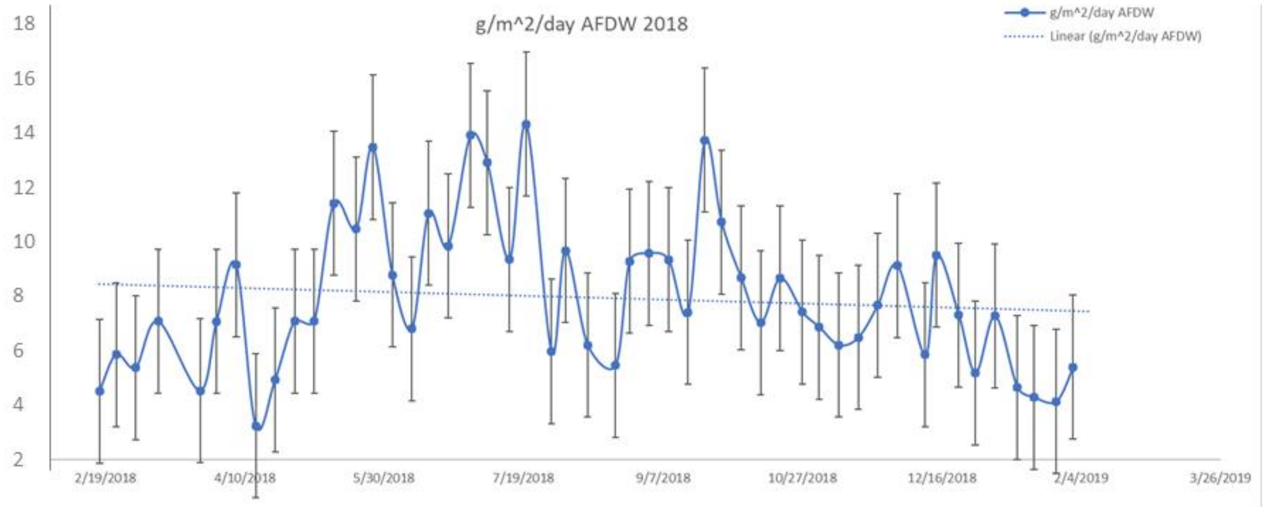
- 900-ft floway near Brawley, CA on Alamo River tributary to Salton Sea
- State of California interested in bioremediation potential of ATS to prevent heavy metals (esp. As & Se) accumulation in wetlands and associated bioavailability
- Austere site: no physical security or facilities, pumping provided by renewable power pumping station
- Source water: 95% agriculture runoff (N = 5-11 ppm, P = 1 ppm, TSS >260 ppm)

10’ 700’

System optimization for biomass productivity + nutrient removal

- Floway length optimization: 900' initial length deployed to capture variation based on nutrient loading

- Biomass yield decreases by ~50% beyond 500'



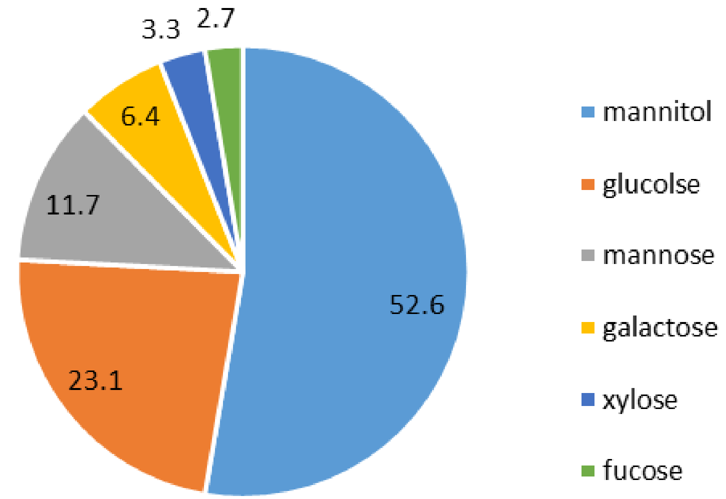
- Analysis of remediation potential: N/P removed at 50-80% depending on initial loading: significant potential for combatting HAB

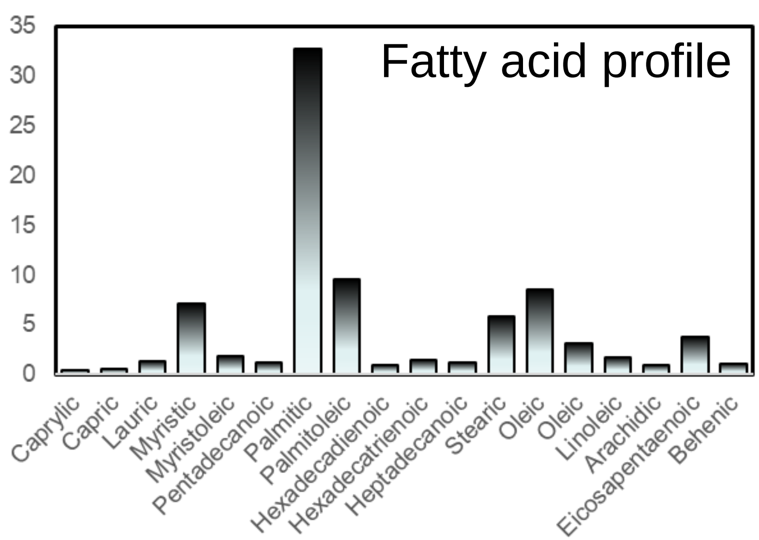
  Trace metals analysis suggest significant removal of many problem species – tissue quantities of several metals are RCRA regulated

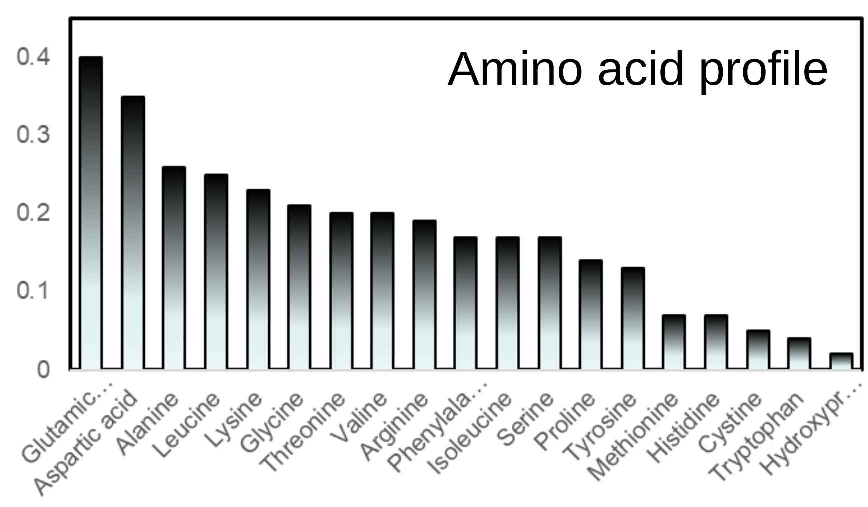
Element	Average values based on ICP-MS (aqua regia) (triplicates)	Standard deviation (ICP-MS)
Zn	159.89	5.22
Cr	42.93	13.24
Pb	20.06	0.16
Cu	18.36	2.98
Ni	26.18	6.13
As	13.46	2.37
Se	9.69	1.55

Composition of Salton Sea Periphyton

- Dominant benthic algae strain appear to be relatively insensitive to source water salinity: filamentous diatoms and *Cladophora* in most marine and fresh source waters
- Proximate analysis: 52±2% carbohydrates, 35±4% protein, 7% lipid (almost 0% TAG)
- Potentially valuable polysaccharide & protein fractions!

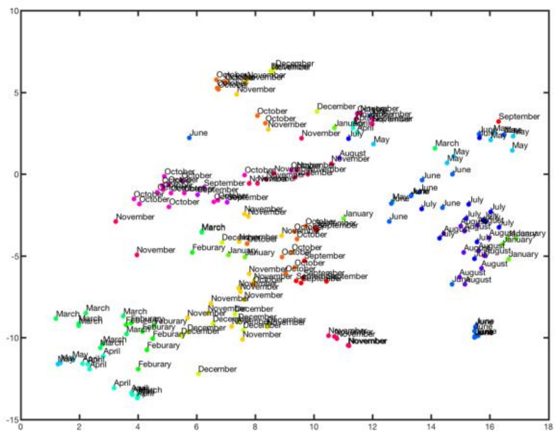


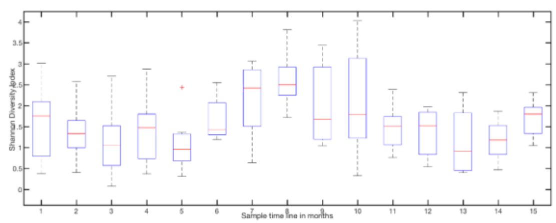


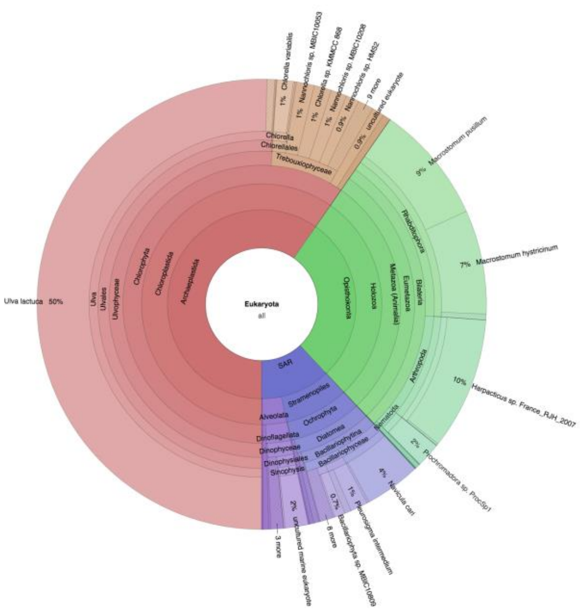


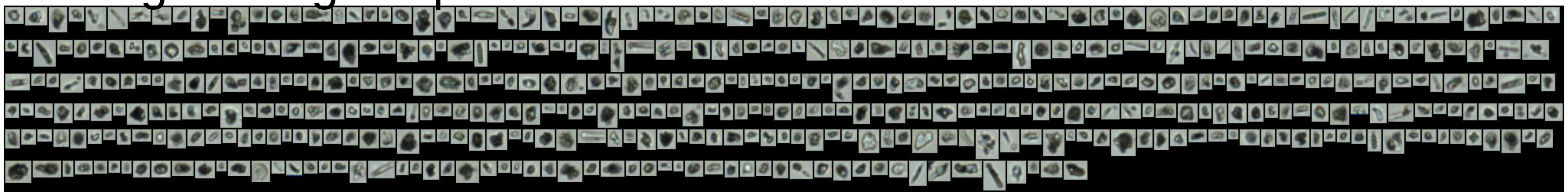
Microbiome analysis for characterizing microbial ecology & culture seeding

- 300,000 OTUs, 8 – 10x more than raceway algae polycultures
- Diversity in samples mimics seasonal variation
- Data being used to identify strains that are associated with high productivity for development of seed cultures for rapid onset of high yield biomass production.
- No indication of system harboring toxigenic algae species



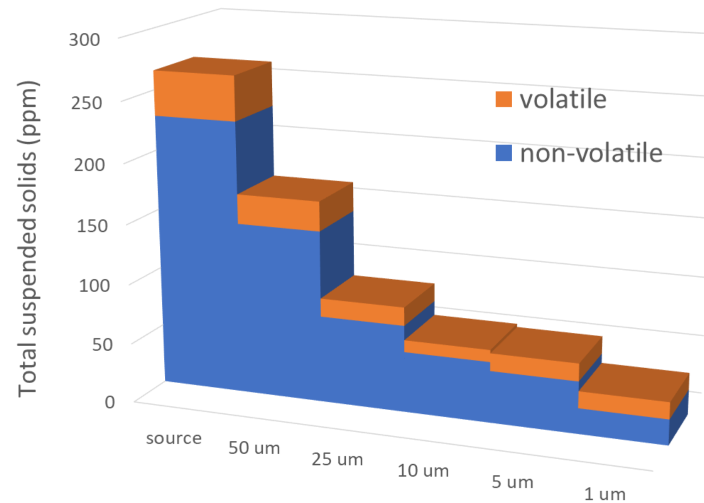


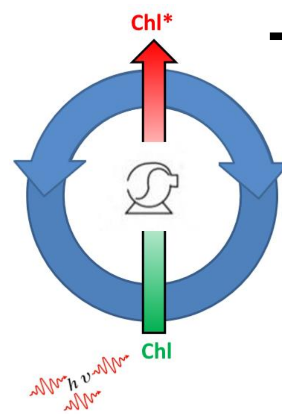


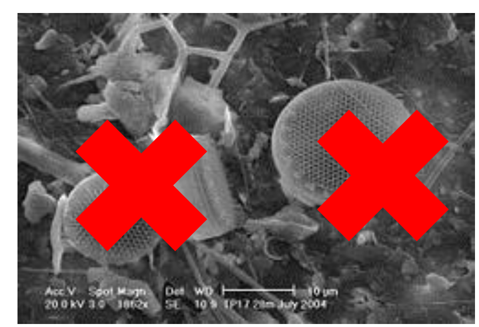


Progress toward minimizing ash accumulation

- Ash quantity is cost driver for bio- and thermochemical processing
- Must address both biogenic & non-biogenic ash accumulation
- Low cost filtration of source water tested at Salton Sea site in Q1 of FY19: non-biogenic ash reduction by 77% using 25µm pore size
- PAR-feedback pump-back for minimizing non-productive ash accumulation
- Culture seeding by high productivity non-diatomaceous strains should minimize biogenic ash







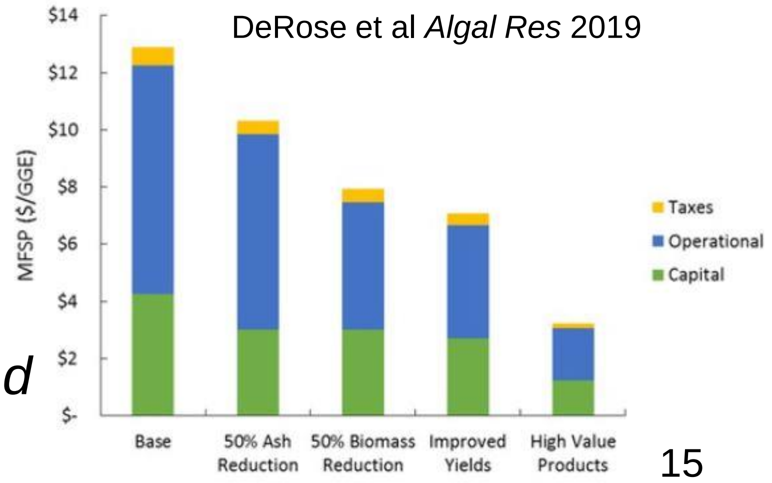
4 – Relevance

- *Developing means for coupling algae production with remediation of nutrient pollution for improving algae biomass sustainability and economic feasibility*

- *Management of nutrient pollution, including nitrogen and carbon dioxide, but especially <u>high efficiency phosphorus and trace metal utilization/sequestration is unique value proposition for algae</u> that addresses key issue exacerbated by 1st generation biofuels*

- *Approach addresses several of the technoeconomic barriers that will be difficult to implement in open raceway cultivation, incl. crop protection, carbon delivery, harvesting*

- *Tasks designed to directly address technoeconomic drivers for scale-up and utilization of variable water sources*



DeRose et al *Algal Res* 2019

5 – Future Work

- *Deploy flow-rate feedback using water chemistry and productivity indicators (e.g. based on nutrient content, and photoperiod to minimize night-time ash accumulation and operational cost)*

- *Identify means for efficiently seeding cultures with native periphyton for improved productivity and biomass value (i.e. lower ash) using lessons from thin-film cascading systems*

- *Evaluate species selectivity and biomass production and quality improvements from variation of substrate materials*

- *Quantitative assessment of evaporation losses in arid environments and estimation of value of environmental services, including fisheries, recreation, migratory bird impacts, and property value*

Summary

1. Overview: Develop scalable attached algae cultivation for coupling remediation of compromised surface water with biomass production
2. Approach: comparing yield and remediation impacts from field deployments with various source water to environmental simulated algae flow ways
3. Technical Accomplishments: Demonstrated continuous attached algae cultivation with multi-month productivities >15 g m^{-2} day^{-1}, plausible path towards reduction of ash to 25%.
4. Relevance: Provides path for demonstration-scale production of algae-based biofuels at a total production cost of $3/GGE incorporating water clean-up credits.
5. Future work: Improve productivity to 24 g m^{-2} day^{-1} and reduce ash to 25% by culture seeding and feedback control

Additional Slides

(Not a template slide – for information purposes only)

- *The following slides are to be included in your submission for Peer Evaluation purposes, but will* ***not*** *be part of your oral presentation –*
- *You may refer to them during the Q&A period if they are helpful to you in explaining certain points.*

Responses to Previous Reviewers' Comments

- If your project is an on-going project that was reviewed previously, address 1-3 significant questions/criticisms from the previous reviewers' comments (refer to the 2017 Peer Review Report, see notes section below)
- Also provide highlights from any Go/No-Go Reviews

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Publications, Patents, Presentations, Awards, and Commercialization

- List any publications, patents, awards, and presentations that have resulted from work on this project
- Use at least 12 point font
- Describe the status of any technology transfer or commercialization efforts

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