“Novel Algae Technology to Utilize CO_2 for Value Added Products”

DE-FE0031710

PI: Frederick Harrington, PhD

Helios-NRG, LLC

August 30, 2021

U.S. Department of Energy

National Energy Technology Laboratory

Carbon Management and Natural Gas & Oil Research Project Review Meeting

Virtual Meetings August 2 through August 31, 2021

Project Overview

- **Project Partners:**
  - University at Buffalo
  - Linde, Inc
  - Northwestern University
  - Membrane Technology & Research
  - National Carbon Capture Center
- **DOE Federal Project Manager: Naomi O'Neil**
- **Project Funding**:
  - Total: $1,734,486
  - Government: $1,387,588 Cost Share: $346,898
- **Project Period: 5/1/19 – 7/31/22**

Overall Project Objectives

- Design, build and operate a first-of-a-kind integrated MSC system
- Achieve high performance in outdoors operation
- Conduct NCCC field test on real flue gas
- Develop algae technology for 2 high value products
- Improve dewatering technology
- Perform LCA and TEA
- Achieve projected net CO2 capture cost at commercial scale of <$30/ton

Commercial Schematic of Technology

Coal Power Plant

Post FGD flue gas

Sunlight

~1% CO2

Algae MSC Process for CO2 capture

Dewatering

Algae Slurry

HTL + Upgrading

Bio-fuels

Residue

Waste water nutrients

Water + Nutrient Recycle

Make-up water & nutrients

Algae for nutraceuticals

Dewatering

Commercial Extraction

Nutraceuticals

Water

Algae for Animal feed

Dewatering

Feed Blending

Feed Products

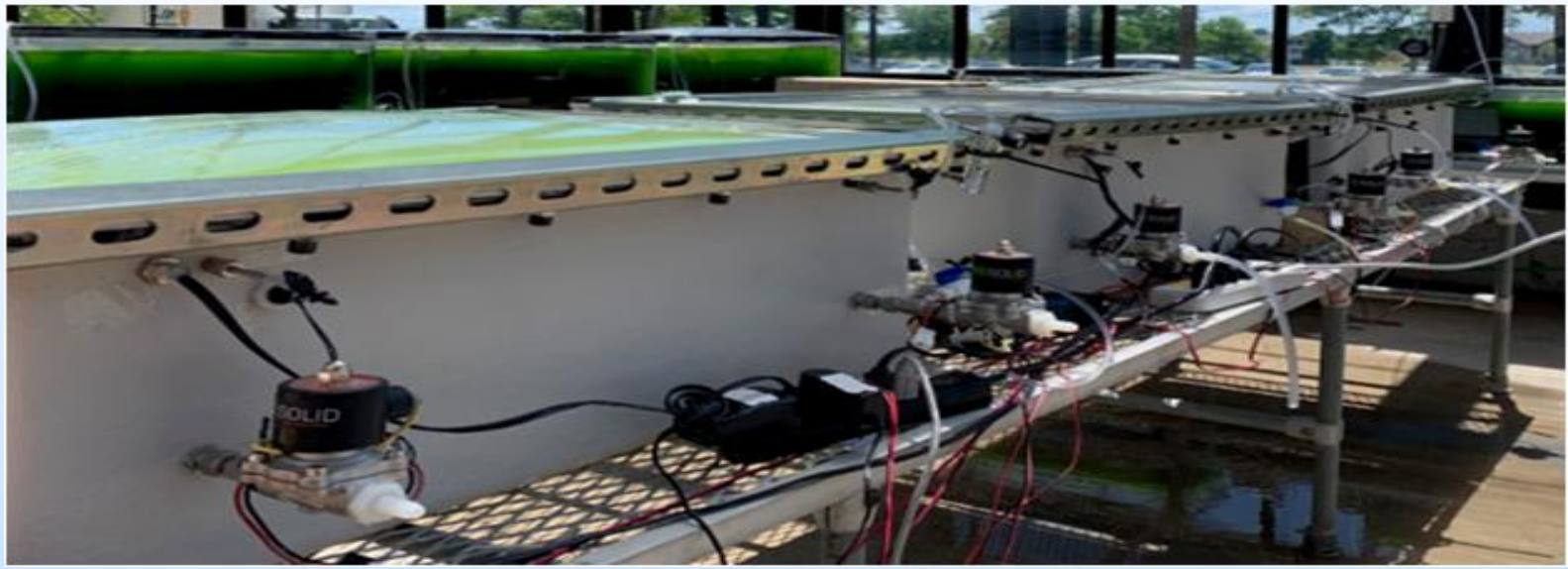
Water

Technical Approach/Project Scope

Project Area	Detail	Completed	To Be Done
Capture Technology	Gas Type: Sim Flue gas; Actual Flue gas	Sim Flue gas	Real flue gas at NCCC
	Algae strain	H-1903 Selected	
	Capture System: Algae MSC	Designed, Built & tested in GH	Test Outdoors & at NCCC
	Target 25 g/m2/d and 80% capture	Met in GH	Validate outdoors
Dewatering	Stage 1: Adv Gravity Table	50% reduction in energy on 2 species	
		Target perf exceeded	
		Use of recycle water in growing validated	
	Stage 2: Dewatering membrane	Surface modified membrane developed	Complete regen process
		Lab module built & tested	Build & test larger module
Products	Algae type	Strains H-0326 & H-1601 selected	Enhance culturing
	Components	Multiple components identified	Increase product levels
	Separation	New extraction process conceived	Improve recovery

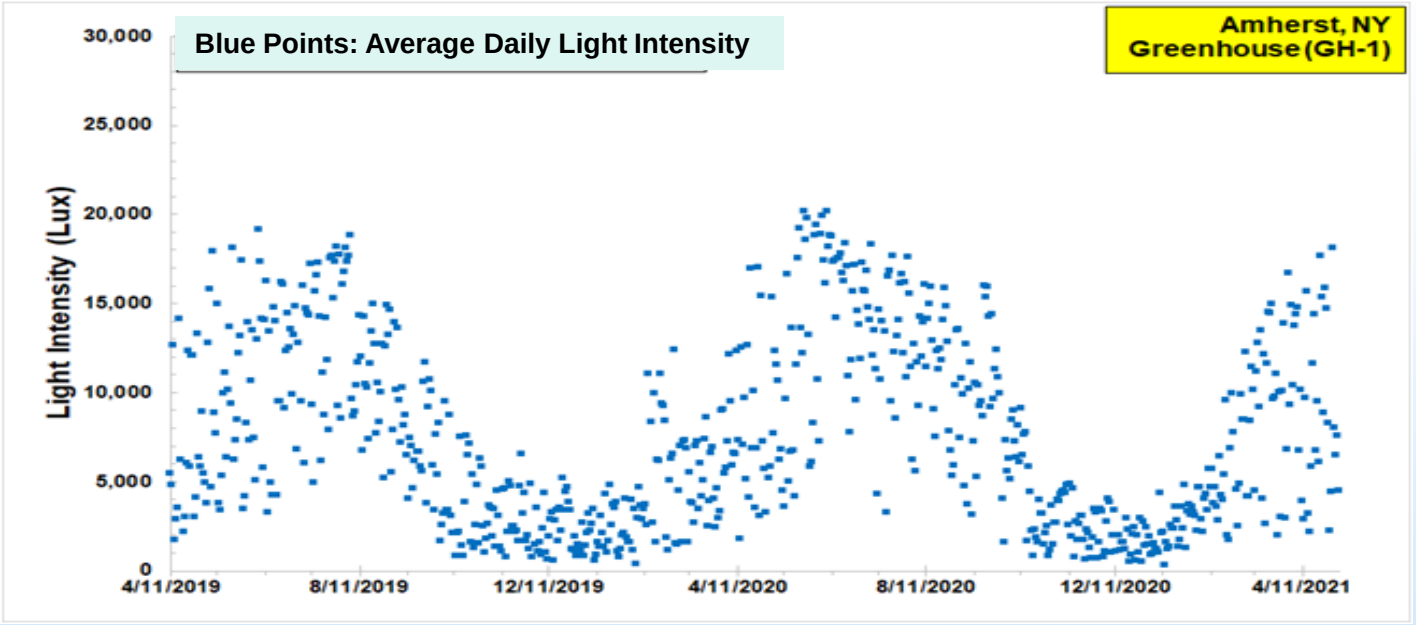
Technology Background - MSC

- Multi-stage continuous process
- Top lit closed system
- Stable algae concentrations
- High productivity & capture efficiency
- Predictable, controllable operation
- Can be tailored to application
  - e.g. Natural gas power plants



Integrated MSC test unit in greenhouse

MSC Evolution



- Needs to operate in variable sunlight
  - Initial lab development in constant light
  - Next moved to GH - sunlight
  - Highest light intensity is outdoors (future)
- Algae must survive and grow in flue gas with high CO2, acid gases and heavy metals
- PBR design varied over time used to improve productivity and capture efficiency

Evolution in MSC Development

Tank Type	Light		Feed Gas		# of Stages	Overall Performance	
	Facility	Intensity Avg (Lux)	CO2	Post FGD Cont		Avg Prod (g/m2/day)	Total CO2 Cap Eff (%)
E	Lab	~9,000	12.0%	N/A	3	14.1	54%
R	Lab	~9,000	12.0%	N/A	3	19.9	80%
H	GH	~11,000	12.0%	SOX/NOX + HM	3	21.2	73%
C	GH	~14,500	12.0%	SOX/NOX + HM	2	30.8	74%

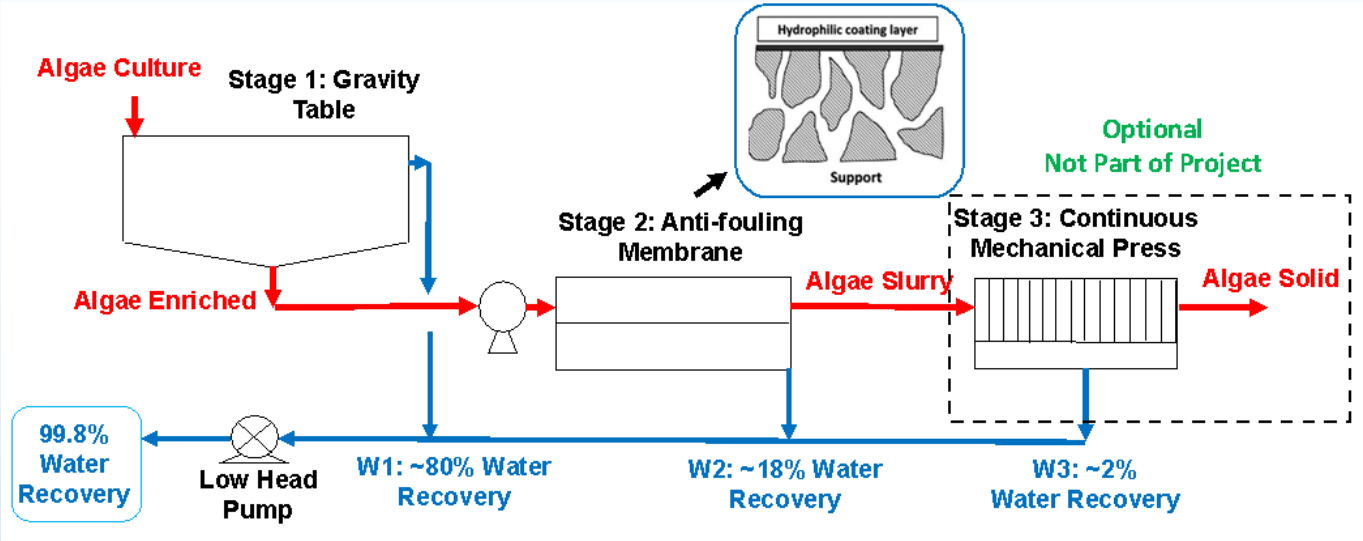
Project Progress - MSC

- Integrated 3-stage MSC fabricated with improved closed raceway design
- Advanced control system enables unattended operation
- Stable GH operation 60+ days
- Various process options mapped
- Performance validated in sunlight
- Transitioning from GH to outdoors
- Components enclosed for outdoors
- Readying system for transport to NCCC

Integrated Raceway-MSC at Greenhouse

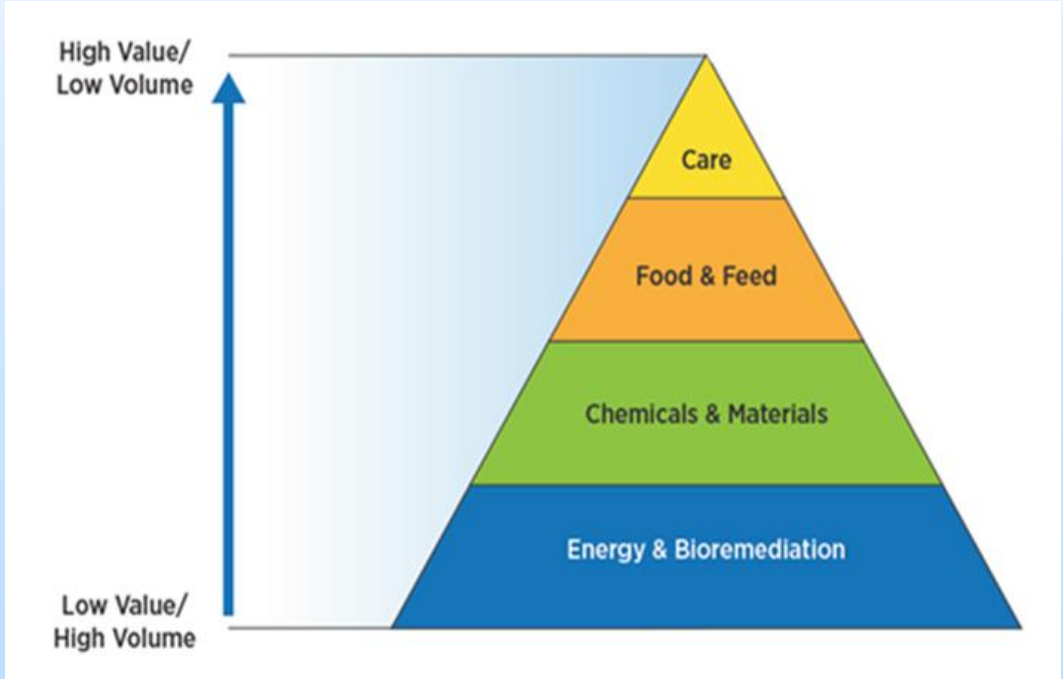
Species: H-1903; Tank Design: G;
Gas: 12% CO2 (simulated flue)

Dewatering and Products



- Dewatering is a key, enabling technology
- Must be low energy
- As water is removed, rheology changes
- Extent of dewatering dictated by needs of downstream product

- Products represent CO2 utilization
- Several products possible with a range of market sizes/prices
  - Biofuels
  - Animal feed
  - Nutraceuticals

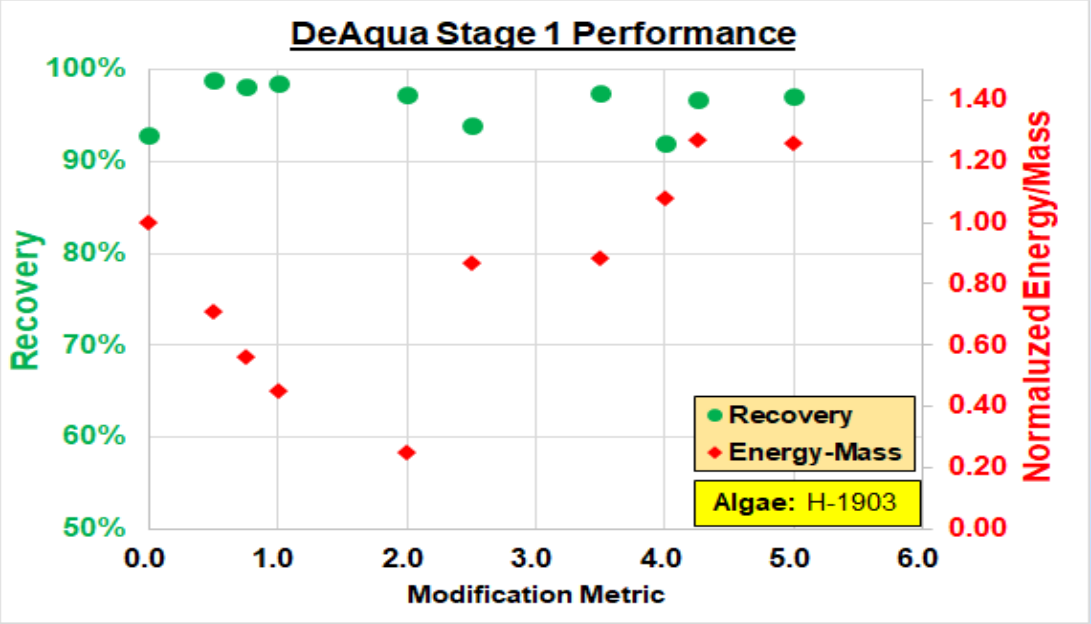


Project Progress – Advanced Gravity Table

	DeAqua Stage 1 Performance Specification		
Project	**Conc Ratio**	**Performance Index**	**Recovery**
Prior work	3-6	0.12-0.37	70%
Initial Project Target	3-6	1.5	80%
Current work	20-25	5.0-12.5	80-95%

$$\text{Conc Ratio} = \frac{\text{Product Algae Conc}}{\text{Feed Algae Conc}}$$

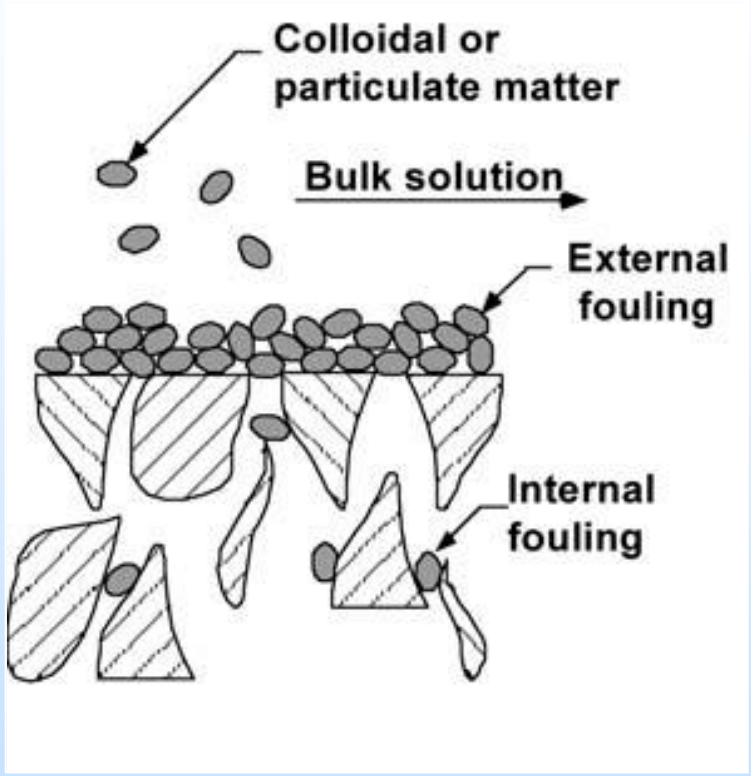
$$\text{Perf Index} = \frac{\text{Conc Ratio}}{\text{Time}}$$

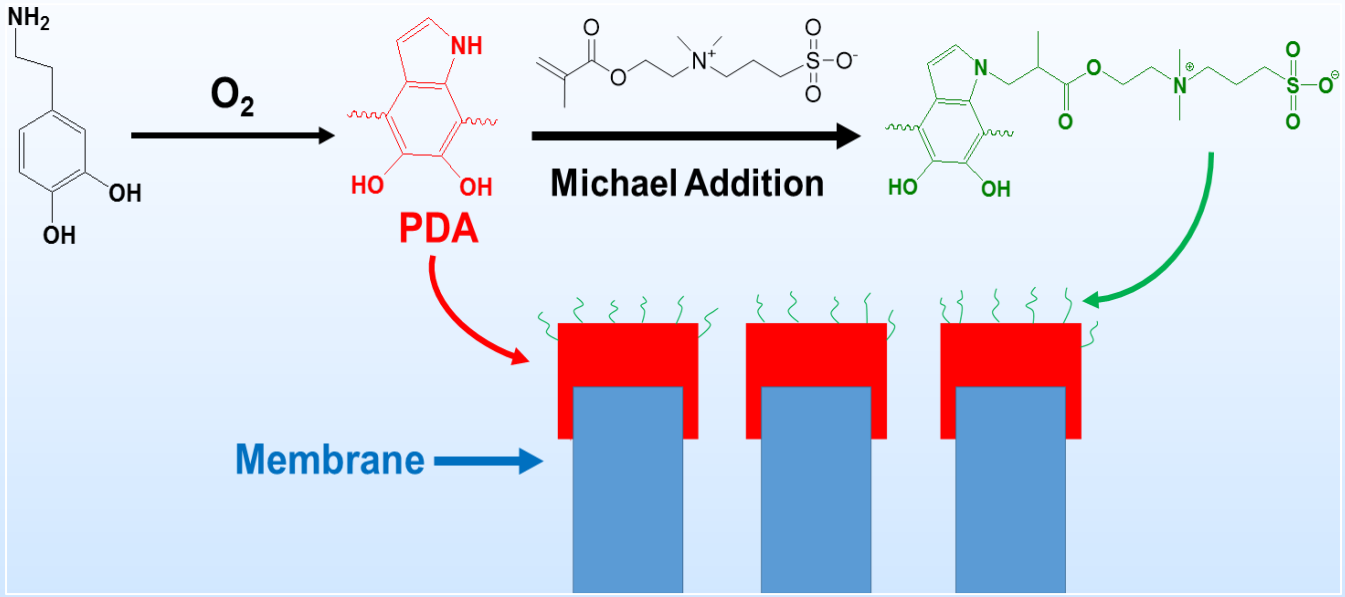


Significant progress in Stage 1 through culture modification:

- Now removes >90% water vs ~70% in prior projects
- Goal of 4X improvement in Perf Index greatly exceeded
- Validated water re-use from dewatering step

Dewatering Membrane Rationale and Approach



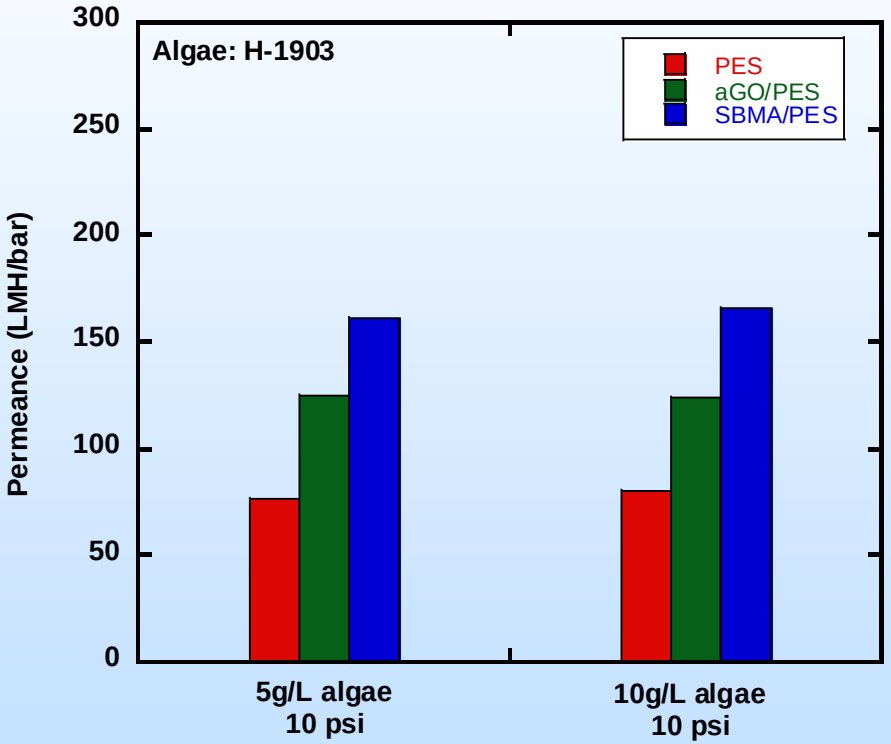


- **Membrane is energy-efficient**
- **But fouling is a critical challenge**

Advantages:

- Surface modification reduces fouling
- Simple process at 23 °C, aqueous solutions
- Covalent bonds to achieve long-term stability
- Post-modification of commercial modules

Project Progress - Dewatering membrane



Cleaning solution	Solution permeance (LMH/bar)		
	Water	5 g/L algae	Water after cleaning
Pure Water	1268	184	1007
HCl pH~3	1282	163	516
NaOH pH~11	1203	175	935
0.04% NaClO	1417	155	1097

- Surface modification decreases water permeance
- But improves the performance of algae dewatering

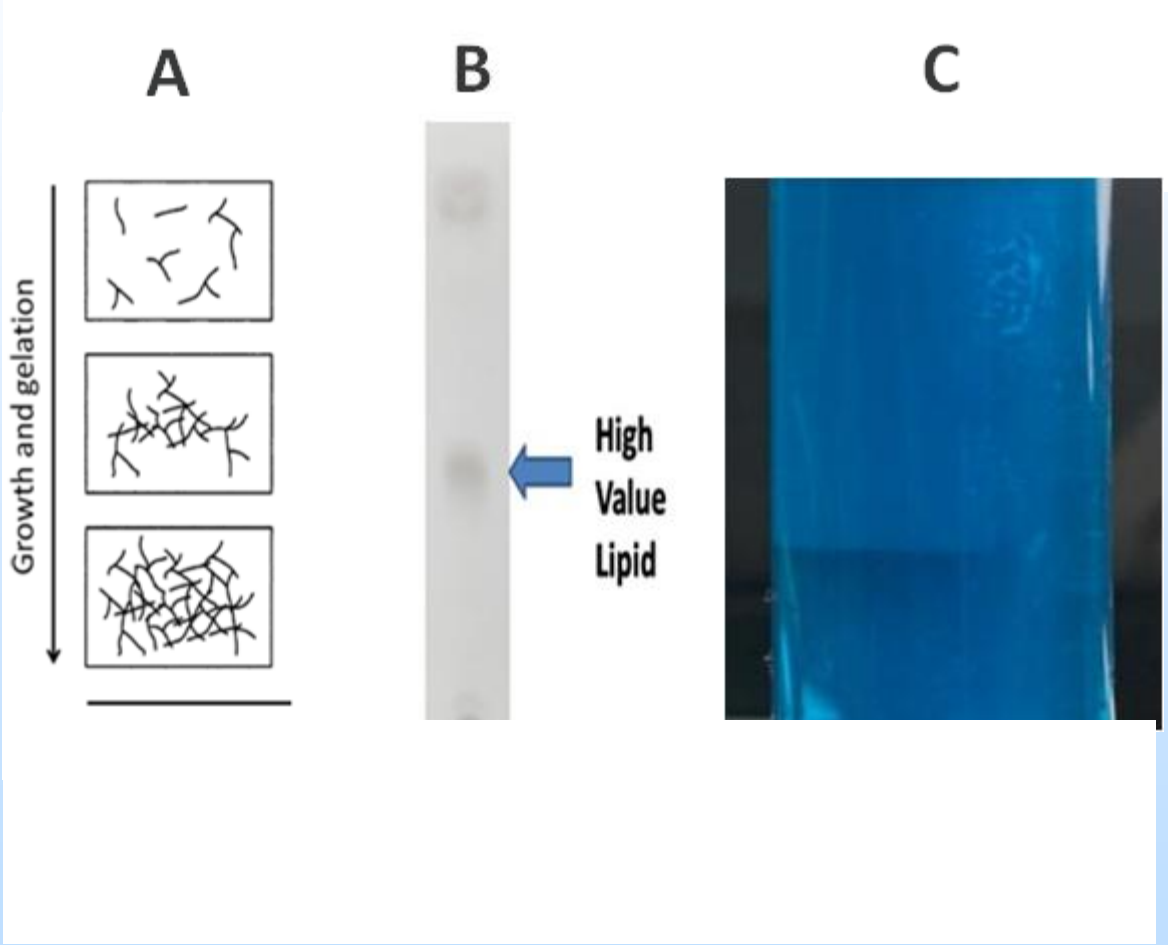
Project Progress - Nutraceuticals

Algae Strain: H-0326

- Requires induction
- Products similar to those found in prior work

Algae Strain: H-1601

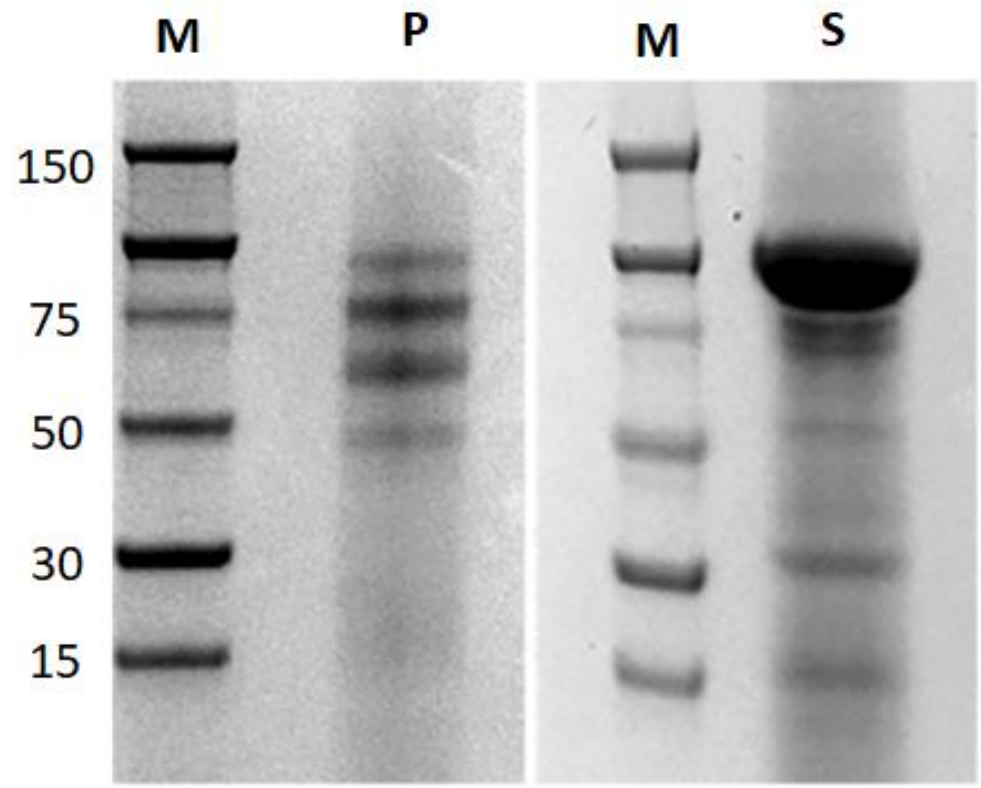
- Requires no induction
- **Product A -** Food & pharma applications
- **Product B -** High value lipids
- **Product C -** Potential for food coloring & pharma applications



Project Progress – Nutraceuticals
2 phase product extraction

- Enables recovery of added products
- Step1: extract soluble material in fraction S
- Step 2: Insoluble fraction P used for second extraction

Species H-1601 M=mol wt in k-daltons



Plans for future development

MSC CO_2 Capture:

- Implement dynamic process control
- Develop in-ground system that will be the building block for commercial application
- Integrate MSC with dewatering and operate with high recycle rate
- Utilize municipal WW for purchased nutrient reduction & significant remediation credits

Utilization:

- **Biofuels:** Optimize HTL process for higher efficiency & reduced costs
- **Animal Feed:** Develop feed applications
- **Nutraceuticals**: Utilize commercial extraction, advance purification & define products

Summary

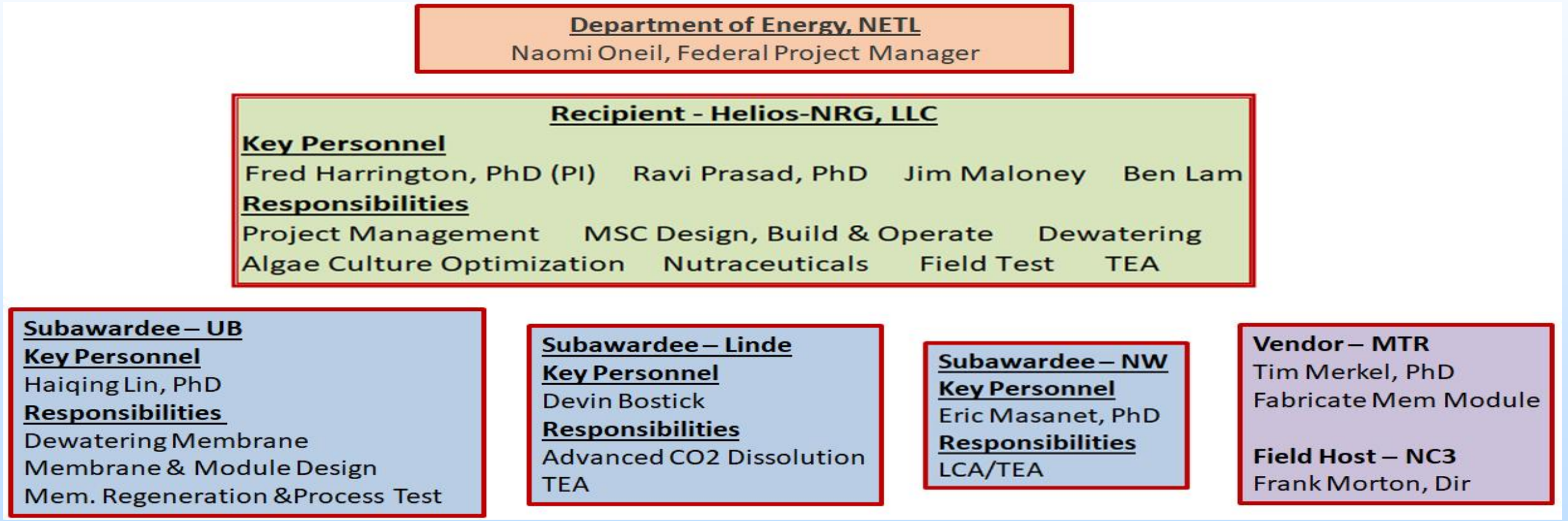
- First of a kind integrated MSC system designed, built and tested
  - Stable long term operation achieved
  - Capture efficiency and productivity targets met in GH/outdoors operations
- Good progress in de-watering technology
  - Stage 1 targets exceeded
  - Dewatering membrane lab module fabricated
- Nutraceutical production from new strains looks promising
  - Multiple compounds identified
  - Advanced extraction process conceived
- System being readied for NCCC field test

Acknowledgement

Acknowledgement

This material is based upon work supported by the Department of Energy under Award Number DE-FE-0031710.

Organization Chart



Gantt Chart

DOE Award Number DE-FE0031710		Organization: Helios-NRG, LLC													
Task #	Task Title	Start	End Date	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
	Overall Project	5/1/2019	7/31/2022													
1	Project Management and Planning	5/1/2019	7/31/2022													
2	Design, build, operate MSC system	8/1/2019	4/30/2022													
3	Optimize Nutraceuticals production	2/1/2020	4/30/2022													
4	Advance DeAqua Gravity Table Performance	8/1/2019	7/31/2021													
5	Advance DeAqua Anti-fouling Membrane	8/1/2019	7/31/2021													
6	DeAqua Module Performance Tests	5/1/2021	7/31/2022													
7	Field Test of Carbon Capture	11/1/2021	4/30/2022													
8	Life Cycle Assessment	8/1/2021	7/31/2022													
9	Perform Techno-economics Analysis	5/1/2021	7/31/2022													