Novel Algae Technology for CO2 Utilization

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U.S. Department of Energy

National Energy Technology Laboratory

2020 Annual Review Meeting

Project Overview

- **Project Type: SBIR Phase2**
- **Team:**
  - **Helios-NRG, LLC - Lead**
  - **University at Buffalo, SUNY (UB)**
  - **Membrane Technology & Research (MTR)**
  - **Technology Opportunity Consulting (TOC)**
- **PI: James Maloney**
  Co-PI's: Dr. Haiqing Lin; Dr Tim Merkel
- **Federal Project Manager: Isaac Aurelio**
- **Start: 8/27/18 End: 12/31/20**
- **DOE Phase2 Grant: $1,009,588**

Project Objectives

- **Develop a novel algae technology for efficient, cost effective CO2 capture from coal power plant flue gas**
- **Phase II builds on the progress made in Phase I and is intended to:**
  - Develop first-of-a-kind MSC system
  - Demonstrate high CO2 capture efficiency
  - Demonstrate high productivity
  - Advance dewatering technology
  - Demonstrate potential for nutraceutical products

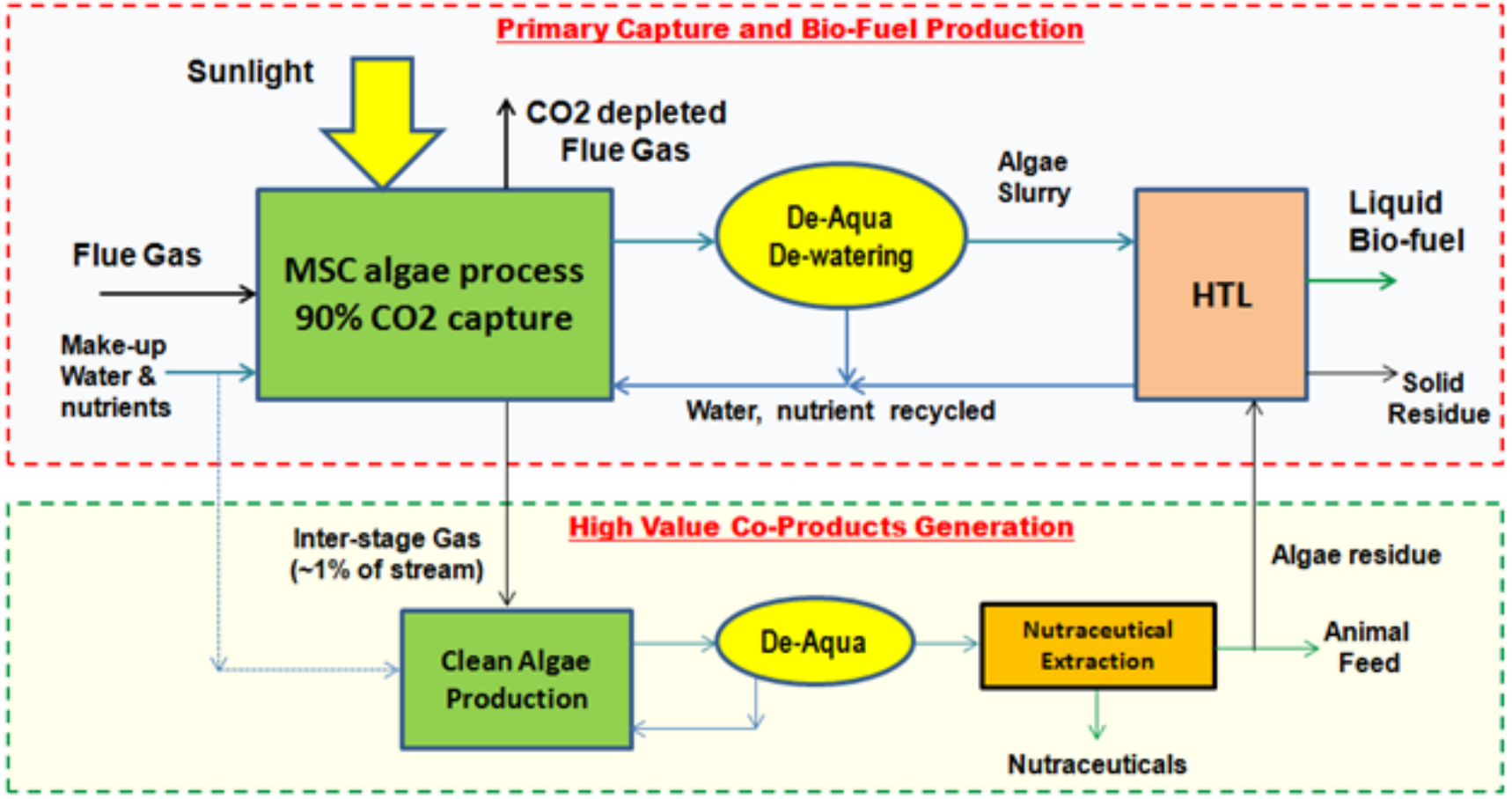
Technology Overview

- **Cost effective CO2 capture from flue gas is difficult**
  - Low pressure, low CO2 conc, huge volume, contaminants
  - High purity product; limited market; sequestration expensive

- ***For CO2 capture to be commercially viable, a revenue stream is required to offset cost of capture***

- **Helios-NRG strategy:**
  - Develop algae capture technology for high CO2 capture efficiency + high productivity from coal flue gas
  - Reduce cost via operational efficiency, credits, products
    - Bio-fuels; Animal feed; Nutraceuticals
    - Low cost dewatering
    - Negative cost wastewater nutrient inputs

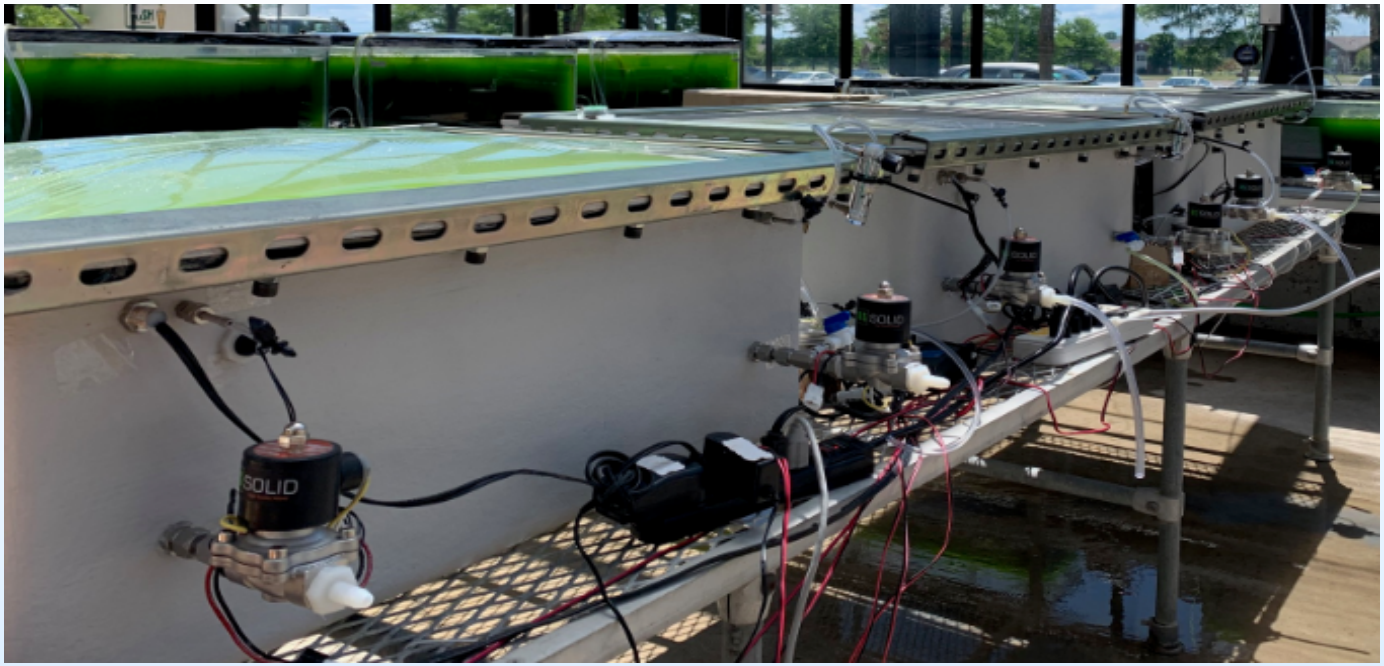
Process Schematic



Advances in Project

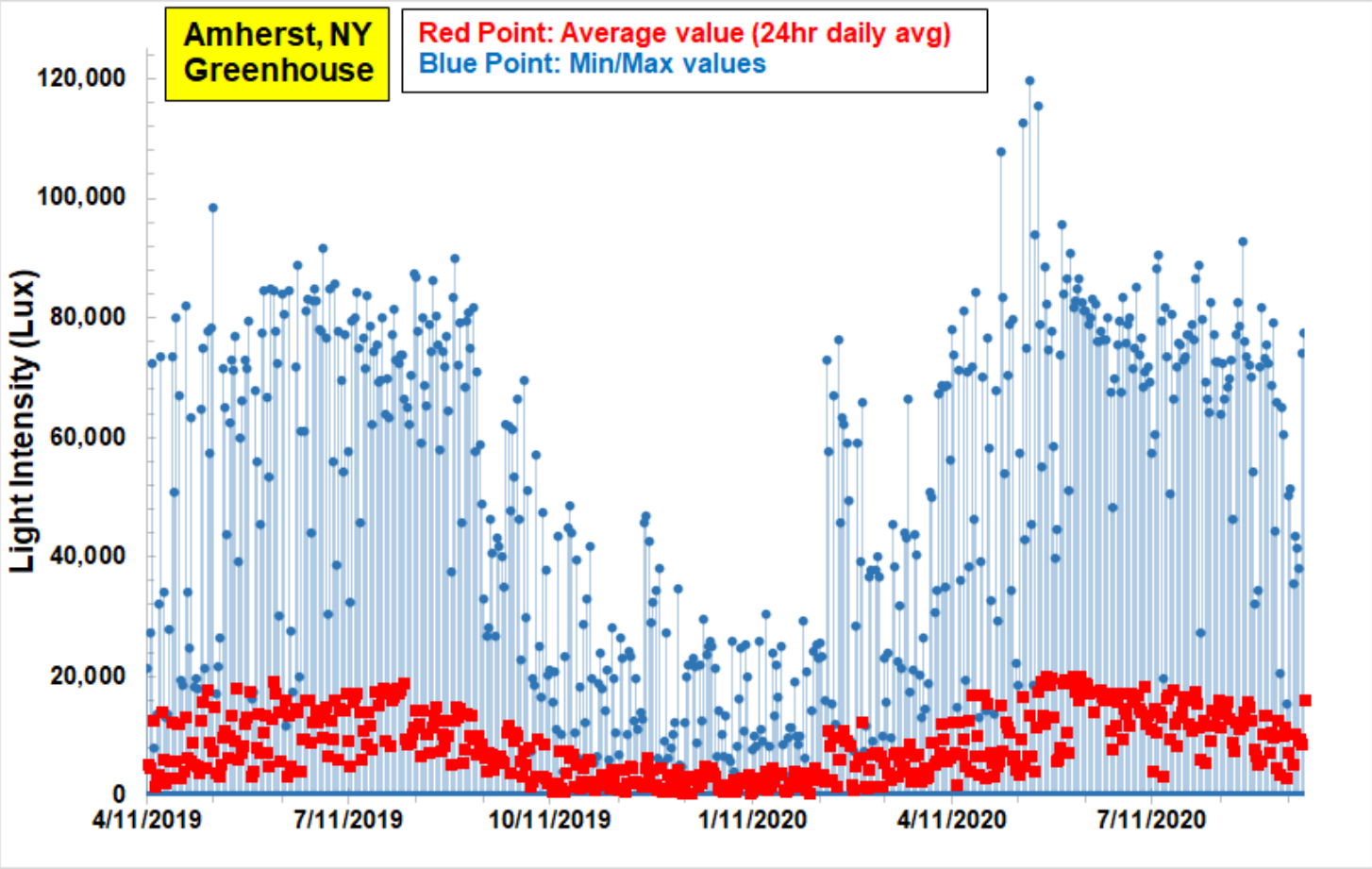
- **MSC system development**
- **Testing in natural sunlight**
- **Progress in dewatering**
- **Value added products**
- **Projected capture cost**

MSC CO2 Capture Technology



- First 3-stage integrated MSC system built
- Gas/liquid flow control system built & validated
- Stable performance of automated MSC system demonstrated
- Tested in natural sunlight - greenhouse & outdoors

Natural Sunlight Variation in Greenhouse



MSC operation tailored/optimized for large intensity variation

MSC Performance Evolution

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

Performance dependent on PBR design, operation & light intensity
Heavy Metals (HM): As, Se, Hg, Cu, Cr

MSC Performance Outdoors

Light variation between indoor and outdoor operation

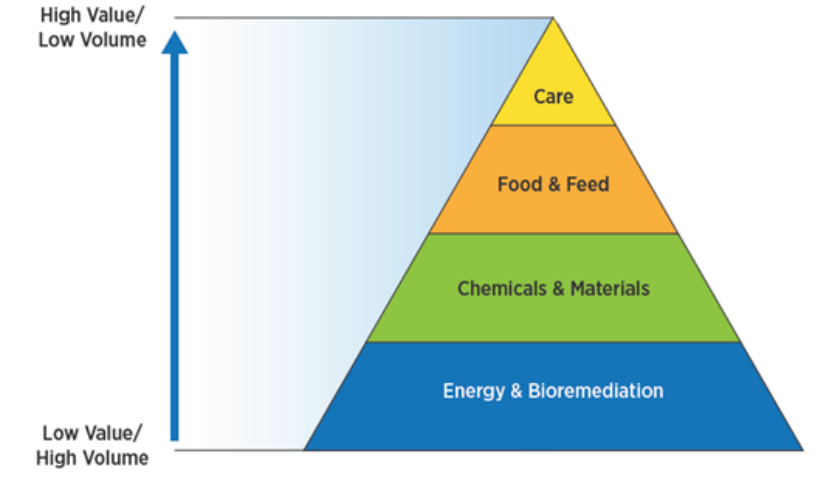
Month	Month Avg Light Intensity (Lux)	
	Internal GH	External GH
Apr-19	6893	
May-19	9423	
Jun-19	11306	
Jul-19	12981	23336
Aug-19	12144	20421
Sep-19	7808	15395
Oct-19	3909	9450
Nov-19	3002	4759
Dec-19	2354	3463
Jan-20	2236	3842
Feb-20	4874	7049
Mar-20	4963	10190
Apr-20	8211	13397
May-20	10888	16116
Jun-20	15577	22690
Jul-20	13675	19071

PBR Type	Light		Feed Gas		# of MSC Stages	Perf in Long-Term Test	
	Location	Intensity Avg (Lux)	CO2	Post FGD Cont		Avg Prod (g/m2/day)	Total CO2 Cap Eff (%)
F	GH	~10,500	12%	N/A	3	15.3	51.9%
H	GH	~12,000	12%	N/A	3	21.8	59.3%
C	Outdoor	~17,500	12%	N/A	2	33.2	81.2%
C	Outdoor	~26,500	12%	N/A	2	36.1	88.3%

- ~1.5-2x reduction in light intensity inside GH vs outside
  - Due to blockage from facility infrastructure
- MSC performance highly dependent on incident light intensity and PBR design
- Outdoor operation demonstrates ability of MSC system to achieve high productivity + CO2 capture efficiency

Progress in Products

- **Selected species for high value products**
  - Developed new culture method
  - Scaled up to GH operations
  - Tested range of CO2 feed
  - Products include nutraceuticals and feed additives

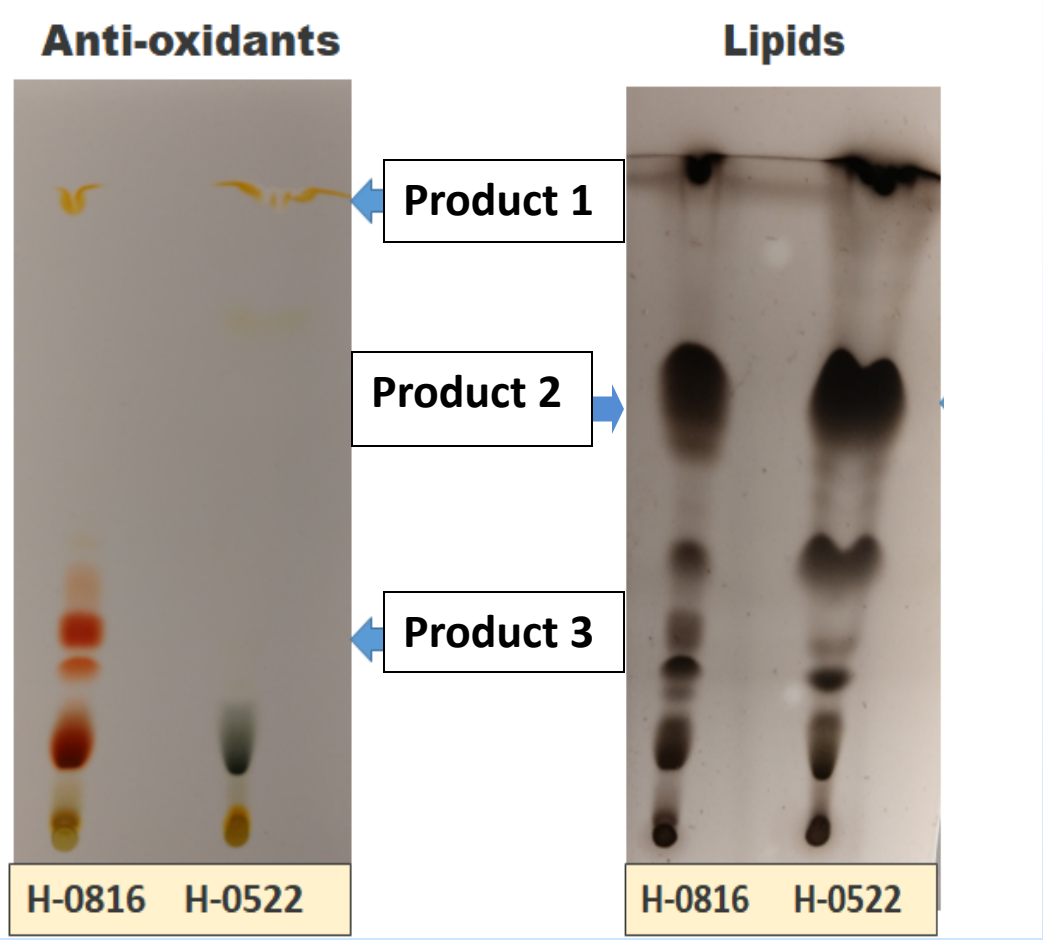


Value Proposition

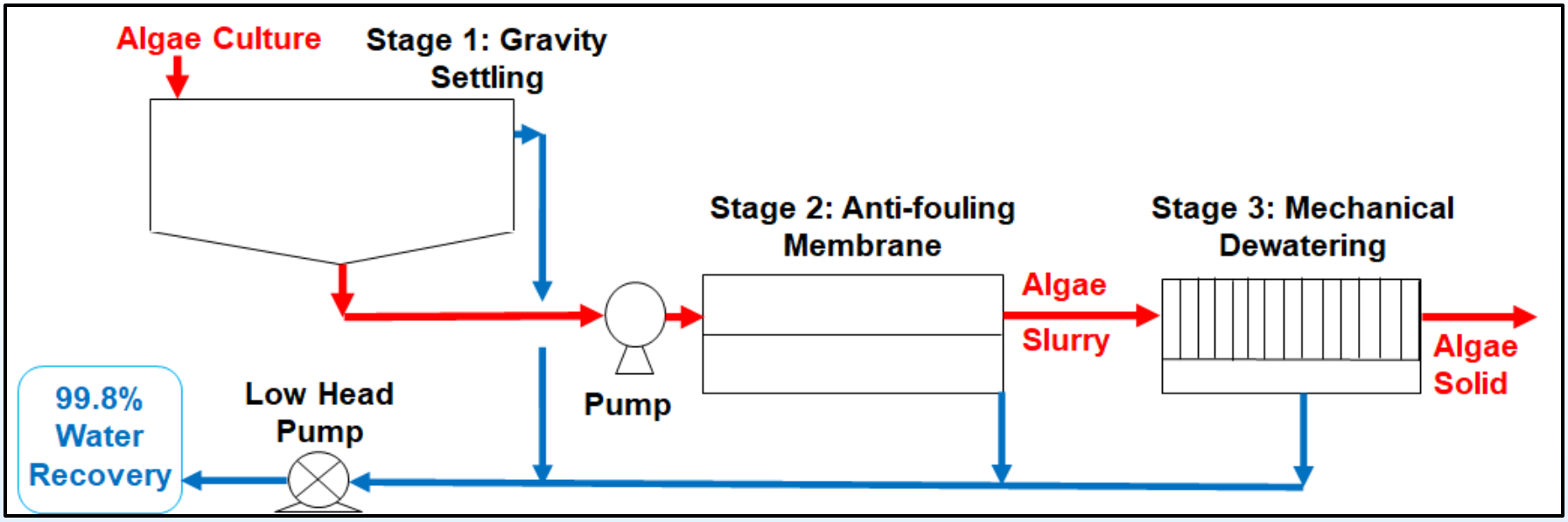
- **Induction, Extraction, Analysis**
  - Tested three methods of induction - Time reduced by over 50%
  - Extracted several products from each species
  - Analysis by TLC & HPLC

H-0816 before and after induction

TLC analysis of induced algae extracts



DeAqua - Algae Dewatering



DeAqua Stage	Initial Target		Current Work	
	Product Conc Ratio	Water Recovery (%)	Product Conc Ratio	Water Recovery (%)
1 - Gravity Table	~5	~80.0	~25	~96.0
2- Anti-fouling Membrane	~12	~18.3	~8	~3.5
3- Mechanical Dewatering	~10	~1.5	~3	~0.3

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

Advanced Gravity Table

Project	DeAqua Stage 1 Performance Specification		
	Product Conc Ratio	Performance Index	Product Recovery
Phase I Work	3-6	0.12-0.25	70%
Current Work	20-25	5.0-12.5	80-95%

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

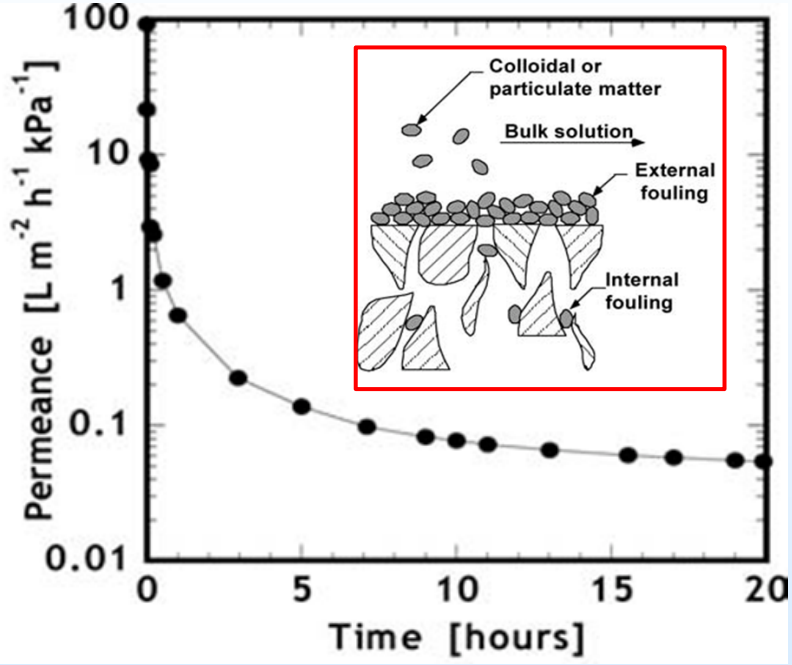
$$\text{Performance Index} = \frac{\text{Prod. Conc Ratio}}{\text{Process Time}}$$

Significant progress in Stage 1:

- Now removes >90% water compared to ~60% in Phase 1
- Energy reduced to ~5% of total algae energy content
- Original objective of 4X improvement in Perf Index greatly exceeded

Advance Anti-fouling Membrane

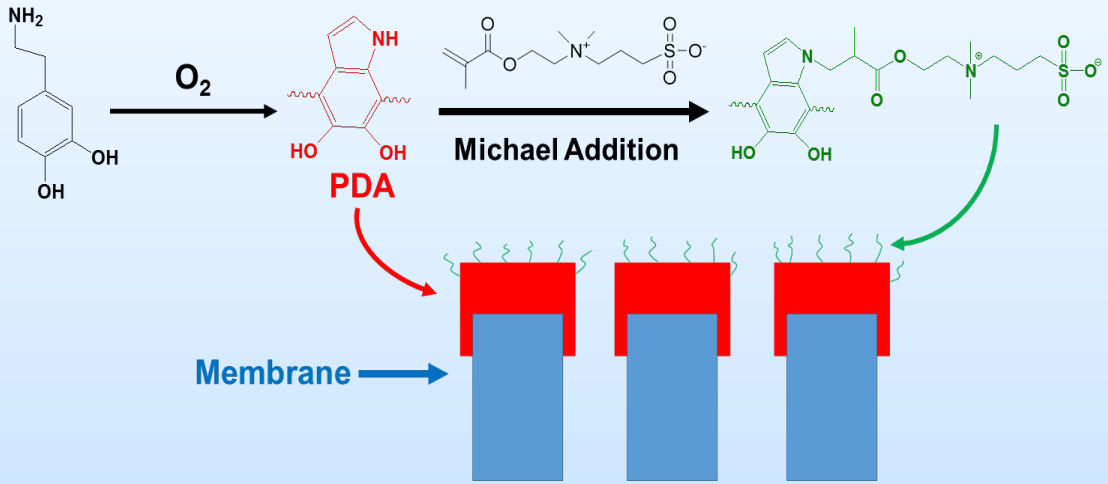
Impact of fouling on dewatering membrane



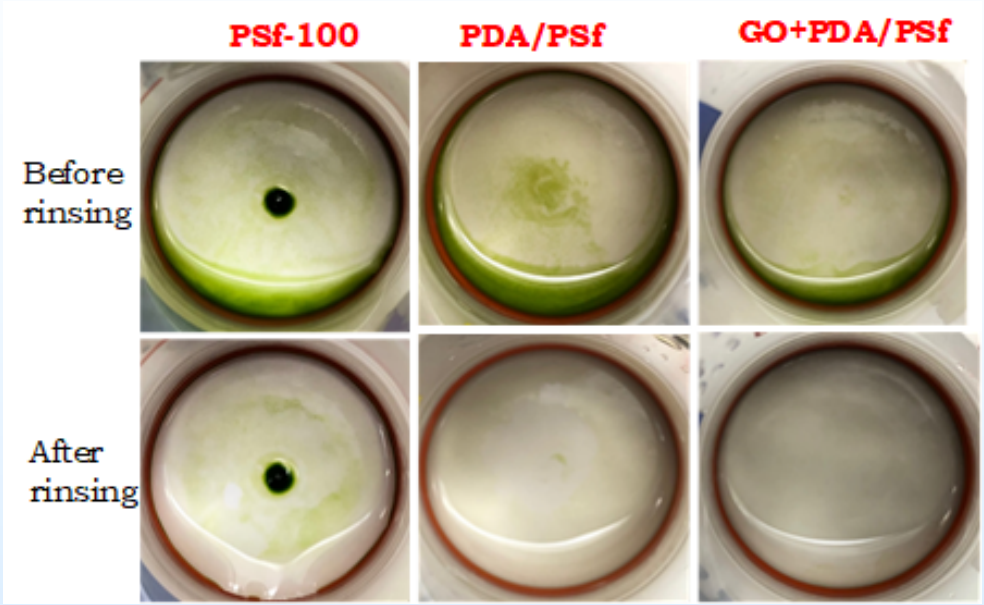
Typical membranes for algae dewatering: 10–20 LMH

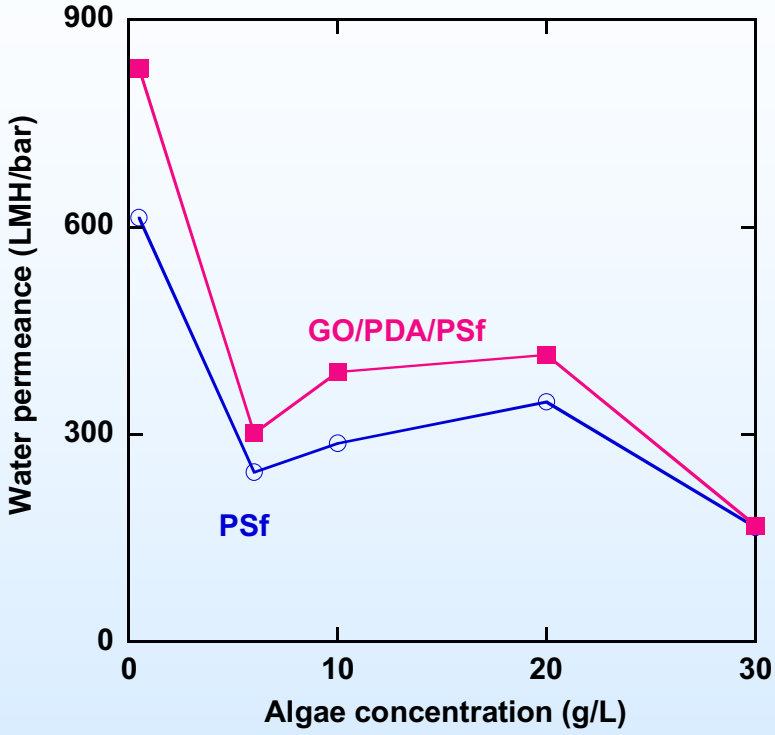
Our approach:

- **Surface modification with zwitterions (SBMA coating)**
- **Surface modification with graphene oxide (GO coating)**



Impact of surface modification on water permeance

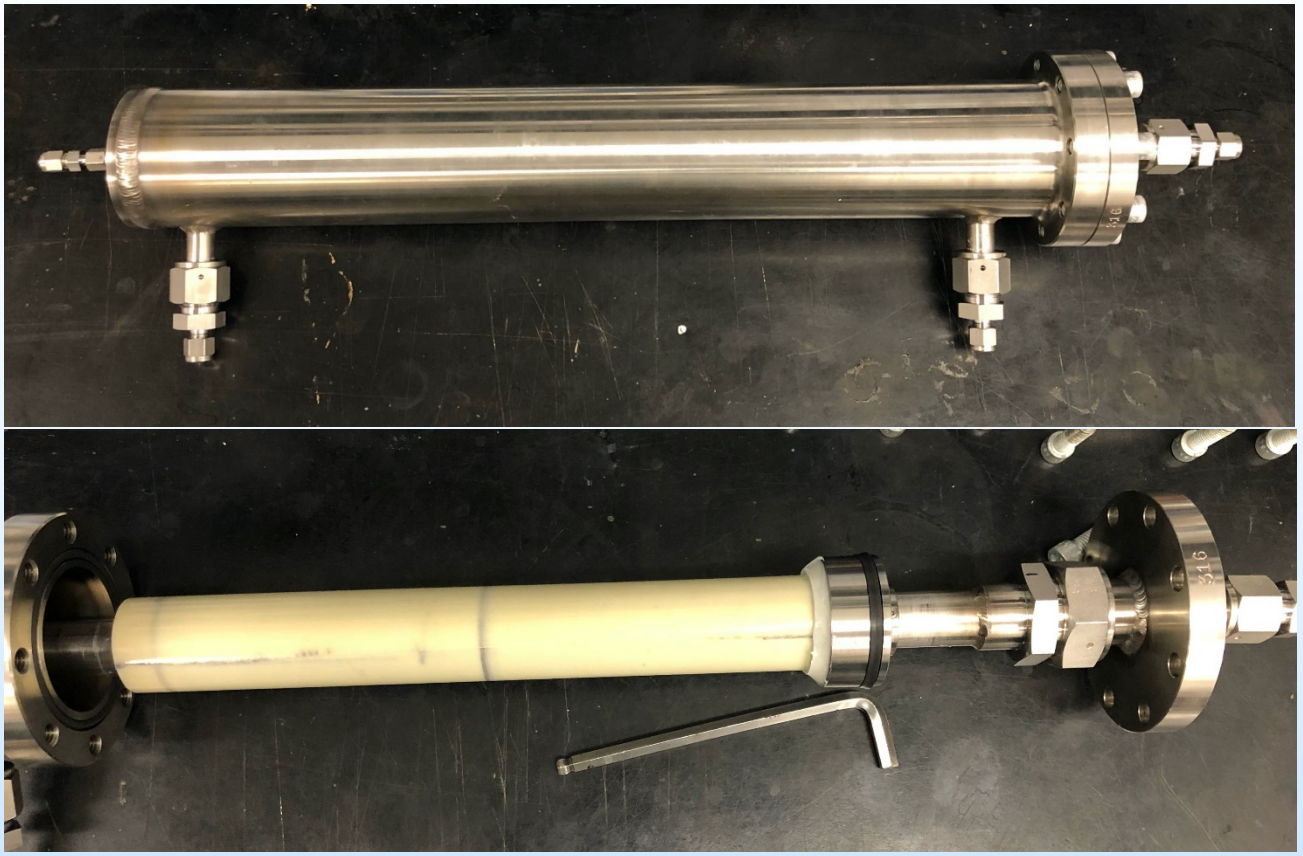




- Algae solutions can foul membranes
- Algae can accumulate on the surface
- Surface modification reduces fouling & increases water permeance

Surface modification improves performance in the critical regime

Fabrication of surface modified membrane module



0.14m2 spiral-wound module fabricated and parametric tests with algae to be conducted

Techno-Economic Projection

- **Algae biomass production cost:**
  - 2022 DOE Projection (25 g/m2/day): $494/dry ton
  - Project Target (25 g/m2/day): $ 510/dry ton
  - Current Projection (30 g/m2/day): $455/dry ton

- **Algae biomass utilization can generate $260-760/ton-algae**
  - 50% for biofuel ($2.5-4/gge)
  - 48% for animal feed ($200-700/ton)
  - 2% for nutraceuticals ($500-700/kg)

- **Credits can add significant value:**
  - CO2 capture credits: 0-30 $/ton CO2
  - Waste water credits for N & P removal ($210-500/ton)

- ***Net CO2 capture cost range: from +18 to -400 $/ton***

=> Cost neutral CO2 capture possible even without credits

Summary

- First of a kind integrated MSC system built and tested
- >80% CO2 capture efficiency demonstrated
- Average productivity >30 g/m2/day demonstrated outdoors
- Robust operation
- Several high value nutraceuticals validated in algae
- Substantially increased performance of dewatering

"Algae technology can enable a cost effective approach to high efficiency CO2 capture from coal flue gas"

Acknowledgement

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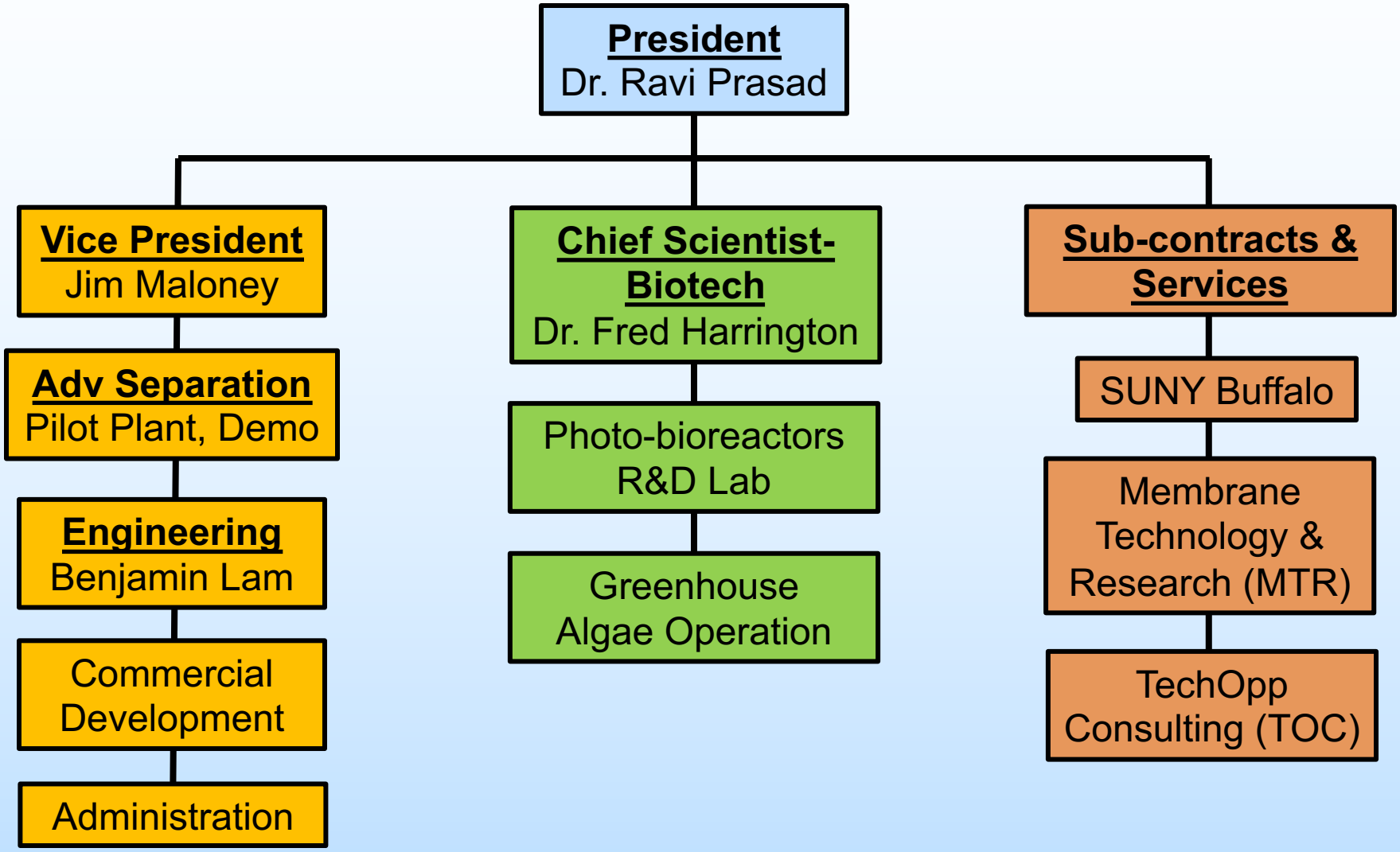
Appendix

Organization Chart



Gantt Chart

			Quarters from Project Start							
Task#	Task Description	Milestones	1	2	3	4	5	6	7	8
1	Design, Build, and Validate MSC	- MSC Design Complete - System fabricated - Capture eff >80% - Productivity >25 g/m2/day								
2	Optimize Nutraceuticals Production	- Inter-stage MSC stream defined - Preferred algae selected - Nutritional content validated								
3	Advance DeAqua Gravity Table	- Conc ratio of >4X achieved - >80% recovery from bottom								
4	Advance DeAqua Anti-fouling Mem	- Membrane water flux doubled - Module fabricated - Module perf demonstrated								
5	Refine Techno-economics	- TEA updated								
6	Project Management									