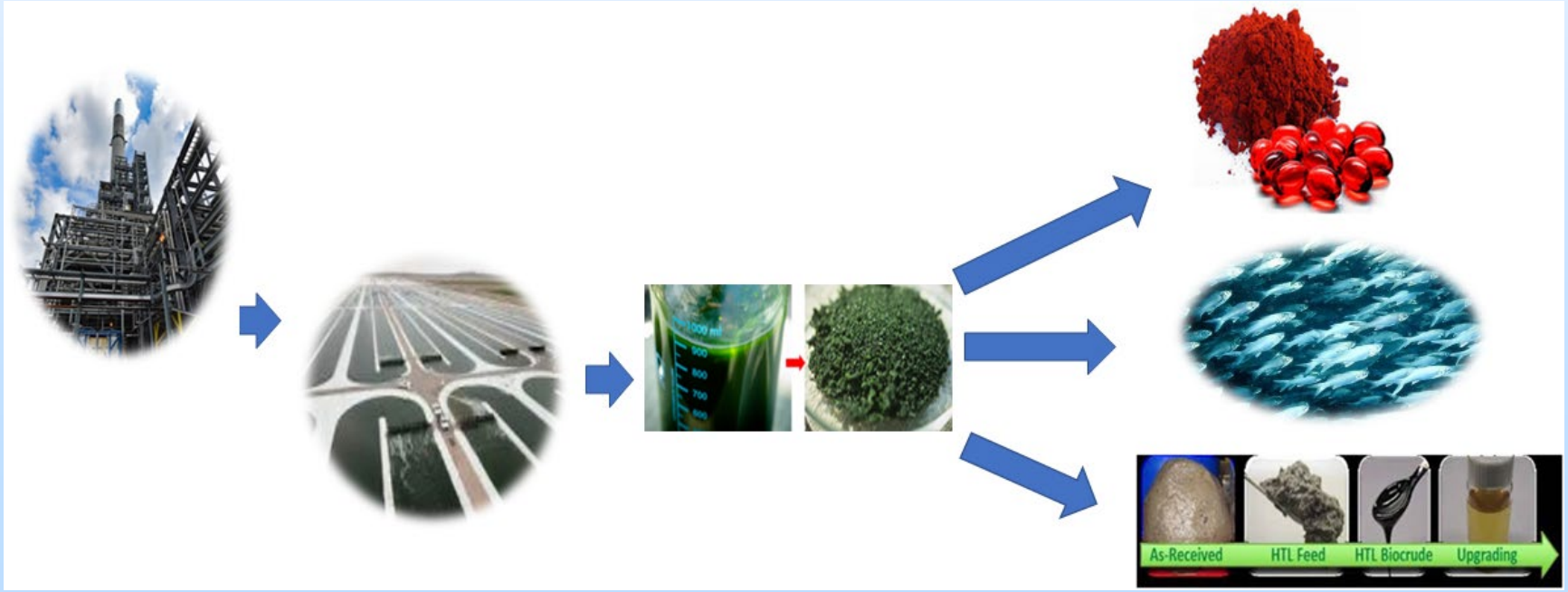
Engineering-Scale Validation of Novel Algae CO_2 Capture and Bioproducts Technology

Award No: DE-FE-0032103

PI: Dr. Fred Harrington

NETL/DOE Federal Project Manager: Naomi O'Neil

2023 FECM/NETL Carbon Management Research Project Review Meeting



General Project Information

- **Title: Engineering-Scale Validation of Novel Algae CO_2 Capture and Bioproducts Technology**

  - Recipient: Helios-NRG, LLC
  - PI: Fred Harrington, PhD, Chief Scientist
  - Business Mgr: Jim Maloney, VP
  - DOE Federal Project Manager: Naomi O'Neil

- **Project Funding:**
  - **Total: $2,499,030**
  - **Government Share: $1,999,228 Cost Share: $499,802**

- **Project Period: 10/1/21 – 9/30/24**

Project Partners

- University of Buffalo-Lin
- University of Buffalo-Bradley
- Bozeman Fish Technology Center
- The Conservation Fund - Freshwater Institute
- National Carbon Capture Center

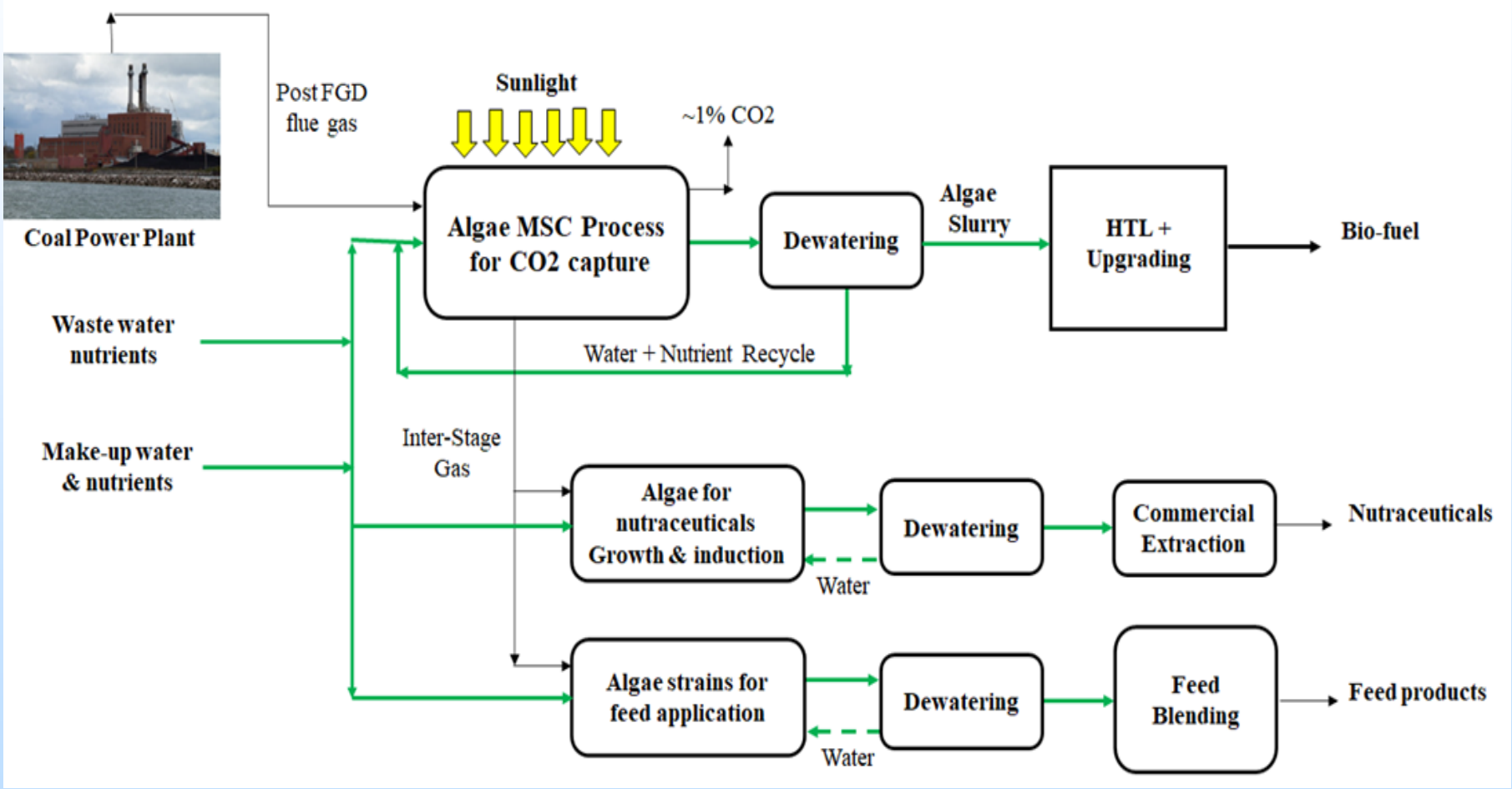
Overall Strategy

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

- **Develop scalable algae technology for high CO2 capture efficiency and high productivity from coal flue gas (fossil fuel power plants)**

- **Reduce capture cost via operational efficiency, wastewater credits & product revenue**

Process Schematic at Commercialization



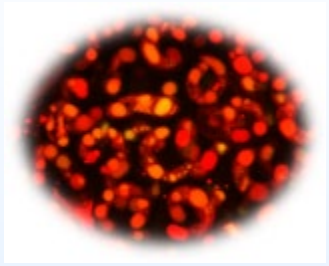
(Bio-fuel and dewatering are not part of current project)

Key Advantages of the Technology

- **CO2 captured as a biomass - avoids gas sequestration**
- **Sustainable primary energy source (sunlight)**
- **Capture cost offset by revenues products with existing markets**
- **High productivity + capture efficiency**
- **Closed system minimizes contamination & water loss**
- **Continuous process compared to many other biological approaches**
  - **Easier integration with upstream/downstream processes**
  - **Lower operational cost**

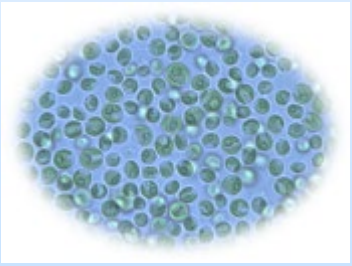
Algae Species Selection

- **Primary criteria for CO_2 Capture**
  - High growth rates in presence of flue gas contaminants
  - Can utilize wastewater (Municipal and HTL-aqueous)
  - Adapted naturally occurring species – no GMO's
  - Prior Helios experience & well characterized



H-1903

- **Capture species selected for project (H-1903)**
  - Backup species available (H-0322)



H-0322

- **Species are application & product specific**

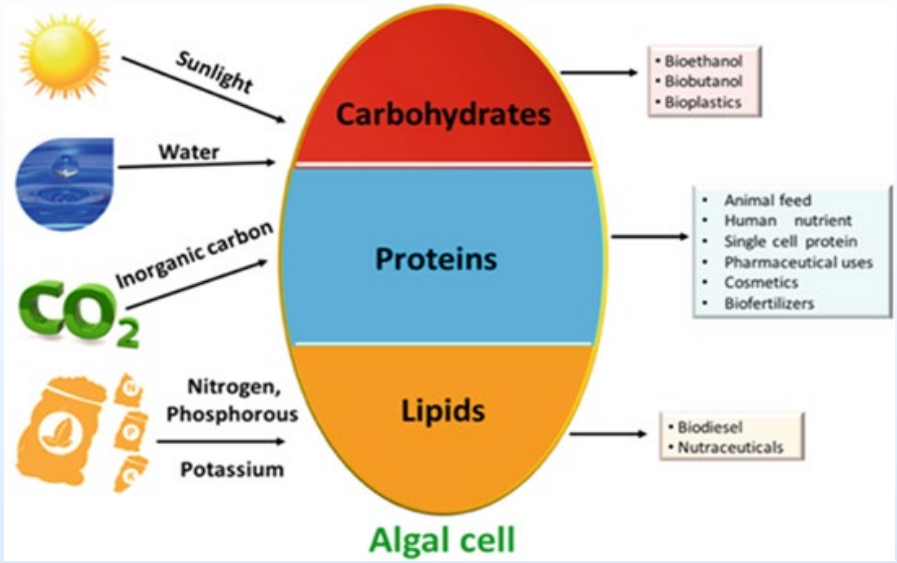
MSC process for Carbon Capture

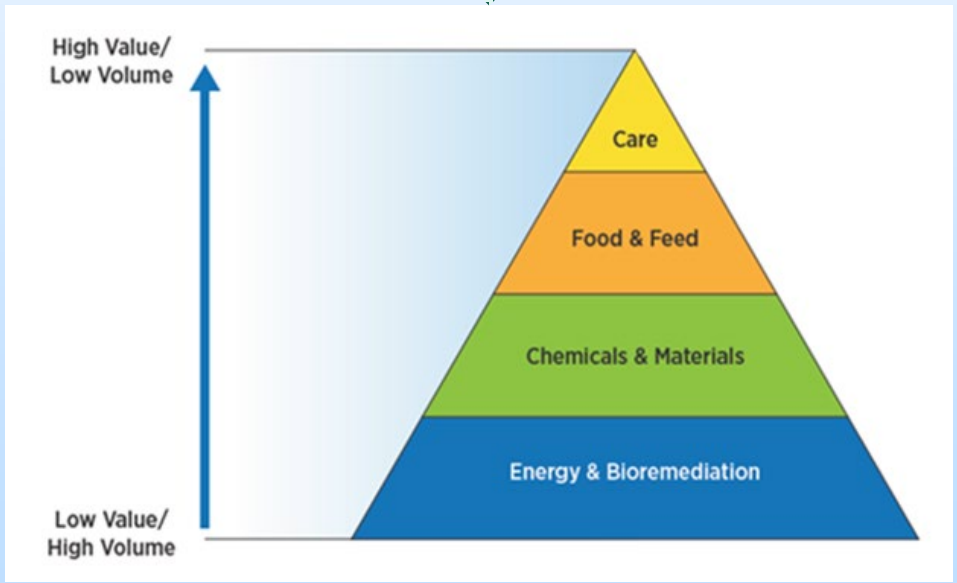
- **Concept developed using proprietary model**
  - Predictable operation - automated control
  - Top lit closed system
  - High productivity & capture efficiency
  - Various MSC tank designs developed & tested

- **Integrated multi-stage operation demonstrated**
- **Stability demonstrated in ~100 day outdoor test**
- **MSC operation validated at NCCC test in 2022**
  - Performance exceeded project targets

Location	Sim. Flue Gas Contaminant	Nutr-WW Replacement	Normalized Algae Prod	Avg CO2 Capture
GH-1 Indoor	SOX/NOX + 5HM	50%	92%	59%
Outdoor	N/A	N/A	139%	81%
Outdoor	SOX/NOX + 5HM	80%	141%	76%
Outdoor	N/A	N/A	142%	77%
FE-0031710 NCCC'22	**NCCC SSTU Flue Gas**	**N/A**	123%	**87%**

Products from Algae with Existing Markets

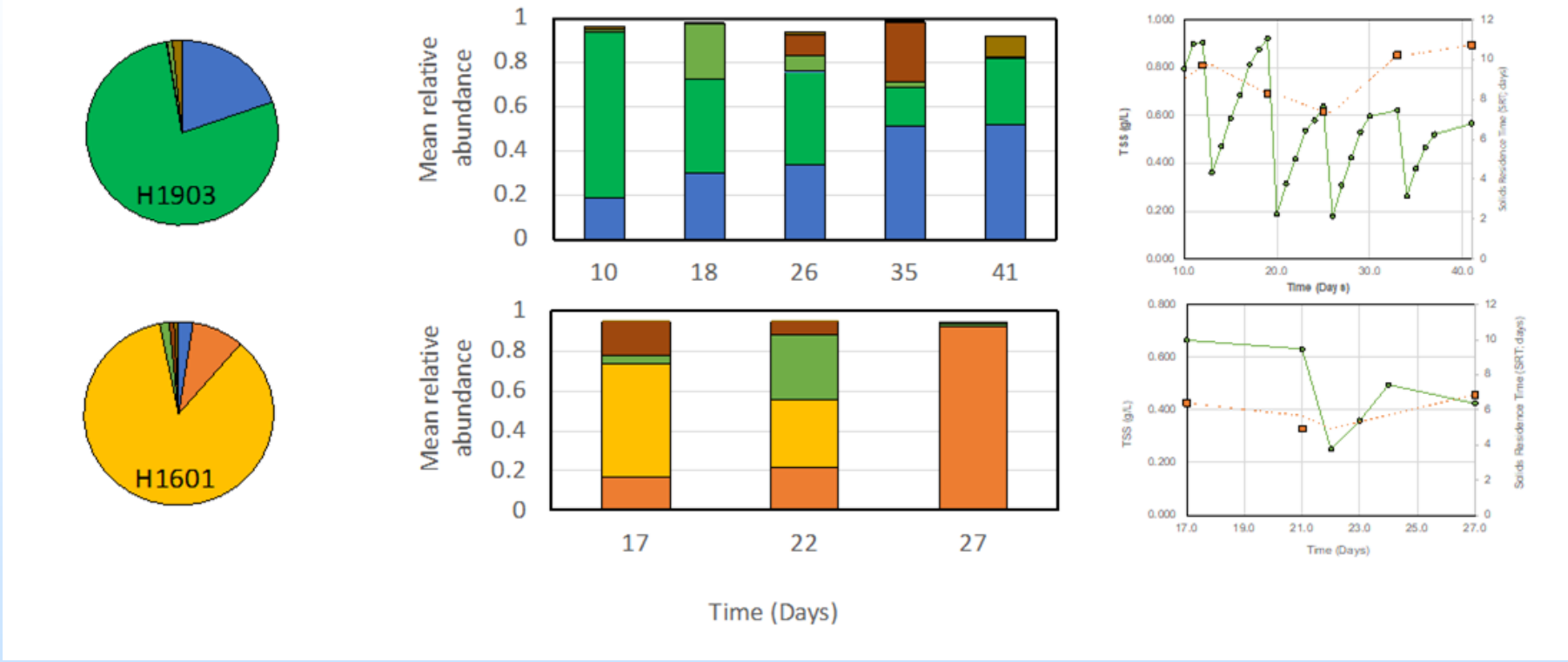




Primary Goals of Current Project

- **Develop 2nd Gen MSC to maximize productivity, capture eff & scalability**
  - **Improved control system to maximize operation**
  - **Innovations for scaling**
  - **Biocontamination control to improve productivity**
- **Advance products from algae to increase revenue potential & reduce risk**
  - **Fish feed that utilizes valuable components**
  - **Additional nutraceutical compounds**
- **Demonstrate performance in outdoors operation & at NCCC**

Bio-contamination control strategy



- Sequencing results indicate eukaryotic contamination
- Primarily predators (e.g., amoeba, ciliates) vs bacterial/fungal infection

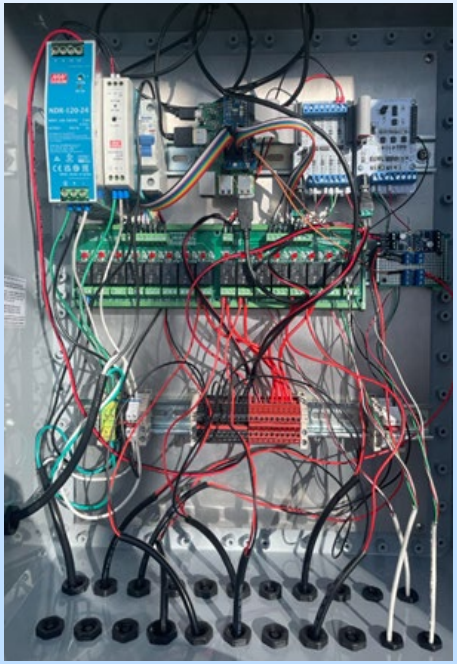
MSC operation for optimal performance

- **Improved MSC system designed & fabricated**
  - Advanced control-system built & being tested
  - Efficient culture circulation
  - Scalable mass transfer device for efficient gas-liquid contacting
  - Scalable, low cost seal for top cover
- **Ongoing greenhouse tests to demonstrate system functionality**

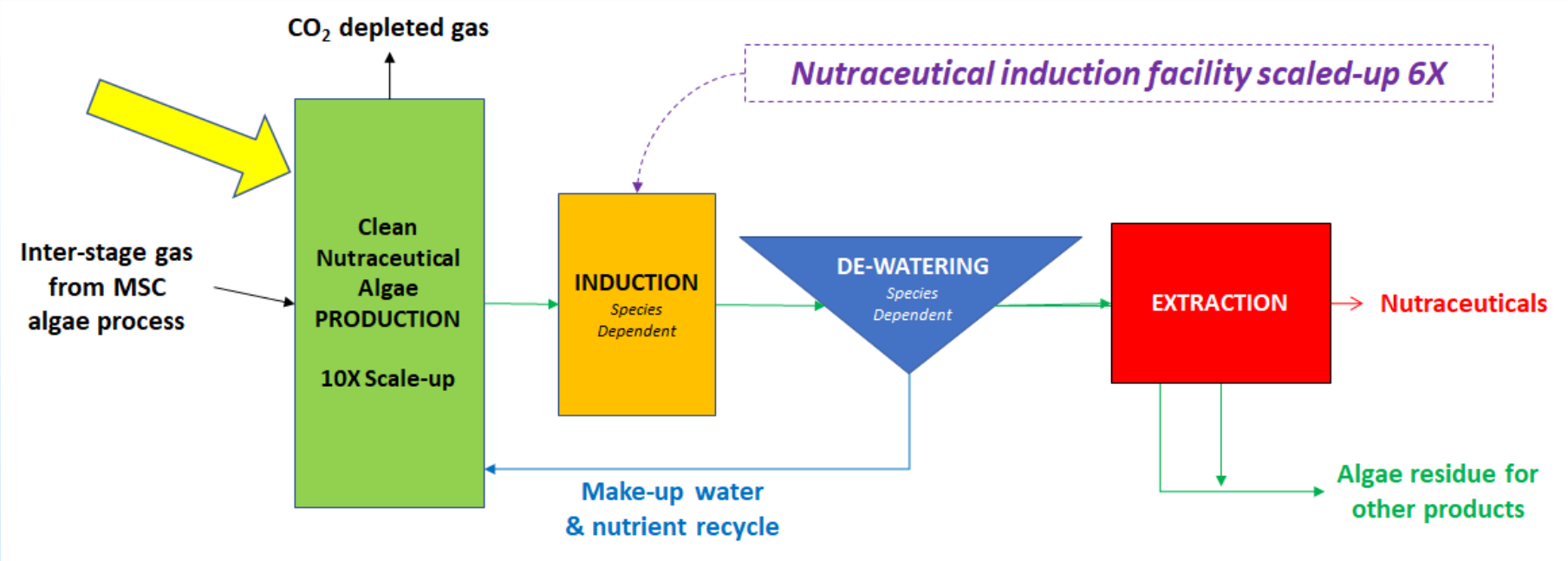
Sealed, scalable raceway

Flow Controller

Controller breadboard



Nutraceutical Production Process



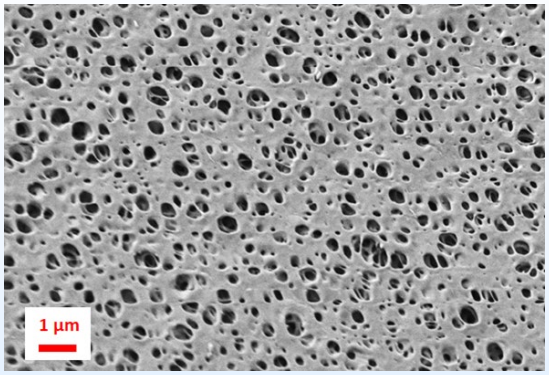
- Multiple process improvements increased production significantly
- Identified 4 product groups to advance pathways towards commercialization

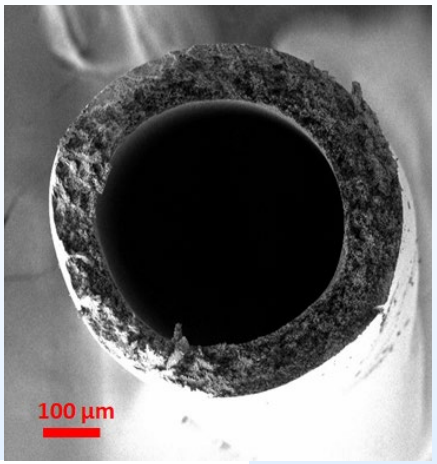
Hollow fiber membrane surface morphology for CO2 dissolution

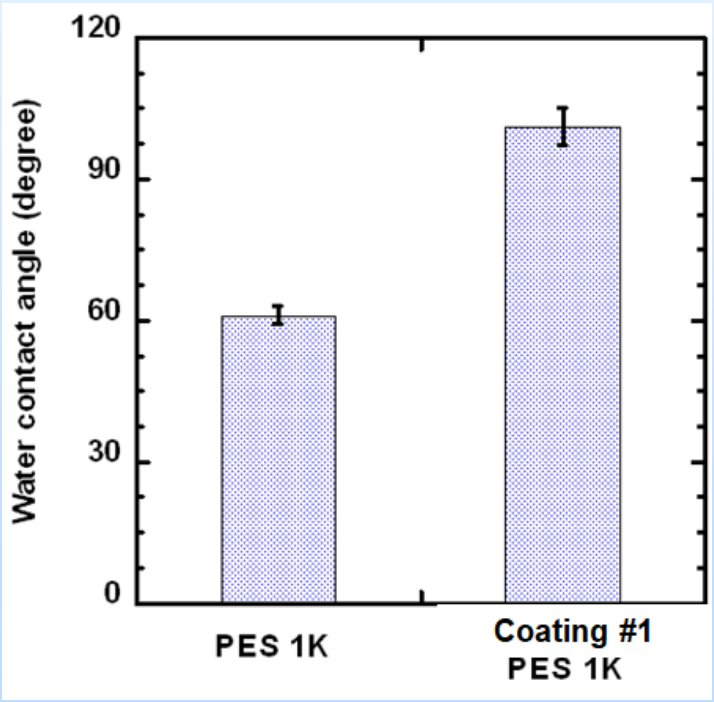
After coating (before)

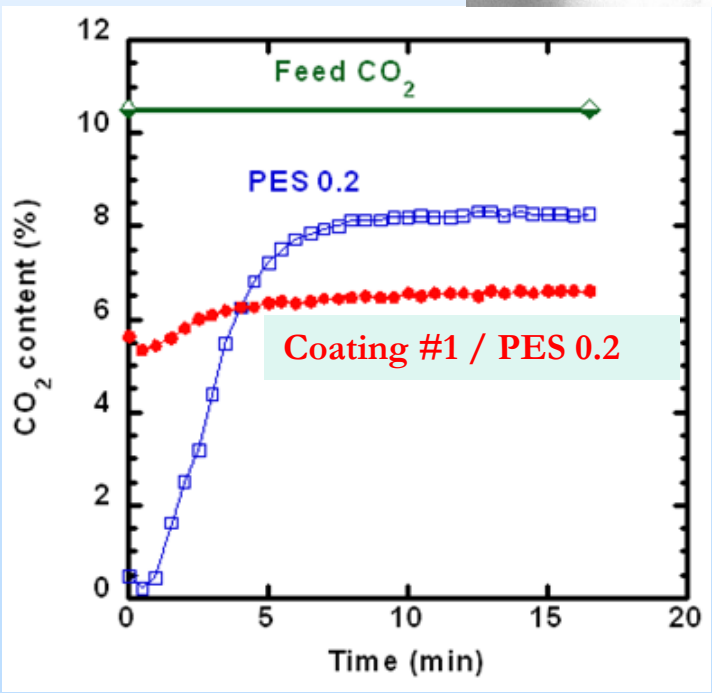
Pore size: ~190 nm (200)

Porosity: ~19% (22)



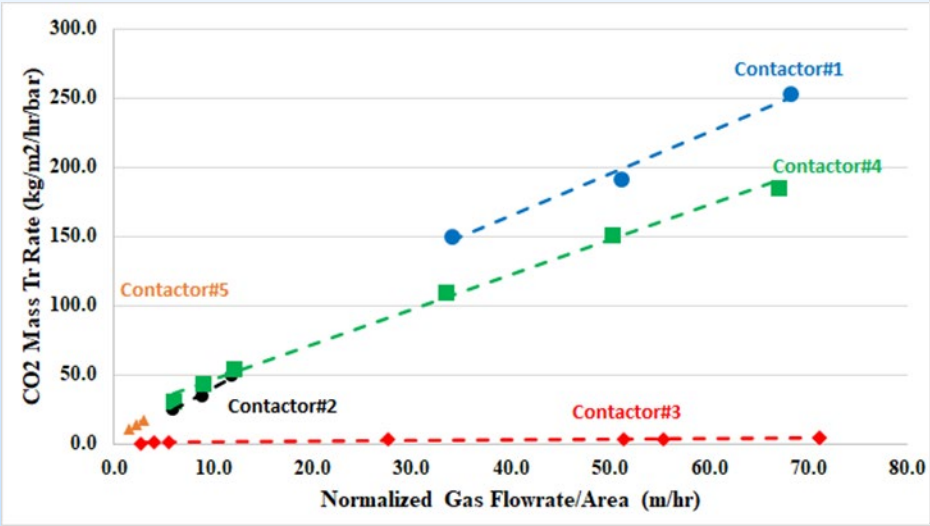


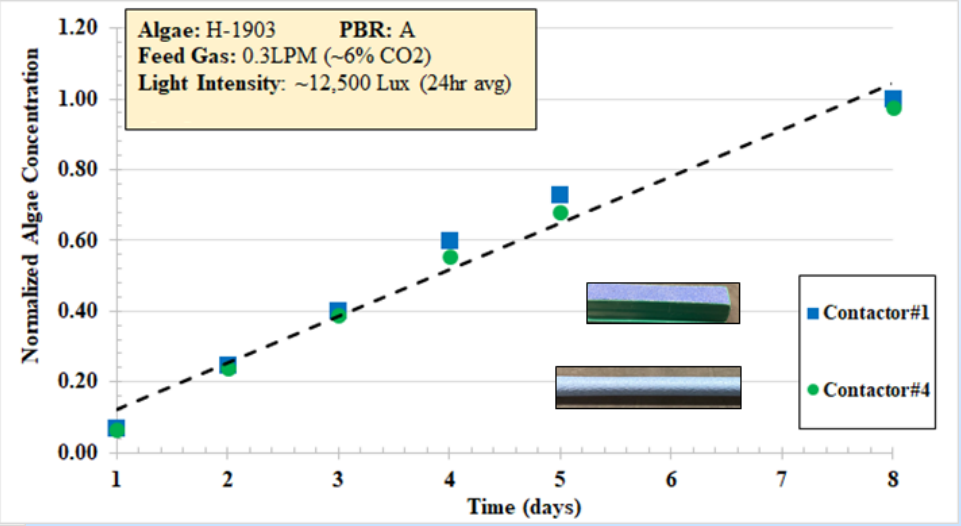




Evaluation of Mass Transfer Devices

- Several designs evaluated
  - (Left Panel) Reactive buffer solution
  - (Right Panel) Algae cultures
- Selection Criteria :
  - Mass transfer rate
  - Pressure required
  - Scalability potential & Cost





Contactor#4 preferred due to its high mass transfer rate and scalability

Algae qualification for aquaculture feed blends

	Reference diet
Squid - CSF	25.00
Soy Protein Concentrate	11.00
SBM (Standard ADM 47%)	3.00
Corn gluten meal	8.34
Wheat flour	35.94
Stay-C 35	0.20
Vitamin premix ARS 702	1.00
TM ARS 640	0.10
Choline Cl 50%	0.60
Taurine	0.50
Yttrium oxide	0.10
Menhaden fish oil	14.22

Test diets = 70% reference diet plus:

1&2 - 30% Menhaden fishmeal

3 - 30% Algae H-0116

4 - 30% Algae H-1903

- Content Analysis – both algae species showed potential
- Digestibility – Algae H-0116 exceeded control
- Completion of short-term growth test is next

BP-2 Work Plan

- **Protocols for biocontamination control & mitigation**
- **Utilization of wastewater for nutrient replacement**
- **Validate improved MSC operation**

  - greenhouse, outdoors and NCCC field test
- **Advance nutraceutical production**
- **Conduct field test of algae blended fish feed**

  - demonstrate fish growth, health and meat quality
- **Perform LCA and TEA**

Plans for future testing/development/ commercialization

- Implement dynamic process control for improved operation
- Develop in-ground, closed raceway stages that will be the basic unit for commercial MSC systems
- Operate the system with biocontamination control to improve culture health, productivity and culture longevity
- Improve CO_2 dissolution system
- Integrate MSC with de-watering and operate with high water/nutrient recycle
- Utilize municipal wastewater to replace purchased nutrients for cost reduction and significant remediation credits

Summary

- **Key learnings:**

Productivity Improvements:
- **Decreased biocontamination**
- **Controlled operation in variable conditions**
- **CO_2 dissolution with lower energy**

Products
- **Nutraceuticals**
- **Aquaculture feed**

- **Take-away:**
  - **Advancements in a variety of aspects of algal productivity/carbon capture with costs offsets from product revenue lead towards commercial path**

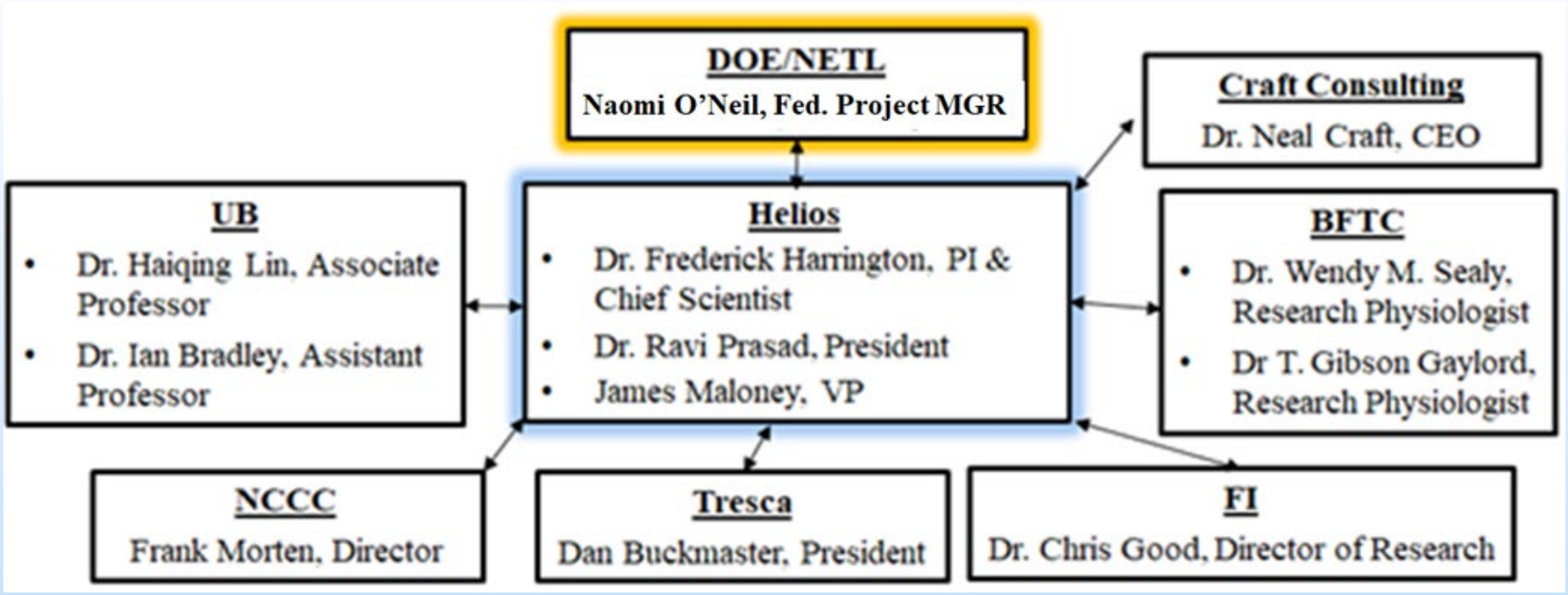
Thanks to DOE, NETL and our Partners

Acknowledgement

This material is based upon work supported by the Department of Energy under Award Number DE-FE-0032103.

Appendix

Organization Chart



Gantt Chart

			Budget Period 1						Budget Period 2					
Task #	Subtask	Quarter	1	2	3	4	5	6	7	8	9	10	11	12
1, 7		Project Management & Planning												
2		Bio-contamination control strategy for algae culture												
3		MSC operation for optimal utilization of varying sunlight												
4		Maximize nutraceutical production from algae												
5		Develop membrane contactor and evaluate in algae cultures												
6		Initial qualification of algae for aquaculture feed blends												
8		Implement bio-contamination control in algae cultures												
9		Build and test MSC with new components												
10		Demonstration of algae based products												
11		Algae carbon capture engineering-scale field test at NC3												
12		Refine LCA/TEA												