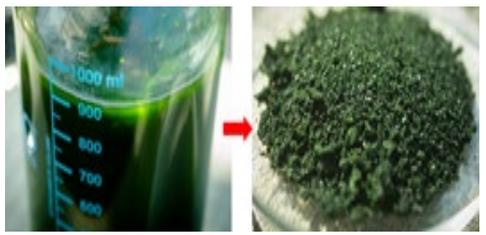
Engineering-Scale Validation of Novel Algae CO_2 Capture and Bioproducts Technology

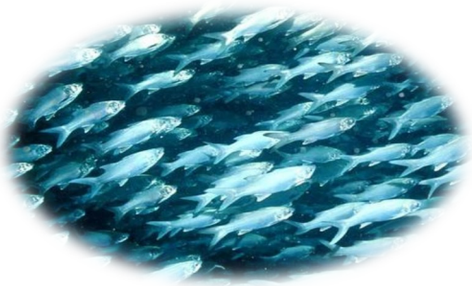
Award No: DE-FE-0032103

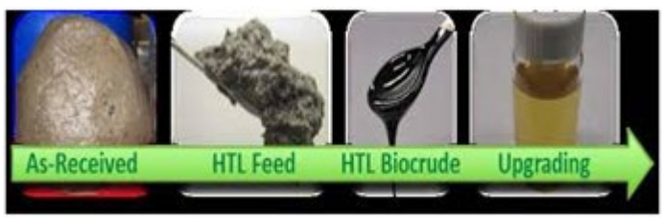
PI: Dr. Fred Harrington

NETL/DOE Federal Project Manager: Naomi O'Neil

***Online* Kickoff Meeting- October 26, 2021**







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: $1,999,228** **Cost Share: $499,802**
- **Project Period: 10/1/21 – 9/30/24**

Project Participants

- Project Partners:
  - University of Buffalo-Lin
  - University of Buffalo-Bradley
  - Bozeman Fish Technology Center
  - Freshwater Institute
  - Craft Nutrition Consulting
  - Tresca Design
  - National Carbon Capture Center

Bozeman Fish Technology Center

Overall Strategy

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

- **Develop scalable, multi-stage, algae technology for high CO2 capture efficiency and high productivity from coal flue gas (fossil fuel power plants)**
  - Continuous process – efficient upstream & downstream process integration
  - Controllable and predictable system with high capture efficiency

- **Reduce capture cost via operational efficiency, credits and product revenue**
  - Range of products
  - Low cost, efficient, high productivity operation
  - Negative cost wastewater nutrient inputs

Process Schematic

Coal Power Plant

Post FGD flue gas

Sunlight

~1% CO2

Algae MSC Process for CO2 capture

Dewatering

Algae Slurry

HTL + Upgrading

Bio-fuel

Waste water nutrients

Water + Nutrient Recycle

Make-up water & nutrients

Inter-Stage Gas

Algae for nutraceuticals Growth & induction

Dewatering

Commercial Extraction

Nutraceuticals

Water

Algae strains for feed application

Dewatering

Feed Blending

Feed products

Water

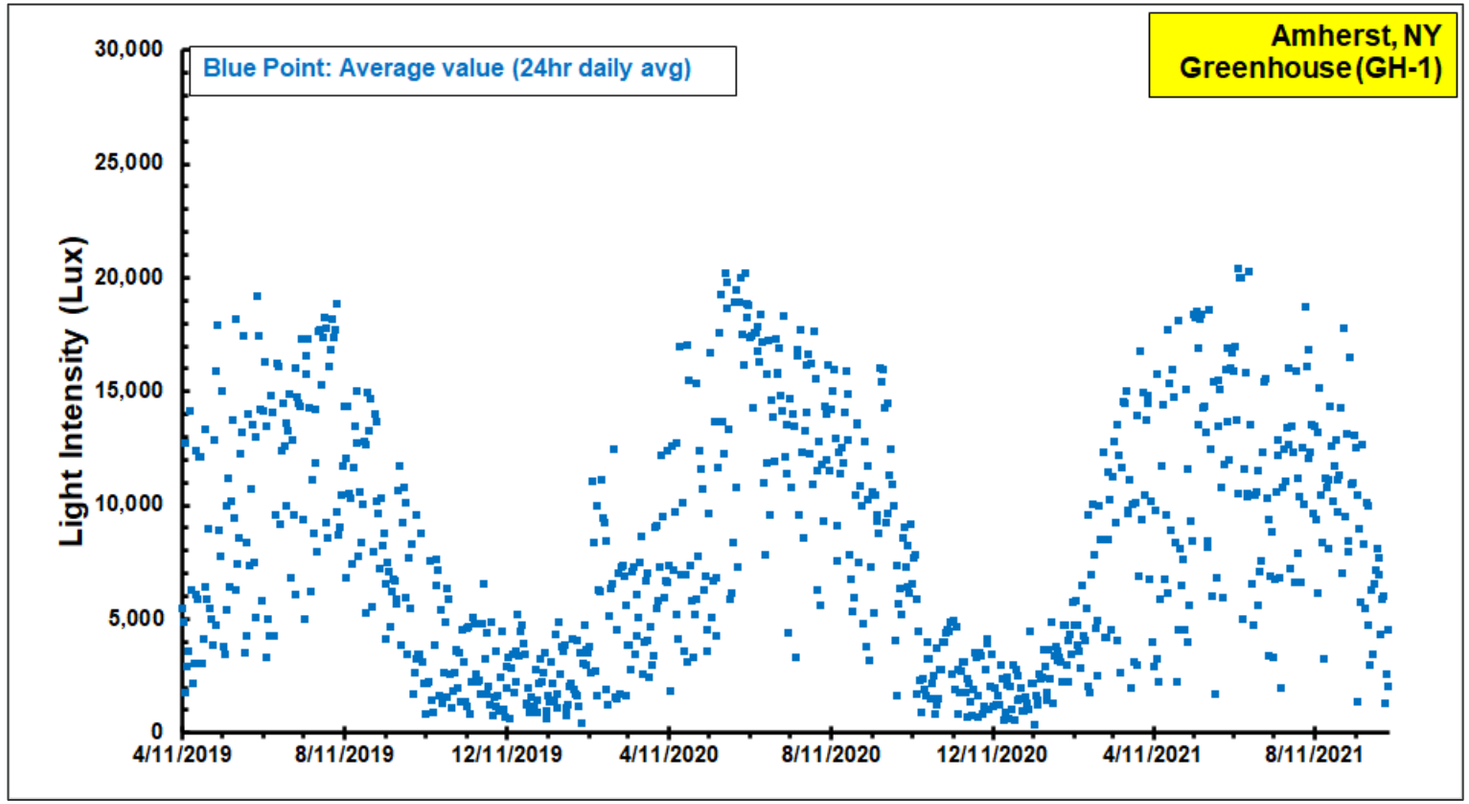
Technology Background

MSC Technology for Carbon Capture

- Multi-stage continuous (MSC) process
- Continuous gas & liquid
  flows between stages
- Top lit closed system
- Stable algae concentrations
- High productivity & capture efficiency
- Predictable operation
- Amenable to automated control
- Can be tailored to application
  - e.g. Natural gas power plants

Integrated Raceway-MSC at Greenhouse

MSC Operation in Sunlight



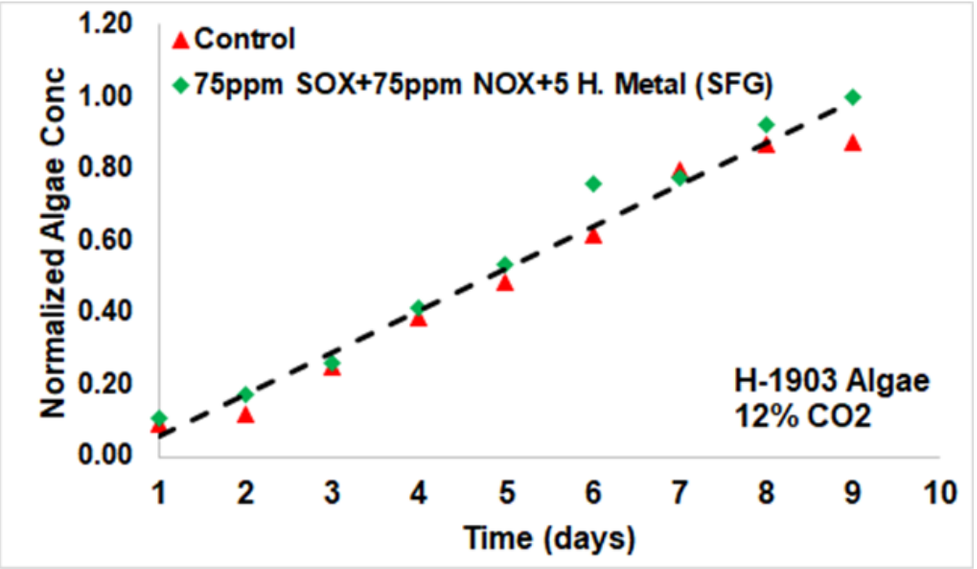
	GH-1 Avg Light Intensity (Lux)	
	Internal	External
Q2 2019	9207	
Q3 2019	10978	19717
Q4 2019	3088	5890
Q1 2020	4024	7027
Q2 2020	11582	17401
Q3 2020	11636	14819
Q4 2020	3128	6626
Q1 2021	5284	9034
Q2 2021	11571	16198
Q3 2021	10042	15005

- MSC performance dependent on light intensity
- Natural sunlight has variable intensity
  - Monitored at test sites for 2+ years to correlate with performance
- Significant reduction in light intensity inside the GH vs outside

MSC Development

- Preferred, high growth algae species selected (H-1903)
- Concept developed using proprietary predictive model
- MSC operation simulated using 1-stage PBR's in lab
- Various MSC tank designs developed & tested
- Non-integrated MSC validated in GH
- Stability of operation demonstrated in ~100 day test

Algae Survival with Contaminants



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%
FE-0031710 Target			**Actual NCCC Flue Gas**		**TBD**	**25**	**80%**

MSC Development

- **Integrated 3-stage MSC fabricated with improved closed raceway design**
- **Advanced MSC control system developed**
  - Enables unattended operation
- **Long term stability demonstrated outdoors**
- **Met targets outdoors**
  - 80% capture efficiency
  - 25 g/m2/day productivity
- **Readying system for NCCC field test**

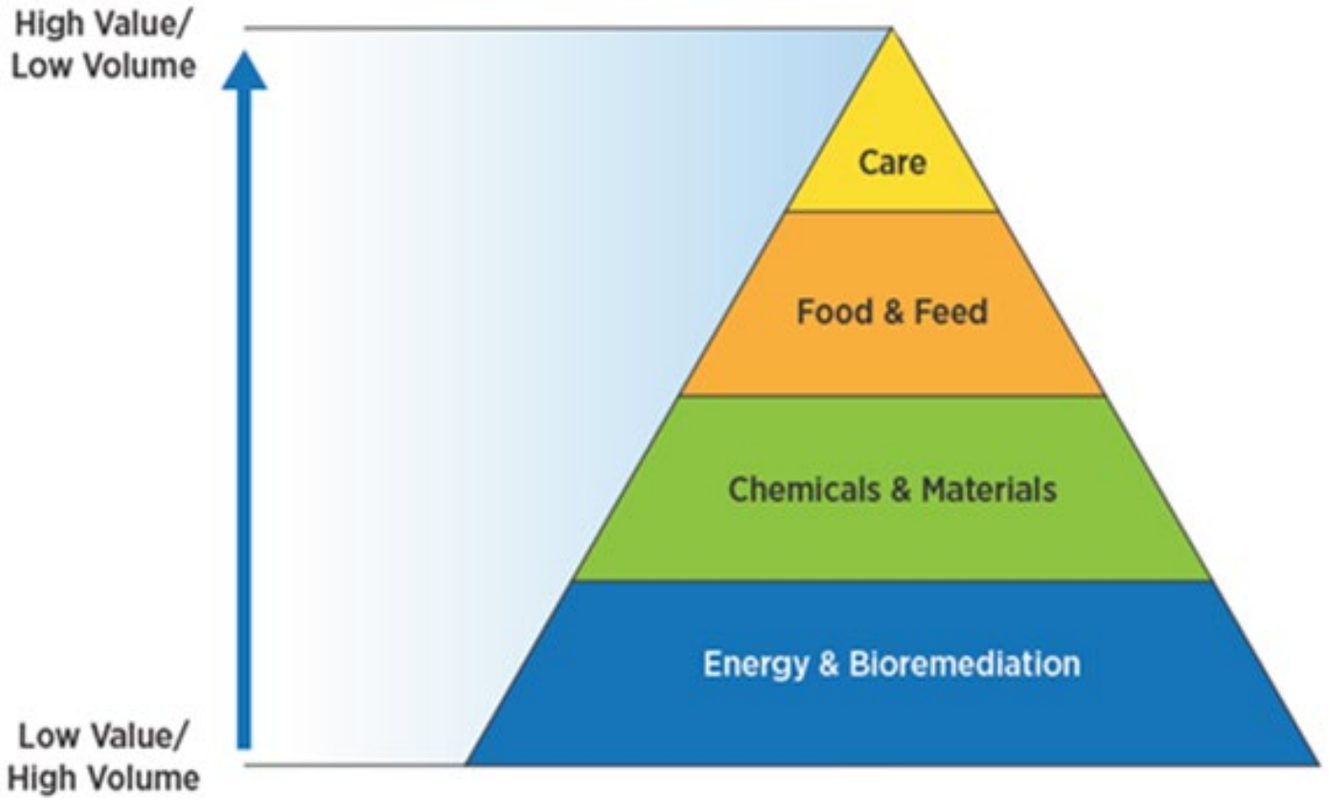
Integrated Raceway-MSC Outdoors

Products from Algae

Small Market, Highest Value
Nutraceuticals

Large Market, High Value
Animal feed

Largest Market, Lower Value
Biofuels

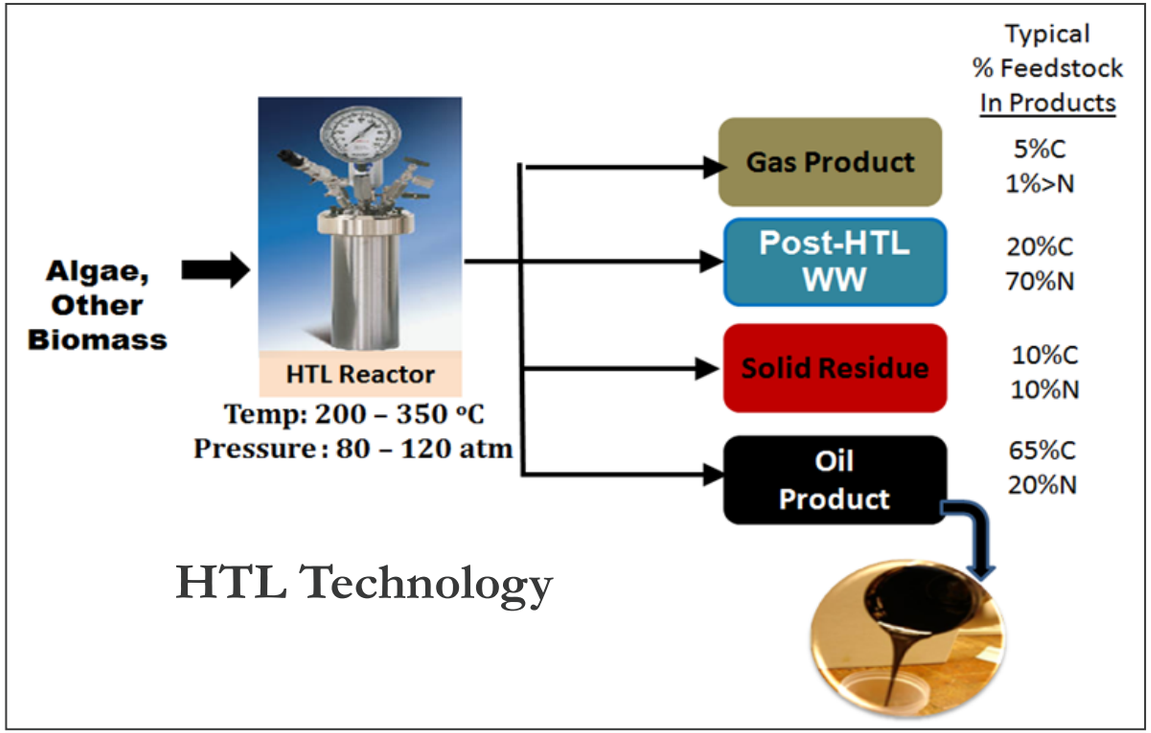


Biofuel & Feed from Algae - Univ of Illinois collaboration

NATIONAL ENERGY TECHNOLOGY LABORATORY

Biofuels:

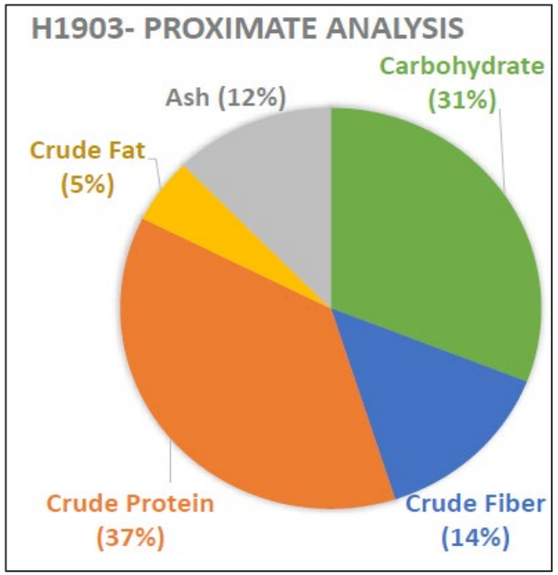
- Conversion via HTL demonstrated
- Uses algae slurry (avoids drying)
- ~40% yield and >38MJ/kg obtained
- Significant potential for further improvement

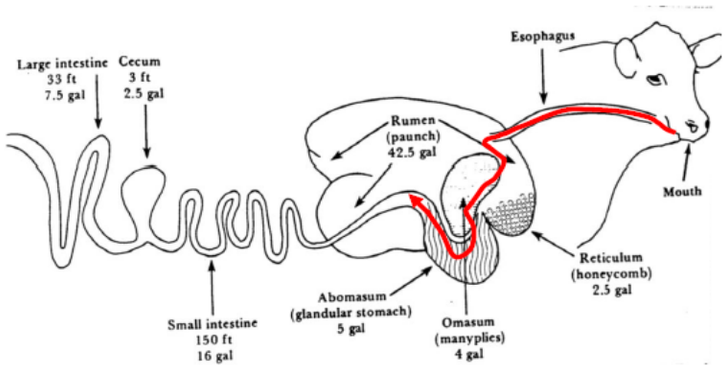


HTL Technology

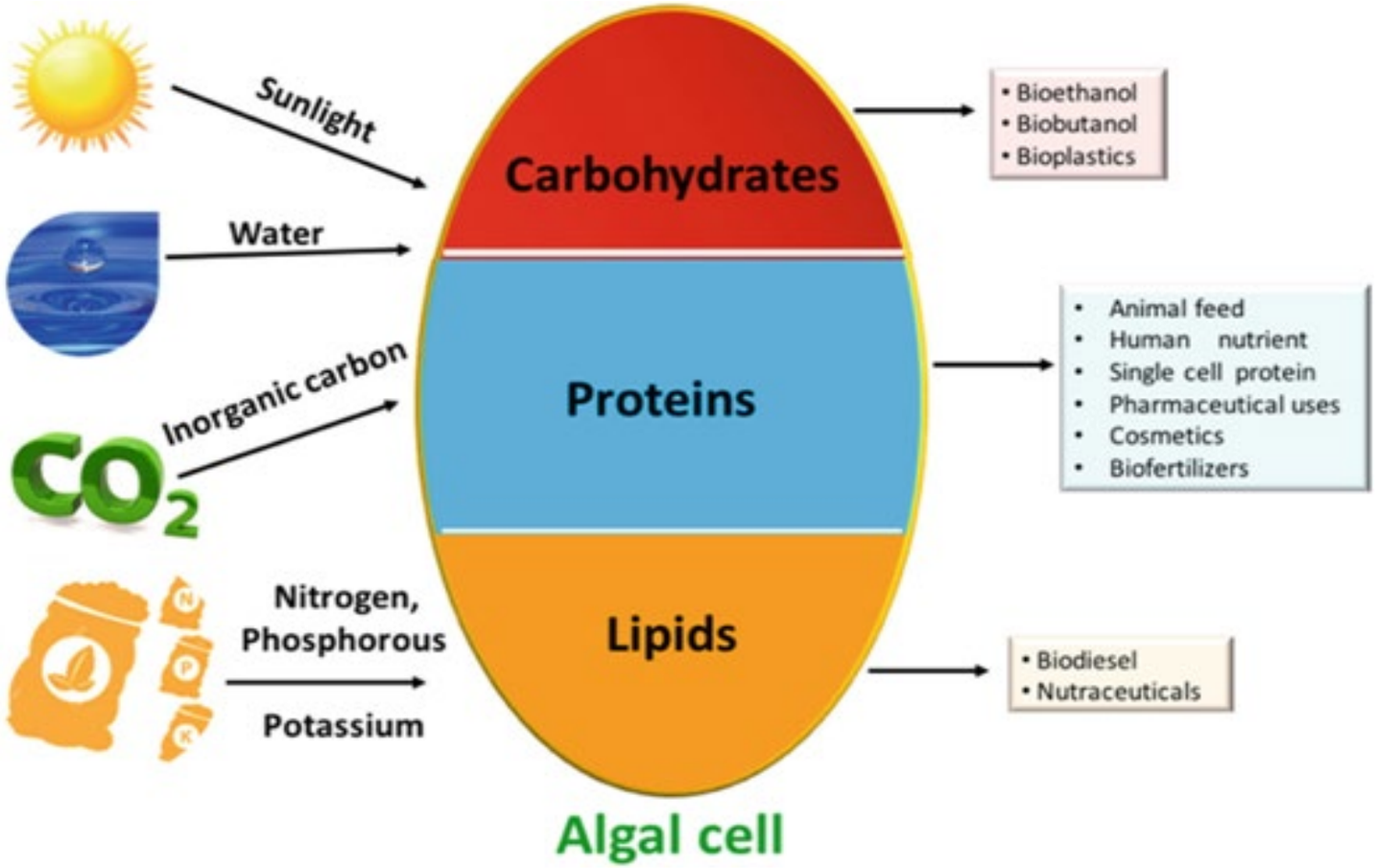
Cattle feed from Algae:

- Excellent feed blend ingredient
- Potential replacement for soy
- High protein-low lipid content
- Minimal post processing
- Preliminary studies using enzyme from cattle digestive tract





Nutraceuticals from Algae



Market

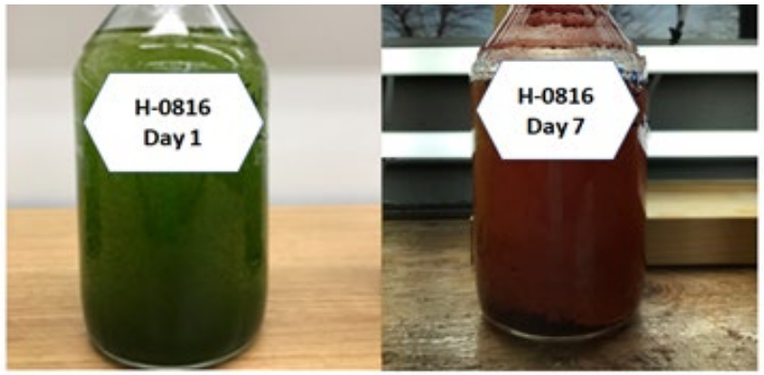
- Ingredients for human health
- Anti-oxidants, omega fatty acids etc
- High-value product

Technology

- Select species
- Several nutraceuticals possible
- Conc in algae up to ~5 %
- Some products require induction
- Extraction & refining

Nutraceuticals

- Four species investigated in prior work
  - H-0816, H-0522, H-1601, H-0326
- Content increased through induction (color change - Figure A)
- Each species has at least two products per extract



A) Before Induction/After Induction

B) Visualized TLC Panels H-0816

C)

Product 4, H-1601
(Color of Extract)

D)

Novel multiple step extraction process developed:

- **Extraction 1 (Components in Fig C and D)**
- Blue component in figure C ~12% by weight
- Concentration of Product 5 is light dependent

- **Extraction 2 (Components in figure B)**
- Two classes of products recoverable
- Product 3 up to about 6% by weight

Current Project

Project Objectives

Budget Period 1	Budget Period 2
1. Develop technologies to increase algae productivity and reduce culturing costs	4. Implement and test the integrated technologies to increase algae productivity and reduce cost in the MSC
2. Develop algae, refine processing and verify content for nutraceuticals	5. Identify marketable nutraceuticals products and path to commercialize
3. Develop algae, incorporate into fish feed blends and conduct preliminary tests	6. Validate algae feed blends and MSC capture technology in field tests
	7. Complete TEA and LCA

Project Tasks

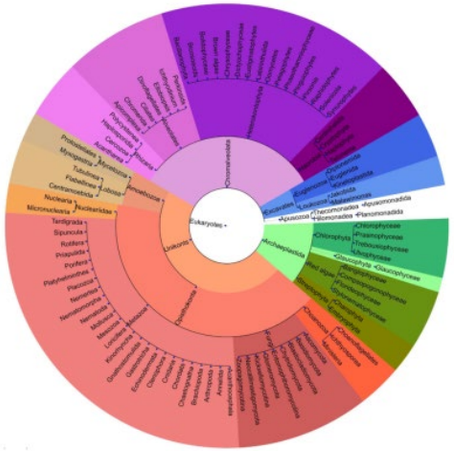
- Budget Period 1
  - Task 1. Project Management and Planning
  - Task 2. Bio-contamination control strategy for algae culture
  - Task 3. MSC operation for optimal utilization of varying sunlight
  - Task 4. Maximize nutraceutical production from algae
  - Task 5. Develop membrane contactor and evaluate in algae cultures
  - Task 6. Initial qualification of algae for aquaculture feed blends

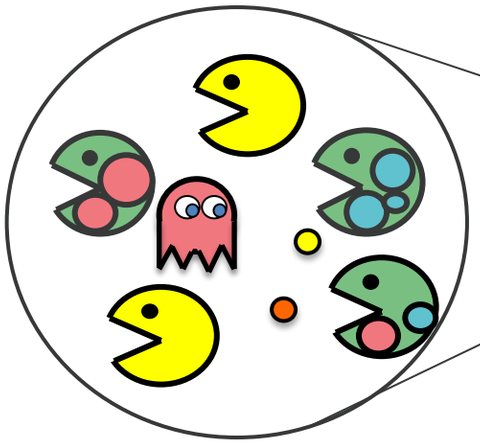
- Budget Period 2
  - Task 7. Project Management and Planning.
  - Task 8. Implement bio-contamination control in algae cultures
  - Task 9. Build and test MSC with new components
  - Task 10. Demonstration of algae-based products
  - Task 11. Algae carbon capture engineering-scale field test
  - Task 12. Refine LCA and TEA

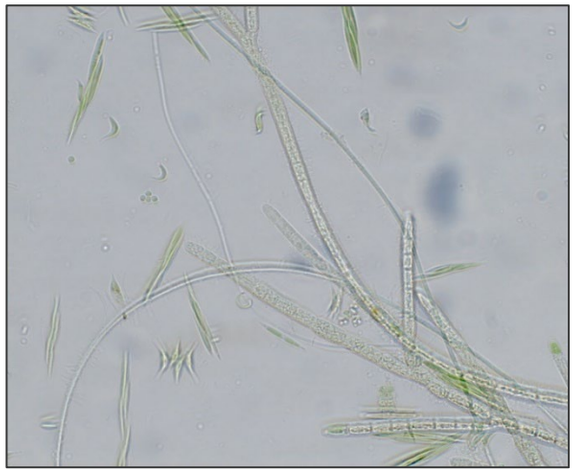
Task 2: Bio-contamination control in algae culture

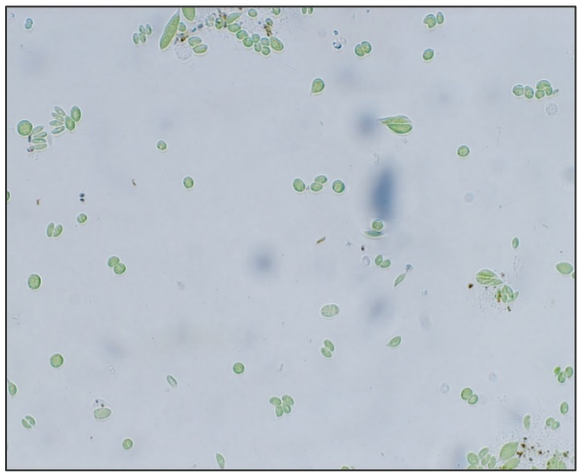
UB - Bradley Research Lab

- Monitor culture health and identify species linked to loss of performance
- Characterization of biofilm growth and aqueous chemistry



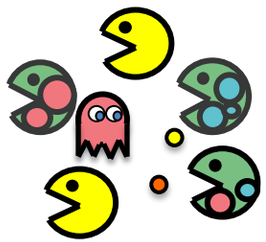






Bio-contamination Control (cont.)

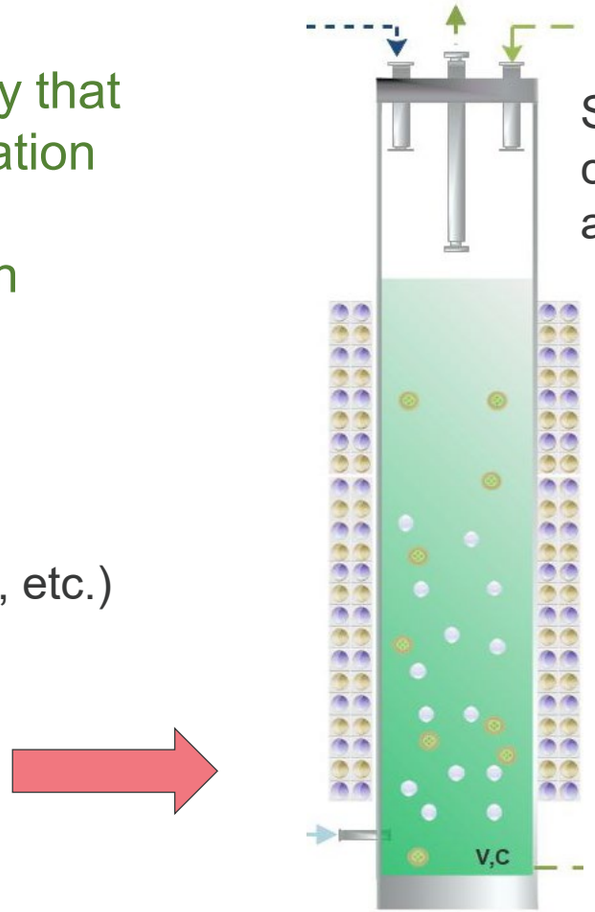
- Examine variations in aqueous chemistry that affect surface attachment and contamination
- Identify surface and liquid contamination control to mitigate contaminants

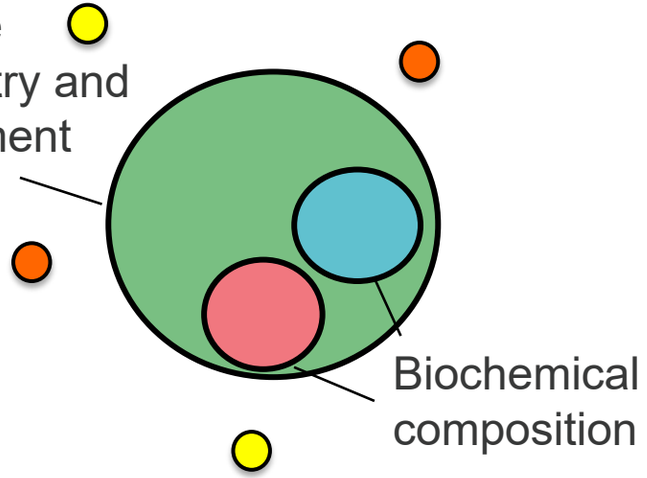


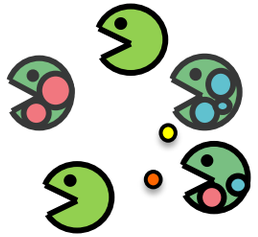
Water chemistry (pH, Ca^{2+}, Mg^{2+}, etc.)

Surface coatings (Cu, Ag)

Liquid additions







Engineering Controls

Bioprocess

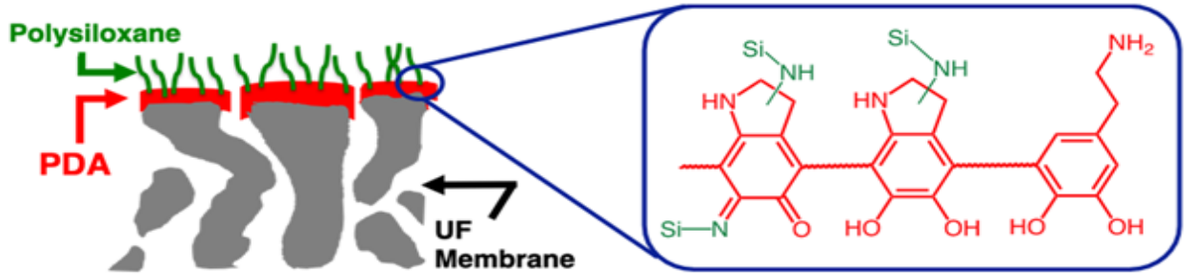
Performance

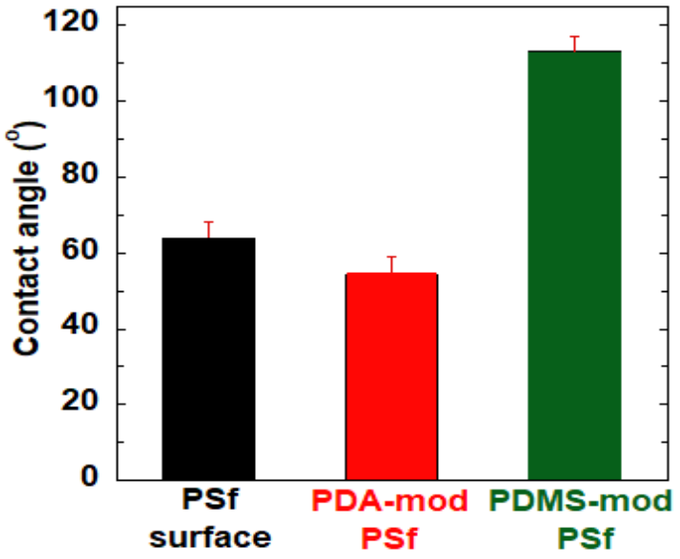
Task 5 - Membrane Contactor

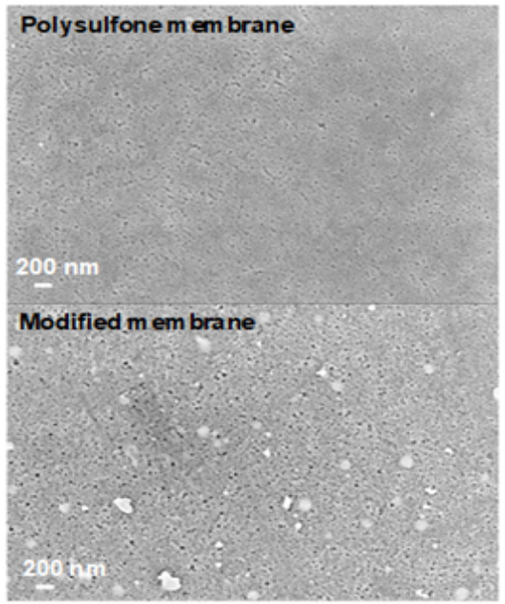
UB - Lin Research Lab

Hollow fiber membrane contactor
http://www.originblue.com/m/e_productshow/?442-MBR-Hollow-Fiber-Membrane-442.html

- Hollow fibers to maximize area
- Surface modification to improve antifouling properties and lifetime
- Mass transfer characterization
- Fiber/module geometry to achieve target algae growth & pr drop







MSC Development

- **Will incorporate many advances - enable next level of performance**
- **Develop dynamic process control with solar tracking**
  - Optimum MSC conditions are light dependent
  - Operating parameters in each stage regulated to sync with sunlight variability
  - Utilizes proprietary process model
  - Expected to improve performance
  - Will enable optimal operation with geo-spatial translation
- **Incorporate active bio-contaminant control from Task 2**
- **Incorporate membrane gas liquid contactor developed in Task 5**
- **Develop scalable, closed raceway stages**
- **Will use algae already qualified in prior projects**
- **Outdoors test in Buffalo + NCCC field test**

Task 6: Initial qualification of algae for fish feed blends

Bozeman Fish Technology Center (BFTC); Freshwater Institute consulting

Wendy M. Sealey, Ph.D. T. Gibson Gaylord, Ph.D.

- **6.1 Quantify composition of Algae**
  - Analyze protein, amino acids, fat, fatty acids and gross energy

- **6.2 Develop blended fish feed**
  - Determine nutrient digestibility for rainbow trout
  - Protein, amino acids, fat, fatty acids, gross energy

- **6.3 Perform research scale feeding trial to assess efficacy of algae as a trout feed ingredient**
  - Formulate feeds to use algae to replace fishmeal and/or fish oils on a digestible nutrient basis
  - Quantify fish growth
  - Quantify feed efficiency
  - Quantity protein and energy retention efficiencies

Task 10: Demonstration of algae-based fish feed

BFTC

- Formulate algae based feeds with the greatest commercial relevance

- Extrude feeds and ship to The Freshwater Institute to field test in a commercial recirculating aquaculture system with rainbow trout.

Task 10: Recirculating Aquaculture System – feed study

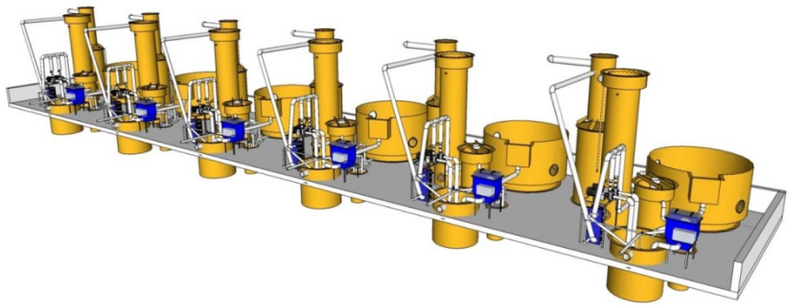
The Freshwater Institute - Conservation Fund

Chris Good - DVM, PhD, DACVPM, CertAqVet

- **Algae-based diets and control diets prepared by BFTC will be fed to rainbow trout (start / finish fish weights ~ 10g to 400-450g)**

- **Typical data collection:**
  - Monthly fish length and weight for growth performance and mortalities
  - Water quality assessments

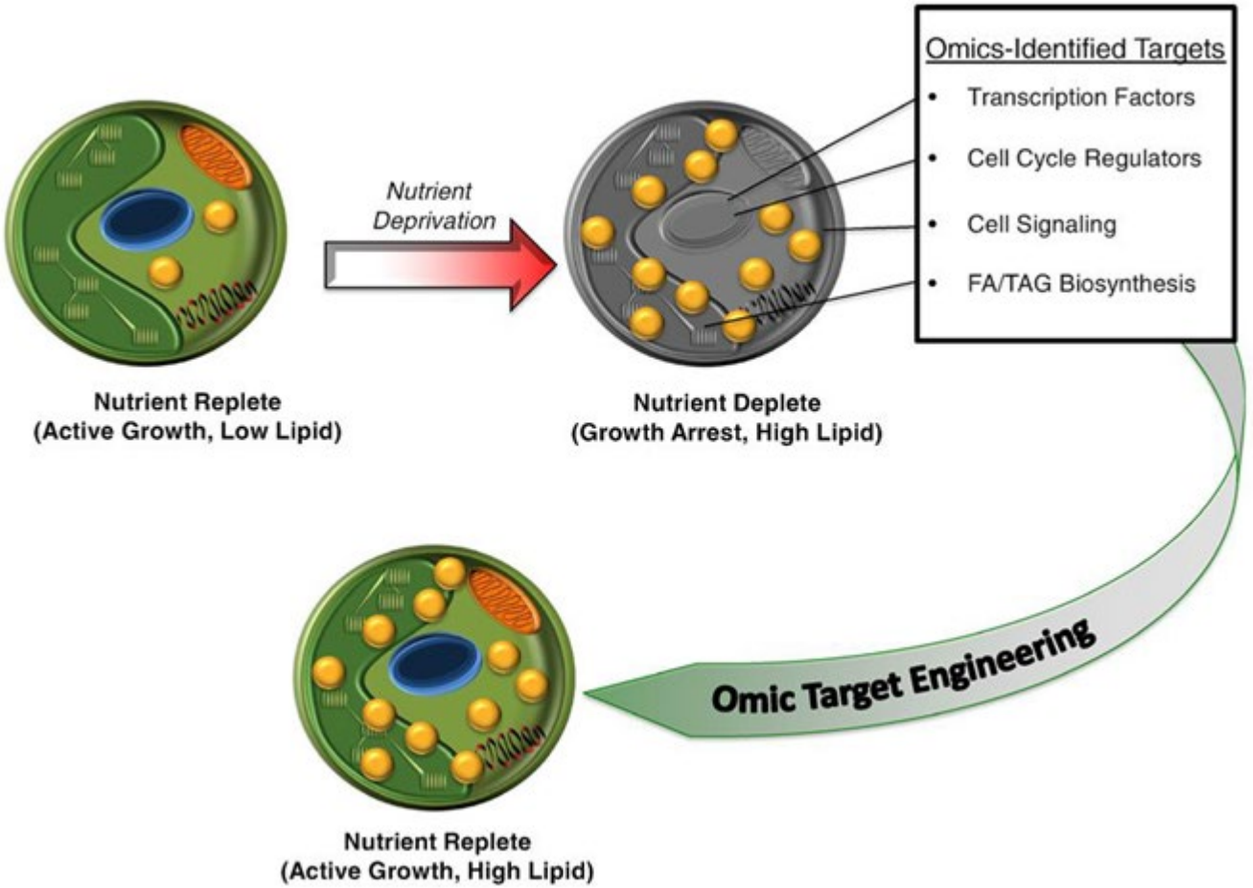
- **Final sampling data collection will include:**
  - Fillet yield and proximate analysis and fatty acid profiles
  - Histopathology: skin, gill, liver, and proximal & distal intestine
  - Organ collection for hepatosomatic, splenosomatic, and viscerosomatic indices
  - Whole fish proximate analysis



Nutraceutical Production

Helios and
Craft Nutrition Consulting

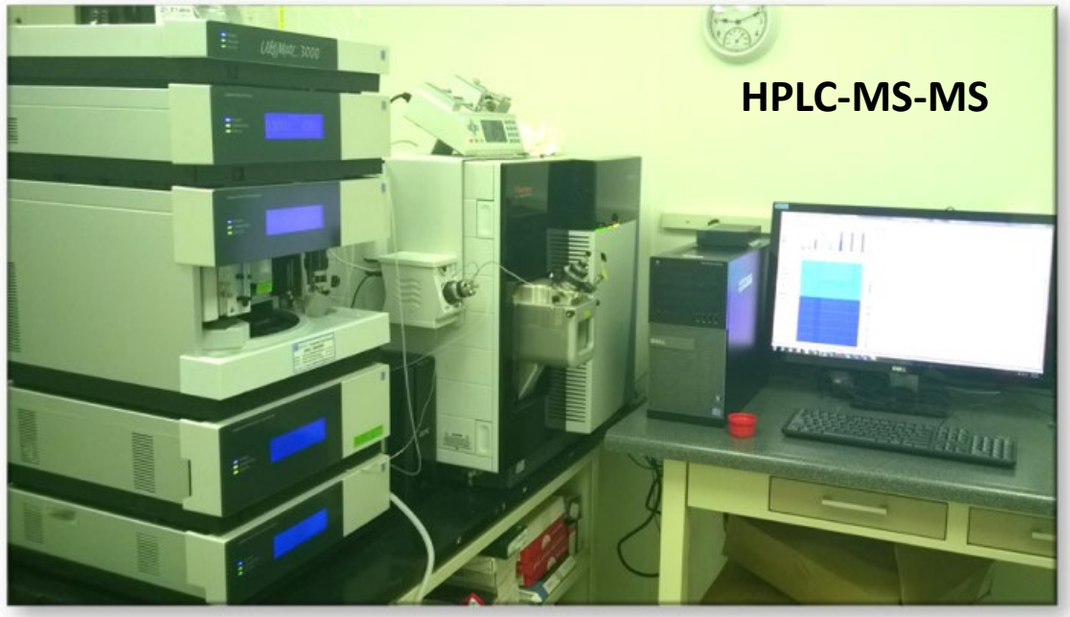
- Select & grow preferred algae
- Stress induction to increase nutraceutical levels
- Extraction



Maximize nutraceutical production from algae

Craft Nutrition Consulting, Neal Craft, PhD

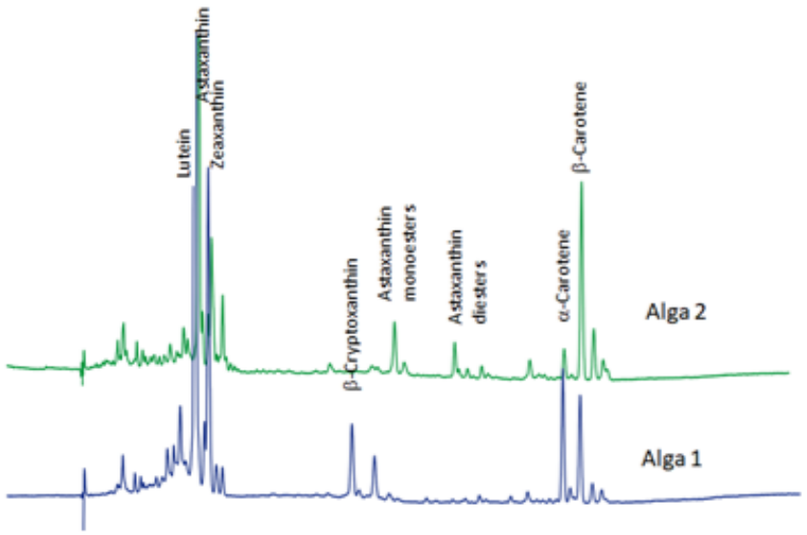
- Identify algal nutritional components
- Identify contaminants and anti-nutritional/toxic components
- Utilize culture conditions to increase nutritional component levels
- Evaluate extraction parameters for efficient recovery

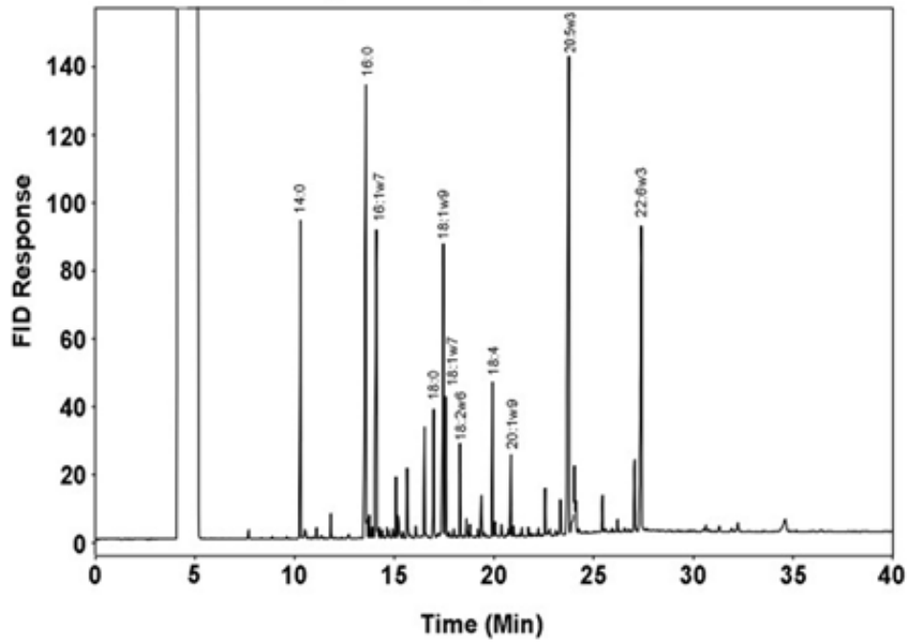


Algae-to-nutraceuticals

Craft Nutrition Consulting

- Assessment of potential forms for nutraceuticals (oleoresin, extracts, powder, oils, etc)
- Provide guidance for the use of supercritical CO2 extraction (SFE)
- Determine applicability of products for use in animal or human foods/dietary supplements
- Identify options to improve product mix for commercialization pathway





LCA/TEA

- **Refine TEA & LCA**
- **Will be based on productivities & capture efficiency measured**
- **Scaled version of improved MSC design**
- **Will be projected to future commercial scale operation**
  - ~5000 acre wetted area
  - ~10 acre ponds
  - Wastewater nutrients (with & w/o credits)
  - Revenue from product mix
  - Sensitivity analysis to key parameters
  - Impact of capture efficiency
  - Baseline analysis will assume zero CO2 capture credits
- ***Expected to confirm potential for revenue positive carbon capture***

Project Gantt Chart

DE-FE-0032103			2021-23						2023-24					
			Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep
			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												
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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												

Future Work to Commercialize Technology

- Develop in-ground MSC system
- Design/validate building block for commercial MSC
- Integrate MSC with dewatering and utilize municipal wastewater nutrients
- Optimize various products & confirm performance attributes
- Add commercial partners
- Validate in field demonstration project
- Validate feed products in live studies & confirm price point
- Validate biofuel production; refinery use; performance; price point
- Develop & qualify slate of nutraceutical products; test market; verify price point

Acknowledgement

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