Marine AlGae Industrialization Consortium (MAGIC)

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Algae Platform Review

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Goal Statement

- **Our Project Goal**

  Demonstrate and validate high-value co-products – *drive down the cost of biofuel by increasing the value of algae "co-products"*

- **BETO MYPP Goals (2)***

  •Model the sustainable supply of 1 million metric tonnes ash free dry weight (AFDW) cultivated algal biomass (2017)

  •Demonstrate valuable co-products produced along with biofuel intermediates to increase value of algal biomass by 30% (2019)

- **Relevance**

  Increased selling price for total algae biomass is one of the key drivers of economics and adoption

- **Outcome**

  A clear pathway to economically competitive, sustainable biofuels

*goals when project selected

Timeline

Project Start Date: 02/2017

Project End Date: 09/2019*

Percent Complete: ~40%

*current end date (expect 1 y NCE)

Budget Summary

in M$	Total Costs pre FY17	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 17-End)
DOE Funded	$0.27	$3.0	$1.9	$4.9
Project Cost Share (Comp.)*	$0.03	$0.76	$0.52	$1.3
Partners: ADM (5%), Bentley (2%), Bucknell (1%), Cornell (8%), Nord (8%), UTEX (8%), Shell (2%), UHH (23%), UHM (7%), USM (2%), Valicor (8%), Duke (26%)				

Barriers addressed

- **Aft-B. Sustainable Algae Production:** Demonstrate sustainable biorefinery systems via TEA and LCA
- **Aft-E. Algal Biomass Characterization, Quality, and Monitoring:** Quantify efficacy of biofuel intermediates and co-products for up to 10 strains produced at 25-kg scale**
- **Aft-H. Overall Integration & Scale-up:** Show that "integrated" unit operations deliver sustainable production of biofuel intermediates and co-products

Technical Goal

Demonstrate a combined product value of >$1,000/MT that yields a biofuel intermediate that exceeds the RFS for advanced biofuels, EROI>3, and sells for <$5/gge. This will primarily be achieved by enhancing the value of the co-products (i.e. LEA)

1 - Project Overview – History/Formation

- The Consortium began in 2008, funded by Shell, built a 6-acre demonstration facility (Cellana), and funded 4 years of commercial R&D, ended 2012 – developed platform technology
- With support from DOE & USDA (2010-2015) we demonstrated the feasibility of the production of commercially viable, sustainable biofuels and animal feed co-products from marine algae
- Based on this success, the Duke Consortium was developed to increase valuation of LEA by testing across algae strains and co-product types
  - *Are there combinations that lead to increased LEA value, while maintaining biofuel production, to drive down the cost of biofuel?*
  - Achieved through marine algae strain selection, production of biomass, evaluation of different separation technologies, testing of multiple algae products (experimentally evaluating biofuel, animal/aquafeeds) and integrative TEA/LCA

Team Characteristics

- Academic and Industrial Partners (major & emerging)
- Long history and expertise in algae assessment/cultivation, separation, diverse product assessment (animals, biofuels), TEA & LCA of algae systems
  - Much of the team has worked together in past projects, new members brought in for mission critical expertise
- Broad geographic representation including international representatives. Cultivation centered at a marine facility (Duke Marine Lab) to recognize challenges of freshwater availability and to leverage existing infrastructure

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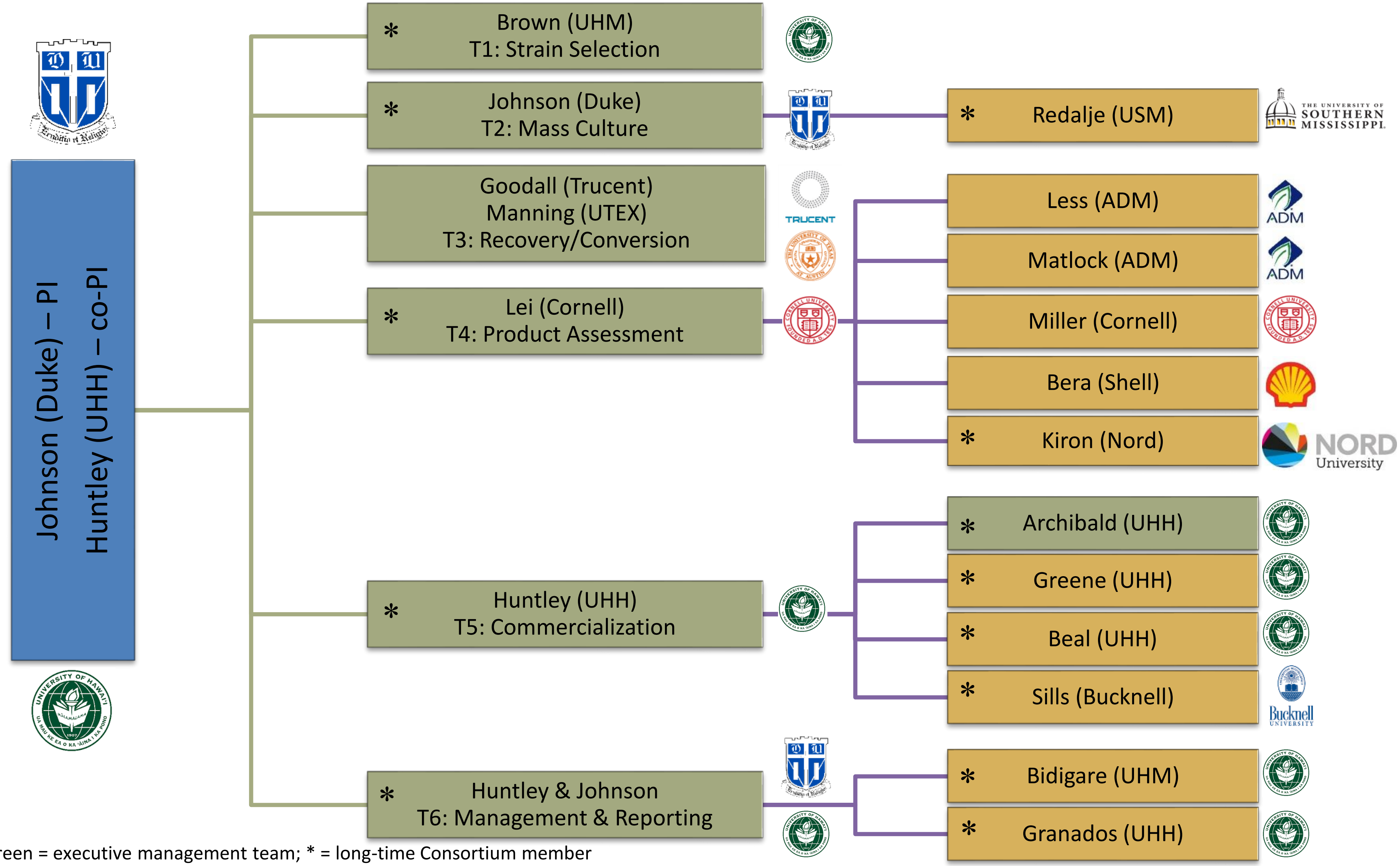
2 – Approach (Management Structure)



Green = executive management team; * = long-time Consortium member

Management Tools: Website, Database, Project Management Software, Remote/In-person meetings (group/sub-groups)

2 – Approach (Technical)

Integrated Process (not all activities are co-sited)

1) ***Strain development*** will deliver 10 new strains to meet product specifications for biofuel and animal feed applications for
2) ***Mass culture*** using an innovative hybrid system of PBRs and open ponds to produce ~30-50 kg quantities of 10 strains for
3) ***Recovery and conversion*** of algal feedstock to refined biofuels and food and feed ingredients – by two pathways - to be used in
4) ***Product demonstrations*** to experimentally assess product efficacy and value, and
5) ***Commercialization analyses*** of relevant scale facilities based on demonstrated results using an iterative TEA/LCA process

Unique features: marine algae, PBR/pond hybrid technology, co-products

Top challenges: co-product value, LCA, EROI, productivity (challenging temperate environment)

Critical success factors: production, processing, product viability

3 – Technical Accomplishments/Results

Task 1: *Strain development*

Subtask Summary**:** Strains will be selected from our collection of >600 strains, cultivated at bench-scale, and their growth characteristics and biochemical profiles compared to explicit product specifications. The 10 best-performing strains will be selected for Mass Culture.

Milestone 1.1: Identify and deliver 10 strains for *mass culture* that meet/exceed product specifications

Key Variables for Strain Selection

- Growth Rate (d^{-1})
- Sinking Index upon harvest
- % Ash upon harvest
- Lipid Proxy at harvest - Nile Red:AFDW
  - Lipid Proxy at assessment and harvest
- % Protein at assessment and harvest

Assessment = replete growth

Harvest = nutrient deplete (cells stressed)

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Rank order results

Strain	GR	Strain ID	%ash	Strain ID	Lipid proxy NR:AFDW	Strain ID	Lipid Proxy H:AS	Strain ID	BR proxy %protein	Strain ID	BR pro H:AS
C649*	1.42	C959*	3.4	C920*	85.00	BORAD02*	46.01	C985*	26.6	C985*	1.01
H1117*	0.99	C856*	3.6	STICH02*	30.49	C920*	13.9	C782*	19.2	C782*	0.80
C959*	0.94	H1117*	3.7	C649*	29.20	C417*	7.64	STICH02*	13.1	STICH02*	0.77
C954*	0.92	STICH02*	3.9	C417*	19.25	H1117*	4.70	C103*	11.1	C417*	0.73
C930*	0.89	Pleur01*	4.0	C584	13.50	Pleur01*	3.79	C930*	11.0	C933*	0.72
C1041*	0.80	C584*	5.6	C933	12.25	STICH02*	3.79	H1117*	10.9	H1117*	0.70
D046	0.77	C103	6.3	BORAD02	12.17	C856*	3.53	C959*	10.1	C103*	0.69
C920*	0.77	CHLOC01	6.7	H1117	11.54	C782*	2.58	C933*	9.8	Pleur01*	0.68
CHLOC01*	0.75	C649	7.2	C930	11.02	C985*	2.32	C966*	9.7	C966	0.65
C417*	0.70	C782	7.3	C985	10.70	C1000	2.05	C1041*	9.4	C584	0.62
C1000*	0.69	C985	7.3	C856	10.50	C933	2.04	C417*	8.7	C920	0.61
C985*	0.66	C1041	7.4	C782	9.45	C584	1.92	C959*	8.2	C1041	0.60
C782*	0.62	BORAD02	7.8	CHLOC01	9.13	C966	1.88	Pleur01	7.9	C959	0.53
BORAD02*	0.62	C930	8.5	C966	8.61	C103	1.72	CHLOC01	7.7	BORAD02	0.50
C966	0.54	D046	8.6	C1000	8.08	C930	1.70	C584	7.6	C856	0.44

*** Exceeds baseline strain (C046)**

Top Candidates: H1117, C417, C920, C985/C782, Borad02, C930, STICH02[1], C649, CHLOC01

Further biochemical characterization (AA/FA) of top strains under way to refine selection

[1]Exceeds baseline in all categories but growth rate threshold at 20˚C, may grow better at higher temperatures.

Task 2: ***Cultivation***

Task Summary: *Mass culture* will produce algae feedstock (10-30% total suspended solids, 25 to 50 kg per strain) for ten strains identified by Strain Validation (Task 1). All mass culture will be done using a hybrid cultivation system and following key operating parameters specified in the TEA/LCA and described in a cultivation design analysis.

Subtask 2.1: *Cultivation design and analysis* (M1-M12)
Task Summary: This task will deliver a defined cultivation plan for *mass culture*, describing methods for inoculation, growth, and harvesting, and a sampling regimen for specified parameters. Analysis will provide quality assurance for data from mass culture trials on a regular basis.

M2.1 Deliver a Cultivation Plan for *mass culture* to be adopted by the Consortium (M7)

REPORT DELIVERED

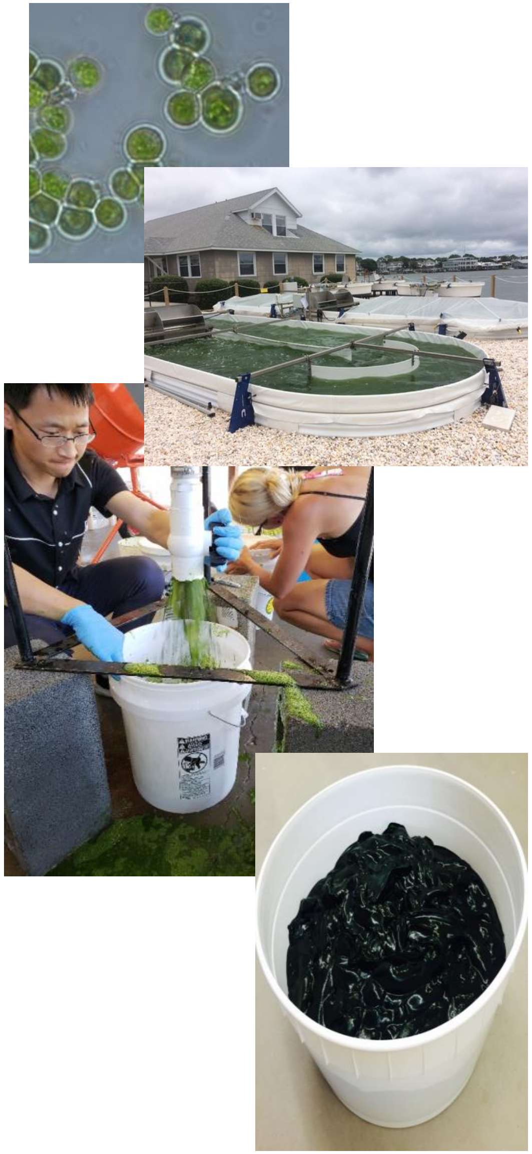
Task 2: ***Cultivation (cont)***

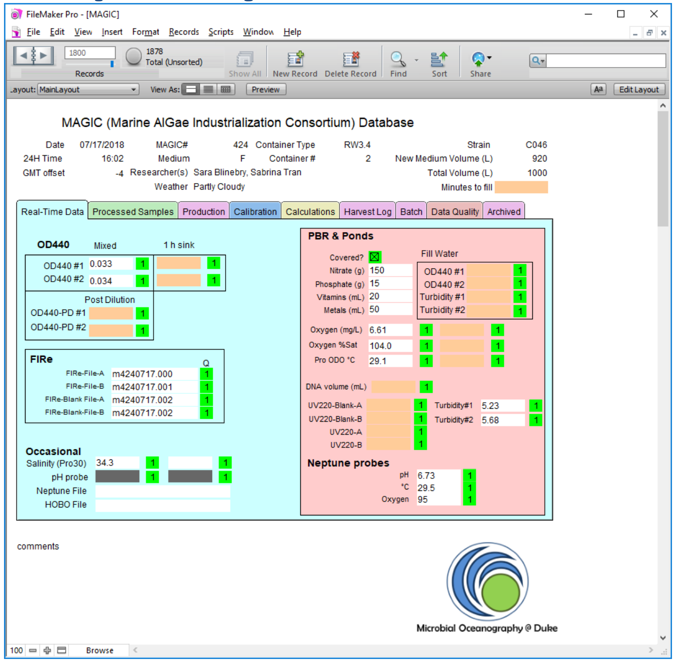
Subtask 2.2 *Product assessment* (M7-M24)
Task Summary: Produce and harvest 10 selected strains of algae at process development scale, providing 25 to 50 kg DW per strain. Feedstock from production runs will be used for extraction and product assessment.
M2.2 (DP) Deliver feedstock for processing from 10 strains, 25 to 50 kg DW per strain (M24)

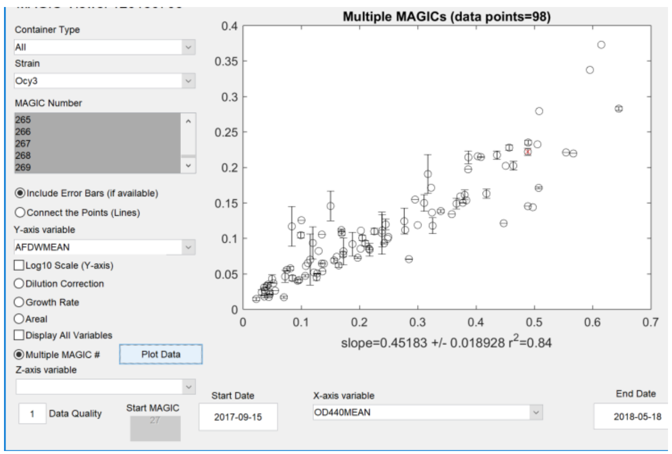
https://www.ml.duke.edu/webcam/algae/

4 strains, 108 pond runs, >120 kg DW

Task 2: ***Cultivation (cont)***







- Tested multiple cultivation strategies (DIN/PON)
- Tested/optimized multiple harvesting approaches
- Integrated databases for data storage / query / output digests
- ‘*plotmagic*’ MATLAB analysis tool
- Provided pilot biomass for startups
- Many outreach / educational demonstrations!

Task 3: ***Recovery and Conversion***

Task Summary: This task will use two alternative methods to process a total of 25 to 50 kg dry weight (DW) per strain from 10 strains produced from Task 2, delivering the fractions to Consortium partners for targeted biofuel and nutritional product efficacy trials.

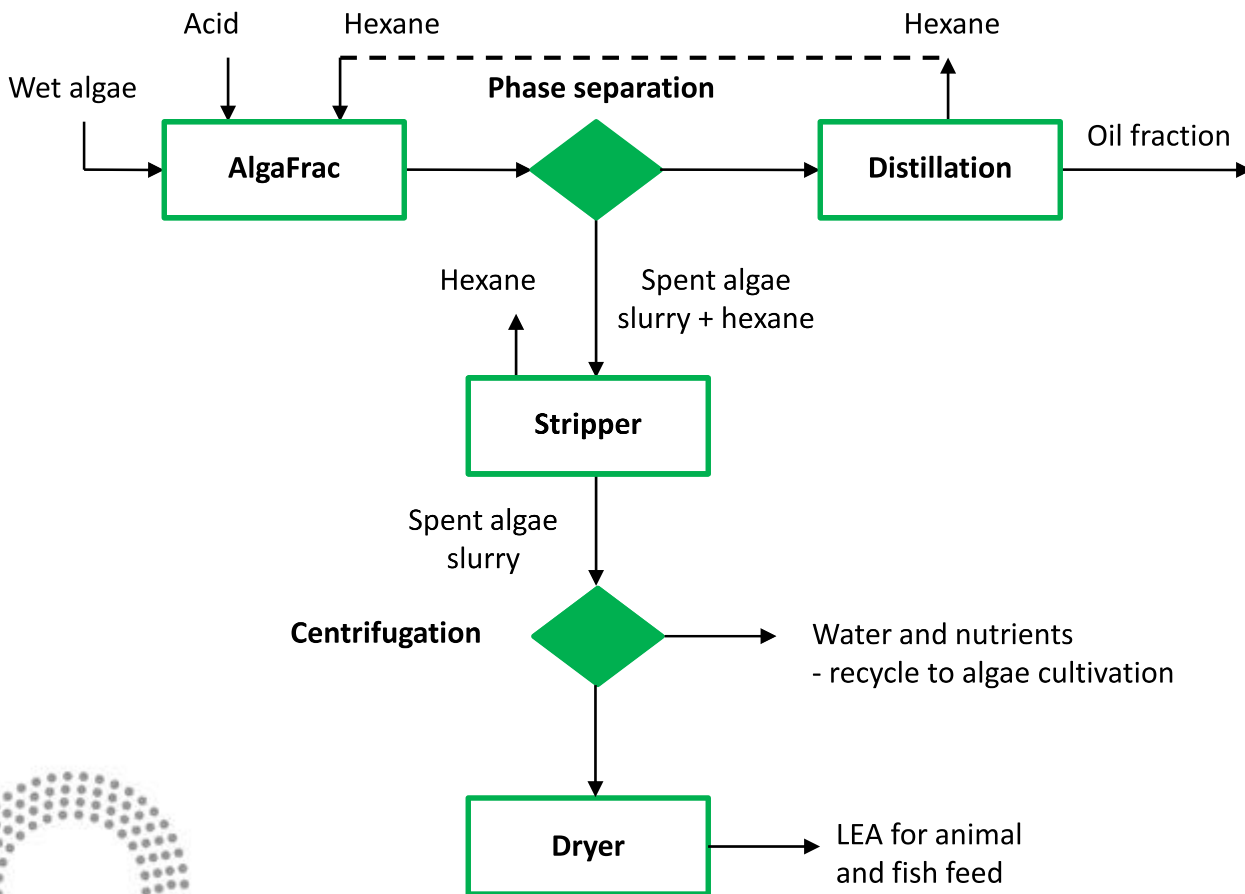
M3.1 Set up an operational process integrated with mass culture production and demonstrate processing of 10 kg DW algal feedstock, delivered for analysis (M12)

DONE

M3.2 (DP) Process 10 strains of feedstock from Mass Culture Task 2.2 and deliver to Product Assessment (M25)

3 Strains Done (but high ash on 2 strains lead to poor recovery – high ash problem solved)

Fuels Platform "Gen 1"



Typical data from earlier programs:
Resulting oil is clean enough for hydrotreating!

%	strain 1	strain 2
C	77.97	77.85
H	11.74	12.1
N	0.04	0.03
O	11.03	10.57
S	0.01	0.01
Ash	<0.1	<0.1
ppm		
Al	0.3	0.8
As	<0.1	<0.1
Ba	<0.1	<0.1
Ca	0.9	3
Cr	<0.1	<0.1
Cu	1.8	4
Fe	<2	10
Mg	0.2	1.2
Mn	<0.1	0.1
Mo	<0.01	<0.1
P	4	4
K	<1	1
Na	3	10
Ti	0.4	0.5
V	<0.1	<0.1
Zn	0.3	2.6

C046: Total algal crude oil yield – 1669 g (>95% Eff.)
~14 kg of LEA for co-product trials

TRUCENT

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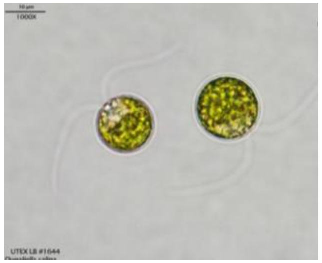
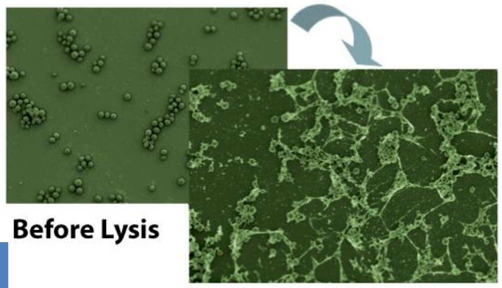
UT-OpenAlgae Oil Extraction Process



UT-Austin
PI: Manning

Pulsed-Electric Field Lysis Unit



Before Lysis

After Lysis

Membrane Oil Recovery Skid

Strain	% neutral lipid recovered
OCY3	7.4
S002	12.8
C046	In progress

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Task 4: ***Product Assessment***

Task Summary: Product specifications are defined in four market areas: <u>biofuels</u> and three nutritional product markets: <u>aquafeed</u>, <u>poultry feed</u>, and <u>nutritional products</u>. Product efficacy will be evaluated by comparing performance of 10 strains at laboratory scale.

M4.1 (DP) Deliver product specifications for at least one product, updated to consider current market factors, and how they will be used to measure performance (M6)

DONE

M4.2 Initiate *Product assessment* trials: 10 strains, 2 separation processes, ~5-10 kg ea; (M15)

DONE

M4.3 *Product assessment*: efficacy demonstrated for at least one strain (M30)

M4.1 Feed Calculators

Feed and Oil Calculators Beal 102218.xlsx - Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Ingredient	Price as-fed ($/t)	Intake - (% DM)	Intake - DM (kg DM)	Intake - As-fed (kg)	DM (%)	TDN (%)	AEM (MJ/kg)	CP (%)	Crude Fiber (	ADF (%)	NDF (%)	Crude Fat (%)	Crude Ash (%)	Ca %	P %
2	Generic LEA Estimate	1200	10%	0.031	0.035	90.00%			35.00%				5.00%	20.00%		
3	Soymeal	$465	6%	0.020	0.023	88.70%		9.92	47.74%	2.70%	5.00%	8.65%	2.05%	6.45%	0.32%	0.(
4	Fishmeal	$1,510	15%	0.047	0.051	92.10%		13.3	65.20%	0.00%	0.00%	0.00%	9.20%	16.80%	4.12%	2.(
5	Corn	$179	68%	0.210	0.239	88.00%		13.92	8.00%	1.85%	3.05%	10.90%	3.45%	1.15%	0.04%	0.
6																
7	**Total Feed**	**$505**		**0.309**	**0.347**	**88.9%**			**22.1%**				**4.4%**	**5.8%**		
8	Fails Spec															
9	OK															
10																
11																
12																
13	**TARGET DIETS**															
14	Starter Diet			0.31	0.35	89.03%		12.69	22.00%	3.36%	4.04%	10.19%	6.47%	7.13%	0.90%	0.
15	Grower Diet			1.38	1.56	88.94%		12.97	19.50%	3.15%	3.78%	10.19%	6.47%	6.38%	0.84%	0.
16	Finisher Diet			3.03	3.40	88.92%		13.31	18.00%	3.02%	3.62%	10.15%	6.99%	5.65%	0.76%	0.(
19						From Industry										
20						From Feedtable.com		https://feedtables.com/content/fish-meal-protein-65								
21						From Cobb500 Nutrition Supplement			http://www.cobb-vantress.com/docs/default-source/cobb-500-guides/Cobb500_Broiler_Performance_Anc							
22						From NRC2001										

Poultry Feed Starter Diet | **Poultry Feed Starter Diet LEA** | Aquafeed | Algal Biomass LEA | Poultry Feed STRAWMAN | Aquafeed STRAWMAN | Biocrude STRAWMAN

M4.2/4.3 Product Assessment

- Performed poultry experiments as part of other related projects:
  - to optimize EPA/DHA enrichments
  - to explore benefits of phytochemicals in heat stress
  - to evaluate different whole meal biomass
    - *Nannochloropsis oceanica*
    - *Haematococcus pluvialis*
    - *Aurantiochytrium sp*.]
  - Investigated microalgae as an iron supplement

- Microalgae can help enrich n-3 fatty acids in chicken and eggs:
  - > 200 mg/egg
  - 80-100 mg/100 g fresh muscle tissue
- Microalgae can serve as a dual source of protein and micronutrients (Fe and phytochemicals)

- **Initiated analysis of biomass (LEA) from MAGIC and started feed formulation for similar trials**

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Task 5: ***Commercialization***

Task 5.1 *Techno-Economic Analysis and Life Cycle Assessment*
Task Summary: Use TEA/LCA as an iterative design tool to guide product development. Include consideration of target markets, competitors, and distribution channels.
M5.1: Deliver revised TEA/LCA for each product based on updated product specifications from the Target Product Workshop (M6)

DONE

M5.2 Updated TEA/LCA based on results of *Strain development* and initial *Recovery and Conversion* analyses (M18)

DONE

M5.3 Updated TEA/LCA based on results of *Product assessment* (M33)

Ongoing

Demonstration of updated TEA (M5.2)

SUMMARY OF RESULTS (MBCSP; $/gge)	Baseline Valicor	Baseline OpenAlgae	Target Valicor	Target OpenAlgae
Poultry Co-Product, $600/tonne				
Published[1]	$10.44	$10.02	–	–
Validation	$10.48	$10.73	$7.31	$7.19
M5.2	$81.98	NA	–	–
Aquafeed Co-Product, $1500/tonne				
Published[1]	$6.22	$3.15	–	–
Validation	$5.80	$3.64	$2.56	$0.39
M5.2	$63.81	NA	–	–
Nutritional Co-Product, $2000/tonne				
Published[1]	–	–	–	–
Validation	$3.19	-$0.30	-$0.09	-$3.40
M5.2	$53.72	NA	–	–

- M5.2 based on initial cultivation data (9 g m^2 d^{-1})
- Low lipid content in preliminary batches (~14%)
- High ash due to suboptimal harvesting (NaOH floc.), reduces value
- 5.2 TEA results based on data are less favorable, but
  addressed challenges with ongoing strains / processes

[1] data from Beal et al. 2015 DOI: 10.1016/j.algal.2015.04.017
GGE - Gallon of gasoline equivalent
MBCSP - Minimum Biocrude Sale Price

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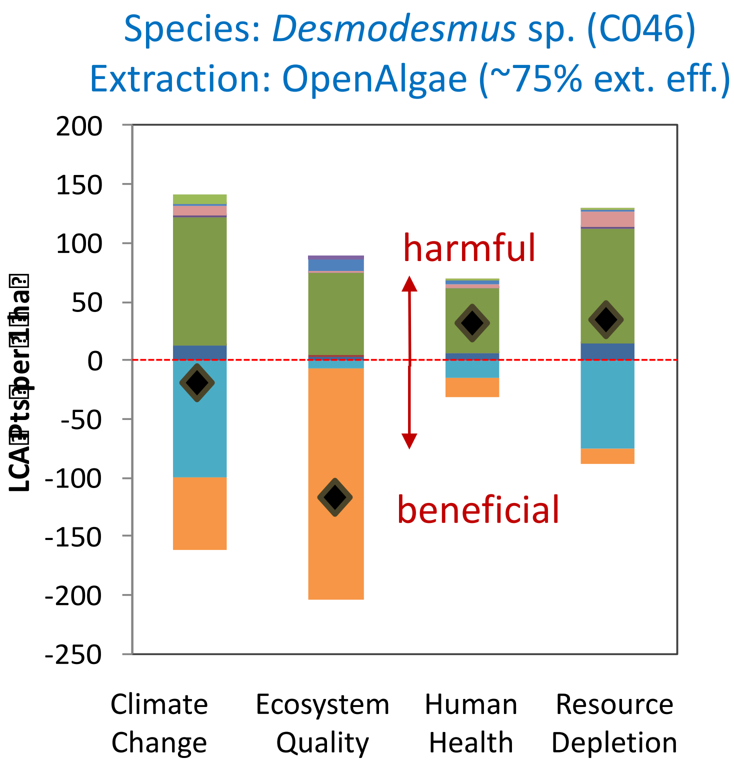
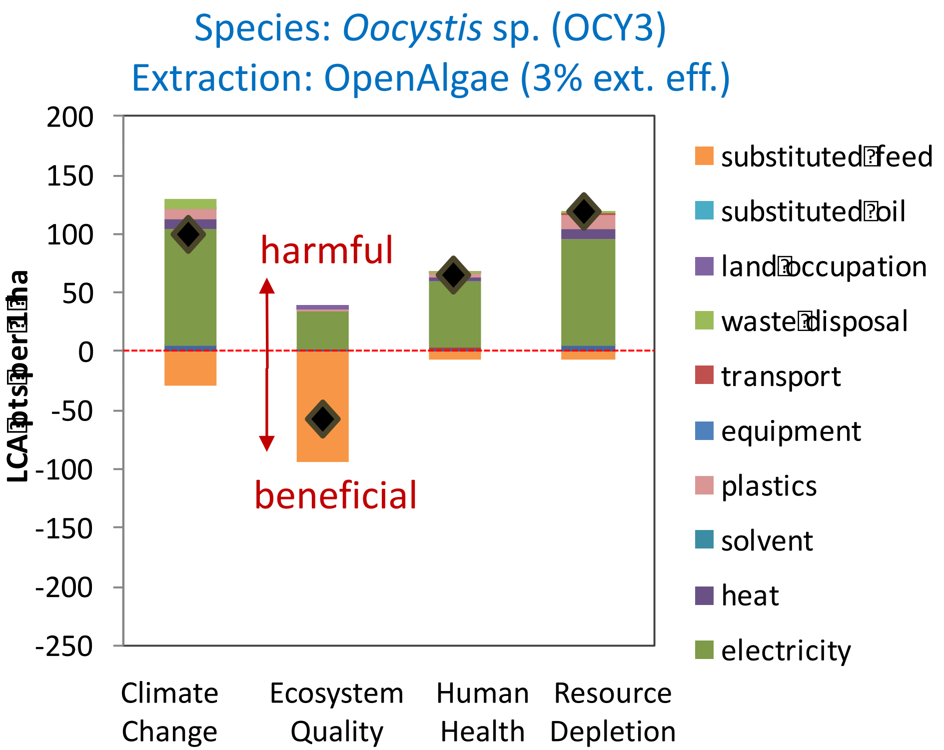
Demonstration of updated LCA (M5.2)

Life cycle impacts more beneficial for *Desmodesmus* (C046) than *Oocystis* (Ocy3), because C046 exhibited higher growth, lower ash, and higher oil yield during OpenAlgae extraction.





❖ There are differences among stains, the details of which impact the LCA (and TEA)

Task 6: ***Project Management***

Task Summary: Provide administration, reporting, data management, and communications support.

Subtask 6.1: *Biochemistry analysis*
Summary: Provide scope of work and QA review for centralized biochemical analyses performed by qualified subcontractor(s). Approve biochemical data for Consortium database.
M6.1 Technical report including analyses required and cost/benefit analysis of different approaches (M7)

DONE

Subtask 6.2 *Data Management Plan*
Summary: Establish a comprehensive Data Management Plan (DMP) for the Consortium and ensure access to Consortium data products
M6.2 Database available on Consortium website for all data produced (M36)

Subtask 6.3 *Communications and Organization*
Summary: This task will be responsible for coordinating all aspects of project management, administration, reporting, and liaison with DOE.

ONGOING

4 – Relevance

- **To the BETO MYPP**

  Project Goals directly address major BETO MYPP Goals –

  (i) sustainable supply of 1 million MT AFDW algal biomass and

  (ii) production of valuable co-products that increase value of algal biomass by 30%

- **Impacts on science and the bioenergy industry**
  - High value *food and animal feed co-products* improve revenues
  - *Costs* are reduced; *EROI* is increased
  - *Sustainability* enhancement is demonstrated

- **Global impacts of large-scale production**
  - No impact on *freshwater resources* – near-zero waste of *N and P*
  - Simultaneous supply of *fuel and feed* – global scales match
  - *Reduced atmospheric* CO_2 are achieved at global scale
  - *Enormous land-use change impacts* result from intensified cultivation of fuel and feed products replacing corn, soy, palm, and sugarcane

Course Corrections

- **Post Go/No-Go**
  - Improve consortium communications – a challenge in large groups separated by distance
    - More frequent meetings
    - Project Management Software (Basecamp) calendaring
    - Project Management Software (Basecamp) task list management
  - Better integration among tasks
    - Improved information flow
    - Sub-meetings
    - ‘Live’ Gantt chart
  - Adjust goals to current production levels, ash and separation technology maturity
    - Changed from 10 strains → ~7 strains
    - Changed from 25-50 kg DW → 40 kg AFDW per strain
      - Better analytics
    - OpenAlgae (UTEX) separation skid to be moved to cultivation site (Duke) for enhanced experimental work

5 – Future Work

Experimental Work:

Task 1: finish biochemical analyses of top strains

Task 2: complete cultivation of top strains (at ~10,000 L scale) for biomass delivery

Task 3: process biomass (provide process data and products to partners)

Task 4: continue to assess products

Task 5: assimilate data from tasks 1-4 and iterate TEA/LCA

Task 6: continue assimilating data/output from tasks 1-5 and make available to consortium and others

Publish, publish, publish. The Consortium has ~24 papers to date (details in supplementary material), but we expect many more as the results from these datasets and analyses become available.

Maintain public access to Consortium results. The Consortium continues to maintain and build upon its website (*https://www.AlgaeConsortium.com*) providing both internal and public access to the most recent results.

Summary

Overview This Consortium has demonstrated a fully "integrated" process flow for the production of biofuels and high-value bioproducts at a relevant scale.

Approach Demonstrate and validate high-value co-products – *drive down the cost of biofuel by increasing the value of algae "co-products"*

Technical Accomplishments/Progress/Results

- Demonstration of each project component
- Demonstration of overall integration
- 24+ Peer-reviewed publications since project approval

Relevance Results address central BETO MYPP goals for 2017 *and* 2019. Rigorous demonstration and enhancement of co-product value, based on an integrated production process and efficacy trials are expected to increase revenues. Global impacts are significant.

Future work Complete outdoor cultivation/seperation, product assessments and TEA/LCA work. Report on "integrated" process flow

Thank you

EERE #DE-EE0007091

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Additional Slides

Publications (24+)

Gerber LN, Tester JW, Beal CM, Huntley ME, Sills DL (2016). Target Cultivation and Financing Parameters for Sustainable Production of Fuel and Feed from Microalgae. Environmental Science & Technology. http://doi.org/10.1021/acs.est.5b05381

Greene C, Huntley M, Archibald I, Gerber L, Sills D, Granados J, Tester J, Beal C, Walsh M, Bidigare R, Brown S, Cochlan W, Johnson Z, Lei X, Machesky S, Redalje D, Richardson R, Kiron V, Corless V (2016). Marine microalgae: Climate, energy, and food security from the sea. Oceanography 29: 10-15. http://doi.org/10.5670/oceanog.2016.91

Greene CH, Huntley ME, Archibald I, Gerber LN, Sills DL, Granados J, Beal CM, Walsh MJ (2017). Geoengineering, marine microalgae, and climate stabilization in the 21st century. Earth's Future 5: 278-284. http://doi.org/10.1002/2016EF000486

Hulatt CJ, Berecz O, Egeland ES, Wijffels RH, Kiron V (2017a). Polar snow algae as a valuable source of lipids? Bioresource Technology 235: 338-347. http://doi.org/10.1016/j.biortech.2017.03.130

Hulatt CJ, Wijffels RH, Bolla S, Kiron V (2017b). Production of Fatty Acids and Protein by Nannochloropsis in Flat-Plate Photobioreactors. PLOS ONE 12: e0170440. http://doi.org/10.1371/journal.pone.0170440

Publications (cont.)

Johnson ZI, Bidigare RR, Blinebry SK, Brown SL, Cullen JJ, Loftus SE, Redalje DG, Swink C, Van Mooy BAS (2017). Screening for Lipids From Marine Microalgae Using Nile Red. In: Lee SY (ed). Consequences of Microbial Interactions with Hydrocarbons, Oils, and Lipids: Production of Fuels and Chemicals. Springer International Publishing: Cham. pp 1-22. http://doi.org/10.1007/978-3-319-31421-1_382-1

Kim J, Barcus M, Magnuson A, Tao L, Lei XG (2016a). Supplemental defatted microalgae affects egg and tissue fatty acid composition differently in laying hens fed diets containing corn and flaxseed oil. The Journal of Applied Poultry Research 25: 528-538. http://doi.org/10.3382/japr/pfw034

Kim J, Magnuson A, Tao L, Barcus M, Lei XG (2016b). Potential of combining flaxseed oil and microalgal biomass in producing eggs-enriched with n − 3 fatty acids for meeting human needs. Algal Research 17: 31-37. http://doi.org/10.1016/j.algal.2016.04.005

Kiron V, Sørensen M, Huntley M, Vasanth GK, Gong Y, Dahle D, Palihawadana AM (2016). Defatted biomass of the microalga, Desmodesmus sp., can replace fishmeal in the feeds for Atlantic salmon. Frontiers in Marine Science 3. http://doi.org/10.3389/fmars.2016.00067

Publications (cont.)

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Publications (cont.)

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Tao L, Sun T, Magnuson AD, Qamar TR, Lei XG (2018). Defatted microalgae-mediated enrichment of n-3 polyunsaturated fatty acids in chicken muscle is not affected by dietary selenium, vitamin E, or corn oil1. *In Press at J. Nutr*.

Presentations

2018

- “Microalgae on food, energy, and health,” College of Animal Science and Technology, Hunan Agricultural University, Changsha, China. [Lei, XG] – September
- “Intestinal health of Atlantic salmon *Salmo salar* fed with microalgae *Nannochloropsis* and *Tetraselmis*,” Aqua 2018 (Joint conference of World Aquaculture Society and European Aquaculture Society), Montpellier, France. [Sørensen SL, Ghirmay A, Gong Y, Dahle D, Vasanth G, Sørensen M, Kiron V] – August
- “Microalgal DHA enrichment of meat and eggs of poultry,” PSA National Meeting, San Antonio, Texas. [Lei, XG] – July
- “Microalgal DHA enrichment of meat and eggs of poultry,” ASAS-CSAS Annual Meeting & Trade Show, Vancouver, Canada. [Lei, XG] – July
- “Reversing Climate Change,” United World College, Phuket, Thailand. [Huntley, M.] – June
- “A new generation of sustainable feed protein,” College of Animal Science and Technology, Northwest A & F University, Yangling, Shanxi, China. [Lei, XG] – June
- “Microalgae as feed ingredients for Atlantic salmon – an update on ongoing research at Nord University,” Water and Fish: 8th International Conference, Belgrade, Serbia. [Sørensen M, Gong Y, Sørensen SL, Ghirmay A, Kiron V] – June

Presentations

2018 (cont)

- “Fractionation and characterization of AOM responsible for growth inhibition in the recycled culture medium of *Scenedesmus* spp.,” AlgalBBB 2018, Seattle, Washington. [Lu Z, Sha J, Wang W, Zhang X, Hu Q, Johnson Z] – June
- “Defatted microalgae as effective fishmeal substitutes in salmon feeds,” AlgalBBB 2018, Seattle, Washington. [Kiron V, Sørensen M, Gong Y, Huntley M, Greene CH] – June
- “Microalgae – a boon to the aquafeed industry,” AlgalBBB 2018, Seattle, Washington. [Kiron V, Sørensen M] – June
- “A new generation of sustainable feed protein,” Guangdong Province Key Laboratory of Waterfowl Healthy Breeding, Guangzhou, China. [Lei, XG] – May
- “Reversing Climate Change,” Friday Harbor Laboratories, University of Washington, Friday Harbor, Washington. [Huntley, M.] – April
- “Reversing Climate Change,” Scripps Institution of Oceanography, La Jolla, California. [Huntley, M.] – April
- “A new generation of feed stock: evidence that microalgae serve as high-quality, sustainable alternative feed protein,” Feed Protein Vision, Amsterdam, Netherlands. [Lei, XG] – March

Presentations

2018 (cont)

- “New perspectives on microalgae in sustaining global energy and food production,” 24th International Conference on the Unity of the Sciences (ICUS XXIV): Scientific Solutions to the Earth’s Environmental Challenges, Seoul. Korea. [Lei, XG] – February
- “Commentary on Presentation by Dr. Luc Montagnier (2008 Noble Laureate),” Session 3, Food and Toxins, 24th International Conference on the Unity of the Sciences (ICUS XXIV): Scientific Solutions to the Earth’s Environmental Challenges, Seoul. Korea. [Lei, XG] – February
- “Can microalgae make eggs and chicken replace fish?” Nutrition Field Seminar, Division of Nutritional Science, Cornell University, Ithaca, New York. [Lei, XG] – February
- “Marine Microalgae: Achieving Climate, Energy, and Food Security in the 21st Century,” 2018 Ocean Sciences Meeting, Portland, Oregon. [Greene, CH] – February

- **2017**
- “Renewable Transport Fuels,” Institute of Oceanography, Shanghai Jiao Tong University, Shanghai, China, [M Huntley] - October
- “What is the correct functional unit for life cycle assessment of an algal biorefinery,” Algae Biomass Summit, Salt Lake City, Utah. [Sills, DL] – October

Presentations

2017 (cont)

- "Integrated Assessment of Algal Food & Fuel Technologies Demonstrates Avenues to Sustainable Large Scale Deployment," Algae Biomass Summit, Salt Lake City, Utah. [Walsh, MJ] – October
- "Microalgae as a novel feed protein, at the plenary symposium: Sustaining the Future of Fish and Animal Feed," 11th Annual Algae Biomass Summit, Grand America Hotel, Salt Lake City, Utah. [Lei, XG] – October
- "Phytochemicals in microalgae and benefits in heat stress," 79th Cornell Nutrition Conference, East Syracuse, New York. [Lei, XG] – October
- "Microalgae from biorefinery as potential feed ingredients for Atlantic salmon *Salmo salar," Aquaculture Europe 2017, Dubrovnik, Croatia.* [Kiron, V] – October
- "Startup pitches & emerging technologies: Microalgae in chicken feed," CTL Partnership forum: Innovations in Food Systems: Feeding a Growing World, Cornell University, Ithaca, New York. [Lei, XG] – June
- "Accounting and Economic Analysis of a Carbon Capture and Utilization Market Algae Cultivation for Carbon Capture and Utilization," U.S. DOE Workshop, Orlando, Florida. [Walsh, MJ] – May

Presentations

2017 (cont)

- “Using Data to Forecast the Financial and Economic Potential of Future Food Technologies,” Analytics without Borders Conference, Smithfield, Rhode Island. [Walsh, MJ] – March

2016

- “Can we use defatted microalgae as a new feed protein to produce healthier animal foods for humans,” College of Fishery Science, Huazhong Agricultural University, Wuhan, Hubei, China. [Lei, XG] – December
- “Food and Energy from Marine Algae: Enabling deep transformation in agriculture & bioenergy,” 9th Annual Integrated Assessment Modeling Consortium Meeting, Beijing China. [Walsh, MJ] – December
- “Can we use defatted microalgae as a novel feed protein to produce healthier animal foods?” The 11th Annual Oilseed & Grain Trade Summit, Minneapolis, Minnesota. [Lei, XG] – November
- “Financial and Integrated Assessment of Algae for Food and Energy,” MIT: Joint Program on the Science and Policy of Global Change: Economic Projection and Policy Analysis Seminar, Cambridge, MA. [Walsh, MJ] – November

Presentations

2016 (cont)

- “New perspective of nutrient digestibility and retention in diets containing defatted microalgae,” The 77th Cornell Nutrition Conference, East Syracuse, New York. [Lei, XG] – October
- “Co-products are key to economic success,” Algae Biomass Summit, Phoenix, Arizona. [Gerber, LN, MJ Walsh, JW Tester, CM Beal, ME Huntley, DL Sills] – October
- “Substitution of fishmeal with defatted microalgae (Nannochloropsis sp.) from biorefinery in diets for European seabass (Dicentrarchus labrax)” Aquaculture Europe 2016, Edinburgh, Scotland. [Custódio, M, H Fernandes, S Batista, V Kiron , LMP Valente] – October
- “Molecular insights into the hidden majority of the ocean’s biological engine” [ZI Johnson] – September
- “Can we use defatted microalgae to produce healthier animal feeds and human foods,” ENN (energy) Group, Langfang, Hebei, China. [Lei, XG] – August
- “Microalgae in poultry nutrition,” Joint ASAS/ADSA Meeting, Salt Lake City, Utah. [Lei, XG] – July
- “Natural Products from Microalgae,” Annual Meeting of the Phycological Society of America, John Caroll University, Cleveland, Ohio. [Manning, SR] – July

Presentations

2016 (cont)

- “Large Scale Algae Production: The Basis for a Sustainable Shrimp Aquaculture Industry in Thailand,” Prince of Songkla University, Hat Yai, Thailand [M Huntley] (July)
- “Will microalgae make protein green for better nutrition, health, and environment,” The 1st Conference of Translational Nutrition and Medicine, the Chinese Nutrition Society, Chongqiang, China. [Lei, XG] – June
- “From Test Tubes to Tonnes: Updates on Lab Trials to Commercial Scale Relevance (and some paths forward)” San Diego, California. [ZI Johnson] – May
- “Microalgae: the good, the bad, and the ugly,” Plant Biology Seminar, University of Texas, Austin, Texas. [Manning, SR] – May
- “Current State of Technology in Algae Cultivation: Hybrid Cultivation Systems,” World Congress on Industrial Biotechnology, San Diego [M Huntley] – April
- “Can we use defatted microalgae to produce healthier animal feeds and human foods,” to a delegation of Vietnam hosted by the Cornell Technology Transfer and License Office, Cornell University, Ithaca, New York. [Lei, XG] – March
- “Climate, Energy, and Water Security from the Sea,” Computer Assisted Process Engineering (CAPE) Forum, Swiss Polytechnic Institute (EPFL), Valais, Sion, Switzerland. [Sills, DS, Walsh, MJ, Gerber Van Doren, L, Greene, CH] – March

Presentations

2016 (cont)

- “Prymnesium parvum: Killer Algae in the Southwest,” American Society of Microbiology, Texas Tech University, Lubbock, Texas. [Manning, SR] – March
- “Use of Marine Microalgae for Biofuels Production: Reduction in Ash Content for Potential Improvements in Downstream Processing,” Poster for Ocean Sciences Meeting, New Orleans, Louisiana. [Redalje, D, S Brown] – February

2015

- “Green crude or brown crud?: Economic and environmental assessment of algal biofuel,” Mechanical and Environmental Engineering Seminar, Tel-Aviv University, Israel. [Sills, DS, MJ Walsh, L Gerber Van Doren, CH Greene] – December
- “From Test Tubes to Tonnes: Scaling up Lab Trials to Commercial Scale Relevance,” Washington DC. [Johnson, ZI] – September

Patents, Awards, and Commercialization

No patents have been applied for based on the work supported by DOE.

No special awards have been received.

All primary results from this project are being published in the open, peer-reviewed literature. The publications from this project – cited above – provide a comprehensive and detailed analysis of commercialization potential. This information will be available to anyone with access to the open literature.