Marine AlGae Industrialization Consortium (MAGIC)

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March 7, 2019
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)

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

Budget Summary

<table>
<thead>
<tr>
<th>in M$</th>
<th>Total Costs pre FY17</th>
<th>FY 17 Costs</th>
<th>FY 18 Costs</th>
<th>Total Planned Funding (FY 17-End)</th>
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<td>DOE Funded</td>
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<td>Project Cost Share (Comp.)*</td>
<td>$0.03</td>
<td>$0.76</td>
<td>$0.52</td>
<td>$1.3</td>
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</table>

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%)

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
2 – Approach (Management Structure)

- **Brown (UHM)**
  - **T1: Strain Selection**

- **Johnson (Duke)**
  - **T2: Mass Culture**

- **Goodall (Trucent)**
  - **Manning (UTEX)**
  - **T3: Recovery/Conversion**

- **Lei (Cornell)**
  - **T4: Product Assessment**

- **Huntley (UHH)**
  - **T5: Commercialization**

- **Huntley & Johnson**
  - **T6: Management & Reporting**

- **Redalje (USM)**

- **Less (ADM)**

- **Matlock (ADM)**

- **Miller (Cornell)**

- **Bera (Shell)**

- **Kiron (Nord)**

- **Archibald (UHH)**

- **Greene (UHH)**

- **Beal (UHH)**

- **Sills (Bucknell)**

- **Bidigare (UHM)**

- **Granados (UHH)**

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
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)*
Rank order results

<table>
<thead>
<tr>
<th>Strain</th>
<th>GR</th>
<th>Strain ID</th>
<th>%ash</th>
<th>Lipid proxy NR:AFDW</th>
<th>Strain ID</th>
<th>Lipid Proxy H:AS</th>
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<td>0.65</td>
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<tr>
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<td>Pleur01*</td>
<td>0.53</td>
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<td>BORAD02*</td>
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<td>C930</td>
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<td>1.70</td>
<td>C584</td>
<td>7.6</td>
<td>C584</td>
<td>0.44</td>
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</tbody>
</table>

* 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)

July 2017

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)
C046: Total algal crude oil yield – 1669 g (>95% Eff.)

~14 kg of LEA for co-product trials
UT-OpenAlgae Oil Extraction Process

Pulsed-Electric Field Lysis Unit

Membrane Oil Recovery Skid

UT-Austin
PI: Manning

<table>
<thead>
<tr>
<th>Strain</th>
<th>% neutral lipid recovered</th>
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<tr>
<td>OCY3</td>
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<td>S002</td>
<td>12.8</td>
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<tr>
<td>C046</td>
<td>In progress</td>
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</table>
Task 4: *Product Assessment*

**Task Summary:** Product specifications are defined in four market areas: biofuels and three nutritional product markets: aquafeed, poultry feed, and nutritional products. 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

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Price as-fed ($/t)</th>
<th>Intake - (%) DM</th>
<th>Intake - DM (kg DM)</th>
<th>Intake - As-fed (kg)</th>
<th>DM (%)</th>
<th>TDN (%)</th>
<th>AEM (MJ/kg)</th>
<th>CP (%)</th>
<th>Crude Fiber (ADF (%))</th>
<th>NDF (%)</th>
<th>Crude Fat (%)</th>
<th>Crude Ash (%)</th>
<th>Ca %</th>
<th>P %</th>
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<tbody>
<tr>
<td>Generic LEA Estimate</td>
<td>1200</td>
<td>10%</td>
<td>0.031</td>
<td>0.035</td>
<td>90.00%</td>
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<tr>
<td>Soymeal</td>
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<td>9.92</td>
<td>47.74%</td>
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<td>5.00%</td>
<td>8.65%</td>
<td>2.05%</td>
<td>6.45%</td>
<td>0.32%</td>
<td>D</td>
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<tr>
<td>Fishmeal</td>
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<td>0.051</td>
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<td>13.3</td>
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<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>9.20%</td>
<td>16.80%</td>
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<tr>
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<td>13.92</td>
<td>8.00%</td>
<td>1.85%</td>
<td>3.05%</td>
<td>10.90%</td>
<td>3.45%</td>
<td>1.15%</td>
<td>0.04%</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Total Feed**

- Price as-fed ($/t): $505
- Intake - (%) DM: 0.309
- Intake - DM (kg DM): 0.347
- DM (%): 88.9%
- TDN (%): 22.1%
- Crude Fat (%): 4.4%
- Crude Ash (%): 5.8%

**TARGET DIETS**

<table>
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<tr>
<th>Diet</th>
<th>Starter Diet</th>
<th>Grower Diet</th>
<th>Finisher Diet</th>
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<td></td>
<td>89.03%</td>
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<td>88.92%</td>
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<td></td>
<td>12.69</td>
<td>12.97</td>
<td>13.31</td>
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<tr>
<td></td>
<td>22.00%</td>
<td>19.50%</td>
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<td>6.47%</td>
<td>6.47%</td>
<td>6.99%</td>
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<td></td>
<td>7.13%</td>
<td>6.38%</td>
<td>5.65%</td>
</tr>
<tr>
<td></td>
<td>0.90%</td>
<td>0.84%</td>
<td>0.76%</td>
</tr>
</tbody>
</table>

From Industry
- Feedtable.com: https://feedtables.com/content/fish-meal-protein-65
- Cobb500 Nutrition Supplement: http://www.cobb-vantress.com/docs/default-source/cobb-500-guides/Cobb500_Broiler_Performance_Anc

From NRC2001

From Duke University

Poultry Feed Starter Diet
- Aquafeed
- Algal Biomass LEA
- Poultry Feed STRAWMAN
- Biocrude STRAWMAN
• 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**
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)

<table>
<thead>
<tr>
<th>SUMMARY OF RESULTS (MBCSP; $/gge)</th>
<th>Baseline Valicor</th>
<th>Baseline OpenAlgae</th>
<th>Target Valicor</th>
<th>Target OpenAlgae</th>
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<tbody>
<tr>
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<tr>
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- M5.2 based on initial cultivation data (9 g m² 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
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.

- **Species**: *Desmodesmus* sp. (C046)
  - **Extraction**: OpenAlgae (~75% ext. eff.)

- **Species**: *Oocystis* sp. (OCY3)
  - **Extraction**: OpenAlgae (3% ext. eff.)

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

[Graphs showing life cycle impacts for each species with different extraction efficiencies.]
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 CO₂* 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/separation, product assessments and TEA/LCA work. Report on “integrated” process flow
Thank you

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Additional Slides
Publications (24+)


Publications (cont.)


Publications (cont.)


Publications (cont.)

[https://doi.org/10.1016/j.algal.2017.11.039](https://doi.org/10.1016/j.algal.2017.11.039)

[https://doi.org/10.1089/ind.2018.29120.xgl](https://doi.org/10.1089/ind.2018.29120.xgl)

[https://doi.org/10.1021/acs.jafc.8b00860](https://doi.org/10.1021/acs.jafc.8b00860)

[https://doi.org/10.1016/j.algal.2018.04.031](https://doi.org/10.1016/j.algal.2018.04.031)

[https://doi.org/10.1038/s41598-018-33504-w](https://doi.org/10.1038/s41598-018-33504-w)
In Press

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)


• “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)
- “Can microalgae make eggs and chicken replace fish?” Nutrition Field Seminar, Division of Nutritional Science, Cornell University, Ithaca, New York. [Lei, XG] – 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)


• “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


• “Microalgae from biorefinery as potential feed ingredients for Atlantic salmon Salmo salar,” Aquaculture Europe 2017, Dubrovnik, Croatia. [Kiron, V] – October


Presentations

2017 (cont)


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
• “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
Presentations

2016 (cont)


• “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, Chongqing, 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
- “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
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.