DOE Bioenergy Technologies Office (BETO) 2021 Project

Peer Review

Pilot-Scale Algal Oil Production

3/26/2021

SDI

Dave Hazlebeck
Global Algae Innovations
Design a pilot-scale algae facility incorporating advanced technologies to demonstrate the viability of algae for oil and protein meal commodities

Current commercial algae farms only produce high value products because the costs are an order of magnitude too high

Achieving commodity prices requires scaling up and integrating many innovations simultaneously, which is inherently challenging and risky
Two Step Scale-up

Facility:
- Current: 8-acre
- Step 1: 160-acre
- Step 2: 5000-acre

Raceways:
- Current: 3.2-acre
- Step 1: 25-acre
- Step 2: 200-acre

Scaling:
- Facility: 8x, 20x, 30x
- Raceways: 8x, 8x
Economical Algae Commodities Are Important Because Algae Offers an Unprecedented Productivity Increase

Algae increases yield by 40x

Green Revolution
Soybean yield increased almost 3x over 60 years

Graph showing protein yield (mt/ha-yr) and oil yield (gal equivalent / ac yr) for various commodities.
The IMPACT of ALGAE

- Create Jobs
- Improve Health
- Rural Rejuvenation
- Sustainabale Food
- Decrease Poverty
- Restore Forests
- Prevent Mass Extinction
- Mitigate Climate Change
- Replenish Ocean Ecosystems
- Preserve Water

Algae: 40x yield, Global Algae Price: $1/kg, ROI: 20% scalable on 10,000 acres.
Large-scale algae for feed and fuel: 13.3 Gt/year in reduced CO₂ emissions

Algae for animal feed and biofuels:

- Agriculture – 5.4 Gt/y, 32% with algae, 60% GHG reduction = 1 Gt/y
- Fuels - 12 Gt/y, 20% with algae biofuel, 94% GHG reduction = 2.3 Gt/y
- Stopping deforestation = 5 Gt/y
- Restoring forests = 5 Gt/y

Eventually replace all fuels for 20 Gt/y total


1 – Management
Team and Communications

**Team**
- Global Algae Innovations
  - Algae cultivation and processing experts and full technology suite
- University of California at San Diego
  - Algae strain library, design review
- TSD Management Associates
  - Algae processing expertise, PE
- Permitting Consultant – TBD
  - Best Best & Krieger LLP
- Engineering, Procurement, and Construction (EPC) firm – TBD
  - Specialty Construction

**Management**
- Weekly telecoms
  - Business assessment, permitting, and site selection
  - Design
  - Strain library
- Actively manage technical progress and budget
  - Microsoft project schedule
  - Track critical path and near critical path
  - Regular meetings with DOE project team and independent engineer
  - Quarterly reports
- Integration with ongoing R&D in other projects
  - 18 partner organizations (universities, national labs, commercial, non-profit)
  - Results that have implications on design and techno-economic analysis
  - Results from this project that impact techno-economic model and R&D targets
- Formal risk management table
  - Identify risks
  - Determine mitigation strategies
  - Track through resolution
Excellent Technical Advisory Committee

**Technical Advisory Committee**

- **Ahma Belay, PhD**
  - 40+ years of commercial algae production
- **Bill Barclay, PhD**
  - 40+ years of commercial algae production
- **Greg Mitchell, PhD**
  - 40+ years of algae research & development
- **Ike Levine, PhD**
  - 40+ years of algae cultivation and consulting
- **Phil DeDominicis, MBA**
  - 30+ years of investment banking experience

**Review and Recommendations**

- Conceptual design
- Risk Table
  - Other risks
  - Adequacy of mitigation strategy
- Business assessment
- Preliminary Design
2 - Approach

Integration into Pilot-Scale Design
- Breakthroughs & innovations
- Commercial production environment
- Local weather variations
- Site constraints
- Business assessment
- Permitting assessment

Preparatory R&D
- Photobioreactor testing for inoculum
- California Strain Library
Integrate Many Breakthroughs and Innovations into the Pilot-Scale Design

Cost Reductions ($/kg)

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Cultivation</th>
<th>Harvesting</th>
<th>Nutrient Supply</th>
<th>Stability &amp; Inoculation</th>
<th>CO₂ Supply</th>
<th>Extraction</th>
<th>Drying</th>
<th>Global Algae</th>
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<tbody>
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<td>Major Breakthroughs</td>
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<td>Other Key Innovations</td>
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<td>19</td>
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<td>R&amp;D in progress</td>
<td>37</td>
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</tbody>
</table>
Business Assessment

Parallel financing routes

- Commercial investment
  - Future off-take rights
  - Rotate high value product/biofuel so can leverage with USDA guaranteed loan
  - Financial partner

- Non-profit grants/loans/investments
  - Solutions to environmental/societal dilemmas needed now
  - Move to pilot & commercial-scale faster
  - Spur algae industry: biofoundry, regulatory approvals, proof of viability

- Federal and state grants/loans

• Algae oil - validate economics and quality
  - ¼ of time, ~1wk per month
  - Oil for polymers, fuel, omega-3
  - Protein meal for feed trials and testing to support regulatory approvals

• High value product / biofoundry – pay the freight
  - ¾ of time
  - repay loans and/or ROI
  - support long-term operation

5000-acre, Commodities $1/kg

FARM 160 $5/kg

Current facilities High-value $20/kg

12 5000-acre, Commodities $1/kg

Current facilities High-value $20/kg

GLOBAL ALGAE
3 - Impact

- Facilitate financing of pilot-scale algae oil facility through completion of design and permitting
- Integration and scale-up design for 65 innovations including 11 major breakthroughs
- Patents based on the design and scale-up work (6 invention disclosures from conceptual design effort)
- 12 trade studies each advance state-of-the-art through evaluation of options and optimization, e.g.
  - Water management – rain, evaporation, cleaning, recycle, blowdown, evaporation pond, etc.
  - Raceway pumping and circulation
  - Harvesting configuration and operational mode/time
- Scale-up and cost estimates
  - Validate economic and sustainable attributes of the advanced algae process
  - Higher fidelity economic model will benefit general industry through our partnerships
  - Better R&D because the techno-economic model is used to guide all of our research projects
- Once built and operating
  - Plan to finance plant and then licensing/franchise model for dissemination
  - Biofoundry will spur industry
  - Existence proof for lower cost algae production will invigorate investment
4 – Progress and Outcomes
Milestones Completed

• Strain collection, isolation, initial down selection and characterization
• Photobioreactor validation
• Permitting and regulatory assessment
• Business assessment
• Risk assessment
• Conceptual design
  - Design basis, block flow diagram, mass and energy balance
  - Technology selection, process description, control and operating plan
  - Major equipment sizing, site layout, technoeconomic model update, cost estimate
• Conceptual design review
• Site selection
• Process document updates (block flow diagram, mass and energy balance, techno-economic model)
UC San Diego Strain Library Progress

1) Bioprospecting

~~400 Isolated Strains from Imperial Valley and San Diego

Sampling sites chosen by presence of seasonal water and high-light

2) Strain Down Selection

~~400 Isolates to ~10 Final Strains

Based on pH tolerance during growth on agar plates and in liquid media

3) Experimentation and Genomic Sequencing

~10 Final Strains

Lipid and biomass productivity in flask-scale growth trials, determine taxonomy

4) Experimentation and Down Selection

~10 to ~4 Strains

Flask-scale trials with GC/MS lipid quantification; large-scale pond growth trials
Strain Collection and Isolation

Sample Site IV-03

Plated Environmental Sample

IV-003(Stichococcus)

IV-023(Tetracystis)
# Technology Selection

<table>
<thead>
<tr>
<th>System</th>
<th>Conventional Technology</th>
<th>Farm 160 Technology</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>Manual algae and media analysis</td>
<td>Robotic algae and media analyses</td>
<td>Less labor, greater accuracy, more information about the system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Microbiota measurements</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Algae stress measurement</td>
<td></td>
</tr>
<tr>
<td>Inoculum</td>
<td>Photobioreactor, ~5% of system area</td>
<td>Mini-raceways, ~0.05% of system area</td>
<td>99.9% lower cost and energy use</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Fertilizer mix</td>
<td>Lower cost fertilizer formulation</td>
<td>25% cost reduction</td>
</tr>
<tr>
<td>CO₂</td>
<td>Purchased CO₂</td>
<td>Direct air capture</td>
<td>95% cost reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improved life-cycle analysis</td>
<td></td>
</tr>
<tr>
<td>Cultivation</td>
<td>~0.5 ha paddle wheel mixed raceway pond</td>
<td>Scalable, sloped, open raceways</td>
<td>2-3x higher productivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Advanced cultivation methods</td>
<td>10x lower energy use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Automated controls</td>
<td>100x greater scalability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermal &amp; water management</td>
<td>80% cost reduction</td>
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<tr>
<td>Harvesting</td>
<td>Centrifuge</td>
<td>Zobi harvester®</td>
<td>100x lower energy use</td>
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<tr>
<td></td>
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<td>90% cost reduction</td>
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<tr>
<td>Drying</td>
<td>Drum or spray dryer</td>
<td>Ring Dryer using waste heat or Global Algae’s novel drying process</td>
<td>30x lower energy use</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>90% cost reduction</td>
</tr>
<tr>
<td>Extraction</td>
<td>Extruder &amp; solvent extraction</td>
<td>Extruder &amp; solvent extraction or Global Algae’s novel extraction process</td>
<td>10x lower energy use</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>95% cost reduction</td>
</tr>
</tbody>
</table>
Mass and Energy Balance (average daily flows)

- **Laboratory**
  - 60L H₂O
  - 6 g algae
  - 0.1 ML H₂O

- **Inoculum**
  - 1 kWh
  - 100L H₂O
  - 22 mt CO₂
  - 0.2 ML H₂O

- **Cultivation**
  - 1200 kWh
  - 6000L H₂O
  - 10 mt algae
  - 10 mt algae
  - 1.2 ML H₂O
  - 17 mt O₂

- **Harvesting**
  - 600 kWh
  - 1.15 ML H₂O
  - 11.9 ML H₂O
  - 10 mt algae

- **Drying**
  - 6000L H₂O
  - 0.05 ML H₂O
  - 10 mt algae
  - 0.05 ML H₂O

- **Extraction**
  - 20 kWh, 1800 MJ
  - 10 mt algae

- **Baseline: 1100 kWh**
  - 60,000 MJ

- **Baseline: 900 kWh**
  - 14,000 MJ

- **Algal Oil**
  - 2.5 mt

- **Algal Meal**
  - 7.5 mt

- **Nutrients**
  - 200 kWh
  - 0.1 ML H₂O

- **Laboratory**
  - 5 mt fertilizer
  - 0.1 ML H₂O

- **Extraction**
  - 20 kwh, 1800 MJ

- **Baseline: 1100 kWh**
  - 60,000 MJ

- **Baseline: 900 kWh**
  - 14,000 MJ
## Site Selection Matrix

<table>
<thead>
<tr>
<th>Location</th>
<th>Access Support</th>
<th>Temp range</th>
<th>Days of Sun</th>
<th>Water</th>
<th>Topo</th>
<th>Permit &amp; Reg</th>
<th>Fert. Supply</th>
<th>Oil &amp; Feed Use</th>
<th>CO₂</th>
<th>Total</th>
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<td>Imperial Valley: El Centro</td>
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<td>Kern: Bakersfield</td>
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</table>
Summary

• Large-scale algae production for commodities is essential to mitigate climate change
  - Stopping and reversing deforestation is pivotal in the IPCC pathways to achieve our climate change goals
  - Algae is the only solution to deforestation that meets the world’s protein requirements

• The design and trade off studies are advancing the state-of-the art for algae oil production
  - Integrating many innovations to achieve an order-of-magnitude reduction in costs and energy
  - First scale-up design of an open-algae cultivation system with advanced technologies
  - Identifying and addressing the challenges and opportunities in commercial application of these innovations
  - Design effort has resulted in 6 invention disclosures to-date
  - Better scaling and cost estimate will improve algae R&D programs through technoeconomic model fidelity
  - R&D advances in other projects are being tracked for incorporation of results into the design

• Technical advisory board has wealth of experience and expertise to help ensure the pilot is successful

• On-track for completion of the preliminary design, permitting, and execution plan this year

• Construction and operation of this pilot facility will hasten development of the algae industry
Quad Chart Overview

**Timeline**
- Project start date: 1-15-17
- Project end date: 12-31-21

<table>
<thead>
<tr>
<th></th>
<th>FY20 Costed</th>
<th>Total Award</th>
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<tbody>
<tr>
<td>DOE Funding</td>
<td>211,097</td>
<td>2,235,790</td>
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<tr>
<td>Project Cost Share</td>
<td>190,018</td>
<td>2,235,790</td>
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</tbody>
</table>

**Project Goal**
The goal is to scale-up an open-raceway algae biofuel process that is economically viable and sustainable
- Preliminary planning and design
- High fidelity technoeconomic analyses for a full-scale facility that verify the process is economically viable and sustainable
- Business plan for financing and operation that enables long-term algal oil production

**End of Project Milestones**
- FEL-3 design documents with -5% / +15% cost estimate accuracy.
- Business plan including technoeconomic analysis results.
- Project management plan for detailed design, construction and start-up.

**Project Partners**
- TSD Management Associates
- University of California at San Diego
- California Energy Commission
- Engineering, procurement, construction - TBD
- Permitting consultant - TBD

**Funding Mechanism**
DE-FOA-0001232; Topic Area 1; 2016
Additional Slides
## Responses to Previous Reviewers’ Comments

<table>
<thead>
<tr>
<th>2019 Peer Review Questions/Comments</th>
<th>Project Changes</th>
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<tbody>
<tr>
<td>Not clear that project advances the state-of-the-art.</td>
<td>Added more information into the 2021 presentation about how the project advances the state-of-the-art.</td>
</tr>
</tbody>
</table>
| Need alternative financing plans | Pursing five financing approaches:  
  • Commercial investment for future off-take rights  
  • Commercial investment & USDA loan for high value product & biofuel  
  • Financial partner for Global Algae  
  • Non-profit grants/loans for environmental and societal benefits  
  • Government grants/loans |
| Pilot plants are too small to be profitable | 160-acres is pilot-scale for algae biofuels but is commercial-scale for higher value algae products.  
Design basis already included strain rotation to improve contamination control.  
Added rotation between high value product ($20/kg) and algae oil ($1/kg) so composite sales revenue is commensurate with pilot-scale costs. |
Publications, Patents, Presentations, Awards, and Commercialization

- Patents
  - 6 invention disclosures with patent applications planned
- Presentations
- Commercialization
  - Project is an integral part of Global Algae’s plan for deployment of commercial algae facilities
  - Project results are impacting multiple industry leading technoeconomic analyses