Algal Biodiesel via Innovative Harvesting and Aquaculture Systems

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Algal Feedstocks

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Goal Statement

• **Goal 1:** Demonstrate a prototype algal harvesting process at a sufficient scale (>300,000 U.S. gallons [1,135,632 liters] of algae culture processed per day) to facilitate commercial scale-up.

• **Goal 2:** Show that the energy intensity of the harvesting process does not exceed 10% of the energy content of the algal biomass being processed.

• **Algal Feedstock Logistic Area:** Harvest: Dewatering & Concentrating

• **BETO MYPP Goal Addressed:** “Demonstrate technologies to produce sustainable algal biofuel intermediate feedstocks that perform reliably in conversion processes to yield renewable diesel …”

• **U.S. Relevance:** Demonstrated harvesting technology brings algal oil closer to commercialization as a feedstock for renewable diesel.
Quad Chart Overview

Timeline
• Project start date: 10/1/10
• Project end date: 9/30/14
• Percent complete: 100%

Barriers
• Barriers addressed
  – AFt-D. Sustainable Harvesting
  – AFt-H. Overall Integration and Scale-Up

Budget

<table>
<thead>
<tr>
<th></th>
<th>Total Costs FY 10 – FY 12</th>
<th>FY 13 Costs</th>
<th>FY 14 Costs</th>
<th>Total Planned Funding FY 15</th>
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<tr>
<td>DOE Funded</td>
<td>$1,716,953</td>
<td>$524,944</td>
<td>$750,000</td>
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Partners
• Partners
  ▪ None
• Other interactions/collaborations
  ▪ **Neste Oil** – algal oil analysis
  ▪ **ABB, Inc.** – process control, automation, and equipment
1 - Project Overview

• History:
  – RAE Successfully completed DOE Phase I and II Small Business Innovation Research (SBIR) Grants to collect harvester scale-up data

• Context:
  – RAE Scientists and Engineers have commercial experience with algae since 1993

• Objectives:
  – Demonstrate scalable algal harvesting technology that can be deployed at commodity scale
2 – Approach (Technical)

• Apply scalable technology that is commonly deployed in mining and minerals to algae harvesting.

• Confirm that the technology can be scaled from 10 to 208 gallons per minute (gal/min) [38 to 787 liters/min] by utilizing data collected during Phase I & II SBIR Grants to design and engineer the 208 gal/min harvester.

• Prove the harvester can be constructed and operated at 208 gal/min at desired rates to minimize technology scale-up risks.

• Implement full automatic process control so that the automation technology is directly transferable to a 2,000 gal/min [7,571 liters/min] commodity harvester.

• Demonstrate technology performs reliably with automatic process control.
2 – Approach (Management)

• Validate that the technology produces algal oil suitable for use in transportation fuel.

• Demonstrate the value of the algal protein and other co-products as they impact the overall project value.

• Validate that the technology facilitates production of algal oil at a cost that is economically viable in the commodity marketplace.

• Confirm that technical support is available around the world so that the technology can be deployed globally.

• Deploy project management tools typical of industrial projects to achieve the desired project goals.
3 – Technical Accomplishments/Progress/Results

• **Goal 1:** Demonstrated a prototype algal harvesting process at a sufficient scale (>300,000 U.S. gallons of algae culture processed per day = 208 gal/min [787 liters/min]) to facilitate commercial scale-up.
  
  – Designed and engineered the harvester (208 gal/min scale)
  – Constructed and tested the harvester
  – Demonstrated robust operation with automatic process control
  – Operated harvester continuously for more than 24 hours with automatic process control at a rate of 208 gal/min

• **Goal 2:** Demonstrated that the energy intensity of the harvesting process does not exceed 10% of the energy content of the algal biomass being processed.
  
  – Process control offered continuous measurement of energy usage
  – Algal biomass recovery from harvesting was quantified
3 – Technical Accomplishments/Progress/Results (cont’d)

Figure 1. Continuous harvester capable of processing more than 300,000 U.S. gallons/day of algae culture (=208 gal/min [787 liter/min]).
3 – Technical Accomplishments/ Progress/Results (cont’d)

Figure 2. Night operation of harvester.

Figure 3. IO panel for the process instrumentation and control.
3 – Technical Accomplishments/Progress/Results (cont’d)

Figure 4. Aquaculture pond used to feed the harvester during trials.
3 – Technical Accomplishments/Progress/Results (cont’d)

Cell Count Associated with an Expenditure of ≤10% of the Recoverable Algal Energy
(200 & 330 gpm, Efficiency of 80 & 90%, Two Scavenger Cells)

Harvester energy ≤10% of recoverable biomass energy
3 – Technical Accomplishments/Progress/Results (cont’d)

![Graph showing technical accomplishments and progress/results with data points. The graph includes a line for 11.7 micron, 200 gal/min, 80% efficiency and another for 11.7 micron, 330 gal/min, 90% efficiency.](image-url)
3 – Technical Accomplishments/Progress/Results (cont’d)

Harvester Recovery Efficiencies Based on Surrogate Parameters

![Graph showing percent recovery vs run number with data points for Betacarotene and Chlorophyll recovery.](image-url)
3 – Technical Accomplishments/Progress/Results (cont’d)

Cell Diameters in Ponds Operating Under Similar Conditions

- **Sample Day**
- **Cell Diameter, microns**

- **Pond 1**
- **Pond 2**
- **Pond 3**
- **Pond 5**
4 – Relevance

• This project fits the goals of the BETO MYPP by demonstrating algal harvesting technology that is commercially scalable and operates at an acceptable energy usage level.

• The off-take agreement with Neste Oil (world’s largest producer of renewable diesel) is a significant step forward for the algal bioenergy industry, because it validates that the harvesting technology can produce algal oil of sufficient quality at a price point that is commercially viable.

• The strategic partnership agreement with ABB (global leader in power and process automation) supports the technical approach used and facilitates its global deployment.
Summary

• **Goal 1:** Demonstrated a prototype algal harvesting process at a sufficient scale (>300,000 U.S. gallons of algae culture processed per day = 208 gal/min or [787 liters/min=47,242 liters/hour]) to facilitate commercial scale-up.

• **Goal 2:** Demonstrated that the energy intensity of the harvesting process does not exceed 10% of the energy content of the algal biomass being processed.

• The off-take agreement with Neste Oil is a significant step forward for the algal bioenergy industry, because it validates that the harvesting technology can produce algal oil of sufficient quality at a price point that is commercially viable.

• The strategic partnership agreement with ABB, Inc. supports the technical approach used and facilitates its global deployment.
Additional Slides
Publications, Patents, Presentations, Awards, and Commercialization

• Publications, Patents, Presentations, Awards
  – Recognized by the DOE/BETO as one of top five algal biomass accomplishments in 2014
  – Presented at the plenary session of the 2014 Algal Biomass Summit in San Diego, CA

• Commercialization
  – Successful results support raising Series A equity investment
  – Leveraging oil off-take agreement to secure protein off-take agreements for both human and animal nutrition – engaged in multi-party commercial evaluations of technology and products
  – Evaluating North American production locations to support commodity-scale technology deployment for secured off-take agreements
  – Engaged international bank for project finance structuring
The Energy Content of the Algae
(on an ash free dry weight basis)

• The heat of combustion, \( h = (R/7.89 + 0.4) \times 1,000 \)
• \( R = 100 \times \left[ (\%C \times 2.66) + (\%H \times 7.94) - (\%O_2) \right]/398.9 \)
• If a typical algal cell is composed of 56.0% carbon, 8.1% hydrogen, and 31% oxygen, all expressed in percentage of ash-free weight, then: \( R=45.7 \)
• And, \( h = 6,200 \text{ cal/g} = 24.6 \text{ BTU/g} = 0.00966 \text{ hp/g} \)