ON THE WAY TO INEXPENSIVE MICROALGAE PROTEIN

Miguel Olaizola and Grace Stearman
Heliae Development, LLC
Heliae’s founders are focused on the application of algae technology to solve the significant challenges of the 21st century. These needs define our long-term goals.
2008-2016 Technology and facility development

- **Basic R&D** Small scale production
- **2008**
- **2009**
- **2010**
- **2011**
- **2012**
- **2013**
- **2014**
- **Demo Facility Completed. Work on Production Systems Initiated**
- **Commercial Scale Platform Facility Completion Q3 2013**

- **2016**
  - 2 families of commercial products
  - 1 international joint venture
  - World’s Largest Indoor Photo-Bioreactor

Heliae © 2016
High/mid/low value microalgae

High value product
ASTAXANTHIN

Mid value product
OILS/PROTEINS

Low value product
WASTE WATER

Lower value product
CO₂ CAPTURE

Aquasearch, HI
**Promise of Algae… problems too!**

## Problem of cost

Estimated ranges of costs for microalgal biomass and microalgal products.

<table>
<thead>
<tr>
<th>Product</th>
<th>Hatchery</th>
<th>Haematococcus</th>
<th>Scenedesmus</th>
<th>Several</th>
<th>Hatchery</th>
<th>Arthrospira</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source</strong></td>
<td>Coutteau and Sorgeloos 1992</td>
<td>Astax industry</td>
<td>Acien et al 2012</td>
<td>Acien et al 2010</td>
<td>Coutteau and Sorgeloos 1992</td>
<td><strong>Market price</strong></td>
</tr>
<tr>
<td><strong>US$/kg dry biomass</strong></td>
<td><strong>$400.00</strong></td>
<td><strong>$300.00</strong></td>
<td><strong>$82.80</strong></td>
<td><strong>$55.20</strong></td>
<td><strong>$50.00</strong></td>
<td><strong>$5.00</strong></td>
</tr>
<tr>
<td><strong>Production and processing</strong></td>
<td>??</td>
<td>Much</td>
<td>Substantial</td>
<td>Substantial</td>
<td>Minimal</td>
<td>Minimal</td>
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<tr>
<td><strong>Cost of 1 kg of</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>70% component</td>
<td>$571</td>
<td>$429</td>
<td>$118</td>
<td>$79</td>
<td>$71</td>
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<tr>
<td>30% component</td>
<td>$1,333</td>
<td>$1,000</td>
<td>$276</td>
<td>$184</td>
<td>$167</td>
<td>$16.67</td>
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<tr>
<td>3% component</td>
<td>$13,333</td>
<td>$10,000</td>
<td>$2,760</td>
<td>$1,840</td>
<td>$1,667</td>
<td>$167</td>
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<tr>
<td>1% component</td>
<td>$40,000</td>
<td>$30,000</td>
<td>$8,280</td>
<td>$5,520</td>
<td>$5,000</td>
<td>$500</td>
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</table>

**We need to lower the cost of production**
Problem of scale

Scale of large microalgal farms. From left to right and top to bottom: Earthrise, Cyanotech, Sapphire and Parry Nutraceuticals/Valensa.

We need to get much bigger
The promise of Green Water Polyculture

GWP

1. Consumes very little energy.
2. Consumes biological waste.
3. Uses natural or man-made impoundments.
4. Primary producers and consumers occupy the same footprint.
5. Consumers harvest the primary producers.
6. Water quality improves.
7. Produces ~240 mill tons of algae/yr worldwide.
8. Demonstrably, the cheapest source of aquatic protein today.

Evaluate what aspects of green water polyculture can be adapted to modern biotechnological practices.
Experimental design

1. Wild algae population
   a. Mixture of contaminated cultures at Heliae
   b. Mostly *Scenedesmus*

2. Run 4 pond reactors of 5.5 m2 surface area
   a. 10 cm deep
   b. 4 pH conditions (7.0, 7.5, 8.0, 8.5) controlled with CO₂
   c. Maintained nutrient sufficiency
   d. Approximately once/week harvest/dilution (~70-90%)

3. Experiment started on 11/17/2015
   a. Ponds were NEVER re-inoculated
Growth conditions

- **Daily PAR (Mol/m²/s)**: The graphs show the daily PAR variation from 11/17 to 9/12. There is a peak in the middle, around 6/4.
- **pH**: The pH values range from 6.0 to 9.0. The graphs indicate stability with slight fluctuations across the months.
- **Temperature (°C)**: The temperature graph displays values from 5°C to 40°C. A peak is observed around 6/4.
- **Nitrate (mg/L)**: The nitrate concentration is stable with values ranging from 0 to 250 mg/L. There is a slight decrease observed in the last quarter of the year.
Biomass productivity
Contamination (autotrophs)
Contamination (heterotrophs)
Quality of the product

Lipid: Not much, between 5-20% of DW
Protein: Not bad, between 38 and 60% of DW
Multivariate

Correlations

<table>
<thead>
<tr>
<th>Date</th>
<th>Amoeba</th>
<th>Ciliates</th>
<th>Flagellates</th>
<th>Helminths</th>
<th>Rotifers</th>
<th>Total grazers</th>
<th>DW (g/L)</th>
<th>Vol Prod (g/L/d)</th>
<th>Area Prod (g/m2/d)</th>
<th>NO3</th>
<th>Temp (°C)</th>
<th>pH</th>
<th>Light</th>
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<tbody>
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<td>-0.0079</td>
<td>0.0348</td>
<td>0.3365</td>
<td>0.4050</td>
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<td>0.2124</td>
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<td>0.4338</td>
<td>0.1637</td>
<td>0.055</td>
<td>0.0015</td>
<td>-0.1266</td>
<td>-0.2921</td>
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<tr>
<td>Flagellates</td>
<td>-0.0099</td>
<td>-0.0099</td>
<td>0.1000</td>
<td>0.0151</td>
<td>0.0348</td>
<td>0.4338</td>
<td>0.1637</td>
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<td>-0.1266</td>
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<tr>
<td>Helminths</td>
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<td>0.0151</td>
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<td>-0.1266</td>
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<tr>
<td>Rotifers</td>
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<td>-0.1266</td>
<td>-0.2921</td>
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<tr>
<td>Total grazers</td>
<td>0.4050</td>
<td>0.0055</td>
<td>0.0055</td>
<td>0.0055</td>
<td>0.0999</td>
<td>0.6941</td>
<td>0.055</td>
<td>0.055</td>
<td>0.0015</td>
<td>-0.1266</td>
<td>-0.2921</td>
<td>-0.1166</td>
<td>0.1551</td>
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<tr>
<td>DW (g/L)</td>
<td>0.0999</td>
<td>0.0151</td>
<td>0.0151</td>
<td>0.0151</td>
<td>0.0999</td>
<td>0.6941</td>
<td>0.055</td>
<td>0.055</td>
<td>0.0015</td>
<td>-0.1266</td>
<td>-0.2921</td>
<td>-0.1166</td>
<td>0.1551</td>
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<tr>
<td>Vol Prod (g/L/d)</td>
<td>0.0348</td>
<td>0.0348</td>
<td>0.0348</td>
<td>0.0348</td>
<td>0.0348</td>
<td>0.6941</td>
<td>0.055</td>
<td>0.055</td>
<td>0.0015</td>
<td>-0.1266</td>
<td>-0.2921</td>
<td>-0.1166</td>
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<tr>
<td>Area Prod (g/m2/d)</td>
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<td>0.0348</td>
<td>0.0348</td>
<td>0.0348</td>
<td>0.0348</td>
<td>0.6941</td>
<td>0.055</td>
<td>0.055</td>
<td>0.0015</td>
<td>-0.1266</td>
<td>-0.2921</td>
<td>-0.1166</td>
<td>0.1551</td>
</tr>
<tr>
<td>NO3</td>
<td>0.0055</td>
<td>0.0055</td>
<td>0.0055</td>
<td>0.0055</td>
<td>0.0055</td>
<td>0.6941</td>
<td>0.055</td>
<td>0.055</td>
<td>0.0015</td>
<td>-0.1266</td>
<td>-0.2921</td>
<td>-0.1166</td>
<td>0.1551</td>
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<tr>
<td>Temp (°C)</td>
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<td>0.0055</td>
<td>0.0055</td>
<td>0.0055</td>
<td>0.0055</td>
<td>0.6941</td>
<td>0.055</td>
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<td>0.0015</td>
<td>-0.1266</td>
<td>-0.2921</td>
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<tr>
<td>pH</td>
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<td>0.0055</td>
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<td>0.6941</td>
<td>0.055</td>
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<td>0.0015</td>
<td>-0.1266</td>
<td>-0.2921</td>
<td>-0.1166</td>
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<tr>
<td>Light</td>
<td>0.0055</td>
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<td>-0.1166</td>
<td>0.1551</td>
</tr>
</tbody>
</table>

There are 392 missing values. The correlations are estimated by Pairwise method.
1. Strong seasonality in biomass productivity
   Correlates with temperature and with light

2. Little seasonality in protein and lipid content
   In spite of contamination events
   In spite of population changes

3. Strong seasonality in protein and lipid productivity
   Correlates with temperature and with light
Use economic model to determine savings and direct research effort

<table>
<thead>
<tr>
<th></th>
<th>4 x 550 m² ponds</th>
<th>4 x 1250 m² ponds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$/kg biomass</td>
<td>%</td>
</tr>
<tr>
<td>Materials (water)</td>
<td>$1.05</td>
<td>6.2%</td>
</tr>
<tr>
<td>Materials (CO₂)</td>
<td>$4.77</td>
<td>28.2%</td>
</tr>
<tr>
<td>Materials (Nutrients)</td>
<td>$4.52</td>
<td>26.7%</td>
</tr>
<tr>
<td>Energy</td>
<td>$3.06</td>
<td>18.1%</td>
</tr>
<tr>
<td>Wastewater/sewage</td>
<td>$0.95</td>
<td>5.6%</td>
</tr>
<tr>
<td>Labor/Supervision</td>
<td>$2.59</td>
<td>15.3%</td>
</tr>
<tr>
<td><strong>Gross Cash Cost</strong></td>
<td><strong>$16.94</strong></td>
<td><strong>15.3%</strong></td>
</tr>
</tbody>
</table>

1. Wild algae population
   a. No need to maintain sanitizing conditions
   b. No need to maintain heavy inoculum train
   c. Assume that we need to re-inoculate twice/yr: Save ~ 83% of costs (2/12)

2. Eliminate full harvests/cleaning
   a. Assume that we need to do full harvest/cleaning cycle twice/yr.
   b. Save ~ 83% of costs (2/12)
Thanks!

Heliae’s

- Tech Services
- QC Lab
- Operations
The promise of Green Water Polyculture

GWP

1. Consumes very little energy
2. Consumes biological waste
3. Uses natural or man-made impoundments
4. Primary producers and consumers occupy the same footprint
5. Consumers harvest the primary producers
6. Water quality improves
7. Produces ~240 mill tons of algae/yr worldwide
8. Does not need:
   1. Expensive control systems
   2. Expensive seed trains nor unialgal cultures
   3. Expensive QC laboratory equipment/personnel
   4. Expensive harvesting
   5. Expensive nutrients nor CO₂
   6. Expensive amount of labor
The promise of Green Water Polyculture

GWP

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8. Demonstrably, the cheapest source of aquatic protein today.

Evaluate what aspects of green water polyculture can be adapted to modern biotechnological practices.
Heliae regularly partners with large and small organizations in research collaborations and engages in contract research for customers.
International collaborations/JV

- Industrial group (Poland) – high value crops
- Energy group (Italy) – fuel crops
- Cattle group (US) – farm waste water remediation
- Alvita (Japan) – high value crops
How Heliae Stands Apart

• **Focus**
  – *Scale production, quality, affordability*

• **Skills**
  – Best in class microalgae production expertise
  – Deep cross-functional teams (engineering, biology, chem.)
  – Experienced with *several systems in several areas*
    • *Phototrophic, heterotrophic, and mixotrophic*

• **Strategy**
  – Simultaneous product application and production development
  – Stage gated project management
  – Take commercialization opportunities, but focus on the technology
• Heliae has partnered to develop industry recognized best in class phototrophic production systems

• Heliae reduced phototrophic system production processing time by 50% by changing the basic paradigm of production
Mixotrophy Platform Development

• Heliae® developed a proprietary alternative system for large scale production of microalgae, overcoming significant challenges and industry skepticism
  – Up to ~100x yield as compared to phototrophic systems on a land area basis
What Heliae seeks

• New products and technologies
• Research and commercialization partnerships
• Excellent people

To better understand what problems algae technology can solve for our partners, customers, and society.
Points for Further Discussion

• What needs does your organization face that might be addressed through algae products and technology?

• How can Heliae work with or provide service to your organization?

• Please learn more at www.heliae.com
Introduction to Heliae: Our mission

Heliae® is an innovative algae technology company

Our mission is

– to **unlock** the potential of algae through our **research & innovation** and

– turn the results of our research and innovation into **products** and **solutions** that sustain and improve life
Promise of Algae

Free Sunlight

Wastewater

Industrial CO₂

Food & Feed

Drop-in Fuel

Bio-Chemicals
Cost and scale

Predicted relationship between crop value and farm size based on present knowledge.

- Need small markets (scale issue) of higher value (1→2)
  - Nutraceuticals and high value ingredients
- Next, larger markets of less value (2→3)
  - Specialty feeds and foods
    - Larval feeds
    - Starting diets
    - Finishing diets
    - Spirulina
- Finally, commodities (3→4)
  - HUFA and
  - Proteins
- Future, fuels/environmental (4→5)

Challenges remain

X-axis represents the scale of real or predicted microalgal production facilities and parallels the progression in scale expected for the different products in the industry as a whole.
Neori, 2011 ("Green water" microalgae: the leading sector in world aquaculture. J app Phycol)

So much!!!
So inexpensive!!!

Species?
Quality?
Contamination?
Data?
Lab support?

Does it matter?
Understanding the savings

1. Eliminate the inoculum train - partial
   a. Assume that we need to re-inoculate twice/yr
   b. Save ~ 83% of costs (2/12)

2. Eliminate full harvests/cleaning - partial
   a. Assume that we need to re-inoculate twice/yr
   b. Save ~ 83% of costs (2/12)

3. XXX
   a. XXX
   b. XXX
Understanding the possible downfalls

1. Quality of the product
   a. Wild algae!
   b. Protein content? Lipid content?

2. Repeatable?
   a. Population may (will!) change over time
   b. Performance (productivity)

3. Does it matter?
   a. Perhaps more if specialty lipids are the desired product
   b. Perhaps not if we are looking for bulk lipids and protein
Nitrate Data

Mean (Nitrate (ppm)) vs. Date

Date

Nitrate (ppm)
Acknowledgements

- **Tech Services**
  - Britt BeGell
  - Cody Blair
  - Scott Kuhlman
  - Joel Izzett
  - Anthony Shaver

- **Lab services**
  - Brenda Cranmer
  - Jaclyn Euler
  - Dana Geislinger
  - Van Nguyen
  - David Ou
  - Melissa Spencer
  - Alicja Sztorc
  - Brandon Turkiewicz
  - Stacey Uzzell

- **Operations**
  - Kevin Boyd
  - Josh Wilkenfeld
  - More….