Commercial Production of Spirulina
Cyanotech

- Specializing in Microalgae Technology
- Operating since 1984
- 100 Employees
- GMP Certified by NPA
- Non-GMO, environmentally friendly products
- Public Company: NASDAQ:CYAN

Keahole Point, Hawaii
Cyanotech’s Production Facility

- 90 acre facility in Kona, Hawaii.
- Consistent sun and temperature year-round
- Separate production facilities for *Spirulina* and *Haematococcus*
- Major Spirulina production capacity
- Astaxanthin production is consistent and growing to meet market demand
Spirulina-High Nutritional Value

- 60% Protein
- Rich in carotenoids
  - Beta Carotene
  - Zeaxanthin
- Phycocyanin
  - Liver and Kidney protection
- Immune stimulating compounds
- Antiviral compounds
Microalgae Production In Kona, Hawaii

- **Ideal Climate**
  - Warm year round
  - High solar insolation
  - Low rain fall
  - Unique resource
    - Cold deep seawater

- **High Costs**
  - Land Clearing (hard lava)
    - $85,000/Acre
  - CO₂
    - $440/ton
  - Power
    - $0.37/Kwh
Spirulina Production

- 40 Culture ponds
- Average size 30,000 sq. ft.
- Culture media 150,000 gal
- Total area 29 acres
Spirulina Culture Ponds

• Lined with Reinforced Plastic

• Paddle Wheel Agitation

• Cost per 30,000 ft² Pond
  • Land Leveling $56,800
  • Lining $22,000
  • Agitation $24,900
  • Piping $15,100
  Total $118,800
## Spirulina Typical Growth Media

<table>
<thead>
<tr>
<th>Item</th>
<th>Grams/Liter</th>
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<tbody>
<tr>
<td>NaHCO₃</td>
<td>16.0</td>
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<tr>
<td>NaNO₃</td>
<td>2.5</td>
</tr>
<tr>
<td>NaCl</td>
<td>1.0</td>
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<tr>
<td>K₂SO₄</td>
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<tr>
<td>K₂HPO₄</td>
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<tr>
<td>MgSO₄·7H₂O</td>
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<tr>
<td>FeSO₄·7H₂O</td>
<td>0.01</td>
</tr>
<tr>
<td>Na-EDTA</td>
<td>2.5</td>
</tr>
<tr>
<td>Trace minerals</td>
<td></td>
</tr>
</tbody>
</table>
Highly Alkaline Growth Media

• Operation Necessities
  • Recycle growth media
    • Each 30,000 ft² ponds contains $7,500 sodium bicarbonate ($330,000 on farm)

• Operation Opportunities
  • Reduced or no culture contamination
  • Carbon dioxide recovery
Simplified Bicarbonate Cycle in Spirulina Cultivation

Light and carbon dioxide go in. Photosynthesis produces cell mass, oxygen, and hydroxide. Oxygen and cell mass come out. Bicarbonate is regenerated from carbon dioxide and hydroxide.

\[
\text{Light} \\
\text{HCO}_3^- + \text{H}_2\text{O} \rightarrow \text{OH}^- + \text{CH}_2\text{O} + \text{O}_2 + \text{Cell mass} + \text{CO}_2
\]
\[
\text{CO}_2 / \text{HCO}_3^- / \text{CO}_3^-= \text{Equilibrium}
\]

\[
\text{OH}^- + \text{CO}_2 \rightleftharpoons \text{HCO}_3^-
\]

\[
+ \quad \text{OH}^- \rightleftharpoons \text{CO}_3^- = + \text{H}_2\text{O}
\]
Highly Alkaline Growth Media

• At pH 10.5  40% of C is HCO$_3^-$
• At pH 10.0  68% of C is HCO$_3^-$
• At 16 g/l of NaHCO$_3$:
  • A pH decrease from 10.5 to 10 absorbs sufficient CO$_2$ (carbon) to produce 1.3 g dry wt/l cells
    \[(\text{CO}_2 + \text{OH}^- \rightarrow \text{HCO}_3^-)\]
  
• All carbon can be absorbed in media for a complete growth cycle. (at pond injection is not required)

Cyanotech
Ocean-Chill Spray Drying
Low Oxygen with CO₂ Recovery

Wet Microalgae In

Dryer Gas Recycle
10% CO₂, < 1.0% O₂, N₂

Low Oxygen Spray Drying Chamber

Cyclone

Fresh Dried Product

Stochiometric Burner

Air

Propane

CO₂ Capture

CO₂ Rich Vent Gas

Seawater In

Seawater Out

CO₂ Enriched Media to Ponds

Culture Media From Ponds

Cyanotech
Ocean-Chill Spray Drying

- Low Oxygen environment
  - protects sensitive nutrients
    - Beta carotene, Zeaxanthin, Phycocyanin

- Cold Deep Seawater Cost Effective
  - 4.5 °C seawater--US$0.21 per 1000 gallons
  - Electric power for identical cooling—US$ 5.60

- Carbon dioxide recovery reduces costs
Haematococcus (Astaxanthin) Production

- 28 Culture ponds
- Average size 28,000 sq ft
- Total area 18 acres
Haematococcus Cells

Motile, green *Haematococcus* cells

Encysted cells produce massive amounts of astaxanthin (400x magnification)
Productions of Haematococcus

- Two Stage System
  - Closed Culture
  - Outdoor Open Culture
- All cultures scaled up from 200 ml lab shake flasks
  - 20 liter
  - 400 liter
  - 30,000 liter
  - 500,000 liter reddening ponds
- Haematococcus spores cracked and dried
- Production 10 times more difficult than Spirulina!
Productions of Haematococcus

• Dried, cracked biomass currently sent offsite for extraction
  • Supercritical CO₂ extraction
    • New Jersey
    • New Zealand

• Bringing Supercritical CO₂ extraction on site
  • 1,000 bar (15,000 psi) system
  • Operational April 2016
  • Will generate 60,000 kg/yr of extracted biomass
Productions of Haematococcus

• Extracted Haematococcus Biomass (60,000 kg/yr)
  • 35 % Protein
  • 52 % Carbohydrates
  • 2.6 % Fat
  • 7% Ash
  • 370 calories/100 grams

• Successfully tested in shrimp and fish feeds
  • Detailed analysis available
  • Samples available
  • Biomass available April 2015
Extracted Haematococcus Biomass