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Accordion Photobioreactor for Algae Production

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Algae constitute a rich Biochemical Factory that remains largely untapped!
Global Annual Microalgae Production

**Spirulina** 3000 t DW  
China, India, USA, Myanmar, Japan

**Chlorella** 2000 t DW  Taiwan, Germany, Japan

**Dunaliella salina** 1200 t DW  Australia, Israel, USA, China

**Haematococcus pluvialis** 300 t DW  USA, India, Israel

**Cryptothecodinium cohnii** 240 t DHA oil

Total = about 5000 t DW/yr,  
US$1.25 x 10^9/yr
1.0 Algae for Biofuels

Biodiesel Yield (L/ha-yr)

- Soybeans: 446
- Rapeseed: 119
- Mustard: 1300
- Jatropha: 1892
- Palm Oil: 5950
- Algae (Low): 45000
- Algae (High): 137000
Demand for food in 2050 will be 70 percent higher than it is now

-- Oxfam
2.0 Algae for Food

Nutraceuticals
(Omega 3/6 -- DHA, EPA, AA)
3.0 Algae for Animal Feed
Food/Nutraceutical Mass Production from Algae

Species/Strain Selection

Mass Production of Algae

Harvesting

Dewatering

Product Extraction/Processing
Two Ways to Mass Produce Algae

Open Ponds

Photobioreactors
Open Pond Systems

Earthrise Nutritionals Spirulina Farm
Imperial Valley California USA

Cyanotech, Hawaii
Photobioreactor Systems
### Comparisons

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Open Ponds</th>
<th>Photobioreactors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Energy</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Land Area</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Water Loss</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Productivity</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Risk of contamination</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
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Environmental sustainability criteria must be part of system assessment.
ACCORDION Photobioreactor
Low-Cost and High-Performance Photobioreactor

U.S. and International Patents

Licensed to Biopharmia, LLC
Accordion Photobioreactor

Improves:
Light incidence
Liquid mixing
Bubble breakup
Accordion Photobioreactor
ACCORDION Photobioreactor

A Vertical series of angled flat plates

Advantages:

Low-cost
Simple design
Modular design
Simple maintenance
Lower power requirement
Adjustable light incidence
Adjustable flow
Ease of scale up
Ease of harvesting
Accordion Photobioreactor
Commercial-Scale Operation
<table>
<thead>
<tr>
<th>Authors</th>
<th>Photobioreactor</th>
<th>Volume (L)</th>
<th>Biomass Productivity /Area (g m⁻² d⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuwahara et al. (2013)</td>
<td>Accordion</td>
<td>35</td>
<td>73.0</td>
</tr>
<tr>
<td>Lu et al. (2002)</td>
<td>Helical</td>
<td>75</td>
<td>64.5</td>
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<tr>
<td>Lu et al. (2002)</td>
<td>Bubble Column</td>
<td>57</td>
<td>35.8</td>
</tr>
<tr>
<td>Hu et al. (1996)</td>
<td>Flat Plate</td>
<td>25</td>
<td>36.2</td>
</tr>
<tr>
<td>Hu et al. (1997)</td>
<td>Flat Plate</td>
<td>14</td>
<td>38.1</td>
</tr>
<tr>
<td>Vonshak et al. (2001)</td>
<td>Horizontal Tubular</td>
<td>140</td>
<td>9.5</td>
</tr>
</tbody>
</table>
EPA contents and Growth of *M. subterraneus* in ACCORDION and control Laboratory Flask

<table>
<thead>
<tr>
<th></th>
<th>Flask (1 L)</th>
<th>Air Accordion (35 L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA content (% biomass)</td>
<td>2.0 - 2.8%</td>
<td>2.2 - 2.86%</td>
</tr>
<tr>
<td>EPA content (% total Fatty Acids)</td>
<td>17 - 21%</td>
<td>20 - 22%</td>
</tr>
<tr>
<td>Total Fatty Acid (% biomass)</td>
<td>12 - 14%</td>
<td>11 - 13%</td>
</tr>
<tr>
<td>Max biomass productivity (g L^{-1} day^{-1})</td>
<td>0.198</td>
<td>0.433</td>
</tr>
</tbody>
</table>

Faster growth in Accordion

*M. subterraneus* in ACCORDION

Proximate Analysis

- Ash, 11.69%
- Protein, 32.60%
- Fat, 21.45%
- Carbohydrates, 34.26%
Microalgae Production Pathway

Species/Strain Selection
↓
Mass Production
↓
Harvesting
↓
Dewatering
↓
Product Extraction
↓
Conversion

Water & Nutrients Recycle

Minimal water loss
Roald A. Flo, Ph.D.
Managing Director PhD
Biopharmia, LLC
Oslo, Norway
Accordion Photobioreactor for Algae Production