Aquaculture, Algae and Biofuels; Three Decades of Microalgae Lessons

D.E. Brune, Professor
Bioprocess and Bioenergy Engineering
University of Missouri, Columbia MO., 65211
Where?

- Oregon State University, 1975
  - Research assistant
- University of Missouri, 1975-1978
  - PhD Student
- University of California-Davis, 1978-1982
  - Assistant Professor
- Pennsylvania State University, 1982-1987
  - Associate Professor
- Clemson University, 1987-2009
  - Professor and Endowed Chair
- University of Missouri, 2009-Present
  - Professor
Oregon State; 1975

*Protein and Energy from Swine Manure*

**Lessons**
- algal harvesting costly
- culture stability issues
- bacterial competition from organic loading
Lessons

- lab-data time consuming
- complex interactions
- plasticity of algal growth
- limited field applicability

Table 2. CO₂ threshold concentrations for six algae

<table>
<thead>
<tr>
<th>Species</th>
<th>Temp. (°C)</th>
<th>Light (ft-candles)</th>
<th>CO₂ threshold (μM L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>600</td>
<td>420</td>
</tr>
<tr>
<td>Scenedesmus quadricula</td>
<td>33</td>
<td>0.00060</td>
<td>3.18100</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>0.00047</td>
<td>0.00015</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>0.00063</td>
<td>0.00239</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>0.00457</td>
<td>0.00119</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>0.00520</td>
<td>0.01069</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>0.00229</td>
<td>0.00257</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Oscillatoria sp.</td>
<td>27</td>
<td>0.33280</td>
<td>0.11010</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>0.45790</td>
<td>0.31830</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>0.00224</td>
<td>0.00343</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.00444</td>
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<td>21</td>
<td>0.16490</td>
<td>0.88900</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.27900</td>
<td>0.21850</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.27900</td>
<td>0.21850</td>
</tr>
</tbody>
</table>

Fig. 13. Specific growth rates of three algae at varying light and temperature.
Lessons

- 4-5X algal productivity in high-rate ponds
- algal harvesting costly; discharge land applied
- culture stability issues
Lessons

• 10-20,000 lb/acre shrimp production in raceway systems
• water discharge to lagoon with sand-well filtration and dilution to bay not sustainable
University of California-Davis, 1981
*Brine Shrimp Algal Harvest and Conversion*

**Lessons**

- aquatic-animal algal-harvest cost effective and energy efficient
- biological vs. mechanical harvest not widely accepted
University of California-Davis, 1981

*Inland Saltwater for Algal Biomass Production*

**Lessons**

- high-rate algal production from inland saltwater possible
- inland saltwater highly variable
- evaporation limiting factor

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**Fig. 2.** Locations of inland saltwater samples.

**Fig. 6.** Log plots of algal (*Phaeodactylum*) growth in both saline groundwater and control. (▲) Synthetic seawater (control 2); (●) Saline County plus secondary effluent.
Lessons

- RBC aquaculture not cost effective
- PA climate not suitable for algae
Lessons

• pond algae populations unstable and unpredictable
• mixing and aeration of large ponds inefficient
• management of animals in large ponds ineffective
• harvesting of animals labor intensive

Transport limitation of oxygen in shrimp culture ponds

Albert Garcia and David E. Brune
Agricultural Engineering Department, Texas A&M University,
College Station, Texas 77843, USA
Agricultural & Biological Engineering Department, Clemson
University, Clemson, South Carolina 29634, USA
Clemson University, 1989-2001
Partitioned Aquaculture Systems (PAS)

Lessons

- 15-20,000 lb/ac fish production
- tilapia stabilizes algal density and composition, eliminates zooplankton blooms
- algal harvest maximizes system performance
Clemson University, 2000

Zero-Discharge PAS Marine Shrimp Culture

Lessons

• 35,000 lbs/acre routine in “designed ecosystems”
• weather sensitivity of algal systems
• energy and cost sensitivity of bacterial systems
In-Situ Determination of Algal Growth Kinetics

Lessons

• algal density and water velocity/depth interaction
• field production 50 - 80% of lab-data projections
Clemson University, 2002

The Controlled Eutrophication Process

Lessons

- tilapia-driven algal harvest
- high inert solids in algae harvested from earthen ponds
- multiple products needed to off-set systems cost
Lessons

• photosynthesis max, 20 g-vs/m²-d
• aeration requirement dependent on algal/bacterial interaction
• 20,000 lb/acre shrimp in algal
• 35,000 lb/acre shrimp in bacterial
Clemson University, 2007
Aquacultural Processes for Biodiesel Production

Lessons

• high-lipid algae not needed
• low-cost extraction of animal lipids possible
• integrated systems needed
Lessons

- 50 MW power-plant needs 2,000 acres of algae
- 30% of algal energy needed to grow and process algae
- 25% reduction in natural gas usage possible

### Projected power-plant GHG avoidance

<table>
<thead>
<tr>
<th>CO2 Utilization (%)</th>
<th>Gross GHG Avoidance (%)</th>
<th>Parasitic Loss (%)</th>
<th>Net GHG Avoidance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td></td>
<td>7%</td>
<td>60% 70% 80%</td>
</tr>
</tbody>
</table>

#### Algal Product
- Biogas methane\(^1\) 26.0 7 13.7 – 16.0 – 18.3
- Soybean Feed 17.0 7 8.6 – 10.0 - 11.4
- Replacement\(^2\) 20.0 10 8.6 – 10.0 -11.4

#### Combination
- Methane 7.8
- Soybean Protein 8.5
- Biodiesel 20.0
- Total (@ 70%) 36.3 10 22.3 – 26.3 – 29.7
Questions?

- 2.2/1 energy yield from direct gasification of 5% algal solids
- cost-effective?
Biomass driven electricity generation with waste-heat utilization supporting marine shrimp production
Aquaculture/Bioenergy Co-Production; Cash-Flow Potential

- High-rate algal production maintaining water quality in zero-discharge aquaculture yielding 25,000 lb/acre-yr fish or shrimp
- Algal biomass of 40,000 lb/acre-yr yielding 10 tons/yr fish-meal replacement
- 10 kW/acre of stationary power (as syngas and/or biogas) with 1,000 gallons of liquid fuel/yr
- 60% of the cash-flow provided by fish and shrimp, 30% from animal feeds, and 10% from bioenergy co-production

QUESTIONS: To what degree can “green-energy” prices support profitable year-round temperate-climate aquaculture production? Bacterial or algal systems?
Potential of Microalgae?

- Aquaculture must expand
- Sustainable aquaculture best application of algal technology
- Animal feeds and bioenergy as co-products
Algae applications could:

• Increase aquaculture production 3 to 4-fold
• Reduce fish production costs $0.05-0.10/lb
• Reduce N, P discharge from agriculture and municipal waste streams
• Provide higher-value industrial chemicals, nutraceuticals, pharmaceuticals
• Algae on ~ 5 million acres of desert yielding protein and oil equal to 60 million acres of soybeans
• Avoid 20-30% of GHG from gas-fired power-plant
Algae not likely;

- Algae NOT carbon sequestration; carbon avoidance only
- GHG reduction potential NOT significant for base-load coal-fired power-plant
- Algal liquid-fuel likely not cost effective primary application

**Algae PP-CO$_2$ capture potential** *

- <10% favorable location
- <10% have 10,000 ha for algae
- ~10% of CO$_2$ could be captured
- Cumulative CO$_2$ capture < 0.1%

* (Benemann 2011)
We’ll likely **NOT** be successful promoting system designs focused primarily on production of biofuels, bioenergy, or sustainability

….. given current economic constraints
PROPOSED APPROACH; Developing a Transitional Agriculture

We must cultivate knowledge and techniques supporting capability and capacity to:

• Integrated systems providing nutrient recycle
• Maximize resource use and energy efficiency
• Target environmental remediation and recovery
• Cost effective within current FF economy
• With potential to transition to solar-based production
Algae-powered cars: Science fiction or science?

Say algae, and most people think of those unpleasant green organisms found in swimming pools and fish tanks. But to the scientists and engineers of ExxonMobil, algae conjure something far more appealing: Opportunity. Why? Because algae can create renewable energy while absorbing CO₂.

The energy from algae might someday produce biofuels that are compatible with those made from conventional crude oil. That's why ExxonMobil is committed to a major long-term research and development program aimed at developing algae as a viable fuel source. Unlike other biofuel sources such as corn and sugar cane, algae do not compete with our food supply. And because they consume CO₂, algae could help reduce greenhouse gases.

ExxonMobil is partnering with Synthetic Genomics Inc., pioneers in biotechnology, on this groundbreaking research effort. Our goal is to produce biofuels from algae in the future to supplement the fuels we use in our vehicles today, while visions. Algae have never looked so inviting.