Introduction: Early Algal Studies

After World War II, there was a high level of interest in using algal systems in bioregenerative designs. Much of this interest was stimulated by the development of the space program where algae were being examined for use in bioregenerative life support systems. Algae strongly influence gas dynamics through photosynthesis, absorbing and releasing CO₂ and O₂ through their metabolism. A variety of laboratory studies with algal bioregenerative systems undertaken that demonstrated high and efficient levels of photosynthesis under artificial light conditions. In some cases the magnitudes of photosynthesis were higher than found in nature, which lead some researchers to imagine that algae might provide an important source of food for humans.

Fallacy and H.T. Odum

At the same time that the early algal studies were being undertaken, H.T. Odum was developing field techniques and making measurements of primary productivity (photosynthesis) at the scale of the ecosystem in a number of different systems. When he learned of the lab studies he became alarmed at the projection of algal yields that were far beyond those found in the terrestrial food production (Fisher 1961). Odum called the projections “fanciful dreams” and he exclaimed:

“...a cruel illusion was proffered by laboratory scientists and writers who proposed that we could feed the world on algae which they implied were productive per unit energy input) than energy-subsidized grain agriculture. Despite the high yields reported...”

To evaluate some of the fallacy with the lab projects, H.T. Odum was developing field observations in the late 1950s while still in his laboratory experiments, as later shown by Odum.

H.T. Odum’s Early Energy Calculation

In Odum’s original energy analysis he used a literature reference that included some economic cost values of a potential algal pilot plant experiment (Fisher 1961). He converted these dollar costs into energy by multiplying by an energy-to-dollar ratio (10,000 Cal of fossil fuel/$ spent) in order to quantify the energy subsidy. He then compared the algal system to other agricultural systems, with reference to energy subsidy vs. yield.

We re-evaluated Odum’s original analysis with more recent approaches of energy analysis (Odum 1996) as shown in the accompanying energy circuit diagram, tables and footnotes. The total energy input to the algal pilot plant was $4.8 x 10^{12}$ sej/day and the dominant inputs were from labor and materials/infrastructure. Based on the projected yield of the plant, the transformity of algae was $4.3 x 10^5$ sej/J.

Transformity (T) = \( \frac{\text{energy output}}{\text{energy input}} \)

Transformity calculations

<table>
<thead>
<tr>
<th>Note</th>
<th>Item</th>
<th>Data</th>
<th>Units</th>
<th>Energy (sej)</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Solar Insolation</td>
<td>1424</td>
<td>kcal/m²-yr</td>
<td>6.1 x 10^10</td>
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<tr>
<td>2</td>
<td>Minerals/Infrastructure</td>
<td>1.257</td>
<td>$/m²-yr</td>
<td>1.9 x 10^13</td>
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<tr>
<td>3</td>
<td>Labor</td>
<td>1.46</td>
<td>$/m²-yr</td>
<td>1.5 x 10^13</td>
<td>35.27%</td>
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<tr>
<td>4</td>
<td>Lighting Supplies</td>
<td>0.325</td>
<td>$/m²-yr</td>
<td>5.13 x 10^12</td>
<td>11.45%</td>
</tr>
</tbody>
</table>

Total (sej/m²-yr) = 4.6E+13

Transformity (sej/J) = 4.3 x 10^5

Conclusions

H.T. Odum’s original energy analysis of an algal pilot plant is historically important. It represents one of the first examples of energy analysis, which was later described as a new scientific discipline. Odum’s analyses quantified the magnitude of energy subsidies to a biomass yield system that had previously been ignored in assessments of the system. The analyses also exposed some incorrect thinking about the performance of the system that could have lead to inappropriate policy advocating algal agriculture.

In fact, algal systems for food production have never developed, perhaps for the reasons Odum studied. However, wastewater treatment applications are being studied that have potential for economic development. One benefit of systems such as the algal turf scrubber is that they have byproducts of both clean water and algal biomass. Interestingly, both of these byproducts have similar transformities as calculated for the USDA system shown above (4.3 x 10^5 sej/J for clean water and 5.36 x 10^5 for algal biomass).

Comparison of Analyses

We evaluated three experimental studies of algal turf scrubbers with energy analysis. Overview energy diagrams were developed for systems with artificial lighting and sunlight at the University of Maryland at College Park (UMCP) and one at USDA agricultural research lab in Beltsville, Maryland, which also utilizes artificial lighting. Transformities for algal biomass are shown in the chart. Odum’s original analysis of the algal pilot plant was conducted before the system was not designed for wastewater treatment. All of the algal turf scrubber transformities are similar, demonstrating the interesting result that transformity is not qualitatively affected by the use of ambient light sources (sunlight vs. artificial lighting with electrical lamps).

References


Madison, Wisconsin.


