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Algae Production from Wastewater Resources: An Engineering and Cost Analysis

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Environmental Sciences Division

Algae Production from Wastewater Resources: An Engineering and Cost Analysis

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ABSTRACT

Co-locating algae cultivation ponds near municipal wastewater (MWW) facilities provides the opportunity to make use of the nitrogen and phosphorus compounds in the wastewater as nutrient sources for the algae. This use potentially benefits MWW facilities, the algae biomass and biofuel or bioproduct industry, and the users of streams where wastewater would be discharged. Nutrient compounds can lead to eutrophication, hypoxia, and adverse effects to some organisms if released downstream. This analysis presents an estimate of the cost savings made possible to cultivation facilities by using the nutrients from wastewater for algae growth rather than purchase of the nutrients. The analysis takes into consideration the cost of pipe transport from the wastewater facility to the algae ponds, a cost factor that has not been publicly documented in the past. The results show that the savings in nutrient costs can support a wastewater transport distance up to 10 miles for a 1000-acre-pond facility, with potential adjustments for different operating assumptions.

1. INTRODUCTION

Microalgae are a potential source of liquid biofuels and bioproducts, but production of algae is costly. As discussed by Lundquist, Benemann and others [1][2][3][4], one of the advantages of co-locating algae cultivation ponds near municipal wastewater (MWW) facilities is the opportunity to make use of the nitrogen and phosphorus compounds in the wastewater to feed the algae. This co-location can provide benefits to algae production, wastewater treatment, and downstream stakeholders, as compounds in the wastewater can be directly toxic to organisms downstream or can lead to hypoxia [5][6], but they can serve as nutrients to the algae in cultivation facilities [7].

This analysis presents an estimate of the cost savings made possible by using the nutrients from wastewater for algae growth, compared to the purchase of nutrients. The analysis takes into consideration the cost of pipe transport from the wastewater facility to the algae ponds, a topic previously undocumented in scientific literature [8]. Additional benefits, such as carbon removal [9], are excluded from the analysis. Some previous studies of the topic of co-location assume that the wastewater treatment and biofuel generation are at the same site [9].

2. ANALYSIS

2.1 SYSTEM DESCRIPTION

Figure 1 is a simple depiction of the system analyzed. All preprocessing of the wastewater takes place prior to transport to the algae ponds. The transport system consists of pipeline and hydraulic pump. Electric power for the pump is provided at the origin.

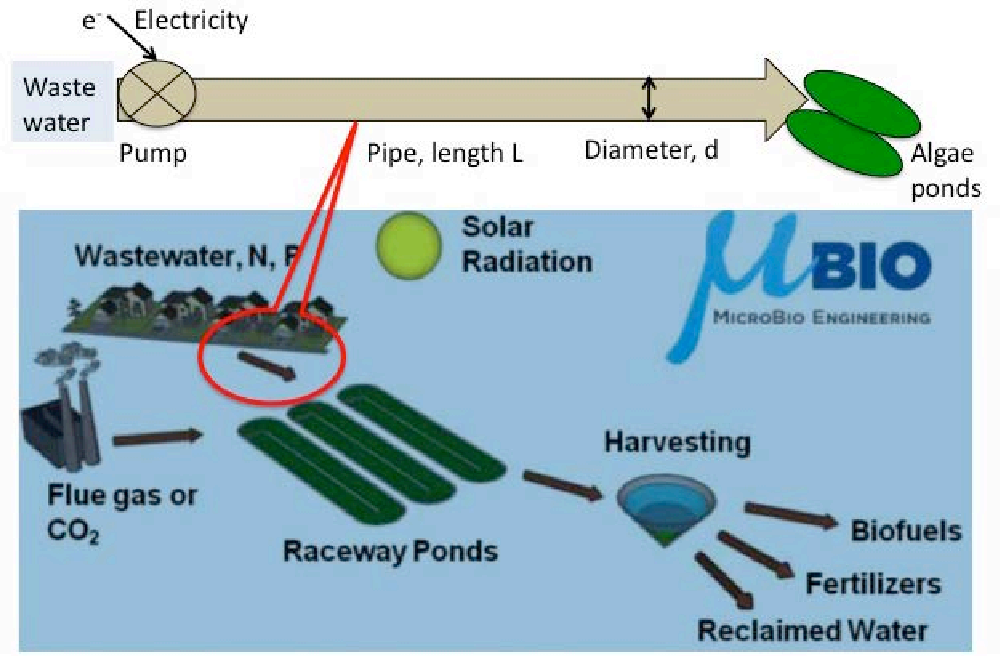

Figure 1. Simple depiction of a wastewater transport system for an open-pond algae production system, based on a MicroBio Engineering approach [10]. Used with permission from Microbio Engineering, Inc.

Basic assumptions for the size of the system are based primarily on the United States Department of Energy-supported research of Lundquist, Benemann and colleagues [11]. To take advantage of economies of scale, these authors assume a relatively large facility consisting of 1000 acres of algae ponds making use of 14 million gallons per day of wastewater influent. This volume of wastewater represents the typical effluent from a population of 80,000 people [12]. The algae system assumptions for this study are listed in Table 1.

Table 1. Algae system assumptions used in the engineering and cost analysis for wastewater transport to an open-pond algae cultivation system.

Parameter	Value	Units
Algae pond size	1000	acres
Algae productivity	33	g/m2/day
Influent flow	14 million	gallons/day

2.2 ENGINEERING METHODOLOGY

Conventional fluid flow equations for pipes [13] are used to size the pipeline diameter. Conventional pump hydraulic equations are used to size the pump and motor and to calculate energy (electricity) [14] requirements.

Similar to results of an analysis of gas flow of CO_2-containing gases co-located with algae cultivation [15][16], a driving parameter of cost and cost-effective distance is the diameter of the pipe. The larger the diameter, the more expensive is the pipe, but the lower the pressure drop along the pipe. This larger diameter results in a lower-power pumping requirement than for a narrower pipe. An example is shown in Figure 2. Although the capital cost can be minimized for this example by selecting an intermediate pipe diameter, all cases in this analysis use a relatively larger steel pipe to minimize the pump size and energy requirement, at the expense of purchasing a larger pipe. Minimizing the electricity requirement to operate the pump also minimizes greenhouse gas emissions in a life-cycle analysis (LCA). Pipe diameters range from 25 to 30 inches, as the pipe length ranges from 1 to 10 miles. The efficiency of the combined pump/motor is assumed to be 63% [13].

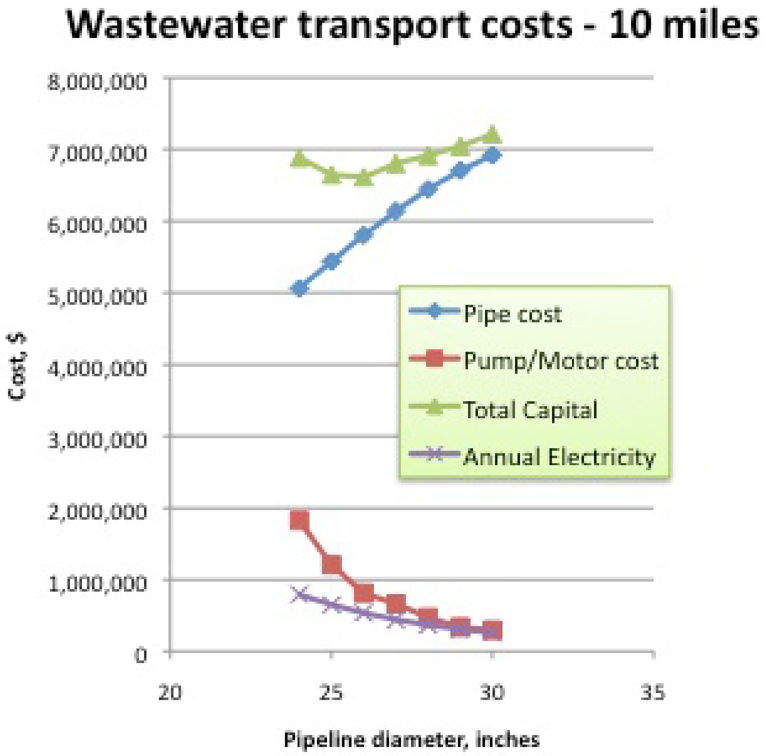

Figure 2. The tradeoff between cost of pipe and cost of pump/motor and electricity for a 10-mile transport system depends on diameter of pipeline.

2.3 ECONOMIC ANALYSIS

The capital cost of the pipe and pump/motor are estimated from engineering handbooks [17]. Electricity to operate the pump is calculated at 8 cents/kWh, as in the related CO_2 transport analysis [15].

The cost of the pipeline system is compared with the avoided cost of purchased nutrients N and P, from anhydrous ammonia (NH_3) and diammonium phosphate (DAP), respectively. The cost of the nutrients is derived from estimates in Davis et al. [18] for large-scale algae production. Davis et al. assumed a productivity value for the algae of 25 g/m^2/day, whereas Lundquist et al. assumed a high value of 33 g/m2/day [11]. The nutrient requirements were adjusted accordingly for this analysis. Under these assumptions, the annual cost of nutrients is $1.15 million dollars.

This analysis does not assume any return of nutrients to the ponds following downstream processing, which may be possible [11] and would reduce the annual nutrient requirements, and piping or purchased nutrients.

Annual costs for operation of the transport system, compared with the cost of nutrients, are considered for a 30-year system lifetime. This lifetime is typically assumed for capital-intensive projects, such as wastewater facilities. Cost assumptions are listed in Table 2.

Table 2. Cost and Economic Assumptions

Parameter	Value/Units	Reference
Pipe cost	$430/m for 30-inch pipe	[17] adjusted to 2017 dollars
Electricity	8 cents/kWh	
NH_3	0.1908 $/kg	[18] adjusted to 2017 dollars
DAP	0.1557 $/kg	[18] adjusted to 2017 dollars
Capital charge	10%/year	

3. RESULTS

The results of the analysis are presented as savings for building the pipeline, compared with the avoided cost of nutrients. Figure 3 indicates these savings for the Lundquist base case [11] for pipeline distance up to 10 miles. Beyond 10 miles, the savings are minimal.

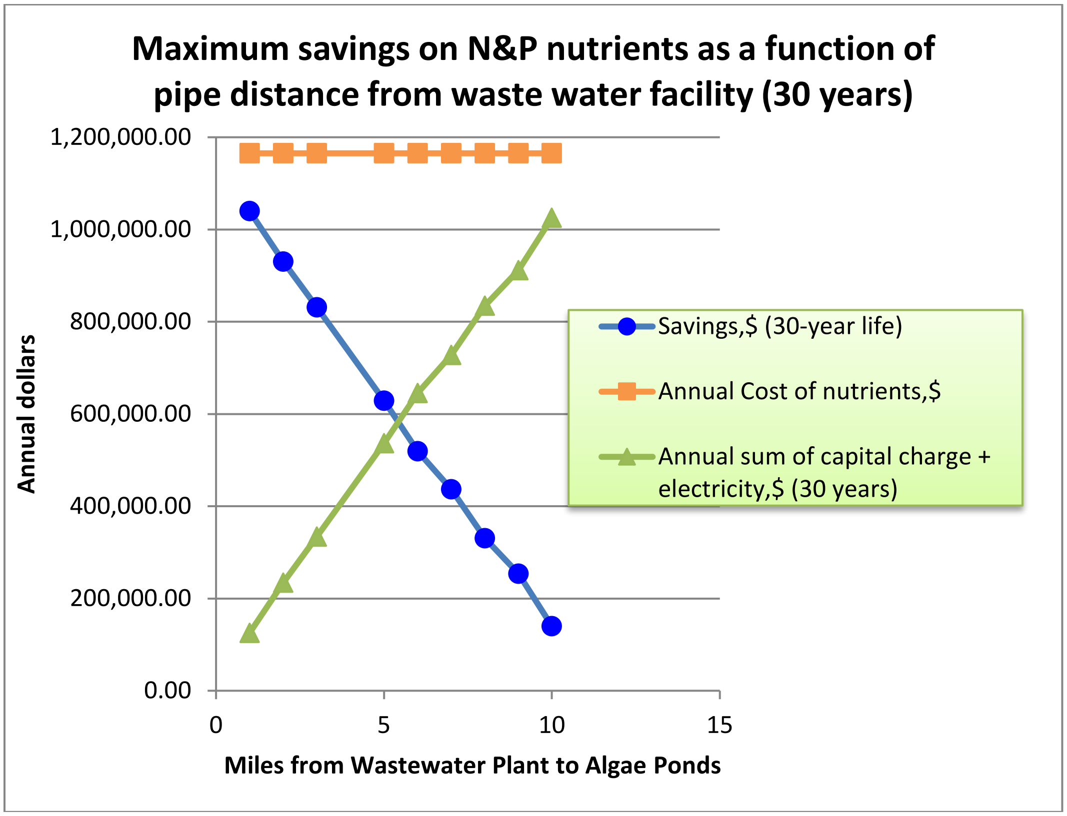

Figure 3. Savings results for using replacing purchased nutrients with municipal wastewater for a 30-year system

A sensitivity comparison was also calculated to compare the 30-year lifetime with a 20-year lifetime, as the lifetime of the algae pond is not well established. This comparison is shown in Figure 4. Although the savings for the shorter-lived system are lower, the difference between the savings for different lifetime assumptions is small. The cost of electricity dominates the annual cost in either case.

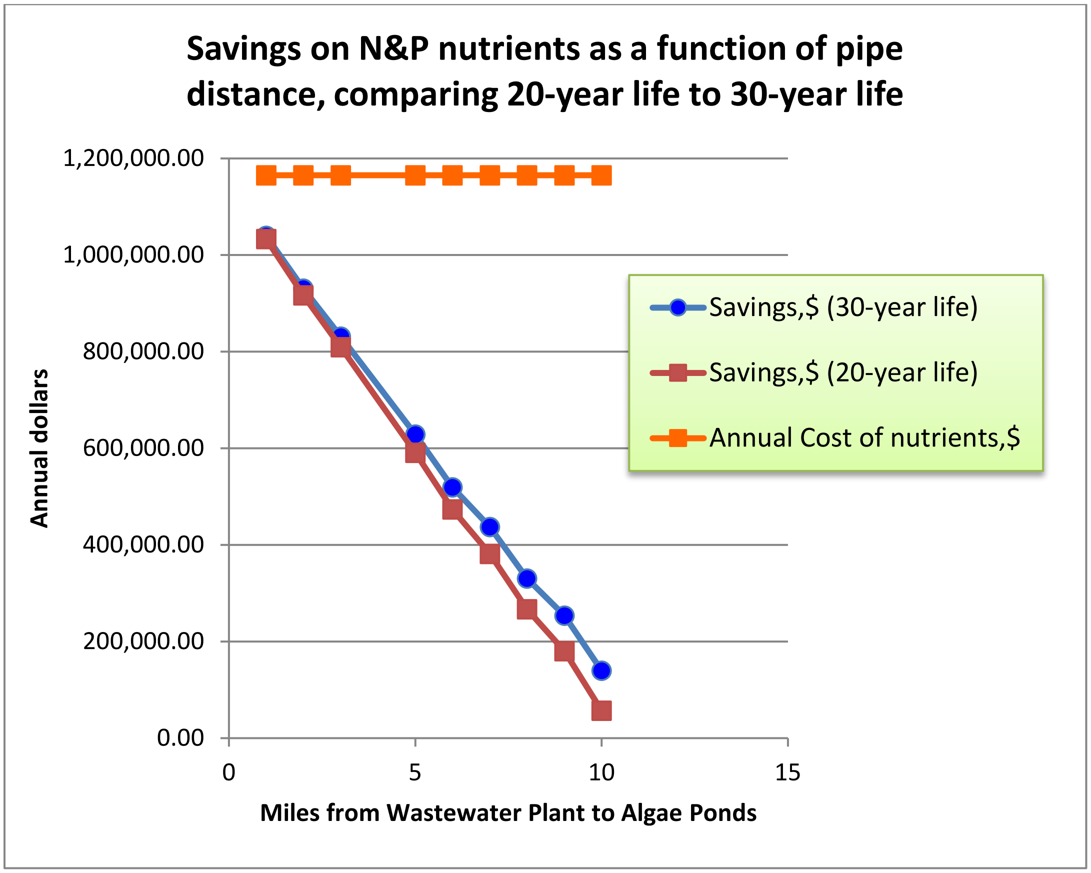

Figure 4. Cost comparison between 20-year system and 30-year system that replaces purchased nutrients with municipal wastewater as a source of nutrients for open-pond algae production.

4. DISCUSSION

Cost savings are needed before commercial production of algae for fuel and other bioproducts is economically viable. Savings of over $1 million dollars per year on the purchase of nitrogen and phosphorus compounds are possible for 1000-acre algae open-pond cultivation systems that make use of MWW to provide these nutrients. Under our assumptions, this savings occurs at a distance of one mile or less between the wastewater plant and the algae facility. This cost savings offsets the cost of the pipeline system that transports the wastewater to the ponds. The greater the distance is between the wastewater and the algae ponds, the lower are these savings.

Compared to the overall cost (capital and operating expenses) of the algae facility, this is a small savings. Compared to the annual operating cost of approximately $9 million dollars for the 1000 acres of cultivation ponds [Ref 11, page 40], the use of N and P from MWW is significant and important for reducing the cost of the algae bioproducts.

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