An Economic Assessment of Algal Turf Scrubber Technology for Treatment of Dairy Manure Effluent

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OBJECTIVE

The purpose of this study is to assess the economics of algal turf scrubber technology at the farm scale for a hypothetical 1000-cow dairy.

INTRODUCTION

Dairies and other livestock operations release significant amounts of nutrients to the watersheds in which they are located. Most of the waste from these domestic animal operations is applied as fertilizer to croplands, substantial portions of which run off the land or seep into the shallow groundwater. For example, recent estimates suggest that animal waste contributes 18% of the nitrogen and 25% of the phosphorus inputs to the eutrophic Chesapeake Bay.

The purpose of economic analysis in engineering is to evaluate costs and benefits of alternatives, especially critical in ecological engineering since new ecotechnologies are being suggested as substitutes for old, conventional alternatives. **For a new ecotechnology to be adopted and applied, the cost-benefit ratio should be favorable.**

ALGAL TURF SCRUBBERS

An alternative to land spreading of animal manure is to grow crops of algae on the nutrients present in the wastewater and convert the nutrients into algal biomass. **Algal turf scrubbers are a new technology for treating wastewater** that utilize multispecies assemblages dominated by benthic, filamentous algal taxa. The system consists of an attached algal community growing on screens in a trough through which polluted water flows. The living community provides the water treatment by uptake of inorganic compounds in primary production.

Figure 1: Laboratory-scale algal turf scrubber. Recycled effluent is continuously pumped into a wave surge bucket from a plastic drum below . The bucket fills and tips every 15 s. The effluent washes over the turf screen before draining into the drum below to be recycled. Water depth over the screen is 1–2 cm. Metal halide lamps are located approximately 42 cm above the growing turf.

Many pollutants are taken up in algal biomass and are removed from the system through harvest. Harvesting is particularly important since this action rejuvenates the community and leads to high growth rates. The harvested material can be processed into a useful byproduct such as a fertilizer or feed, if pollutants are not toxic.

Figure 2. Pilot-scale ATS raceways at the Beltsville Dairy Research Unit.

ANALYTICAL DESIGN

The economic potential of algal turf scrubbers as an alternative for manure wastewater treatment was evaluated by constructing an economic analysis of a hypothetical 1000-animal dairy operation. The proposed treatment system (Figures 3 and 4) is designed on the basis of operations at the Dairy Research Unit of the USDA/ARS Facility in Beltsville, Maryland (Figures 1 and 2). Manure effluent is treated with a large algal turf scrubber and the algal biomass is harvested and dried. All of the unit processes have been evaluated in the Animal Manure and Byproducts Lab at USDA/ARS or at a field scale, commercially-operated algal turf scurbber in south Florida that treats agricultural runoff waters.

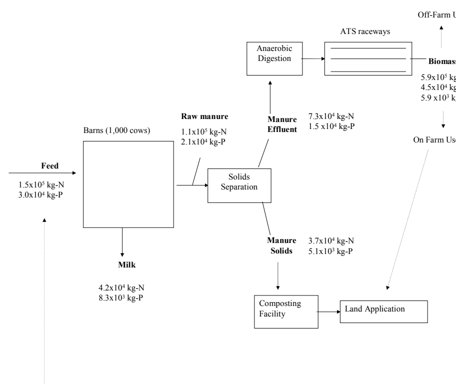

Figure 3. Schematic diagram of nutrient flow in the proposed treatment system. Manure from dairy cows in free-stall barns is mechanically scraped (or flushed with water) and the resultant manure slurry is subjected to a solids separation step prior to treatment of the solids by composting and treatment of the effluent by anaerobic digestion and algal scrubbing. Biomass from the algal scrubbers is either recycled back into farm operations (as a feed supplement or fertilizer) or exported from the farm.

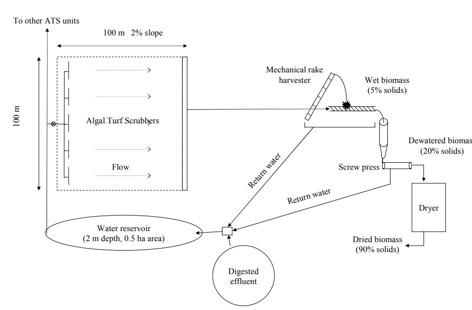

Figure 4. Schematic diagram of 1 ha ATS unit with associated equipment and water reservoir. Manure effluent is added continuously to equalization reservoir. Algal biomass is harvested weekly, removed from ATS effluent using a mechanical rake, dewatered with a screw press, and dried using a drum drier. A 1000-animal farm scale system would be composed of eleven 1-ha ATS units that would share a reservoir and the harvesting, dewatering, and drying equipment.

CONCLUSIONS

For perspective, the cost of manure treatment must be compared with the profits from dairy operations. Long-term annual profits for dairy farmers in Maryland average about $500/cow.

- **Costs of waste treatment projected in this study for an algal turf scrubber system are very high and would consume most of the profit ($463/cow for a system with anaerobic digestion pretreatment) or exceed profit ($631/cow for a system without pretreatment).**
- **The economic balance becomes more favorable if values from algae as a byproduct (e.g., fertilizer sale) can be realized or if a nutrient trading credit system can be devised.**

ECONOMIC ANALYSIS

Estimated capital and annual operational costs for the proposed treatment system are shown in Tables 1 and 2. Costs are shown for a system without and with anaerobic pretreatment. Results show that:

- **The majority of the capital costs were due to land preparation, installation of liner material, and engineering fees (Table 1).**
- **The majority of operational costs were due to energy requirements for biomass drying, pumping water, and repayment of capital investment (Table 2).**
- **Under the best case (algal system coupled with anaerobic digestion pretreatment), the yearly operational costs were $463 per cow, $6.40 per kg of N removed, $31.70 per kg of P removed, and $0.78 per kg of dried biomass produced.**

Table 1. Capital cost estimates for manure effluent treatment system for 1000 cows.

<table>
<tr><th></th><th>No pre-treatment</th><th>Pre-treatment with anaerobic digestor</th></tr>
<tr><td>Site preparation, grading, compaction ($34,000/ha) [1]</td><td colspan="2">374,000</td></tr>
<tr><td>HDPE liner and installation costs ($33,000/ha) [1]</td><td colspan="2">363,000</td></tr>
<tr><td>Pump [2]</td><td colspan="2">93,000</td></tr>
<tr><td>Carbon dioxide sumps, diffusers ($4,000/ha) [3]</td><td colspan="2">44,000</td></tr>
<tr><td>Roads, drainage ($7,000/ha) [1]</td><td colspan="2">77,000</td></tr>
<tr><td>Electrical supply and distribution ($3,000/ha) [1]</td><td colspan="2">33,000</td></tr>
<tr><td>Instrumentation and machinery ($500/ha) [3]</td><td colspan="2">5,500</td></tr>
<tr><td>Land cost ($3500/ha) [1]</td><td colspan="2">38,500</td></tr>
<tr><td>ATS Screen ($6090/ha) [1]</td><td colspan="2">67,000</td></tr>
<tr><td>Algal harvester [1]</td><td colspan="2">85,000</td></tr>
<tr><td>Mechanical dewatering to 20% solids [4]</td><td colspan="2">35,000</td></tr>
<tr><td>Algal drier [5]</td><td colspan="2">135,000</td></tr>
<tr><td>SUBTOTAL</td><td colspan="2">1,350,000</td></tr>
<tr><td>Engineering & Contingencies (15% of subtotal cost) [3]</td><td colspan="2">202,500</td></tr>
<tr><td>Total Direct Capital</td><td colspan="2">1,552,600</td></tr>
<tr><td>Working Capital (25% of net operating cost) [3]</td><td>123,000</td><td>81,900</td></tr>
<tr><td>TOTAL CAPITAL INVESTMENT</td><td>1,675,600</td><td>1,634,500</td></tr>
</table>

[1]Values provided by Hydromentia, Inc based on a proposed 11 ha 50 mgd treatment facility for agricultural wastewater.
[2]Value based on a single 50 mgd pump for the 11 ha treatment area.
[3] (Benemann and Oswald, 1996)
[4]FAN screw press (www.fsaconsulting.net/pdfs)
[5]Drum drier with capacity of 9000 kg/day (at 5% solids) to yield biomass at 90% solids

Table 2. Annual operational cost estimates for manure effluent treatment system.

<table>
<tr><th></th><th>No pre-treatment</th><th>Pre-treatment with anaerobic digestor</th></tr>
<tr><td>Power for mixing [1]</td><td colspan="2">165,500</td></tr>
<tr><td>Power for harvesting and dewatering [2]</td><td colspan="2">13,200</td></tr>
<tr><td>Power for drying [3]</td><td>173,300</td><td>8,800</td></tr>
<tr><td>Labor and Overheads [4]</td><td colspan="2">62,400</td></tr>
<tr><td>Maintenance, Taxes, Insurance [5]</td><td colspan="2">77,600</td></tr>
<tr><td>Total Net Operating Cost</td><td>492,000</td><td>327,500</td></tr>
<tr><td>Capital Charge [6]</td><td>139,100</td><td>135,700</td></tr>
<tr><td>Total Annual Costs</td><td>631,100</td><td>463,200</td></tr>
<tr><td>Cost per cow if biomass is dried [7]</td><td>631</td><td>463</td></tr>
<tr><td>Cost per cow if biomass is not dried [8]</td><td>458</td><td>454</td></tr>
<tr><td>Cost per kg N if biomass is dried [9]</td><td>8.70</td><td>6.40</td></tr>
<tr><td>Cost per kg P if biomass is dried [10]</td><td>43.20</td><td>31.70</td></tr>
<tr><td>Cost per kg N if biomass is not dried [11]</td><td>6.30</td><td>6.20</td></tr>
<tr><td>Cost per kg P if biomass is not dried [12]</td><td>42.00</td><td>30.20</td></tr>
<tr><td>Cost per kg of dried algae [13]</td><td>1.06</td><td>0.78</td></tr>
</table>

[1]Electricity cost for 50 mgd pump for 270 days (assuming $0.06 per kWh)
[2]Electricity cost for mechanical rake harvester and FAN screw press.
[3] Electricity cost to remove 7000 kg d^{-1} water from 11,000 kg d^{-1} wet biomass for 270 days assuming energy consumption of 1.389 kWh/kg H_2O at 46% thermal efficiency.
[4] Estimate for two full-time equipment operators at $15 h^{-1}.
[5] Calculated as 5% of total direct capital cost (Benemann and Oswald, 1996)
[6] Calculated as 8.3% of total capital investment
[7]Total annual cost divided by 1,000 cows
[8]Total annual cost minus the cost of power for drying divided by 1,000 cows
[9]Total annual cost divided by 73,000 kg N from 1,000 cows
[10]Total annual cost divided by 14,600 kg P from 1,000 cows
[11] Total annual cost minus the cost of power for drying divided by 73,000 kg N
[12]Total annual cost minus the cost of power for drying divided by 14,600 kg P
[13]Based on 594,000 kg algal biomass produced during 270 days