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Environmental and economic assessment of integrated systems for dairy manure treatment coupled with algae bioenergy production

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HIGHLIGHTS

- ▶ Life cycle assessment (LCA), costing (LCC) of four dairy manure management options.
- ▶ Reference (REF) exhibits net energy consumption, negative net present value (NPV).
- ▶ Digestion with/without algae cultivation yields net energy production, positive NPV.
- ▶ Nutrient credits are critical to financial tenability of LCA-preferred options.

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ABSTRACT

Life cycle assessment (LCA) and life cycle costing (LCC) are used to investigate integrated algae bioenergy production and nutrient management on small dairy farms. Four cases are considered: a reference land-application scenario (REF), anaerobic digestion with land-application of liquid digestate (AD), and anaerobic digestion with recycling of liquid digestate to either an open-pond algae cultivation system (OPS) or an algae turf scrubber (ATS). LCA indicates that all three "improved" scenarios (AD, OPS, and ATS) are environmentally favorable compared to REF, exhibiting increases in net energy output up to 854 GJ/yr, reductions in net eutrophication potential up to 2700 kg PO_4-eq/yr, and reductions in global warming potential up to 196 Mg CO_2-eq/yr. LCC reveals that the integrated algae systems are much more financially attractive than either AD or REF, whereby net present values (NPV) are as follows: $853,250 for OPS, $790,280 for ATS, −$62,279 for REF, and −$211,126 for AD. However, these results are highly dependent on the sale price for nutrient credits. Comparison of LCA and LCC results indicates that robust nutrient credit markets or other policy tools are required to align financial and environmental preferability of energy production systems and foster widespread adoption of sustainable nutrient management systems.

1. Introduction

Algae are increasingly considered a promising feedstock for bioenergy production, because they are highly productive, can be grown on marginal land in fresh, brackish, or even saline water, and they do not directly compete with food production (Benemann and Oswald, 1996). Despite this, there are significant environmental and financial challenges that must be overcome before algae cultivation and conversion can be made sustainable (Clarens et al., 2010; Lundquist et al., 2010). One particularly important challenge is procurement of low cost, low energy-intensiveness nutrients, most notably nitrogen (N) and phosphorus (P). It has been demonstrated that nutrient procurement is one of the most energy intensive processes and can constitute up to 50% of energy consumption during algae cultivation when fertilizers are used (Clarens et al., 2010; Stephenson et al., 2010). On the other hand, nutrient-rich wastes from animal agriculture pose significant environmental challenges such as regional eutrophication and global warming potential. As an example, water quality impairment in the Chesapeake Bay (the largest estuary in the United State) has been partially attributed to excess runoff and discharge of nutrients from farms, of which 18% of N and 25% of P arises from animal wastes (Chesapeake Bay Foundation, 2004). Animal waste is also an increasing source of greenhouse gas (GHG) emissions, including methane (CH_4) and nitrous oxide (N_2O). The US Environmental Protection Agency (EPA) estimates that GHG emissions from

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