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Evaluating the Economic and Environmental Feasibility of Electrochemical Nutrient and Energy Recovery from Municipal Wastewater

DIVISION OF AGRICULTURE RESEARCH & EXTENSION University of Arkansas System

Center for Agricultural and Rural Sustainability

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INTRODUCTION

Nutrient recovery in domestic wastewater treatment plants (WWTP) has increasingly become an important area of study as the supply of non-renewable phosphorus decreases. Recent bench-scale trials indicate that co-generation of struvite and hydrogen using electrochemical methods may offer an alternative to existing recovery options utilized by municipal wastewater treatment facilities (1-3). However, implementation has yet to be explored at plant-scale. In the development of novel nutrient recovery processes, both economic and environmental assessments are necessary to guide research and their design. The aim of this study was to conduct a prospective life cycle assessment and cost analysis of a new electrochemical struvite recovery technology that utilizes a sacrificial magnesium anode to precipitate struvite and generate hydrogen gas. The P-Street WWTP in Fort Smith, AR was used as a case study.

METHODS

Wastewater treatment software, GPS-X (V.8.1) and Capdet Works (v.4) by Hydromantis were used to construct the process simulation modeling and the economic estimation, respectively, under ten scenarios. Scenario B1 is a base case scenario that represents "business-as-usual" operation of the WWTP. Scenarios B2-45 and B2-90 add a struvite recovery step using an assumed struvite yield (fraction of theoretical yield) of 45% and 90% for B2-45 and B2-90, respectively. A 45% yield is assumed as a current performance yield of the bench-scale technology where as a yield of 90% represents a theoretical "best case scenario". B3-45 and B3-90 are similar to the B2 scenarios with the addition of H2 capture. The A scenarios are similar to their respective B scenarios, but all include an anaerobic digester.

Costs for non-standard processes (i.e., struvite recovery, hydrogen capture, and biogas utilization) were derived from available literature and GPS-X simulation outputs. Capital costs were annualized and combined with operating costs to determine the total project cost for each scenario. Estimated revenues stemming from the sale of struvite fertilizers and hydrogen gas were subtracted from the total costs to determine the expected net costs per m3 of wastewater treated. Capital and input costs for struvite recovery and hydrogen capture were used to estimate break-even prices per kg of struvite and hydrogen gas produced.

SimaPro (v.9.1) by Pre-Consultants was used to conduct the life cycle inventory and impact assessment for six commonly examined Life Cycle Impact Assessment categories. Due to poster space constraints, details on the methods associated with plant construction, scenario development, and economic and environmental assessments can be found in Morrissey et al., 2022 (4).

RESULTS

FIGURE 1: LCIA results for wastewater treatment scenarios (IMPACT World +)

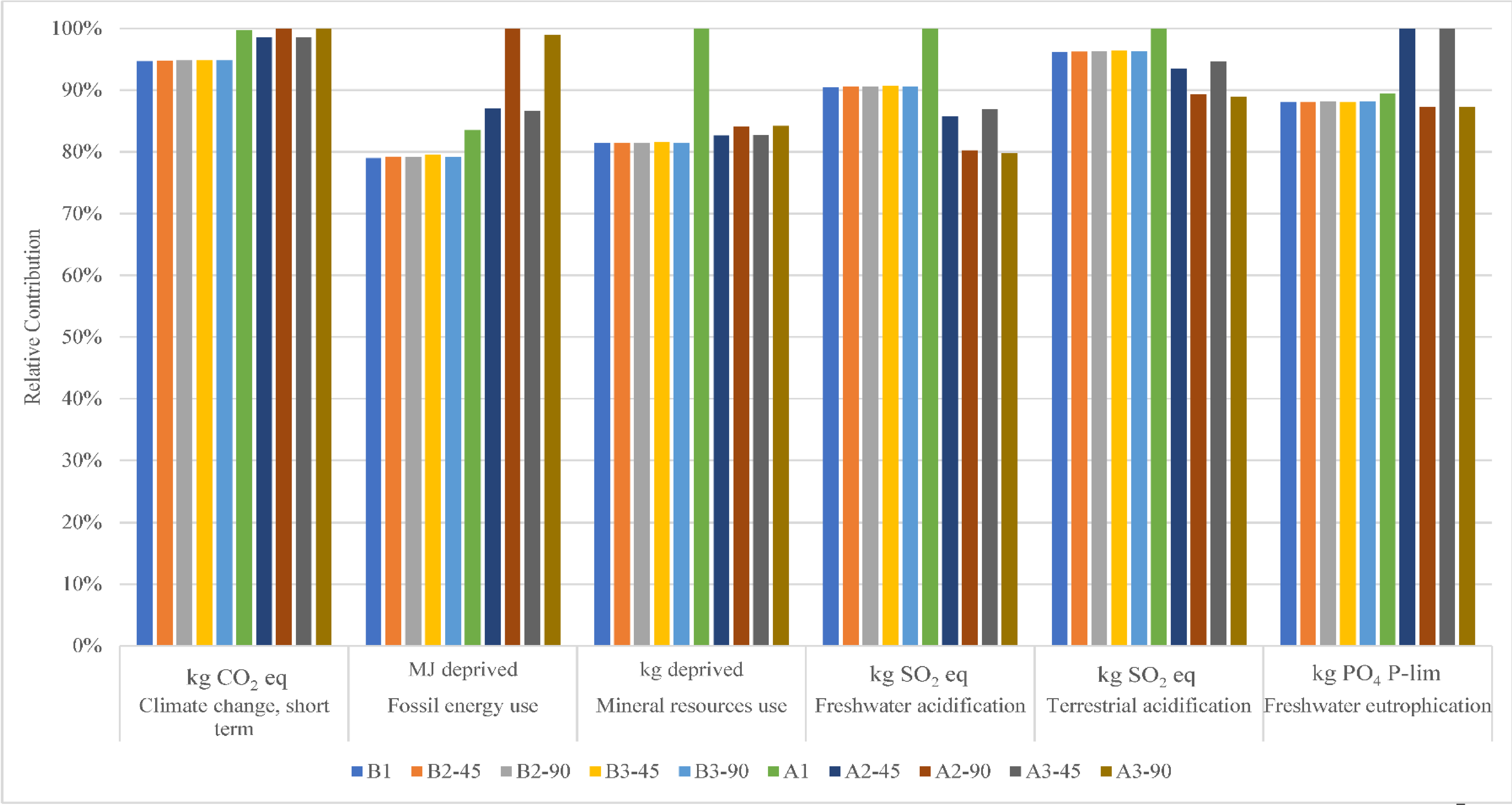

TABLE 1: Annualized cost and revenue streams

	B1	B2-45	B2-90	B3-45	B3-90	A1	A2-45	A2-90	A3-45	A3-90
Capital Costs										
Standard Processes	$3,688,420	$3,688,420	$3,688,420	$3,688,420	$3,688,420	$3,785,057	$3,607,614	$3,605,763	$3,605,787	$3,604,067
Sludge Management	$60,357	$60,357	$60,357	$60,357	$60,357	$46,189	$44,797	$44,797	$44,797	$44,797
Anaerobic Digestion	$0	$0	$0	$0	$0	$144,679	$124,041	$124,041	$124,041	$124,041
ECST Reactor	$0	$11	$21	$11	$21	$0	$307,108	$554,500	$307,108	$554,500
H_2 Compression	$0	$0	$0	$119	$162	$0	$0	$0	$13,401	$17,590
H_2 Storage	$0	$0	$0	$0	$1	$0	$0	$0	$11,114	$20,066
Total Capital Cost	**$3,748,777**	**$3,748,788**	**$3,748,798**	**$3,748,907**	**$3,748,961**	**$3,975,925**	**$4,083,560**	**$4,329,101**	**$4,106,248**	**$4,365,062**
Operational Costs										
O&M	$485,400	$485,402	$485,403	$485,447	$485,465	$540,000	$560,570	$599,696	$565,684	$606,408
Materials	$598,063	$598,596	$599,483	$598,596	$599,483	$530,248	$493,634	$482,719	$495,763	$485,559
Chemicals	$141,000	$141,016	$141,031	$141,016	$141,031	$317,015	$598,327	$968,341	$598,327	$968,341
Energy	$202,720	$204,248	$203,786	$204,248	$203,786	$171,036	$212,991	$240,074	$213,828	$241,583
Total Op Cost	**$1,427,183**	**$1,429,261**	**$1,429,704**	**$1,429,306**	**$1,429,766**	**$1,558,299**	**$1,865,522**	**$2,290,829**	**$1,873,603**	**$2,301,891**
Potential Revenues										
Struvite Fertilizer [a]	$0	$6	$11	$6	$11	$0	$163,627	$295,438	$163,627	$295,438
H_2 Gas [b]	$0	$0	$0	$0	$1	$0	$0	$0	$12,624	$22,793
Total Revenue	**$0**	**$6**	**$11**	**$6**	**$12**	**$0**	**$163,627**	**$295,438**	**$176,251**	**$318,230**
Net Cost										
$/yr	$5,175,960	$5,178,043	$5,178,491	$5,178,207	$5,178,715	$5,534,224	$5,785,455	$6,324,493	$5,803,600	$6,348,722
$/m³	**$0.31**	**$0.31**	**$0.31**	**$0.31**	**$0.31**	**$0.33**	**$0.35**	**$0.38**	**$0.35**	**$0.38**

[a] Struvite sold at $1.15 per kg (the June 2022 price of diammonium phosphate).
[b] Hydrogen gas sold at $8.00 per kg (the gasoline equivalent of $3.20 per gallon).

DISCUSSION

LCIA results (presented in Figure 1) show that B scenarios had lower relative impacts compared to A scenarios for photochemical oxidant formation, particulate matter formation, short and long-term climate change, fossil energy use, and mineral resources use. For land occupation-biodiversity and human toxicity cancer, this trend is similar with the exception that the A1 scenario has the lowest environmental impacts overall. The B scenarios have higher relative impacts in the categories of water scarcity and human toxicity non-cancer.

Table 1 shows costs and potential revenues for each scenario. Although costs across the B scenarios remained constant, very little struvite or H2 was recovered. Although adding anaerobic digestion improved recovery potential, the costs were not offset by the sale of outputs at current market prices. Based on the costs, the breakeven prices per kg for struvite and hydrogen capture are $6.03 and $15.58 respectively.

Results from this study show electrochemical struvite recovery and hydrogen capture appear to offer some benefits in the form of environmental credits and revenues generated through the sale of captured outputs. However, under current operating conditions, costs outweigh these benefits, with magnesium inputs being the largest limiting factor in both environmental and economic feasibility of the process. Future research and development of this technology should focus on this input to increase economic feasibility in addition to designing for the environment.

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