Incorporating Sustainability Considerations into Wastewater Treatment Process Selection for Nutrient Removal

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Until recently, sustainability has been an afterthought in process design; however, if considered as an integral part of the design process, the sustainability of wastewater treatment can be improved. This article examines various treatment methods and unit processes that can result in a more sustainable treatment system.

Several modifications to a base case Modified Ludzak-Ettinger (MLE) process were evaluated to identify the sustainability of each scenario in terms of greenhouse gas (GHG) emissions and capital cost. Also, construction and operations and maintenance (O&M) costs for each alternative were estimated and compared.

This analysis demonstrates that GHG emissions from the conventional MLE process can be reduced by incorporating unit processes that reduce energy consumption (fine-pore aeration, primary clarification, anaerobic treatment) or recover energy from primary and waste sludge (anaerobic generation with co-generation). At current power costs, lowering GHG emissions increased life cycle costs, but for most alternatives, the increase was less than 10 percent.

Background & Objectives

Society's expectations for wastewater treatment and disposal evolve over time. While protecting public health and the aquatic environment are paramount concerns, the need to consider solutions that meet increasing demands for water resources and the environment now affect public policy for wastewater treatment more frequently.

Gradually water quality standards established to meet multiple resource objectives have been expanded and made more stringent in response to the evolution of societal expectations. Similarly, treatment technologies have advanced as utilities have stretched to find affordable solutions to meet the expectations of their customers, the environment, and their communities.

The next driver advancing treatment technologies is sustainability. Wastewater treatment is an energy-intensive process, accounting for approximately 3 percent of electricity use nationwide (EPA, 2006). While obtaining higher water quality goals is desirable, and in some cases required by law, advanced technologies used to meet very low limits for pollutants tend to increase energy consumption significantly. As sustainability concerns grow, wastewater treatment processes must be improved to increase energy efficiency while still being affordable and meeting more stringent standards.

The wastewater industry has been entrusted to provide clean water to ensure protection of public health; however, there is also growing recognition that natural systems must also be protected, now and into the future.

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Sustainability has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987) or as "providing satisfying lives for all within the means of nature" over generations (Chambers, et al., 2000). Sustainability can be described as the process of meeting three broad objectives or demands: social, environmental, and economic. This is often referred to as the triple bottom line.

Although there is no direct measure of sustainability, several concepts have been used to broadly describe the concept, such as GHG emissions (or global warming potential), resource depletion, human toxicity, acid rain formation potential, lifecycle cost, and equity between societal groups. This article evaluates two specific aspects of sustainability—GHG emissions and cost—for a conventional 3 million-gallons-per-day (mgd) MLE process through comparison of a series of alternative process modifications.

Table 1: Main Features of Treatment Alternatives Evaluated

Alternative	Primary Clarifiers	Aeration	Digestion
MLE Base Case	No	LSSA[1]	Aerobic
MLE with Fine-Pore Aeration	No	FPA[2]	Aerobic
MLE with Primary Clarifiers	Conventional	LSSA	Aerobic
MLE with CEPT[3]	CEPT	LSSA	Aerobic
MLE with Anaerobic Digestion	Conventional	LSSA	Anaerobic
MLE with UASB[4] and Anaerobic Digestion	UASB	LSSA	Anaerobic

Notes:
1. LSSA: Low-speed surface aerators
2. FPA: Fine-pore aeration
3. CEPT: Chemically enhanced primary treatment
4. UASB: Upflow anaerobic sludge blanket

Methodology

The base case was a conventional 3 mgd MLE process using an oxidation ditch (no primary clarifiers) with aerobic sludge digestion. A series of modifications of the base

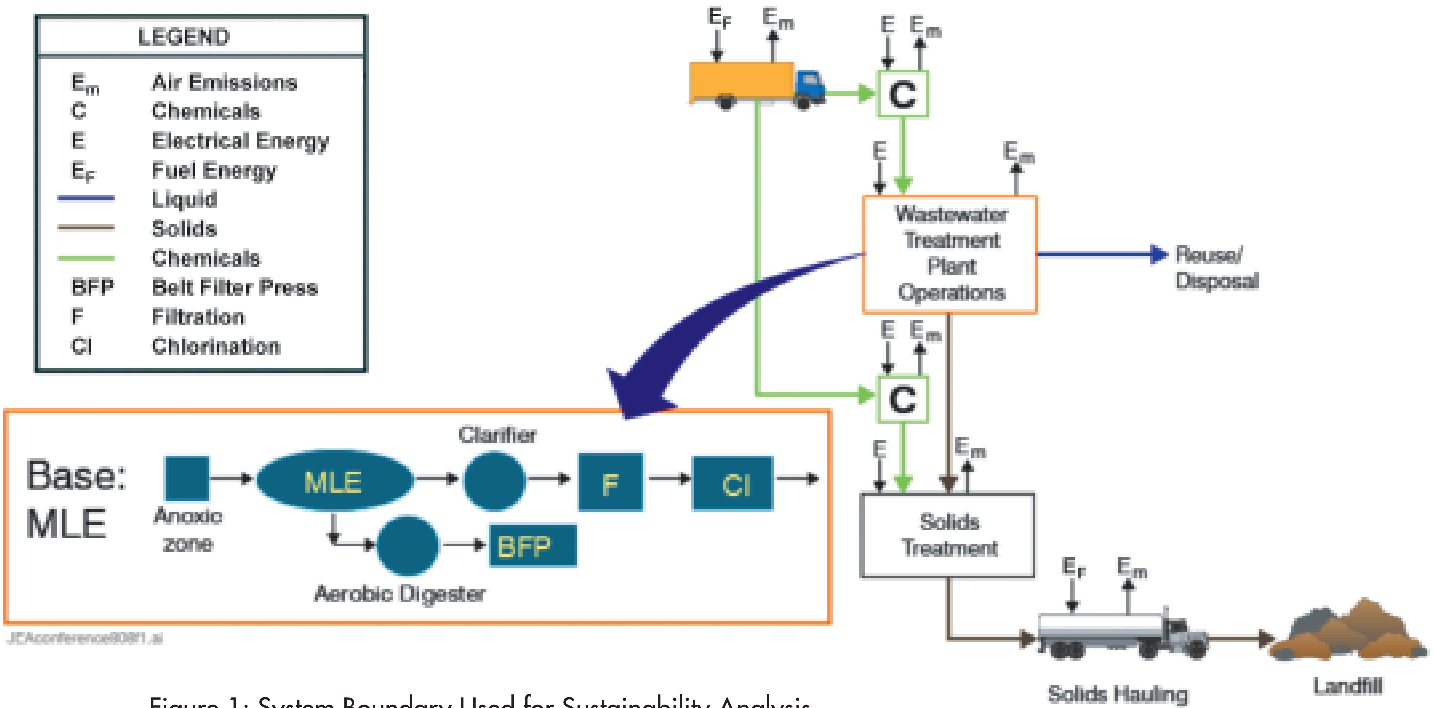

Figure 1: System Boundary Used for Sustainability Analysis

case were considered, including fine-pore aeration, primary clarifiers, chemically enhanced primary clarifiers, anaerobic sludge digestion, and an upflow anaerobic sludge blanket (UASB) reactor for liquid pretreatment.

For most alternatives, only one change was made to the base case so the effect of that one change could be clearly identified. These modifications were then ranked by GHG and cost. The key features of each alternative are summarized in Table 1.

All alternatives considered the same influent water quality characteristics and treated wastewater to the same nutrient limits (effluent total nitrogen of 10 mg/L). The analysis considered effects of material and energy flows for each process alternative within the set boundaries illustrated in Figure 1. Only energy inputs that had greater than 5 percent of total impact on GHG emissions were included in the analysis, including electrical energy consumed in treatment, fuel combusted for the transport of digested sludge and chemicals, and energy produced from biogas created during treatment.

Carollo's GHG inventory model was used to estimate the total annual metric tons of carbon dioxide equivalent (CO_2e) emissions, accounting for carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) gases, for each alternative. This tool is based on the GHG Protocol Initiative, an accounting protocol de-

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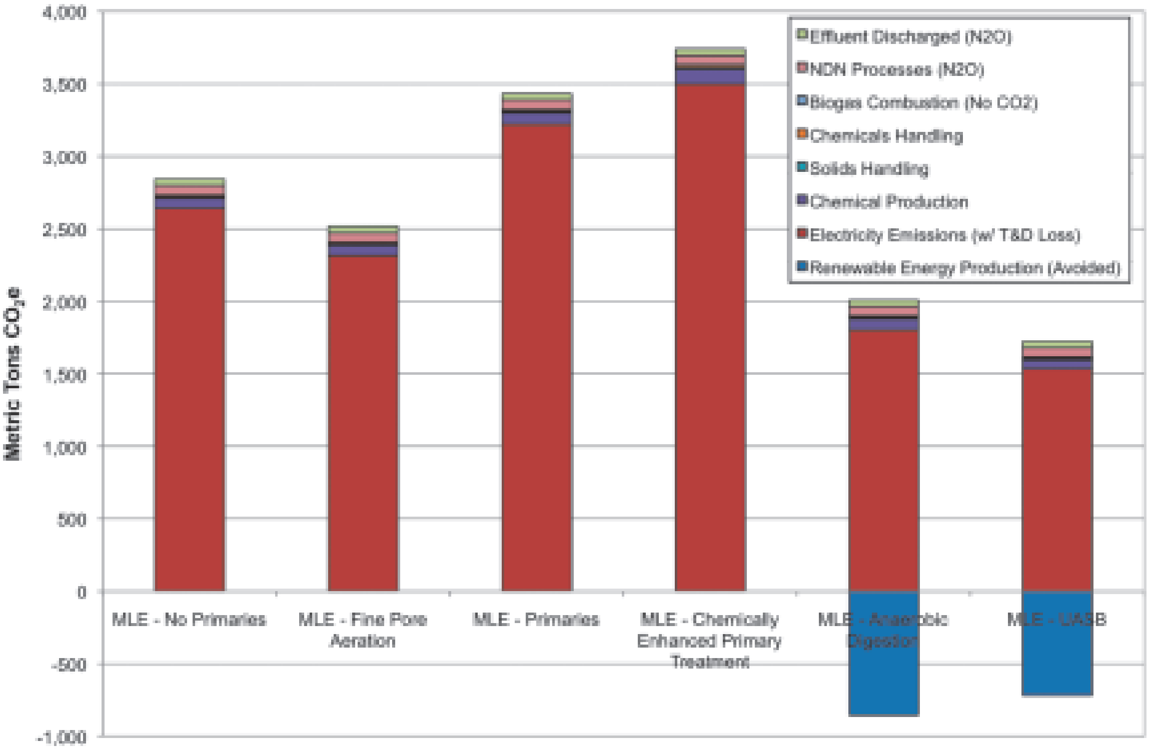

Figure 2: Annual Total Metric Tons of Carbon Dioxide Equivalent (CO_2e) Emissions

Table 2: Present-Worth Costs of Process Alternatives

Alternative	Capital Cost ($ Million)	O&M Costs ($ Million / Year)	Present Worth Cost ($ Million)
MLE Base Case	$74	$2.20	$106
MLE with Fine-Pore Aeration	$75	$2.16	$107
MLE with Primary Clarifiers	$75	$2.47	$111
MLE with CEPT	$75	$2.59	$114
MLE with Anaerobic Digestion	$80	$2.30	$114
MLE with UASB and Anaerobic Digestion	$86	$2.26	$120

Table 3: Energy Consumption of Process Alternatives

Alternative	Total Energy Consumption (Million kWh/year)	Per Capita Energy Consumption (W)	Net Energy (Biogas Minus Energy – Million kWh/year)
MLE Base Case	4.02	16.1	-4.02
MLE with Fine-Pore Aeration	3.52	14.1	-3.52
MLE with Primary Clarifiers	4.90	19.6	-4.90
MLE with CEPT	5.32	21.3	-5.32
MLE with Anaerobic Digestion	2.74	11.0	0.34
MLE with UASB and Anaerobic Digestion	2.33	9.3	0.26

Continued from page 39

veloped by the World Resources Institute and the World Business Council for Sustainable Development (World Resources Institute, 2004). The GHG Protocol Initiative serves as an accounting framework for almost all GHG standards and programs in the world, including those of the Organization of International Standards, the EU Emissions Trading Scheme, and the Climate Registry.

The development of any GHG emissions estimate requires a set of boundary conditions be established to define the life cycle stages (construction, operations, etc.), the unit processes, and the period (present or future year) that is included in the analysis. The GHG tool has the flexibility to accommodate these boundary conditions on a case-by-case basis, accounting for emissions generated either directly or indirectly from wastewater collection, treatment, and reuse/disposal systems. As a result, the tool is capable of meeting multiple objectives: 1) estimating emissions for reporting purposes or project alternatives comparison, 2) establishing a baseline inventory, 3) identifying areas for potential reductions and carbon offset projects, 4) setting reduction goals, and 5) measuring progress toward reduction goals/targets on an annual basis.

Results

GHG emissions generated by each process alternative are summarized in Figure 2. GHG emissions were calculated for each contributing source, including the treatment processes (nitrification and denitrification); discharged effluent; chemicals handling; solids handling; chemical production; and purchased electricity emissions, including transmission and distribution (T&D) losses. Renewable energy production (biogas combustion emissions[1] and avoided emissions from purchased electricity) was also calculated.

Spreadsheet cost models were used to determine budgetary capital and O&M costs for each alternative. Energy or O&M costs recovered from biogas electricity generation were included. Capital, O&M, and present-worth costs are summarized in Table 2. Estimated energy consumption/production is summarized in Table 3.

Adding primary clarifiers or chemically enhanced primary treatment (CEPT) increased CO_2e emissions compared to the base case MLE process. Adding primary clarifiers with aerobic digestion increased project capital costs, as well as O&M costs, because of the increased energy required for aerobic digestion.

In contrast, converting to the fine-pore aeration system decreased CO_2e emissions because of improved oxygen transfer efficiency, which decreases overall air and electricity needs. The capital cost for fine-pore aeration is only slightly higher than surface aerators (approximately $1M in additional capital cost), and the annual O&M costs are approximately $40,000 less.

Plants typically require more energy for biological nutrient removal (removal of BOD_5 and TKN) when using aerobic treatment. Switching to anaerobic treatment (or CEPT) for the bulk carbon removal does not change the power required for nitrification significantly. The need to remove nitrogen significantly limits the ability to reduce the power required for treatment. Clearly, one of the most important avenues to improve the sustainability of wastewater treatment is the development of low-energy nitrogen removal technologies.

Conversion to anaerobic digestion provides the largest decrease in CO_2e emissions because this treatment does not require the electrical demand for process aeration in aerobic digestion. Based on an assumed 30-per-

Continued on page 42

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[1] Biogas combustion generates carbon dioxide, methane, and nitrous oxide emissions. The carbon dioxide emissions are considered natural or biogenic (meaning the carbon was recently fixed in living organic matter). Biogenic emissions are not included in Figure 2 because these types of emissions are not considered to be contributing to global warming and are not the target of reductions in current regulations.

Continued from page 40

cent biogas energy conversion efficiency, the two anaerobic digestion alternatives are net energy producers. The MLE/UASB alternative produces slightly less energy because of lower digestion temperatures in the UASB reactor, resulting in decreased biogas production. Also with a UASB process, more of the biogas becomes dissolved in the wastewater and is not captured for conversion to power. This effect was not included in our analysis.

Adding anaerobic treatment into the treatment train results in energy savings but requires a higher initial investment. Providing anaerobic digestion for a conventional MLE can result in much lower GHG emissions at a slightly higher capital cost.

Conclusions

Sustainability is normally an afterthought in process design; however, if GHG emissions and life cycle analyses are incorporated early in the design process, the sustainability of wastewater treatment can be improved. As stated previously, this analysis demonstrates that GHG emissions from the conventional MLE process can be reduced by incorporating unit processes that reduce energy consumption (fine-pore aeration, primary clarification, anaerobic treatment) or recover energy from primary and waste sludge (anaerobic generation with co-generation). At current power costs, lowering GHG emissions increased life cycle costs, but for most alternatives, the increase was less than 10 percent.

Although this analysis determined that additional anaerobic treatment would lower GHG emissions, adding anaerobic treatment is not a simple matter. Anaerobic pretreatment of wastewater, while not a new concept, is not in use anywhere in the developed world for large-scale municipal wastewater treatment. Anaerobic pretreatment is being implemented widely in some tropical and sub-tropical regions of the developing world; its use in these regions is under much different circumstances than would be required in North America.

In the developing world, a UASB reactor is often the only biological unit process employed, where it provides 40 to 80 percent BOD_5 removal with minimal input of power and reduced sludge production. Post-treatment, if provided, may be simply a lagoon or wetlands.

In North America, anaerobic treatment would be a pretreatment step used to reduce power consumption and GHG emissions. Post-treatment by secondary activated sludge or a higher level of treatment, such as the MLE process used in this evaluation, would be mandatory.

Because of the many uncertainties surrounding the sizing and performance of anaerobic treatment for municipal wastewater in a temperate climate, our analysis used conservative assumptions. The current evaluation indicates that in situations where nitrification and denitrification are required, conventional primary treatment with anaerobic digestion can be as energy efficient as the UASB process, and it can be delivered for a lower present-worth cost.

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