

## Process Design and Optimization for Wastewater Treatment Efficiency and Resilience

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### Focus Area(s)

This white paper focuses on the optimization of energy use in wastewater treatment processes. By leveraging advanced open-source modeling and optimization techniques, the proposed work aims to enhance the resilience and efficiency of wastewater treatment facilities, ultimately contributing to more sustainable water management.

### Existing Challenge

Current wastewater treatment facilities face numerous challenges that hinder their operational efficiency and resilience [1-4]. Key issues include:

1. **Energy Consumption:** Wastewater treatment is energy-intensive, with facilities often using significant electricity for aeration, pumping, and other internal processes. This not only increases operational costs but also may contribute to the carbon footprint of these facilities depending on the source of electricity.
2. **Regulatory Compliance:** Wastewater facilities must adhere to stringent regulatory standards regarding effluent quality. Variability in influent conditions, such as flow rates and concentrations of contaminants, can complicate compliance efforts.
3. **System Resilience:** The ability of wastewater treatment systems to withstand and recover from disruptions, such as equipment failures or extreme weather events, is critical. Current systems may lack the flexibility to adapt to changing conditions, leading to potential service interruptions.
4. **Data Utilization:** Many facilities struggle to effectively leverage operational data to inform decision-making and optimize processes. This can result in missed opportunities for efficiency improvements and cost savings.

The existing challenges highlight the need for innovative approaches to improve energy efficiency and system resilience.

### Near-Term Opportunity

Given the current context of energy consumption, there is an opportunity over the next years to develop and implement rigorous, site-specific wastewater treatment plant models that optimize energy use and enhance resilience. This can be achieved through partnerships between Sandia National Laboratories, Lawrence Berkeley National Laboratory, and utility operators by leveraging the Water treatment Technoeconomic Assessment Platform (WaterTAP) [5] and the IDAES Integrated Platform [6], both developed at the National Laboratories.

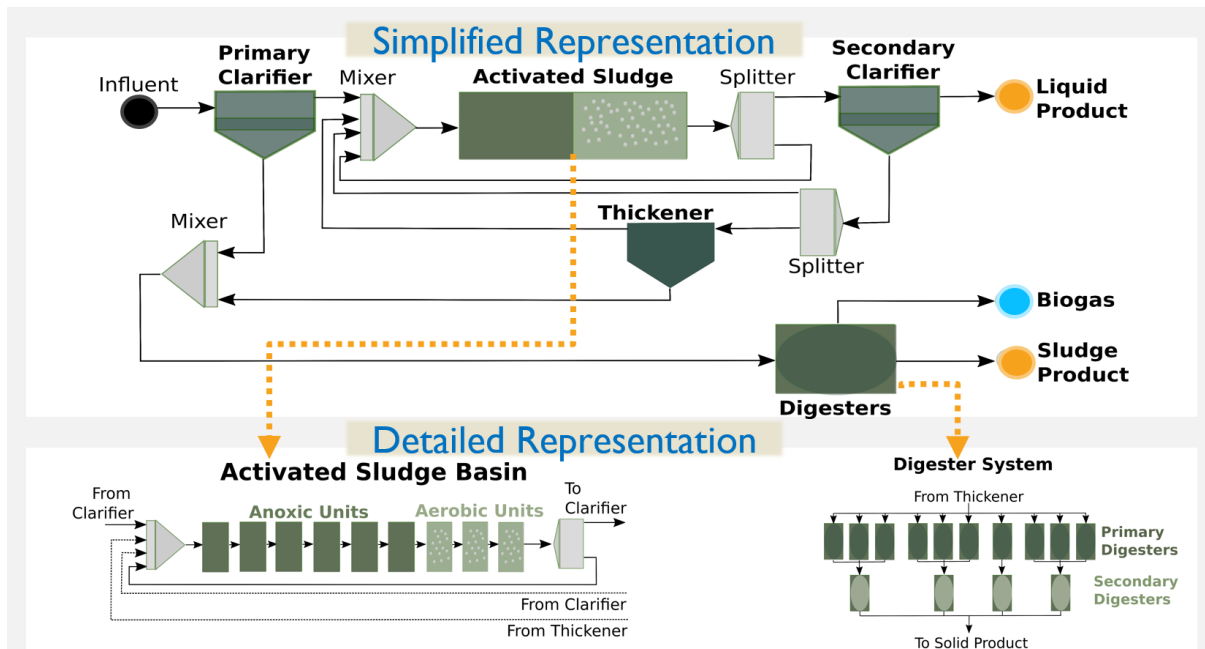


Figure 1. Diagram of a digital twin flowsheet created with unit models from WaterTAP and IDAES, featuring both simplified and detailed representations of a wastewater facility that use real operational data to set operational limits and ensure compliance with product specifications.

By creating digital twin flowsheets (virtual representations of physical systems that mirror real-time performance, as illustrated in Figure 1) and utilizing actual operational data, wastewater facilities can simulate various scenarios to identify potential energy-saving opportunities, improve process efficiency, and ensure compliance with regulatory standards. Implementing diverse case studies within a digital twin model allows facilities to test and validate proposed optimization strategies on a smaller scale before full-scale implementation. These cases provide valuable insights into the practical challenges and benefits of new technologies and methodologies, refining approaches and demonstrating their effectiveness in real-world settings.

This approach enables a detailed optimization analysis of facility operations, helping to identify critical opportunities for improving both process design—such as optimal equipment sizing and unit selection—and operational conditions (including temperature, concentration, reaction parameters, etc.). The analysis can be used to uncover valuable strategies to reduce energy consumption while simultaneously increasing overall process efficiency, leading to significant reductions in operational costs.

Key opportunities include:

1. **Explore cogeneration or resale of biogas as a viable opportunity to offset energy costs.** The cost benefit analysis can include interactions with the electricity market, given that biogas can be stored and used as a dispatchable electricity source. Optimization and AI-enabled scheduling has the potential to improve plant energy costs and provide flexibility to electricity grid operations.
2. **Evaluate influent conditions and their impact on system performance.** Fluctuations in influent flow and concentration, which can occur as a city grows or diverts stormwater from a combined sewer system, can have a large impact on wastewater treatment operations, including the efficiency and cost.

3. **Increase access and understanding through decision support tools.** Input variables, model generation, and analysis can be conducted through a graphical user interface to increase access and understanding of analysis results.

The implementation of this advanced approach, combined with collaborative efforts between the laboratories, will facilitate the adoption of innovative simulation and optimization techniques and best practices in wastewater management.

### Success Measure

Success for this initiative will be measured through increased adoption of advanced open-source modeling and optimization techniques at wastewater treatment facilities to improve their operation. The modeling and optimization will use several metrics to communicate results to facilities operators and discuss potential changes to the system operation that could improve efficiency and resilience. Potential metrics include:

1. **Energy Savings:** A quantifiable reduction in energy consumption per unit of wastewater treated, demonstrating the effectiveness of optimization strategies.
2. **Regulatory Compliance Rates:** An increase in the percentage of scenarios that treatment plants meet or exceed regulatory standards for effluent quality, indicating improved operational performance.
3. **Operational Cost Reduction:** A decrease in annual operating costs associated with energy use and maintenance, reflecting the financial benefits of optimized processes.
4. **Resilience Metrics:**
  - a. *Operational Continuity:* The capacity to maintain operations during disruptions, measured by the frequency and duration of service interruptions. This metric helps identify the hazards that present the greatest challenges in the environment where the facility is located and operated.
  - b. *Adaptative Operational Conditions:* The ability to adjust operational parameters in response to fluctuations in influent characteristics, such as flow rates and contaminant concentrations. This can be evaluated by analyzing the quality of treated water and monitoring key pollutants (e.g., COD, BOD, TSS, etc.), comparing these values against a baseline scenario.
  - c. *Biosolids Management Efficiency:* The effectiveness of managing biosolids, which can impact environmental sustainability and regulatory compliance. This metric can include the percentage of biosolids recycled or reused within the facility.

In conclusion, by focusing on the development of advanced models and optimization techniques, the wastewater treatment sector can overcome existing challenges and seize near-term opportunities to enhance resilience and efficiency in their facilities. The success of these initiatives will not only benefit individual facilities but also contribute to broader environmental and public health goals.

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