Framework for Enabling Energy Reliability for Wastewater Utilities

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Focal Area(s): This white paper addresses **Energy for Water**, focusing on enabling energy reliability at wastewater (WW) utilities with an emphasis on grid-interactive operations.

- *Specific energy system:* on-site electricity generation, on-site heat generation, electricity storage.
- *Specific water system:* wastewater collection, treatment, and discharge.
- *Sector directly impacted:* WW utilities. *Sectors influenced:* community (public health and sanitation), eco-system (wastewater discharge water bodies and landfills), electric utilities.

Existing Challenge:
WW sector is highly energy intensive, heavily dependent on external grid power to sustain critical operations. This dependency leaves them exposed to price volatility and outages, exacerbated by growth in advanced industrial sectors energy demand impacting rates and grid reliability (Josh Saul et al., 2025; Shehabi et al., 2024). Conventional mitigation include investing in dual utility feeds or diesel-backup generators to support emergency operations (upto 1-day). Despite these measures, facilities are vulnerable to acute stresses i.e., electric grid power disruptions (quarterly or less[1]), extreme weather or natural disasters (e.g., wildfires). In addition, expanded WW infrastructure to better treat the complex influent WW will either add or replace conventional WW treatment to advanced, yet energy-intensive (potentially energy-efficient)[2] treatment, thereby increasing sector's overall electricity demand (chronic stress).

Although multiple options exist for wastewater treatment plants (WWTPs), implementing energy reliable strategies lack a decision framework to enable cooperation, flexibility, and co-optimization of energy-water systems. Such decision framework is crucial to (a) enable optimal asset utilization; (b) feed into WW sector's vulnerability assessments and reliability plans; and (c) support state energy programs to develop, implement, and direct WW resiliency grants (Illinois EPA, 2025).

Near-Term Opportunity
The focus of this white paper is to provide key elements to frame the energy reliability planning for WW utilities. There are primarily two key established levers for WW utilities in this space.

Grid-interactive operations and flexible demand. Managing load profiles is the fastest near-term lever. Facilities can couple wastewater storage and flexible loads to ease grid stress, e.g., defer filter backwashing and solids dewatering, or temporarily delay portions of treatment. Proven measures include advanced aeration control (dissolved-oxygen setpoint optimization, intermittent aeration, off-gas analytics) with variable frequency drives (VFD) blowers and real-time monitoring to maintain effluent quality during curtailments; scheduling of non-critical processes outside peak windows; and

[1] From a limited survey of 9 WW utilities hosted during US Department of Energy's Enhanced Reliability and Operations Planning for WRRFs Webinar Series' Energy Enhancement Session on 09/23/2025 as part of Sustainable Wastewater Infrastrucuture of the Future (SWIFt) program offerings. Recordings and participant discussions publicly available at: https://bptraining.ornl.gov/swift/.

[2] Our limited discussion with WW utiltiies via the SWIFt program (2023-2025) notes that nitrification-denitrification is being increasingly evaluated in conjunction with side-stream nutrient recovery treatment processes to meet nutrient (nitrogen, phosphorous) discharge/pollution criteria. These advanced technologies (may/often) provide improved process efficiency (e.g., % contaminant removal) at the cost of energy and equipment with expanded treatment trains. For example, the overall potable water sector energy consumption increased 25% from 2013-2018, due to increased adoption rate of reverse osmosis (Liu & Mauter, 2020).

high-service distribution pumping optimization (VFD-controlled tank setpoints) to arbitrage time-of-use (TOU) tariffs and participate in demand energy response (DER) programs. *Evidence gap for future work: Although many of these tactics appear individually in the literature, a systematic, U.S.-focused analysis that quantifies energy savings, cost impacts, and reliability benefits from bundled DER and load-flexibility strategies specifically for WWTPs remains limited*[3]*.*

On-site energy and microgrids. Onsite generation options include combined heat and power (CHP) using self generated biogas limited to larger WWTPs (>10 MGD[4]), onsite renewables, and conventional backup generation. Electric utility interconnection policies favor use of induction generators for CHP systems, which require grid power for excitation and continued operation. Using synchronous generators with CHP system allows for the option to "black start", and use during periods of grid outages. Integrating generation and controllable loads into a microgrid allows the WW facility to control generation, storage and site electric loads to maximize use of energy assets and minimize dependency on the electric grid. They enable islanding critical buses (influent/effluent pumping, aeration, controls) from the primary electric grid and allow coordinated load shedding/shifting among non-critical processes to stretch limited fuel during extended events. Battery energy storage systems (BESS) is emerging for WW utilities as priority is placed on hardening sites against extreme conditions to support fast transitions, manage motor inrush currents, and reduce peaks.

An emerging space (added third lever) for WWTPs is "co-locating with new manufacturing". Where regions are adding advanced manufacturing (e.g., semiconductor, biopharma), co-locating utility-anchored microgrids allows shared interconnection upgrades, create stable anchor loads, and accelerate permitting, while providing additional flexible capacity for the grid during stressed conditions. This approach also positions WW utilities to capture wastewater heat, waste-to-energy opportunities, or shared backup capacity where appropriate.

Framework for applying energy reliable measures.

1. Develop asset energy load profile overlaid with influent and effluent flows, primary influent characteristics (biological oxygen demand and total suspended solids). *Evidence gap for future work: The variability in WW treatment process types, influent quality, effluent requirements, and size necessitate the development of normalized energy demand profiles to compare and contrast the diverse WW sector.*
2. Segment by criticality (equipment based tiers):

- *Tier 1 (must-run loads):* influent/effluent pumps, minimum aeration, process controls, and Supervisory Control and Data Acquisition (SCADA)
- *Tier 2 (shiftable loads):* sludge dewatering, filter backwash, and non-essential heating, ventilation, and air conditioning (HVAC)
- *Tier 3 (shed/curtail loads):* discretionary processed and maintenance that can be curtailed without affecting permit compliance.

Design guardrails. Validate black-start sequences and large-motor starts before equipment procurement, using soft-start or VFD strategies to manage inrush currents and to sequence loads safely.

3. Segment by plant configuration and flow

- *Small WWTPs (<5 MGD; typically no digesters):* Use efficient diesel or natural-gas backup sized to Tier-1 loads; add solar photovoltaic (PV) where roof or land is available; consider limited BESS

[3] Limited auto-DER case studies available from WWTPs in California (Aghajanzadeh et al., 2015; Lekov et al., 2009)
[4] MGD: million gallons per day

for ride-through and demand-charge management; participate in DER primarily through process scheduling (for example, dewatering and backwash).

- *Mid/Large WWTPs (>10 MGD) with anaerobic digesters:* CHP sized to biogas, heat recovery, PV + BESS to extend islanding and enable DER; consider a microgrid for critical buses.
- *Mid/Large WWTPs without digesters:* combine engine-generator sets + PV + BESS; evaluate procured natural gas vs produced biogas for CHP (extended renewable natural gas) if available; DER and TOU optimization.

4. Site identification for microgrids (weighted score).
   Prioritize facilities in sensitive areas where grid outages happen by scoring and weighting:

- Electricity cost and tariff risk (for example, demand charges and TOU differentials).
- Outage risk (utility System Average Interruption Duration Index (SAIDI); System Average Interruption Frequency Index (SAIFI).
- Climate and weather vulnerability (hurricane, extreme heat, wildfire, and flood indices).
- Population and criticality served (for example, proximity to hospitals, defense installations, and clusters of data centers).
- Adjacency to other critical loads (shared or “co-microgrid” opportunities with nearby wastewater, drinking-water, or energy assets such as data centers).
- Peak load and Distributed Energy Resource hosting capacity (distribution-system interconnection constraints).
- Market access (availability of ISO/RTO/DER aggregators).

Relevant existing or new partnerships needed: Water/Wastewater utilities; WWTP operators; electric utilities; ISO/RTO and DR aggregators; State Energy Offices; financing partners; national labs

Success metrics to evaluate energy reliability effectiveness:

Quantitative energy and cost metrics

- Energy intensity: reduction in kilowatt-hours per million gallons (kWh/MG) relative to baseline.
- Peak-demand management: reduction in kilowatts (kW) and event-based DR performance measured in kW and megawatt-hours (MWh).
- Reliability: hours of islanded operation supported; uptime of critical processes during grid events; avoided spill/bypass incidents; avoided grid outages.
- Cost performance: Simple pay-back period, Net Present Value (NPV) inclusive of avoided energy purchases, demand-charge savings, DER revenues, and operations and maintenance impacts.

Wastewater quality and process performance metrics

- Effluent quality during DER and islanding: Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), Total Nitrogen (TN)/Total Phosphorus (TP), and ultraviolet (UV) disinfection dose.
- Process Performance Indicators: blower kWh per pound of oxygen (kWh/lb O_2) and pump kWh/MGD.
- Wet-weather handling: ability to treat peak flows without violations (number of permit violation per weather event).

Societal metrics

- Rate stability from electric utility and to WW customers; avoided service disruptions to customers.
- Operator acceptance and usability of controls; coordination effectiveness among partners; and reproducibility (templates, and training).

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