Water Reuse Energy Demands and Water Quality Metrics

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Focal Area

This white paper addresses the intersection of energy and water resilience by advancing water reuse/reclamation technologies to mitigate water scarcity in arid and remote environments. Enabling the use of gray water to reduce energy-intensive water sourcing, transportation, and treatment processes while enhancing operational sustainability will help meet ever increasing water demands.

Existing Challenge

Current practices in water management, particularly in water-scarce regions like desert military installations, rely heavily on energy-intensive methods such as desalination from distant sources and trucking water over long distances. For instance, at Camp Buehring in Kuwait, a 4.9 square mile U.S. Army base, approximately 3.6 million gallons of water are trucked in monthly, incurring significant fuel costs for transportation despite the host nation providing the water at no charge. This setup not only strains logistical resources but also consumes substantial energy in the form of diesel for trucks, contributing to operational vulnerabilities in contingency environments.

The Idaho National Laboratory-developed Water Reclaim System (WRS) demonstrated at Camp Buehring exemplifies a targeted approach to gray water recycling.[(1)] (Figure 1). The system collects shower runoff (gray water), processes it through filtration, chlorination, and storage in an 800-gallon tank, and reuses it for toilet flushing or land applications like dust control. Installed in a 20-foot shipping container, the WRS uses pumps, variable frequency drives, filters, and calcium hypochlorite for disinfection, achieving up to 63% water reuse efficiency. In its initial configuration, connected to a wet trailer with 8 showers and 8 toilets, it processes over 800 gallons daily, reducing the need for imported water and associated energy and personnel for trucking.

The demonstration faced challenges such as corrosion from transit exposure, chlorine decay due to heat and humidity, and supply chain issues for specialized components like calcium hypochlorite tablets, which are not locally available. Improvements could include integrating sensors for remote, real-time monitoring to track performance and alert when maintenance or repair is needed, reducing downtime.

A critical area for further investigation is understanding water quality across different reuse processes and the associated energy consumption. The effectiveness of filtration systems, such as the non-metallic high-flow filters used in the WRS, in meeting water quality standards for various applications (e.g., toilet flushing, irrigation, or industrial cooling) is of significant interest. Evaluating filtration efficacy through metrics like bacterial counts (via PCR testing) and chemical contaminant levels ensures compliance with local and federal water quality regulations, such as those for non-potable reuse in military or industrial settings.

Additionally, quantifying the energy consumed by filtration and chlorination processes—potentially 2-5 kWh per 1,000 gallons based on pump and control system demands—versus the energy saved from reduced water trucking (e.g., diesel fuel savings) is essential for assessing net energy benefits. For instance, the WRS employs calcium hypochlorite for disinfection, but its decay in harsh environments and the energy required for frequent replenishment highlight the

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need to optimize treatment processes. Developing energy-efficient treatment methods, such as low-pressure membrane systems or UV disinfection, could further enhance system performance while maintaining water quality standards.

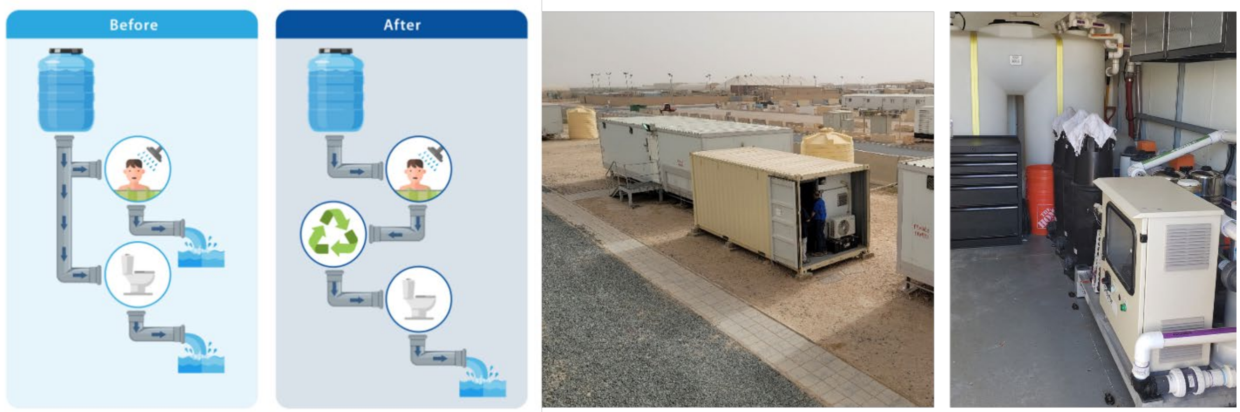

Figure 1. **Left**: Schematic of Water Reclaim System operations (right) versus a traditional single use process (left). **Center**: The Camp Buehring WRS conex (center) and connected shower and bathroom trailer (left). **Right**: Process components inside the WRS conex.

Beyond shower-to-toilet reuse, opportunities exist to expand recycled water use. In data centers, reclaimed water could cool servers, offsetting energy for traditional evaporative cooling systems. For biomass processing, reclaimed water could be used to moisten feedstocks during pretreatment, conserving fresh water and the associated energy demand. Manufacturing facilities might employ it for non-potable processes like rinsing or cooling, while agricultural or military applications could include irrigation or dust suppression. Key questions include quantifying the system's power consumption (e.g., pump and filtration energy use) versus savings from reduced trucking fuel consumption, exploring alternative treatment technologies, and identifying scalable designs to minimize net energy footprint.

Near-Term Opportunity

In the next 3-5 years, opportunities to advance energy-water resilience lie in scaling and optimizing water reuse systems like the WRS for diverse applications. For military and remote locations, modular WRS units could be deployed in arid theaters, reducing fresh water demand, fuel consumption for water logistics, and enhancing mission resiliency. Landscape irrigation, fire suppression water storage, and vehicle washing stations could use treated gray water, conserving potable supplies. As an example, water savings at Camp Buehring could exceed 106 million gallons annually, if the WRS system were expanded to serve the whole base.

In manufacturing, reclaimed water could integrate into closed-loop systems for cooling and processing, partnering with industries facing water restrictions. Power plants and data center cooled by reclaimed gray water could cut energy use by 20-30% compared to freshwater systems.

Many states are actively working on their reuse regulations and guidelines as they face water scarcity, water volatility, and water quality concerns. Current water reuse rules and guidelines vary by state and are dependent on the end use: potable, agriculture, landscape, and onsite non-potable water reuse. Some states have additional requirements based on the water source. There is significant opportunity to inform decision makers as these rules are developed. For example, in 2024, both California and Arizona released draft regulations for direct potable reuse. Meanwhile Florida is currently exploring rulemakings for both direct and indirect potable reuse. Idaho National Laboratory (INL) has experience operating three reuse water permitted facilities for over 20 years as Idaho was an early adopter of wastewater land application rules.[(2)]

The Water Security Test Bed (WSTB) and integrated energy facilities at INL are well positioned to advance research and development of water reuse systems.[(3,4)] The WSTB, a large-scale replica of a municipal drinking water distribution system constructed with real-world piping and components, enables controlled experiments on water treatment, decontamination, and system efficiency. While primarily focused on security and resilience against contaminants, the WSTB's infrastructure can be adapted to study water reuse processes, such as gray water filtration and disinfection, in a realistic setting. Complementing this capability, INL's integrated energy test beds, like the Power and Energy Real-Time Laboratory (PERL) and microgrid systems, facilitate research on the energy-water nexus by measuring electrical efficiency and testing hybrid setups that combine water reclamation with energy generation, such as solar-powered pumps and closed-loop cooling systems.[(5,6)] These capabilities allow INL to quantify power draws in reuse systems, optimize for net-zero operations, assess water quality implications, and explore expansion into industrial wastewater recycling. These efforts would unlock resilient water supplies, lower energy demands, and foster innovation through shared data from demonstrations like Camp Buehring, while establishing a national testing and development asset for enabling deployment of water re-use systems.

Success Measure

Success can be measured quantitatively by the cost of the water delivered to remote military bases or communities. Reduced water delivery cost will be achieved by reducing water importation volumes (targeting 50-70% reuse rates as demonstrated in the WRS), energy savings from decreased trucking (e.g., gallons of diesel avoided per reclaimed gallon), gains in system power efficiency (e.g., kWh per 1,000 gallons processed), improved water quality metrics (e.g., consistent chlorine levels and low bacterial counts), and enhanced system reliability (e.g., uptime > 95% through predictive maintenance and automated monitoring of system health). Integrating on-site electricity generation could further reduce the per unit water cost delivered by water reclamation systems.

Broader impacts could be assessed by adoption rates in non-military sectors, such as data center or power plant cooling operations. In addition to quantitative metrics focused on lower water costs or wider adoption of water reuse, increased resilience and stability of operations in remote locations will be an important qualitative benefit. These measures would validate the WRS, and water reuse technology more broadly, as a scalable solution for advancing energy-water resilience.

References

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