Converting Wastewater to Distributed Power and Energy: Addressing Two Critical Utility Needs of the Future Army with One Advanced Technology

Dr. Aaron C. Petri, Energy and Environment Planner, ERDC-CERL

Dr. Dawn Morrison, Human Geographer, ERDC-CERL

Mr. Nicholas Josefik, Energy Engineer, ERDC-CERL

Mr. Nathan Peterson, Electrical Engineer, ERDC-CERL

Dr. Kathryn Guy, Chemist, ERDC-CERL

The future Army multi-domain operating (MDO) force will face significant changes and challenges over the next 15 years in terms of who, where and how they fight, and the tools and technology they use and confront on the battlefield. What will not change is the Army's need to supply consistent power and energy (P&E) to deployed forces, and the Army's requirement to manage human wastewater. The bottom line: no matter where the future soldier goes or what they do, the saying "everybody poops" will continue to hold true. The Distributed Low-Energy Wastewater Treatment (DLEWT) system, developed by the U.S. Army Corps of Engineers, Engineer Research Development Center, Construction Engineering Research Laboratory (ERDC-CERL), is a compact, portable containerized wastewater treatment system that converts wastewater into P&E, and reusable water. As a Tier 1 technology, DLEWT has significant potential to increase operational energy and water endurance with a low-maintenance portable treatment system that will help future deployed forces overcome their dependence on resupply chain logistics.

Former Secretary of Defense James Mattis referred to the constraining dependence of deployed forces on resupply chain logistics—liquid fuel and water— between the forward-deployed forces and the port of debarkation as the "Tether of Fuel." Liquid fuel and water comprised 80% of the weight of ground resupply convoys in Iraq and Afghanistan. As of 2009 more than 3,000 service members and contractors have been killed or wounded defending the ground resupply convoys (ASAIEE, 2018) that provide fuel and water. Current MDO scenarios identify the large footprint of logistics supply chains and their inherent vulnerabilities as a critical target that adversaries will seek to disrupt using asymmetric means (JCS, 2012). Generation of electricity in contested environments usually depends upon diesel generators. Water depends on storage tanks. Extending the days of supply for energy will not reduce water needs or reduce the tether of water. Thus, energy and water dependencies tied to these supply chains will be vulnerable and can potentially cripple U.S. force projection and sustainment. Developing a new strategy that enables a globally agile force, resilient to logistical disruption, requires the ability to break the Tether of Fuel.

The future success of deployed forces will depend on their resilience and autonomy, which in turn depends on their ability to generate energy, harvest water, and treat wastes without relying on supply chain logistics. Energy, water and wastes categorically represent the greatest challenges facing the future of combat and force projection. Reimagining the needs of deployed forces using the concept of a *metabolism* to describe resource flows, evokes a more holistic depiction of how deployed forces operate. This engineering concept compares a military unit to a living thing that takes in resources, uses them, and discharges waste. The metabolism concept has been used at larger industrial and urban scales to study resource constraints (Kennedy et al. 2007; Kierstead and Sivakumar, 2012), changes in resource flow over time (Papaioannou, 2013), and to study resource impacts (Baker, 2009; Gandy 2004). Deployed forces operate similarly, evidenced by the tether of fuel and water. In a deployed environment, resource flows are relatively consistent if resupply chains keep up with demand. However, as convoys are attacked or resources become scarce, the flow of resources becomes unreliable, and the ability of the unit to perform its mission is compromised. Rethinking the metabolic flow of energy, water, and waste is the key to increasing resilience and extending the operational capacity of the deployed unit. In other words, if the deployed force is meant to exist relatively independent of the world around it, understanding the interdependencies of energy, water, and waste will help establish a resilient metabolism capable of supporting troop operations independent of resupply convoys.

Establishing a resilient metabolism for future forward deployed MDO forces that increases agility and force projection capabilities in theatre will require flexible onsite energy production and water harvesting. Creating a resilient metabolism also requires a fundamental shift in how the Army views and addresses wastewater in deployed environments. Current approaches to wastewater treatment are primarily focused on removal of waste and approach wastewater as a burden. For example, the Deployable Aerobic Aqueous Bioreactor (DAAB) employs a scaled-down version of conventional aerobic treatment that requires a 30kW generator and 200 gallons/week of diesel to operate without producing usable water.[1] The Deployable Baffled Bioreactor (dBBR) system is another technology currently used that treats wastewater to the point of being safely discharged to the environment with no energy recovery or water re-use component.[2] Aerobic systems, like DAAB, are the standard treatment method. However, aeration can account for over half a plant's electrical costs (Gandiglio et al.; Pabi et al. 2013). Additionally, since the microbes are converting the organic matter in wastewater to new cell growth, aerobic digestion produces a large volume of biomass sludge that must be subsequently treated before disposal.

DLEWT offers multiple benefits over current deployable wastewater treatment technologies developed for the US Army. Advanced and emerging technology, such as DLEWT, treats wastewater as an asset rather than a nuisance byproduct, and has significant potential to break the Tether of Fuel for deployed forces. Using wastewater generated onsite by deployed forces to provide P&E and water removes the need for continued supply chain logistics. The system is housed in a standard waterproof, steel Conex box which translates to durable portability

[1] https://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476638/deployable-aerobic-aqueous-bioreactor-daab-wastewater-treatment-facility/

[2] https://www.thefreelibrary.com/Wasting+less+water%3a+deployable+wastewater+treatment+system+tested+at...-a0461364801

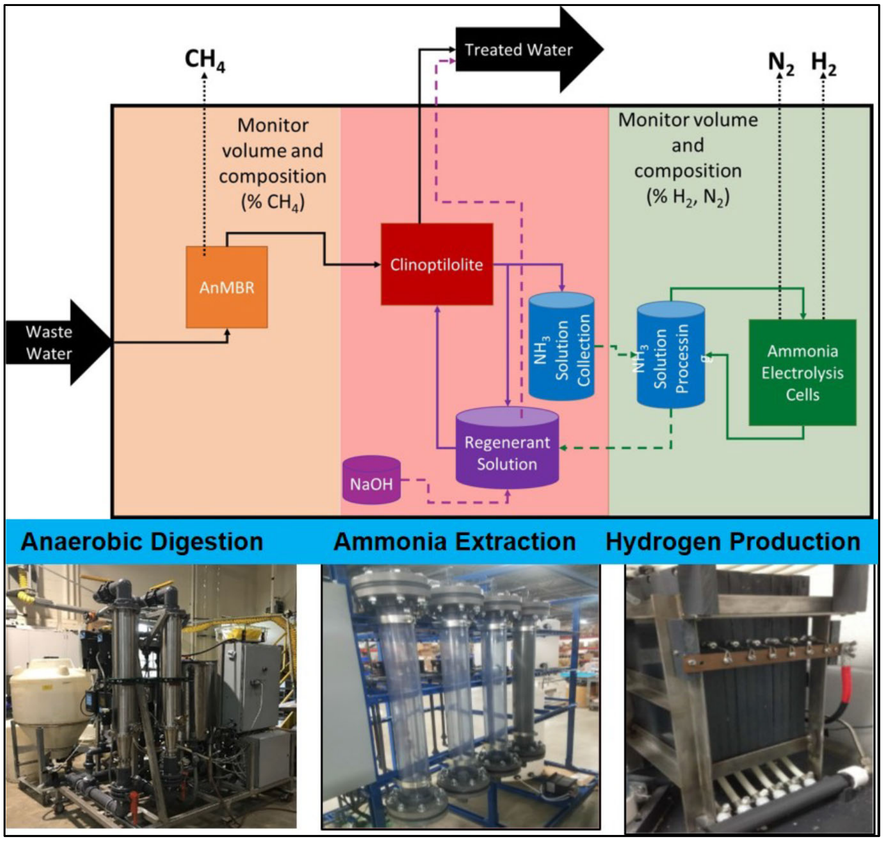
(Figure 1). The portable design of DLEWT means the system travels with the deployed forces as and where they move within the operating environment, and so long as food supply logistics are functioning, soldiers should have no problems producing the required influent needed to supply DLEWT. The use of a standard Conex box further offers asset protection for critical infrastructure in the deployed environment; DLEWT does not present a distinct target to adversaries as it blends in with other cargo. The compact nature of DLEWT also allows for distributed wastewater treatment and P&E generation in forward operating environments—individual critical mission facilities can isolate their P&E and water supply by installing their own DLEWT system.

Figure 1. DLEWT System.

The DLEWT system uses a unique combination of advanced wastewater treatment technologies that offer at least 75% water reuse and energy harvesting, upwards of 28 grams of hydrogen (H_2) and 0.17 therms of methane (CH_4), per every 1,000 gallons of influent wastewater. The hydrogen and methane are converted to electrons which can then supply combustion generation or fuel cells, or the energy can be stored in batteries. On average, 5.4 kilowatt hours of electricity can be generated per every 1,000 gallons of influent wastewater. An individual typically produces 2.1 gallons of wastewater per day, which means a forward operating battalion of 800 troops has the potential to generate 8.6 kilowatt hours of energy per day using DLEWT. Current unit costs for a DLEWT system are $300,000/unit, but are anticipated to be lower in future based on economies of scale.

Specifically, this emerging technology introduces a packaged anaerobic membrane bioreactor and ammonia electrolysis system that converts black water contaminants into potable water and harvestable fuels, hydrogen (H_2) and methane (CH_4) gases, for energy generation. The system harnesses the benefits of anaerobic digestion while treating ammonia as a resource. The innovative approach symbiotically integrates technologies to treat wastewater in a manner that reduces energy consumption and generates useful fuels (see Guy 2017 for a detailed description of the DLEWT system). The system is comprised of three major subsystems (1) Anaerobic Membrane Bioreactor (AnMBR), (2) clinoptilolite ion-ex-change and (3) ammonia electrolysis (Figure 2).

Figure 2. DLEWT system diagram and components.



The AnMBR contains microorganisms that degrade organics in wastewater and generate methane during the process. Further, the novel approach applied in the DLEWT system does not require solid and liquid separation for biogas production, which is the first stage of the conventional treatment process. Keeping both solids and liquid waste in the same vessel increases the amount of dissolved organics and thus, the quantity of harvestable methane. The methane can be harvested for electrical and thermal energy generation. Anaerobic based digestion significantly reduces the required process energy for treatment when compared to conventional treatment plants. In the DLEWT system, a filter after the anaerobic bioreactor tank retains the solids for longer processing times while allowing liquid to pass through to subsequent stages. In the DLEWT system, the AnMBR effluent is sent to clinoptilolite polishing step to remove ammonia below discharge limits. At this point in the treatment process, effluent is comparable to that of secondary treatment in a conventional plant.

Clinoptilolite, a naturally occurring ion-exchanging zeolite, removes ammonia from the AnMBR treated water. Traditionally, clinoptilolite regeneration has resulted in a concentrated ammonia and salt brine (Hegger 2010). In DLEWT, the regeneration product becomes the feedstock for the ammonia electrolysis process. Using a sodium hydroxide regenerant results in a concentrated ammonia solution with the proper pH for ammonia electrolysis. After ammonia electrolysis, the clean sodium hydroxide is re-cycled back to regenerate the clinoptilolite again. Effluent from the ion ex-change system is comparable to a tertiary level of treatment and can be used as gray water.

Ammonia electrolysis converts ammonia to useful hydrogen fuel using a small current and metal electrodes to drive the thermodynamically favorable electrolytic conversion of ammonia to hydrogen and nitrogen gas (Bonnin et al. 2008; Vitse et al. 2005). The hydrogen gas is available for capture and energy generation. Since the electrolysis is selective for ammonia at the voltages used, the sodium hydroxide remains in solution and is re-turned to the clinoptilolite process.

Currently, the DLEWT technology is at TRL 6 and is being assessed at the pilot scale of 1,000 gallons per day. A 12 month evaluation using real wastewater is scheduled for 2020 at Mountain Home Air Force Base in Idaho. The DLEWT system reduces the energy used to treat wastewater compared to traditional aerobic based systems while also producing usable water and energy. Energy savings are the result of recovered energy (hydrogen and methane) and the avoidance of costly aerobic treatment processes utilizing large aeration systems. The current version of DLEWT treats water to a quality suitable for reuse applications, such as irrigation, which would reduce the water demand of the site.

The next version of DLEWT, scheduled for development in 2020, will employ onsite energy storage and offer methods for capturing potable water for reuse. It is anticipated that DLEWT 2.0 will be operational at TRL 8 within 5 years. Internally, the system will include compressed gas storage (H_2 and CH_4). Hydrogen can either be utilized directly by an internal fuel cell and stored by batteries for recharging equipment or used to power smaller fuel cell technology currently in development across DoD for autonomous vehicles. Water is polished and stored for reuse.

DLEWT offers a solution that addresses both water and energy constraints, and enables a resilient, functioning metabolism for the future Army in MDO. The DLEWT system has the potential to save over $45 million annual in water and fuel cost savings in Iraq and Afghanistan based on 2009 data (Eady et al., 2009). The flexibility of DLEWT technology provides the ability to realize energy and water savings in a multitude of applications representing the diverse wastewater needs of the Army. Its efficient and durable design make it ideally suited for operations in austere and hazardous environments. The system employs emerging anaerobic wastewater treatment technology that treats wastewater in a low energy manner while generating harvestable fuels. The energy efficiency of DLEWT results in a small energy and heat signature which makes it ideal for Silent Camp. The DLEWT technology reorients the view of wastewater, treating it as a resource instead of a burden that will enable the future force to break the Tether of Fuel and achieve agility and independence of P&E and water in the forward MDO environment of the future.

The DLEWT system has the potential to not only reduce water but fuel and fuel resupply convoys. Table 1 provides an analysis of energy and water savings through implementation of DLEWT in both Afghanistan and Iraq. Significant cost savings in excess of $45 million annually could be realized. Further, these savings result in an extension of the tether of fuel reducing resupply convoys by 2,100 trips. Over 5-years 175 water re-supply casualties could be avoided through implementation of DLEWT (Eady et al., 2009).

Table 1. Analysis of Fuel and Water Savings through Implementation of DLEWT

	Current Practice					With DLEWT Technology			
	Annual Convoys	Miles Traveled	Miles/gallon	Fully Burdened Fuel Cost	Total Cost	Annual Convoys	Annual Water Savings (gals)	Annual Fuel Savings (gals)	Total Savings
Iraq	3287	450	8	$400	$73,957,500	1,438	65,082,600	104,003	$41,601,093.75
Afghanistan	438	450	8	$400	$9,855,000	192	8,672,400	13,859	$5,543,437.50

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