Regional energy and water resilience strategies for critical thermoelectric power generation and data center technologies

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Focal Areas

This white paper focuses on water for energy, namely technical strategies for reclamation and management of thermoelectric power plant and data center cooling water. The goal is to efficiently and economically close the water loop for these plants by post processing discharged cooling water, recovering valuable minerals in the process. This will have the additional benefit of reducing capital costs of energy secure generators and data centers by minimizing their required water management. In doing so it will alleviate their siting constraints thus enabling data centers and power plants to economically operate in water stressed areas of the US. Furthermore, extracting useful revenue streams from the concentrated wastewater can aid with addressing critical material needs in the United States. These technologies already face water-related challenges that we must address before they can be deployed at significantly larger scale to promote U.S. energy abundance.

Background and Existing Challenge

Existing data centers and power plant assets already make use of wastewater for cooling (Figure 1). This water is typically sourced from municipal wastewater. As the water is recirculated for cooling at the thermoelectric generator or data center, it becomes concentrated as a proportion is evaporated to the atmosphere. The remaining liquid has a high total dissolved solid (TDS), of which many of the salts are valuable. Currently this “waste” stream must be discharged to evaporative cooling ponds or deep well injected. If this water is returned to the surroundings or wastewater treatment facilities it can overwhelm them, causing issues due to its high salinity. Discharging this water demands significant capital,

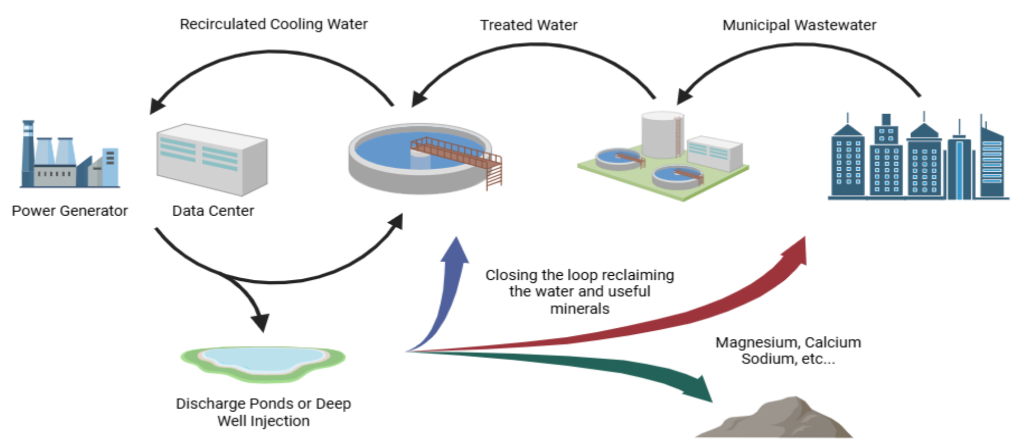

Figure 1: Closing the cooling water cycle; post processing rejected wastewater to reclaim potable water and valuable minerals

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consumes valuable land, and wastes a critical resource. In addition, evaporation rates or the feasibility of deep well injection is very site specific, limiting the areas where these techniques can be used to discharge wastewater.

As the US looks to achieve energy dominance the water resilience of these key technologies will be brought into sharp focus. The new executive orders surrounding nuclear energy and data center capacity require significant buildout of new generation and power uprating of existing assets. Data centers can consume upwards of 5 million gallons per day [3] with a single GPT-3 query associated with 2.2 mL water use at the data center and 14.7 mL to produce the power [4]. These data centers are already expanding in water stressed areas with Phoenix playing home to the second largest hub for data centers in the country. Expanding data centers and energy generation technologies in water-stressed areas, such as much of the western United States, requires a way to reduce the capital impact of water management.

Advanced desalination and brine concentration technologies can close these cycles by efficiently using low-grade heat and power from the energy technology the water serves. They can simultaneously reclaim potable water but more importantly concentrate the useful salts within the brine to sell as commodities. Discharged waters frequently carry critical minerals. For example the waste waters at Palo Verde are rich in magnesium, a critical material for aerospace and automotive industries that is no longer domestically produced in the US.

Near-Term Opportunity

US data center electricity could be as high as 580 TWh by 2028 [5]. Furthermore, the US aims to quadruple new nuclear generation by 2050 to meet the demands for reliable energy. To achieve the growth in both sectors we need to utilize new efficient solutions to identify, manage, and reclaim this water. Solutions should include:

Case Study: Palo Verde Nuclear Power Plant

The Palo Verde Nuclear Generating Station, located in the Arizona desert, faces unique water challenges due to its remote location and lack of nearby natural water sources. Unlike most nuclear plants, it relies entirely on treated wastewater—about 65 million gallons daily—piped from Phoenix for cooling its reactors [1]. This reclaimed water is becoming increasingly expensive, with costs projected to rise from $53 per acre-foot in 2010 to $300 by 2025, and even higher under a new tiered pricing model starting in 2026 [1].

Additionally, the plant contends with high evaporation rates due to the desert climate, losing up to 60,000 gallons per minute during summer [2]. As a zero-liquid discharge facility, it also is required to manage all wastewater on-site. As such any power expansion will incur high costs as current evaporation pond capacity is operating at maximum capacity.

Figure 2: Evaporative ponds at Palo Verde

1. Scaling up existing brine concentration and mining technologies and exploring new economic and energy efficient pathways for mineral separation. Efficient combinations of membrane desalination technologies, thermal concentration stages and solvent extractions using heat and electricity from the thermoelectric generators will unlock commercial water mining and reclamation. An example of one such scheme is shown in Figure 2 for reclaiming salts from a high TDS brine stream.
2. Design and Optimization of thermal and electrical couplings with existing power generation in an integrated energy system. INL's developed FORCE toolset is well suited to the optimization of process coupling and economic assessment of multi-commodity integrated energy systems [6]. Used in conjunction with existing water modelling tools such as WaterTap [7] and IDEAS [8] then efficient reliable designs can be obtained to reclaim water and minerals from plant waste streams
3. Identification of the most important use cases by leveraging existing industrial connections. A significant part of this project is identifying current or planned projects where this water reclamation may be profitable. By leveraging connections with public utilities and data center companies, different strategies may be sought for different regions

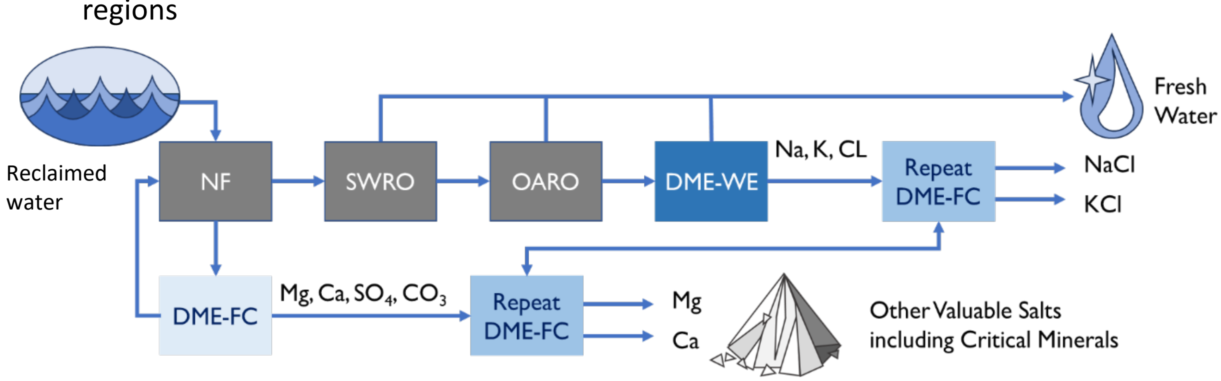

Figure 3: A potential method of combining desalination technologies to extract fresh water and valuable minerals from the brine. The commercial adoption of Nanofiltration (NF) as a pretreatment for Seawater Reverse Osmosis (SWRO) as well as the development of Osmotically Assisted Reverse Osmosis (OARO) makes the application of Dimethyl Ether Water Extraction (DME-WE) and Dimethyl Ether Fractional Crystallization (DME-FC) economically viable for mineral recovery.

Success Measure

We define success as discovering profitable new methods to reclaim water and minerals that would otherwise need to be lost through discharge to expensive evaporation ponds or deep well injection. Any successful approach would include the development of one or more implemented integrated water and mineral reclamation strategies for regional water use. Any developed strategy must include demonstration to ensure widespread adoption for future integrated data center and power assets. In conjunction with ensuring the success of reliable power generation and data centers for AI, the means to which the work supports and grows nascent brine mining technologies would be a powerful success measure. These industries are targeting critical mineral extraction from seawater or industrial wastewater. By providing a profitable and important use case now, this work will help ensure this sector can secure US access to critical minerals in years to come.

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