Title: Energy-Water Interdependence Network (EWIN) of Regional Water Supply using Nonconventional Water for Energy-Water Resilience

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Focal Area(s): Energy and Water interconnection

Nonconventional water (NCW) including the impaired water (brackish, reclaimed) and produced water will be an inevitable resource to address the scarcity of water and/or contaminated surface water for sustainable water supply network. The cooling water currently used in thermoelectric power plants already reaches > 40% of entire US water supply [1]. The withdrawal for cooling water will be significantly escalated for future AI data centers in addition to the extra energy needed that also require more cooling water. Besides water conveying energy, the energy intensity (EI) of NCW supply largely depends on the purification (e.g., desalination) energy from various water technologies and the quality of NCW. The extra energy needed to treat NCW, however, will impact the energy-water resilience. Therefore, development of effective strategies will rely on reliable region-dependent energy-water interconnection relationships.

Existing Challenge

1) Extra energy to treat NCW

The low energy efficiency of purifying NCW is one of the key barriers using state-of-the-art technologies. Current large-scale, e.g., >500,000 m^3/day, seawater desalination technology the reverse osmosis (RO), has relatively low thermodynamic energy efficiency (TEE) (illustrated in Fig. 1), ~ 15% to produce portable quality water from the impaired water (< 5 g/l salinity). It is due to its high irreversible operation energy needed compared to the ~ 46% TEE from seawater (35 g/l). The emerging water technologies capable of removing salt with higher TEE from impaired water, for example the electrochemical separations technologies (EST), reported to be >35% TEE[2-4]. The 20% higher TEE in energy saving would be equivalent to the energy produced by **35** 500 MW electric power plants if NCW were used as the cooling water for entire power plants. It, thus, will have a transformational impact on the ecosystem of water supply and conservation. Therefore, the assessment of energy intensity in water supply from NCW for cooling needs the field data of high TEE emerging water technologies for energy-water resilience. Currently, there is no accurate field demonstration data of NCW desalination with TEE > 40% available in large-scale operation. Establishing regional water technology testbed is necessary to standardize the measurement metrics for any projection and planning of energy and water resilience since the variations of local NCW quality will influence the energy intensity of water supply.

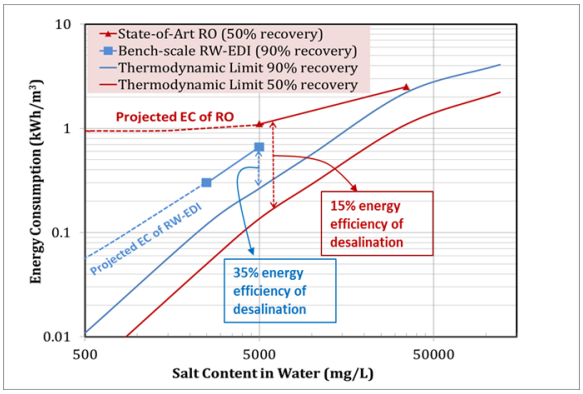


Figure 1 Energy consumptions of brackish water desalination by EST; and RO

2) High reginal energy intensity of water supply using NCW

Because of the water scarcity that limits the use of surface water for cooling, water technology developed to handle nonconventional water for cooling faces economics, energy and implementation challenges. Direct cleaning of the low-quality nonconventional water needs numerous extra energies. Technology alone cannot address the challenges of water-energy nexus. The extra energy and cost can be reduced if the limited water resource can be shared regionally, a concept of water chain.

Near-Term Opportunity:

1) Establish energy-water interdependence network (EWIN) to for water-chain concept and mode:

Figure 2 illustrates the flow algorithm of EWIN[5]. The water used by major customers (e.g. power plants, chemical plants, etc.) are modeled as entities which have the capability to consume or process certain amounts water with configurable water treatment technologies. An entity in general has three stages for its internal water process/use: pre-process, process, and post-process stages. There is a set of process technologies for selection in each stage. Each technology may have the capability to process water in terms of quantity and quality with cost and energy consumption. The entity can select the most appropriate technologies for each stage to minimize the cost or energy use, subject to quality and quantity requirement and technique constraints. In regional scale, there are multiple entities connected in many ways related to water use. For example, entities might be connected in a tandem queue as upstream or downstream. Entities can also connect to the same upstream or downstream entity. The relationship can be modeled as a water flow network, as shown in this figure. In a network environment, an entity might need to comply with constraints in terms of the quantity and quality of water it can dispose of with its downstream entities, which in turn have impact on its water process. By modeling the water flow and process of several connected entities, it can be used to optimize the energy/water use by determining the fit-to-use water treatment technologies for entities within the self-sustained network system for a given length of period, subject to physical, operational, regulatory, environmental constraints. The impact of environmental issues can be analyzed as well, e.g. carbon footprint, water footprint.

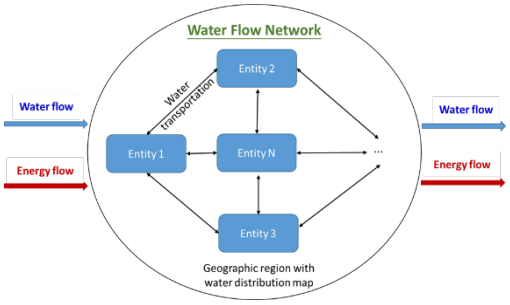


Figure 2 Flow diagram of water and energy flow in EWIN

2) Establish Energy Intensity Database of Water Supply via High-efficient Water Technologies Testbed Guided by Regional Water-Chain Network

Among the emerging technologies with high EE and cost effective, innovation on improving the performance of EST provides the most promising, linear scale-up technology. For example, the electrodeionization that is currently used commercial for ultra-pure water production may be feasible to be used for the testbed to evaluate the energy intensity of various water flows following the entities mapped by the EWIN. Currently, EDI can achieve >35% TEE using commercial components. Its TEE can potentially be improved to 50% with innovative material. Because of its current commercial status with large-scale operation, innovative material with manufacture supply chain can make immediately and transformational impacts to energy-water resilience. Upon achieving the near-term opportunity, low TRL emerging technologies, such as capacity deionization (CDI)[6], shock-wave electrodialysis (SWE) will have potential to improve EE with practical and large-scale operation of impaired water desalination.

Success Measure:

To create economically viable and energy saving in treating impaired water for industrial water supply, the new water technology needs to have operation with close to 50% EE, < $0.25/m3 and > 40% footprint to replace current investment in new RO plants.

References:

[1] EPRI. Water Treatment for Power Plant Cooling Towers. Electric Power Reseach Institute, 2012.

[2] Shu-Yuan Pan, Seth W. Snyder, Aaron I. Packman, Yupo J Lin, Pen-Chi Chiang. Cooling Water Use in Thermoelectric Power Generation and its Associated Challenges for Addressing Water-Energy Nexus. Water-Energy Nexus Journal, Vol. 1, Issue 1, June , 26-41 (APT#. 2018.

[3] Shu-Yuan Pan, Seth W. Snyder, Yupo J. Lin,,Pen-Chi Chiang. Electrokinetic desalination of brackish water and associated challenges in the water and energy nexus. Environ. Sci.: Water Res. Technol., , 4, 613-638. 2018.
[4] S. Pan, S. Snyder, Y. Lin and P. Chiang, Energy-Efficient Resin Wafer Electrodeionization for Impaired Water Reclamation, Journal of Cleaner Production 174:1464-1474 · February 2018
[5] Li-Heng Chen, Pei-Chiun Li, Yupo Lin, I-Chun Chen, Hwong-wen Ma, Chang-Ping Yu. Establishing a quantification process for nexus repercussions to mitigate environmental impacts in a energy-water interdependency network. Resources, Conservation and Recycling, AUG. 2021.
[6] L. Weinstein, R. Dash, Capacitive Deionization: Challenges and Opportunities Desalination & Water Reuse. 2013.