An integral approach for water treatment and the use of water-energy interdependency network

Y. Lin, Z. Zhou, S-Y Pan and S. Snyder

Energy System Devision, Argonne National Laboratory
Argonne 60439, USA,
corresponding address: yplin@anl.gov

ABSTRACT

In this presentation, a water-energy interdependency network (WEIN) model is proposed to directly correlate the quantity and quality of energy and water during the development of the most fit-to-use water treatment technologies in a chain of water use entities, to minimize associated cost or water/energy use. A simpler but commonly existing relationship between water use entities: chain model (tandem model), is setup where entities are connected as a tandem queue as upstream and downstream. Using the WEIN, water use entities can be connected in any way and any direction by a network model. A water treatment technologies database including process performance of energy consumption, purification ratio, processing rate and process economics is used to establish different decision model. Given the degree of information sharing and coordination between entities, the decision models of "no coordination" and full coordination are compared. For coordinated network, the objective is to optimize the energy use/cost saving for all related entities by selecting the most appropriated water treatment technologies and treatment schedule/strategies. For entities without coordination with any others, its decision is optimized individually given whatever water it receives and complies.

Keywords: impaired water, water chains, energy efficiency, optimization, thermoelectric power.

1 INTRODUCTION: SIGNIFICANCE AND IMPORTANCE

Freshwater stress and scarcity is one of the most challenging emerging issues due to climate change, rapid population growth, urbanization, and improved standards of living. Desalination of impaired water, such as brackish, reclaimed and plant (process) water, is a resource-efficient solution of "fit-to-use" water service strategies. A major part of energy-water nexus concerns the energy efficiency and energy consumption for supplying and treating water. Because the interdependency of water and energy, the paradigm shift from surface water supply to the use of impaired or reused water, energy efficiency to prepare the water became extremely critical to sustainability.

As shown in Figure 1, "removing the salt" would be the preferred approach to improve energy efficiency in relatively low saline water. One of the emerging industries will be profoundly impacted is the thermoelectric power plants that use the single largest source of surface water withdrawal in the United States (~196 G gal/day, 40% total water withdraws in US) for cooling [1]. Desalination is the most energy-intensive and expensive operation for cooling water to prevent scaling and corrosion. In an improvement of energy efficiency, e.g., from 12% to 30% (i.e., 0.5 kWh/m^3 water energy saving) in cooling water desalination of the entire power plant industry, the energy saving each year would equal to the energy produced by 30 of 500 MW power plants (or $6.5 billion worth of electricity).

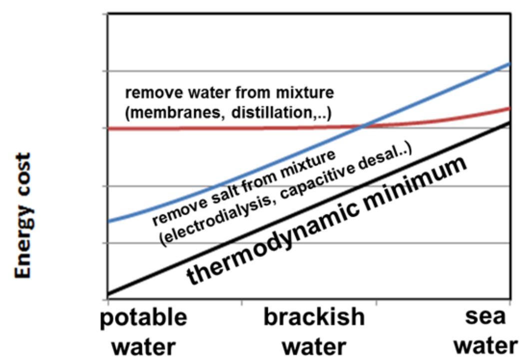

Figure 1: Comparison of energy cost to purify saline water using two different approaches: removing water or salts from the aqueous mixture

Existing technologies, such as reverse osmosis (RO) and electrodialysis (ED), are well established for seawater desalination. However, these technologies have not been optimized for impaired water because they were operated far from the thermodynamic efficiency limit of desalination. There is significant difference in energy efficiency of RO from near maximum 46% for seawater desalination to 11.3% for impaired water (e.g., the brackish water) desalination. This is due to the nature of energy costs in purification strategy, i.e., removing either the water or the salts from the aqueous mixture. Therefore, the needs of technologies other than RO desalination for reclaimed water are emerging in order to improve energy efficiency. Due to the irreversible energy consumption in RO

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operation, there is no room to improve its energy efficiency for impaired (e.g., brackish) water desalination.

To minimize the extra energy consumption of nontraditional water treatment, multiple uses of the same water from the root source, a sophisticated water chain could make a true impact on the regional-scale of energy efficiency in water treatment technology. With efficient management, the users inside the chain will also be benefited economically and in the same time contribute to environmental sustainability. From regional scale, it will result reducing overlapped water treatment, more efficient water distribution/usage. For water technology users, "best suitable" operation condition for technology could contribute to less energy consumption, less investment in water treatment and more options in securing water resilience.

Therefore, in this study, we developed a new energy–water nexus analysis framework, so-called water energy interdependency network (WEIN), and water chain models to evaluate the availability of "fit-to-use" water to guide the development of advanced water technology with minimum energy consumption and water treatment cost. Both energy used for impaired water (pre-)treatment and wastewater treatment, and water consumed for electricity generation were evaluated.

2 CONCEPT OF WATER-ENERGY INTERDEPENDENCY NETWORK (WEIN) TOOL

The required water quality for cooling in power plants are strongly depending on the key constitutes in the water sources. Selective separation in the water desalination is a crucial technology design factor to only selectively remove the key constitutes for quality water to save energy consumption and increase water reused cycles.

With its large throughput of water flow, integrating the water management and treatment of power plants and other water users in the region will make an even bigger impact on energy and water savings. The degree of water treatment and selection of effective technologies for treatment are influenced strongly by the water sources and management in every water end user site. Total water treatment stages may be reduced by passing on the water output with minor or no treatment into the next user site in a water chain network. Once integrated into regional water management systems, selection and operation of the water technologies in the power plant will become dynamic.

Figure 2 shows a typical water and energy flows for a geographic region or a water distribution map. The considerations of a water-energy flow network should include time period, physical and operational constraints, regulatory barriers, and environmental conditions. With the water-energy flow analysis, the key performance indicators (KPIs), such as carbon footprint, water footprint, and ecology footprint, coould be determined.

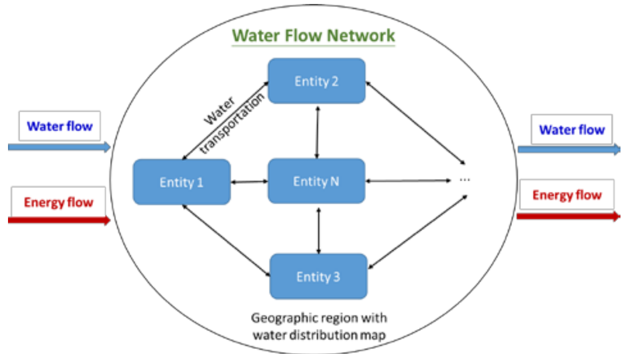


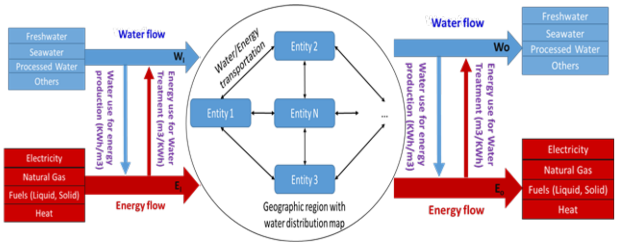
Figure 2: Water and energy flows for a geographic region.

Therefore, we developed a system modeling with basic algorithm and database to assess the complex effects of water source quality/water reuse strategy on the selection and operation of water technologies and their influences on other water users in a water chain. Extensive research has been carried out to examine the relationship between water and energy for power generation, e.g, wind power [2]. Although it is common acceptance that water and energy have interdependency, however, most of the assessment of water and energy resources and consumption were treated separately in analysis model

3 COORDINATED WATER TREATMENT AND ENERGY PRODUCTION/CONSUMPTION

Each water sources into the regional or the specific end-users also including the energy consumption for convey and treatment. There were not taken into account. In the similar situation, most of the energy sources may also including the use of water during the energy generation which was also not considered. Therefore, to effectively reflect the actual situation of both water and energy flows, the water and energy interdependency should be quantitatively considered during any assessment or process optimization.

Figure 3 shows an illustration of the interdependency of water and energy flows. A WEIN model was developed to define the interdependent parameters. The WEIN could be used not just in all the assessment models or life-cycle analysis for regional sustainability. In addition, it can be used to determine the process optimization of energy and water technologies development in specific local users to gain the maximum benefits from a regional water chain or contribute to water-energy nexus.



$$E_{I,T} = E_I + E_{W,I}\,;\quad E_{O,T} = E_O + E_{W,O}$$
$$W_{I,T} = W_I + W_{E,I}\,;\quad W_{O,T} = W_O + W_{E,O}$$

$E_{I,T}$ is the total energy input; $W_{I,T}$ is the total water input; $E_{O,T}$ is the total energy output; $W_{O,T}$ is the total water output;

Figure 3: Illustration of water-energy interdependency network (WEIN) to implicitly correlate the water and energy flow in system model.

The inputs of the WEIN for power plant operation, for example, with water constraints include load demand (in a non-market environment), market prices (in a market environment), and power plant physical parameters. Information on the water chain parameters, such as (1) water sources (quality and quantity); (2) pretreatment performance of source water; in term of energy consumption and quality (3) post treatment performance of blowdown water, in terms of energy consumption; and (4) cooling water quality and quantity. In this case, the outputs of the WEIN would include electricity output/ or consumption, water used / reclaimed amount, and revenue/cost/profit.

4 CASE STUDY: THERMOELECTRIC POWER PLANT

The illustration of water chain system modeling framework is to determine the most fit-to-use water treatment technologies in a chain of water use entities to minimize associated cost or water/energy use. They include three stages for internal water process/use in power plants: 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. We will select the most appropriate technologies for each stage to minimize the cost or energy use, subject to quality and quantity requirements and technique constraints.

In this study, the water-energy nexus of a thermoelectric power plant was evaluated via the inputs defined by WEIN. To optimize the energy use and water consumption. Figure 4 illustrates the typical water and energy flows in a thermoelectric power plant for water chain model. In general, for a thermoelectric power plant, it is associated with the amount of generation, which depends on time of a day, temperature, etc.

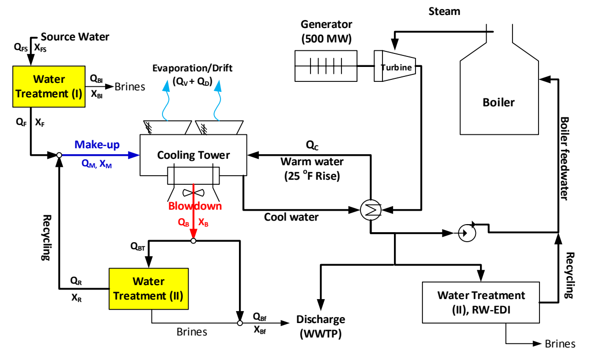


Figure 4: Typical water and energy flows in a thermoelectric power plant for WEIN model.

Excercise in the case of different energy and ware supply constrains, we will demonstrate the potential impacts of water management and treatment on energy generation in power industry that consumes more than 40% of water withdrawal in the US. In addition, in the short-term, the results will assess the feasibility for a directly beneficial to the power plant industry without major applied technology changes while reducing energy consumption and the operation cost. The increase of water treatment efficiency also indirectly provides water conservation. The evaluation and methodology developed in this study are applicable to most of the water treatments. Therefore, it would also be beneficial to other industries for water reuse.

5 CONCLUSIONS

In this study, a water chain network model was developed and established to optimize the energy use/cost saving of cooling water supply for a thermoelectric power plant. The water-energy interdependency network (WEIN) tool was employed as input for analysis of the coordinated water/energy network. In a case study, the interactions of water and energy dependency of a power plant with different constrains of water supply and quality, energy consumption were assessed using the water chain model. These constraints were considered to evaluate the dynamics and uncertainty of the water/energy flow network in the thermoelectric power plant.

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