Executive Summary

INTRODUCTION

Our knowledge of the opportunities for, and the multiple benefits of, the conjoined management of water and energy resources is not new. In his heralded 1994 *Annual Review of Energy and the Environment* article, which established the field of integrated water-energy studies, Peter Gleick employed a full-scale life cycle analysis of water and energy resources to explicate and quantify the water intensity of energy resource development from extraction through power generation, as well as the energy intensity of the water sector from extraction through conveyance, treatment, distribution and end use. Policy and planning for state and national regulatory innovation have slowly emerged on a limited basis to foster the conjoined savings and management of water and energy resources, and a limited array of water and energy utilities have initiated the optimization of operations for integrated resource management. Yet the depth of Gleick's call for regulatory and operational innovation, and for more interdisciplinary research to capture the full benefits of integrated water-energy resource management, largely remains unmet.

As we contemplated establishing a Stanford University interdisciplinary water-energy research program to bring the university's substantial faculty and research expertise to this still-nascent field, we determined that a significant place to begin was to employ Gleick's full water-energy life cycle approach to evaluate the current state of the highly interdisciplinary water-energy studies field. This Water-Energy Literature Review utilizes the full water and energy life cycle approach to survey the literature from the academic, government and nonprofit sectors, and particularly underscores opportunities for future research to forward this critically important research arena. This executive summary previews some of our more salient findings.

ENERGY USE IN THE WATER SECTOR: CRITICAL FINDINGS

Perhaps one of the most well-documented arenas of water-energy nexus research is the energy embedded in the water and wastewater sectors. Much of the energy in water research emanates from academic, nonprofit and state agency researchers and policy analysts in California, the nation's first state to adopt statewide energy efficiency programs, as well as to pass climate change legislation (AB 32, Global Warming Solutions Act of 2006).

While informed by California-based efforts, our research review particularly employs Gleick and Wilkinson's water life cycle approach to examine energy for water extraction, energy for water conveyance, energy for water treatment and distribution, and energy for wastewater treatment. Forthcoming sections of this review will address water and energy end use across the commercial, industrial and residential sectors.

Our review of existing literature on the **energy for water extraction** reveals the critically important challenge of developing a more robust database for groundwater supplies across the United States. A key research need is to encourage and develop national-scale groundwater data collection efforts to enumerate existing groundwater supplies and groundwater pump energy consumption at local, regional and state levels of aggregation. Case studies are also needed to assess the energy costs associated with the overdraft of aquifers, as depleted aquifers require pumping remaining water supplies from greater and greater depths, thereby requiring greater energy investments in water extraction. In order to better coordinate peak load energy demand management, localized studies of groundwater pump populations are critically important to better understand the energy use of these pumps across pump age, fuel, type and total number, among other attributes.

In California, along with energy employed in water distribution, the **energy for water conveyance** comprises the greatest source of energy use in the water sector, and managing energy use in water conveyance nationally is directly tied to reducing water loss during conveyance. Research is needed to investigate and quantify the magnitude of water losses across the nation's large-scale local, regional, state and federal water conveyance projects, and to assess the energy embedded in those losses.

The energy deployed in **water treatment and distribution** is a principal target for reducing the embedded energy in the nation's water supplies. Our research assessment reveals the need for developing and administering a national survey of water treatment plants to assess the potential differences in practices across the nation's plants, and to analyze these findings in light of expert recommendations on the benefits of, and processes and technologies for, achieving greater energy efficiency in the nation's water sector. The potential for innovation in the nation's regulation and processes for water treatment also merits serious attention. Life cycle analyses of recycled water are needed to explore whether the energy employed to build, maintain and operate new and separate water distribution systems would result in net energy savings when weighed against the energy saved by forgoing treatment of recycled water to national drinking water standards. Studies are needed as well to assess the energy intensity of advanced treatment systems such as nanofiltration, and forward and reverse osmosis.

As chemicals, or constituents, of emerging concern (CECs) – including pharmaceutical products, industrial by-products and fertilizers, among others – enter the nation's water supplies, state and federal regulations are being developed to target their removal. Assessments are needed to determine how much additional energy will be required to remove CECs from the nation's water supply using the existing treatment technologies, and to identify new technologies which might be used to remove CECs at lower energy intensities. Other research opportunities include the development of holistic methodologies to optimize municipal investments in green infrastructure and watershed protection in terms of avoided treatment costs and other benefits, including flood control and ecosystem management, among others. As the so-called smart technology/clean technology expands in the water/wastewater arena, assessments are also needed to explore the benefits which these new technologies may bring to capturing energy efficiency and greenhouse gas emissions reductions in water and wastewater treatment.

One of the greatest opportunities for reducing the energy intensity in the water sector is in the **energy for wastewater treatment**. In order to assess the prevalence of the deployment of Best Management Practices (BMPs) for energy efficiency and management in the wastewater treatment sector, comparative studies are needed to compare the data derived from the U.S. Environmental Protection Agency (EPA) surveys on in-situ wastewater practices with the current BMPs. On-site, decentralized sewage facilities are also gaining renewed attention as a means to generate new revenues through the development of new waste-to-energy products while reducing the energy intensities generally associated with larger, centralized municipal treatment systems. Research is needed to compare the benefits and costs of innovative on-site sewage facility technologies across centralized treatment plants and septic systems, where applicable. Finally, assessments are needed to identify the barriers to, and pathways toward, incentivizing the optimization of water treatment plants to lower their energy use. Interviews with operators and agency managers will provide critically important information about these barriers, as they are the industry's practice leaders, daily engaged with the processes and mechanics which constitute ground zero for wastewater systems energy optimization.

WATER USE IN THE ENERGY SECTOR: CRITICAL FINDINGS

Our review enumerates and evaluates the body of literature assessing water-use intensities, and associated water quality and wider environmental impacts, across the extraction, processing, storage and transport of the array of energy sources, including coal, natural gas, uranium, thermoelectric generation, oil and transportation biofuels. A subsection on hydropower is forthcoming. Like Gleick, we identified the continuation of significant gaps in the collection and reporting of consistent and reliable water use data and water quality impacts across these energy resource arenas. As we discuss below, there remains a paucity of national and state regulatory requirements for quantifying the water use in, and assessing water quality impacts across, the energy sector. The need for energy-sector case studies and policy and regulatory innovation addressing water use consumption, as well as water quality for produced water, continues to be a critical priority.

Though **coal** extraction and processing use substantially less water than that deployed in thermoelectric generation, substantial challenges remain to fully understanding the magnitude and impact of water use in the expanding extraction of coal in concentrated areas across the American West. The expansion of mountaintop mining using valley fill techniques merits assessment for the presence of, and extent of damage due to, the loss of headwaters and associated habitats as well as its impacts on freshwater supplies. Case studies are also needed to assess the impacts of both open-pit mining and mountaintop mining techniques on groundwater, including direct degradation from contaminated drainage and rainfall infiltration and indirect degradation employing blasting, respectively, as well as the effects of subsidence on overlaying aquifers. Coal processing has also produced numerous coal slurry spills, and case studies of the environmental impacts of these spills will make critical contributions to understanding the nexus of water and coal.

Natural gas extraction, processing and storage are currently expanding across the United States. The unconventional extraction of natural gas through the development of shale and tight sand gas supplies particularly calls for attention to the need for reporting requirements and research on the effects of such extraction on both consumed and produced water. Impact studies are needed to determine the effects of degraded flowback water containing chemical constituents, which are discharged into surrounding municipal water systems. Additional studies to evaluate the environmental impacts of the various disposal methods for contaminated flowback water are needed, including assessments of flowback re-injection at shallow depths and deeper formations, as well as evaporation into solid waste. Case studies of the environmental impacts of both groundwater extraction and wastewater/produced water reuse associated with coal bed methane extraction are also critically important to forward our understanding of the potential consequences of this form of natural gas extraction on water supplies. Newer sources of natural gas employ a host of newer process technologies, and little information is available regarding the water intensity of the deployment of these process technologies. The water intensity of Liquefied Natural Gas also merits assessment through studies of the impact of water withdrawals at LNG terminals.

Uranium mining in the United States is now principally concentrated at four "In-Situ Leaching" (ISL) mines accounting for 90 percent of U.S. uranium production, and each is located in water-stressed regions across the West. Evaluations of the wider environmental impacts, of potential groundwater quality effects and of calculations of the water intensity of uranium mining are needed to fully understand the importance of uranium mining on water. The last studies of the water intensity of uranium mining were completed in the 1970s, and newer studies are needed to understand the current water intensity of uranium processing and transporting.

The **thermoelectric generation** power sector is particularly water intensive, accounting for almost 52 percent of surface freshwater withdrawals and 43 percent of total water withdrawals. While only 7 percent of this water is consumed by power plants and the remainder is returned to the environment, the impacts of both water withdrawals and the quality of returned water are a primary concern. Well-placed monitoring and assessments are critically important in order to understand the long-term impacts of groundwater withdrawals on aquifers coterminous with power plants located in rapidly growing areas of the American Southwest. There is also a need to evaluate the effects of closed-loop cooling system power plant operations on local water quality, with particular attention to the wide array of chemical constituents — i.e., chlorine, bromine, sulfuric acid, sodium hydroxide and hydrated lime — released in waste streams, as well as water quality issues associated with blowdown water with high Total Dissolved Solids (TDS). The long-term effects of climate change on water supplies also call attention to the need for fostering technological innovation and research to develop, and to improve, dry and hybrid cooling technologies to achieve lower water intensities in power plant operations, and to generally target the causes of water loss in cooling towers. Equally important is enhancing opportunities for expanding the use of recycled water for power plant operations, including industrial and municipal wastewater, gray water and non-potable brackish water.

Data on the water intensity of the oil sector remains limited. Future analyses of the effects of transportation fuel and other petroleum goods on water resources should employ a full life cycle analysis extending from the production and transport to the storage of fuel. Research is also needed to estimate or determine the volume of leaked transportation fuels from underground fuel storage tanks into groundwater, and to evaluate the environmental impacts of leaked chemical compounds such as benzene and toluene associated with those fuel leaks.

The water and energy intensity of **transportation biofuels** particularly merits study as their popularity increases as a means of reducing the carbon footprint of the transportation fuel sector. Research addressing biofuel feedstock should include regional analyses of forest and switchgrass fuel potential based on water extraction costs, potential water quality impacts and production water intensities. More generally, there is both a need and an opportunity for the development and implementation of a water accounting system to evaluate biofuel production at local levels. Finally, a plethora of different metrics are currently employed to describe the water and energy intensity of biofuels, and there is a need to harmonize these metrics and to employ a single metric for publishing an Annual Biofuel Report as an additional component of the existing U.S. Energy Information Administration (EIA) annual report.

CONCLUSION

This Water-Energy Literature Review is offered as a snapshot of current understanding about the water-energy nexus. It is meant to invite engagement and investments in future interdisciplinary research to target water use efficiency in the energy sector and energy efficiency, or reductions in energy intensities, in the water and wastewater sectors. While it constitutes a broad overview of national water-energy research, this Review has been informed by the robust public-policy and utility-sector efforts to address the energy intensity of California's water supplies across the water life cycle. Readers interested in more information about the water-energy nexus are encouraged to delve deeper into the considerable literature reviewed in this document.