A WATER-ENERGY RESEARCH AGENDA:
Building California's Policy Foundation for the 21st Century

WATER IN THE WEST
STANFORD WOODS INSTITUTE FOR THE ENVIRONMENT
THE BILL LANE CENTER FOR THE AMERICAN WEST

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Building California's Policy Foundation for the 21st Century

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About Water in the West:

Water in the West is a partnership of the faculty, staff and students of the Stanford Woods Institute for the Environment and the Bill Lane Center for the American West. Its mission is to design, articulate and advance sustainable water management for the people and environment of the American West. Linking ideas to action, Water in the West accomplishes its mission by engaging in cutting-edge research, creative problem solving, active collaboration with decision-makers and opinion leaders, effective public communications and hands-on education of students.

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Executive Summary

Energy and water, while often managed separately, are closely linked. Water is an integral part of energy development and production. Energy is needed in every step of the water use cycle, from water extraction, treatment and distribution, to wastewater collection and treatment. As different communities reach the limits of their supplies of both water and energy and look to alternatives to meet demand in both sectors, the interdependency between water and energy and the potential cross-sector challenges are increasingly evident. In the recent decades, California has been dealing with various water and energy issues. From extensive droughts to rising energy costs, the state is realizing that supplies of cheap water and abundant energy have limits.

In 2012, Water in the West – a collaboration between the Bill Lane Center for the American West and the Woods Institute for the Environment at Stanford University – launched the Water-Energy Research Program to build knowledge, pursue solutions and demonstrate success in promoting efficiency in the management of energy and water in California.

The program first published a comprehensive Water-Energy Nexus Literature Review to articulate the current state of knowledge on the subject. While California has been in the forefront of evaluating the interlinks of water and energy, there is little understanding about how policymakers can effectively use the findings and knowledge generated to change the way they manage and plan water and energy, while considering cross-sector tradeoffs. The following water-energy policy research agenda intends to fill this gap. It reflects many of the key components that merit research investments to move the public policy and implementation arena forward in order to achieve effective coordination of water-energy planning and management in California. High-impact research priorities identified in the agenda include:

- Realign water and energy policy and decision-making processes
- Develop decision support tools to assess the socioeconomic value of potential statewide energy saving strategies across the water-use life cycle
- Develop a comprehensive, high-resolution water-energy data platform
- Study effective and improved water pricing policies
- Evaluate the socioeconomic return of investment in more energy-efficient water and wastewater systems, as well as water conservation
- Evaluate the impacts of energy production and use on water availability and security as they pertain to river basin
- Evaluate potential energy-demand management and savings through integration of regional/local water and wastewater management
- Develop and incorporate new waste-to-energy technologies, systems and processes
- Evaluate the co-benefits of decentralized water treatment technologies as part of the water-energy nexus
- Evaluate how technological innovations and advancements would improve energy reliability
- Design effective communications and outreach platforms

We envision that the results of these research paths will enable decision-makers and policymakers to craft more comprehensive, coordinated and science-based policies and regulations. In this way, California can reach sustainable water-energy equilibrium with cost-effective investments.

Background

In July of 2012, Water in the West – a collaboration between the Bill Lane Center for the American West and the Stanford Woods Institute for the Environment at Stanford University – launched the Water-Energy Research Program[1] with a focus on California's water-energy nexus targeting three areas:

- Building knowledge to strengthen and sustain the intersection of research and policy to achieve innovation across integrated water and energy efficiency metrics, regulatory innovation to "de-silo" the management of California's water and energy resources, and regulatory alignment to facilitate the full implementation of the water-energy measures enumerated in California's Climate Change Scoping Plans
- Pursue solutions and demonstrate success by employing pragmatic, credible and collaborative approaches to achieve and promote integrated resource efficiency in the water-energy nexus
- Promote collaboration among diverse interests to commit and engage in actions moving California and the West toward integrated water and energy resource management across regulatory, implementation and funding arenas

The Program initially focused on convening key water-energy nexus experts in Uncommon Dialogues, which are conversations focused on finding solutions to major issues, such as "(Re)Aligning California Climate Change Policy and Innovation in the Water Sector." At these meetings, Water in the West has engaged water/wastewater utilities, energy utilities, regional water associations and institutions, state interagency committees, the California Governor's Office and key environmental nonprofit organizations, among other actors in California's water-energy policy sphere.

In August 2013, the Program completed an updated *Water-Energy Nexus Literature Review* modeled after the Gleick (1994) water-energy life cycle research review, which first articulated the water-energy research sphere. The Program was also tasked to develop a research agenda to highlight research gaps and opportunities to promote coordination of water-energy management and advance cross- sector learning and knowledge transfer to inform contemporary policy and practice. This research agenda emerged from the Dialogues; the initiative's team members experience and activities in water-energy related public policy development, implementation and innovation efforts in California; and from opportunities identified in the updated Water-Energy Literature Review. While this research agenda is crafted to further guide relevant research that would facilitate more effective collaboration and cooperation between the water and energy sectors in California, many of the research opportunities identified here may apply to other regions and the U.S. as a whole.

This research agenda will guide some of the water-energy research projects that will be conducted by the Water-Energy Research Program in coming years. Through this research, the initiative expects to establish cross-learning opportunities among academia and other water-energy actors, and build a foundation for future cross-sector collaboration to inspire informed, science-driven and integrative water-energy policy innovation.

1 With the help of Dr. Cynthia Truelove and funding from the S.D. Bechtel, Jr. Foundation

The Water and Energy Nexus

Energy and water, while often managed disjointedly, are closely linked. Water is an integral part of energy development and production, and energy is needed in every step of the water-use cycle (Figure 1).

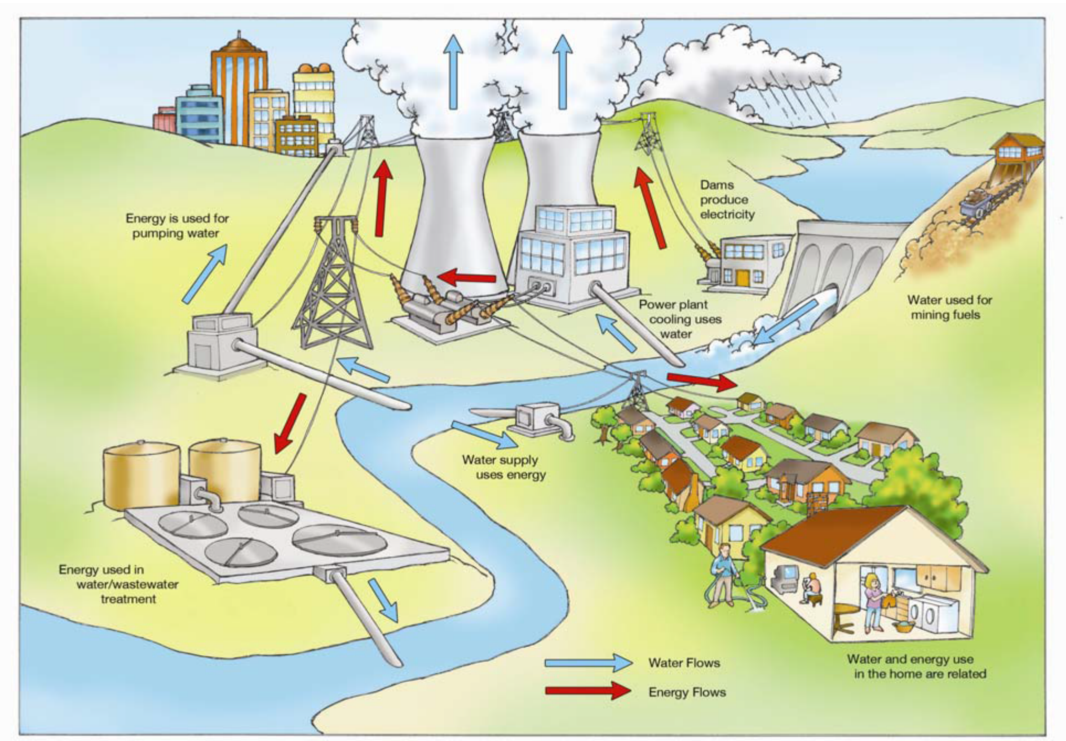

Figure 1: Illustration of water and energy interdependencies

Source: DOE, 2006

Water for Energy

The energy sector impacts both water availability (quantity) and quality. Water is used in energy extraction, production, transportation and storage; refining and processing fuel; electricity production; and power plant cooling among other functions (DOE, 2006). Through these processes, some water is consumed (lost through evaporation), or contaminated and impaired, making it unfit for further use. There is limited data available on energy-related water consumption in California, but nationwide, the energy sector (including biofuels, thermoelectric and fuel production) constitutes 14 percent of consumptive use of water, second to agriculture at 71 percent (Carter, 2013). Table 1 illustrates the impacts energy sector can have on water quality and quantity.

Energy Element	Connection to Water Availability (Quantity)	Connection to Water Quality
ENERGY EXTRACTION AND PRODUCTION		
Oil and Gas Exploration	Water for drilling, well completion and hydraulic fracturing	Impact on shallow and deep groundwater quality
Oil and Gas Production	Large volume of produced, impaired water	Produced water can impact surface and groundwater
Coal and Uranium Mining	Mining operations can generate large quantities of water	Tailings and drainage can impact surface water and groundwater
Biofuels and Ethanol	Water is used to grow biomass	Pesticides and fertilizers can contaminate surface water and groundwater
ENERGY REFINING AND PROCESSING		
Traditional Oil and Gas Refining	Water needed to refine oil and gas	Refinery operations can contaminate water
Biofuels and Ethanol	Water used for refining into fuels	Refinery wastewater produced
Synfuels and Hydrogen	Water used for synthesis or steam reforming	Wastewater produced
ENERGY TRANSPORTATION AND STORAGE		
Energy Pipelines	Water used for hydrostatic testing	Wastewater produced
Coal Slurry Pipelines	Water used for slurry transport; water not returned	Final water is poor quality and highly contaminated
Barge Transport of Energy	River flows and stages impact fuel delivery	Spills or accidents can impact water quality
Oil and Gas Storage Caverns	Slurry mining of caverns requires large quantities of water	Slurry disposal impacts water quality and ecology. Contaminants can leak, polluting surface and groundwater
ELECTRIC POWER GENERATION		
Thermoelectric (Fossil, Biomass, Nuclear)	Surface water and groundwater are used for cooling and scrubbing	Thermal and air emissions impact surface waters and ecology
Hydroelectric	Reservoirs lose large quantities to evaporation	Can impact water temperatures, quality, ecology
Solar PV and Wind	None during operation; minimal water use for panel and blade washing	

Table 1: Connections Between the Energy Sector and Water Availability and Quality

Source: Modified from DOE (2006) and Cooley and Christian-Smith (2012)

Energy for Water

Energy is used throughout the entire water supply system. From water extraction, treatment and distribution to wastewater collection and treatment, energy plays a vital role. Figure 2 maps the energy demand of the water use cycle. In California, the water-use cycle is very energy intensive due to a highly engineered water supply system that transfers water long distances from north to south and east to west. According to the California Energy Commission, 19% of the state's electric power requirements and 32% of non-power plant natural gas consumption are related to the water use cycle (CEC, 2005; The Climate Registry and Water Energy Innovations, 2013). Much of the electricity is used to convey water across the state through our sophisticated water distribution and delivery system, and for treatment of water and wastewater, while most of the natural gas goes to heating water in homes.

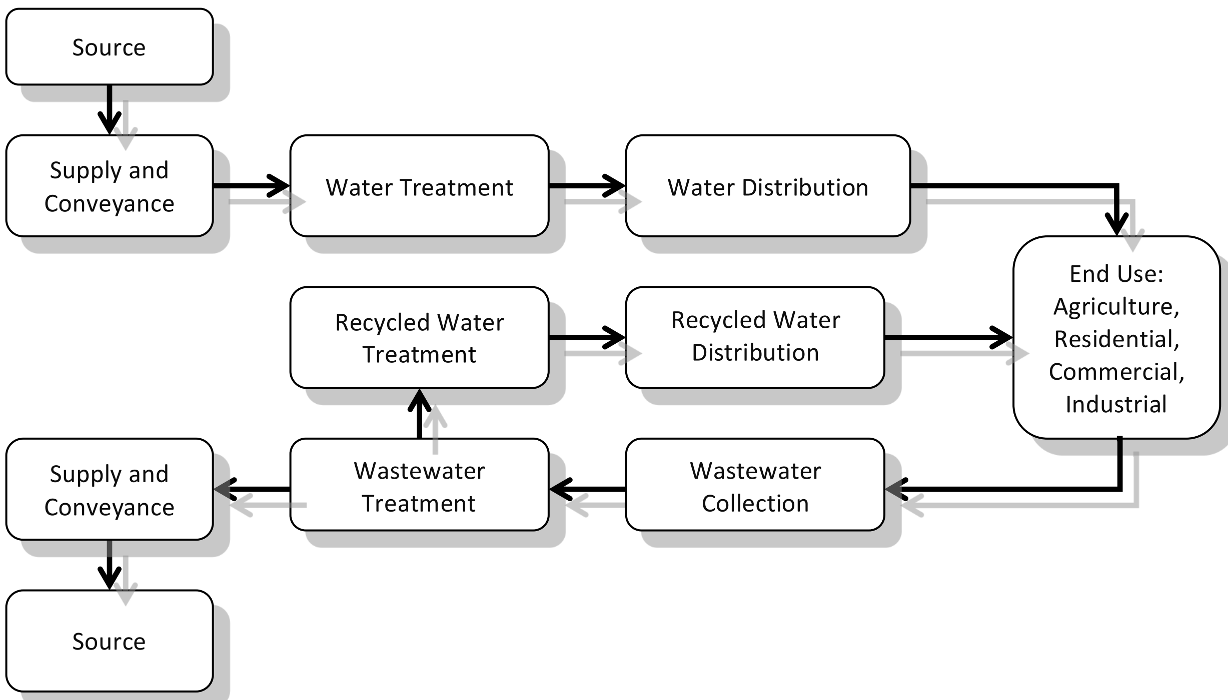

Figure 2: The water use cycle

Source: Modified from The Climate Registry and Water Energy Innovations, 2013

As communities exhaust their water and energy supplies and look to alternatives to meet demand for both, the interdependency between water and energy and the potential cross-sector challenges are increasingly evident. The future water supply portfolio tends to be more energy-intensive:

- *New and alternative water sources* such as water recycling and desalination require more energy than traditional surface and groundwater sources.
- *Groundwater extraction* is becoming more energy intensive due to declining groundwater levels.
- *Stricter water quality standards* (e.g., addressing contaminants of emerging concern) are making water treatment more energy intensive.

At the same time, the new energy and fuel production options are more water intensive:

- *Unconventional oil and gas production methods* such as hydraulic fracturing have significant local and regional water quality and quantity implications. Extraction requires large amounts of water and produces low-quality wastewater, which is the combination of injected water, groundwater and chemical compounds used in hydraulic fracturing.

- *Bioenergy* consumes water in various levels of production and has both water quality and quantity impacts. The water intensity of bioenergy production is closely tied to local climate and soil conditions, crop types and irrigation management practices. Currently, bioenergy production in California for both electricity and biofuel is small (only 3 percent of the state's electricity generation is from biomass). An increase in this share will put pressure on water resources.

- *Expansion of nuclear energy* can have significant regional water availability and quality impacts, due to the temperature of the discharged water. Nuclear power plants use and consume more water than some of traditional energy options such as coal plants (Glassman et al., 2011). There is very limited data available on the exact water footprint of nuclear energy production. However, the estimate is that 45 to 50 percent of the water consumed for energy production in the U.S. can be attributed to thermoelectric cooling (Carter, 2010).

While nationwide and statewide energy and water policies and regulations are crafted independently, their direct and indirect impact on each sector's demand levels and availability is evident at every scale. Water demand growth in the next 20 years is closely linked to the size and mix of our future energy portfolio. It is projected that 85 percent of U.S. domestic water consumption between 2005 and 2030 will be attributed to the energy sector (Carter, 2010). California's decision-makers must consider energy while putting together the state's future water portfolio. Likewise, they must consider water while crafting California's future energy portfolio.

The Evolution of California's Water-Energy Policy

In recent decades, California has been dealing with various water and energy challenges, including extensive droughts and rising energy costs, and there has been a growing realization of limitations in access to cheap and abundant water and energy sources. Nevertheless, while much effort has been expended to study and evaluate California's energy intensity of water use and potential energy savings through water conservation and efficiency, water intensity of energy industry in the state is still very much unknown. Even though water is in the fabric of everything that we consume, there is very limited understanding of the energy impacts on water availability, use and quality within any given region or watershed in California.

This disconnect is partly driven by two facts. The first is that in California saline water is mostly used for electricity generation, which decreases the pressure on and competition for freshwater sources. However, as we expand energy production in various regions of California, this practice may change and the energy sector may become a more dominant user or polluter of freshwater sources (e.g., hydraulic-fracturing in the Central Valley). The second fact is that the water quality and quantity impacts of energy production are generally concentrated at the source (where energy generation happens), rather than throughout the energy supply chain, making it harder to evaluate the overall socioeconomic costs. Consequently, there is limited information available on energy-related water use and its impact on the water resource supply and demand equilibrium. The recently enacted water efficiency law, the Water Conservation Act of 2009, also does not address the potential water savings through energy efficiency.

The energy footprint of the water sector has been closely watched and studied in the past few decades due to two driving factors:

California's energy crisis: In the late 1990s, an energy crisis emerged that was brought on by the failure of energy deregulation in California. From this crisis, the California Public Utilities Commission (CPUC) and the California Energy Commission (CEC) developed statewide energy efficiency regulations, mandated by the Electric Utility Industry Restructuring Act of 1996 (Chapter 854, Statutes of 1996 [AB 1890, Brulte]), that positioned California as the nation's leader in energy savings and program innovation design. Central to the earliest designs of the state's Energy Efficiency Program[2] was the recognition of the potential for garnering substantial energy savings through the conservation of both hot and cold water, and particularly from reducing the energy used to transport, treat and convey water over long distances from north to south, and from east to west, across California.

In 2003, the three major California energy agencies – the CEC, the CPUC and the California Power Authority (CPA) – joined forces to create an energy action plan to set forth specific goals and actions to achieve the state's Energy Efficiency Program goals. These regulating agencies called for a loading order prioritizing the deployment of the state's energy resources and state-sponsored research[3] to assess the potential for saving electricity and natural gas through water conservation

2 http://www.energy.ca.gov/efficiency/
3 Financed through the energy use surcharge

and water use efficiency measures. The research was to focus specifically on (1) quantifying the amount of energy employed to transport, treat and convey water throughout the state and across the water supply life cycle; and (2) determining if investments in measurable energy savings from the implementation of conjoined water and energy projects would be cost effective. The CEC's 2005 water-energy report (CEC, 2005) and the subsequent CPUC 2010 study embedded energy in water studies (Bennett et al., 2010 a), estimated that close to 20 percent of the state's electricity and 32 percent of its natural gas resources are utilized by the water sector. Furthermore, the 2010 study established metrics quantifying the energy embedded in the state's water supplies across the water life cycle, as well as across the state's distinct regions (Bennett et al., 2010 b, GEI, 2012). These results led to the inclusion of water and energy projects in the 2013-14 Energy Efficiency Program Portfolio, particularly in energy saving through leak eradication and systems optimization by water and wastewater utilities.

California Global Warming Solutions Act of 2006:

The development, passage and implementation of California's climate change legislation, the 2006 Global Warming Solutions Act, brought additional attention to the benefits of integrated resource management across water and energy with the ultimate goal of lowering the energy intensity of the state's water supplies. The 2008 Climate Change Scoping Plan called for the implementation of six water-energy measures: enhancing the production of recycled water in order to promote local water supply reliability and the reduction in energy intensive water imports; increasing storm water capture and reuse and promoting low-impact development strategies; optimizing water systems for energy and water use efficiency; promoting water conservation and water use efficiency; increasing renewable energy generation in the water/wastewater sector across biomass, in-conduit hydro, solar and wind sources; and developing financing mechanisms to facilitate the adoption of these measures throughout California.

Charged with implementing these six measures, the state interagency Water Energy Team of the Climate Action Team[4], or WET CAT, has worked to identify the barriers and obstacles to the implementation of these measures and to collaborate on realigning the policy and regulatory practices necessary to facilitate their implementation.

Despite all the research efforts to evaluate the energy footprint of water use cycle (CEC, 2005; Bennett 2010a,b), it is still less understood how policymakers can use this information to change the way they manage and plan water and energy (White and Zafar, 2013) or what kind of research is needed to further advance understanding of embedded water in energy. And what is the compromise in conjointly managing these resources, including the cross-sector tradeoff?

4 WET CAT is comprised of policy staff and/or appointed officials from the California Energy Commission, the California Public Utilities Commission, the State Department of Water Resources, the State Water Resources Control Board, the California Air Resources Control Board, the California Department of Food and Agriculture and the California Department of Public Health, with informal consultation by the U.S. Environmental Protection Agency's Water Division.

The following water-energy policy research agenda reflects many of the key components that merit research investments to move public policy and implementation forward in order to achieve effective coordination of water-energy planning and management in California.

Research Opportunities for California

The agenda will first broadly address research opportunities for enhancing energy savings, including clean energy generation, in the water and wastewater sectors. Subsequently, it will lay out the potential research paths that can improve our understanding of water use for energy and what it means in the context of the water-energy nexus. It will particularly address the opportunity for research across the broad areas of regulatory and policy alignment, utility business modal innovation, and technological and process innovation.

➢ Evaluate pathways to realign water and energy policy and decision-making processes

Despite the fact that water and energy are highly interdependent, these two resources are regulated and managed with no coordination of funding sources, accountability mechanisms, governance structure, or government oversight and legislative committees. Cross-sector coordination and integration is essential to inform more effective and comprehensive policies. Understanding the potential opportunities to better align the state's multiple water and energy regulations and financing options can play a key role in amplifying water-related energy efficiency and reducing the energy intensity of California's current and future water supply portfolio. Such research can:

- Map California's broad water and energy policymaking and regulatory process and financial mechanisms in order to identify opportunities for cross-sector learning and coordination, and paths for innovation, as well as barriers to implementation
- Assess the potential benefits of requiring energy and water audits as a prerequisite for obtaining a permit and/or funds for various water, wastewater and energy-related projects. Doing so will help the investments provided by one sector to have cross-sector benefits. For example, water utilities that are planning to apply for California State Revolving Loan funding from the State Water Resources Control Board could be required to meet certain energy-efficiency requirements to qualify for funding. On the other hand, some of the energy-efficiency funds or cap and trade monies could be restrained from going to water-intensive energy projects by requiring water audits. Such efforts will also encourage cross-sector innovation and collaboration.

➢ Develop decision support tools to evaluate the socioeconomic value of potential statewide energy savings strategies across the water use life cycle

Most of the residential consumption of natural gas in California goes to heating water, while almost 20 percent of the state's electricity supply is used to convey water across the state. Efforts that can reduce the energy intensity of our water system can have great socioeconomic and environmental implications, such as increasing ecosystem health, drought security and greenhouse gas emissions reductions, and reducing the fixed costs of water systems (Cohen et al., 2004). Key opportunities for incentivizing enhanced energy efficiency through reductions in the energy intensity of California's water supplies exist. However, there is a need for a set of decision-support tools that would reflect the energy impacts of water decisions to:

- Enable decision-makers and policymakers in the water sector to evaluate and identify the most effective energy-saving strategies throughout the California water supply life cycle in various scales. These tools particularly could assist leaders both locally and statewide to capture the socioeconomic value of avoided energy across the water supply life cycle, and evaluate the energy footprint of alternative water sources (i.e., recycling and desalinization), innovative wastewater treatment strategies, and water conservation and efficiency policies.
- Offer new methodological approaches to determining how the avoided costs or "societal benefits" would be allocated in proportion to the investments from the distinct water and energy ratepayers. Development of such tools will be fundamentally important to identify the potential for "cross subsidization" across the distinct utility sectors both regionally and statewide.

Such efforts can build upon some of the existing frameworks and tools available to decision-makers, such as the framework designed by the Lawrence Berkeley National Lab (Dale et al., 2008) and the Water-Energy Stimulator of the Pacific Institute (Cooley et al., 2012), and expand them in scale and scope.

➢ Develop comprehensive, high resolution water-energy data platform

The integrated management of California's water and energy resources requires the availability of comprehensive and high-resolution (both temporal and spatial) data. For water, this data includes information on flows (quantity), quality and use. For energy, it includes various types and amount of energy produced, their water source and requirements and location. In today's information-rich era, water data are collected in different ways and at a variety of temporal and spatial scales, from local stream gauges to global satellites. Yet, it is difficult to assess what data are available and how to access them. Data for energy, especially production type and level, are more accessible and centralized,[5] but limited information is available on the water intensity of various energy production methods.

To enable cross-sector research and real-time decision making under uncertainty, there is a need for a platform designed to:

- Collect and share real-time water/energy data, including water use by the energy sector
- Connect existing water and energy databases and websites

In addition, efforts are needed to improve the collection, compilation and reporting of comprehensive water-related data in a centralized manner in order to promote (1) greater efficiency of water-management systems, (2) streamlined data collection and reporting (less redundancy), and (3) cross-sector real-time decision making and long- and short-term resource planning. Additionally, standard data formats and sharing arrangements are needed to promote the efficient exchange of information.

There is also a dire need in California to identify and catalog existing water data, create a water data dictionary, and develop standards for water data monitoring, collection and reporting. Doing so is not

5 Energy Information Administration, http://www.eia.gov

only vital to the effectiveness of the water sector but also the energy sector, which relies heavily on water.

- **Evaluate more effective and improved water pricing policies**

Designing cost-reflective pricing structures for water and wastewater services can be an effective tool to promote water conservation and efficiency and, consequently, energy efficiency (Donnelly and Christian-Smith, 2013). Research on water and wastewater utility rate designs is critical to determine how best to incentivize energy and water optimization while systematically incorporating opportunities for infrastructure upgrades. The energy sector has long adopted such pricing structures and policies (e.g., decoupling mechanisms and rate stabilization funds), which can be used by the water sector in crafting effective and cost–reflective water rates (Ajami and Christian Smith, 2013; Donnelly et al., 2013). As pricing policies are being evaluated in both sectors, it is important to understand how the price increase of one will change demand for the other. For example, in water an increased cost of surface water may lead to an increase in energy-intensive groundwater pumping. Such impacts and trade-offs should be evaluated as part of new pricing policies across both sectors.

- **Evaluate the socioeconomic return of investment in more energy-efficient water/wastewater systems, as well as water conservation**

The current design of the California Energy Efficiency Program limits investments in the water/wastewater sector to capture substantial potential energy savings. Socioeconomic research focusing on the identification of opportunities to capture energy savings in the water and wastewater sectors is particularly needed to inform the redesign of energy-efficiency regulatory paradigms for financing water sector capital improvements. Currently, the design of California's Energy Efficiency Program does not recognize the relatively high costs and long-term payback of capital improvements in the water sector, as the Savings by Design Program limits investments in capital improvements to $500,000, an inadequate amount for sound investments in water sector capital improvements. Such research can also further inform the investment strategies of cap and trade auction proceeds in the coming years.

- **Evaluate the impacts of energy production and use on water availability and security as they pertain to river basin**

The energy sector has major impacts on the availability and quality of California's water resources. As discussed earlier, water is used in every step of the energy life cycle. New approaches for energy production, such as solar thermal, geothermal and energy extraction (e.g., oil shale and shale gas), also have water-related impacts. However, there is limited understanding of how change in energy production may affect water stress (availability, quality and accessibility) in individual river basins. Research projects using watershed-based analysis are needed to evaluate the impacts of energy production on water availability and quality under different scenarios, with a focus on California watersheds. Various scenarios should be tested to assess the sensitivity of the water-related impacts as a function of energy type, energy trends, climate effects, policy and regulatory reforms, and technology options, and prepare an analysis to evaluate the watershed scale impacts on water stress under each scenario.

- **Evaluate potential energy demand management and savings through integration of regional/local water and wastewater management**

California's Integrated Water Resources Management (IRWM) planning process, which promotes regional water planning and management to achieve sustainable water uses and reliable water supplies (among other goals), requires each region to integrate energy and greenhouse gas (GHG) impacts in planning proposed water projects. However, there are no specific guidelines or best management practices on how such energy savings and GHG reduction can be achieved as part of regional integration and how such savings should be evaluated and measured. In order to enable an effective coordination of water/energy management, it is important to:

  - Develop a set of principles and goals that would guide incorporation of energy savings and GHG reduction plans into IRWM projects. This plan can be based on case studies or success stories that harvest lessons learned from regional scale integrated regional water management planning (IRWM). For example, case studies of innovative water-energy partnerships across regional water and wastewater agencies can provide a roadmap to be adapted or replicated in other regions. Such case studies might include the Santa Ana Watershed Project Authority One Water One Watershed Integrated Regional Water Management Plan, as well as regional-scale water and green infrastructure plans developed by Sonoma County Water Agency, the City of Los Angeles and others.
  - Develop a framework based on the developed best management practices and guiding principles to assess the value of trade-offs between water and energy, enabling the regions to evaluate and measure the energy saving and GHG reduction potentials through short-term and long-term management of the regional water/wastewater portfolio.

- **Develop and incorporate new waste-to-energy technologies, systems and processes**

Generating energy through wastewater streams is an innovative technological advancement that lies at the intersection of water and energy. Such technologies aim at turning waste into an asset. However, for wastewater utilities to adopt these innovations to help manage their waste stream, curb their energy footprint through energy self-sufficiency and generate new revenue streams, there are still two barriers: (1) these technologies are still in their early stages of development and require more research as well as onsite demonstration; and (2) they require substantial upfront investments, which are currently not foreseen in utility rate structures.

  - Overcoming these barriers requires more focused technological and process research to escalate the development and utility-scale deployment of new waste-to-energy technologies, systems and processes for application in the wastewater sector. Current engineering life-cycle assessment research seeking renewable energy development across the water life-cycle holds rich opportunity for revenue generation.

- Research is needed to evaluate upfront implementation cost and long-term payback through energy saving. In addition, there is a need for research on societal benefits of such projects, with a focus on ways to bring California cap and trade dollars to incentivize the development, on-site use and potential export to the grid of waste-to-energy technologies.

Evaluate co-benefits of decentralized water treatment technologies as part of the water-energy nexus

Traditional centralized wastewater treatment systems are very energy intensive and lack flexibility to incorporate tailored water[6] into the water supply system. Decentralized water treatment systems, on the other hand, are closer to wastewater sources and have a lower energy footprint for collecting and treating wastewater, and for redistributing and reusing treated water. Decentralized wastewater treatment is not a new idea. Such plants are used in various communities throughout the U.S. and California. However, as the environmental and socioeconomic limitations of centralized systems are highlighted, there is a renewed commitment to implementation of more advanced and efficient decentralized technologies. New research should approach the decentralized water treatment technologies as one solution to enhance water supply and curb energy intensity of water use cycle. More research is needed to:

- Design more innovative, decentralized, closed-loop engineered or natural systems such as green infrastructure (to capture rain and storm water) and constructed wetlands, to collect water locally, treat it to different grades, and redistribute it for irrigation or industrial use.
- Undertake a socioeconomic analysis to evaluate the up-front implementation cost of such systems, versus long-term payback through energy saving, augmented water supplies and other societal impacts; and potential methodologies for bringing California cap and trade dollars to curb energy footprint and reduce greenhouse emissions.
- Study new ways that existing regulatory and incentive programs related to both water and energy can be better integrated and used to promote adoption of more distributed water treatment systems.

Evaluate technological innovation and advancement that would improve energy reliability

Currently, California Electric Rule 21[7] limits the water and wastewater sectors from exporting their excess energy to the grid for net-metered energy to prevent possible grid overload and instability. From the perspectives of these sectors, current restrictions limit their ability to free wheel self-generated energy across the full range of their own facilities, and make it difficult to establish regional energy partnerships that might be helpful during declared power emergencies. To address this issue, there is a need for:

6 The term "tailored water" refers to flexible wastewater treatment systems that can be operated under different conditions to produce water of different quality for different beneficial reuse.

7 A tariff that sets forth the interconnection, operating and metering requirements for generation facilities to be connected to a utility's distribution system, is specific to each of the state's investor-owned energy utilities, and is enforced by the California Public Utilities Commission.

- Research related to regulatory and policy tools and energy and water utility business model innovation, as well as technological and process innovation to identify barriers, obstacles and opportunities for enhancing the ability of the water and wastewater sectors to export power to the grid
- Research on the advancement of microgrid technologies that may be used to facilitate regional power sharing while protecting the larger California grid from unintended electric spikes that can result in automated outages
- Evaluation of pathways to create regional water-industry interconnections to permit power sharing during periods of electric grid crisis or grid instability

Design effective communications and outreach platforms

There is limited public understanding about how water and energy use are linked. In order to curb water and energy use simultaneously, there should be deliberate efforts to help the public understand the water/energy nexus. Joint messaging to address the need for, and the potential benefits of, the combined savings of water and energy is critical. Social science research (including polling) is needed to inform the design and dissemination of various communications and outreach platforms, increase effectiveness of these messaging campaigns, and aid in educating the public about the relationship between water and energy savings.

Concluding Remarks

A key driver of California's water and energy policy and regulatory innovation is to garner the multiple benefits of integrated resource management in order to enhance the opportunities for greenhouse gas emission reductions across the state. The recent call by Governor Jerry Brown for renewed attention to the conjoined savings of water and energy in the wake of the San Onofre nuclear power station closure in Southern California has reestablished partnerships across the water/wastewater, energy, regulatory, policymaking and research communities to secure the implementation of water and energy savings measures.

As the nation's only state to pass climate change legislation (the 2006 AB 32 Global Warming Solutions Act) that enumerates integrated resource efficiency mitigation measures across water and energy, California constitutes a rich research terrain for exploring and understanding the paths beyond singularly focused regulation and management of water and energy resources. This Water-Energy Research Agenda outlines a series of comprehensive and timely research opportunities that specifically target the long-standing, yet rapidly evolving, California water-energy state and regional policy arenas.

The immediate and long-term effect of climate change on California's water and energy resources demands a balanced perspective of energy and water supply reliability. We envision that the results of the proposed research paths proposed in this document would enable decision-makers and policymakers to craft more comprehensive, coordinated and science-based policies and regulations. In this way, California can reach sustainable water-energy equilibrium with cost-effective investments.

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