Alliance for Water Efficiency

ACEEE
American Council for an Energy-Efficient Economy

Water-Energy Nexus Research

Recommendations for Future Opportunities

FINAL REPORT

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GEI Consultants

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Acknowledgements

This report, written by GEI Consultants, Inc. on behalf of the Alliance for Water Efficiency and the American Council for an Energy Efficient Economy, explores ongoing and prospective research regarding the water-energy nexus. It contains the results of an assessment into the status of research on the relationship and trade-offs between the water and energy sectors and identifies areas where additional research may be needed to facilitate decisions regarding effective research investments in this area.

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Abstract

Increasing interest and attention are being directed at the relationship between water and energy resources in the United States. To better weigh the trade-offs and take actions to optimize these resources in concert, the Alliance for Water Efficiency (AWE) and the American Council for an Energy-Efficient Economy (ACEEE) teamed up to investigate what relevant research and studies exist that can inform these actions. Even a modest inventory can inform choices about effective and relevant research investments as a fundamental method for addressing issues and challenges inherent to this relationship.

This paper, prepared by GEI Consultants, Inc. on behalf of and in collaboration with AWE and ACEEE, provides the results of an assessment into the status of research on the relationship or "nexus" between the water and energy sectors. Publicly available research papers and studies that met certain criteria were collected and catalogued into a database. These included investigations that addressed the water sector's impacts on energy resources and the energy sector's impact on water resources, including development, operations, and end-uses. The compiled research was then assessed to determine the scope of topics investigated, the key results, and possible gaps. Finally, gaps in the research were identified and inventoried. From this information, a roadmap for future research investments is recommended to enhance multi-sector resource management and overall resource efficiencies. A summary of the major findings from the collected research is provided and is compared to the major policy objectives and issues as identified in the AWE-ACEEE publication, *Addressing the Water-Energy Nexus: A Blueprint for Action and Policy Agenda* (*Blueprint*). From this comparison, final recommendations were developed that address additional research needs.

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Alliance for Water Efficiency and American Council for an Energy-Efficient Economy

The Alliance for Water Efficiency (AWE)[1] is a stakeholder-based 501(c)(3) non-profit organization dedicated to the efficient and sustainable use of water. Located in Chicago, AWE serves as a North American advocate for water-efficient products and programs, and provides information and assistance on water conservation efforts.

AWE has embarked on seven key tasks to support and enhance water conservation efforts, providing benefit to water utilities, water conservation professionals, planners, regulators, and consumers:

- Stand as a clear and authoritative national voice for water efficiency.
- Provide comprehensive information about water-efficient products, practices, and programs—what works and what doesn't.
- Represent the interest of water efficiency in the development of codes and standards.
- Transform the market for fixtures and appliances.
- Coordinate with green building initiatives to institutionalize water efficiency.
- Train water conservation professionals to support the development of a professional water conservation work force.
- Educate water users by providing up-to-date information on water efficient products, practices, and behaviors for the general public.

The American Council for an Energy-Efficient Economy (ACEEE)[2], a nonprofit, 501(c)(3) organization, acts as a catalyst to advance energy efficiency policies, programs, technologies, investments, and behaviors. We believe that the United States can harness the full potential of energy efficiency to achieve greater economic prosperity, energy security, and environmental protection for all its people. ACEEE carries out its mission by:

- Conducting in-depth technical and policy analyses
- Advising policymakers and program managers
- Working collaboratively with businesses, government officials, public interest groups, and other organizations
- Convening conferences and workshops, primarily for energy efficiency professionals
- Assisting and encouraging traditional and new media to cover energy efficiency policy and technology issues
- Educating consumers and businesses through our reports, books, conference proceedings, press activities, and websites

AWE recognizes the need for collaboration between the efforts for energy conservation and efficient use and the efforts for water conservation and efficient water use, which have historically been separate but parallel efforts.

AWE and ACEEE recognize the need for collaboration between the efforts for energy conservation and efficient use and the efforts for water conservation and efficient water use, which have historically been separate but parallel efforts. Both organizations published *Addressing the Energy-Water Nexus: A Blueprint for Action and*

1 "About Us." Alliance for Water Efficiency. n.d. Web. 25 Apr 2013. <http://www.allianceforwaterefficiency.org/about/default.aspx>.
2 "Overview/Mission." American Council for an Energy-Efficient Economy. n.d. Web. 25 Apr 2013. <http://aceee.org/about>

Policy Agenda (*Blueprint*),[3] a document aimed at laying the groundwork for future energy-water joint efforts and to envision a policy agenda that could drive actions at the federal, state, local, and watershed levels.

The *Blueprint's* thematic elements are:

1. Increase the level of collaboration between the water and energy communities in planning and implementing programs.
2. Achieve a deeper understanding of the energy embedded in water and the water embedded in energy.
3. Learn from and replicate best practice and integrated energy-water efficiency programs.
4. Integrate water into energy research efforts and vice versa.
5. Separate water utility revenues from unit sales, and consider regulatory structures that provide an incentive for investing in end-use water and energy efficiency.
6. Leverage existing and upcoming voluntary standards that address the energy-water nexus.
7. Implement codes and mandatory standards that address the energy-water nexus.
8. Pursue education and awareness opportunities for various audiences and stakeholders.

AWE and ACEEE hope to do further research on opportunities and barriers to joint energy and water utility programs. To recognize possible future directions for program delivery, AWE and ACEEE published in January 2013 *Tackling the Nexus: Exemplary Programs that Save Both Energy and Water*,[4] which documents one of the first in-depth looks at the kinds of efficiency programs that save both water and energy and are being implemented across the country. This report is a valuable resource, as it provides a directory of programs and their design details, implementation, and performance, as well as being cost-effective and replicable in manner.

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3 *Addressing the Energy-Water Nexus: A Blueprint for Action and Policy Agenda*. Alliance for Water Efficiency, American Council for an Energy-Efficient Economy. May 2011.

4 Young, Rachel and Eric Mackres. *Tackling the Nexus: Exemplary Programs that Save Both Energy and Water*. January 2013. Report Number E131.

1 Introduction

With increasing interest and attention being directed at the relationship between water and energy resources, it is important to understand what research and studies have been completed. Using the results from these previous efforts, we can inform actions and decisions that will address issues and challenges inherent to this relationship and define what work remains to be done.

Even a modest inventory informs choices about future investments into additional investigations that may be needed to advance understanding and actions that can mutually optimize these resources. The purpose of this paper is to provide the results of an assessment into the status of research on the nexus or relationship between water and energy sectors and areas where additional research may be needed to advance understanding about ways to enhance multi-sector resource management and overall resource efficiencies.

1.1 What is the Water-Energy Nexus?

The water-energy nexus is a term used to describe the interaction and interdependencies between water and energy resources. Understanding the dependencies, synergies, conflicts, and trade-offs between these two critical resources is necessary to identify and implement mutually beneficial strategies for their management and use. As stated above, water is required extensively in the energy sector for developing, refining and using the electricity, gas, and petroleum we need. On the other hand, significant energy is required to capture, convey, treat, and use the water that supports our society and its health. Only by knowing and understanding these resource dependencies and interactions can one analyze how to reduce or enhance these dependencies, where to reduce costs effectively, and where to maximize the benefits of their use.

The relationship between these two resources goes beyond simply the demand of one resource on the other, but includes many shared challenges and issues that may pose opportunities for collaboration by management agencies and markets to more effectively address them. These included:

- Growing demands resulting from increases in population, economic growth, and changes in land uses
- Aging infrastructure that impacts reliability and dependability of services
- Fractured regulatory authority and jurisdictions with differing goals and objectives
- New mandates and policies that required increased investments and at times conflicted between the sectors

- Increased consumer demands for resource adequacy and improved quality
- Requirements for environmental protection and enhancement
- Insufficient or ill-suited systems to meet changing demands and markets requirements
- Potentially different future hydrologic conditions resulting from climate change
- Long-term resource uncertainty and availability
- Rising costs of service and insufficient funding resources

To realize the efficiency of addressing these challenges in a collaborative and integrated way requires the removal of several barriers that exist.

1.2 Nature of Research Today

In recent years, there has been a sharp increase in research focused on the interactions between water and energy. Granted, the need for water to produce the energy we use goes back to the days of the first hydroelectric facilities. The importance of embedded energy in water systems has been recognized as far back as the 1970s when early investigations into the issues associated with energy use for water systems focused mainly on costs to water and wastewater treatment plants. Yet, within the past 10 years, more emphasis have been placed on better understanding the full implications of the dependencies between energy and water as a way to make better resource management and investment decisions. These studies have provided valuable tools and information for effective plans and actions that improve society's access to and use of these resources to enhance health, productivity and sustainability.

1.3 Water and Energy Research Work Group[5]

As an extension of the *Blueprint*, AWE and ACEEE assembled a working group to explore ongoing and prospective research regarding the water-energy nexus. Of specific concern is the amount of water needed for and thus "embedded" in electric power generation and the amount of energy "embedded" in drinking water treatment and pumping and wastewater treatment and pumping.

The AWE-ACEEE Water and Energy Research Work Group (Work Group) meetings consisted of presentations and discussions that help to promote, track, and understand water and energy research. The Work Group is made up of representatives from all sides of the water-energy nexus: water utilities; power utilities; public works and county agencies; universities and other private and public research groups; local, state, federal, and international agencies; climate and resource advocate groups; industry and consulting firms.

5 "AWE-ACEEE Water and Energy Research Work Group." Alliance for Water Efficiency. n.d. Web. 25 Apr 2013. <http://www.allianceforwaterefficiency.org/Water-Energy-Research-Group.aspx>.

2 Investigation Methodology

To focus the investigation, the team developed guidelines and criteria that would aid in meeting the aims and goals of this effort.

Research to be collected had to be publicly available and was identified mainly through internet searches, supplemented by contributions from the Work Group and internal knowledge of available research. In this case, "publicly available research" was interpreted to mean that the research can be easily accessed by the public and is not confidential. Some research catalogued in the database is available only for a fee and thus has limited access. In these cases we have provided what information is readily available without cost. These criteria ensure that research that is obscure, too narrowly focused, overly technical, or purely in the conceptual phases are not included in this effort to characterize the status of research on the nexus between the water and energy sectors.

The scope of the investigation was primarily focused on research conducted within the United States, but was not limited to this research only. This criterion ensures that the research collected captures the issues that are relevant to the country's regulations and policies, current and standard practices, climatic and geographic constraints and benefits, and available resources.

Both embedded energy and end-use energy research was included in the investigation. The amount of energy in these categories changes drastically depending on what the water is being used for and how it is treated and transported. Therefore neither category can be ignored in this investigation.

To be included in the database, the investigators focused on water-energy nexus research that addressed the water impacts of energy and/or the energy impacts of water. Reports that discuss the relationship of water to energy or energy to water as peripheral to the main focus of a research project were not included in this investigation, although their sources may be considered for inclusion in the investigation and were noted for future efforts.

Similarly, secondary research was not included in the investigation, but their sources could be used to identify other primary research papers. Primary research includes, but is not limited to, case studies, pilot studies, utility surveys and collected data, roundtable discussions and workshops, best practices handbooks and utility manuals, and roadmaps. Secondary research is usually a review of existing (primary) research, with little or no original analysis done by the author. Avoiding secondary work such as literature reviews and compilations ensures that the research collected advances the knowledge about some aspect of the energy-water nexus and that what is collected is not artificially skewing the amount of research done in a certain area. In this way, the investigation team can present an accurate representation of the state of research on the energy-water nexus.

Investigators focused on water-energy nexus research that addressed the water impacts of energy and/or the energy impacts of water.

Finally, the database was cataloged by paper title; author(s); sponsoring or authoring organization; date of publication; if primary discussions were about energy for water (E-W) or water for energy (W-E); and key words and phrases. Documentation of each research paper also includes the source link and key findings, which include recommendations. Once the bulk of the database was compiled, the papers were organized by E-W and W-E and then by date of publication to facilitate the assessment.

Further categorizations of research include:

- Types and methods of research conducted
- Stages within resource process (i.e. production, treatment/refinement, transport/distribution, consumption)
- Types of technologies
- Types of findings, conclusions, and recommendations

The compiled database is a snapshot in time of the body of research readily available to the public on the topic of the water-energy nexus. It is not intended to be exhaustive or definitive, but informative and representative. Work Group members identified additional resources that their own organizations maintain or contribute to that can further inform individuals interested in this topic area. Such resources include OpenEI, a large repository of energy-related information and data.[6] The project team made no attempt to duplicate or completely reflect all these resources, but rather include highlights of research included in these other collections and provide reference to these other sites. The project team consulted these additional sites and resources in their evaluation of available resources and in determining gaps and needs for future research.

6 "Water and energy studies." OpenEI. n.p. Web. 23 May 2013. <http://en.openei.org/wiki/Water_and_energy_studies>

3 Results

More than 200 research documents are contained in the compiled Water-Energy Research Database. The organization of the database allowed us to make initial and broad observations on which part of the energy-water nexus has received more focus through the decades:

- The energy used in the water sector has been a concern as far back as the 1970s, whereas the issues surrounding the water used in energy production has only received attention starting in the 2000s.
- Few detailed studies exist that audit embedded energy in water and wastewater systems, and no such assessments have been done at a regional or national level. What do exist are very high level assessments.
- Overall, this effort catalogued far more studies related to the energy used in the water system (E-W) than the water used in the energy sector (W-E). It is unclear if that is simply because there has been less study of the impacts of power generation or energy development on water resources, or that it is just not easily accessible in internet sites.
- Most of the available research for either E-W or W-E has been published within the past 10 years.
- Research addresses both E-W and W-E and some trade-off considerations, but this appears to be an emerging area of investigation.
- Continued public funding of research is cited as necessary to spur additional investigations into alternative, clean sources of energy and water.

More specific observations are discussed below.

3.1 Research on Energy Use for Water Resources (E-W)

Primary research papers for E-W included the results of pilot and case studies, and workshops and conferences for utilities, planners, and policy advocates. Multiple roadmaps and handbooks were found, which presented industry-wide operating suggestions based on operating experience and estimated energy and cost savings informed by case studies. However, no comprehensive studies were found that provide a detailed audit of embedded energy demands for an entire local, regional or national water/ wastewater system. Rather only high level, generalized assessments exist.

Most of the E-W research found focused on the economic and energy efficiencies for primary energy usage associated with water and wastewater treatment, with little information found on secondary energy uses such as source pumping, transport and distribution. Research in the area of energy-efficient technologies for water focused mainly on the treatment stage of water and wastewater.

Some E-W research quantified possible energy savings in water/wastewater treatment plants, but most of the conclusions and recommendations were more programmatic and policy considerations. Similarly, while it appears that energy efficiencies for treatment technology is well researched, most of the research papers focused their conclusions and recommendations on implementation and management strategies of energy saving policies and programs, rather than new technology and barriers to their use. In addition, these studies tended to look at individual actions or measures, with few focusing on implementation of a portfolio of options across an entire system.

Research into treatment technologies can be labeled using the convention set by the U.S. Environmental Protection Agency (EPA): embryonic, innovative, and established. Research was done on all types of technologies but tended toward innovative and established technologies.

3.1.1. Key Findings – Energy Use for Water Systems and Associated End Use

1. Only limited assessments of embedded energy in water systems have been conducted. No comprehensive studies were found that provide a detailed audit of embedded energy demands for an entire local, regional or national water/wastewater system.

   Most studies, as described below, tended to look at individual components of a system for evaluation of possible improvements in energy efficiency of that component and rarely in context of overall system operations.

2. Numerous studies have been done on the cost effectiveness, energy impacts, and public health performance of traditional wastewater treatment processes as well as advanced treatment processes, especially activated sludge and anaerobic digestion.

   Early studies assessed the increasing costs of advanced processes that are mostly due to increased energy demand.[7] While earlier research papers focused on energy conservation and more efficient technologies, more recent research (within the past 10 years) is focused on the multi-attribute character of WWTPs, presenting them as possible resource recovery facilities rather than solely waste facilities. These more recent research efforts explored further development of technologies; practices and strategies to maximize resource recovery and lower costs, increase process efficiency and improve environmental and public health performance.[8,9,10,11] Of particular interest are two studies that document research into zero net energy facilities, namely the Oregon Association of Clean Water Agencies' 2008

   report documenting the potential costs and benefits of converting the Oregon domestic wastewater treatment plants to operate as energy independent[12] and the 2011 report by ARCADIS that documents the Zero Net Energy utilization at the Gloversville-Johnstown Joint Waste Water Treatment Plant.[13]

3. An understanding of water pricing practices and the consequences thereof can support better management and operations of water and energy resources.

   The 2008 study for the Delta Vision Process looked into the consequences as well as the potential correction of California's current water pricing practices. This study calls for a pricing method to improve water use efficiency that considers water opportunity costs and also makes further recommendations for additional studies.[14]

4. In terms of treatment facilities, the largest per unit users of energy are small water and wastewater treatment plants that treat less than 1 million gallons per day, as well as those that employ an activated sludge and or tertiary treatment process.

7 United States Environmental Protection Agency. *Electrical Power Consumption for Municipal Wastewater Treatment*. By Robert Smith. Cincinnati, Ohio: National Environmental Research Venter Advanced Waste Treatment Research Laboratory, July 1973. (Environmental Protection Agency report number, EPA-R2-73-281).

8 Wett, B., K. Buchauer, and C. Fimml. "Energy self-sufficiency as a feasible concept for wastewater treatment systems." *Asian Water*. September 2007.

9 Tavares, Luis M., Richard M. Cestone, and Robert M. Gerard. *Framework of a Sustainable Energy Master Plan for the Bergen County Utilities Authority Little Ferry WPCF*. Proceedings of the Water Environment Federation, WEFTEC 2008: Session 61 through Session 70 , pp. 4551-4563(13).

10 ASERTTI. *Combined Heat and Power Case Study: Gloversville-Johnstown Joint Wastewater Treatment Facility*. September 2009.

11 Stillwell, Ashlynn S., David C. Hoppcock, and Michael E. Webber. *Energy Recovery from Wastewater Treatment Plants in the United States: A Case Study of the Energy-Water Nexus*. University of Texas, Austin. April 2010.

12 Monteith, Hugh D. *State-of-the-Science Energy and Resource Recovery from Sludge*. Oregon Association of Clean Water Agencies. June 2008.

13 Ostapczuk, Robert E. et. al. "Achieving Zero Net Energy Utilization at Municipal WWTPs: The Gloversville-Johnstown Joint WWTP Experience." *Energy and Water 2011*. Clifton Park, NY: Malcolm Pirnie, the Water Division of ARCADIS, 2011.

14 Mann, Roger. *Economic Efficiency of Water Use and Allocation in California a Scoping-Level Analysis*. For Delta Vision Process. July 2008.

These studies document the importance of scale of a facility and that different strategies may be needed based on the size of a plant and the types of technologies or services provided. These studies do, however, note certain best practices that can be used regardless of size or treatment process which supports some efforts to develop a cadre of best practices and program offerings for energy efficiency improvements.

5. Multiple research papers are in conflict about whether end use conservation is more of a driver for water sustainability than technology and program management.

   This project does not seek to resolve this issue, but rather expose it and suggest that both points of view may be correct depending on location, hydrologic conditions and the nature of services provided or energy costs.

6. Studies conducted within the last 15 years have focused on determining wastewater treatment plant energy use baselines; however the challenge still remains of how to develop baselines for comparison purposes.

   A 2003 Pacific Gas and Electric Company study observed that the variations in influent flow and composition and discharge requirements make it impractical to determine a baseline as a metric that can inform the development of potential efficiency savings.[15]

7. Treatment technology is well researched in terms of energy use, but other factors (costs, policies, environmental concerns) constrain implementation of the optimal technologies.

   In 1973 the U.S. EPA conducted an in-depth energy assessment on the electrical power consumption for all the possible processes involved in a municipal wastewater treatment plant. This assessment took into consideration plant capacity and treatment methods, as well as reporting the energy used for advanced and emerging technologies such as reverse osmosis, ammonia stripping, and granular carbon adsorption.[16] Although this kind of research is common and has revealed the cost effectiveness of energy efficient technologies over time, additional effort is needed to overcome additional hurdles such as educating end-users of the value of the resources and available ways to conserve, integrating the water and energy markets, and encouraging local, state, and federal commitment to energy and water efficiency standards.[17]

8. Membrane treatment technology research seems relatively up-to-date, however energy impacts and increased efficiency is either not addressed or not quantified.

   Knowing the importance of compliance with ever more stringent water quality regulations has resulted in much of this research. However, ensuring the cost-effectiveness of these technologies and their uptake will result in their use. Ignoring energy efficiency or the costs associated with energy over time, may result in significantly high costs of operation which could adversely impact their use.

9. Renewable energy for water and wastewater treatment represents a portion of the research; biogas is the most commonly used renewable energy source at treatment plants, followed by solar. Wind turbines, micro-hydro, fats, oils, and greases (FOGs), and green waste are being researched as possible sources of energy for treatment plants.

   Case studies and reviews of wastewater treatment systems utilizing biogas for in-plant energy show that an improved fuel efficiency of 30% to 70% can be achieved.[18,19,20,21,22] This research also includes case studies and papers that evaluate ways and methods in which facilities can become energy neutral through the use of a portfolio of options for energy efficiency, conservation, and development. The Gloversville-Johnstown

Multiple research papers, reports, and best management handbooks recommend that improved data collection and auditing of water and wastewater utilities is integral for determining appropriate actions they can take to improve operations, lower costs, and reduce their energy footprint.

15 *Municipal Wastewater Treatment Plant Energy Baseline Study*. PG&E New Construction Energy Management Program. San Francisco, CA: M/J Industrial Solutions, June 2003.

16 US Environmental Protection Agency, July 1973

17 Gleick, Peter H., et. al. *Waste Not, Want Not: The Potential for Urban Water Conservation in California*. Pacific Institute. November 2003.

18 United States Environmental Protection Agency. *Case Studies in Residual Use and Energy Conservation at Wastewater Treatment Plants Final Report*. By Dianne Stewart. Golden, Colorado: National Renewable Energy Laboratory, June 1995. (NREL/TP-430-7974).

19 *Final Energy Independence Report*. Kennedy/Jenks Consultants. Prepared for Oregon Association of Clean Water Agencies (ACWA) and Energy Trust of Oregon. July 2008.

20 Rogers, Chuck and Mark D.Wakins. "City of Thousand Oaks Uses Innovative Power Purchase Agreements for Renewable Energy at Its Hill Canyon Wastewater Treatment Plant." Water Environment Federation's Annual Technical Exhibition and Conference. 2008.

21 United States Environmental Protection Agency. "Domestic Wastewater Treatment as a Net Energy Producer – Can This be Achieved?" By Perry L. Mccarty, Jeonghwan Kim, and Jaeho Bae. *Environmental Science & Technology*. July 2011.

22 "Energy Production and Efficiency Research – The Roadmap to Net-Zero Energy".Water Environment Research Foundation. Fact Sheet. August 2011.

Joint Wastewater Treatment Plant uses biogas to produce 98% of its own energy.[23] Solar power is currently utilized at treatment plants including the City of Thousand Oaks WWTP[3] and the City of Pittsfield Wastewater Treatment Facility;[24] however, recent potential energy savings estimates have not been studied.

10. Multiple research papers, reports, and best management handbooks recommend that improved data collection and auditing of water and wastewater utilities is integral for determining appropriate actions they can take to improve operations, lower costs, and reduce their energy footprint.

    The Massachusetts Energy Management Pilot for Drinking Water and Wastewater Treatment Facilities and the New York State Energy Research and Development Authority achieved zero-net or near zero-net energy use at their wastewater treatment plants, and have relied heavily on collected data to develop energy and water use benchmarks and potential savings.[25,26] Moreover, other recent studies have addressed gaps in knowledge or resources to facilitate collaboration and better resource management, such as the 2007 Sandia National Laboratory (Sandia) study titled *Overview of Energy-Water Interdependencies and the Emerging Energy Demands on Water Resources*, which highlighted the need for models and decision-making tools to improve integrated multi-resource planning.[27]

    The Decision Support System for Sustainable Energy Management Tool (DSS Tool) from the Water Environment Research Foundation (WERF) has the capability of analyzing a system configuration for energy cost reduction, energy consumption reduction, and energy generation/recovery and has been pilot tested by four utilities, including the JEA, an electric, water, and sewer utility in Florida. JEA used the tool to compare options for biosolids handling and found that they were on track to meet their reduced energy goals.[28]

    In addition, two U.S. DOE tools, the Pumping System Assessment Tool (PSAT) and MotorMaster+, were used at the Metropolitan Syracuse Wastewater Treatment Plant (Metro WWTP) to upgrade and optimize several processes. Since 2004, Metro WWTP has been able to save about 2.81 million kilowatt-hour (kWh) per year, reduce their natural gas purchases by 270 million British thermal units (MMBtu) annually, and save $207,500 per year, while achieving a 13-month simple payback.[29]

23 Ostapczuk, Robert E. et. Al, 2011.
24 United State Environmental Protection Agency. "Achieving Zero-Net Energy at Drinking Water and Wastewater Facilities." August 2010. (EPA-830-F-10-002).
25 Tavares, Luis M., Richard M. Cestone, and Robert M. Gerard, 2008
26 ASERTTI, September 2009
27 Pate, Ron, Mike Hightower, Chris Cameron, and Wane Einfeld. *Overview of Energy-Water Interdependencies and the Emerging Energy Demands on Water Resources*. Sandia National Laboratories. March 2007.
28 Conrad, Steve. "Case Studies in Utilizing a Decision Support System for Sustainable Energy Management." Energy and Water 2011. Presentation.
29 United States Department of Energy Industrial Technologies Program. "Onondaga County Department of Water Environment Protection:

11. Outreach to the public is necessary to implement water and energy efficiency programs and policies.

    The American Water Works Association (AWWA) recommends "working with the public to increase awareness of the challenge ahead, assess local rate structures, and adjust rates as necessary. …Comprehensive, focused, and strategic communications programs serve the dual function of providing consumers with important information about their water systems and building support for needed investments in infrastructure."[30]

    In 2003, Sandia and the United States Bureau of Reclamation examined public perception issues related to desalination and use of certain technologies. The unromantic reality that all water on the planet is and must be reused is susceptible to manipulation and exploitation to foment public opposition to desalination and water supply purification technologies and facilities. They concluded that educating the public was important to smoothing the path for deployment of these technologies.[31]

12. Education and training about new methods, technologies and systems as well as input by staff and operators regarding the implementation of these improvements is key for successful energy efficiency program management.

    Multiple case studies cite the importance of diverse management teams that are made up of operators, managers, financial administrators and energy utility representatives.[32,33,34,35] A 2008 U.S. EPA guidebook recommends this type of management team, as it is the best way to gain support and buy-in of the new programs and management systems. Moreover, the perspectives and input provided from this cross section of personnel ensure a program and system that is realistic, practical, and add value.[36]

13. Energy and/or water efficiency programs and policies work best when well-funded and are a collaborative effort across utilities.

    Collaboration improves buy-in as well as communication. The Electric Power Research Institute (EPRI) recommends that a successful energy efficiency auditing team for a water or wastewater treatment plant consists of operational staff, engineering/management staff, and the electric utility representative. In this way, suggestions from operations staff will be included and electric utility personnel can see that program measures do not cause unnecessary difficulties.[37]

    It is only due to significant Federal support of R&D programs in the past that radical advances in water treatment technologies have been realized in spite of under-investment in R&D by the private sector. However, in the recent past, budgets for water supply technology research and development have been smaller and less stable, resulting in reduced R&D programs.[38]

14. Recent research has brought a new element to the water-energy nexus: climate change. As more has been learned about the potential effects of climate change on various resources and hydrologic/climatic conditions regionally, more is understood about how the water and energy resource interdependencies may be affected.

    The body of work conducted by the Water Research Foundation (WRF) concerning climate change points to the need to develop planning and adaptation strategies to ensure resilient water systems.[39]

15. Many papers and a significant body of research were found regarding desalinization; however only a small fraction address energy directly or

Primary research papers for W-E included the results of case studies, collection and analysis of community (consumer) and utility surveys, and workshop and conference summaries for utility operators, planners, and policy makers.

Process Optimization Saves Energy at Metropolitan Syracuse Wastewater Treatment Plant." December 2005. (DOE/GO-102005-2136).

30 American Water Works Association. *Dawn of the Replacement Era, Reinvesting in Drinking Water Infrastructure*. May 2001.

31 United States Bureau of Reclamation and Sandia National Laboratories. *Desalination and Water Purification Technology Roadmap – A Report of the Executive Committee*. Denver, CO: Bureau of Reclamation, Denver Federal Center Water Treatment Engineering Research Group, January 2003. (DWPR Program #95).

32 Ostapczuk, Robert E. et. al., 2011.

33 United States Environmental Protection Agency. *Summary Report 2009-2011 Indiana Energy Management Pilot*. Environmental Protection Agency Region 5, April 2012.

34 Ostapczuk, Robert E., et. al. "Achieving Zero Net Energy Utilization at Municipal WWTPs: The Gloversville-Johnstown Joint WWTP Experience". Water Environment Federation. 2011.

35 United States Environmental Protection Agency. *Evaluation of Energy Conservation Measures for Wastewater Treatment Facilities*. By The Cadmus Group, Inc. Washington, DC: US Environmental Protection Agency Office of Wastewater Management, September 2010. (EPA 832-R-10-005).

36 United States Environmental Protection Agency. *Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities*. January 2008.

37 Electric Power Research Institute. *Energy Audit Manual for Water/Wastewater Facilities*. July 1994.

38 Pate, Ron, Mike Hightower, Chris Cameron, and Wane Einfeld, March 2007.

39 Martinez, Roy. *Climate Change & Greenhouse Gas Emissions*. Water Research Foundation. November 2007.

were of the technical level to inform the water-energy nexus questions being addressed here.[40,41]

Although energy is not directly addressed, some notable work includes a 2005 paper that provides a trend and costs analysis of water desalination and transport and a 2012 white paper that presents and discusses the costs associated with desalination compared to other water supply alternatives.[42,43]

3.2 Research on Water Use for Energy Resources (W-E)

Primary research papers for W-E included the results of case studies, collection and analysis of community (consumer) and utility surveys, and workshop and conference summaries for utility operators, planners, and policy makers. Like those found for E-W, roadmaps and handbooks found presented industry-wide operating suggestions based on experience and estimated savings.

A majority of the W-E papers focused their research and recommendations on energy production and refinement; however a good number of the papers went into energy usage and efficiency on the consumer end, with some mention of transmission improvements.

Some of the collected research included the quantification of water use per unit energy produced/refined, as well as the environmental impacts that energy production can have on water supplies and quality.

Like those for E-W research, much of the recommendations were focused on programmatic and management changes and improvements for water savings related to energy. Unlike E-W however, recommendations were also made to reduce energy use consumption by the utilities and public end-users alike in order to reduce water consumption and impacts to the environment.

Technology research for W-E included papers addressing technology and methods for energy production and refinement. These technologies can also be labeled according to the U.S. EPA convention, and were evenly spread between embryonic, innovative, and established technologies.

3.2.1. Key Findings – Water Use for Energy Development and Related End Use

1. Water efficient energy generation technology research is more in the emerging category, and greater focus is given to policy and management changes rather than equipment changes.

   In a 2006 report, the U.S. Department of Energy (DOE) identifies technologies and processes that can allow power plants to use degraded and reclaimed water, however, these technologies and processes are mainly in the early phases of research.[44]

40 Pate, Ron, Mike Hightower, Chris Cameron, and Wane Einfeld, March 2007.

41 California Department of Water Resources. *Water Desalination Findings and Recommendations*. By Charles F. Keene. California: Water Desalination Task Force, October 2003.

42 Zhou, Yuan and Richard S. J. Tol. "Evaluating the costs of desalination and water transport". *Water Resources Research*, Vol. 41, W03003, doi: 10.1029/2004WR003749. 2005.

43 *Seawater Desalination Costs*. WateReuse Association. September 2011; Revised January 2012.

44 United States Department of Energy. *Emerging Issues for Fossil Energy and Water, Investigation of Water Issues Related to Coal Mining, Coal to Liquids, Oil Shale, and Cabon Capture and Sequestration*. By Melissa Chan et. al. United States Department of Energy National Energy Technology Laboratory, June 2006. (DOE/NETL-2006/1233).

2. A handful of research papers, especially those looking at energy in water scarce regions of the U.S., recommend that the energy sector include drought and climate change in planning for water supplies for use in the energy sector.

   Multiple research papers point out that although places like Arizona would, on the surface, seem ideal for the use of conventional solar power collectors, the amount of water required by these systems makes them prohibitive.[45,46,47]

3. Although defining the boundaries around electricity imports and exports simplifies the accounting, the problem is that energy acquisition methods other than electricity production, such as direct injection of pipeline gas or production of biodiesel fuel would not be factored into the equation and credited as energy outputs.

4. Cooling methods are the largest water uses in energy generation, and also the most studied for new and efficient technology.

   A 2011 publication by the Pacific Institute estimated 15 to 18 billion cubic meters of freshwater resources are affected annually by fossil-fuel production.[48]

5. Regulations and rules need to be laid out and coordinated, not only within the energy sector, but the federal government as well, to reduce water use, particularly in cooling water use.

   The United States Government Accountability Office (GAO) produced a report in 2012 that urges federal and local energy stakeholders to coordinate their planning efforts in order to take into account all the possible tradeoffs and interrelationships of water and energy planning. The GAO report specifically calls for the implementation of the Energy Policy Act of 2005, which requires the U.S. DOE to "implement a program of research, development, demonstration, and commercial action to address energy and water issues and assess existing federal programs", as well as action by U.S. EPA, U.S. Department of Agriculture, and the U.S. Department of the Interior.[49]

6. There needs to be a resolution of the current regulation impasses that balance the economic and environmental costs.

   A 2010 Congressional Research Service paper points out that although small hydropower projects have little to no fuel costs, can operate with lower flows, and are easier to gain permitting and regulation requirements, the relatively higher cost relative to size will impede their implementation on a wide scale without government incentives, using clean energy policy as a driver.[50]

7. Several relatively new methods of fossil-fuel extraction, such as hydraulic fracturing (fracking), can cause negative impacts to groundwater resources, affecting drinking water systems and both surface water and groundwater. This problem is additionally aggravated by a lack of understanding and credible and comprehensive data, which according to the Pacific Institute, "is a major impediment to identify or clearly assess the key-water related risks… and to develop sound policies to minimize those risks".[51] The problem is more complex than just the process of hydraulic fracturing, and involves good drilling practices. A recent Center for Strategic and International Studies report indicates that "faulty well construction improper casing or intersection with old abandoned wells" is a more likely source of groundwater contamination.[52]

8. Low-carbon electricity technologies are not necessarily low-water.

   There is a need for a method or tool to help accurately calculate a power plant's water footprint based on primary and secondary factors. The actual water footprint of electricity

From the collected research we can also observe gaps in collected Water-Energy Nexus related research.

45 Water Policy Considerations. *Deploying Solar Power in the State of Arizona: A Brief Overview of the Solar-Water Nexus* – May 2010. Washington, DC: Office of Senator Jon Kyl, May 2010.

46 Elcock, Deborah. "Future U.S. Water Consumption: The Role of Energy Production". *Journal of the American Water Resources Association*. Volume 46, Issue 3. June 2010.

47 Scott, Christopher A. et. al. "Policy and institutional dimensions of the water-energy nexus". *Energy Policy*. 2011.

48 Allen, Lucy et. al. "Chapter 4 (v.7): Fossil Fuel and Water Quality". *The World's Water*. October 2011.

49 United States Government Accountability Office. *Energy-Water Nexus Coordinated Federal Approach Needed to Better Manage Energy and Water Tradeoffs*. Washington, DC: Government Accountability Office, September 2012.

50 United States Congressional Research Service. *Small Hydro and Low-Head Hydro Power Technologies and Prospects*. By Richard J. Campbell. March 1, 2010. (7-5700).

51 Cooley, Heather and Kristina Donnelly. *Hydraulic Fracturing and Water Resources: Separating the Frack from the Fiction*. Pacific Institute. June 2012.

52 Hyland, L.A., S.O. Ladislaw, D.L. Pumphrey, F.A. Verrastro and M.A. Walton. 2013. *Realizing the Potential of U.S. Unconventional Natural Gas*, Center for Strategic and International Studies, Washington, D.C. (http://csis.org/files/publication/130409_Ladislaw_RealizingPotentialUnconGas_Web.pdf)

varies tremendously by fuel, generating efficiency, cooling technology, climate, geography, the body of water used for cooling and the physical layout of the power plant site.

9. Multiple papers recommend improved data collection and auditing of energy utilities. Those utilities that already have those programs in place have cited improved operating efficiencies.

   Obviously the adage "You manage what you measure" is quite appropriately applied to water use by energy utilities and power plant operators. Only through understanding water demands and then investigating ways to reduce that demand can water use efficiency be achieved at existing power plants.

3.3 Observed Gaps in Current Water-Energy Nexus Research

From the collected research we also can observe gaps in collected Water-Energy Nexus Research, including:

1. Comprehensive studies and associated guidelines to conduct a detailed audit of embedded energy demands for an entire local, regional or national water/wastewater system for purposes of determining system optimization.
2. Estimates of technical and economic energy efficiency and demand response potential in water and wastewater systems and industry accepted guidelines for doing such studies on individual systems.
3. Discussions of regulatory barriers to co-implementation of efficiency programs in the water and energy sectors and ways to eliminate or overcome them.
4. Evaluation, Measurement and Verification (EM&V) protocols for use in W-E efficiency programs that are industry-accepted by both water and energy sectors.
5. Industry standards, technologies, protocols and business models for maximal renewable energy development that is water efficient and facilitate compliance with regulatory and environmental requirements, such as advanced biogas development programs (gas clean-up and emissions controls) and net zero facilities.

6. Landscape irrigation equipment efficiency potential studies that can support establishment of efficiency standards targeted for urban applications.
7. Rate structures, pricing constructs or financing mechanisms that eliminate the financial disincentives of water efficiency programs and more properly fund sustainable development and management strategies.
8. Technologies and practices that can reduce the energy demand of desalination and lower its environmental and economic costs.
9. Tools to evaluate the water energy trade-offs of differing resource development and management choices that can better inform multi-sectorial integrated resource planning.
10. Cost-effective technologies and protocols that can reduce water demand, increase water use efficiency, support water supply switching, increase productivity and reduce water quality impacts at electric generating stations, especially at existing power plants and hydroelectric facilities.
11. In depth assessment of potential impacts to water supplies and quality of energy (all fuels and electricity) resource development, such as fracturing for natural gas and biofuels; identify methods, practices and technologies that reduce or eliminate these impacts.
12. Supply chain and product embedded water-energy evaluations that can inform consumers of the energy and water intensity of the products or services they buy.
13. Effective engagement and communications methods, practices and mechanisms to ensure commercialization and adoption of preferred research results and technological developments that maximize acceptance and application in the marketplace and public service industry.

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4 Recommendations

Targeting future water-energy nexus research investments on the gaps will help significantly to advance the development, understanding and implementation of dynamic management strategies and programs that can improve water and energy resource's supply reliability, economic efficiency, environmental protection, and resource quality. The compiled research reveals much about the knowledge that has been gained from more emphasis on the relationships between water and energy resources. However, many questions remain to be answered such as:

- What is the overall economic or technical potential for cost-effective energy efficiency in the water sector? Of water efficiency in the energy sector?
- What percentage of a water or wastewater facility energy load can reasonably be shifted or reduced? What service or activity is most affected by demand response?
- What are the overall effects of end-use efficiency programs on embedded energy demand of the water sector? On embedded water demand of the energy sector?
- What incentive programs exist or are needed that could offset costs to end users?
- When and how should utility representatives be engaged to ensure maximal consideration of efficiencies and qualification for funding?
- What is the overall potential for power plant water use efficiency and what benefits could this water use efficiency have on water supplies and quality? How can existing power plants significantly reduce their water consumption and or use cost-effectively?
- What is an acceptable policy framework for evaluating trade-offs between water and energy resources that ensures the long term enhancement and responsible management of each?
- How best to ensure adoptions and acceptance of promising research results and technologies development in the water and energy marketplace and service industry.

Significant water and energy constraints in many areas of the country demonstrate the need to continue focused and deliberate research into the relationships and tradeoff between energy and water resources. With increasing demands for, costs of, and constraints on each of these resources, as well as the significant interdependencies between them, a more comprehensive and cross-cutting multi-resource approach to research is warranted. Although a sizable body of research already exists, much more can be done to pro-actively evaluate strategies and methodologies that can reduce conflicts and issues between the two resources and maximize the benefits that provide for long-term reliability and sustainability. Too frequently we have seen that knowledge and understanding of this body of work, much less the use of it, is severely lacking or non-existent. To this end, AWE and ACEEE recommend additional research that can support and advance efforts outlined in the *Blueprint, s*pecifically:

1. Develop comprehensive studies and associated guidelines to conduct a detailed audit of embedded energy demands for an entire local, regional or national water/ wastewater system for the purposes of determining system optimization.

These studies could benchmark systems to determine performance against other systems and identify options for optimizing both energy and water/ wastewater services performance of an entire system. To be able to comprehensively integrate management of water and energy resources, more information is needed about the energy demands of an entire water/wastewater system and how it must operate to provide needed services to customers at any point in time. Such studies could be expected to include benchmarking system components performance and dependencies, number of accounts and amount of service, geographic conditions, projected demands over time of water/wastewater services, etc… Only in this manner, can operators make decisions that optimize system performance to achieve significant energy demand reductions, maximal energy production (in the case of wastewater facilities) and reliable water-related services.

2. **Assess technical and economic energy efficiency and demand response potential in water and wastewater systems and develop industry accepted guidelines for such studies on individual systems.**

Although the research compilation identified some studies of energy efficiency and demand response at water and wastewater facilities have been done, they are few and rather out of date. These studies also tend to be focused only on a facility rather than an entire system. Others are at too high a level for meaningful regional or local decisions, such as the World Bank study.[53] These studies can be useful for baseline considerations or for historical perspective, but may be inadequate for consideration of recently advanced practices or technologies that can affect overall potential estimates. However, a thorough assessment of water and wastewater infrastructure is needed in order to better understand where energy is used, what opportunities for improvement exists, and establish the priorities for action. Also valuable would be a historical review of energy records to water and wastewater facilities during drought that tracks energy use to water service over time. In addition, new research could also produce guidelines or protocols for water AND energy industry-accepted assessments.

53 Liu, Feng et. al. *A primer on energy efficiency for municipal water and wastewater utilities*. Washington, DC: The World Bank, February 2012.

3. **Identify and eliminate regulatory barriers to co-implementation of efficiency programs in the water and energy sectors.**

Investigations in recent years have focused on the interactions between and opportunities among the water and energy sectors to advance both water and energy system optimization with an emphasis on barriers and was to overcome them. However, many obstacles remain and continue to plague more progressive implementation strategies. Some of these issues include:

- Whether or not electric and gas utilities can effectively partner with their water utility counterparts for the successful implementation of mutually beneficial programs without expressed approval from regulators?
- Can issues of cost-effectiveness and the appropriate way to value and allocate benefits be resolved under existing regulatory requirements. If not, what must be changed and how?

4. **Develop water AND energy industry-accepted Evaluation, Measurement and Verification (EM&V) protocols for use in efficiency programs.**

EM&V is a critical component of any efficiency program. However, traditional EM&V protocols may be too limited to address the many benefits of multi-sectorial projects and properly value the outcomes. Such restrictive or ill-suited protocols can exclude actions that have multiple benefits and may otherwise be cost-effective when these benefits are included in the calculation.

For example, PG&E identified the challenges associated with defining a baseline for comparison purposes at wastewater treatment facilities that can be used in energy efficiency programs.[54] Research could help to better inform what proxies or assumptions are appropriate in multi-sectorial, multi-benefit programs that better evaluate potential efficiency savings.

5. **Develop industry standards, protocols and successful business models for advanced biogas development programs and net zero facilities at wastewater treatment plants.**

When it comes to biogas, specifically, research has transitioned from questions of whether it is cost effective to even develop such projects to questions

54 PG&E New Construction Energy Management Program, June 2003.

of how to continue to use the biogas effectively with increasing regulatory and operational constraints. Investment in research that can address these issues (i.e., gas quality on engine operations, gas clean-up, and ways to address derivatives of personal care products) and also create the foundation for industry-accepted standards will do much to ensure maximal beneficial use of this renewable resource. In addition, identification of business practices that maximize renewable potential such as co-digestion and increasing the anaerobic performance of digestion (perhaps through re-digestion, other methods, etc…) to maximize generation of gases, could support more cost-effective programs. These studies could also include reducing the costs of gas clean-up and reducing emissions.

The Gloversville-Johnstown Joint wastewater treatment plant[55] is a wonderful example of the extent to which such facilities can maximize their energy efficiency and use available renewable energy resources to offset their remaining energy demand. This and similar facilities can be used to develop regional and national standards, protocols and business models to encourage and facilitate other utilities to do the same.

6. Conduct landscape irrigation equipment efficiency potential studies that can support establishment of efficiency standards

Significant amounts of water are used in landscape irrigation, especially in the arid West. Although much research has been conducted in the area of agricultural water use efficiency, it is not entirely transferrable to landscape irrigation. For example, agricultural water use efficiency seeks to achieve maximal yields and production with the least amount of water use. For landscape water use efficiency, especially in areas that are seeking to reduce landscape-related waste, maximal yield and production is not the goal; rather aesthetics attributes are. Research into development of proper metrics and standards for landscaping would do much to reduce water use that achieves these aesthetics goals.

7. Identify rate structures, price constructs, and financing mechanisms that eliminate the financial disincentives of efficiency programs and alternative water supply use in the water sector.

In many cases, successful water efficiency programs reduce revenues for water agencies under typical rate structures. However, in the energy sector, investments in supply programs, even conservation and efficiency related supplies, no longer reduces revenues in many states. This concept, known as decoupling revenues from expenditures, has eliminated the financial disincentives associated with efficiency and conservation programs. Research is needed into the potential for decoupling investments from revenues in U.S. water markets and other financial methods that

55 Ostapczuk, Robert E. et. al., 2011.

would make conservation and efficiency programs more sustainable and encourage supply switching. Better valuing of the different qualities and sources of water would also facilitate better choices of water resource applications that take the real cost/value of the supply and quality into consideration. Research can also include development of new business models and guidelines that support better asset management and utilization, and diversify revenue portfolios.

8. Evaluate technologies and practices that can reduce the energy demand of desalination and lower its costs.

A significant body of research was found regarding desalination in the course of this project, however, most of it was not included because it did not address energy directly or was too technically focused to inform the water energy nexus questions being addressed by this paper. In many regions of the country, desalination is increasingly seen as the only remaining option for increased water supplies, but impacts and costs are major barriers. The National Research Council in 2008[56] identified many areas and topics related to desalination that need further research and we concur with their recommendations. Further research related to desalination should address: (1) increased understanding of environmental impacts of desalination that result in the development of approaches to minimize these impacts relative to other water supply alternatives, and (2) new approaches to lower financial costs of desalination, in particular, those associated with energy demand.

9. Continue investigations into the water energy trade-offs of differing resource development and management choices that can better inform multi-sectorial integrated resource planning.

Growing constraints on water and energy resources, an increased appreciation for the role of energy in water and water in energy, climate change, and unacceptable conflicts between policies and programs have brought "multi-resource" or "regional" integrated resource planning (IRP) to the forefront. Methods and strategies that can be implemented at various stages in the IRP process to improve the consideration and integration of energy related opportunities and address constraints to reduce energy demand and costs are needed. Long-term or integrated resource planning strategies that effectively addresses energy-water interactions in both the water and energy sectors will ensure these resources are more sustainable. Most management plans only include short term goals and strategies. Consideration in such research should also be given to energy and water production and use during droughts and the role of storage of water and energy, including further investigation on micro-utilities for small or rural communities.

56 Committee on Advancing Desalination Technology, National Research Council. *Desalination: A National Perspective*. Washington, DC: National Academies Press, 2008.

Identification of opportunities for representatives of these two sectors to work more closely together and the "best practices" of successful collaboration are also needed to meet goals and objectives for reduced demand, lower costs, increase renewable energy generation, enhanced and more resilient resource management, and reduced GHGs. These investigations should include the development of a Water-Energy-Carbon Calculator that helps optimize resource management decisions.

10. Develop technologies and protocols that can increase water use efficiency and re-use, support water supply switching, and reduce water quality impacts of power generation facilities and other energy fuels development.

The 2006 Sandia Report to Congress provides an important assessment of the electric generation systems impacts on water resources in the U.S.[57] Unfortunately, this study did not address potential for increase water use efficiency or strategies that could be considered to reduce demand. Several other studies identified in this project addressed various advanced cooling technologies that are water efficient, but tend to have an energy or cost penalty. Further research is needed into reducing or eliminating these penalties. In addition, many existing power facilities still use high quality or even potable grade water supplies. With the vast majority of water at these facilities used for cooling purposes, opportunities exist to switch water supplies to those of lower quality, especially where recycled water is now being produced. And with increasing water quality regulations and goals, further investigations are needed into ways of eliminating water quality impacts of electric generation, such as zero liquid discharge systems, but at lower cost and increased ease of retrofits.

11. Assess potential impacts to water supplies and quality of energy resource development, such as fracturing for natural gas and biofuels development; identify methods, practices and technologies that reduce or eliminate these impacts.

As geologic fracturing becomes the standard practice in natural gas development, water demand and quality impacts from these activities on water resources is needed to address and mitigate for these impacts and avoid them in the future. This project found some research related to impact of energy development on water quality supplies and quality, but it was most associated with new development or assessing trends. Some new research is underway in this area, such as the U.S. EPA's investigation of potential impacts of hydraulic fracturing on drinking water resources,[58] but more is needed. Whether it is focused on reducing water demands associated with biofuel development or identifying more effective clean-up methods for produced water, more study is needed that can inform best practices, use of more efficient or cleaner technologies, and ways to protect water supplies and quality from energy resource development.

12. Supply chain and product embedded water-energy evaluations that can inform consumers of the energy and water intensity of the products or services they buy.

Consumers' choices about everything from the food they eat to car they drive impacts both water and energy resources. Unfortunately, there is little information available to consumers that they can understand regarding the life cycle costs of

Much research has been done on the water-energy nexus. Works such as this must continue to communicate and engage the potential benefactors of this information.

57 United States Department of Energy. *Energy Demands on Water Resources Report to Congress on the Interdependency of Energy and Water.* December 2006.

58 United States Environmental Protection Agency. "EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources." n.d. Web. 25 Apr 2013. <http://www2.epa.gov/hfstudy>

these choices. Research is needed in developing information for key products that can better inform consumers about the real and total costs to society for the marketplace choices they make. A prime example is bottled water – few consumers understand the total energy costs of this convenient, potable water supply as compared to the water from their household tap.

13. Identify effective methods, forums, practices and other mechanisms for communication and engagement by the research and policy communities with practitioners and adopters to ensure commercialization and adoption of preferred research results and technological developments that maximize acceptance and application in the marketplace and public service industry.

This report and its associated database and references to other research repositories clearly show that much research has been done on the water-energy nexus. Works such as this must continue to communicate and engage the potential benefactors of this information. Additional research is needed to identify effective methods of communicating the results of this research, ensure its consideration in policy, program and marketplace choices. In addition, research into the most effective methods of engagement and social influence are needed to ensure people make choices to act on and adopt the preferred results of these research efforts. Without acceptance and application in the marketplace and public service industry of the preferred research results, change and improvements in the water and energy sectors will be difficult to achieve.

Appendix A – Acronyms and Terms

ACEEE	American Council for and Energy-Efficient Economy
ACWA	Oregon Association of Clean Water Agencies
Advanced treatment	Process beyond secondary treatment of wastewater with the purpose of higher water quality; tertiary treatment and treatment through chemical and physical processes are included as advanced treatment.
AWE	Alliance for Water Efficiency
AWWA	American Water Works Association
Best practice	The method or process that industry accepts as most effective for achieving the desired results.
Carbon footprint	The total volume of carbon released to the atmosphere by a process.
Climate change	The phenomenon in which a significant variance of the climate is occurring for an extended period of time (over several decades).
DOE	United States Department of Energy
DSS Tool	Decision Support System for Sustainable Energy Management Tool
E-W or Energy for Water	The half of the water-energy nexus referring to the energy required for water conveyance, water treatment, water distribution, and wastewater treatment.
Embedded energy	The energy required by the water sector for conveyance, treatment, distribution, use and re-use.
Embedded water	The water required for electric power generation and fuels development and use.
Embryonic technology	Technologies in the development stage and/or tested at laboratory or bench scale. New technologies that have reached the demonstration stage overseas, but cannot yet be considered to be established there, are also considered embryonic with respect to North American applications.
EM&V	Evaluation, Measurement and Verification
Embryonic Research	Technologies in the development stage and/or tested at laboratory or bench scale.
Energy	Includes: electricity, natural gas, petroleum, biofuels and other fuels.
Energy footprint	The amount of energy consumed in a process.
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
Established Research	Technologies widely used (i.e. generally more than 25 facilities throughout the U.S.) are considered well established.[59]
Established technology	Technologies widely used (i.e. generally more than 25 facilities throughout the U.S.) are considered well established.
FOG	Fat, oil, and grease.

59 *Emerging Technologies for Biosolids Management*. Office of Wastewater Management, U.S. Environmental Protection Agency, Washington, D.C. September 2006.

Fracking	Hydraulic fracturing
GAO	United States Government Accountability Office
GHGs	Greenhouse gases
Innovative Research	Technologies meeting one of the following qualifications: (1) have been tested at a full-scale demonstration site in this country; (2) have been available and implemented in the U.S. for less than five years; (3) have some degree of initial use (i.e. implemented in less than 25 utilities in the U.S.; and (4) are established technologies overseas with some degree of initial use in the U.S.
Innovative technology	Technologies meeting one of the following qualifications: (1) have been tested at a full-scale demonstration site in this country; (2) have been available and implemented in the U.S. for less than five years; (3) have some degree of initial use (i.e. implemented in less than 25 utilities in the U.S.; and (4) are established technologies overseas with some degree of initial use in the U.S.
IRP	Integrated Resource Planning. A resource planning approach that manages both the supply and demand side for the purpose of developing and implementing dynamic management strategies and programs that can improve a resource's supply reliability, economic efficiency, environmental protection, and resource quality.
kWh	Kilowatt-hour
m^3	Cubic meters
Metro WWTP	Metropolitan Syracuse Wastewater Treatment Plant
MMBtu	Million British thermal unit
NYSERDA	New York State Energy Development Authority
PG&E	Pacific Gas and Electric Company
Primary research	Research that consists of original ideas and does not rely on work conducted by others.
Primary treatment	Wastewater treatment process that removes large solids via settling or filtration.
PSAT	Pumping System Assessment Tool
Publicly available research	Research that can be easily accessed by the public and is not confidential.
R&D	Research and development
Reclamation	United States Bureau of Reclamation
Sandia	Sandia National Laboratory
Secondary research	Research that uses other sources of research to develop ideas.
Secondary treatment	Wastewater treatment process that removes smaller particles remaining after primary treatment through fine filtrations such as membranes or microbes.
Tertiary treatment	Wastewater treatment process that removes suspended solids and dissolved materials. This is a type of advanced treatment.
Treatment facility	A facility at which water or wastewater is treated to a specific quality.
U.S.	United States

W-E or Water for Energy	The half of the water-energy nexus referring to the water required by the energy sector developing, refining, and using
Water-energy nexus or Energy Water Nexus	The terms used to describe the interaction, relationship and/or interdependencies between water and energy resources and sectors.
Water footprint	The total volume of water consumed in a process.
Work Group	AWE-ACEEE Water and Energy Research Work Group
WERF	Water Environment Research Foundation
WRF	Water Research Foundation
WWTP	Wastewater treatment plant
WTP	Water treatment plant
Zero liquid discharge	The type of power plant process that reuses or recovers the final brine within the plant or disposes of the waste brine by evaporating it into a solid.

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