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DEVELOPMENT OF A TECHNOLOGY ROADMAP FOR THE ENERGY AND WATER NEXUS

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INTRODUCTION

Energy and water are critical resources that are inextricably and reciprocally linked. The production of energy requires large volumes of water, and the treatment and distribution of water depends upon readily available, low-cost energy. For example, electricity production from thermoelectric power plants can use ~140,000 million gallons of water per day for cooling—accounting for 39% of all freshwater withdrawals in the nation, second only to agriculture in the United States (Figure 1). Significant amounts of water are also needed for hydropower, extraction/refining of minerals for energy, and bio-fuel production. Electrical energy, on the other hand, is needed for water treatment (e.g., desalination, wastewater), pumping, and distribution. The amount of electricity used in water and wastewater industries is equivalent to the amount used in chemical, petroleum refining, and paper industries. These interdependencies, coupled with increasing demands for energy and diminishing availability of freshwater supplies, pose significant challenges to ensure the sustainability of these two critical resources. Examples of the interrelationships between energy and water use are shown in Figure 2.

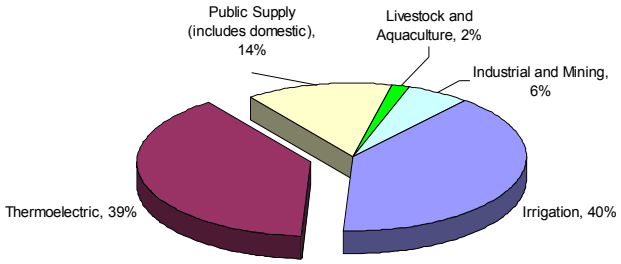

Figure 1. Estimated Freshwater Withdrawals in the U.S. by Sector in 2000 (adapted from Hutson et al., 2004).

APPROACH

As requested by Congress, a National Energy-Water Roadmap Program led by Sandia National Laboratories (and guided by an executive committee of experts in energy and water) was initiated in 2005. Sandia National Laboratories was selected to oversee and coordinate the Energy-Water Research and Development Roadmap activities. The Utton Transboundary Resources Center, a water law center at the University of New Mexico, and Lawrence Berkeley National Laboratory were selected to provide assistance in identification

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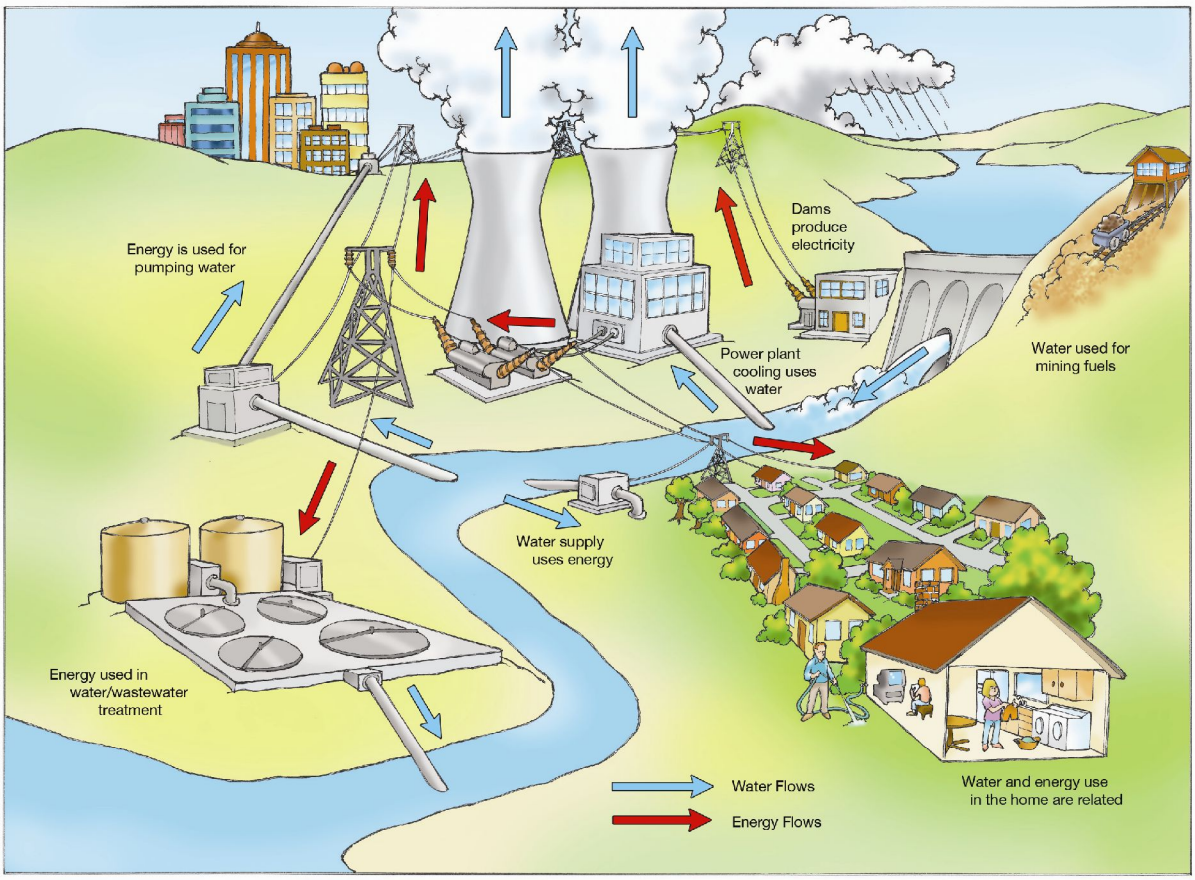

Figure 2. Examples of Interrelationships Between Energy and Water.

and analysis of policy, regulatory, and economic needs for the Roadmap efforts. McNeil Technologies was selected to professionally facilitate outreach efforts and workshops with energy and water sectors and stakeholders to help identify regional and national emerging issues and needs.

The purpose of the Roadmap is to assist the Department of Energy (DOE) in defining needs and research directions to address interrelated issues of energy and water. The Roadmap process consists of several stages. First, three regional needs-identification workshops were held in 2005-2006 to identify specific regional issues and needs associated with the energy and water nexus. Then, the needs were grouped into six primary research categories: (1) thermoelectric power generation, (2) emerging and renewable energy sources, (3) water efficiency in biofuels and biomass production, (4) non-traditional water utilization and treatment, (5) water-resource characterization, and (6) integrated energy-water resource planning. Finally, a Technology Innovations Workshop was held in May 2006 to allow researchers to suggest specific research topics and approaches that would address each of these primary needs areas. A seventh area regarding science and technology implementation and facilitation was also reviewed and discussed. Needs and recommendations regarding the six technical research areas are summarized below.

RESULTS

Water Efficiency in Thermoelectric Power Generation – Electric power generation needs are projected to increase by 30% by 2025 (EIA, 2004). Much of this increase in demand will likely be served by plants using closed-loop evaporative cooling systems. While these systems withdraw less water than plants using once-through cooling, these systems consume more water, and water consumption by the thermoelectric power sector could double by 2030 (Hoffmann et al., 2004).

Availability of fresh-water supplies for increased power generation and thermoelectric cooling will be challenged by competing water needs from agriculture, industry, and domestic uses driven by a growing population. Research and improvements in the performance and cost-effectiveness of advanced cooling technologies, advanced scrubbing, innovative source water intake designs, new materials and processes that

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use non-traditional waters, and overall power-plant efficiencies are major research directions. Over the next 10-20 years, if these new technologies can be implemented cost effectively, they could reduce the projected increase in fresh-water consumption for electric power generation by as much as 50%, while also improving the ecological and environmental impacts of thermoelectric power generation.

Renewable & Emerging Energy Resources – It is expected that hydropower and renewable energy technologies could become increasingly important components of the nation's energy mix, especially as part of the efforts to reduce fresh water use intensity in electric power generation. While the chances for new, large-scale hydropower impoundments and dams may be small, there is significant potential for installing new fish- and environment-friendly hydropower infrastructure at existing dams and deploying new non-impoundment kinetic hydropower technologies across the nation. Such installations could provide approximately 70,000 MW of generation, about 20% of projected needs by 2030, with potentially significantly reduced environmental impacts.

Renewable electricity generating technologies have generated much discussion and excitement. Solar and wind technologies are seen as integral components of tomorrow's energy mix due to their water and fuel independence. While these technologies will not, in the term covered by the Roadmap, replace conventional electric generating technologies, they have a very real potential for significant integration in areas with severe or growing water limitations. Research efforts are needed to improve intermittency and cost performance of these technologies, to improve integration and hybrid approaches, and to assess ways to accelerate applications in water stressed regions.

While oil shale resources in the U.S are significant, and could reemerge as a major alternative for imported oil, it is becoming increasingly clear that water availability and the uncertainties of oil shale development on groundwater quality could be a significant limiting factor in the scale and success of future oil-shale development. Thus research and development of water-efficient extraction and processing approaches, and approaches to minimize ground water contamination during extraction and processing, were identified as major directions needed to help support utilization of these vast resources.

Water Efficiency in Biofuels and Biomass Production – It is clear that biofuels production from conventional starch and sugar commodity crops will continue to grow and become an increasing source of domestically produced transportation fuels. As demand for biofuels increases, it will be necessary to accelerate the production of biofuels from cellulosic biomass and exploit the use of algae and other microorganisms for biofuels production that do not need fresh water or arable land for production.

An overarching research need is to better understand and manage the water impacts due to increasing bioenergy production. This includes the development of new technologies, processes, and systems that will allow for the production of large volumes of biofuels to significantly offset oil imports and other fossil fuel usage within a sustainable water budget. Also, research to understand the green house gas emissions of various alternative bioenergy processes and paths is important for assessing the carbon balance needed to reduce the adverse environmental aspects of expanding bioenergy use. Research on integrating valuable co-products (chemicals, materials, petrochemical substitutions, etc.) and services (environmental bioremediation, waste treatment and productive use, nutrient removal from contaminated water, emissions abatement, etc.) to leverage the revenue streams and efficiencies that result from an integrated system or "biorefinery" approach will enable greater overall economic viability and resource use efficiency. Finally, research on assessing the legal, policy, regulatory, economic, and market incentives framework is critically important to increase development and adoption of sustainable bioenergy options.

Non-traditional Water Utilization and Treatment - The volume of produced water from domestic oil and gas extraction is expected to grow significantly over the next few decades, especially with increased coal-bed natural gas development. Presently, an inadequate understanding of the ecological effects of produced-water disposal options, regulatory gaps and uncertainties, and recent pending court decisions have contributed to limitations on oil and gas development and production, especially related to coal-bed natural gas.

Research is needed to develop mobile, modular, cost-effective water treatment technologies for produced water that are fitted to a variety of proposed end-uses including re-injection, agricultural, surface discharge, surface impoundment, or industrial uses. Research is also needed to establish a science-based framework that clearly outlines appropriate treatment standards and methods for proposed end-uses of produced water that can be implemented. Ideally, the regulatory framework would be developed with participation and consensus of federal agencies and affected coal bed natural gas producing states as a goal.

A third important direction is research and development of water treatment technologies that are specifically tailored for the treatment of saline or brackish waters. This would provide an alternative or supplemental source of water for thermoelectric power plants cooling or for uses that could supplement water resources in water stressed areas. This research should be conducted in tandem with new thermoelectric power plant research on the use of nontraditional waters, as well as with agencies and organizations trying to improve energy use efficiency for water treatment, an emerging major national need. The Southeast, Southwest, and Mountain West are areas that will especially benefit from this research.

Water Supply Characterization – While water resources research has generally remained constant (in real dollars) since

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1973, per capita spending for water research decreased almost 30 percent from 1973 to 2001. In some critical areas such as water resources data collection and planning, funding levels have decreased by a factor of four. Also, there has not been a comprehensive assessment of water availability and future water demands in 25 years. While a nation-wide water monitoring program and system already exists, many regions and states lack a good understanding of fresh and brackish water availability, emerging water needs, and the emerging impacts of changing climates and changing water needs on water availability and costs. This uncertainty over future water availability and competing demands has already slowed new energy development in many regions of the country.

Research on improved sensors, water data collection, and data management is needed to improve the understanding of fresh water and nontraditional water availability. Also, a better understanding of the emerging and competing demands for water is needed. Research on regional climate variability and the impacts on future water supplies and energy demands are also needed. Finally, research on ecological water needs that compete with or drive energy development is needed to improve ways to manage water and energy production in a way that minimizes ecological and environmental impacts.

Integrated Resources Planning, Decision Support Tools, and Policy Issues – Collaboration on energy and water resources planning is critically needed among federal, regional, and state agencies as well as with industry. In most regions, energy planning and water planning are done independently. Mechanisms, approaches, and working groups to encourage collaborations between water and energy management and regulatory agencies are needed to ensure energy development and water needs are incorporated into state and regional water resources planning and management.

Research and development to improve information collection, data management, and decision support tools are needed to help integrate energy and water databases and provide tools for energy, water, and other sector managers to improve energy and water management for multiple uses and needs. This will require research and development of system-level models that can evaluate the impact of major changes in infrastructure or policy on energy and water sustainability. With these new models, improvements in energy and water conservation and cost-effectiveness can be quantified by co-location of energy and water facilities and improvements to energy and water infrastructures.

Often, polices or regulations developed to support or enhance one area, such as increasing domestic energy supplies through incentives, could have unintended negative impacts on regional or national freshwater availability or water quality, unless these policies are closely evaluated for both energy and water impacts. A key to the success of any program is the ability to get industry and state and local governments to implement and endorse innovative concepts. Critical needs include developing joint government/industry working groups to support technology demonstrations, collect appropriate cost and performance data, reduce implementation risks, and accelerate the use of new technologies. There is also a critical need to include system-level evaluations and a technical understanding of how emerging energy and water policies, regulations, or economic incentives can impact regional energy and water reliability and sustainability. We must also establish working groups to provide science-based recommendations on policies and regulations that could impact energy and water availability.

SUMMARY

Over 500 participants representing water and energy managers, water and energy utilities, regulatory agencies, environmental groups, industry associations, technology developers, and academia joined in the Roadmap process. A final report to DOE, "*Energy-Water Research Directions—Essential Elements for a Reliable Energy Future*", will provide a detailed explanation of the Roadmap process, participants, and the key science and technology research and development directions identified through the Energy-Water Roadmap process. The final report is expected to be published in the Fall of 2006.

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