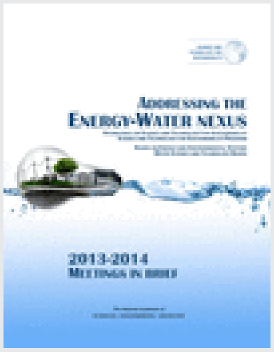

Addressing the Energy-Water Nexus: 2013-2014 Meetings in Brief

DETAILS

44 pages | 8.5 x 11 | | ISBN 978-0-309-38087-4

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SCIENCE AND TECHNOLOGY FOR SUSTAINABILITY

ADDRESSING THE ENERGY-WATER NEXUS

ROUNDTABLE ON SCIENCE AND TECHNOLOGY FOR SUSTAINABILITY
SCIENCE AND TECHNOLOGY FOR SUSTAINABILITY PROGRAM

BOARD ON ENERGY AND ENVIRONMENTAL SYSTEMS
WATER SCIENCE AND TECHNOLOGY BOARD

2013-2014 MEETINGS IN BRIEF

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

Preface

Adequate water and energy are critical to the continued economic security of the United States. The relationship between energy and water is complex, and the scientific community is increasingly recognizing the importance of better understanding the linkages between these two resource domains. Federal agencies, the private sector, and academic researchers have noted that the lack of data on energy-water linkages remains a key limitation to fully characterizing the scope of this issue.

In an effort to bridge these resource domains, the U.S. Senate Committee on Energy and Natural Resources introduced bipartisan legislation, titled the Nexus of Energy and Water for Sustainability (NEWS) Act of 2014 (S. 1971), to coordinate and streamline federal activities related to the management of the energy-water nexus. The Senate Committee noted that "all forms of energy production require water and that our use of water requires energy. Together, energy and water resources are the foundation of our nation's economy and are essential to our nation's future and international security."[1]

The National Academies of Sciences, Engineering, and Medicine's Roundtable on Science and Technology for Sustainability (STS Roundtable), in collaboration with the Board on Energy and Environmental Systems (BEES) and the Water Science and Technology Board (WSTB), contributed to the emerging dialogue on the energy-water nexus by holding four related meetings in June and December 2013, and May and December 2014. These meetings were designed to examine emerging technical and policy mechanisms to address energy-water issues, including:

- Discussing a strategy for addressing the energy-water nexus in various sectors;
- Identifying data and research needs for addressing energy-water linkages, including ways
- to leverage ongoing data collection and dissemination efforts;
- Refining mechanisms for encouraging partnerships among key players in all sectors and furthering technological innovation to advance the field; and
- Examining linkages beyond those of energy and water, to include land use, transportation and technology.

The purpose of the meetings was to provide a national forum for identification of core energy-water nexus issues, to encourage the application of broader sustainability frameworks in thinking about these two inter-related resource domains, and to stimulate new initiatives to meet energy-water nexus challenges in a sustainable manner.

The first event, held in June 2013, provided a broad overview of the energy-water nexus, including examining key data and partnership needs for addressing energy-water issues. This meeting was developed in coordination with staff from the Cynthia and George Mitchell Foundation, who were actively involved in engaging foundations to call attention to the issue and to gain their perspective on how to move forward. Over 60 participants attended the event, including nearly a dozen foundations, representatives from 13 federal agencies, and numerous private sector entities, including Siemens, IBM, and Dow Chemical Company.

The December 2013 meeting delved more deeply, focusing on energy-water nexus issues associated with electric power production. Specifically, the meeting addressed how changing water conditions have affected the operations of thermoelectric power plants and the role of research on new water-saving technologies for power plants.

The STS Roundtable held two additional meetings on particular energy-water nexus issues in 2014. The May 2014 meeting focused on the role of technological innovation in addressing energy-water nexus challenges. Panels of experts examined research needs for optimizing current technologies, existing barriers, emerging technology innovations,

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[1] The U.S. Senate Committee on Energy and Natural Resources. 2014. Wyden, Murkowski Introduce Legislation on the Energy and Water Nexus. Online. Available at: http://www.energy.senate.gov/public/index.cfm/2014/1/wyden-murkowski-introduce-legislation-on-the-energy-and-water-nexus. Accessed April 22, 2015.

and approaches for advancing the integrative field of the energy-water nexus to best address key challenges. A one-page infographic was created to highlight some of the issues discussed at first three meetings.

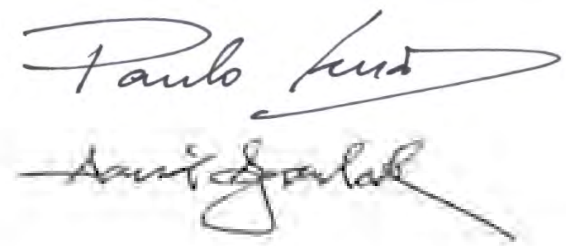
The fourth and final meeting in December 2014 examined improved data for water use, decision support tools, and frameworks for local and regional decision making. The panel discussions built on progress made at the three prior meetings, as well as a 2013 workshop at Massachusetts Institute of Technology's (MIT's) Center for Strategic and International Studies (CSIS) workshop on the energy-water-land nexus[2] and a 2013 National Science Foundation workshop on developing a research agenda for the energy-water nexus.[3]

This volume compiles the Meetings in Brief for the four events:

- Sustainable Energy and Materials: Addressing the Energy-Water Nexus (June 6, 2013)
- Addressing the Energy-Water Nexus: Power Plants and Partnerships (December 5, 2013)
- Addressing the Energy-Water Nexus through Technological Innovation (May 20, 2014)
- Addressing the Energy-Water Nexus: Need for Improved Data and Decision Support Tools (December 10, 2014).

A Meeting in Brief provides a short synopsis of the presentations and discussions at a public meeting or workshop that can be produced quickly and inexpensively after the event. Written by an individual rapporteur, it is a reasonably accurate and objective summary of what occurred at the meeting. It does not contain findings or recommendations, and all opinions are attributed to individual or small groups of participants. A Meeting in Brief is subject to external review by experts other than its authors prior to release to the public, helping to make it as accurate and effective as possible. The committee's role is limited to planning and hosting the meetings. The statements in the documents are those of the authors or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, the STS Roundtable, or the Academies. Each Meeting in Brief was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Academies Report Review Committee.

This project was made possible with support from the Academies' George and Cynthia Mitchell Endowment for Sustainability. We want to express our thanks and appreciation to our Roundtable co-chairs, Thomas Graedel, Yale University (through June 2014), Ann Bartuska, U.S. Department of Agriculture (through December 2013), and Lynn Scarlett, The Nature Conservancy (from August 2014), for the time and effort they put into planning these meetings. We also thank James Zucchetto of BEES and Jeffrey Jacobs of WSTB for their collaborative support with these activities.



Paulo Ferrão, *Chair* (2013)
David Dzombak, *Chair* (2014)
Planning Committee on Addressing the Energy-Water Nexus

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[2] http://mitei.mit.edu/publications/reports-studies/mit-csis-energy-water-land-nexus-workshop

[3] http://www.iwawaterwiki.org/xwiki/bin/view/Articles/WorkshopReportDevelopingaResearchAgendafortheEnergy-waterNexus#HWorkshopReport%3ADevelopingaResearchAgendafortheEnergy%2DWaterNexus

Addressing the ENERGY-WATER Nexus

Most energy technologies are water intensive

Thermoelectric Power Plants—primarily coal, nuclear, and natural gas—withdraw **136 billion gallons of freshwater each day** to produce our nation's electricity.

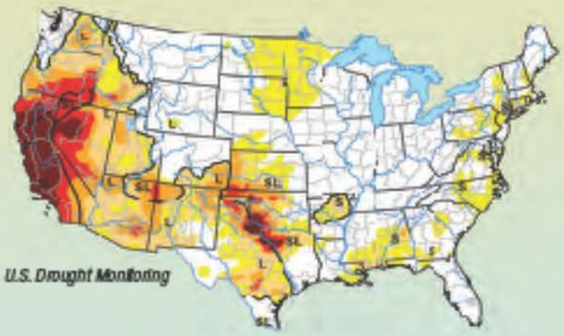
40% of U.S. freshwater withdrawal goes directly to electricity production.

U.S. population growth is primarily in areas with water scarcity

By 2060:

Population in the **southwest** will increase by **43%**

Population in the **southeast** will increase by **32%**



U.S. Drought Monitoring

Related energy technologies—oil refineries, shale oil production, biofuels, and even carbon capture and sequestration—are water intensive activities, too.

How can we reduce consumption of freshwater for electricity production?

Use wastewater and brackish water in power plants

—University professor

Link the electrical grid with water utilities so that waste from one sector feeds the needs of the other

—Industry executive

Increase production of Wind Power and Photovoltaic Solar Panels, energy technologies that consume no water

—National lab researcher

Better coordinate how energy and water systems are connected

—Congressional staffer

This infographic summarizes discussions held at meetings of the National Research Council's Roundtable on Science and Technology for Sustainability, held in collaboration with the Board on Energy and Environmental Systems and Water Science and Technology Board in 2013-2014. For additional information, see http://sites.nationalacademies.org/PGA/sustainability/PGA_152676.

Contents

Sustainable Energy and Materials: Addressing the Energy-Water Nexus June 6, 2013

Adequate water and energy are critical to the continued economic security of the United States. The relationship between energy and water is complex, and the scientific community is increasingly recognizing the importance of this connection. A recent statement by global leaders from 15 science academies noted that the "needs for affordable and clean energy, for water in adequate quantity and quality and for food security will increasingly be the central challenges for humanity: Water and energy are inextricably linked and mutually dependent, with each affecting the other's availability." Other high- profile entities have studied this relationship, including the World Economic Forum and the Government Accountability Office, and have noted that the lack of data on energy-water linkages remains a key limitation to fully understanding the scope of this issue.

The National Academies' Roundtable on Science and Technology for Sustainability, in collaboration with the Division on Engineering and Physical Sciences' Board on Energy and Environmental Systems (BEES) and the Division on Earth and Life Studies' Water Science and Technology Board (WSTB), has developed a year-long initiative focused on examining core water-energy nexus issues.

These issues include:

- Primary linkages and trade-offs between increasing energy demands and production, and related water supply implications and water quality goals;
- Criteria and a framework(s) for evaluating energy-water linkages and trade-offs;
- Available technologies and strategies, and barriers, for balancing increasing energy demands with increasing water supply demands and water quality goals and concerns; and
- Available public and private sector funds for leveraging further technological development, innovations, and research to address core energy-water nexus issues and trade-offs.

On June 6, 2013, the Roundtable held the first in the series of events, convening technical experts from the philanthropic community, private industry, and representatives from government and academia to examine key questions, including data and partnership needs for addressing the energy-water nexus.

Ideas voiced by some of the speakers and participants at the workshop include:

- The discussion of the energy-water nexus should be broadened beyond energy and water to encompass food, climate, and human security, including international security. Addressing these challenges requires a holistic, comprehensive view and approach.
- The energy-water nexus is a regional and temporal issue which depends on weather, fuel, and water availability.
- To address the energy-water nexus, there is a need to encourage an integrated approach that includes developing long-term strategies to address these issues; harnessing new technologies; developing regional water policies in the absence of federal policy; and identifying opportunities for water reuse/recycling/capture.
- There are bountiful data on every power plant's emission; however, there is no real comprehensive dataset for water. An Annual Water Outlook, equivalent to what is being produced for the Annual Energy Outlook, which includes climate data, segregated by sector, is needed.
- Water use needs to be incorporated into public utilities' decisionmaking to improve the resilience of this sector in a changing climate. Power sector decisions are made projecting out 20-60 years so it is vital that these types of considerations be addressed now as these decisions are being debated.
- Water should also be considered as a factor in grid planning, which has historically not been the

case. Beginning to think about efficient water markets will be key and a significant challenge.

- Several platforms, which include datasets, tools, and models of the energy-water nexus, have been developed by the Department of Energy and other federal partners. These include Watertoolbox.us and the Open Energy Information website (openei.org).
- A key energy-water issue is the emerging cybersecurity threat to critical infrastructure, including the energy and water sectors. A recent report from the Department of Homeland Security indicates that the number of cyberattacks is increasing; 67 percent of the attacks discussed in the study targeted critical water and energy infrastructure, water plants, wastewater plants, energy plants, fossil fuel, and nuclear plants.

Peter Gleick of the Pacific Institute provided keynote remarks to introduce the energy-water nexus, noting that all of the participants were aware of the basic premise that energy and water are closely connected: It takes water to produce energy and vice versa. It is well understood that we should integrate our policies, economies, institutions, and strategies to address these complex links between energy and water, but we currently do not, he said. A path forward is needed to address these linkages.

Dr. Gleick posited that we are currently going through a period of transition. Currently, we have a fragmented pre-industrial and partially industrialized world with isolated decision-making; incomplete data, information, and knowledge; and competing, often-diverging interests. We are moving toward a world that is integrated politically, financially, environmentally, and socially. Many factors are driving this transition, including globalization in areas such as trade, communications, and impacts on the environment. This transition is moving us toward a more sustainable world, and discussions about the connections between energy and water are an example of this transition. However, the discussion should be broadened beyond energy and water to include food, climate, and human security, including international security. Addressing these challenges requires a holistic, integrated, comprehensive view and approach.

Breaking down traditional academic, political, and institutional barriers will also be crucial, Dr. Gleick continued. The approaches, tools and institutions that were used in the past to solve our problems have not been able to address the ones we face now. For example, there are currently two and a half billion people worldwide without access to adequate water and sanitation services. This results from a failure of institutions and a lack of consideration of critical connections when developing policies.

Another area where the integration of policies has not been considered is corporate water use, said Dr. Gleick. Corporate water activities have all sorts of implications for the water sector, yet the corporate sector has often been left out of discussions about federal water policy and local water policy, management, and use. The corporate sector needs to be included in these discussions, because there are enormous risks to failing to integrate water issues into corporate operations.

Climate models suggest that there is likely to be a long-term decrease in water availability in the Tigris and Euphrates Basin—an issue that integrates energy policy, water policy, and food security. A failure to think about them in an integrated way can lead us to make poor decisions. There is also a need to address these challenges in a different way, particularly to address issues of scale and scope.

Another important factor, Dr. Gleick said, is the different actors involved in these discussions, such as foundations and the federal, state, international, and local funding organizations as well as operating entities in the energy and water sectors—all of which have difficulty crossing disciplinary boundaries. Some corporations, too, have particular interests and expertise and have begun to think differently about scale and scope and other issues. In addition, there are disenfranchised communities that have not had a role to play because policymakers have had competing interests and short-term priorities.

Dr. Gleick added that globally we are moving toward a day when the population of the planet is going to be lower than it was the day before. The entire concept of growth is going to be brought to our attention in a pretty dramatic way. Our institutions and our economic philosophies have been predicated to some degree on the concept of inexorable growth. Factors slowing this transition toward a sustainable world include the failure to consider institutions, different players, and scale and scope. Overcoming the barriers to this transition is the key challenge.

Overview of the Energy-Water Nexus: Characterizing the Issue

Paulo Ferrão of the Technical University of Lisbon introduced the subsequent presentations by describing the meeting objectives, including understanding primary links and trade-offs between increasing energy demands and goals for water supply and quality, and identifying criteria and a framework to analyze these trade-offs. Other objectives include understanding the technologies and strategies that are available to achieve sustainable solutions and the public and private funds available to leverage them.

The Honorable Katherine Hammack of the U.S. Department of the Army described how the Army approaches “sustainability,” with emphasis on its Net Zero initiative. The Army typically thinks about sustainability in terms of sustaining supply lines, ammunition, and logistics. Also, the sheer size of the Army’s infrastructure demonstrates the challenge of becoming more sustainable. The Army has approximately one billion square feet of permanent buildings, including 106,000 homes utilized by 2.2 million people. The number of permanent installations the Army owns globally is equivalent to about 152 small cities. The Army is one of the top consumers of energy and a large consumer of water; it also generates a significant amount of waste. The Net Zero initiative is a standard that allows the Army to be fiscal and environmental stewards in the approximately 14 million acres of land the Army occupies in the United States.

A Net Zero installation applies an integrated approach to managing energy, water, and waste to capture and commercialize the resource value and/or enhance the ecological productivity of land, water, and air (see Figure 1), explained Ms. Hammack. A Net Zero Energy installation produces as much energy on-site as it uses, while a Net Zero Water installation limits the consumption of freshwater resources and returns water back to the same watershed so as not to deplete the groundwater and surface water resources of that region in quantity or quality. A Net Zero Waste installation is one that reduces, reuses, and recovers waste streams and converts them to resource values with zero solid waste to landfills.

Although the Army has been mandated by Congress to meet several sustainability targets, with the right approach, they were able to motivate installations to volunteer to meet these Net Zero standards, said Ms. Hammack. Rather than using mandates, leadership asked for installations to volunteer to develop strategies to meet NetZero goals in waste, water, and/or energy. Over 100 installations applied to participate. Installations had an incentive to participate because they were

Figure 1 Net zero hierarchy.
Source: K. Hammack. June 6th presentation to the National Academies Roundtable on Science and Technology for Sustainability.

convinced that adopting Net Zero policies could enable a more successful implementation of their primary mission.

Security experts have found that the combined utilities and energy industries are vulnerable and rank high on the list of potential targets for terrorists. And in 2011 and 2012, there was a fourfold increase in the number of power outages experienced on military bases, posing a significant risk. Reflecting this reality, the military needs to be thinking about ways to generate more energy within a controllable boundary to address this risk. The Army believes it also needs to better manage energy and water use to ensure resiliency to natural disasters. By becoming more resource independent, and thus more sustainable, the Army could better support its primary mission.

David LoPiccolo from Siemens said that the company has adopted an integrated approach to sustainability and is identifying new and significant opportunities to save water and energy for clients in areas not previously considered or understood.

Sixty to 80 percent of an industrial facility's energy use is impacted by water, and 95 percent of a facility's water has energy added to it to perform some work for that operation. Historically, water and energy were considered independently, but the industry is now more acutely aware of the water crisis and is living with increased pressure to optimize energy use and operate sustainably. Consumers are making active choices based on the ecofriendly products a company may or may not make. Industry's awareness of this trend is driving it to take action and is reshaping the industrial perspective on water and energy.

To address the need to reduce water use, Siemens takes a four step approach with its clients. The first step is "awareness," which encompasses a review of the client's water and energy sustainability practices, including their attitude, awareness, and capabilities to improve sustainability metrics, including ensuring that a sufficient management structure is in place. After this review, Siemens conducts an onsite assessment using a team of water and energy engineers to perform a holistic end-to-end assessment of all water users and all energy users, and identify gaps in efficiency. Filling these gaps is referred to as conservation measures.

When step 2 is completed, the facility has a road map for sustainable improvement, with conservation measures that are targeted, qualified, prioritized, and integrated. In step 3, Siemens commits to remaining with the client as a partner to help implement change. Life cycle services are conducted in step 4 to ensure that clients maintain the gains achieved.

Finally, Mr. LoPiccolo discussed a key energy-water issue, the emerging cybersecurity threat to critical infrastructure, including the energy and water sectors.

Industrial Control Systems, the systems that actually control the processes and machinery in Siemens' facilities, are networked, and it is this connectivity that provides an open, unprotected portal that affords access and opportunity for disruption and disaster. These controls are in charge of critical infrastructure—water, wastewater, energy, tunnels, oil and gas distribution—in a variety of industries that make up the defense industrial base, specifically chemicals.

From a national perspective, the annual report from the Department of Homeland Security's Cyber Emergency Response Team on the Industrial Control System describes the critical need to protect our infrastructure from cyberattacks, said LoPiccolo. The report shows that the number of attacks is increasing; 67 percent of the attacks in the 2011 report targeted critical water and energy infrastructure, including water plants, wastewater plants, energy plants, fossil fuel plants, and nuclear plants (see Figure 2).

On February 2013, President Obama signed an Executive Order (E.O. 13636), designed to improve critical infrastructure cybersecurity. Siemens is actively working to respond to the Executive Order by improving plant security, network security, and system integrity.

David Wegner, a professional staff member from the U.S. House of Representatives' Subcommittee on Water Resources and Environment, said that water policy issues have become more politicized in recent years, as evidenced by greater congressional interest in the Water Resources Development Act currently being debated. He suggested that energy and water issues be dealt with collaboratively and collectively by the Congress. Regarding energy and water policy, members of Congress need to develop an understanding of these issues and recognize their importance. There is also a need to demonstrate how to integrate water and energy issues so that members can develop an understanding of how to leverage the energy-water nexus to meet the needs of constituents.

Federal water policy is extremely challenging, Mr. Wegner added. A national water policy does not exist in the United States. Regional concerns about water use are very strong, but the possibility of

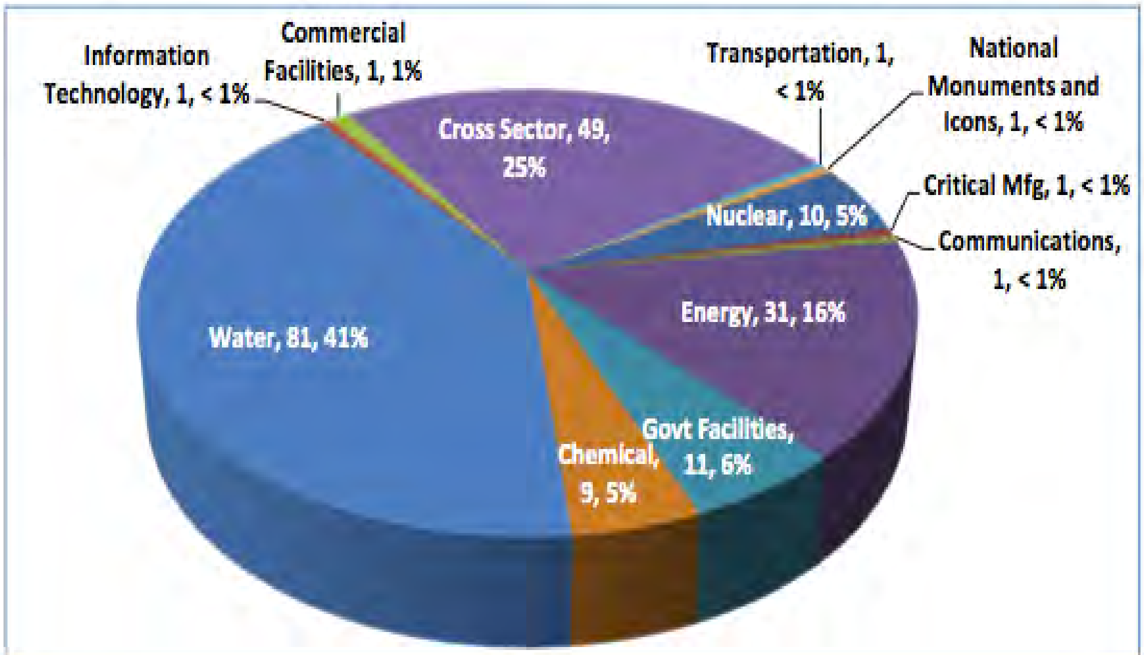


Figure 2 Cyber threats to Industrial Control Systems (ICS).
Source: D. LoPiccolo. June 6th presentation to the National Academies Roundtable on Science and Technology for Sustainability.

developing a national policy is complicated by the fact that water use issues in the western United States are dramatically different from those in the East. In addition, the federal government is not designed to address water issues in a collaborative way. Twenty-six federal agencies have "water" specified in their mission statement.

Water policy thus far has been based on historical data, which is not necessarily a good predictor of the future, Mr. Wegner continued. We are starting to see many more extreme events, which are significantly impacting water and energy infrastructure. To address the energy-water nexus, it will be necessary to encourage an integrated approach; develop long-term strategies to address these issues; harness new technologies; develop regional water policies in the absence of federal policy; and look at opportunities for water reuse/recycling/capture. These resources must be measured so that they can be managed appropriately, and the new water norm must be integrated into our everyday thinking. Finally, Mr. Wegner noted that Hurricane Sandy has enabled a conversation on climate change in Congress, an issue that has been difficult to discuss in recent times; this is an opportunity to start a dialogue on these issues.

Data and Research Gaps

Corinne Scown of Lawrence Berkeley National Laboratory discussed data and research gaps related to the energy-water nexus. Renewable resources such as wind and solar are inherently intermittent; water resources are also intermittent—perhaps increasingly so because of growing pressures from climate change.

Presenting data on water withdrawals by state, Dr. Scown noted that geographic specificity is important, as evidenced by the difference in how water is used as we move from the West coast to the East coast. A significant amount of water is used for irrigation in the West, while in the East, water is more typically withdrawn for industrial facilities and open loop cooling systems at power plants.

To assess life cycle water impacts, an inventory is needed that tracks all water consumption, including location, evaporative loss, and total withdrawals. In her field, Dr. Scown noted, there is a disconnect between the availability of detailed lifecycle inventories of water use and a lack of robust water use impact assessments. There are methods for quantifying the impacts of biodiversity and human health, etc.; however, the data in the inventories are not available in terms of geographic specificity, timing, and other factors needed to conduct detailed impact assessments. There have been some calls to track life cycle water use in the same way there is a life cycle framework being applied to regulating greenhouse gas emissions.

Dr. Scown posed several big questions as major challenges moving forward, including: What geographic boundaries do we want to apply to energy and water co-management? How do we balance competing demands for water during times of scarcity among farmers, power plants, industry, and public supply? How will climate change affect water needs for power production and agriculture?

Matthew Eckelman of Northeastern University described the state of variability and uncertainty in the data available to address the energy-water nexus. Much of the data focus on the supply side of the discussion, but addressing demand is a key issue. Studies largely report direct water usage, but indirect usage can also be significant.

Regarding datasets available for energy and water, on the energy side, there are bountiful data on power plant use; however, there is no comprehensive dataset for water, said Dr. Eckelman. Some industry associations collect data—the American Water Works Association, for example, has a rich historical data set and established protocols for measurements—but these data are not open for analysis. Similarly, data on water use by wastewater utilities are not comprehensive or publicly available.

There may be some opportunity to access detailed end use data on water through the Commercial Buildings Energy Consumption Survey (CBECS), which is asking comprehensive water use questions for the first time. Some recent work is also projecting future water use by pairing regional water use data with electricity use data from Annual Energy Outlook, an effort which may provide an opportunity for future analyses. Dr. Eckelman added that what is needed is an Annual Water Outlook, equivalent to what is being produced for the Annual Energy Outlook[4], which includes climate data, segregated by sector.

[4] The Annual Energy Outlook is produced by the U.S. Energy Information Administration and can be found at: http://www.eia.gov/forecasts/aeo/.

Current Approaches and Strategies for Addressing Data and Research Gaps

Ahmed Ghoniem of the Massachusetts Institute of Technology described several opportunities for addressing data and research gaps related to the energy-water nexus, include four overarching observations (see Box 1). Dr. Ghoniem noted that solar, thermal, geothermal, and nuclear power plants run at lower temperatures than combustion plants; they have lower thermal efficiencies and higher water footprints but lower carbon footprints. The effect of the environment on cooling tower consumption and the choice of tower technology can also play a big role in water use decisions. The same cooling tower design can consume a different amount of water depending on its location and what time of year or time of day it is operating. The largest consumers of water include plant technology, thermal energy cooling technologies, and other uses such as desulfurization, cleaning up mirrors, etc.

Box 1 The Energy-Water Nexus: Four Overarching Observations (Ghoniem, 2013)

1. The energy-water nexus is about a fundamental trade-off between fuel, efficiency, power plant technology, and cooling technology, carbon dioxide, and water use.
2. The nexus is a regional and temporal issue which depends on weather, fuel, and water availability.
3. Regarding modeling, intermediate fidelity (physics-based) is needed to cut through the complexity for optimizing the solution and accounting for uncertainty.
4. Data for validation are also needed, including both coarse and fine grain, spatial and temporal, over fuel and technology.

Several research opportunities exist, added Dr. Ghoniem. Opportunities for reducing use in the energy sector could be more fully explored through operational changes to combined heat and power; fuel switching; improvements in plant efficiency; the aggressive application of hybrid and dry cooling; recycling of locally used water; and the use of lower quality water. Finally, multiscale physics-based models that account for the local conditions (space and time) are able to include economics to more fully describe the tradeoffs. These models provide an overall framework to address the challenges. Fine-grained data (plant by plant, location, time, and plant technology) are needed, both at the monthly and the day-to-day level.

Nancy Stoner of the U.S. Environmental Protection Agency (EPA) noted that the agency has not traditionally focused on the intersection between water and energy but has taken steps to develop programs and strategies to address these issues, particularly given challenges related to the impact of a changing climate on water resources. When thinking about challenges related to water, EPA tends to focus on issues related to population growth, urbanization, decay of infrastructure, and climate change. Water resources are critical, not only for public health and the environment but also for our economy. How we treat, filter, and distribute water has significant energy implications.

EPA has taken several steps to try to address some of these challenges, including completing a Climate Change Adaptation Plan, said Ms. Stoner. In addition, about a year ago EPA's Office of Water adopted principles for an energy-water future. EPA has identified a range of long-range goals and strategic actions that need to be taken in coming years. Three such policy goals include energy neutrality at sewage treatment plants, improved water use efficiency, and integrated water resource management.

In addition, the EPA in 2007 initiated the Water Sense Program, which helps consumers make smart water choices by identifying products and services with the Water Sense label that are at least 20 percent more efficient than standard products. To date, the Water Sense Program has helped consumers save 287 billion gallons of water and $4.7 billion in water and energy bills. EPA is looking at ways to expand the number of Water Sense partners and increase the range of products with Water Sense labels. Although EPA's Energy Star program[5], which is focused on educating consumers about better energy efficiency in appliances and other goods, is more widely known than Water Sense, the agency is looking at ways to better communicate the Water Sense program to a broader audience.

Holmes Hummel of the U.S. Department of Energy (DOE) said that the intelligence community has identified water stress as a major national security issue in an international context. The technology solutions that DOE and other partners can continue to contribute to the solution set are important to resolving national security concerns that can arise.

Congress, understanding the need for a federal role in addressing these concerns, passed the Energy Policy Act of 2005. Section 979 of the Act obligates the Secretary of Energy to develop strategies to address issues associated with stress on energy and water supplies. A cross-cutting technology team that reaches across the agency was established; the team includes 50 experts in more than 20 programs. Team members have subdivided into three main groups: cooling technologies; water in fuels production; and monitoring, modeling, and forecasting.

The cooling technologies group is working on novel materials and fluids and non-fouling materials that would allow for expansion to non-traditional water sources. The water in fuels group is improving risk assessment for water use in gas and oil development and management; addressing demands for data; assessing the use and treatment of unconventional water sources; and improving the efficiency of refineries. Finally, the monitoring, modeling, and forecasting group is developing computational power to address identified modeling challenges.

Dr. Hummel noted that DOE is outnumbered in its ability to meet the demands of the local decisionmakers. To help bridge this gap, the agency is developing self-service platforms for engagement. For example, the agency has partnered with the Army Corps of Engineers to launch the Watertoolbox.us web site. This platform includes more than 600 data sets, tools, and models from nine Federal agencies; it is also designed to support community collaboration, including forums for providing peer-to-peer support and expert guidance.

DOE has also developed the Open Energy Information website (openei.org), a Wiki platform

[5] Additional information about the Energy Star program can be found at http://www.energystar.gov/.

that allows for direct contributions from scholars and experts across the field. This site was launched as part of President Obama's call for the Open Government Initiative, and it is complemented by the agency's commitment to the Open Data Initiative.

BUILDING A COMPREHENSIVE STRATEGY FOR ADDRESSING THE ENERGY-WATER NEXUS

Steve Clemmer of the Union of Concerned Scientists (UCS) explained that his organization is collaborating with a team of independent experts to build and synthesize policy-relevant research on water demands for electricity in the context of a changing climate. A first report from this initiative was released in 2011 and included a baseline assessment of current fresh water use by U.S. power plants. A second major report[6] released in July 2013 examines future water demands of the power sector under different electricity technology pathways in the context of climate change.

To model electricity and water futures, UCS relied on the National Renewable Energy Laboratories Regional Energy Deployment System because of the amount of geographic resolution in the model, which is relevant from a water management perspective, said Mr. Clemmer. The analyses included 134 power control areas in the continental U.S.; for each area, the model estimates electricity generation from all major conventional and renewable energy technologies. Another advantage of this model is that it allows this information to be aggregated at the state level, for regional electricity reliability regions, and even for the larger Eastern, Western, and Texas interconnects. This model was coupled with a model from the Stockholm Environmental Institute called the Water Evaluation Analysis and Planning System (WEAPS), a decision support tool that is also an integrated water simulation tool.

The UCS is interested in what the power sector might look like in the context of climate change, as well as in how to reduce emissions to avoid climate change's worst consequences. Mr. Clemmer added that carbon dioxide emissions from existing power plants have declined steadily since 2007 due to the decline in coal generation and its replacement with natural gas, renewables, efficiency measures, and other lower-carbon or no-carbon options. However, emissions from the power sector are projected to steadily increase as both natural gas and coal generation increase to meet electricity demand.

Assessing the water implications for various energy scenarios, UCS found that all scenarios showed a substantial reduction in water withdrawals; however, carbon capture and storage (CCS) and nuclear scenarios—which rely on more water intensive technologies—demonstrated a larger consumption of water than the baseline assumption. These data indicate that water use needs to be incorporated into decisionmaking by public utilities to improve this sector's resilience in a changing climate. Power sector decisions are made projecting out 20-60 years, so it is vital that such considerations be addressed now while these decisions are being debated.

Paul Faeth of CAN stated that typical energy projections such as those developed by DOE's Energy Information Administration and EPA, do not incorporate water. The power sector could be substantially different if the models assumed that water is constrained, which is a key missing component in most energy policy models. Mr. Faeth noted that his model, which incorporates water use, was run using four case studies: Texas, France, India and China. In reviewing his model's China scenario, for example, there appears to be a necessary shift towards renewable energy, which is not as water intensive.

Another issue not routinely considered in these types of analyses is the co-benefits of reducing water use in energy production, including improvements in air quality, he added. Through analyses of the four case studies, his team found that reducing water use in the power sector requires (1) improvements in efficiency; (2) increased use of renewables; and (3) a shift from the use of coal to natural gas. The analyses also looked at the impact of carbon cap policies and found that such policies could be favorable in terms of managing water withdrawals and consumption.

Michael Webber of the University of Austin, Texas, presented cross-sectoral solutions to the energy-water nexus, including ways to use the water sector to solve energy problems and vice versa. For example, energy could be recovered from wastewater treatment plants, for example by the production of biogas. Many wastewater treatment plants could become energy independent. Power plants could also use reclaimed water for cooling; there are already several dozen power plants in the United States that do so. Another opportunity is integrating power plants and desalination systems.

[6] The report can be found at http://www.ucsusa.org/news/press_release/water-smart-power-0394.html.

Water considerations can also be integrated into power generation, similarly to air quality and other environmental considerations. Electricity generation and output is based on three key factors: price, availability, and demand; however, one could also determine output based on where water is located. For example, water should be considered as a factor in grid planning. Taking power generation and efficient water markets into consideration together will be an important but significant challenge moving forward. ■ ■ ■

PARTICIPANTS: Steve Clemmer, Union of Concerned Scientists; **Matthew J. Eckelman**, Northeastern University; **Paul Faeth**, CAN; **Ahmed Ghoniem**, Massachusetts Institute of Technology; **Peter Gleick**, Pacific Institute; **Katherine Hammack**, U.S. Department of the Army; **Marilu Hastings**, Cynthia and George Mitchell Foundation; **Holmes Hummel**, U.S. Department of Energy; **David LoPiccolo**, Siemens; **Corinne Scown**, Lawrence Berkeley National Laboratory; **Nancy Stoner**, U.S. Environmental Protection Agency; **Michael Webber**, University of Texas; and **David Wegner**, U.S. House of Representatives.

PLANNING COMMITTEE: Paulo Ferrão, Technical University of Lisbon (Chair); **Steve Bergman**, Shell International Exploration & Production Company; and **Carl Shapiro**, U.S. Geological Survey.

NRC Staff: Marina Moses, director, Science and Technology for Sustainability Program (STS); **James Zucchetto**, director, Board on Energy and Environmental Systems (BEES); **Jeffrey Jacobs**, director, Water Science and Technology Board (WSTB); **Dominic Brose**, program officer, STS; **Jennifer Saunders**, program officer, STS; **Emi Kameyama**, program associate, STS; and **Dylan Richmond**, research assistant, STS.

DISCLAIMER: This meeting summary has been prepared by **Jennifer Saunders** as a factual summary of what occurred at the meeting. The committee's role was limited to planning the meeting. The statements made are those of the author or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, STS, or the National Academies.

The summary was reviewed in draft form by **Ben Grumbles**, U.S. Water Alliance and **Paul Sandifer**, National Oceanic and Atmospheric Administration, to ensure that it meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

Addressing the Energy-Water Nexus: Power Plants and Partnerships December 5, 2013

A meeting of the National Academies' Roundtable on Science and Technology for Sustainability was held on December 5, 2013, as a second event of a Roundtable's year-long initiative, to examine issues related to the energy-water nexus, a key sustainability issue. Following a June 2013 Roundtable panel that provided a broad overview of the energy-water nexus,[7] the December event delved deeper, focusing on energy-water nexus issues associated with power plants. The meeting was convened in collaboration with the Division on Engineering and Physical Sciences' Board on Energy and Environmental Systems (DEPS/BEES) and the Division on Earth and Life Studies' Water Science and Technology Board (DELS/WSTB).

To open the Roundtable, **Michael Hightower,** who leads the Water for Energy project at Sandia National Laboratories, provided an overview of water use and power generation. Sandia, a national security laboratory, became involved in water and energy issues after the Central Intelligence Agency and other organizations issued reports around the year 2000 that identified energy and water as two of the top three areas of stress worldwide. Water availability is going to impact energy availability—a big driver for economic development—and there are potential conflicts between these two resources and how they are being managed.

Another trend Mr. Hightower and his colleagues noticed was that some new energy technologies—carbon-capture and sequestration, biofuels, hydraulic fracturing, and traditional nuclear energy systems—are very water-intensive. Climate change is impacting water availability, and there will probably be less water in the future in many locations to meet energy demands. Those developing energy did not seem to be considering those issues. If for sustainability reasons we are pursuing energy technologies to reduce greenhouse gas emissions and yet are increasing the demand for water by a factor of four or five, that may not be sustainable either, said Mr. Hightower.

The U.S. has not built any large reservoirs since the early 1980s and does not have any new fresh surface water resources to draw upon. In terms of climate change, many existing reservoirs are being mismanaged for current levels of precipitation. In the future, we expect to have less surface water to utilize for economic development, energy, domestic supplies, and agriculture. In addition, most of the major groundwater aquifers have had poor management practices and have been over pumped.

The biggest use of water at a power plant is for cooling, explained Mr. Hightower, noting the water demands for different types of thermal electric power plants and their cooling technologies. As a baseline, consumptive water use at a biomass or coal plant is about 400 gallons per megawatt hour. Nuclear plants use about twice that. Power plants with natural gas combined cycle, in contrast, use about half of that—one of the reasons that many plants use this type of electricity generating technology, along with cost and environmental benefits. Geothermal steam and concentrating solar technologies are both high in water consumption.

There is a lot of interest in dry cooling as a new technology, which has many advantages from a water availability standpoint. However, it also has thermodynamic limits; for a plant where the operating temperature is in the 90s, the efficiencies of current dry cooling systems go down significantly. Many plants are looking at hybrid technologies, which are much less water-intensive than closed-loop.

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[7] A meeting summary of the June 2013 Roundtable event can be found at: http://sites.nationalacademies.org/PGA/sustainability/PGA_083596.

A study[8] recently done by the Union of Concerned Scientists looked at power plants across the nation that are being impacted by water availability, said Mr. Hightower. It is occurring across the U.S. and at solar power plants, nuclear power plants, and coal power plants. From a national security standpoint, India, China, Southern Europe, Northern Africa, Southern Africa, Brazil, Argentina, and Australia are also going to be impacted. Approaches that we undertake in the U.S. to improve our water-energy situation could be applied internationally.

Because of the limited fresh water available, there is a movement to look at non-traditional waters—wastewaters, brackish waters, water produced from oil and gas—as a major source for electric power generation. It is important that the National Academies are looking at this intersection, said Mr. Hightower, because it changes the way discussions on sustainability will be presented in the next decade or so.

WATER AVAILABILITY AND POWER GENERATION

The day's first panel opened with remarks by **Donna Myers,** chief of the Office of Water Quality and senior water quality advisor for the U.S. Geological Survey (USGS), who offered a perspective on how USGS and other federal agencies are collecting data on water.

USGS is the nation's and the world's largest water data collection and observation agency. It has been authorized by Congress to conduct a water census for the U.S. every five years and to issue reports based on the census, the first[9] of which came out in December 2013. The reports will include an assessment of undeveloped resources, such as freshwater and brackish and saline waters; trends and changes in surface water, groundwater storage, water quality and water use; and an assessment of the status of reserves, reservoirs, and groundwater aquifers. USGS will also conduct some in-depth studies at small, regional scales where there are water conflicts.

Water budgets are a unifying theme for the water census, said Ms. Myers. These budgets account for inputs to and outputs from the amount of water in various components of the cycle—the hydrologic equivalent to a checking account. This approach is necessary to understanding our storage, our reserves, and our depletions.

USGS also has a program whose goal is to analyze how water is being used at various scales—local, state, and national—and to publish reports with data on that usage and trends. The next water use compilation will estimate the water consumed for thermoelectric power generation, meaning the water lost through evaporation.[10]

Ms. Myers explained that USGS also has sensors in over 1,000 river and stream locations that give local people, at the plant-level, real-time information on water temperature on the Web; about 300 of these 1000 locations are relatively close to power plants. The agency also collects data on streamflow at 5 to 15 minute intervals at 8,000 locations. Over the last 10 years, 97 percent of the agency's stream gauging information has become available on the Web to the public. And they have used that information to show other national maps about drought conditions on a daily and hourly basis. Groundwater levels, and how far they are deviating from 30 year averages, are available as well.

It is important not just to have all of these dots on the map, but to integrate them with a national hydrography data layer—the stream network—so that you can know where these points are in the watershed and what flows to them and from them, said Ms. Myers.

USGS is applying this information by looking at some focus areas where there are water stresses, such as the Colorado River Basin and the Apalachicola-Chattahoochee-Flint part of the basin in the southeastern U.S., where a huge drought a couple of years ago resulted in dangerously low levels of water for cooling at the basin's terminus, where there was a large nuclear thermoelectric power plant. The agency is also working with the National Weather Service and the Army Corps of Engineers to try to integrate information on precipitation and reservoirs, creating a common operating picture for the nation's water resources.

The next presentation was given by **Vince Tidwell** of Sandia National Laboratories, who discussed the relationship between technology, water use, and cost, focusing on the issue of quantity and availability. Thermoelectric power withdraws a lot of water—42 percent of national

[8] Additional information about the study can be found at: http://www.ucsusa.org/assets/documents/clean_energy/ew3/power-and-water-at-risk-with-endnotes.pdf.

[9] The report can be found at: http://pubs.usgs.gov/circ/1384/support/c1384.pdf.

[10] Additional information about methods for computing thermoelectric water consumption can be found at: http://pubs.usgs.gov/sir/2013/5188/pdf/sir2013-5188.pdf.

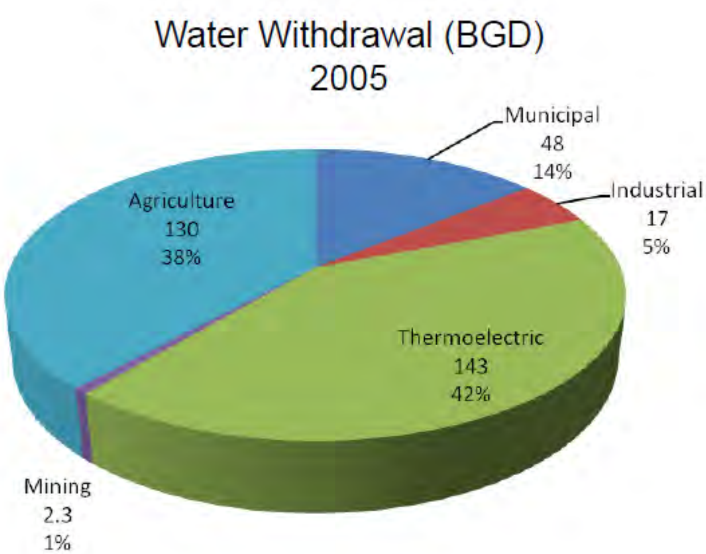
freshwater—but the consumptive water use—that which is consumed and cannot be used again—is only the 3 to 5 percent lost to evaporation (see Figure 1). Why should energy managers and others worry about what seems to be a small amount? The reason to worry is that water will not be there for someone else downstream to use, said Dr. Tidwell. People are already using all of the water they have, and the population is growing, and a growing population needs even more water, which demands more electricity, which in turn demands more water.

Dr. Tidwell offered an overview of the two types of basic cooling systems, open loop and closed loop. With open loop, water is withdrawn from a stream or river via a pipe and transferred through a condenser to cool the steam cycle, and the water goes directly back to the river it came from. There are large withdrawals, but the only consumption is due to the elevated temperature after the water is put back into the river. With a closed loop system, the water is pulled completely out of the reservoir and run through the condenser in order to cool the steam cycle. Then the water needs to be cooled again, and is put into a cooling tower or pond before it is used for cooling again; what is withdrawn is almost completely consumed. A third type of system, dry cooling, uses almost no water.

Nuclear and coal tend to use a large amount of water compared to natural gas, solar PV or wind, Dr. Tidwell said. Some renewables such as biofuels or biomass and concentrated solar or thermal solar still use a lot of water. Sandia did a study a few years ago of future demand for electricity and how it would be met, and they expect that the mix of coal, natural gas, renewables, etc., will not change very much in the near future.

The likelihood of there being large volume new water withdrawals is low because the looming 316(b) ruling from the Environmental Protection Agency (EPA), which concerns environmental issues related to entrainment and impingement, will make the construction of new open-loop cooling plants unlikely. Water consumption is a very different case; from 2009 to 2035 it is projected to increase by 20 percent, because there may be more solar thermal and geothermal power plants, with high consumptive water use.

Policy is important, and with the exception of the 316(b) rule, some of it does not consider water implications, said Dr. Tidwell. The rule may be great for the environment, but limiting water withdrawals and restricting the use of open-loop plants may have unintended consequences on water consumption. Renewables are very important, but if this



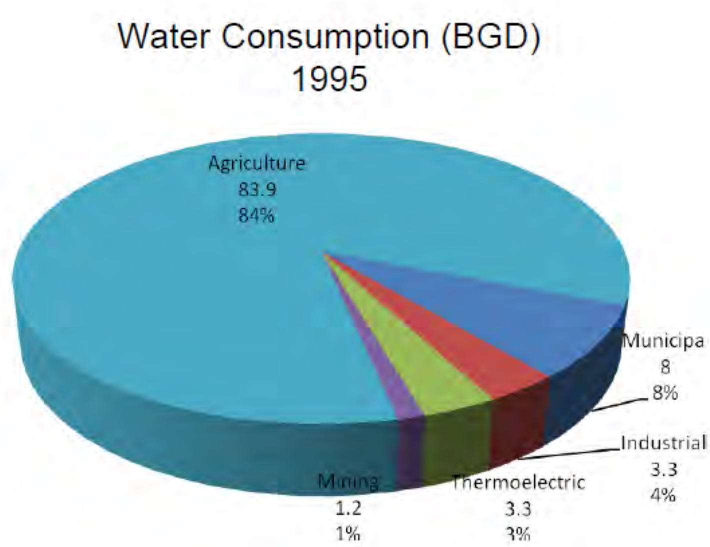


Figure 1 Water withdrawal (billion gallons per day), 2005; and water consumption (billion gallons per day), 1995. Source: V. Tidwell. December 5th presentation to the National Academies Roundtable on Science and Technology for Sustainability.

development is done using a lot of solar thermal or geothermal power plants, depending on how those technologies continue to improve, a lack of water may become a problem. We need to consider the water-related implications of policies that are important and good for other reasons.

An important step beyond policy is to get energy and water managers together to make an integrated plan, said Dr. Tidwell. The Department of Energy (DOE) is funding a project to do so, bringing the Western States Water Council and the Western Governors Association together with the Electric Reliability Council of Texas and Western Electricity Coordinating Council, the big transmission planners out west. They are considering where to place the next power plants and the next transmission lines in the western U.S. over the next 20 years.

Dr. Tidwell and his colleagues analyzed what it would take to convert all of the existing power plants so that they used no freshwater. The cheapest alternative was using treated wastewater, and the next cheapest was brackish water, which is less available. If those two are not available, then dry cooling is an option, along with wet/dry hybrid cooling. Over 50 percent of all of the existing power plants could be converted, and it would add less than 10 percent of the current operating cost. It needs greater study, but there are some opportunities there, said Dr. Tidwell.

WATER USE AND POWER GENERATION: TECHNOLOGICAL ADVANCES, GAPS, AND RESEARCH NEEDS

The next panel was opened by **Jessica Shi,** who heads the Electric Power Research Institute's (EPRI) research on innovative water conservation cooling technologies. Dr. Shi focused her remarks on developing potential game-changing technologies that could dramatically reduce water use and consumption at power plants. The root cause is the water use and the consumption for cooling; for thermoelectric power plants, about 90 percent of water is used for cooling (Figure 2).

The cooling systems currently used at power plants can be divided into three groups, including water cooling, dry cooling and hybrid cooling systems, explained Dr. Shi. Ninety-nine percent of U.S. power plants are using water to condense the steam because water heat transfer is a much more efficient than air heat transfer. About 1 percent of U.S. power plants use direct dry cooling, in which the air is pulled up by the fan and blown through condenser tubes. A few power plants in the world are using an indirect dry cooling system, in which water is the intermediate cooling fluid, said Dr. Shi.

These dry cooling systems are rarely used because of three major drawbacks: 1) the power production penalty, which can be as high as 10

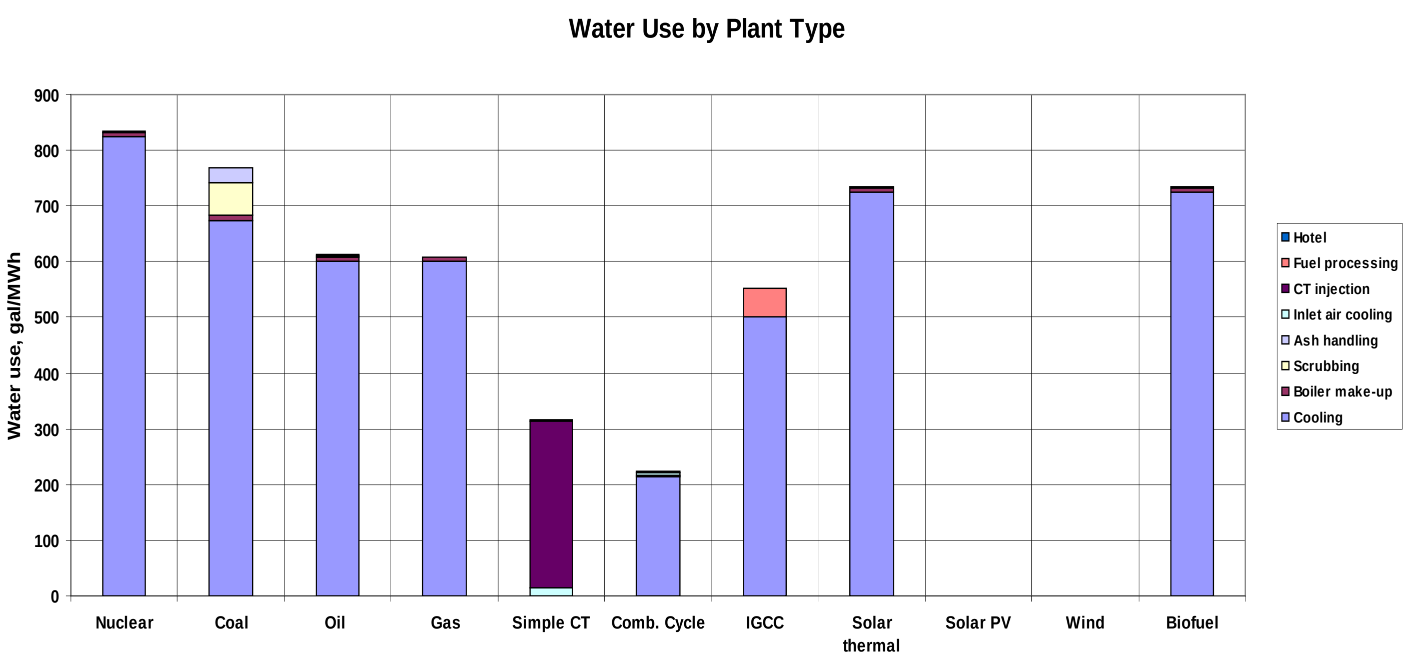


Figure 2 Root cause of thermal power plant consumptive water use.
Source: J. Shi. December 5th presentation to the National Academies Roundtable on Science and Technology for Sustainability.

percent during hot summer hours when electricity is in peak demand; 2) the cost, which is about three to five times that of a wet cooling power system; and 3) the footprint. To minimize the power production penalty and water consumption, a few power plants are using a hybrid of wet and dry cooling systems.

These water conserving technologies are not broadly adopted yet, but there is a trend in that direction, said Dr. Shi. To make dry cooling technologies more widely adopted, the three challenges discussed earlier need to be addressed. The research community also needs to be encouraged to think outside the box to develop alternatives to dry cooling solutions, rather than only focusing on enhancing current ones. Alternative hybrid cooling technologies are needed as well.

About three years ago, EPRI initiated an effort to identify and develop potential game-changing technologies to dramatically reduce water use and consumption by power plants. They have identified 12 projects[11] to fund, and all of them are moving forward. In addition, EPRI's recent solicitation with the National Science Foundation was released in May 2013, and they expect to see a lot of exciting potential game-changing technologies. EPRI also is currently working on alternative dry cooling technologies and alternative hybrid cooling technologies—including one that could achieve 75 percent water saving in typical weather and climate conditions.

Dr. Shi closed by explaining three big take-away messages. First, the most promising opportunity to dramatically reduce power plant water use and consumption is to address the root cause—water use and its consumption for cooling. Second, through EPRI's years of research, they see a high potential to achieve their mission. Third, more research and collaboration is instrumental to achieving their mission.

The next presentation was given by **Robert Lotts,** water resource manager at the Arizona Public Services Company, who focused his remarks on the region where he works, the American Southwest. Energy demand will continue to increase, and while there has been a lot of discussion about national energy policy, not much has come out of it, said Mr. Lotts. At a state level more actions have been taken, especially in Arizona, Nevada, and California, which have considered the impacts of rising demand on energy and water and on rate payers. In Arizona, mandatory use of alternative cooling technologies or alternative water supplies has been proposed.

The Census Bureau is projecting a 43 percent increase in population in the Southeast and almost 30 percent increase in the Southwest. Couple that growth with the imbalance that the Bureau of Reclamation is projecting for the Colorado River supply system, and a real water-energy conflict is looming. As the strain on water supplies increases, so too does the cost of water. Arizona will put greater emphasis on conservation, but it probably will not be enough. The state is also looking at augmentation, cloud seeding, and rainwater harvesting. The energy demanded to acquire, treat, and convey water will continue to increase.

The energy cost of alternative water supplies—saline, brackish, and groundwater—is very high. Palo Verde is still the only nuclear power plant in the world that uses 100 percent reclaimed water for its cooling water supply. Dry cooling has not been implemented in the state of Arizona, but it has been implemented in Nevada. Mr. Lotts is considering hybrid cooling, and also is hopeful about experimenting on a small scale with thermos-siphon cooling technology, which uses a refrigerant as a cooling medium.

Going forward, if Arizona implements the same cooling technologies it has today, given power needs, water use will increase from 56,000 acre feet a year to over 80,000 acre feet a year. With some water conservation measures and alternative cooling technology, it would only increase to about 60,000 acre feet. When the cost of water gets high enough, the cost of putting in alternative cooling looks better, he said.

PUBLIC-PRIVATE PARTNERSHIPS ON ADDRESSING THE ENERGY-WATER NEXUS

The day's third panel opened with a presentation by **Maribeth Malloy,** director of environmental sustainability and external engagements for Lockheed Martin Corporation. In her position, she identifies ways Lockheed Martin can develop as an energy and environmentally sustainable company, as well as ways to leverage their internal approaches for global benefit.

Ms. Malloy's group embarked on an assessment of water as a strategic resource and told the company's senior executives that Lockheed Martin should be thinking differently about water. The returns on investment for infrastructure upgrades or

[11] Examples of on-going advanced dry cooling technology projects can be found at: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001025771&Mode=download&Mode=download.

new technologies do not trade, she said, because the commodity is so underpriced. She called a colleague who directs a big industrial facility in Texas and asked him to help her quantify the cost of water. She asked him to take a gallon of water as it comes into his plant, and follow it to see the costs associated with it—for example, how much the energy costs to pump and pipe the water, how much chemical cost they are adding to treat the water to perform a specific task, etc. He called back about two weeks later, astonished at what was beginning to emerge as the total cost of water in his facility. In some systems, the cost of water ranged somewhere from $3 per 1,000 gallons to something like $140 per thousand gallons, with all of the additive costs.

Lockheed Martin is exploring a few novel approaches to energy generation that do not require as much water, said Ms. Malloy. Microgrids, for example, may allow critical operations to be self-sustaining on a grid structure designed for that particular use. The company has also developed operational optimizations, such as demand response and energy efficiency management tools, which it both uses and sells to its customers.

The company also has a lot of experience in satellites and space-based climate modeling, and this technology could perhaps be harnessed to aid issues at the energy-water nexus. The satellites may be able to provide advanced warning for catastrophic or severe events that may affect farmers or infrastructure operations; they may also be able to monitor farmlands to look at soil quantity and freshwater availability.

Partnerships to consider how innovation could solve problems at the energy-water nexus might involve universities and agricultural colleges, state and local governments, water purveyors, energy companies, and utilities, said Ms. Malloy in conclusion.

The next presentation was given by **Frank Rusco,** director of the Natural Resources and the Environmental Team in the Government Accountability Office (GAO). Part of the legislative branch of the federal government, GAO tries to answer questions Congress has and also audits federal programs for efficiency and efficacy. The agency has done a large body of work on the energy-water nexus.

Dr. Rusco spoke about some of the big challenges in this area, pointing out that the part of the energy sector that accounts for the biggest growth in water use is not thermoelectric power plants, but biofuels. Shale oil is another challenging area, since pulling it out of the ground to make oil takes large amounts of both energy and water. GAO has released a report on the energy it takes to move and purify and treat water, and is next planning to release a report on water that comes up as a byproduct during the production of oil and gas.

One of the most important things in the federal bailiwick is collecting data on the energy-water nexus, said Dr. Rusco. Such a dataset has been hard to maintain, but it is a key component of the partnership between federal, public, state, local, and private entities. While information on water is improving, there are still many unknowns about where water is being used, the type of water being used and its source, and what happens to it after use.

One of the places where there is not an inherent conflict between energy use and water use is in coal bed methane, he noted. It may be possible to take water from coal bed methane, treat it, sell it, and pipe it through the arid west at an energy cost that is acceptable. And if something were done to rationalize the price of water, there is an opportunity to marry energy and water in a way where there is not constant conflict.

Dr. Rusco then turned over the presentation to his colleague, **Anne-Marie Fennell,** who spoke about some of the findings from a 2003 report[12] that examined states' views on water availability and use and on federal actions that were needed. One need they identified was for water data for more locations. As GAO updates that report they are finding that there is still a need for data, particularly on fresh water availability and use. Research and data on hydrological processes—interactions between groundwater and surface water, aquifer recharge rates, and groundwater movement—are needed as well.

Another theme that has come through in their work is the need for coordination and to overcome stovepiping in the federal government. Per their missions, the agencies focus only on one side of the nexus—either energy or water—which sometimes makes it difficult to deal with cross-cutting issues. Many stakeholders—academia, industry, environmental groups—also have an important role to play, and coordination needs to occur there. Coordination is also needed to implement the Energy Policy Act of 2005 provision that directed the energy secretary to carry out a program of research,

[12] See Freshwater Supply: States' Views of How Federal Agencies Could Help Them Meet the Challenges of Expected Shortages (GAO-03-514), available at: http://www.gao.gov/new.items/d03514.pdf.

development, demonstration and commercial application to address the energy-water nexus.

The next presentation was given by **Tony Willardson,** executive director of the Western States Water Council, which was created by the western governors in 1965. In 2006 the council issued a report that identified a number of challenges to water sustainability, growth, and meeting water demands. Energy was only mentioned once in the report. The council followed up with a report in 2008 that identified a number of steps to be taken, including 42 recommendations, which they are still working on.

Part of that effort is looking at the unprecedented population growth in the west. Rarely are decisions about how and where to grow influenced by water: Our solution has been to bring water to the people. There is a need to integrate water policy and land use policy, and to include energy policy in that, said Mr. Willardson. While per capita water use from municipal purposes has leveled off, demand as it relates to energy is expected to continue to grow. As the background materials from GAO mentioned, 85 percent of future water demands could be related to energy.

A part of our future is going to be in water transfers, said Mr. Willardson. The council has helped the governors prepare a report on how to facilitate transfers of water from agriculture to other uses while still protecting rural communities and economies and the environment.

If we are going to be able to measure and manage our water resources and be more efficient in our use, we need a better way to assess the quantity and the quality of water, and how that will change over time, said Mr. Willardson. Gathering and disseminating real-time information is becoming more important, and the council is constantly trying to convince Congress of the importance of supporting federal data programs. The Landsat satellite is especially important, in part because its thermal infrared imaging lets them thermally measure the heat exchange from evaporation from a crop, which they can translate into consumptive water use—critical for managing water in the west. Because the satellite's archive goes back to 1982, it is possible to see how water use has changed over time on any particular piece of land.

Other important technologies include the view of atmospheric rivers that have been identified by the National Oceanic and Atmospheric Administration; if floods can be predicted, it could have a tremendous impact on the west coast, in terms of controlling floods and reducing damage.

The next presentation was given by **William Brandt,** director of Strategic Integration for LightWorks, an Arizona State University (ASU) Initiative that capitalizes on ASU's strength in solar energy. It takes about 3000 kilowatt hours per person per year residentially to be in the U.S. middle class, Mr. Brandt said, and there is a world that aspires to reach that point, which means that a lot of energy will be required. This means that a lot of water will be required, because water is kind of liquid energy. LightWorks' institutes and initiatives work across the university to harvest all of the various networks in order to create sustainable solutions.

There will be no shortage of fossil carbons, Mr. Brandt said, but those sources of energy take a lot of water. We can continue on the route of oil and fossil fuels, or we can do some of the things that are more exotic, like renewable fuels. The university is focused on giving decision makers tools that help them make better choices.

California is starting to think about the problem as the state moves toward higher penetration of renewable energy. How do you supply the energy the system needs when the sun is not shining or the wind is not blowing? These are challenges we are going to have to work out. The good news is that we are working on them, said Mr. Brandt. ASU is going carbon neutral by 2025, and they have 25 megawatts of solar sitting on top of university rooftops. The university is working with utilities to find ways to better manage that. They are also working on how to create value propositions that cause industry and the university to connect, and in a way that the industry will be happy to make it sustainable.

The meetings final presentation was given by **Ron Faibish** from the U.S. Senate Committee on Energy and Natural Resources, who spoke about the work the committee has been doing around the energy-water nexus. The committee held two meetings in July 2013 to hear from stakeholders about the energy-water issues they care about, some of the problems that exist, and the types of national activities needed to address energy-water issues. The committee received strong interest and good feedback from both meetings.

A few areas are identified during the meetings where the issue can be addressed on a national level, said Dr. Faibish. The first thing is the lack of true cross-government coordination on the federal level on energy-water nexus issues. Many activities are being performed by individual agencies, but there is no national agenda on these issues.

A national platform is needed to facilitate a constructive future interaction on these topics.

Another area highlighted by speakers at both meetings was the issue of data gaps, and the need to gather all of this comprehensive data on the energy used for water and water used for energy. A national platform is needed to facilitate information exchange, collect and disseminate data, identify innovative technologies and best practices—not for a regulatory regime, but to enable more efficient use of energy and water resources—and carry out R&D projects. The platform could reside within the government or outside the government. Incentives to create public-private partnerships are also needed.

This may involve a two-tier approach, said Dr. Faibish. We need to enable better coordination across the existing programs within federal agencies, and we think that coordination is best done by some type of body that oversees those agencies at the highest levels. That body would also coordinate between agencies and outside stakeholders. To enable actual implementation of activities such as R&D, data collection, identification of best practices, and information exchange, we should create some type of organization manned by experts who are talking about energy-water on a daily or frequent basis. One such idea is to create a type of foundation—within the government or outside of it—that would be able to raise the necessary resources to make this happen.[13] ■ ■ ■

[13] On January 30, 2014, U.S. Senates Ron Wyden (D-Oregon) and Lisa Murkowski (R-Alaska) introduced bipartisan legislation recognizing the important connection between energy and water. Additional information about legislation can be found at: http://www.energy.senate.gov/public/index.cfm/featured-items?ID=8378f0b9-bcdf-4a6e-8fcc-e6152a5e3864.

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DISCLAIMER: This meeting summary has been prepared by **Sara Frueh** as a factual summary of what occurred at the meeting. The committee's role was limited to planning the meeting. The statements made are those of the author or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, STS, or the National Academies.

The summary was reviewed in draft form by **William Cooper**, National Science Foundation and **Michael Webber**, The University of Texas at Austin to ensure that it meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

Addressing the Energy-Water Nexus Through Technological Innovation May 20, 2014

During its spring meeting in May 2014 in Washington, DC, the Roundtable on Science and Technology for Sustainability convened a panel to examine technological innovation to address the energy-water nexus. The panel included public- and private-sector participants and discussed initiatives currently underway in the energy-water nexus to encourage the application of broader sustainability frameworks within these two interrelated resource domains. The panel examined research needs for optimizing current technologies, existing barriers, emerging technology innovations, and approaches for advancing the integrative field of the energy-water nexus to best address key challenges. The panel was convened in collaboration with the NRC Board on Energy and Environmental Systems (DEPS/BEES) and the Water Science and Technology Board (DELS/WSTB).

Donald C. Jackson, professor of history at Lafayette College, provided a historical perspective on the energy-water nexus with a focus on the role of dams. Linking water and power has always been an American tradition, he explained, and damming rivers and using the bounty of flowing water has played a major role in transforming the American environment. Mills erected as early as the 18th century in Maine are early examples of harnessing water for energy; this approach has been extensively utilized across the American landscape, resulting in early agricultural production being very dependent on it. The industrial revolution originated with the use of water for power in mills to process food, wool, and other commodities, and later transitioned into using coal and steam power. Mill technology significantly changed in the 19th century when electricity transformed the scale at which mills operated, providing energy transmission across many miles of newly developed infrastructure. By the turn of the 20th century, electricity was being generated by hydropower and transmitted as far as 100 miles away. Several decades later, extensive dam networks were created for many additional purposes, including flood control, navigation, and recreation, with diverse and conflicting interests.

This was a new revolution in the connection between hydropower and electricity, which quickly expanded from simply capturing the energy of flowing water to storing large amounts of water in reservoirs for municipal use, said Dr. Jackson. Over the course of the early 20th century, and especially during the New Deal years of the 1930s, dams were constructed across the United States to capture water to provide expanding metropolitan regions with electricity and water supplies. By the 1970s and into the 1980s, however, the social, economic, and environmental trade-offs associated with dams had spurred a movement calling for dams to be removed in order to restore and protect aquatic ecology. The linked histories of dams and hydropower illustrate changing political and economic priorities across the American landscape, and highlight the challenges in maximizing the benefits of the social, economic, and environmental pillars of sustainability.

Optimizing Current Technologies

Silvia Secchi, assistant professor of agribusiness economics at Southern Illinois University, discussed the impacts of biofuels on current markets and the natural environment. Corn is used to produce ethanol, which is a very energy-intensive crop. Corn production requires energy-intensive inputs in the form of nitrogen fertilizer and tillage machinery. Increasing land use for corn production has resulted in increased nitrogen and phosphorus loading into the Mississippi River and other basins, contributing to hypoxia in the Gulf of Mexico. Although corn was historically grown in sequence with soy beans, production has trended toward more continuous corn, resulting in a doubling of nitrogen applied to farmland in the form of fertilizers. As corn prices increase, productive land is continuously planted with corn instead of rotating soy beans or other crops into that field's production, which results in an overall increase in energy use and soil degradation.

Much of the land enrolled in the Conservation Reserve Program (CRP) has also significantly degraded, said Dr. Secchi. CRP land is typically non-crop land planted with perennial grasses, a step that reduces the amount of nitrogen entering rivers, provides habitat for wildlife, and provides a host of other ecosystem services beneficial to the environment. Significant portion of that land, however, has been brought into continuous corn production due to economic and policy drivers.

Using corn stover and stalks to produce advanced biofuels will provide a second stream of revenue for farmers, said Dr. Secchi. As corn stover prices increase, farmers will move away from traditional corn production without stover removal to corn production with stover removal, resulting in more negative environmental impacts. Current incentives—financial gains for farmers—promote more continuous corn production, and there are no regulatory consequences to prevent excess nutrient loading into local waterways. Regulatory challenges and policy innovations are needed so that the Clean Water Act or other policy instruments can provide the U.S. Environmental Protection Agency with the authority to regulate nutrients from farmlands the same way it sets total maximum daily loads for point sources, said Dr. Secchi. Nutrient loading is not the only way biofuel affects water issues. Most of the cropland in production across the Midwest requires irrigation, and the resulting demands on groundwater and surface water have reached critical levels in some regions. Although new markets have been developed to address water quantity issues, markets by their economic nature promote efficiency and not conservation. They are designed not to reduce water use but to make water available to the highest-value use. Dr. Secchi also highlighted innovative programs, such as the Willamette, Oregon TMDL water temperature mitigation market, in which farmers plant trees instead of crops that cool the adjacent river water with compensation from hydroelectric units.

George Barclay, research and development director for water and process solutions at Dow Chemical Company, discussed water sustainability in industrial applications. Diverse sustainability challenges are involved with treating source water and wastewater, such as declining feed water quality and increasing discharge requirements. Technological innovations are critically needed to solve these challenges, and water purification is central among the solutions, he continued. Many different desalination and purification technologies are available, including reverse osmosis, ion exchange, nanofiltration, and ultrafiltration. Reverse osmosis requires a semipermeable membrane, which is a composite material made up of a polyester fabric, polysulfone, and an ultrathin polyamide layer.

The recent challenge has been to develop polymer chemistry that optimizes filtration while reducing the energy needed to force water through these membranes. A variety of materials, mainly bacteria and oil, can foul the membrane, affect salt passage across the membrane, and increase energy requirements. Partnering with end users is a key component in pulling together a complete system of many technologies, said Dr. Barclay. He described some of the barriers to solving challenges at the energy-water nexus, including rising energy costs, inconsistent feedwater, increasing regulations, outdated system designs, increasing competition, and the need for commercial expansion without increasing water withdrawals. He provided an example of coal production in China, a nation that heavily relies on coal for energy. Most of the coal resources in China are located in the north, where only 21 percent of water resources are available, making innovative technologies to reuse and recycle water very important.

It is important to assess the entire system of technologies available, including various streams of raw water from industries, boilers, cooling towers, and filtration, while also recycling water and optimizing energy flows along the whole pathway. Success is optimizing the available technologies while building real partnerships with other industries and governmental organizations to implement solutions to these challenges.

EXISTING AND EMERGING TECHNOLOGY INNOVATIONS

Radisav Vidic, William Kepler Whiteford professor and chair in the department of civil and environmental engineering at the University of Pittsburgh, discussed water consumption in power production and shale gas development. Conventional thermoelectric power plants account for up to 50 percent of water withdrawals in the United States but only 10 percent of water consumption, since most of the water used by the thermoelectric industry is circulated through cooling systems and then discharged. Still, due to recent requirements limiting water withdrawals for new power plants, innovative solutions will be required to address their water needs (Figure 1). Municipal waste water may provide a solution, as

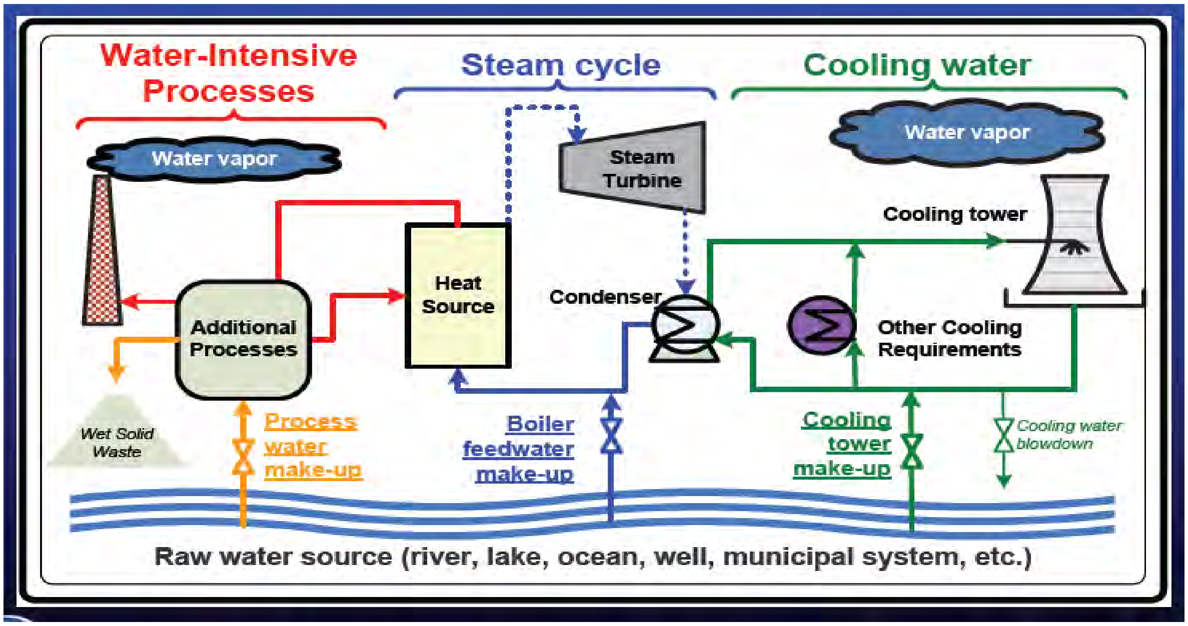

Figure 1 Water use in the thermoelectric industry.
Source: Radisav Vidic. May 20th presentation to the National Academies Roundtable on Science and Technology for Sustainability.

approximately 11.4 trillion gallons of water are annually produced from municipal wastewater treatment plants.

Dr. Vidic described opportunities for existing power plants to utilize municipal wastewater for meeting their water requirements. He added that despite this potential, using a low-quality water source introduces challenges, such as precipitation, scaling, corrosion, and biomass growth inside recirculated cooling systems. One approach would be to treat the water using conventional technology, such as reverse osmosis, prior to circulating it through the plant; however, managing water quality inside the cooling tower system would be more cost-effective and efficient. Determining the optimal approach for managing water quality inside the system requires testing, modeling, assessing the lifecycle cost, and conducting a lifecycle assessment of alternative treatments.

The commercial gas industry is often perceived to be a large consumer of water, said Dr. Vidic; however, recent research has found that 7,000 natural gas wells in the Marcellus shale deposits of Pennsylvania accounted for only 0.2 percent of total water use and withdrawals in the state. Impaired waters could also be used for hydrofracking in the Marcellus shale, and one major source of impaired water is abandoned mine drainage from coal mines. Water from mine drainage is high in sulfate, which would generally make it unusable for hydrofracking; however, mixing flowback water with elevated levels of barium, strontium, and calcium causes these cations to bind with sulfate and precipitate out of solution as a solid salt. These innovative approaches, such as reusing otherwise unusable sources of water, help advance the integrative field of the energy-water nexus to address key challenges.

Amy Childress, professor and director of environmental engineering at the University of Southern California, presented innovative technologies for desalination and discussed the energy implications of producing desalinated water. Global water stress in coastal regions is forcing water providers to rely on alternative sources of water, while increasing energy costs and greenhouse gas emission considerations require new technologies. Because of the need to remove contaminants from source water, using saline water as an alternative water source, presents challenges in terms of minimizing energy requirements while maximizing clean water recovery. Dr. Childress' research includes membrane distillation, forward osmosis, and pressure-retarded osmosis. Typical salinity concentrations for drinking water are < 500 mg/L total dissolved solids (TDS); however, fresh water can reach 1,000 mg/L, brackish water 1,500 - 20,000 mg/L, and seawater 33,000 - 41,000 mg/L

TDS. Salts do not degrade naturally over time and will accumulate until removed. Increasing salinity levels in soils, especially in California's Central Valley region, have been exacerbated by human activities and have resulted in increasingly negative agricultural, environmental, and economic impacts.

Desalination capacity has increased across the world, Dr. Childress said, and currently exceeds 70 million cubic liters of fresh water per day. The United States currently produces approximately 10 million cubic liters per day and is second to Saudi Arabia as the largest desalination market. Reverse osmosis can produce water with less than 500 mg/L and uses less than one tenth of the energy required by distillation processes; however, the membrane technology used for reverse osmosis has limitations, such as membrane fouling due to contaminants removed from source water. Additionally, the reduced osmotic driving force at high salt concentrations increased pressure changes, thus more energy and electricity. New technologies, including membrane distillation and pressure-retarded osmosis can address these problems. Membrane distillation targets energy requirements and contaminant removal issues and, unlike reverse osmosis, is a vapor pressure and temperature-driven process. A heated aqueous feed stream is provided on one side of a membrane, a cooler distillate stream on the other, and a hydrophobic microporous membrane separates the two streams. Only water vapor passes through the pores, which is the key advantage. The other major advantage of membrane distillation over reverse osmosis is its ability to remove nearly 100 percent of trace organics such as pharmaceuticals. Membrane distillation can utilize recycled thermal energy, such as waste heat from diesel generators or other sources.

Pressure-retarded osmosis entails freshwater passing into seawater through osmosis with water overflowing a pressure chamber turning a waterwheel to generate energy; it involves the transformation of chemical potential into hydraulic potential. An osmotic pump pulls water from wastewater or an impaired water source in order to dilute the high salinity concentrate and bring in a greater volume of water to a higher pressure, resulting in energy generation. These two technologies are innovative, hybrid processes that can expand the portfolio of technologies for seawater and wastewater treatment, Dr. Childress concluded, which will be important in addressing the economic and environmental challenges at the energy-water nexus in which nothing is "wasted."

THE PATH FORWARD: ADVANCING THE FIELD OF THE ENERGY-WATER NEXUS TO ADDRESS KEY CHALLENGES AND NEXT STEPS

Bryan Hannegan, associate laboratory director at the National Renewable Energy Laboratory, discussed innovation employed to integrate energy systems within an expanded economic theme of "full utilization of resources." Energy systems integration aims to optimize and integrate the nation's infrastructure to achieve a clean and sustainable energy future. Regional electric grids have limited flexibility to absorb renewable energy production, such as wind and solar energy, which have increased in capacity because of a number of economic and policy incentives. Linking the electrical grid with natural gas infrastructure, transportation, and water utilities will allow for waste from one sector to feed the resources needed for another. An example would be using excess electricity generated from solar panels on a home's roof to heat and cool that house, power a vehicle, and clean grey and rain water systems (Figure 2). Taking these systems into account and considering associated cost reductions (e.g., water utility bill, gasoline) generates as much value for the price of solar panels as any technological improvement, such as advancements in thin film or other technology.

Dr. Hannegan predicted that the water utility of the future will transition from a commodity-based utility structure (gallons) to a service-based structure (monthly), a shift that will provide more opportunity to incorporate sustainability into how a utility functions, taking advantage of all available resources. At one time, cell phone plans were based on a per-minute fee structure; that has changed, however, and now a monthly payment provides all data and phone services.

Similarly, electricity is now purchased per kilowatt-hour, but the future may be similar to current cell phone utilities. Changes in economic policy are needed in addition to technological transformations so that water systems can be holistically analyzed, said Dr. Hannegan. Water issues are political and often localized, and stakeholder involvement is needed to address water demand and availability challenges. High quality understandings of the states of watersheds and water use across the nation are required, and more and better data are needed to support decision making and decision support tools. Assessing the full water cycle allows for the development of a multiyear sustainability plan to capture water metrics, such as reuse and

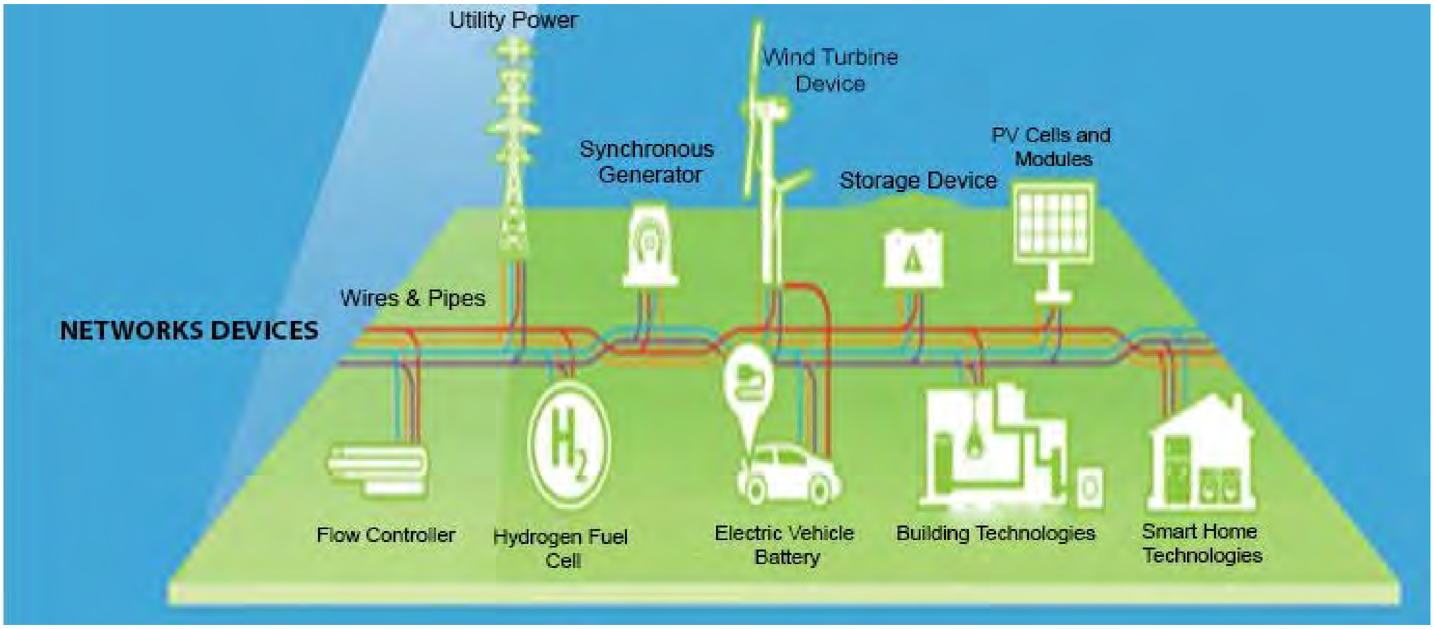

Figure 2 Linking the electrical grid with other infrastructure connects related systems resulting in overall efficiency. Source: Image by Joelynn Schroeder, courtesy of the National Renewable Energy Laboratory, 2014.

efficiency, and also requires linkages to energy systems.

The future of the energy-water nexus needs to be further addressed at the federal level, Dr. Hannegan observed, where efforts are currently being led by the Department of Energy (DOE); however, water issues are dispersed across many DOE departments and other federal agencies (Interior, Agriculture, Defense, etc.), which makes it challenging to coordinate efforts. Better coordinating how energy and water systems can be connected, what technology opportunities exist, and what data and modeling are needed are key issues that will require efforts across many federal agencies. Examining energy and water flows has shown that the intersections of agriculture, water, and electricity generation are priority areas that need to be further investigated. These domains can be examined in a way that, for example, finds flexibility in a water system that can be exploited to absorb more renewable energy when it is available, increasing the capacity of the electric grid to bring more wind and solar online, or enable distributed energy systems.

Diane Taniguchi-Dennis, deputy general manager at Clean Water Services (Washington County, Oregon), provided a water utility's perspective on energy-water nexus challenges. Communities face challenges in making timely investments to replace old infrastructure, provide water capacity for community growth, and efficiently operate and maintain facilities. Talented staff who embrace technology are needed, as are scientists, technologists, and engineers who have the social skills to work in a collaborative environment and who understand investment and policy decisions. In line with the social pillar of sustainability, it is important to understand the citizens comprising the community and try to reconnect them with and educate them about natural systems.

The Effective Utility Management (EUM) concept takes a systems integrated approach and involves three evolutionary status levels utility management agencies. Level I status is a utility that develops and executes robust programs to attain and meet regulatory compliance. Level II is a utility that has achieved regulatory compliance but which needs to streamline and optimize programs while maintaining compliance. Level III is the more ideal utility of the future—one that takes a systems approach to managing the utility and integrates multiple systems. Effective Utility Management focuses on using sustainable practices in resource use and recovery, involving ecosystems, water, energy, and nutrients.

The core of effective utility management, continued Ms. Taniguchi-Dennis, is linking a robust business strategy and planning to the "ten attributes of highly effective utilities," ranging from product quality and operational optimization to water

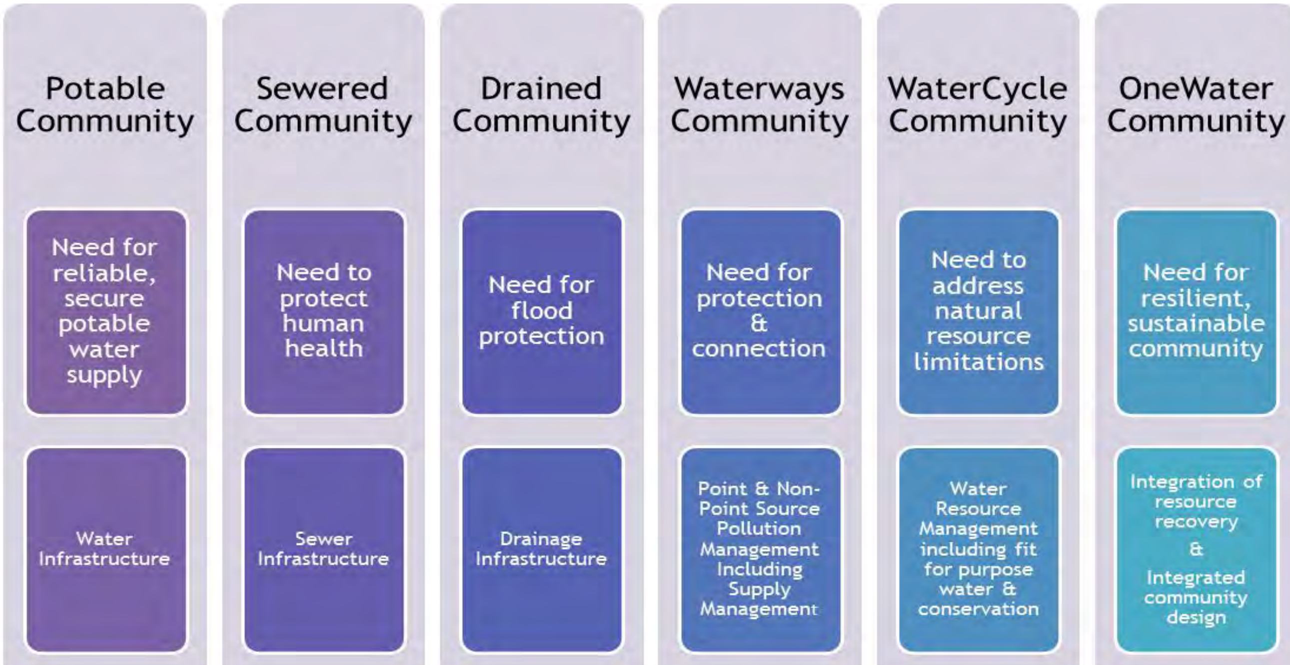

Figure 3 Six stages in development of water utilities.
Source: Diane Taniguchi-Dennis. May 20th presentation to the National Academies Roundtable on Science and Technology for Sustainability Program.

resource adequacy, financial viability, operational resiliency, and infrastructure stability (see www.watereum.org). Water utilities roughly involve six stages of development (Figure 3). First, they begin as a potable community providing drinking water to their citizens; then they become a sewered community that removes wastes, after which they become a drained community that manages rainwater and flooding. As water quality issues arise in a watershed, utilities must focus on managing water supply and protecting water resources, including managing non-point pollution; this is the fourth stage of development—a waterways community. A water cycle community emerges when water quantity becomes constrained, such as under drought conditions, and water conservation must be implemented.

The final stage is the one-water community, which emerges when communities embrace sustainability, recognize that resources involve cyclical processes, and integrate resource use into community design using distributed systems that benefit the watershed.

As communities develop into waterways communities, water cycle communities, and ultimately one-water communities, they keep water within the urban water cycle, making it available for reuse. Keeping water in the urban water cycle is one element of a one-water community, but addressing the watershed itself and including ecosystems in utility and urban planning are important considerations, said Ms. Taniguchi-Dennis.

Investments need to be made in restoring functions and processes of whole watersheds by restoring riparian zones, connecting waterways to floodplains and wetlands, and allowing groundwater to return to replenish aquifers. Natural areas need to be connected as integral parts and functions of urban communities. Water quality trading and integrated planning for watershed-based permits are needed as part of the National Pollutant Discharge Elimination System (NPDES) permitting framework, which would allow some regulatory flexibility to incorporate these investments into watershed planning. ■ ■ ■

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The summary was reviewed in draft form by **Steve Bergman**, Shell International Exploration & Production Company and **Michael Hightower**, Sandia National Laboratories. The review comments and draft manuscript remain confidential to protect the integrity of the process.

Addressing the Energy-Water Nexus: Need for Improved Data and Decision Support Tools December 10, 2014

The Roundtable on Science and Technology for Sustainability held its winter meeting on December 10-11, 2014, in Washington, DC. As the fourth and final session of the Roundtable's 2013-2014 initiative to examine the energy-water nexus, the December meeting featured panel discussions on improved data for water use, decision support tools, and frameworks for local and regional decision making. The panel discussions built on progress made at the three prior meetings of the Roundtable on Science and Technology for Sustainability, as well as a 2013 Massachusetts Institute of Technology (MIT)-Center for Strategic and International Studies (CSIS) workshop on the energy-water-land nexus and a 2013 National Science Foundation (NSF) workshop on developing a research agenda for the energy-water nexus. The Roundtable's December meeting was convened in collaboration with the National Research Council's Board on Energy and Environmental Systems and Water Science and Technology Board.

To open the Roundtable, **David Dzombak**, Carnegie Mellon University and co-chair of the Roundtable on Science and Technology for Sustainability provided an overview of the 2013-2014 Roundtable focus on the energy-water nexus. The first STS Roundtable meeting in June 2013 set the stage with a broad overview of the energy-water nexus, and highlighted data and research gaps and the regional and temporal elements of the energy-water nexus. The broad overview provided in the first meeting set the stage for the second meeting in December 2013, which focused on power plants and associated issues, including water availability, the role technology plays in addressing the energy-water nexus, public-private partnerships, and the need for comprehensive data on how water is used in energy production and on water supplies. The third meeting held in May 2014 focused on advances in technology, the effect technology has had on the energy-water nexus landscape, and the need for more integration of current technology. The need for improved data and decision support tools was also discussed at the third meeting, which set the stage for the fourth meeting in the series.

Addressing The Energy-Water Nexus: Need for Improved Data and Decision Support Tools

Eric Evenson, coordinator for the Water for America Initiative at the U.S. Geological Survey (USGS), discussed the National Water-Use information Program at the USGS and the need for improved data. The National Water-Use Information Program analyzes sources and uses of water at different scales; documents trends in water use across the United States; collaborates with state and local agencies on water-related projects; and develops local, state, and national water use databases. [13] The program's 2010 report describes eight principal categories of water use: thermoelectric power generation (45 percent of use), irrigation (33 percent), public supply (12 percent), self-supplied industrial (4 percent), aquaculture (3 percent), self-supplied domestic (1 percent), livestock (1 percent), and mining (1 percent). Every 5 years the USGS issues the report *Estimated Water Use in the United States*, said Dr. Evenson. The reports reveal that gross water use for all sectors peaked around 1975 (Figure 1). Since then use has declined to 1950 levels.

The reports also assess water use by geography and sector. Water use in the eastern United States is dominated by once-through water use for cooling in thermoelectric power generation, and in the West it is dominated by irrigation. The 2010 report identified other recent water use trends:

- Water withdrawals in 2010 were at 355 billion gallons per day—13 percent less than total withdrawals in 2005. This is the largest decline in water withdrawals nationally since records have been maintained.

[13] Water use can be generally defined by water withdrawal and water consumption. Water withdrawal is the total volume of water removed from a source, and water consumption is the amount removed for use and not returned to its source.

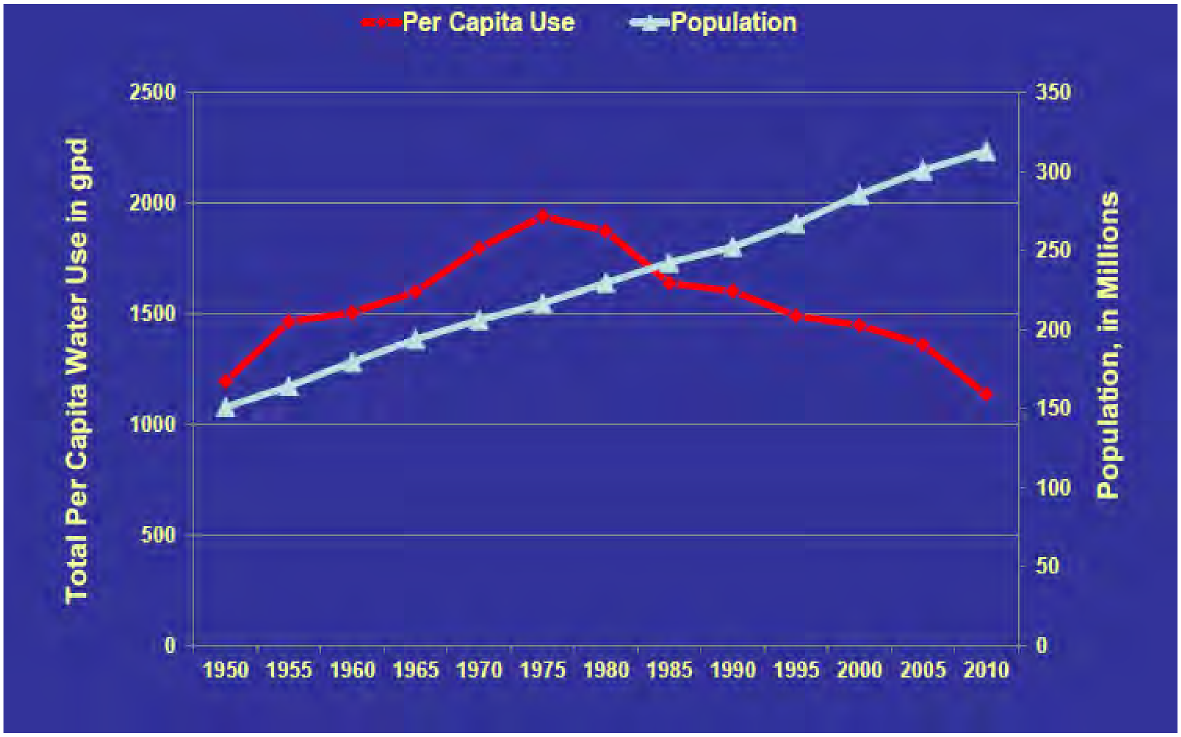

Figure 1 Change in gross per capita water use 1950-2010.
Source: Eric Evenson. December 10th presentation to the National Academies Roundtable on Science and Technology for Sustainability.

- Water withdrawals in 2010 were at levels not previously seen since 1970.

All sectors of use saw declines in water withdrawals, except for mining and aquaculture, which saw increases of 40 percent and 7 percent, respectively.

- Thermoelectric withdrawals declined by 20 percent. In 1950, it took 63 gallons to produce a kilowatt hour of energy; in 2010, it took 19 gallons.
- Many older municipal areas, such as New York City, have instituted water metering, which led to a decline in water use and the elimination of unaccounted water losses and leakage.

Water use information is acquired from other federal agencies, state agencies, and private industry. One challenge in gathering data from different sources is that there are differences in how the data are formatted, how frequently they are collected, what sectors are covered, and what thresholds are reported, said Dr. Evenson. Expanding the use of remote sensing could improve water use data, but characterizing consumptive use and improving how to quantify the uncertainty associated with water use data are key areas that need further improvement.

Sujoy Roy, principal engineer at Tetra Tech, presented on the need for improved data on water consumption, future growth, and new sectors associated with water use. Dr. Roy also attributed the largest water withdrawals to thermoelectric power generation. Dr. Roy noted that the term water use is nonspecific and often refers to withdrawal and consumption; however, these terms have distinctly different definitions.

Dr. Roy's group investigated how water availability compares to consumption (i.e., for agricultural irrigation) and withdrawal (i.e., for electric generation), and possible future trends. Using the watershed model Soil and Water Assessment Tool (SWAT), Dr. Roy analyzed water consumption for irrigation at the county level, incorporating crop distribution and meteorological data from the U.S. Department of Agriculture and the National Weather Service into the model to improve its estimates. The modeling effort identified pockets of high consumption across the United States, particularly in the western states. Overall, the model demonstrated that 73,000 million gallons per day are consumed by irrigation. Approximately 50,000 million gallons per day are consumed by crops, lost at the farm level, or lost as surface runoff; the remainder is considered as base flow in the model and returns to water bodies for reuse.

Thermoelectric power generation withdraws water for cooling systems, Dr. Roy said.

There are two main types of cooling systems: recirculating systems, which use evaporation to reject a fraction of the heat captured; and once-through systems, which withdraw water for cooling purposes but discharge the water back to its source at a higher temperature. This discharged warmer water results in increased water lost to the atmosphere through evaporation.

A major challenge to the study was a lack of plant-level information on water use for many power plants—a problem more common in plants using recirculating systems than once-through systems. For plants lacking data on water use, estimates were made during the assessment. Consistency in how water use data were reported was another challenge, Dr. Roy noted.

Most power plants using once-through cooling systems were in the eastern half of the United States and were mainly coal and nuclear power plants. These plants are large sources of water withdrawal but are low in water consumption. In the western states, most plants use recirculating cooling systems, and so water withdrawal and consumption are closely aligned. Whereas once-through cooling systems in the eastern states consume less than 1 percent of withdrawals, recirculating cooling systems in the west can consume 60 percent of the water withdrawn.

Although there is extensive data available on water use from the USGS and other agencies, Dr. Roy said, more clarification is needed on the methodologies used to estimate water use quantities. Also needed are more information on data quality and greater consistency in how data are reported. More frequent reporting, additional temporal and spatial detail, and better integration with other types of data from various agencies would help to achieve a finer resolution of the data to better support decision making.

Tara Moberg, freshwater scientist with The Nature Conservancy's Pennsylvania Chapter, discussed some of the challenges to freshwater species from water withdrawals for thermoelectric cooling and other uses. Although much is known about the water needs of some species, such as the Eastern Brook Trout, there are many freshwater species whose water needs are unknown. Research focused on ecological flows assesses the flow of water in natural rivers and lakes that sustains ecosystems and the goods and services they provide for humans. Ms. Moberg stated that there has been a shift—known as the natural flow paradigm shift—from protecting a minimum amount of flow in streams to protecting the flow regime as a whole. This new paradigm asserts that freshwater species depend not only on the physical habitat provided by a natural water system but also on the linkages that the natural variability of flows provides in mediating water quality conditions, such as dissolved oxygen and pH. The Nature Conservancy developed a set of ecological flow principles that recognize tradeoffs among shared resources. The overall goal of these principles is to create conditions adequate for the survival of these species and the systems on which they rely.

New demand on water resources for Marcellus shale development across Pennsylvania has put increasing pressure on the ecological flow of rivers in the region, said Ms. Moberg. Developing one natural gas well with hydraulic fracking, for example, requires approximately 4.5 million gallons of water. To better understand increased water demand on a basin-wide scale, the Nature Conservancy scaled up from stream- and species-specific studies to characterizing needs for specific river types and communities. The organization developed a research framework that includes scientific and social dimensions, with four clear steps that address the physical and ecological attributes of a basin. These attributes focus on the hydrologic foundation, river classification, flow alteration, and flow-ecology relationships.

A USGS-developed base flow simulation estimator tool was used to characterize the hydro-ecological settings of the framework, Ms. Moberg said. The hydrology at ungauged stream locations and reference sites was assessed using the Nature Conservancy's indicators of hydrologic alteration software, which created a thumbprint for each of the streams characterizing the inter-annual, annual, and monthly statistics that differentiate a given stream from others. These measurements and modeling were used to help assess how ecosystems depend on stream flow and which processes, such as channel maintenance, are most important. This methodology resulted in the Nature Conservancy representing over 1000 species, with 25 groups and trait groups of species and about 70 individual species.

Ms. Moberg stated that part of the social component of the framework, including the selection, categorization, and classification processes for various species, was carried out with a broad range of stakeholders through a series of workshops. From these workshops, 80 flow ecology hypotheses were developed to describe how a particular species would be affected by a given flow component for a specific month or season within a given habitat. The research established how different species used high and low flows seasonally, and what might change if those particular components were altered. The magnitude of the effect was determined by literature reviews to develop qualitative and quantitative support assessed through a weight-of-evidence approach. The end product was a list of recommendations for all river types for a given basin, which was a key communication tool for water managers and stakeholders in that region. An online tool is also being developed to help state and local water managers in the Susquehanna River Basin implement recommendations. This example of a decision support tool allows regulatory agencies to be better informed on water withdrawals and to account for limitations in predicting water availability.

Michael Webber, deputy director of the Energy Institute at the University of Texas at Austin, emphasized from the panel discussion that the quality of the data reported will strongly influence how those data are interpreted and used. The definitions for the terms in discussing water, such as use, consumption, and waste will also strongly influence how water data are communicated between organizations. More consistent use of terminology, units, and the type of data reported would aid communication efforts, he said.

Dr. Evenson then offered an example of data collection that provides accurate and useful irrigation data. The Georgia Soil and Water Conservation Commission has a program that requires all agricultural irrigation wells and pumps permitted by the Georgia Department of Natural Resources' Environmental Protection Division to have a water metering device installed. Currently, over 11,000 metering devices have been installed to monitor water use in Georgia. In response to a question about how to catalyze improvements in data quality, Dr. Roy commented that data is reported well when there is a regulatory requirement. Generally, thermoelectric power plants are not required to provide information to the Energy Information Agency, and so data quality varies widely. In the absence of having regulatory compliance, a mechanism that provides feedback on the data, such as water use maps, could help to improve data quality, he said.

Decision Support Tools for Addressing the Energy-Water Nexus

James Everett, manager of operations support for the Tennessee Valley Authority's (TVA's) River Forecast Center (RFC), discussed how the Tennessee River reservoir system is managed in an integrated manner in order to provide multiple benefits, including flood control, navigation, power, recreation, water quality, and water supply. Mr. Everett emphasized the importance of maintaining close relationships and collaborating with partnering federal agencies, including the U.S. Army Corps of Engineers, National Weather Service, and USGS. The Tennessee River Valley covers approximately 42,000 square miles, and the TVA owns and operates 49 dams across the valley. Twenty-nine of those dams have conventional hydroelectric power-producing facilities.

The seasonal cycle of reservoir levels drives the operating policies at TVA dams, said Mr. Everett. Tributary dams built in the mountains were designed primarily for flood protection. It is important to draw reservoirs down in the early fall so that they are ready to receive an increase in runoff during winter months. The Tennessee Valley is "water rich" due to an average annual rainfall of 52 inches; however, that amount of water needs to be carefully managed. Holding water in tributary dams reduces flow to the main stem river systems, and reduces damage from flooding. On average, $260 million in damages is averted each year due to this management. In 2013, the Tennessee Valley received over 65 inches of rainfall, and TVA estimates that nearly $1 billion in flood damages was averted in the City of Chattanooga.

TVA operates 109 conventional units for hydropower and is responsible for over 3,500 megawatts of generating capacity, Mr. Everett said. TVA operates an extensive network of over 240 rain and 60 stream gauges and conducts inflow and runoff modeling for storm events in conjunction with the National Weather Service. The data that result from modeling are fed into a routing model, which includes both simulation and optimization and is ultimately used to make decisions about reservoir releases. Optimization models were developed by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) at the University of Colorado, Boulder. Riverware, a routing model developed by CADSWES, can be implemented in both simulation and optimization modes to make decisions about how much water to allow through reservoir systems.

TVA follows the National Weather Service's lead when updating models for estimating inflows, Mr. Everett said. TVA is retiring legacy systems and instead using enhancements and utilizing partnerships with other agencies, such as the U.S. Army Corps of Engineers, to perform faster simulations and optimizations of their systems in order to make better decisions (Figure 2).TVA has a long history of operating the reservoir system, said Mr. Everett in conclusion, and the decision support tools it uses are evolving as demands on the system have evolved.

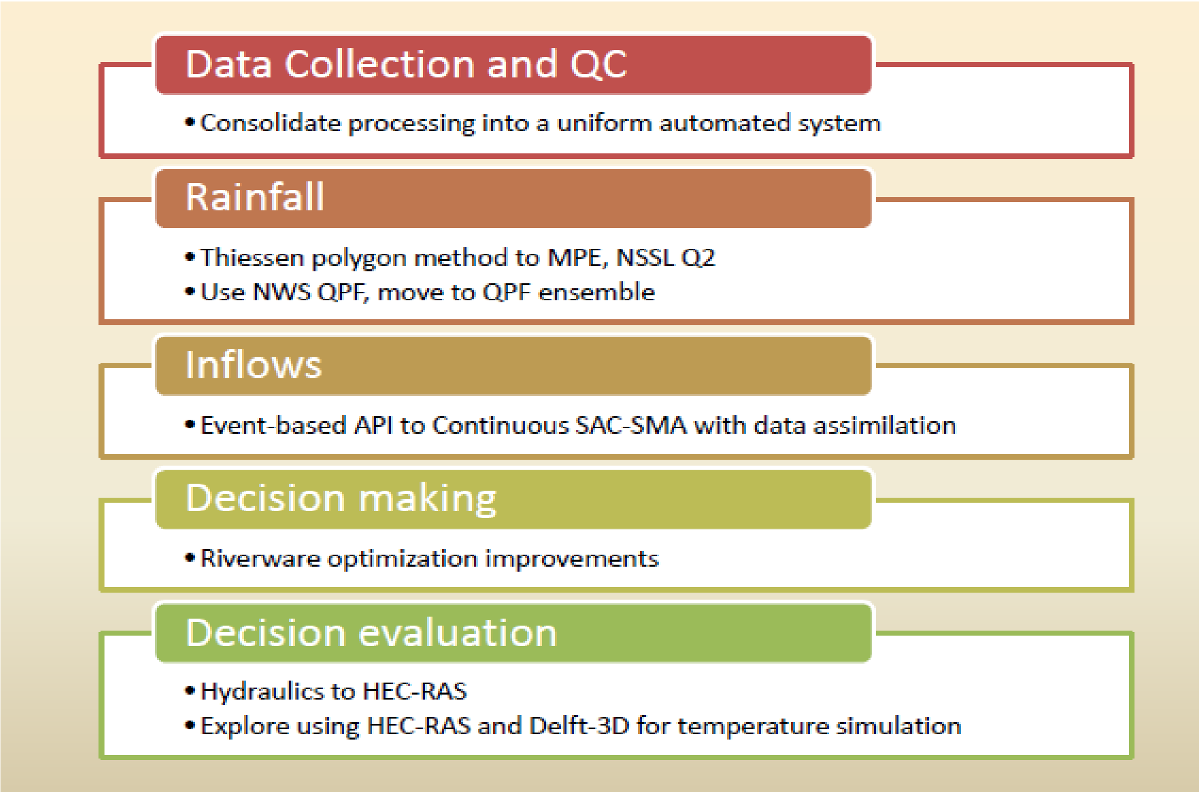

Figure 2 Models and decision support tools used by the Tennessee Valley Authority to manage their reservoir system.
Source: James Everett. December 10th presentation to the National Academies Roundtable on Science and Technology for Sustainability.

Alan Krupnick, co-director of Resources for the Future's Center for Energy and Climate Economics (CECE), discussed the center's risk matrix and survey as a decision tool in shale gas development. Better information needed to be brought into the debate on shale gas development, he said. CECE's expert survey was designed to engage four key groups of stakeholders: government, industry, academia, and nongovernmental organizations (NGOs). The goal was to focus on activities where scientific knowledge could help advance practices, identify research priorities, and provide priority pathways for voluntary actions by industry or further regulation. CECE developed a risk matrix that listed a set of activities in shale gas development at well pads, and then identified the burden to the environment for each of those activities. The result was a series of impact pathways that linked activities to water, land, air, or community effects. For example, on-road vehicle activity resulted in air pollution, noise pollution, and road congestion. A total of 264 impact pathways were identified from the shale gas development activities. CECE then shared the matrix with 215 experts from the four different stakeholder groups to review the pathways and identify top accident and routine priority risks that need further attention from government or industry. Mapping the priorities from the different stakeholder groups in a Venn diagram resulted in 12 of each group's top 20 priorities overlapping.

Dr. Krupnick listed a few surprises from the survey of routine priorities. First, concerns about surface water rather than groundwater dominated priorities across the groups. Only two of the pathways were unique to shale gas development relative to conventional gas development. Also, habitat fragmentation from roads and pad development were identified as a top priority. There were also differences among the stakeholder groups. Experts from NGOs were more concerned about conventional air pollutants, state and federal governments were more focused on groundwater, academia focused on landscape effects and groundwater withdrawal, and industry and academia were focused on seismic effects from fracking.

Diana Bauer, director of energy systems analysis and integration within the Office of Energy Policy and Systems Analysis at the U.S. Department of Energy (DOE), offered a high-level overview of the 2014 DOE report *The Water-Energy Nexus: Challenges and Opportunities.*[14] The report was framed to assess the overall systems related to energy and water, future trends, and the decision-making landscape, said Dr. Bauer. Complexities in decision making arise because policies for water and energy are made by many different agencies and organizations at the federal, state, and local levels. The report examines technology, research and development, fundamental and applied science, and modeling and analysis that can inform decision making, and presents six strategic pillars:

- Optimize the freshwater efficiency of energy production, electricity generation, and end use systems;
- Optimize the energy efficiency of water management, treatment, distribution, and end use systems;
- Enhance the reliability and resilience of energy and water systems;
- Increase safe and productive use of nontraditional water sources;
- Promote responsible energy operations with respect to water quality, ecosystem, and seismic impacts; and
- Exploit productive synergies among water and energy systems.

Dr. Bauer presented a Sankey diagram showing the flow of energy and water through the national economy, derived from DOE and USGS data (Figure 3). An understanding of market drivers, such as water and energy prices and institutional factors, is key to developing decision-making tools, said Dr. Bauer. This understanding led to a more integrated framework that addresses the complexity of the decision-making landscape; the framework encompasses data modeling and analysis, technology and research, and policy analysis in a way that allows for information flow among these three key areas and also incorporates stakeholder involvement.

Another tool Dr. Bauer described was a stacked infrastructure model used for national to regional-scale assessments. It incorporates not only water and energy but also transportation, population dynamics, and other systems to allow for an understanding of indirect effects and trends over time. This type of tool can help estimate future energy demand by fuel type, link it to electricity systems, and evaluate water withdrawals and consumption for thermoelectric power. It is a system of linked models that can respond to changes in the assumptions and data embedded in those models, and help elucidate the implications for energy and water decision making in the future.

In response to a question about the availability of models, Dr. Everett explained that most of the models TVA uses were developed in-house and are not available to users in the general public; however, some other models from the U.S. Army Corps of Engineers and the National Oceanic and Atmospheric Administration are in the public domain. Similarly, Dr. Bauer said that her office uses the GREET model available from the Argonne National Laboratory; however, the modeling that links the different systems – the stacked infrastructure model – is not available for public use. DOE would like to better deliver tools to stakeholders and make them more universally accessible and usable, Dr. Bauer added.

Decision-Based Frameworks for Local Decision-Making

Michael Sale, executive director of the Low Impact Hydropower Institute, discussed the importance of hydropower as a renewable energy source and as part of the U.S. water sector. Hydropower is well established in the United States and has been a foundation of renewable energy, he said. Currently, over 225 hydropower plants in the United States produce an average of 280 terawatts daily. Hydropower is the largest water user in the United States but has largely not been counted in water statistics since 1995.

Advanced technology has helped to improve hydropower operations, Dr. Sale continued. For example, there have been advances in building better turbines, designing better fish passages and ladders, and better compliance with in-stream flow or environmental flow requirements. Excluding hydropower from Renewable Portfolio Standards programs results in lost opportunities to engage the hydropower sector and provide incentives to further improve operations, he said. Market-based incentives have led to improved coordination within river basins, better water quality within river basins that surpasses regulatory requirements, and benefits to local environments.

Gregory Characklis, professor of environmental sciences and engineering at the University of North Carolina, also focused his remarks on hydropower, which he described as a renewable energy source with a significant influence on the environment. One major advantage of

[14] http://energy.gov/downloads/water-energy-nexus-challenges-and-opportunities

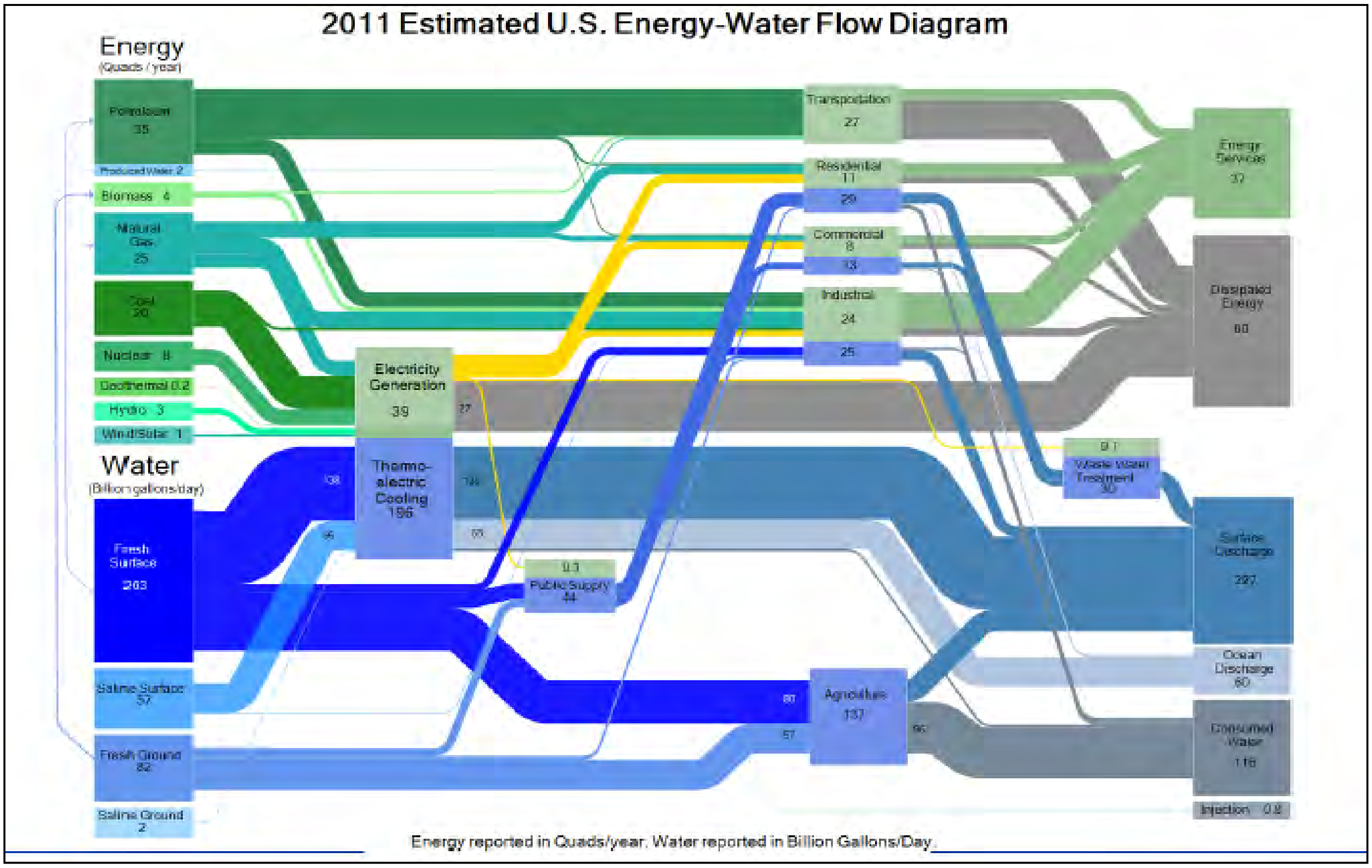

Figure 3 Sankey diagram showing the flow of energy and water through the national economy. Source: Diana Bauer. December 10th presentation to the National Academies Roundtable on Science and Technology for Sustainability.

hydropower over coal or nuclear power generation is the ability to turn power generation on or off. Challenges to hydropower, however, include ensuring financial stability, managing variable flow, and maintaining ecosystem quality.

The key consideration with hydropower is its value as a peaking source for electricity generation. Coal and nuclear power generation are more efficient as base loading, and the variability associated with intermittent solar and wind energy production makes hydropower a more efficient peak energy source due to its ability to be turned on and off with fluctuating demand.

Dr. Characklis pointed to global trends that will impact both the energy and water markets in the future. For example, increasing water scarcity will be a key challenge, one that could potentially impact hydropower because of the water stored behind hydropower dams. The water can either be stored and used to generate electricity or released downstream to feed municipal water supplies; however, it may not be possible to meet both needs.

Dr. Characklis's research in the Catawba Basin, which runs between North and South Carolina, demonstrated that if 100 percent water supply reliability was to be met at the demand projected for 2020, there would need to be a 25 to 30 percent reduction in energy production. One innovative approach to improving the regulatory and economic outcomes is introducing tradable flow credits, which municipalities receiving the water supply would use to pay the hydropower producers to retain water in the reservoirs.

Barton Thompson, Robert E. Paradise professor of Natural Resources Law and Perry L. McCarty director and senior fellow of the Woods Institute for the Environment at Stanford University, discussed the decision-making tools that local governments will need in order to navigate a complex landscape of water and energy policy.

In the future, because of increasing environmental constraints and regulation, local governments will rely less on long-distance imports of water supply such as the Federal Central Valley Project, which imports water from Northern California into the Central Valley and Southern parts of California. Competition for available water will also increase, he said. There are currently more cases involving water disputes before the U.S. Supreme Court than at any other point in recent history. A current case Dr. Thompson is involved in is a dispute between Montana and Wyoming over water in the Yellowstone River system. He noted how little information is available in the case and that more data would help those involved make more informed decisions. Dr. Thompson expects interstate water disputes to increase in the future.

Water supplies will need to place greater emphasis on recycling and desalination; however, these processes will need significant technological advances, said Dr. Thompson. Recycling in California has reached a stage at which it has proven to be economically viable; however, for much of the rest of the country it is still prohibitively expensive. Similarly, desalination is currently not an option for most municipalities because of the cost and the amount of energy required. Technological advances are taking place in research laboratories that would help drive down the energy requirements costs of these technologies. The pace of these developments, however, is slow and they are not being adopted into the market.

Innovative development is stronger in the energy sector than in the water sector, which is exemplified by the number of patents filed in each sector, said Dr. Thompson. A few key drivers explain this pattern: pricing, financing, and regulations. There is often a strong correlation between the price of a commodity and innovation in that particular field. For example, there is a strong relationship between the number of clean energy patents issued in the United States and the price of electricity. In contrast, the price of water in the United States is extremely low compared to other developed countries. Water is the only resource in the United States that can be obtained at no charge, and correcting for the underpricing of water will drive innovation in this sector, said Dr. Thompson.

Financing is another challenge to innovation, he continued. Water utilities face increasing challenges, particularly in replacing aging infrastructure. When the ratio of capital investment to revenue is assessed for various utilities, the water sector is clearly a highly capital-intensive sector. Electric utilities, for example, have a capital investment-to-revenue ratio of approximately 1.8, whereas water utilities have a ratio of approximately 3.8. Water utilities, therefore, are not able to invest in research, because they spend most available funds on operating costs and capital investments. Also, new technology is a challenge to adopt due to the often high capital costs associated with implementation. Another barrier to innovation in the water sector is regulation at local and state levels, he noted, which can result in many new technologies not being adopted. ■ ■ ■

PRESENTERS: **Sujoy Roy**, Tetra Tech R&D; **Eric Evenson**, U. S. Geological Survey; **Tara Moberg**, The Nature Conservancy; **James Everett**, Tennessee Valley Authority River Forecast Center; **Alan Krupnick**, Resources for the Future; **Diana Bauer**, U.S. Department of Energy; **Michael Sale**, Low Impact Hydropower Institute; **Gregory Characklis**, University of North Carolina; **Barton Thompson**, Jr., Stanford University.

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DISCLAIMER: This meeting summary has been prepared by **Dominic Brose** as a factual summary of what occurred at the meeting. The committee's role was limited to planning the meeting. The statements made are those of the author or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, STS, or the National Academies.

The summary was reviewed in draft form by **Michael Kavanaugh**, Geosyntec and **Danny Reible**, Texas Tech University. The review comments and draft manuscript remain confidential to protect the integrity of the process.

Appendix A

Planning Committee on Addressing the Energy-Water Nexus, 2013

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Steve Bergman, Principal Regional Geologist, Shell International Exploration & Production Company

Carl Shapiro, Co-director, Science and Decisions Center, U.S. Geological Survey

Planning Committee on Addressing the Energy-Water Nexus, 2014

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James Zucchetto, Director, Board on Energy and Environmental Systems

Jeffrey Jacobs, Director, Water Science and Technology Board

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Appendix B

Roundtable on Science and Technology for Sustainability

Established in 2002, the National Academies of Sciences, Engineering, and Medicine's Roundtable on Science and Technology for Sustainability provides a high-level forum for sharing views, information, and analyses related to harnessing science and technology for sustainability, and then catalyzing follow-on advisory Academy work. Members of the Roundtable include leading experts from research institutions as well as senior decision-makers from government and industry who deal with issues of sustainable development, and who are in a position to mobilize new strategies and resources for sustainability.

The goal of the Roundtable is to mobilize, encourage, and use scientific knowledge and technology to help achieve sustainability goals and to support the implementation of sustainability practices. Three overarching principles guide the Roundtable's work in support of this goal. First, the Roundtable focuses on strategic needs and opportunities for science and technology to contribute to the transition toward sustainability. Second, the Roundtable focuses on issues for which progress requires cooperation among multiple sectors, including academia, government (at all levels), business, nongovernmental organizations, and international institutions. Third, the Roundtable focuses on activities where scientific knowledge and technology can help to advance practices that contribute directly to sustainability goals, in addition to identifying priorities for research and development (R&D) inspired by sustainability challenges.

The Roundtable has adopted a two-pronged strategy to address sustainability. The first part of this strategy attempts to define inter-sectoral dynamics and linkages essential to long-term science and technology approaches to sustainability. The second looks to apply these concepts to sustainability challenges.

Focus on Long-Term Science and Technology Strategy for Sustainability

Acknowledging that sustainability is an interdisciplinary topic that crosses domains, sectors, and institutions, the Roundtable launched a series of discussions to outline the major connections between human and environmental systems.
In 2013-2014, the Roundtable, in collaboration with the Board on Energy and Environmental Systems and the Water Science and Technology Board, successfully contributed to the emerging dialogue on the energy-water nexus by holding four related events. In 2015, the Roundtable will plan two events focusing on issues related to sustainability indicators and metrics.

Applied Sustainability

As a second area of programmatic emphasis, the Roundtable is sharpening its focus on sustainability challenges in applied situations where STS works with specific communities within our Roundtable membership.

The Roundtable is the key component of the Science and Technology for Sustainability (STS) Program in the division of Policy and Global Affairs at the Academies. The Roundtable is being supported by the Academies' George and Cynthia Mitchell Endowment for Sustainability Science. STS is the institutional focal point within the Academies for examining sustainability science and technology issues. Sustainability leaders in the government, academia, private sector and non-governmental organizations recognize STS as a sustainability leader driving current approaches in the field.

For more information, please visit our website at: www.nas.edu/sustainability or contact Jerry Miller, Director of the Academies' Roundtable on Science and Technology for Sustainability (jlmiller@nas.edu; 202-334-2613).

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