MEETING SUMMARY

SUSTAINABLE ENERGY AND MATERIALS

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
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.

Figure 1. Net Zero Hierarchy. SOURCE: Hammack, K. 2013. June 6th Presentation to the National Academies Roundtable on Science and Technology for Sustainability.

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 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.

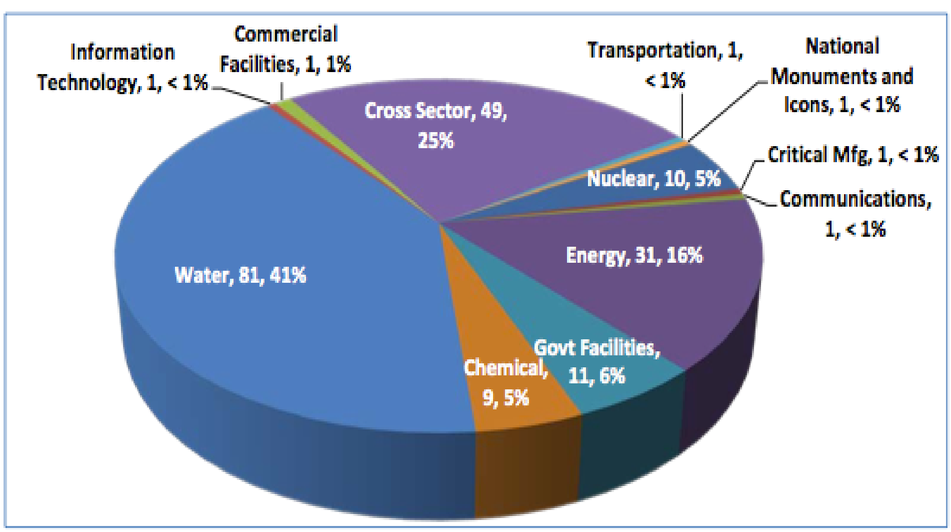

Figure 2. Cyber threats to Industrial Control Systems (ICS). SOURCE: LoPiccolo, D. June 6th Presentation to the National Academies Roundtable on Science and Technology for Sustainability.

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 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[1], which includes climate data, segregated by sector.

[1] 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.

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.

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.

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[2], 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

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

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 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[3] 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

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

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.

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.
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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.

About Science and Technology for Sustainability (STS) Program

The long-term goal of the National Academies' Science and Technology for Sustainability (STS) Program is to contribute to sustainable improvements in human well-being by creating and strengthening the strategic connections between scientific research, technological development, and decision-making. The program examines issues at the intersection of the three sustainability pillars—social, economic, and environmental—and aims to strengthen science for decision-making related to sustainability. The program concentrates on activities that are crosscutting in nature; require expertise from multiple disciplines; are important in both the United States and internationally; and engage multiple sectors, including academia, government, industry, and non-governmental organizations. The program's focus is on sustainability issues that have science and technology at their core, particularly those that would benefit substantially from more effective applications of science and technology.

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