MEETING SUMMARY

ADDRESSING THE ENERGY-WATER NEXUS—POWER PLANTS AND PARTNERSHIPS

Roundtable on Science and Technology for Sustainability
Science and Technology for Sustainability Program

Board on Energy and Environmental Systems
Water Science and Technology Board
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,[1] 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 overpumped.

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

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.

A study[2] 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[3] 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.[4]

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.

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[2] 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.

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

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

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 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

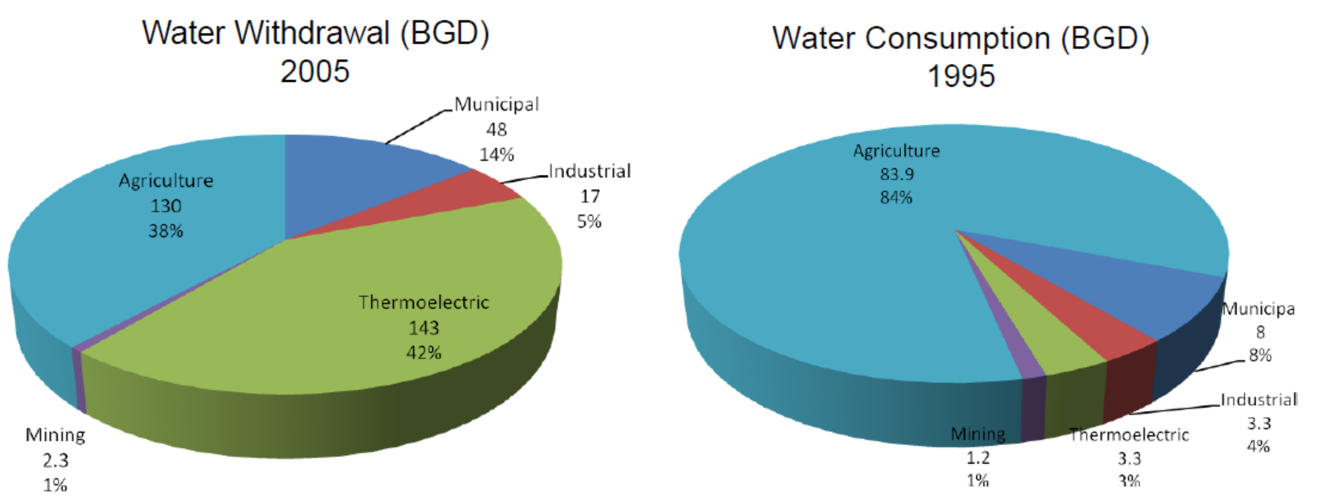

FIGURE 1: Water Withdrawal (billion gallons per day), 2005; and Water Consumption (billion gallons per day), 1995. SOURCE: Tidwell, V. December 5th Presentation to the National Academies Roundtable on Science and Technology for Sustainability.

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 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.

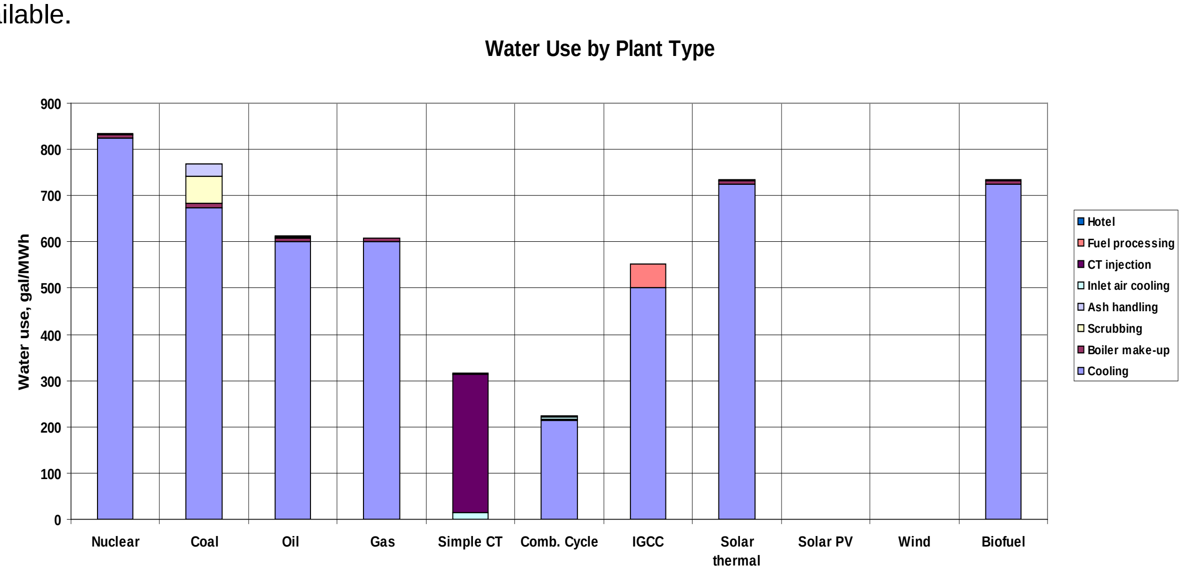

FIGURE 2: Root Cause of Thermal Power Plant Consumptive Water Use. SOURCE: Shi, J. December 5th Presentation to the National Academies Roundtable on Science and Technology for Sustainability.

These dry cooling systems are rarely used because of three major drawbacks: 1) the power production penalty, which can be as high as 10 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[5] 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 thermo 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

[5] 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.

upgrades or 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[6] 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, development, demonstration and commercial application to address the energy-water nexus.

[6] 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.

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.[7]

[7] 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.

Participants: William Brandt, Arizona State University; Ron Faibish, U.S. Senate Committee on Energy and Natural Resources; Anne-Marie Fennell, U.S. Government Accountability Office; Michael Hightower, Sandia National Laboratories; Robert Lotts, Arizona Public Services Co.; Maribeth Malloy, Lockheed Martin Corporation; Donna Myers, U.S. Geological Survey; Frank Rusco, U.S. Government Accountability Office; Jessica Shi, Electric Power Research Institute; Vince Tidwell, Sandia National Laboratories; and Tony Willardson, Western States Water Council.
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; Jennifer Saunders, Senior Program Officer, STS; Sara Frueh, Media Officer II, Office of News and Public Information; Emi Kameyama, Program Associate, STS; and Dylan Richmond, Research Assistant, STS.

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.

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.

For more information about STS, visit our web site at http://sustainability.nationalacademies.org
500 Fifth Street, N.W., Washington, D.C. 20001
sustainability@nas.edu