THE NATIONAL ACADEMIES

MEETING SUMMARY

ADDRESSING THE ENERGY-WATER NEXUS THROUGH TECHNOLOGICAL INNOVATION

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

Board on Energy and Environmental Systems
Water Science and Technology Board
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).

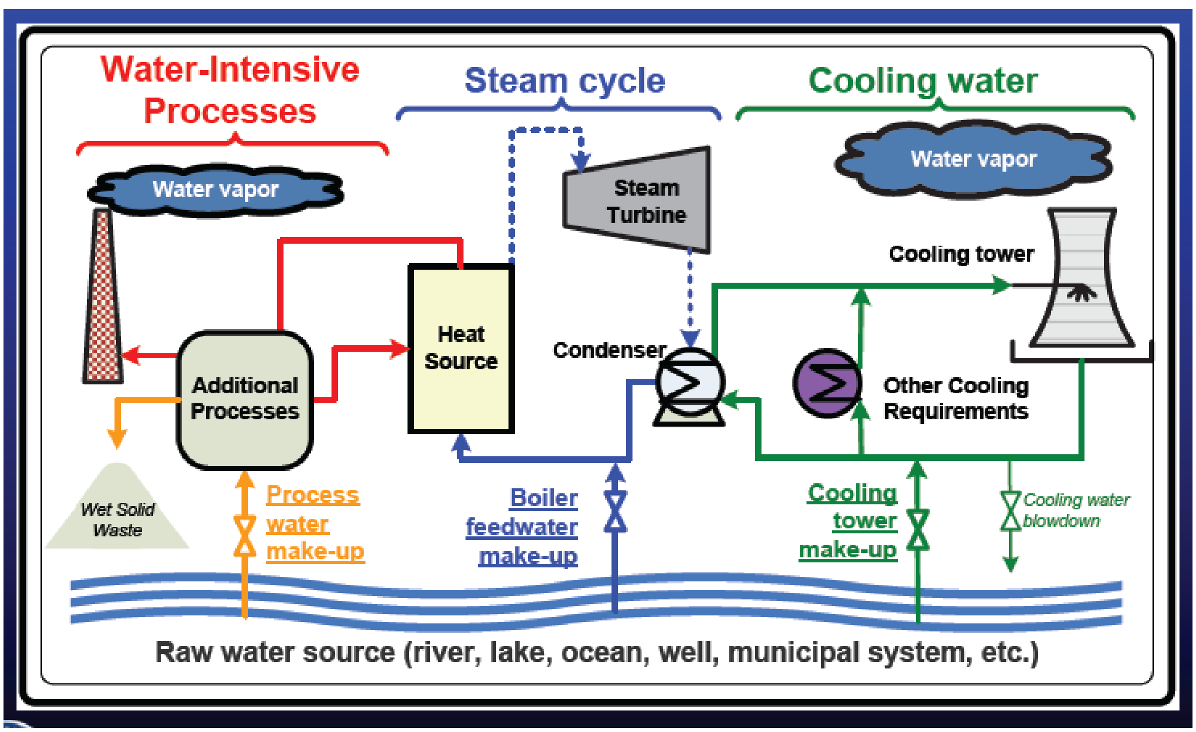

FIGURE 1 Water use in the thermoelectric industry. SOURCE: Radisav Vidic, University of Pittsburgh, presentation on May 20, 2014, Washington, DC.

Municipal wastewater may provide a solution, as 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.

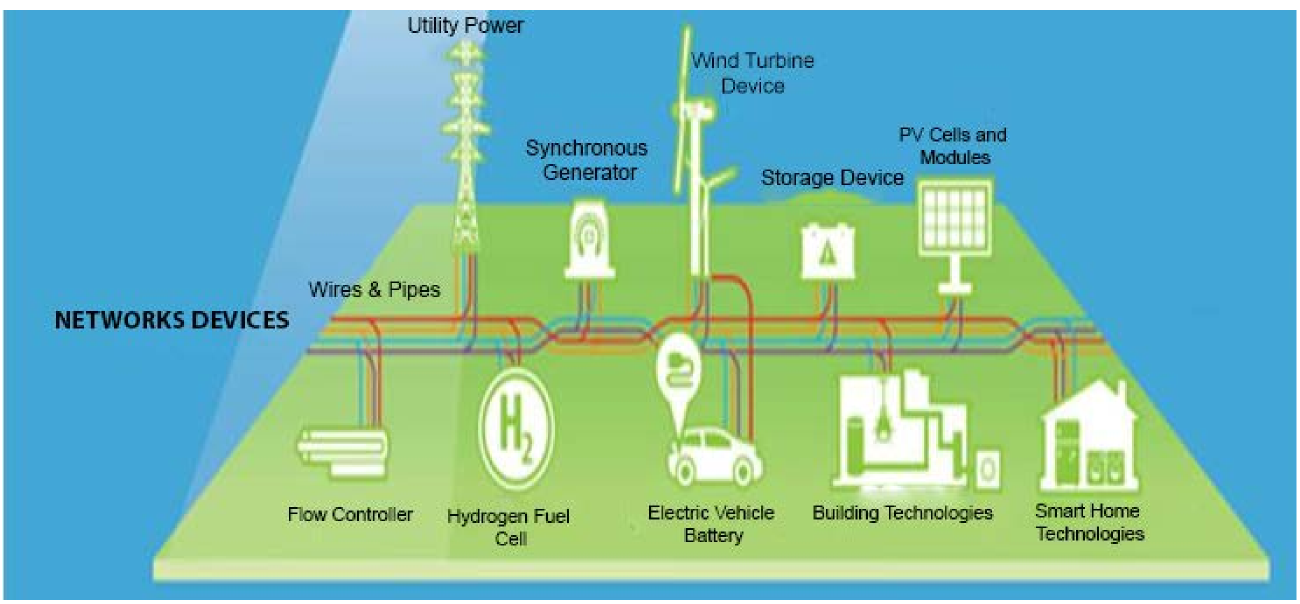

FIGURE 2 Linking the electrical grid with other infrastructure connects related systems resulting in overall efficiency. SOURCE: Image by Joelynn Schroeder courtesy of the National Renewable Energy Laboratory, 2014.

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 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 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.

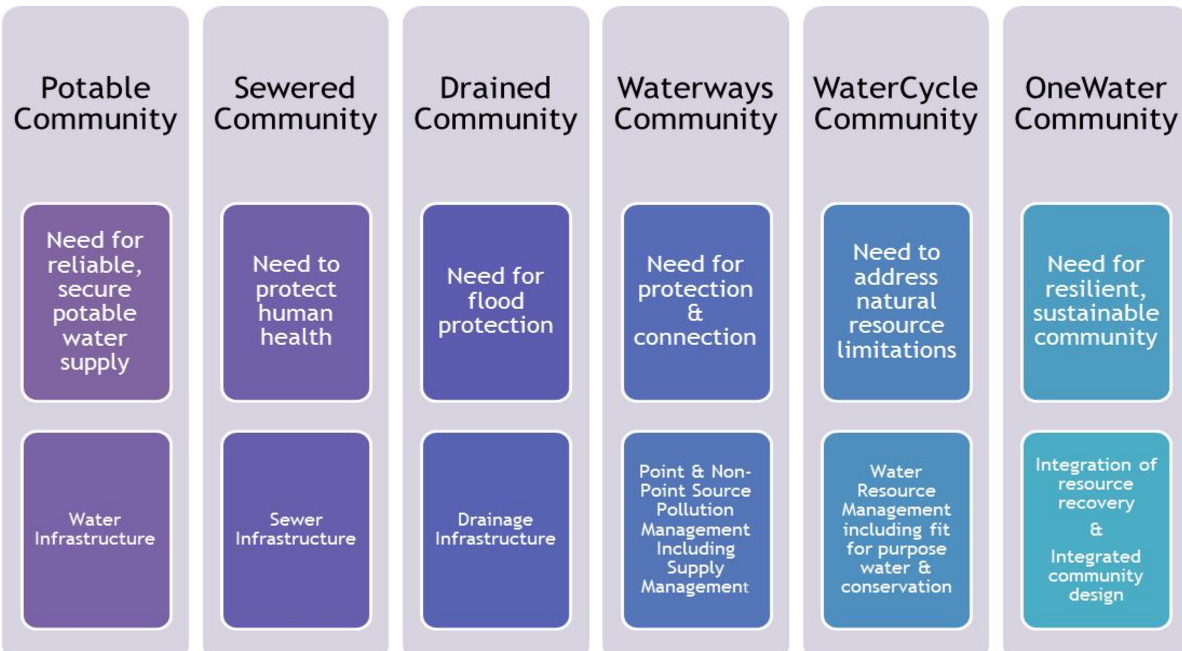

FIGURE 3 Six Stages in Development of Water Utilities. SOURCE: Diane Taniguchi-Dennis, Clean Water Services, presentation on May 20, 2014, Washington, DC

Presenters: George Barclay, Dow Chemical Company; Amy Childress, University of Southern California; Bryan Hannegan, National Renewable Energy Laboratory; Donald C. Jackson, Lafayette College; Silvia Secchi, Southern Illinois University; Diane Taniguchi-Dennis, Clean Water Services; and Radisav Vidic, University of Pittsburgh.

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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 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.

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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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