MEETING SUMMARY

DEVELOPING SUSTAINABLE AND RESILIENT ENERGY SYSTEMS

SCIENCE AND TECHNOLOGY FOR SUSTAINABILITY PROGRAM
BOARD ON ENERGY AND ENVIRONMENTAL SYSTEMS
DECEMBER 6, 2012

As the largest global consumer of energy, the U.S. is facing the need to identify and develop sustainable sources of energy and materials. As U.S. Secretary of Energy Steven Chu has indicated, "access to clean, affordable and reliable energy has been a cornerstone of the world's increasing prosperity and economic growth since the beginning of the industrial revolution. Our use of energy in the twenty-first century must also be sustainable." Energy systems should also be resilient. Resilient energy systems are designed to withstand disturbances from a range of causes—climatic, economic, technological, and social. The increasing number of worldwide natural disasters and the severity of their impact over the past several decades as well as other social and technological factors have raised awareness of the need to develop such resilient energy systems. For example, the vulnerability of the current energy infrastructure on energy supplies was made clear by the impact of Hurricane Katrina and the 2011 Japanese earthquake and tsunami.

On December 6, 2012, the National Research Council's Science and Technology for Sustainability Program, in collaboration with the Division on Engineering and Physical Sciences' Board on Energy and Environmental Systems, convened a meeting of technical experts in private industry and representatives from government and academia to discuss sustainable and resilient energy systems.

Presentations explored approaches to building a sustainable and resilient energy future as well as major policy, research, and technological gaps that need to be addressed. In addition, presentations identified research that could help achieve sustainable energy systems and maximize their benefits; technologies that could strengthen sustainability and resilience; and policy and institutional developments that could advance these goals.

Themes that emerged from the speakers' presentations and discussion at the meeting include:

- The importance of distinguishing among resilience, adaptation, transformation, and sustainability.
- The importance of leveraging technologies, such as the industrial internet, to enhance the resilience of energy systems.

- The linkages between energy and water as important parts of the discussion about sustainable and resilient energy systems.
- The need for data on energy use in the built environment, in the residential sector, in global supply chains, and in resource management.
- The centrality of social science and behavioral science in the discussion of sustainable and resilient energy systems.
- The existence of activities initially intended to focus on long term adaptation have become immediately relevant in the face of climate change.

Thomas Wilbanks of Oak Ridge National Laboratory (ORNL) introduced the meeting by pointing out that Hurricane Sandy offered a vivid reminder that the continuity of energy systems cannot be assumed in the face of environmental and other threats. However, this natural disaster was just one in a long succession of events that have widely disrupted energy system services.

From the perspective of science and technology, Dr. Wilbanks said, responses to natural disasters are related to four key concepts: adaptation, resilience, sustainability, and transformation. It is important to clarify this terminology because it shapes how we think, communicate, and develop strategies for action. Adaptation is defined as an adjustment in a human, human-managed, or natural system to a new or changing environment that moderates negative effects or exploits beneficial opportunities. Resilience is the ability of a system and its components to anticipate, reduce, accommodate, or recover from the effects of a threat in a timely and efficient manner. Sustainability is a development pathway that – in a manner that is participatory and values equity – achieves continuing economic and social progress and assures a balanced relationship with a physical environment that is already under stress. Transformational changes are changes that are fundamental to the attributes, composition, structure, or scale of a system or of its location, rather than small, incremental changes. Transformational adaptations to increase resilience in coastal areas include the construction of seawalls, or dikes, which can protect the whole city or facilities within it.

The four concepts are interrelated in several ways (see Figure 1), said Dr. Wilbanks. First, adaptation focuses on the near-term, resilience on the mid-term, and sustainability on the long-term. Adaptation is focused on action; resilience and sustainability focus on outcomes. Assuring sustainability requires increasing resilience to coastal storm surges, flooding, winds, and sea-level rise, which necessitate near-term adaptations. Strategies and actions for one concept should also be supportive of the others.

Several recent activities have demonstrated how the energy sector has evolved in its approach to climate change, said Dr. Wilbanks. For example, a workshop at the Atlantic Council on Climate Change and Extreme Weather, held in July 2012, included extensive discussion of the energy sector's vulnerability to climate change impacts. Many participants of that workshop were from the private sector and noted that climate policy in the energy industry is still contentious; however, they also acknowledged that climate impacts are a real concern for the industry and are important to business continuity for the energy sector. Similarly, the major oil and gas companies are now discussing

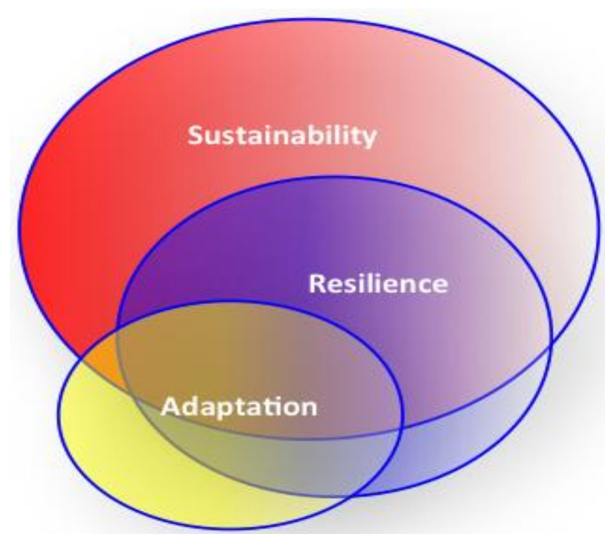

FIGURE 1. Relationship between adaptation, resilience, and sustainability.
Source: Wilbanks, T. 2012. Adaptation, Resilience and Sustainability as Objectives for Energy Systems. Presentation to the National Research Council Roundtable on Science and Technology for Sustainability. December 6, 2012.

the development of strategies for adapting to impacts of climate change.

Dr. Wilbanks noted that water system management has been receiving greater attention as a resilience issue. In 2011 the American Society of Civil Engineers, which is very active in adaptation and resilience discussions, produced a water infrastructure report card that said by 2020, the United States will have fallen $84 billion short of needed investments in critical water systems, which translates to $416 billion in lost gross domestic product and 700,000 lost jobs, as well as increased vulnerability to both flooding and drought.

Dr. Wilbanks also described sustainability in electricity generation. This sector is focused on meeting demands in the regions where they are located; regional markets preclude relocation. For example, Entergy, a major Gulf Coast electric utility, is concerned about the sustainability of its regional customer base in the face of threats from climate change and land subsidence. The company conducted a study of how to assure that the region is resilient to such threats.[1] The study analyzed costs and benefits for a range of adaptation options for enhancing resilience in the face of climate change plus land subsidence. The study assessed scenarios at 2030, 2050, and 2100 and found significant losses, with the losses from nonclimate factors actually larger than losses from climate factors. The study also found a change in both damage and the frequency of exposure to damage. The report suggested nine measures to protect the region; five of the nine are related to the energy sector, oil and gas, and electricity. The estimated cost of completing these in the region would be $44 billion in public funding and $76 billion in private funding.

Dr. Wilbanks also described the Climate Change Adaptation Study, conducted in New York City under Mayor Bloomberg, which produced a map of the 100-year flood zone. The map, which was produced before Hurricane Sandy, closely reflects where the storm surge affected the city. Although the study was produced initially as part of a long-term strategy development issue, it is now an immediate response issue. This adaptation study also focused on energy facilities that would be significantly impacted in a storm surge. Many of the facilities were in fact affected by the storm.

The private sector is moving toward vulnerability assessments, vulnerability reduction strategies, and stronger emergency response capacity, said Dr. Wilbanks. Electric utilities are doing interesting things to improve their emergency response capacities. In many cases, the energy sector is headed for near-term adaptation and also considering transformational actions as current infrastructures are replaced or revitalized over the next 30 years or so.

Michael Webber of the University of Texas discussed data and technology issues related to sustainable and resilient energy systems. Data are lacking in a number of key areas, including on energy use in the built environment, in the residential sector, in global supply chains, and in resource management. Additionally, energy systems are strained because of surging demand from population growth and economic growth, aging infrastructure, an aging workforce, archaic markets with fixed electricity rates, and a mismatch between demand for power and its availability. These systems are vulnerable to massive failure, as was shown by previous blackouts and the impact of Hurricane Sandy on communities in New York and New Jersey. Dr. Webber noted that although there is a need for more data on energy and water use, these data must be coupled with price signals, smart policies, and cultural forces in order to impact consumer behavior.

The electricity grid is in use about 46 percent of the time, stated Dr. Webber. This is a stark contrast to other sectors, such as refineries, which use their capital about 92 percent of the time, or airplanes, which are in use about 90 percent of the time. The energy sector is a capital-intensive industry that does not use its power production capabilities all the time.

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[1] See Building a Resilient Energy Gulf Coast: Executive Report. Online. Available at http://www.energy.com/content/our_community/environment/GulfCoastAdaptation/Building_a_Resilient_Gulf_Coast.pdf. Accessed February 28, 2013.

The gasoline supply system is also subject to vulnerabilities, as evidenced by several natural disasters, including Hurricanes Ike and Gustav, which suppressed oil and gas production in Texas and affected power systems. Houston, the energy capital of the world, had pockets without power for two weeks, a loss that affected the ability to move gasoline, refined products, or natural gas to other markets.

Water systems, too, are vulnerable to failure, Dr. Webber continued. These systems face similar archaic markets with fixed rates that do not match the demand for or availability of water. For example, water availability tends to be higher in the fall, winter, and spring, while water demand is higher in the summer, which is problematic. Dr. Webber highlighted the resiliency problems with both the energy and water systems, stressing the link between the two. Data needs on water systems are complicated by unclear definitions, including a lack of agreement on the definition of water use, withdrawal, consumption, and diversion. It is often assumed that if given more information, consumers will make better decisions about their energy consumption, but that is not always the case, said Dr. Webber. Giving consumers information about energy consumption typically translates into only a small reduction in energy use; often consumers will curb consumption temporarily but return to their typical patterns. Information, labels, and data are not enough to encourage energy-saving behavior, as evidenced by the lack of response to EPA's programs to label cars according to their fuel economy. A combination of information and price signals is the most powerful way to change behavior; EPA's fuel economy labeling programs did not prompt people to buy more fuel efficient cars, but higher fuel prices did.

Dr. Webber concluded by describing the Pecan Street Project, a public-private partnership to support the first large-scale, consumer-focused smart grid demonstration project. This five-year project includes about 500 homes in a Texas community that have been supplied with smart electricity and water, high-penetration residential solar, green appliances, home energy management, and a high concentration of electric vehicles. The demonstration will provide enormous data for understanding consumer behavior related to energy use and opportunities for energy and water savings.

Peter Evans, director of global strategy and analytics for GE Energy, provided an overview of the "industrial internet" in the context of sustainable and resilient energy systems. The industrial internet "brings together the advances of two transformative revolutions: the myriad machines, facilities, fleets and networks that arose from the industrial revolution, and the more recent powerful advances in computing, information and communication systems brought to the fore by the internet revolution."[2] The industrial internet includes three building blocks: creating more intelligent machines; harnessing advanced analytics for the operations of those machines; and designing how people interface with the machines in ways that augment human decision making to improve the machines' performance and operation (see Figure 2). The data generated by these machines can be used for decision making.

For example, there are opportunities to harness information from gas-fired combined cycle plants, stated Dr. Evans. Currently, there are about 4,178 gas-fired combined cycle plants in operation globally. GE estimates that in the next 15 years, another 2,000 of these plants will be built. If one breaks down the combined cycle technology, there are about 105 pieces of critical rotating equipment at each plant, which translates to about 186,000 pieces of rotating equipment in the entire global fleet of combined cycle plants. By 2025, there will be about 400,000 pieces of rotating equipment in that fleet. The equipment associated with operating these plants could be monitored to collect a range of data that could yield a better understanding of maintenance cycles, how to enhance performance, and how to anticipate events. GE estimated the benefits that can be derived from using better analytics on the global combined cycle fleet. Aggregating all the gas that was used in the power sector in 2005, GE estimated that there is about $178 billion worth of gas burned in combined cycle plants globally. By 2015, that number will rise to almost $300 billion.

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[2] Evans, P.C. and M. Annunziata. 2012. Industrial Internet: Pushing the Boundaries of Minds and Machines, November 26, 2012.

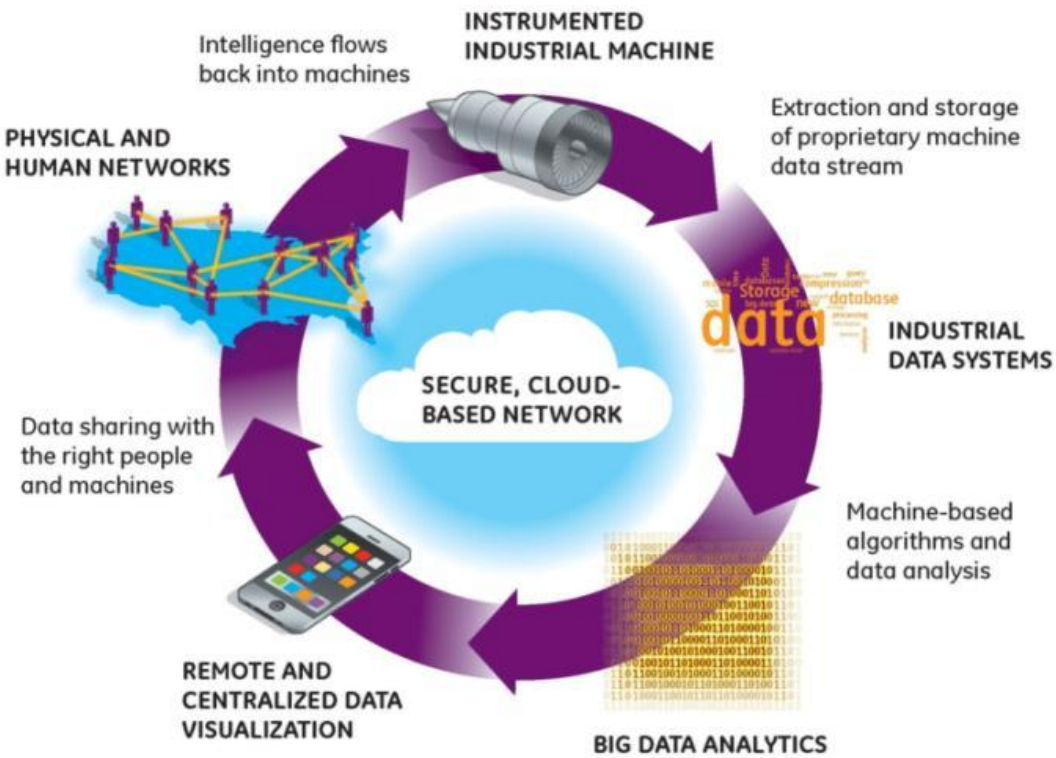

FIGURE 2. Industrial internet: From instrumentation to intelligence and back.
Source: Evans, P. 2012. Resilient-Sustainable Infrastructure (RSI). Presentation to the National Research Council Roundtable on Science and Technology for Sustainability. December 6, 2012.

If the industrial internet is deployed to improve that fleet, it will be possible to improve the efficiency of those plants by one percent, which would result in a sizeable fuel savings; improving the fleet of combined cycle plants around the world would yield approximately $66 billion in savings.

The industrial internet can also assist with recovery from disasters. For example, it can be used for distributed automation, which identifies faults, allowing parts of the grid that have failed to be isolated. Another opportunity is for rapid deployment of backup power solutions. The next steps will be to expand the speed and scope of technology deployment in these areas, Dr. Evans said, adding that the United States is not at the cutting edge of infrastructure deployment. There will be opportunities to blend some industrial internet technologies into newly designed infrastructure, particularly in emerging markets. Sending the right market signals to encourage innovation will be key.

Aristides Patrinos, deputy director for research at New York University's Center for Urban Science and Progress (CUSP), discussed the importance of developing sustainable and resilient urban systems given rapid population growth. The purpose of CUSP, a public-private initiative launched in April 2012 by Mayor Bloomberg, is to use New York City as a laboratory in an effort to help cities around the world become more productive, livable, equitable, and resilient. CUSP observes, analyzes, and models cities in order to optimize outcomes, prototype new solutions, formalize new tools and processes, and develop new expertise, making the program a leading authority in the emerging field of "urban informatics."[3] The program includes a coalition of universities throughout the world, including Carnegie Mellon University, the University of Toronto, the University of York in the UK, and the Indian Institute of Technology in Mumbai, along with many industrial partners, including IBM, Siemens, and Xerox. CUSP's work will be critical to

[3] More information is available at http://cusp.nyu.edu/about/.

informing future discussions about sustainable and resilient urban systems, said Dr. Patrinos, who echoed the importance of social science in discussions about sustainable and resilient energy systems.

Joseph Fiksel, executive director of the Center for Resilience at Ohio State University and special assistant for sustainability at the U.S. Environmental Protection Agency's Office of Research and Development, discussed the role of natural capital in sustainability and resilience. He posed several urgent questions to the group: (1) Can we trust our predictive capabilities in a tightly coupled, complex, and turbulent world? (2) How can the current "risk-based" paradigm be extended to address "inherent" resilience? (3) When does pursuit of resilience support or conflict with sustainability goals? (4) How can the public and private sectors adopt a more "adaptive" approach to decision making? (5) Can we develop a new generation of analytic tools based on "systems thinking" that are suitable for the "new normal"?

Making the distinction between sustainability and resilience is key, Dr. Fiksel said. Sustainability is the capacity for long-term realization of human health and well being, economic prosperity, and environmental protection; however, unforeseen conditions can lead to unintended or undesired consequences. Resilience is the capacity to survive, adapt, and flourish in the face of changing conditions and potential disruptions, assuring continuity. In a complex and turbulent world, resilience is a prerequisite for realizing sustainability goals. Several principles of systems resilience were also discussed, including resilience and adaptive capacity as intrinsic characteristics of all self-organizing systems.

In looking more closely at the relationship between resilience and sustainability, it is possible to identify examples of synergies and tradeoffs (Figure 3), Dr. Fiksel explained. For example, one technology may be more resilient but less sustainable or vice versa. Some may be neither. The use of corn ethanol is not resilient or sustainable, for example; neither is importing fuel from abroad. On the other hand, smart grids are an

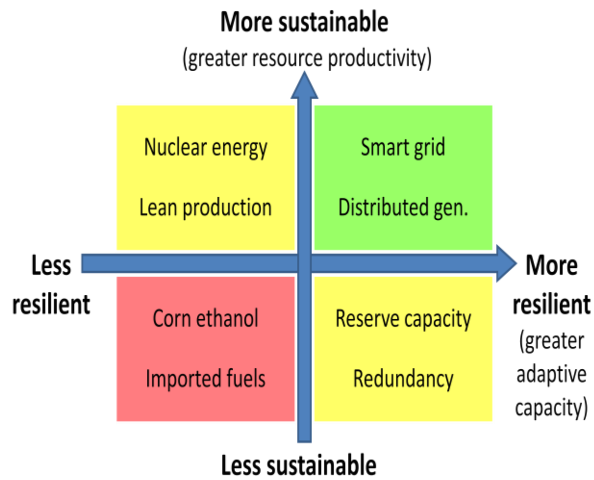

FIGURE 3. Resilience vs. sustainability: Examples of synergies and trade-offs.
Source: Fiksel, J. 2012. Considerations for Developing Sustainable and Resilient Energy Systems. Presentation to the National Research Council Roundtable on Science and Technology for Sustainability. December 6, 2012.

example of a promising technology that can play a role in making energy systems both sustainable and resilient; such grids can reduce the load requirements for our energy supply, contributing to its sustainability, and can also gauge changes in the system. Smart grids also involve distributed generation, which makes the grid more resilient.

The true sustainability challenge is to ensure that we have enough capacity in the environment to support the needs of a growing population, said Dr. Fiksel. There are various ways to achieve this. One option often discussed is redesigning our industrial systems to generate less waste, use fewer resources, and have lower resource intensity. Another option is to nurture ecosystems, restore and protect natural capital, and ensure that we are not degrading the environment or diminishing its capacity. Another interesting approach is trying to harness ecosystem services to replace economic services--for example, using green infrastructure to replace grey infrastructure, or benefiting from wetlands and ecological services in place of canals and combined sewer overflow tunnels.

Dr. Fiksel also discussed the concept of changing the value systems by which decisions are made, policies are established, and governments operate, as well as changing the values consumers use to make purchase decisions.

In addition, Dr. Fiksel discussed an example of sustainability management, a project sponsored by EPA to develop a system dynamics approach to addressing the problem of nutrient pollution in Narragansett Bay. Through this project, Dr. Fiksel and his colleagues developed a software tool that uses a dashboard view to assess the impact of various policy options on the future of the Bay; the tool uses the triple value model to assess social, environmental and economic impacts, as well as possible opportunities to make this region more resilient.

Planning Committee: Thomas Graedel (Chair) (NAE), Yale University; Ann Bartuska, U.S. Department of Agriculture; and Alan Hecht, U.S. Environmental Protection Agency.

DISCLAIMER: This meeting summary has been prepared by Jennifer Saunders, rapporteur, 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 Diana Bauer, U.S. Department of Energy, 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.

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The National Academies' Science and Technology for Sustainability Program (STS) in the division of Policy and Global Affairs was established to encourage the use of science and technology to achieve long-term sustainable development. The goal of the 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 concentrates on activities that are cross-cutting in nature and require expertise from multiple disciplines; important both in the United States and internationally; and effectively addressed via cooperation among multiples sectors, including academia, government, industry, and non-governmental organizations (NGOs).

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