MEETING SUMMARY

JAPAN-U.S. WORKSHOP ON SUSTAINABLE ENERGY FUTURES

Science and Technology for Sustainability Program
Washington, D.C. * June 26, 2012

The earthquake and subsequent tsunami that hit northern Japan on March 11, 2011, led to extensive damage at the Fukushima Daiichi Nuclear Power Plant, the release of dangerous levels of radiation into the surrounding areas, and national power shortages. These events called into question the role of nuclear power as a primary source of energy, and they brought Japan to a crossroads in developing new ways to meet its need for energy security and maintain its economic vitality while promoting sustainable long-term development. While different in scale and immediacy, these challenges are also present in the United States.

The National Research Council's Science and Technology for Sustainability Program hosted a joint Japan–U.S. workshop on sustainable energy futures on June 26, 2012, in conjunction with the spring meeting of the Roundtable on Science and Technology for Sustainability, to examine energy sustainability strategies and better understand how sustainable energy futures can be achieved. The workshop included participants from federal agencies, academia, the private sector, and nongovernmental organizations involved in sustainability issues in Japan and the United States. The one-day workshop examined the strategies, research and technology needed to achieve sustainable energy solutions in both countries. Workshop participants identified possible priorities for sustainable energy research and discussed areas for future collaboration between the two countries.

Several themes were voiced by many participants during presentations[1] and discussions at the workshop. These were summarized by **Marilyn Brown** of the Georgia Institute of Technology and **Mary Neu,** formerly of the U.S. Department of Energy (DOE):

- Disruptions in energy systems have caused the reassessment of sustainable energy futures in both Japan and the United States.
- Japan is in the final stage of revising its current *Basic Energy Plan* and is considering a future energy mix with nuclear energy ranging from 0 to 35 percent. Goals for renewable energy resources and energy efficiency are high in both countries.
- There is a stronger recognition that disasters are occurring with increasing frequency and that the resiliency of energy systems is increasingly important.
- Both countries are grappling with the fragmentation of science and technology funding and the challenge of transferring research into production to help meet clean energy goals. Japan–U.S. research collaborations are strong, and there are opportunities to expand them in many areas, including carbon capture and storage, nuclear energy, materials, unconventional gas, and reshaping innovation systems to meet societal challenges.

[1] Speakers' presentations are available at http://sites.nationalacademies.org/PGA/sustainability/PGA_070400.

GLOBAL TRENDS IN SUSTAINABLE ENERGY DEVELOPMENT

Naoya Kaneko, fellow in the Center for Research and Development Strategy (CRDS) at the Japan Science and Technology Agency (JST), set the stage for the workshop by outlining recent trends in sustainable energy development in Japan, Germany, the United Kingdom, and France. A starting point for Japan's energy research strategy is the *Third Science and Technology Basic Plan*, introduced in 2006 by the Council for Science and Technology Policy (CSTP),[2] which set priorities for Japan's energy research. In 2007 the Cabinet Office announced *Cool Earth 50*, a plan that sets a target for cutting the nation's greenhouse gas (GHG) emissions in half by 2050. In 2008 the Ministry of Economy, Trade and Industry (METI) issued the *Cool Earth Energy Innovative Technology Plan*, which included 21 categories for prioritized technology innovation. In 2010 METI also announced the current version of the *Basic Energy Plan*, which projected a large share of nuclear energy (53 percent) as well as a substantial increase in renewable energy (21 percent) by 2030.

Mr. Kaneko discussed three developments that resulted from the March 2011 earthquake and tsunami. Electricity generated from fossil energy sources increased from 61.8 percent in 2010 to 78.9 percent by the end of 2011, while electricity from nuclear sources decreased from 28.6 to 10.7 percent during the same time period, according to the Federation of Electric Power Companies of Japan; METI introduced the Feed-in Tariff Scheme for Renewable Energy; and METI also announced a draft new *Basic Energy Plan*. According to the new plan, in 2030 renewable energy is projected to account for 25 to 35 percent of total energy generated and nuclear energy from 0 to 35 percent; CO_2 emissions are projected to range from 33 percent under to 5 percent over their 1990 levels (Table 1).

Table 1: A Draft for New Energy Basic Plan / Electricity Generation

		Energy Source (%)						Electricity Generation (10^{12} kWh)	CO_2 emission in comparison with 1990 (%)
		Renewables	Nuclear	Coal	LNG	Oil	Cogeneration		
2010 / Actual		11	26	24	27	9	3	1.1	+25
2030 / Current Plan		20	45	11	12	4	8	1.2	-27
2030 / Revised Plan	Ref. 1	25	35	16	3	4	15	1.0	-33
	Case 1	25～30	20～25	21	8	4	15		-15
	Case 2	30	15	23	11	4	15		-8
	Case 3	35	0	24	17	6	15		+5

SOURCE: Presentation by Naoya Kaneko, JST, June 26, 2012, adopted from the 27th Meeting of Fundamental Issues Subcommittee, Advisory Committee for Natural Resources and Energy, Ministry of Economy, Trade and Industry.

Based on CRDS's Global Technology Comparison (G-TeC) Survey, Mr. Kaneko compared Japan's energy vision with that of the United Kingdom, France, and Germany. In June 2010, the United Kingdom issued *2050 Pathways Analysis*, illustrating six pathways to energy sustainability, including one option in which no new nuclear plants are built. France introduced *Energy 2050* in February 2012, outlining four options for its nuclear system. Germany issued *Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply* in September 2010, developing its overall strategy for sustainable energy by 2050. Germany plans to achieve its energy mix for electricity generation—80 percent renewable energy and 20 percent fossil fuels—by 2050 and reduce its GHG emissions by 90 percent, relative to 1990 levels. Prior to Fukushima, Germany planned for nuclear energy to serve as a bridging technology from current to future energy systems; however, following the accident, the country decided to eliminate nuclear energy after 2022. Wind energy will serve as a bridging technology instead, with offshore development being key.

In Japan, Germany, the United Kingdom, and the United States, fossil fuels are the primary source for electricity generation, with nuclear fuel being secondary. France, however, uses a much higher ratio of nuclear energy relative to fossil fuels. Mr. Kaneko suggested Germany as a unique example for Japan because renewable energy now accounts for 20 percent of Germany's electricity generation, having increased from 6.7 percent in 2001. He further noted that renewable energy development has been an important source of jobs in Germany, where the renewable energy industry had created 367,400 jobs by 2010.

Marilyn Brown, professor in the School of Public Policy at the Georgia Institute of Technology, discussed recent trends in sustainable energy development in the United States. Energy demand is growing more slowly in the United States than in the rest of the world because of higher demand in fast-growing industrialized nations such as

[2] CSTP is a special policy council of the Cabinet Office established in January 2001.

China and India. The United States currently consumes almost 25 percent of global energy production but is projected to consume less than 10 percent in 2100. At the same time, the U.S. green-clean technology economy is growing. Between 2009 and 2035, the amount of U.S. electricity generated by renewable sources is expected to increase from 10 to 14 percent, while the amount generated by coal is expected to decrease from 45 to 43 percent.

Dr. Brown described the U.S. government's current goals for sustainable energy, including reducing energy-related GHG emissions by 17 percent by 2020 (83 percent by 2050); providing 80 percent of U.S. electricity from clean energy sources by 2035; improving the energy efficiency of commercial buildings by 20 percent by 2020 (Better Buildings Initiative); and reducing the cost of solar energy systems by 75 percent between 2010 and 2020 (SunShot Initiative). To address these ambitious goals, DOE's *Quadrennial Technology Review* (2011) outlined 18 technology requirements for a sustainable energy future mapped to six strategies (Figure 1). Energy needs are increasingly linked to energy, climate, health, and air quality and goals for improving them. Areas where significant technological advances could be made include building and industrial energy efficiency, grid modernization, and clean electricity.

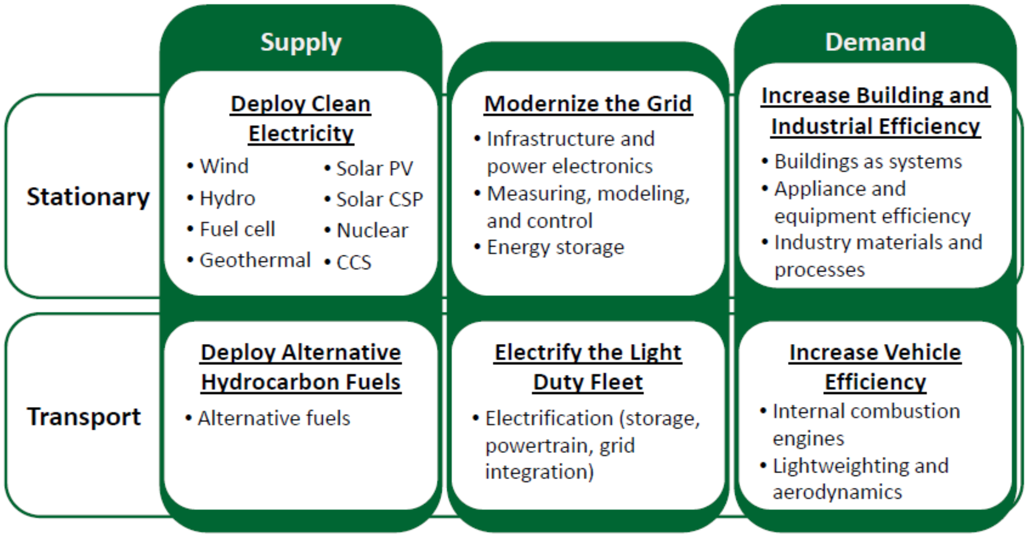

FIGURE 1: Eighteen technology assessments mapped to six strategies
SOURCE: Presentation by Marilyn Brown, Georgia Institute of technology, June 26, 2012, adopted from the U.S. Department of Energy Quadrennial Technology Review (2011)

Energy efficiency has been the United States' most effective energy-saving strategy over the past thirty years, but more could be done, Dr. Brown noted. Lighting, better LED performance, and systems integration, such as the Climate Master Launches Trilogy (which integrates heating, cooling, and hot water in one system) offer significant savings opportunities. Similarly, combined heat and power (CHP) systems can improve efficiency by 30 percent, though there are policy obstacles. Moreover, in developing clean electricity, five new nuclear power plants are currently under construction—two in South Carolina, two in Georgia, and one in Tennessee.

The U.S. electrical grid needs to be modernized, and a smart grid would provide better connectivity and improve the reliability of electrical systems, Dr. Brown said. Natural gas is becoming a bridge to a sustainable energy future in the United States. According to the Energy Information Administration's data on the U.S. natural gas supply, shale gas is expected to grow in the next several decades, leading to reduced net imports and possibly challenging the development of renewable energy technologies. An investment in clean energy could also generate more jobs, and policies could motivate businesses to focus more of their resources on clean energy systems. A policy-making framework would need to take into account social costs and benefits as well as consumer behavior.

Science and Technology Policies Related to Sustainable Energy

Tateo Arimoto, director general of JST, described the transformation of the global energy system from a socioeconomic perspective. Given the globalization and modernization Asia experienced over the past twenty years, there is a strong capacity for both technological and social innovation. Japan's potential for renewable energy is promising, because each prefecture in Japan has a strong interest in promoting sustainable energy.

As the innovation horizon expands, science and technology policy also needs to change, said Mr. Arimoto; thus, it is important to redesign science and innovation systems locally, nationally, regionally, and globally. In Japan the *Science and Technology Basic Plan* is drawn up every five years, based on the Science and Technology Basic Law enacted unanimously in 1995. The *First Basic Plan* (FY 1996-2000), the *Second Basic Plan* (FY 2001-2005) and the *Third Basic Plan* (FY 2006-2010) were based on four principles: life science; information and communication technology; environment; and nanotechnology. The government made considerable changes to the *Fourth Basic Plan* (FY 2011-2015), which was announced in 2011 after the earthquake and tsunami disaster. The plan is focused on three pillars: recovery and reconstruction; green innovation and life innovation; and system reform. The fourth plan also emphasizes bridging science and society, encouraging public participation, and enhancing science and risk communication in light of a growing distrust of science among the public.

Mr. Arimoto stressed the need for redesigning "national innovation systems" or research funding systems to bridge science and society. In particular, Japan's three major funding agencies, including the Japan Society for the Promotion of Science (JSPS), which supports blue sky fundamental research; JST, which supports mission-oriented basic research; and the New Energy and Industrial Technology Development Organization (NEDO), which supports R&D prototype demonstration, need to be well connected to effectively coordinate their research activities.

"Science and technology policy in the twenty-first century needs to focus on well-being and quality of life; safety, security and social cohesion; and sustainability and resilience in addition to traditional values, such as profit, competitiveness, and growth."
Tateo Arimoto, JST

Mamoru Tanaka, chief engineer of the Mitsubishi Heavy Industries' (MHI) Technology and Innovation Headquarters, provided an industry perspective on Japan's research and technology for sustainable energy. MHI's net sales consist mainly of power systems (34 percent of sales), machinery and steel structures (19 percent), and aerospace (16 percent). Dr. Tanaka noted the importance of energy security, environmental protection, and sustainable economic growth for moving toward a sustainable energy system and developing key technologies. Technologies that support environmental protection include flue gas treatment systems and carbon-dioxide capture and storage. MHI, in partnership with U.S. Southern Company, launched the world's largest system for recovering CO2 from flue gases produced at a coal-fired thermal power plant at Plant Barry, Alabama. Additionally, technologies that support sustainable economic growth are important, including those that could help decentralize and stabilize the energy system, such as the lithium-ion battery energy storage system.

As Japan tries to recover from the damage caused by the 2011 earthquake and tsunami, the country will face the challenge of developing a social, environmental, and economical energy system, Dr. Tanaka said. Partnerships and collaborations with industry, academia, and the government will play a crucial role in improving energy efficiency, expanding renewable energy use, operating nuclear power plants with effective safety measures, diversifying energy sources, and identifying the optimal mix of energy technologies.

Henry Kelly, senior advisor to the director at the White House Office of Science and Technology Policy, discussed U.S. science and technology policies related to sustainable energy. Innovation is needed to help achieve energy productivity, which helps drive economic development. Dr. Kelly's presentation focused on the following points:

- *Buildings*. Lighting (which accounts for 18 percent of all electricity used), integrated heat pumps, and smart grids offer potential for energy efficiency; however, both existing and new buildings face challenges in financial regulatory environments. It is essential that financial markets consider the value of these investments.
- *Transportation*. Competition is expected in both fuel efficiency and vehicle types in the next 20 years. Vehicle electrification is a high priority for the administration; however, reducing the cost of batteries—from the current $600 per kilowatt-hour (kWh) to possibly about $200 kWh or $300 kWh—will be necessary for electric vehicles to be cost effective.
- *Manufacturing*. This sector consumes 30 percent of U.S. energy. The White House Advanced Manufacturing Initiatives program supports advances in cheaper batteries, LEDs, and photovoltaic devices.

On the supply side, greater cost reductions will enable renewable energy sources to compete without policy intervention or contingent subsidies. For example, solar energy is expected to be competitive by the end of this decade. Although the United States aggressively promotes wind energy, the cost is still high; both ocean and wind energy experts need to work together on innovative designs, such as ocean engineering combined with advanced blade design and direct drive generators. Dr. Kelly concluded that innovation policies that drive productivity are the key to meeting aspirations for energy sustainability.

Peter Evans, director of the Global Strategy and Planning team at GE Energy, shared his vision of the next decade: building sustainable and resilient systems. Every era has had a different focus: energy security after the oil shocks in 1970s; deregulation in the 1980s; and climate change in the mid- to late-1990s and into the 2000s. The last decade has focused both on mitigation (clean technology) and adaptation (natural disaster management). For the next decade, building sustainable and resilient social, economic, and ecological systems will be imperative in Japan, the United States, and the rest of the world. Resilience is the ability to recover faster after a stress or shock, endure greater stress or shock, and/or minimize the impact of a stress or shock.

Dr. Evans explained that the need for resilience is driven by complex interlinked issues arising from global climate change, including a rapidly expanding built environment, increasing dependence on critical infrastructure, and rising economic damage associated with the impact of natural disasters. According to Munich Re's data on worldwide natural disasters,[3] over 800 events have occurred annually in recent years, including geophysical (earthquakes, tsunamis, volcanic eruptions), meteorological (storms), hydrological (floods, mass movements), and climatological (extreme temperatures, droughts, forest fires) events. This number has more than doubled in the last 30 years, and 12,000 natural disasters are expected worldwide during the next 15 years. The vulnerability of energy infrastructure is evident from recent natural hazards, including Hurricane Katrina (2005), the heat wave in Europe (2006), and the Japanese earthquake and tsunami (2011).

Resilience assessments are important in measuring a system's performance. Japan's oil-fired power generation capacity, which has often generated controversy due to its aging facilities, actually provided resilience in the power system after the earthquake and tsunami, preventing more severe blackouts. Dr. Evans expressed concern about urban agglomerations; more people now live in cities than in rural areas, and megacities need large energy systems. Building resilient energy systems with the capacity to absorb shocks, adapt to changing conditions, and restore electricity after a disruptive event will be vital for a sustainable future.

Japan and the United States are well positioned to lead in this area, said Dr. Evans; both counties face sustainability and resilience challenges due to multiple hazards, have private sectors with significant capacity to develop products, and have highly respected national research and technology capabilities. The next steps would be advancing research on the synergies and trade-offs associated with achieving energy system sustainability and resilience; identifying a suite of technologies and services that could strengthen sustainability and resilience; and recommending policy and institutional developments that advance these goals.

Toward Japan's Sustainable Energy Future

Kazuhiko Ogimoto, professor at the University of Tokyo's Collaborative Research Center for Energy Engineering, discussed energy system integration. Dr. Ogimoto examined Japan's future energy scenarios out to 2030, calculating likely costs and CO_2 emissions under four nuclear scenarios.[4] The analysis indicated that even with greater use of solar- and wind- based power generation, reduced nuclear energy generation will cause a substantial rise in fuel costs because of increased demand for coal, natural gas, and oil. In Japan's future energy system, the increased variability of renewable energy generation will raise the possibility of an imbalance between supply and demand, Dr. Ogimoto stated. To illustrate, there is more than a 100-gigawatt difference in the electricity supplied by a photovoltaic source at noon on a clear day than on a rainy one.

In order to reduce the imbalance between demand and supply economically and reliably, Dr. Ogimoto stressed the need for improved capability and operation of traditional power plants; total demand response (e.g., day-ahead scheduling and real-time control); energy storage devices such as batteries and heat pump water heaters; and operation enhancement by forecasting for renewable energy generation. In particular, he encouraged demand activation using distributed Home/Building Energy Management Systems (HEMS/BEMS), which automatically control demand and energy storage. These systems enable the maximum use of renewable energy and the harmonization of centralized and decentralized energy management, enhancing the capacity to balance demand and supply. For this reason, the value of HEMS/BEMS will be realized in fields beyond energy.

Dr. Ogimoto stressed that for energy systems to be sustainable, they need to be developed based on multiple criteria—economics, stability, fuel prices, environmental constraints, technology development, and socioeconomic conditions. Sustainable energy systems depend on broad and long-term perspectives, including research and development, deployment of technology, and human development.

[3] Munich RE. 2012. Natural catastrophes worldwide 1980-2011: Number of events with trend. Available at http://www.preventionweb.net/files/24476_20120104munichre.pdf. Accessed September 14, 2012.
[4] The four scenarios included: 1) reference scenario under the current Basic Energy Plan; 2) continuation of nuclear development (existing plants demolished in 40 years under 2b); 3) suspension of nuclear development (nuclear eliminated in 40 years under 3b); and 4) abolition of nuclear within 5 years (aggressive thermal development under 4b and aggressive PV and wind development under 4c). Scenario 1 assumed 53 GW PV and 10 GW wind; scenario 2a to 4b assumed 80 GW PV and 28 GW wind; and scenario 4c assumed 160 GW each of PV and wind.

Nobuhide Kasagi, principal fellow at JST/CRDS and Japanese government delegate for the Organization for Economic Co-operation and Development (OECD) Committee on Science and Technology Policy, discussed research and development strategies for green innovation. In order to stimulate nationally focused research and development, CRDS prepares strategic proposals on research and development investment, priority settings, and systems reform for government organizations, such as CSTP, METI and MEXT (Ministry of Education, Culture, Sports, Science and Technology). CRDS tries to integrate scientific "3Cs"—collection, connection, and convergence—with societal goals and design issue-driven research.

Dr. Kasagi described how CRDS' strategic proposals focus on the following areas: energy, environment, economy, and ethics; short-term, mid-term, and long-term research goals; basic scientific rules and principles; cross-disciplinary collaboration; and collaborations among industry, academia, and government with the participation of young researchers. When planning strategic research on advanced energy technologies, CRDS considers the relevance of energy technologies by linking science to innovation, economic growth, and social welfare. Consequently, CRDS produced the following strategic research themes:

- science for energy policy;
- phase interface science for efficient energy utilization;
- energy carriers[5] for transportation, storage, and utilization of renewable energy;
- analysis and control of ions and electrons in battery electrodes;
- advanced technology development for medium- to low-temperature thermal energy;
- technology and system development to enable use of offshore natural energy resources; and
- sustainable nitrogen circulation.

Dr. Kasagi emphasized the need for scientific evidence and methodologies as they move forward with these new technologies. He also stressed that there are many gaps to be filled between Japan's basic and applied research; among scientific disciplines; among industry, business, research laboratories, and universities; between government ministries and funding agencies; and among scientists, engineers, administrators, and society. Currently, each public funding agency runs independently without consolidated efforts; Japan needs a Network of Excellence to consolidate these efforts (Figure 2).

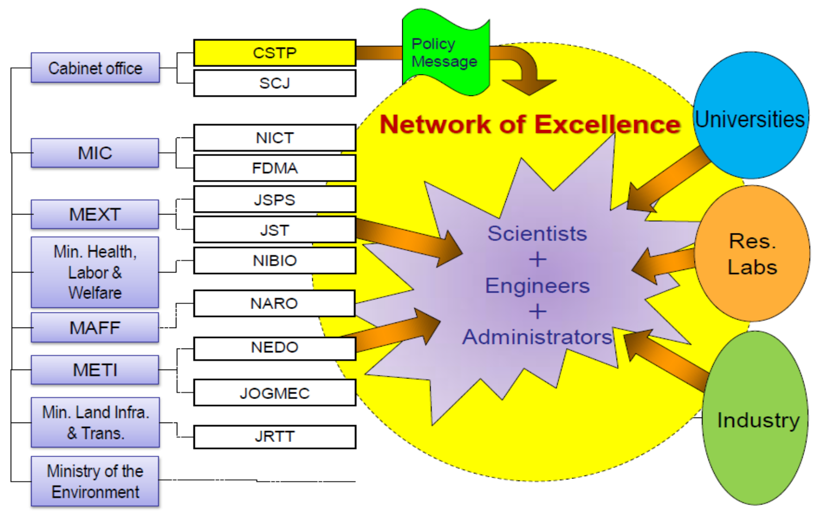

FIGURE 2: Consolidated Funding Schemes
SOURCE: Presentation by Nobuhide Kasagi, JST, June 26, 2012.

Kohei Uosaki, coordinator for Japan's National Institute for Materials Science (NIMS), described the country's funding for renewable energy research. METI has one funding agency (NEDO) and MEXT has two (JST and JSPS). NEDO's funding programs are based on the *Cool Earth 50 Energy Innovation Technology Plan*, introduced by METI in 2008. In addition, independent administrative institutions, such as the National Institute of Advanced Industrial Science and Technology, are supported by METI, while the Institute of Physical and Chemical Research and NIMS are supported by MEXT. To support research on energy-related technologies, CSTP initiated the Funding Program for World-Leading Innovation R&D on Science and Technology in 2009.

Describing these funding institutions' major initiatives on renewable energy technologies, including photovoltaic, electrical energy storage, fuel cell/hydrogen, biomass, and wind energy, Dr. Uosaki said that NEDO's renewable energy funding is five or six times more than that of MEXT. While NEDO's energy and environment division is responsible for these activities, energy funding has not been coordinated in MEXT. Among recent MEXT efforts are the creation of the Program for Development of Environmental Technology Using Nanotechnology and the Global Research Center for Environment and Energy based on Nanomaterials Science (GREEN), where Dr. Uosaki is responsible for its battery and fuel cell division. MEXT recently set up a new environmental energy division, and Dr.

[5] For more information on energy carriers, see Intergovernmental Panel on Climate Change (IPCC). 2007. IPCC Fourth Assessment Report: Climate Change. Available at http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch4s4-3-4.html. Accessed September 14, 2012.

Uosaki expressed hope that energy-related research will now be more consolidated within the agency. While CSTP is not playing an important role in organizing research efforts among ministries, METI and MEXT plan to hold a joint discussion meeting on energy research.

TOWARD A SUSTAINABLE ENERGY FUTURE: U.S. PERSPECTIVE

Robert Socolow, professor of mechanical and aerospace engineering at Princeton University, discussed opportunities for collaboration on nuclear energy and a low carbon energy system. He suggested three areas for collaboration on nuclear energy: risk reduction and cleanup at Fukushima; waste management with dry casks; and the fuel cycle and nuclear weapons proliferation. “After-heat”—a fire that cannot be extinguished—is a potential concern associated with the cleanup at Fukushima. Greater use of dry cask storage for nuclear waste would have resulted in less severe damage at the plant. Because both uranium isotope enrichment and spent-fuel reprocessing to recover plutonium are routes to nuclear weapons, nuclear energy will not become a safe global energy source until much stronger international institutions are developed to govern nuclear energy fuel cycles in all countries.

Dr. Socolow discussed opportunities for collaboration around low-carbon energy systems:

- *Climate change science*. The relentless rise of the atmospheric CO_2 concentration has been observed by the Mauna Loa Observatory in Hawaii, while arctic monthly averages exceeded 400 parts per million in April 2012. Each year, four tons of CO_2 on average are emitted per person globally, which is equivalent to driving 24,000 km/year and lighting 300kWh/month with coal or 600kWh/month with natural gas.
- *Measurement and evaluation of efficient energy use*. There are opportunities for improving energy efficiency in buildings, air conditioning, and transportation. Expanding the efficient use of electricity (e.g., variable-speed-drive motors, cogeneration, and efficient lighting) presents a complex combination of research and behavioral challenges.
- *Power plant retirement*. Grandfathering, retirement, relicensing, retrofits, and repowering of coal-fired power plants are key issues.
- *Low-carbon fossil energy*. Fuel switching (from coal to gas) and carbon capture and storage offer many opportunities. Research programs in the United States and Japan are also exploring pre-combustion with gasification, post-combustion from smoke stacks, oxy fuel, and metal oxide looping.
- *Renewables*. The importance of solar thermal will grow along with advances in wind and photovoltaic technology.

Bobi Garrett, deputy director in the Strategic Programs and Partnerships office at the National Renewable Energy Laboratory (NREL), discussed research and technology needs for sustainable energy development in the United States. A profound transformation will be required to shift from today’s energy system to a sustainable energy system. In 2011, renewable energy provided about 25 percent of electricity generation worldwide,[6] while global investment in clean energy rose to $260 billion. NREL recently released the comprehensive study *Renewable Electricity Futures Study (RE Futures)*,[7] which examines the implications and challenges of increasing renewable electricity generation (between 30 and 90 percent of the U.S. energy supply) in 2050. Ms. Garrett described four key findings from this study:

- Renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, could supply 80 percent of total electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the country.
- Increased flexibility in the electric system is needed to enable balance in electricity supply and demand with high levels of renewable generation. This flexibility can come from a portfolio of supply- and demand-side options, including conventional generation, grid storage, new transmission, more responsive loads, and changes in power system operations.
- The abundance and diversity of renewable energy resources would result in the reduction in electric sector GHG emissions and water use.
- The direct, incremental cost associated with renewable energy generation and published cost estimates of other clean energy scenarios are comparable. Reducing the cost as well as improving performance of renewable technologies are vital.

Ms. Garret said that renewable energy research can contribute to our understanding of resource availability; identify ways to reduce capital costs through policies, such as feed-in tariffs or a Renewable Portfolio Standard; and ensure sustainability by making renewable energy complementary to nuclear and fossil resources. She stressed the

[6] 1360 GW of global renewable power capacity includes 238 GW of wind capacity and 70 GW of solar.
[7] A full report is available at /www.nrel.gov/docs/fy12osti/52409-1.pdf

importance of systems integration research for transforming the U.S. electricity infrastructure. Currently, key system challenges include improving the overall efficiency of the energy system, integrating and operating new technologies within existing infrastructure, engaging consumers, and tailoring solutions to local parameters. In an effort to address science-based approaches to systems, DOE is completing construction of the Energy Systems Integration Facility at NREL, one of the only megawatt-scale test facilities in the country that explores integrated energy systems, devices, and concepts for electric supply and demand systems.

William Brinkman, director of DOE's Office of Science, said that there is a broad consensus on the need for scientific research to support major changes to the energy system.[8] The Office of Science focuses on research, laboratory stewardship, and user facilities. While a large amount of DOE's budget is devoted to the weapons activities and environmental management, science ranks third in the overall budget. He explained that the Office of Science research portfolio includes basic energy sciences, advanced scientific computing research, biological and environmental research, fusion energy sciences, high energy physics, and nuclear physics. In addition to its core research are the 46 Energy Frontier Research Centers, established in 2009 to focus on fundamental research related to energy; and the Energy Innovation Hubs, research centers for integrating basic and applied research with technology development to support transformational energy innovations.

A new focus area for the Office of Science is Science for Clean Energy—applying 21st century science to remove long-standing barriers in energy technologies by employing nanotechnology, biotechnology, and modeling and simulation. The initiative supports the discovery and design of novel materials using nanoscale structures and synthesis for carbon capture, radiation-resistant and self-healing materials for the nuclear reactor industry, highly efficient photovoltaics, and white-light-emitting LEDs. Advances in science increasingly require greater data sharing, access to research facilities, and larger, more complex, and higher cost experiments. The Office of Science leverages international collaborations by establishing legal frameworks, facilitating the mobility of scientists, and joining large-scale international projects such as the U.S. ITER.

In the concluding session, Dr. Neu briefly summarized themes emerging from the speakers' presentations and discussion. She emphasized the importance of sustainable and resilient energy systems and the possibility of future collaborative activities on nuclear energy, materials, and innovation systems that can meet societal challenges.

Planning Committee: Thomas Graedel (NAE) (Chair), Clifton R. Musser Professor of Industrial Ecology, Yale University; Mary Neu, Former Chief Scientist, Environmental Management, U.S. Department of Energy; and Llewelyn Hughes, Assistant Professor of Political Science and International Affairs, Elliott School of International Affairs, George Washington University.

DISCLAIMER: This meeting summary has been prepared by Emi Kameyama and Dominic Brose, rapporteurs, 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 Martin Green, National Institute of Standards and Technology, 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.

[8] National Research Council. 2009. America's Energy Future: Technology and Transformation. Washington, DC: National Academies Press.