MEETING SUMMARY

SUSTAINABLE ENERGY AND MATERIALS
Assessing the Landscape

SCIENCE AND TECHNOLOGY FOR SUSTAINABILITY PROGRAM
BOARD ON ENERGY AND ENVIRONMENTAL SYSTEMS
JUNE 27, 2012

According to Chu and Majumdar (2012),[1] "the world needs another industrial revolution in which our sources of energy are affordable, accessible and sustainable. Energy efficiency and conservation, as well as decarbonizing our energy sources, are essential to this revolution." As the United States is the largest global consumer of energy and of many materials used in traditional and advanced technologies, any such transition in the power system would involve massive infrastructural upgrades requiring an abundance of materials that are beyond our current capacity without significant technological and social adaptation and innovation.

Many in both the public and private sectors recognize the need to identify and develop sustainable sources of energy and materials. Both the federal government and the private sector have increased funding for research and development to begin to address this need. Within the federal government, several agencies have expanded their focus on sustainable energy, including the Department of Energy (DOE), Department of Agriculture, Department of Defense (DOD), Environmental Protection Agency (EPA), and the National Science Foundation (NSF), among others. This increased investment in sustainable energy research and development by the federal and private sectors has intensified the need for transparent and strong collaboration and extensive leveraging of research dollars in this area.

On June 27, 2012, the National Research Council's (NRC) Science and Technology for Sustainability Program, in collaboration with the Division on Engineering and Physical Sciences' Board on Energy and Environmental Systems (BEES), convened a meeting of technical experts in private industry and representatives from government and academia to discuss the future of the energy grid and the potential for a transition to a sustainable energy future. The primary goals for this meeting were to assess the current state of the sustainable energy landscape and identify key policy, research, and technological gaps.

[1] Chu, S. and A. Majumdar. 2012. Opportunities and challenges for a sustainable energy future. *Nature* 488:294-303.

Many participants expressed the following ideas at the meeting:

- Achieving a sustainable energy future requires significant social consensus, which may be enhanced by policy decisions.
- Though many technological options exist to develop a low-carbon-emission grid, cost is a major barrier to deployment.
- The low cost and abundance of natural gas has delayed deployment of carbon-free electricity.
- A transition to a clean electrical grid would require significant adaptation by the utility sector.

Thomas Wilbanks of Oak Ridge National Laboratory (ORNL) stated that energy sustainability involves two related concerns: the sustainability of energy supply and use, and the relationship between this energy trajectory and sociopolitical goals for development. A broader social context is necessary to define sustainability so that service is adequate, affordable, abundant, and reliable, and so that sustainability is integrated with other systems. The linkages between society's different systems need to be robust and sustainable, even in the context of disruptions such as extreme weather events and terrorism. The relevant question is: Is there sufficient infrastructure to produce, deliver, and innovate?

Accelerating technological change through innovation appears to be an essential part of creating a sustainable energy system, said Dr. Wilbanks. A recent analysis at ORNL concluded that meeting the nation's dual goals of climate protection and energy security requires a high probability of success for all energy technologies considered.[2] Therefore, a major issue is how to promote not just incremental change but new discoveries that have the capacity to revolutionize technology. There is a growing sense of urgency about transformational change in the energy sector, including some calls for a national commitment comparable to the Apollo Program or Manhattan Project.

Such a national commitment may be difficult given the current lack of social agreement to transition to a sustainable energy grid. Some energy sectors, such as nuclear power, have been struggling with the perception of risks associated with electricity generation. This was reaffirmed by **William Ostendorff** of the United States Nuclear Regulatory Commission (USNRC), who pointed out that a country's belief in the safe use of nuclear power is directly proportional to its trust in the regulators responsible for overseeing the industry. Evidence of this relationship can be seen in the downturn in public acceptance of nuclear power in Japan after the Fukushima Daiichi nuclear disaster. Engaging the public at an early stage of technology development can help enhance consensus; such conversations help mitigate the perceived risks of novel technologies.

Even with widespread agreement, transitioning to a sustainable energy future is a difficult task, said Dr. Wilbanks. Certain social systems are not designed for rapid change. However, recognition of complementary partnerships can help mobilize significant resources after identifying areas that have net benefits for all parties. Furthermore, recognizing intertwining goals can be a way to improve public consensus for change, such as the link between energy security and sustainable energy.

One energy technology at the center of many of these concerns is nuclear power. In the wake of the Fukushima Daiichi disaster, concerns over safety of nuclear plants, both domestically and internationally, are at an all-time high. However, Mr. Ostendorff noted that a recent USNRC report reaffirmed that there was no reason to shut down any plants in the wake of Fukushima and that the continued operation of U.S. nuclear facilities poses no imminent safety risk.[3] The task force responsible for that report did note a number of areas in need of improvement, which the USNRC will be addressing over the next five years, such as equipment for spent fuel pools to improve reliable cooling in case of fires, explosions, and flooding.

Nuclear plants provide 20 percent of generated electricity in the United States and are mostly concentrated in the East due to the region's density of energy consumption and access to cooling water. While there has been little development of nuclear power since the

[2] Greene, D. L, P. R. Boudreaux, D. J. Dean, W. Fulkerson, A. L. Gaddis, R. L. Graham, R. L. Graves, J. L. Hopson, P. Hughes, M. V. Lapsa, T. E. Mason, R. F. Standaert, T. J. Wilbanks, and A. Zucker. 2010. The Importance of Advancing Technology to America's Energy Goals. *Energy Policy* 38(8):3886-3890.

[3] United States Nuclear Regulatory Commission. 2011. Recommendations for Enhancing Reactor Safety in the 21st Century—The Near-Term Task Force Review of Insights from the Fukushima Dai-Ichi Accident. Rockville, MD: U.S. Nuclear Regulatory Commission.

Three Mile Island accident, six units are currently under construction and are expected to come online by 2018, and ten permits have been filed with the USNRC for the construction of another 16 units. Increasing power outages in Texas and the effect of the San Onofre closure on California's electricity generation capacity reveal a substantial energy demand that could enhance interest in nuclear power. The current level of permitting is only sufficient to replace nuclear reactors that are going offline and will not result in a significant increase in the fraction of total generation from nuclear power.

Despite the widespread interest in nuclear power, however, Mr. Ostendorff noted that a number of licenses granted have been suspended at the request of the business units that submitted them due to business and economic concerns. The upfront cost barriers of a nuclear power plant are sufficiently high that the legacy costs of these plants could inhibit moving forward with construction in the face of economic uncertainty.[4] Furthermore, the plummeting price and sufficient abundance of natural gas offers a low-cost alternative energy source for utilities looking to expand their generation capacity. Small modular reactors (45 megawatt (MW) to 250MW capacity) may offer a lower-cost alternative to the big 1 gigawatt (GW) generating units currently being installed. An added side benefit is that such reactors may provide significant safety upgrades compared to the current generation of reactors.

Cost is not the only barrier facing the expansion of nuclear energy, noted Mr. Ostendorff. With the recent defunding of the Yucca Mountain project, there is currently no long-term storage solution for nuclear waste in the United States. Without this solution, legislation to amend the Nuclear Waste Policy Act may be needed in order to maintain the predictability and stability of federal legislation regarding long-term storage.

Nuclear power is one of the major energy sources needed to achieve a sustainable energy future, but it is not the only source, said **Sam Baldwin** of the Office of Energy Efficiency and Renewable Energy (EERE) within the Department of Energy. Another opportunity for power generation with low greenhouse gas emissions is renewable energy from the sun (both through photovoltaics (PV) and solar thermal), geothermal energy, biomass, wind, and hydropower. Though many of these sources are intermittent, with unpredictable seasonal or daily variations, a recent report from the National Renewable Energy Lab (NREL) found that with current commercial technology and a flexible electrical grid, renewable energy could provide up to 80 percent of the total U.S. energy supply by 2050.[5]

Dr. Baldwin presented five important assumptions made in the report: 1) significant adoption of energy efficiency measures in all sectors, 2) a shift away from fossil fuel-powered vehicles to plug-in electric vehicles, 3) improvements in the electric system to enhance flexibility of both supply and demand, resulting in more efficient integration of variable-output generation, 4) expansion of the transmission infrastructure and access to existing transmission to support renewable energy deployment, and 5) project citing and permitting regimes allowing for renewable electricity and transmission expansion with standard land-use exclusions. Low-demand and high-demand projections were also considered.

[4] According to Mr. Ostendorff, the two reactor units being built in August, GA cost $7 billion each.

[5] National Renewable Energy Laboratory. 2012. Renewable Electricity Futures Study. M. M. Hand, S. Baldwin, E. DeMeo, J. M. Reilly, T. Mai, D. Arent, G. Porro, M. Meshek, D. Sandor, eds. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory. Available at: http://www.nrel.gov/analysis/re_futures. Accessed September 10, 2012.

Demand-side flexibility is a key factor in increasing renewable energy's potential to meet electricity requirements, said Dr. Baldwin. Creating this flexibility would require developments such as thermal storage and dynamic charging of electric vehicles. Conventional generators can be used to fill gaps in electricity generation as well. For renewable energy to penetrate widely, the power system must be highly coordinated across much larger areas than it is today.

The 80 percent Renewable Energy-Incremental Technology Improvement (RE-ITI) scenario (Figure 1) is capable of handling the peak summer load in 2050, said Dr. Baldwin (NREL, 2012). The baseload is largely assumed through increased biomass-based generation and concentrated solar power (CSP), or solar thermal. The temporal nature of PV is visible, and this is then rounded out by gas generators. During low-load situations (such as the spring), these generators are not necessary, and there is a significant overcapacity in the 80 percent scenario leading to a need for curtailment in low-demand situations.

The diversity of renewable energy sources enables such a high-production scenario, Dr. Baldwin continued. Solar energy is most highly concentrated in the Southwest, on-land wind energy in the Midwest (specifically in Tornado Alley), offshore wind in the Northeast, and biomass in the Southeast and Midwest.The variability of a resource in a particular location can be balanced out by another region with a highly-integrated smart grid, which would require significant upgrades to current infrastructure. According to Dr. Baldwin, 110 million to 190 million miles of new transmission lines and annual transmission and interconnection investments of $5.7 billion to $8.4 billion per year would be necessary to reduce congestion and energy losses during transmission and distribution. Further costs are necessary to replace existing generation plants; however, the total costs of the 80 percent renewable energy scenario are comparable to other clean energy and low carbon scenarios evaluated by the Energy Information Administration and the Environmental Protection Agency.

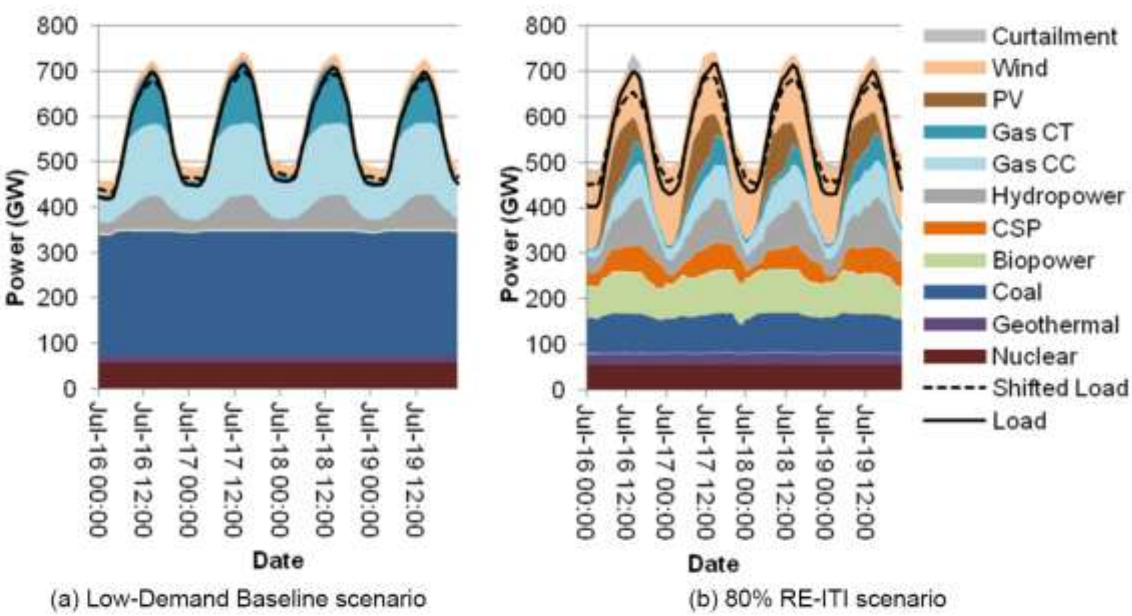

FIGURE1 Renewable Energy-Incremental Technology Improvement (RE-ITI) Scenario
SOURCE: Presentation by Sam Baldwin, U.S. Department of Energy, July 27, 2012, adopted from the NREL Renewable Electricity Futures Study (2012).

Currently, installed renewable energy production is very limited, accounting for 10 percent of total generation. Renewable energy would need to be developed and installed at a much greater rate in order to provide 80 percent of total U.S. generated power. Recent growth in wind has demonstrated sufficient scaleability of renewable energies, but changes in siting practices and regulations may also be necessary to reduce the challenges to scaling up the industry.

One underdeveloped renewable source of electricity is wind power, said **Doug Pfeister,** senior vice president of the Offshore Wind Coalition, who noted that there is over 1 terrawatt (TW) of potential shallow water wind development based on proven technology.[6] Furthermore, while the peak zone for land-based wind is limited mainly to sparsely populated areas in the center of the country, offshore wind offers the potential to bring renewable power to the population centers along the coast.

While the United States currently has no installed offshore wind capacity, Europe already has turbines installed with 3.8 GW capacity, and more permitted with 18 GW capacity. The first offshore wind project in the United States to be installed will likely be Cape Wind, off the coast of Massachusetts, which would have an installed nameplate capacity of 468 MW. Construction could begin as early as 2014. By 2020, projects off New Jersey (1000 MW), Rhode Island (30MW), Delaware (450 MW), Maine (12 MW), and New York (700 MW) could provide over 2 GW capacity.

The biggest barrier faced by the development of offshore wind is the current economic climate, said Mr. Pfeister, citing what he called a “renewable energy tsunami” in the United States. Because of the economic slowdown, demand is down, leading to short-term excess electric capacity and thus lower electric prices. Furthermore, because of the recent boom in natural gas, prices have plummeted, inducing utilities and investors to turn instead to natural gas power plants. A framework is needed to balance competing interests in the ocean (e.g., environmental protection, Coast Guard navigation). But at this point, there is simply no market for offshore wind.

In addition to economic and political challenges, there are technical challenges facing offshore wind, Mr. Pfeister explained. Constructing offshore wind farms often entails building expensive, purpose-built vessels. Bringing these costs down by learning from the oil and gas industry can help, but this construction is still the largest driver of expense for offshore wind farms. For offshore wind to succeed in deeper water (i.e., off the West Coast), the development of a “floating foundation” for wind turbines is essential. Floating technology could solve a number of cost and deployment problems in the coming decades.

In the near term, critical work needs to be done to formulate standards for the industry, Mr. Pfeister said. Coordinating with the International Electrotechnical Commission, the Department of Energy, industry, and other relevant parties will ensure the safe, rapid deployment of offshore wind. They will also need to develop a baseline environmental assessment, as this will both allow the offshore wind industry to streamline the permitting process as well as ensure that they understand the impact of these wind farms. Finally, the deployment of meteorological towers in areas of the highest interest will enable *in-situ*, accurate measurements of the wind resource to help secure funding for these large-scale wind farms.

Karl Rábago, an independent energy consultant and former vice president of distributed energy services at Austin Energy, stated that with the potential shift in power generation to new, sustainable sources as well as a national focus on more efficient energy consumption, utilities are being forced to rethink their business models for the future. There is a need to turn away from the “spin the meter” mentality of the traditional utility model, in which increased demand leads to increases in the amount of power sold and ultimately an increase in profits for the utility. Fixed costs are currently on the rise for utilities, but they are not seeing a concurrent increase in energy sales, and thus profit margins are sliding. Burdened by their legacy investment costs, utilities are resistant to change the way they do business.

[6] National Renewable Energy Laboratory. 2010. Large-Scale Offshore Wind in the United States. Available at: http://www.nrel.gov/wind/pdfs/40745.pdf. Accessed September 5, 2012.

Mr. Rábago sees several major changes that need to occur for utilities to develop a truly sustainable energy plan, including moving from a focus on compliance to prevention; shifting from incremental improvements in services to fully integrated products; improving customer and stakeholder engagement through continuous dialogue; and setting performance-based standards to let consumers dictate how best to meet their needs. By following these steps, it is possible for the energy sector not only to shift from compliance to prevention, but also to continue further, from prevention to true sustainability.

Rene Kleijn of Leiden University, Netherlands, said that moving toward a more sustainable energy future would require significant infrastructure development and that understanding the materials requirements of such a future will be a key component of such a transition. Dr. Kleijn's work focuses on two possible extreme scenarios: the first is a future still based largely on fossil fuels, with a large development of carbon capture and storage (CCS) to limit greenhouse gas emissions and efficiency to further limit use of these fuels; the second is a scenario focused on renewable energy from wind and solar sources.

An energy future with significant CCS would require significant pipeline and well infrastructure, based largely on stainless or specialty steel. For efficiency improvements, this would likely require large volumes of magnesium or other substitutes for lightweight engines as well as significant volumes of rare earth materials for LED and fluorescent lighting.

Energy generation primarily from renewable sources increases the distance between where energy is produced and where it is consumed, said Dr. Kleijn. Additionally, the intermittency of renewable power would require a higher level of interconnectivity and redundancy in the electrical grid, as mentioned by Dr. Baldwin. Such improvements in infrastructure require a significant amount of metal for the cabling and steel for the infrastructure. In terms of the energy sources themselves, wind turbines currently use rare earth metals for a magnet in the generator, while thin film solar cells use a number of other rare elements (cadmium or tellurium). If accompanied by a transition to electric vehicles (EV), rare earth elements will again be used in the motors powering those vehicles. If a fuel cell is used for energy storage on such an EV, then precious metals (platinum, rhodium) will likely be required for the catalyst, and a hydrogen infrastructure would be required. If instead batteries are used, additional rare earths and charging infrastructure will be necessary.

In both scenarios, there are numerous material requirements beyond the energy source. Dr. Kleijn focused primarily on mining and production capabilities. Although copper is typically not considered a critical material, a transition to a global sustainable energy grid could require nearly a quarter of the world's copper reserves. About three times the current annual production of steel, another common material used in building wind turbines, would be needed to produce 15 percent of the world's energy by 2050. The uranium needed for nuclear energy and the nickel needed for magnets used in motors and turbines could exceed the entirety of current levels of production. Rare earth elements needed for wind and solar power represent fractions (1 percent to 5 percent) of what would be required, according to Dr. Kleijn. Such scarcity of critical materials severely inhibits a transition to renewable energy or require significant technological development to move forward.[7]

Nedal Nassar of Yale University observed that beyond the volume of a resource is the question of where it is located. Citing the Herfindahl-Hirschman Index, he noted that many technologically relevant materials can be concentrated in a single country. Developed nations rely on trade to obtain materials for industry, and so there are political concerns that can limit a material's availability. It is necessary to redefine what is meant by "critical" elements, said Mr. Nassar, who offered three main criteria: 1) vulnerability to supply restriction, 2) supply risk, and 3) environmental implications.

A material is considered vulnerable to restricted supply based on how important it is to a country, either as an export or as part of a key technology; whether there are substitutes with equivalent performance; and whether the country is reliant upon imports for its availability, particularly from a single trade partner. The supply risk represents constraints on extraction, whether it is the lack of an independent mining

[7] National Research Council. 2008. Minerals, Critical Minerals, and the U.S. Economy. Washington, DC: The National Academies Press.

infrastructure in the case of mining an impurity (e.g., tellurium in copper) or geopolitical concerns that may affect the country of primary resource. Environmental implications require a cradle-to-grave understanding of the material's lifecycle, including but not limited to concerns about extraction from sensitive areas. By examining these three factors, it is possible to objectively determine the materials most critical to a particular country.

Mr. Nassar cited two ways to mitigate vulnerability to this criticality: use less or find more. One option for using less may be to find substitute materials. As one example, Dr. Kleijn noted a strong research push globally for non-rare earth elements for turbines and motors. Mr. Nassar cited work by General Electric to eliminate the precious metal rhenium in its engines, finding substitutes and improving design characteristics to negate the need for rhenium alloys. Another solution to using less of a mineral is to improve recycling. Dr. Kleijn noted an increasing trend in "urban mining," or recovery of elements from e-waste in urban areas. Mr. Nassar pointed out that there is a greater density of some of these critical elements in handheld electronics than in the rocks currently mined. Recycling is not only limited by the efficiency of the recycling process but also by the need for the end user to choose to recycle.

In addition to using less of a material, it may be possible to find more. Mr. Nassar pointed out that ore grade has been decreasing over time for a number of key minerals. However, new technology may be developed that improves the ability to economically extract these minerals, as has occurred throughout history. Dr. Kleijn pointed out that this situation may limit the size and scalability of future mining operations.

Dr. Wilbanks noted that India and China are going through rapid technological development and are expected to double their energy consumption by 2030—a shift from 10 percent to 25 percent of total global energy consumption. Dr. Kleijn added that developed countries consume significantly more minerals than underdeveloped countries, so economic development in India and China will significantly increase those nations' consumption levels. This will then exacerbate the materials shortages that already exist on the horizon. According to Dr. Kleijn, estimating future scarcity of metals is typically based on current trends in demand. However, solving the climate issue in the next 40+ years will require a rapid transition and increase in material demand.

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

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DISCLAIMER: This meeting summary has been prepared by David W. Cooke and Jennifer Saunders, 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 authors or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, STS, or the National Academies. For more information on the meeting, go to www.nap.edu/sustainability.

The summary was reviewed in draft form by Marilyn Brown, Georgia Institute of 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.

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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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