Exploring Regional Opportunities in the U.S. for Clean Energy Technology Innovation

Insights from University-Hosted Events Held During the Spring and Summer of 2016

Volume 1: Summary Report
October 2016

U.S. DEPARTMENT OF ENERGY

About the Cover

The images on the cover represent regional capabilities and resources of energy technology innovation across the United States from nuclear energy to solar and photovoltaics, and smart grid electricity to clean coal and carbon capture.

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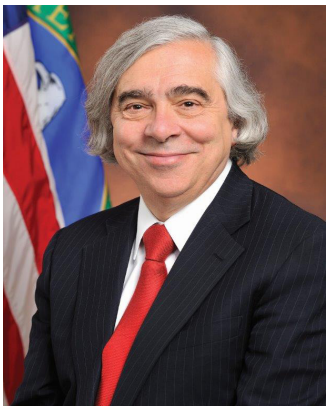
Disclaimer

This volume is one of two volumes and was written by the Department of Energy. This volume summarizes the results of university-hosted regional forums on regional clean energy technology innovation. The report draws on the proceedings and reports produced by the universities noted in Volume 2 for some of its content; as a result, the views expressed do not necessarily represent the views of the Department or the Administration.

Message from the Secretary of Energy



Ernest J. Moniz
Secretary of Energy
U.S. Department of Energy
Washington, DC, USA

The U.S. Department of Energy (Department or DOE) is pleased to present this report, *Exploring Regional Opportunities in the U.S. for Clean Energy Technology Innovation*. The report represents DOE's summary of the insights gained through fourteen university-hosted workshop events held nationwide during the spring and summer of 2016. These events brought together members of Congress, governors, other federal, state, tribal, and local officials, academic leaders, private sector energy leaders, DOE officials, and other stakeholders from economic development organizations and nongovernmental organizations to examine clean energy technology innovation from a regional perspective. In each location, discussion focused on regional energy resources, regional innovation capacity, and regional clean energy technology needs, opportunities and challenges.

Innovation is key to our future low-carbon economy. Roughly half of the growth in productivity in our nation's economy since the middle of the twentieth century has come from innovation. While the United States has significant regional variation in its energy resource base and in its end use energy markets, the linkage between these characteristics and regional clean energy technology innovation has not been fully explored. The development and expansion of regional clean energy technology innovation ecosystems will complement current DOE programs and accelerate the pace of innovation in the United States, spurring economic growth and job creation.

The regional innovation workshop meetings represent an important contribution to this endeavor. At each event, we saw a broad range of new ideas brought forward, each grounded in regional resources and needs. Several technology areas, such as marine and hydrokinetic technology, focused on regionally unique resources and were emphasized in only one or two workshops. More broadly applicable technology areas, such as solar photovoltaics, batteries, fuel cells, carbon capture utilization and sequestration, and materials research, were discussed in several workshops, with unique perspectives offered in each region. Many of the regional workshops identified new, region-specific opportunities to enhance institutional arrangements or improve the mutual leveraging of federal and non-federal resources in ways that promise to accelerate the pace of innovation. The report summarizes—and often directly quotes—the ideas provided by participants.

I want to thank each and every one of the more than 1,700 participants from 37 states and the District of Columbia for their contributions to this dialogue, and the universities that hosted these events. The conversations summarized here offer valuable input for the DOE clean energy technology innovation portfolio planning effort.

Acknowledgement from the Secretary of Energy

I asked my staff to summarize the insights from a series of university-hosted events held across the nation over the past six months to highlight the resources and challenges for clean energy technology innovation in their regions. We were honored to be invited to each of these meetings; I participated in some, and Deputy Secretary Liz Sherwood-Randall, Under Secretary Lynn Orr and other senior Department of Energy leaders participated in others.

The resulting two-volume report, "Exploring Regional Opportunities in the U.S. for Clean Energy Technology Innovation," is the product of dedicated and hard-working team of individuals from across the universities and DOE, including our staff and program offices within the Department and the Chief Research Officers from our national laboratories (NLCROs).

This two-volume report provides a summary of what was learned (Volume 1) and an account of the proceedings from the individual university forums (Volume 2), with the aim of further enabling the sharing of ideas across regions and among policy makers. It draws heavily on the summaries provided by the individual universities and on the expertise of the DOE program and national laboratory representatives who participated in the events.

I thank the team that created and produced this report, very ably led by Kimberly D. Rasar, Associate Deputy Under Secretary for Science and Energy. It was her vision, working as part of, and closely with, a leadership team (with special recognition to Joe Hezir and Melanie Kenderdine) that resulted in what you see here. That leadership team, headed by DOE's Chief of Staff, Kevin Knobloch, also included Lynn Orr, Jetta Wong, Chris King, and Andrew Gumbiner. The DOE authors were Kimberly D. Rasar, Joseph Ayoub, Aurora Edington, Randy Steer, Sam Thomas, Heidi Vangenderen, and Tamara Zelikova. Additional contributors to the report include Thomas Zacharia and Margaret Boone (Bonnie) Nestor from Oak Ridge National Laboratory, Al Sattelberger and Vivian Sullivan from Argonne National Laboratory, Malin Young from Pacific Northwest National Laboratory, Cynthia (Cindy) Powell from the National Energy Technology Laboratory, and Horst Simon from Lawrence Berkeley National Laboratory, with additional review by our staff and program offices and the NLCROs. The Oak Ridge Institute for Science and Education (ORISE) provided exceptional effort in producing the final version of the report.

Of course, I would also like to acknowledge the hard work and foresight of the leadership and staff of universities that conducted what, in retrospect, became a seminal series of events that, I believe, will serve as the basis for fresh thinking around collaborative innovation models. Additionally, I thank our many colleagues and leaders from the U.S. Congress, Governors' offices, other federal, state, tribal, and local offices, industry and non-profit organizations as well as economic development organizations and nongovernmental organizations, along with DOE program and staff offices, for the insights they provided at these events.

Finally, I thank the team (a subset of the report authors and contributors, Carrie Maas, and Georgette Furukawa-Martinez) that coordinated DOE's participation in and reporting on these events, including a webinar that was held on September 29, 2016. I thank the staff of the Secretary, Deputy Secretary, and Under Secretary for Science and Energy for their tremendous effort.

It is my pleasure now to recognize with gratitude all those whose hard work and thoughtful effort are assembled here.

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1 Executive Summary

The research and development (R&D) work underway in the clean energy space is both remarkable and hopeful. In the United States, R&D of new energy technologies is taking place in industry, in colleges and universities, and at the U.S. Department of Energy's (Department or DOE) national laboratories. Cross-sector collaboration among these actors is increasingly evident across an array of technologies as well as at a system and technology integration level. These research collaborations among industry, academia, and the national laboratories were explored on a regional and thematic basis by U.S. colleges and universities during the spring and through the summer of 2016. These events convened stakeholders—including members of Congress, governors, other federal, state, tribal, and local officials, academic leaders, private sector energy leaders, DOE officials, and other stakeholders from economic development organizations and nongovernmental organizations—for strategic discussions about how to overcome challenges and meet regional energy needs to positively impact economic and workforce development through regional collaboration.

DOE heard about the impacts of the changing energy landscape, the tremendous spectrum of robust regional opportunities in clean energy technology innovation, the importance of regional innovation clusters, and technology partnerships to advance market adoption. Furthermore, DOE heard about regional differences and similarities and how to leverage the needs and strengths of specific regions to forge technologies and energy systems for a 21st century low-carbon economy.

Sectors and Systems

Due to the increasing convergence of many energy sectors and integration of systems, huge opportunities exist for understanding, predicting, designing, and controlling integrated energy systems at all levels in transportation and stationary power systems, ranging from the individual or modular level to regional and national scales in a variety of technology areas. The expanding role of hydrogen, natural gas, and biofuels, and electrification in the transportation sector; the transition of the power sector from coal to natural gas and renewables, as well as the modernization of the electric grid; the advances in sustainable fossil energy technologies, including carbon capture, storage, and re-use; and the plans for deployment of small modular nuclear reactors are creating challenges and opportunities for the vast energy infrastructure. Finally, the need for energy efficiency is crucial in both transportation and stationary power systems, and also in industrial applications, which together account for both cost savings and a reduction in carbon emissions in a wide range of technologies.

Areas of Need for Regional Innovation

A wide range of topics, predicated on the regional energy resources, needs, and capabilities, were discussed at the events. See Section 3, Table 1, for the list of topics that range from

clean energy technologies that affect multiple or specific energy sectors, to collaboration, commercialization, and policy. Overarching themes focused on the convergence of integrated energy systems; the increasing diversification of energy resources and infrastructure changes across energy sectors; and the role of scientific facilities and computing that can help accelerate mission innovation and energy efficiency in all sectors of the economy due to the confluence of advances in computing power and software, theory, modeling, synthesis, and characterization that enables "systems by design" for materials, chemicals, and biological science. Regional stakeholders expressed interest in addressing the efficient use of resources linked to energy, including water, agricultural products, land, and rare earth materials. Discussions also included how innovation can make a significant impact on addressing the interdependency of energy, water, and food issues, as well as how coordination and cooperation are vital to develop and execute successful strategies to optimize water utilization and energy use with agricultural irrigation.

A recurring theme in the regional meetings was the need for advances in materials at every stage of the value chain—from innovating new advanced materials to improvements in the way commodities are produced and utilized. Manufacturing was a frequent topic of discussion as it is considered a driver of economic growth and, in particular, a pathway that leverages the unique human resources of regions seeing a downturn in certain industry sectors. Participants agreed with the need to decarbonize the electricity sector and modernize the grid, which is already taking place in their respective organizations and regions. There are huge opportunities and a desire to incorporate more renewables, for both distributed and centralized energy generation, as well as to advance technologies such as energy storage and power electronics.

Collaboration, Commercialization, and Policy

DOE heard about how the differences in energy resources, opportunities for regional collaboration, and the challenges for expanding regional innovation ecosystems require unique commercialization pathways. Workshop participants indicated that market obstacles can limit innovation and impede the transition to a clean energy future and recognized the link between innovation, manufacturing, a diverse workforce, and economic opportunity. Partnerships that leverage public support with private-sector support to encourage industry investment and connect small businesses to resource networks, were highlighted as effective tools for building capacity and sustainable ecosystems. It was recognized that different types of investors are needed at various stages in the innovation cycle and that pathways to commercialization tend to require a range of partners throughout the technology life cycle. This concept is related to the need to develop a shared vision and strategy for regional alignment to leverage the right partners at the appropriate time to commercialize technologies.

One factor frequently raised to encourage technology pathways to the market is better alignment of regulatory frameworks to facilitate energy technology if regions involve multiple states. The general consensus was that effective policy support can assist clean energy stakeholders, R&D performers, and entrepreneurs and investors in commercializing technologies. Stakeholders noted some of the key characteristics to help facilitate technology research, development, demonstration, and deployment (RDD&D) as including public-private partnerships, the need for a strong culture of cooperation within and among regions, educational opportunities, a shared clean-energy "ecosystem" vision, focusing the RDD&D efforts, and exploring new regulatory, business, and finance models.

Key Findings

From the events, it is evident to the Department that clean energy solutions must be tailored to meet regional needs due to the diversity of regional energy resources and needs throughout the nation. It is clear that regional clean energy ecosystems can be created or enhanced by regional partnerships that maximize regional capabilities to effectively address local, regional, and national needs. Advancing clean energy innovation in the United States requires a strategy that builds on the energy infrastructure and markets to meet regional needs. Our universities clearly demonstrate the capability to facilitate the approach for clean energy innovation and partnerships across the nation. This report summarizes key insights from the events based on comments from participants.

2 Introduction

The United States is a partner in Mission Innovation, a landmark commitment to accelerate global clean energy innovation as a means of addressing climate change, making clean energy affordable to consumers, and creating jobs and commercial opportunities. Each of the Mission Innovation partners—20 nations and the European Union—has made a commitment to seek to double its investment in clean energy research and development (R&D) over five years.

The President's FY2017 Budget Request for Mission Innovation spurred interest in regional clean energy technology and innovation across the nation. During April 2016 through September 2016, leading U.S. research universities held regional events to examine the clean energy technology innovation challenges, opportunities, and resources in their regions. In some cases, the conversation also touched on how regional partnerships could be developed and used to accelerate clean energy innovation. As also noted in the report "The Power of Change"[1] (National Academies Press), these events highlighted that a regional approach to clean energy technologies can leverage the broadly recognized strengths of regional innovation, with the drivers to deliver local solutions for sustainable, reliable, affordable energy. The university-hosted events attracted a diverse mix of over 1,700 stakeholders, including members of Congress, governors, leaders from federal, state, tribal, and local governments, industry, U.S. Department of Energy (Department or DOE) national laboratories, academia, economic development organizations, and nongovernmental organizations (NGOs). Agendas for the 14 events, provided in Appendix A, reflect the wide range of energy-related topics that were addressed. Thirteen of the events were focused on clean energy technology innovation, while

U.S. Investment Commitment to Mission Innovation

- Announced by President Obama on February 6, 2016
- Proposes to double federal investment in clean energy R&D
- Increases investment from $6.4 billion in FY2016 to $12.8 billion in FY2021
- Provides as part of the President's Budget Request $7.7 billion for clean energy R&D in FY2017 distributed across 12 federal agencies
- Supports R&D activities ranging from use-inspired basic research to demonstration
- Channels much of the U.S. investment through DOE to support advancing the research, development, and demonstration of a wide range of low-carbon technologies

SOURCE: https://www.whitehouse.gov/the-press-office/2016/02/06/fact-sheet-presidents-budget-proposal-advance-mission-innovation

a fourteenth event held by Tuskegee University focused on Historically Black Colleges and Universities and Advancing Minorities' Interest in Engineering, with an emphasis on science, technology, engineering, and math (STEM) education. A DOE webinar was held September 29 to enable universities that hosted events to share their outcomes.

The purpose of this report is to summarize key discussion points at these events. Each section opens with observations followed by examples (in many cases actual quotes) from various events. DOE is providing insights from these events to further enable the sharing of ideas across regions and among policy makers. The highlights of regional opportunities and challenges can be found in Section 3; Section 4 provides key insights on regional clean energy technology innovation; and Section 5 provides thoughts on moving forward. In addition to this Volume 1 summary, a companion Volume 2 is available that provides a compilation of the individual event reports and notes provided to the Department by many of the universities hosting an event. Volume 1 and Volume 2 can be found at http://www.energy.gov/mission-innovation/university-forums.

A. Summary Description of Mission Innovation

Mission Innovation is a landmark commitment to accelerate global clean energy, announced by the leaders of 20 nations at the United Nations Climate Change Conference 2015 (COP21) in Paris-Le Bourget, France, on November 30, 2015:

> *"In support of economic growth, energy access and security, and an urgent and lasting global response to climate change, our mission is to accelerate the pace of clean energy innovation to achieve performance breakthroughs and cost reductions to provide widely affordable and reliable clean energy solutions that will revolutionize energy systems throughout the world over the next two decades and beyond."*[2]

On November 29, 2015, the White House released a fact sheet on Mission Innovation, outlining the commitment of the U.S. Government to this international effort to accelerate clean energy innovation and stating that "the U.S. Government will seek to double its current level [of] investment in clean energy research and development over five years," with new funding to be strategically allocated to early-stage R&D, "which offers...some of the greatest opportunities for breakthroughs and transformative change."[3] Each of the 20 participating countries and the European Union have made that same pledge. New investments will be focused on transformational clean energy technology innovations that can be scaled to varying economic and energy market conditions that exist in participating countries and in the broader world.

Since its launch in November 2015, Mission Innovation has established an Enabling Framework, approved on June 1, 2016, at the Inaugural Ministerial of Mission Innovation, that outlines a set of actions and describes Mission Innovation organization and processes. The Enabling Framework states that each member should independently determine the best use of its own clean energy R&D funding and define its own path to reach the doubling goal.

Entrepreneurs, investors, and businesses drive innovation from the laboratory to the marketplace. The private sector has launched a complementary effort, called the Breakthrough Energy Coalition (BEC). The BEC is an example of what might be done by investors like Bill Gates. To date, 28 investors from 10 countries have joined BEC, making an unprecedented commitment to invest patient capital in early stage technology development coming out of Mission Innovation countries. These investments will catalyze broad business participation in the commercialization and deployment of clean energy technologies worldwide.

B. Mission Innovation at DOE

Because DOE is the nation's principal sponsor of clean energy R&D, 76% ($5.865 billion) of the proposed Mission Innovation funding in the President's FY2017 budget request would be directed to DOE programs, supporting research, development, and demonstration (RD&D) activities that address a wide range of low-

carbon technologies. For its commitment to Mission Innovation, DOE has established the following definition of clean energy R&D investment:

> *Research, development, and demonstration of energy-related hardware, software, systems, or practices that avoid, reduce, or sequester greenhouse gas emissions or other air pollutants. This includes technologies that convert, convey, or store energy resources, improve energy efficiency, or reduce energy consumption.*[4]

The United States has made a commitment to a set of clean energy R&D focus areas to be emphasized in its Mission Innovation portfolio: industry, advanced manufacturing, and buildings; vehicles and transportation; bio-based fuels and energy; solar, wind, and other renewables; nuclear energy; hydrogen and fuel cells; cleaner fossil energy; CO_2 capture, utilization, and storage; electricity grid; and basic energy research. These focus areas are also well matched to the RD&D activities sponsored by DOE, as outlined in Appendix B.

The President's FY2017 Budget Request includes $110 million for regional clean energy innovation partnerships (RCEIPs), envisioned as cost-shared, public-private partnerships that will develop regional RD&D portfolios tailored to the characteristics of the regions that they serve. As Secretary of Energy Ernest Moniz stated during a March 2016 Senate hearing on the Department's budget request, "The goal of these partnerships is to accelerate the pace of innovation in clean energy technologies and to address clean energy challenges specific to regional energy resources, customer needs, and innovation capabilities."[5]

C. Regional Clean Energy Innovation Partnerships

The value of a regional focus on innovation is widely recognized. A decade ago, the Council on Competitiveness reported that "although national and state policies create a platform for innovation, the locus of innovative activities is at the regional level, where workers, companies, universities, research institutions and government interface most directly....Regions are the building blocks of national innovation capacity because they offer proximity and can provide specialized assets that foster firm-level differentiation."[6]

Through the proposed partnerships, federal funding for RD&D can be leveraged to create synergies among regional stakeholders and to engage partners who have not previously worked with DOE. The Department's intent is to support RD&D in clean energy innovation in new ways through these partnerships, beyond existing DOE clean-energy programs, with the expectation that this funding will be leveraged by investments from other stakeholders to accelerate innovation and facilitate deployment through commercialization.

The proposed RCEIPs respond to a national need, recent program reviews, and suggestions from stakeholders, and have the potential to accelerate innovation, spur the economy, and create jobs. In a 2016 report of the National Academies of Sciences, Engineering, and Medicine entitled "The Power of Change," the value of regional partnerships to accelerate innovation was highlighted. The report states the following:

> *A local, state, or regional public/private partnership—what the committee refers to as a regional energy innovation and development institute (REIDI)—could be created to help spur the development of both early-stage innovations and innovations that show appropriate promise. This type of regional institute structure would complement federal innovation agencies and programs such as ARPA-E, SunShot, and DARPA.*
>
> *The committee estimates that an optimal annual budget for a REIDI would range from $2 million to $40 million and would be linked to scale (whether it covered a metropolitan area, a state, or a multistate region), scope (whether it had a focus on a small or large number of technologies or markets), and stage of development (whether it was a nascent organization focusing on early-state proof of concept and business validation or had the capability and partnerships to accelerate innovations through development to reach commercial demonstration readiness).*[7]

Recent reviews have strongly encouraged DOE's national laboratories to broaden their roles in regional innovation ecosystems.[8,9] The report of the U.S. Senate Appropriations Committee on the proposed FY2017 Energy and Water Development Appropriations Bill suggested that DOE continue to expand its engagement in regional partnerships: "The Committee urges the Department to utilize investments through existing regional capabilities that include industry, universities, and State and regional economic development assets. The Committee further encourages the national laboratories to expand their geographic outreach through people and access to specialized equipment and user facilities in order to contribute to the success of these regional initiatives."[10] This report also states the Committee's support for "the premise and goals set out by Mission Innovation" and its belief that "the Secretary (of Energy) should focus more investment to support the goals of Mission Innovation through the national laboratory system, the Office of Science, and ARPA-E (DOE's Advanced Research Projects Agency–Energy)."[11] Statistics on ARPA-E proposal funding suggest that there is a capability for much more innovation than is currently being supported. As Secretary Moniz noted, "The demand for ARPA-E funding is high—just over 2% of proposals were funded, so it is very likely we're leaving a lot of innovation on the table."[12]

In 2010, scholars with the American Enterprise Institute, the Brookings Institution, and the Breakthrough Institute issued a call to "help reform the U.S. energy innovation system by investing up to $5 billion annually to establish a robust national network of regional energy innovation institutes," each funded at $50 million to $300 million annually.[13] A 2011 report from Jobs for the Future identified a need for "structures at the regional level to bring together key leaders from across public, private, and nonprofit sectors to formulate growth strategies that make the best use of regions' competitive assets."[14] In 2012, the National Research Council's Committee on Comparative National Innovation Policies made several observations[15] that speak directly to the value of regional partnerships:

- Historically, federally funded R&D has not been connected to state and regional industrial development; bridging that gap can create the local talent and technology base needed to convert these U.S. investments into domestic companies, industries, and jobs.
- Private businesses and local education institutions and economic development agencies are in the best position to identify opportunities, gauge competitive strengths, and mobilize wide community support for regional cluster initiatives.
- Regional innovation cluster initiatives should be built upon existing knowledge clusters and comparative strengths of each geographic region.

3 Insights on Regional Opportunities and Challenges

The forums provided a venue for participants to discuss current innovation activities and explore opportunities to expand and strengthen collaborations important to innovation ecosystems. All of the events provided insights on the diverse regional opportunities and challenges pertaining to energy resources and innovation capabilities for each of the respective regions. The regional reach and topical focus of each of the events varied greatly, from small roundtable discussions with approximately 30 participants, to full-day or one-and-a-half-day workshops with panels and breakout sessions, and up to 195 participants from as many as ten states. Taken together, more than 1,700 people from 37 states participated in these events. The identified regional energy resources, needs, and research, development, and demonstration (RD&D) capabilities also varied greatly. Table 1 provides a snapshot of topics discussed at the events and illustrates the wide range of interests across the regions. Summaries of each of the events, including meeting agendas, are provided in Appendix A.

Table 1: Regional clean energy innovation events.

Host university	Agenda topics	State participants
Arizona State University	Energy-water nexus	Arizona, California, Colorado, New Mexico, Nevada, Utah
Brown University (RI)	Offshore wind energy, ocean energy, natural gas, energy efficiency	Connecticut, Massachusetts, Rhode Island
University of California at Los Angeles	Expanding renewable energy, reducing petroleum use by vehicles, doubling efficiency of existing buildings, making heating fuels cleaner	California
The Colorado Energy Research Collaboratory at Boulder	Grid and storage, energy-water-food nexus, renewable resources, energy & climate	Colorado, Idaho, Kansas, Montana, Nebraska, New Mexico, North Dakota, South Dakota, Utah, Wyoming
University of Delaware	Cyber and grid security, energy generation and storage, grid modernization	Delaware, New York
University of Kentucky	Carbon capture, utilization, and storage; new value creation from coal; clean manufacturing	Illinois, Indiana, Kentucky, Missouri, Pennsylvania, Tennessee, Virginia, West Virginia, Wyoming
University of New Mexico	Enabling materials for key clean energy technologies: hydrogen, photovoltaics, electrical energy storage, and advanced nuclear energy systems	Arizona, Colorado, Idaho, New Mexico, Utah

Table 1: Regional clean energy innovation events. Continued.

Host university	Agenda topics	State participants
University of Pittsburgh	Grid modernization	Ohio, Pennsylvania, Virginia, West Virginia
Purdue University (IN)	Energy storage, biomass/synthetic biology, critical materials/advanced manufacturing, wind energy/grid integration	Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin
University of Tennessee	Advanced manufacturing, advanced nuclear energy systems, grid modernization and security, energy systems integration	Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee
University of Texas at Austin	Expanding the nation's transmission infrastructure; addressing methane leakage; conducting large-scale pilot studies of emerging clean energy technologies (e.g., CO_2 management, decarbonizing transportation, creating a hydrogen infrastructure)	New Mexico, Texas
Tuskegee University (AL)	Science, technology, engineering, and mathematics (STEM) programs and opportunities	Alabama, Delaware, District of Columbia, Florida, Georgia, Mississippi, Maryland, North Carolina, Tennessee, Texas, Virginia
University of Washington	Regional challenges and opportunities: regional policies facilitating sustainable clean energy development; regional innovation investment and commercialization ecosystem; renewables (hydropower, wave/tidal power, wind, solar, biomass), nuclear, clean coal; grid modernization; smart buildings; internet of things; transportation; advanced materials for clean energy applications	Idaho, Montana, Oregon, Washington
West Virginia University	Regional challenges and opportunities; the future of clean energy; innovation opportunities for fossil fuels in a future low-carbon economy; Tri-state Governors' Regional Cooperation; opportunities to accelerate other clean energy technologies; policies facilitating sustainable clean energy development; regional innovation investment and commercialization ecosystem	West Virginia, Delaware, Maryland, Kentucky, Ohio, Pennsylvania, Virginia

The events initiated conversations that facilitated developing a clearer understanding of regional clean energy resources and challenges; opportunities and challenges for expanding regional innovation ecosystems; and current and potential future economic and workforce development activities, including policy considerations and key regional characteristics that can be leveraged to develop effective and sustainable partnerships.

A. Regional Energy Resources and Challenges

A key conclusion of the regional events is that clean energy solutions must be tailored to meet regional needs. Participants acknowledged regional diversity in energy resources and challenges, priorities, capabilities, customer demands, and markets. This diversity will necessarily focus and shape regional solutions, as discussed at the events and provided in the individual university reports. The energy resources and challenges were highlighted as follows:

- The Northeast has nuclear, coal, and hydroelectric conventional energy, along with some non-hydro renewables and access to natural gas. Some of the issues and challenges the region is most concerned with include the existential threat of sea level rise and coastal resilience, the need for increased innovation in ocean-related technologies, and general climate change. To address those issues, leaders

highlighted their commitment to clean energy and participation in the Clean Power Plan and Regional Greenhouse Gas Initiative. A number of research, development, demonstration, and deployment (RDD&D) areas were identified as areas of focus, such as offshore wind, marine hydrokinetic technologies, and bioprocesses such as those featured in a demonstration facility at a first-generation ethanol plant, which captures CO_2, grows algae, and uses an algae process to utilize CO_2 for other products. Panelists also discussed the potential of data-driven, power-over-ethernet products described as breaking a "stream" of electricity into droplets and then sending them to a receiver.[16]

- Power generation in the Mid-Atlantic states is dominated by coal but also includes nuclear energy, natural gas, and some wind-power. The principal challenges the participants identified were a need to bring new manufacturing to the region to create coal-based products and a need for expanded electric transmission capacity to fully utilize the region's wind-energy resources. Speakers also commented that the coal industry can no longer rely solely on utilities to advance technologies; they felt the coal industry must partner with technology providers and build pilot plants. The principal challenges they identified were a need to bring new manufacturing to the region to create coal-based products, incentives to replace existing coal plants with higher-efficiency coal plants (ultra-supercritical), a need to realize the full value of the natural gas resource, and a need for expanded electric transmission capacity to fully utilize the region's energy resources. The Mid-Atlantic states are interested in exploring technology innovation opportunities for fossil fuels in a future low-carbon economy, alternate uses for coal, other clean energy technologies, and workforce development and education. They see tax credits for carbon capture and sequestration plants as a key enabler. Additionally, some cities in the Mid-Atlantic (e.g., Pittsburgh) are placing increasing emphasis on modernizing their complex electric power delivery systems.
- The Southeast primarily has coal, nuclear energy, natural gas, and some hydroelectric conventional energy, non-hydro renewables (including access to wind from Oklahoma), and other resources, including biomass. A major challenge discussed was support for manufacturing of lightweight materials and for the manufacturing industries that use them—especially automotive and aerospace. There is a growing need for clean, reliable, sustainable electricity. Research and development is seen as a major path forward; Timothy Lieuwen (Georgia Institute of Technology) noted that "nuclear energy is high

University of Tennessee panelists are pictured with Lynn Orr, U.S. DOE Under Secretary for Science and Energy (fourth from left), after their panel discussion on "Entrepreneurship and Graduate Education to Drive Innovation" at the Southeast Regional Energy Innovation Workshop in Chattanooga, Tennessee, on May 23, 2016. (University of Tennessee)

on the list [of research opportunities in energy] but emphasized hydrocarbon from natural gas as an opportunity."[17] Additionally, there is a focus on "workforce to create the next generation of innovation" and advanced manufacturing for the aerospace and automotive industries to rise to the top.[18]

- The Midwest has a tremendous natural resource base including coal, nuclear energy, biomass, and natural gas, and a large capacity for wind-based renewable energy. The Midwest relies heavily on baseload capacity, but is challenged by an aging energy infrastructure across the region. The need to integrate new technologies as well as renewable and distributed resources is of high importance. With a heavy manufacturing base in the region, an energy strategy is a critical need. Grid modernization presents both challenges and opportunities to take advantage of regional engineering capabilities.
- The Southwest has a legacy of oil and gas operations, natural gas, and tremendous solar and wind resources. The Southwest has water constraints due to long-term climatic conditions and nearer-term increasing populations that will increase water stress. Population growth, rising temperatures, the transition to transportation powered by electricity, and water needs will continue to put increased pressure on the Southwest region. The energy-water-food nexus is a significant focus. American Indian lands are critical for support of next-generation clean energy and efficient water use. Reducing the energy consumption of petroleum refining represents a major challenge for the Gulf Coast region, which hosts 38% of the nation's refineries. In coal-producing regions, finding alternative uses for coal and the development of technologies for carbon capture, utilization, and storage (CCUS) present both challenges and opportunities.
- North Central/Inter-Mountain West holds a substantial part of the U.S. energy reserves and accounts for roughly a fourth of the annual U.S. energy production. The region is energy-rich in crude oil, coal, natural gas, and renewables. The nine states combined account for roughly 14% of the U.S. renewable production.[19] Discussants concluded that they believe the region could be a net exporter of both fossil fuels and renewables. They noted that over half of electricity in this region comes from coal; and

Sarah Porter, J.D., Director of the Kyl Center for Water Policy at the Morrison Institute for Public Policy, Arizona State University, moderates a panel on "Southwestern Challenges and Opportunities in Water-Energy" as part of the Southwestern Regional Water-Energy Nexus Event in Tempe, Arizona, on September 8, 2016. (Charlie Leight/ASU Now)

that there is still a large need for carbon storage and sequestration (CCS), as well as for research in renewable energy to integrate with their extensive fossil fuels. Water integration with energy resources and the balance of water use for energy and food production, natural gas production, methane capture at the well and pipeline were noted as challenges. It was further observed that tribes and villages (with uniqueness of each tribe, and consequently region) are engaged with regional issues and developments and that meaningful consultation should be honored, commence early, and be conducted throughout energy-related activities and decisions.

- The West has abundant sunlight and wind resources, and a mild climate year-round. Natural gas is an important resource, followed by renewables, nuclear energy, coal, and hydroelectric conventional energy. The region shares with the Southwest similar challenges related to the energy-water nexus and increased pressure on its energy system. It was also noted at the University of California, Los Angeles (UCLA) that "southern California continues to face some of the most severe air quality and climate emission challenges. Over the coming decades, population growth, rising temperatures, electrified transportation, and water needs will put increased pressure on the region's energy system."[20] Increased use of efficiency and renewables, and smart buildings connected to smart grids are seen as important paths forward. For example, the city of Los Angeles is working to implement higher energy efficiency penetration across a diverse population and aging residential and commercial/industrial property developments, and integrate smart technologies. Integrating renewables into the grid is a top priority for the West and was the focus of the event at UCLA, where "discussions included everything from increasing our renewable energy power, to energy storage, grid modernization, distributed energy generation and storage, energy efficiency, and energy conservation in the region."[21]
- The Northwest region has a rich and diverse set of natural resources, which make it well-suited to be an "all-of-the-above" energy testbed for a deeply decarbonized economy. Hydropower forms the backbone (followed by non-hydro renewables, coal, natural gas, and some nuclear energy) of the Northwest's clean electricity system and highlights the challenge of balancing multiple resource interests and protecting the environment. The energy-water nexus factors heavily into regional decision-making due to the Northwest's economic reliance on agriculture, fishing, and hydropower. The region is experienced in grappling with complex energy issues and seeks diverse perspectives, such as those from its Indian tribes, in evaluating potential energy options. The Northwest is also a leader in energy efficiency, which has been the second largest resource for the region after hydropower and is seen as a continued target for improvement. Since 1978, the Northwest has reduced power consumption by about 6 GW and met half the load growth in the region through efficiency. There is a growing demand for solar, wind, geothermal, and wave energy. Clean fossil energy is being pursued through CCUS research conducted by universities and national laboratories within the region. The diversity of these alternative resources helps buffer against vulnerabilities related to climate.[22]

B. Opportunities Resulting from Expanding Regional Innovation Ecosystems

The events highlighted the need to work together to leverage shared opportunities and collaboratively overcome challenges. The opportunity for economic and workforce development that can be achieved through partnering to maximize synergies, value, and impact of innovation in energy technology, policy, and finance and business models was discussed at many of the events.

1. Economic Opportunity

It was clear to participants that there is a link between innovation, manufacturing, a diverse workforce, and economic opportunity. Management literature often notes that over time every firm's advantages erode as products, ideas, and practices are copied and become like commodities, which means that U.S. firms and workers

are at their most competitive when they innovate. Innovation in energy requires basic and applied research and development (R&D), but it also requires understanding the needs of industry, including manufacturing, and building close ties with state and local government, universities, and national laboratories. A strategy of "invent here, make it overseas" loses the knowledge and technology associated with manufacture of products, because so many advances begin on a production line or a shop floor that the innovation capability could often follow. Instead, manufacturing and innovation need to be joined with workforce training so that companies in the United States can find the deep, diverse pool of workers that will make their firms more competitive, and the American economy more productive, in the long term.

- Jay Inslee, Governor of Washington, discussed new workforce opportunities associated with clean energy development. He noted that "currently, the clean energy sector employs 90,000 people in Washington State. Clean energy jobs are growing at 9.7% per year in the transit and green energy sectors. Washington's economy is booming; it is in the top five states in job growth." So his bottom line is "embrace clean energy and get a great economy."[23] Additionally, panelists discussed the importance of cooperation in innovation ecosystems. In discussing what he saw as part of the "secret sauce" of the innovation ecosystem in Washington State, Thomas Ranken, President and Chief Executive Officer of the CleanTech Alliance, stated that "cooperation is part of the Northwest culture—people in the region work to 'bake bigger pies, not to take bigger pieces of a fixed pie.' As a result, business people in the community dedicate time and energy to help other clean tech entrepreneurs be successful."[24]

Gary Yang, Chief Executive Officer of UniEnergy Technologies, participates on a panel discussing "The Innovation Ecosystem—From Research to Startup" as part of the Northwest Regional Clean Energy Innovation Partnership Workshop, held at the University of Washington in Seattle on August 15, 2016. (Erin Bennett/Orcas Video)

- William Getty, President of the Claude Worthington Benedum Foundation, spoke at West Virginia University about the governors' agreement among Ohio, West Virginia, and Pennsylvania to collaborate in natural gas and shale gas. He noted, "This action plan is designed to maximize economic opportunity to attract downstream manufacturing. Value flows as you advance down the value chain; and so we must encourage the use of these resources here (manufacturing). The governors understand we have a competitive research presence in physics, geology, chemistry, robotics, additive manufacturing, IT; and it is important that our universities are collaborating around research that can bring economic prosperity to the region. Access to R&D can be an attraction for businesses to do manufacturing

because energy costs are down in this region and nationwide."[25] At the same event, Dennis Davin, Secretary of the Pennsylvania Department of Community and Economic Development, noted, "Pennsylvania has pursued an aggressive economic development policy. The abundance of natural gas in southern Pennsylvania gives them a distinct advantage for development."[26]

- Carol Handwerker, Purdue University, pointed out that "gaps in translation derive from what is often a lack of attention paid to a few key questions, namely (1) is it economic? (2) is there a market for the product? and (3) can the materials use cycle be closed?"[27]
- As noted in the "Southeast Regional Energy Innovation Workshop Report," the Manufacturing Demonstration Facility (MDF) at Oak Ridge National Laboratory "provides industry with affordable and convenient access to facilities, tools and expertise to facilitate rapid deployment of advanced manufacturing technologies to enhance the competitiveness of U.S. manufacturing. The MDF hosts approximately 5,000 core R&D visits a year in projects addressing advanced materials, quality of parts and faster [3D] printers. In addition, the MDF hosts 60–70 summer interns and helps drive curriculum for professional development. For example, the MDF provided training to help Boeing design for additive manufacturing."[28] The "Clean Energy Innovations" panel noted, "Conventional manufacturing and engineering processes are adapting at an unprecedented rate to improve, reducing production times and increasing energy efficiency. Efficient manufacturing techniques and clean energy resources are proving themselves a very strong and ever-increasing economic driver in the region."[29]
- Grant Ervin, Pittsburgh's Chief Resiliency Officer, noted that studies conducted by the Heinz Endowments and Carnegie Mellon University showed the clean tech sector to be one of the fastest growing industrial clusters in Pittsburgh, with a 22% annual growth rate over the past five years.[30]
- In late 2014, the Board of Regents at the University of New Mexico invested local money to foster innovation ecosystems by launching a public-private partnership (PPP), Innovate ABQ, Inc. "This unique concept will cohouse research and commercial labs with science and technology companies and

Senator Joe Manchin (WV) speaks to attendees at the Mid-Atlantic Region Energy Innovation Forum, sponsored by the West Virginia University Energy Institute on September 12, 2016, in Morgantown, West Virginia. (West Virginia University)

business incubators in a single location in the heart of downtown Albuquerque. It will catalyze cross-pollination of ideas and technology, thus providing new high tech jobs and economic opportunity to Albuquerque and the Southwest Region."[31]

- Panelists at Arizona State University observed that "universities can also assist governments and businesses both, not just in researching and developing new technologies and testbeds, but in creating a forum where water and energy stakeholders (including large utilities, industry specialists, and regulators) can come together to share ideas to de-risk the adoption of new technologies and encourage conservation.[32] In discussing opportunities and next steps, "Next-generation water-energy utility development is a local economic development opportunity with the potential to enhance regional sustainability, create jobs, and increase workforce skill deployment across tribal lands and beyond tribal borders."[33] Dr. Christiana Honsberg, Arizona State University, noted, "We have heard about recent growth.... There are more U.S. energy jobs in solar energy than in coal or oil."[34]

2. Workforce Development

Enhancing workforce development through partnerships among universities, industry, and the national laboratories was discussed as a priority among several regions.

- Workforce development was a central topic for the Mid-Atlantic events. While speaking at the University of Kentucky, Earl Gohl, Federal Co-Chair of the Appalachian Regional Commission, remarked on the technology, innovation, and economic development in Appalachia, and noted that coal losses have been acute in the Appalachian region for the past 4–5 years, leading to heightened challenges in workforce development and education levels. He discussed the Appalachian Regional Commission's focus on investing in human capital, community colleges, and supporting broadband connectivity, all with the goal of fostering entrepreneurial activity and growing industry clusters in the region.[35] It was observed at West Virginia that "the workforce in this region has owned up to what's missing; we must have a workforce development system that provides skills needed to obtain initial

Students and administrators attended a Historically Black Colleges and Universities (HBCU) Partnership with Science, Technology, Engineering, and Math (STEM) conference hosted by Tuskegee University in Alabama on September 8, 2016, under the White House Initiative on Historically Black Colleges and Universities Advancing Minorities' Interest in Engineering. Attendees heard panelists from government agencies, as well as representatives from STEM companies such as Lockheed Martin, Boeing, Exelon, Raytheon, IBM and Google, who discussed the role of HBCUs in producing high quality science, technology, engineering, and math graduates. (Tuskegee University)

employment and keep moving up" according to panelists at the West Virginia University. The Tri-state Govenors' Regional Cooperation is taking a three-pronged approach for innovation in the region, which includes a "drug-free and educated workforce which is key to a strong energy environment."[36]

- Joanne Romagni, Vice Chancellor for Research and Dean of the Graduate School, University of Tennessee at Chattanooga (UTC), said that she "would like to develop the workforce and create the next generation of innovators, which is the focus at UT Chattanooga." She noted that "collaboration is key—UTC works with ORNL [Oak Ridge National Laboratory], TVA [Tennessee Valley Authority], and other partners to explore things like electricity generation from solar and wind." Jimmy Cheek, Chancellor, University of Tennessee, Knoxville (UTK), agreed, noting that "UT Knoxville has benefited tremendously from a relationship with ORNL, which has influenced academic programming."[37]
- Bruce Dunn, Professor in Materials Science and Engineering, noted that at UCLA, "an internship program with southern California clean energy industry would provide students and employers additional opportunities. In addition, academic programs must continue to evolve to meet the needs of the clean energy economy. UCLA has the opportunity to train the next generation workforce in clean energy technology. Investments have been made in terms of developing courses and curricula. More can be done."[38]
- "Staffing of high tech activities in clean energy will require an appropriately educated and trained workforce. A regional clean energy center can help bring about a renaissance in clean energy research, development, and utilization in the Midwest," and suggestions that "a cybersecurity course be required of all students (only a few graduate students at the meeting had actually taken a cybersecurity course at this time)" were noted by panelists at Purdue.[39]

3. Partnerships that Foster Success

In nearly all of the forums, participants recognized that harnessing the opportunity to partner can strengthen the vital connections between innovation, manufacturing, a diverse workforce, and economic competitiveness. Several of the forums explored existing PPPs in their region that drive economic development, including helping industries pivot quickly and respond to diverse technologies. The participants provided examples of the importance of U.S. Department of Energy (DOE)-funded labs, facilities, and academic and other institutes partnering with regional businesses, creating jobs, and developing a competitive workforce:

- In Texas, "the SXSWUS [south by southwest region of the United States] region has a history of effective collaboration between industry, government, and academia including the successful public-private partnerships of SEMATECH and MCC in Central Texas during the 1980s. Subsequently, Austin became a hub for clean energy entrepreneurship due in part to the Clean Energy Incubator within the Austin Technology Incubator at UT [University of Texas] Austin and nonprofit consortia such as Pecan Street, Inc. These entrepreneurial infrastructures help foster growth in alternative energy technologies such as wind and solar while also merging the efficiencies of information technology to improve existing oil and gas operations and logistics within the SXSWUS region."[40]
- "There is a significant testbed infrastructure currently residing in the Northwest that can be networked, which includes the UW [University of Washington]-WSU [Washington State University]-PNNL [Pacific Northwest National Laboratory] transactive campus demonstration, the Pacific Marine Energy Center, and small modular nuclear reactors developed at NuScale Power that will be tested at INL [Idaho National Laboratory]." It was also noted that "Indian tribes need to collaboratively develop policy agendas to present to the Secretary of Energy. Tribal-public-private partnerships and loan guarantee programs could be used to fund Indian energy projects which would open up a new dimension of development for the Tribes."[41]
- A panel discussed examples of PPPs at Purdue. PPPs benefit from tax incentives to support small businesses through technical assistance, and an example was given for Sandia National Laboratories. In this example, 2,500 small businesses from around the state are supported through funding of $48

Mark Johnson, Ph.D., Director of the Advanced Manufacturing Office in the DOE Office of Energy Efficiency and Renewable Energy, moderates a panel on PPPs during the Regional Clean Energy Innovation Forum, hosted by Purdue University in West Lafayette, Indiana, June 8-10, 2016. (Purdue University)

million resulting in creation of 5,000 New Mexican jobs. In Chicago, the investment community is involved through Argonne National Laboratory and businesses in the area, which address clean energy, the battery program, and also work through the University of Chicago, to make connections between academics and private companies, as well as the National Lab. The panel also discussed the benefits of the National Network for Manufacturing Institutes and highlighted the PPP between Purdue University, the DOE, the State of Indiana and manufacturing companies that focuses on the development of advanced composites as part of the Institute for Advanced Composites Manufacturing Innovation (IACMI) project, led by ORNL and UTK.[42] Additionally, a number of key points were made during the discussion by the Public-Private Partnerships Panel regarding what might be needed for educating students to pursue projects within this context.

- The National Carbon Capture Center (NCCC) was identified as a key partnership with a focus on carbon capture and storage by Roxann Laird while speaking at the University of Kentucky. The NCCC is located in Alabama and is a partnership with Southern Company, Electric Power Research Institute, Luminant, American Electric Power, Cloud Peak Energy, and Duke Energy. It is also a part of the international test center network, a place where knowledge about carbon capture can be shared for everyone's benefit.[44]
- Josh Brumberger, Chief Commercial Officer of Utilidata, noted that "fifty people in Providence, Rhode Island, worked together for three months on a grant application to DOE to explore security and technology being discussed in the roundtable and noted the importance of the depth and breadth of the partners in this case and that this effort is viewed as regional with a partner from outside of the region. It is good to be forced to partner in a way you otherwise would not."[43] Mark Huang, City of Providence, mentioned the "importance of the Maritime Alliance's 'Blue Tech, Blue Economy' that promotes sustainable science-based ocean and water industries, business development, ecosystem development, and national and international outreach."[45]

In conclusion, panelists noted that resources for integrating people, resources, and data will be important in finding appropriate solutions and building capacity for sustainable ecosystems.

4. Policy that Lowers Barriers

Workshop participants indicated that market obstacles limit innovation and impede the transition to a clean energy future. Panelists across multiple events recognized that policy development and evaluation is required at all levels of government to identify and overcome market failures.

President and Chief Executive Officer of the Duquesne Light Company, Richard Riazzi, articulated the issue as being the importance of helping policy and technologies evolve at a similar pace. He cited experience with "large-scale wind generation in the Northwest and the recent net metering debates in Nevada and Hawaii as examples of the need to balance policy decisions with the business realities of capital investment."[46]

Tax and business policies are essential to address many of the essential elements of innovation ecosystems and to gain the climate change and economic growth benefits offered by clean energy technologies. For instance, tax incentives for CCUS are seen as essential for commercial-scale development of CCUS technologies. Many of the forums emphasized the importance of start-up companies and entrepreneurialism, which indicates that state and local business and tax policies that facilitate new-business creation and start-up investment could have major impacts. Policies that support "patient" capital investment were especially noted.

Doug Esamann, Executive Vice President at Duke Energy, while speaking at Purdue, said that "this [a self-healing grid] requires establishment of foundational standards, which involve technology, industry standards and policy. In 2009, NIST [the National Institute of Standards and Technology], under the America Recoveries Act (ARA)[*sic*], coordinated development of the smart grid and examined many of the issues involved."[47]

Darren Gill, Deputy Director of the Bureau of Technical Utility Services at the Pennsylvania Public Utility Commission, noted that there are two tracks for grid modernization: engineering and policy. Policy should move at a pace that is slightly ahead of the engineering, largely so that engineers know what to design for. The existing system is built to function at full capacity rather than taking advantage of distributed generation, thus demonstrating the need for policy to outpace engineering, if only by a small margin, lest we engineer for the wrong outcome.[48] Regional partnerships and collaboration are themselves potential targets for policy support. In Seattle, participants discussed the possibility of state-level incentives for collaboration.

State and local regulatory policies also were seen as offering opportunities. For instance, policies that enable greater energy data-sharing became a topic in southern California, while state and local building and environmental code updates to facilitate use of new technologies was discussed in multiple forums, including southern California, the Northwest, and the Southeast.

C. Challenges for Expanding Regional Innovation Ecosystems

Challenges shared across regions include (1) development of a shared vision and strategy, to be addressed through open communication and coordination; (2) scaling up from demonstration to deployment, which calls for sustained engagement of investors and industry partners; (3) regulatory uncertainty, which can be addressed through partnering to ensure that policy evolves in parallel with technology; and (4) other challenges. Discussions across the regions amplified the message that resources for integrating people, resources, and data will be important in finding appropriate solutions.

1. Development of a Shared Vision and Strategy

The importance of cooperation in the development of a shared vision and strategy was affirmed throughout the discussions. Participants suggested that collaborative, regional projects could be made stronger through connections with the DOE, national laboratories and other existing nonprofits, private research centers, and industry collaborators. PPPs could make use of data and resources available to different organizations. For example, start-ups could leverage projects from DOE and scale them for efficiency, while large corporations

might gain new visibility into the capabilities of start-ups. Regional and international collaborations could be vehicles to ensure that technologies developed in the universities and laboratories can be more rapidly commercialized to deliver clean energy solutions to the world.[49]

Examples of discussions that highlighted the importance of developing a shared vision and strategy follow:

- "A recurring observation made throughout the [Northwest] workshop, and in post workshop surveys, was that the Northwest innovation ecosystem would benefit greatly from a road map that could be used to align and organize the region's efforts and investments in clean energy. This road map would define a shared vision and provide a mechanism to continue the conversations initiated at the workshop."[50]
- While discussing the Northeast, Jeff Grybowski, Chief Executive Officer of Deepwater Wind, noted that "going forward, the next challenge for the industry is how to build up the infrastructure to scale up." He asked the federal government to focus on building the infrastructure needed to support that scaling process (ships, etc.). He highlighted the need to build a supply chain to help industries go to commercial scale. It was noted that summarizing the offshore wind industry's infrastructure needs in a single document would be helpful.[51]
- Patrick D. Gallagher, Chancellor at the University of Pittsburgh, said, "considering the expansive and somewhat daunting goal—to modernize the nation's electric power grid and energy infrastructure—it's vital that research institutions such as Pitt partner with the utility industry and the community to find solutions addressing security, resiliency, and reliability."[52]

2. Scaling from Demonstration to Deployment

Funding energy projects can be difficult due to the technically challenging and capital intensive process of developing and commercializing next generation energy solutions. Those challenges present themselves across different energy intensive industries such as transportation, manufacturing, and power generation. Participants pointed out that the private sector rarely researches, scales, and commercializes new energy technology because of information barriers, risk aversion, and scarce capital. Partnerships that leverage public support with private-sector buy-in, to encourage industry investment and connect small businesses to resource networks, were highlighted as effective tools for building capacity and sustainable ecosystems.

It was recognized that different types of investors are needed for various stages of the innovation cycle and that pathways to commercialization tend to require an evolution of partners throughout the technology life cycle. This concept is related to the need to develop a shared vision and strategy for a region and aligning the right partners at the appropriate time to achieve that vision.

The importance of public- and private-sector funds to overcome the "valley of death" between prototypes or demonstrations and commercialization was a recurring theme.

Participants at the Brown University Roundtable made comments about the valley of death, needed funding sources, and helping small business move forward through the Manufacturing Extension Center at Rhode Island.

- Michael Miller, Brown University, talked about harvesting energy through flowing fluids, his hydro energy project, the valley of death, and how he wished DOE's Advanced Research Projects Agency-Energy (ARPA-e) could provide further funding for the project.[53]
- Gerry Sonnenfeld, Vice President for Research and Economic Development, University of Rhode Island, noted that "they are also interested in small business and manufacturing development for Rhode Island under the auspices of helping start-up companies move forward. They have a Manufacturing Extension Center."[54]

The valley of death for projects of long durations was discussed by Kentucky panelists, highlighting that "partnerships are effective at bringing people together but need a way to keep everyone engaged through the 'muck' of developing projects and finishing years later. Traversing the technology commercialization valley of

death can be demoralizing."[55] The need for patient capital and the conservatism of utilities were discussed as challenges to deploying technologies:

- "One of the biggest challenges to scaling up CCS [carbon capture and storage] is funding. Projects search for additional income streams, including EOR [enhanced oil recovery]. These projects need extreme patience, and that is where consistent funding from government can play a key role."
- "Utilities are very conservative with their funding and willingness to take on long-term projects and risk."[56]

Attendees at the Northwest event discussed the importance of public and private funds for successful commercialization and recounted their experience:

- "In launching UET [UniEnergy Technologies], the team did not realize all of the challenges up front. Time and money are the principal challenges—the time-to-product in the renewable energy market is 5–10 years. The long time scale is less attractive to investors, therefore companies like UET need support from public funds. Such support from DOE OE [Office of Electricity Delivery and Energy Reliability] and the Clean Energy Fund proved to be critical to developing the largest redox flow battery in operation. UET is currently installing systems in California, New York, Italy, Germany, and other locations around the globe."[57]
- "NuScale Power started in 2000 with DOE funds with the goal to redesign an advanced light water nuclear reactor with safety in mind. In 2011, a board investment hypothesis was presented to Fluor Corporation, which resulted in a major investment by Fluor in 2012. The DOE held a small modular reactor (SMR) competition, and NuScale Power won. Cumulatively, NuScale has received $500 million in investments to construct a SMR that generates 50 megawatts of electricity and is scaled to be built in a factory. NuScale Power has 23 utility partners and five technical advisors (three of which are from the NRC [Nuclear Regulatory Commission]). It plans to submit an NRC application this year after completing eight years of testing."[58]

These challenges could be exacerbated by changes in market conditions. For example, when the price of oil is high, industry supports high-risk investments in innovative technologies to reduce oil demand and increase oil supply.[59] Currently, a big influence on the success of technology commercialization is the price of natural gas. Companies need to project where gas prices are going to be between 2022 and 2023 and invest their time and money accordingly. "Large investments are needed to bridge the valley of death and weather the fluctuations in the market."[60]

3. Regulatory Uncertainty

At multiple events, participants expressed the view that better alignment of regulatory frameworks could serve to facilitate innovation in energy and technology, and if regions involve multiple states, alignment of regulatory frameworks across those states is paramount to maximizing success of regional endeavors. This concern about regulatory environments is key and was echoed in a number of the university-hosted events.

The impacts of the regulatory structure on investment were explored at the University of Texas. The roundtable report notes, "In the electric sector, the regulatory structure inhibits investment. Competitive power markets are often swifter at adopting new technologies. However, it was mentioned that regulated markets could offer unique benefits to large capital projects for low-carbon facilities such as nuclear plants or coal with carbon capture."[61]

The need for regulatory reform was discussed at UCLA, with panelists observing "the major barriers to providing clean energy include much needed regulatory reform and streamlined rules for [electric grid] interconnection and implementation by local utilities. The regulatory rules were set and based on supporting vertical integrated utilities with a rate structure to support monolithic implementation and control of the system. As the paradigm shifts away from centralized plants toward distributed renewable clean generation, regulatory reform is needed to allow and encourage emerging technologies to capture full benefits and

Elizabeth Sherwood-Randall, Ph.D., U.S. DOE Deputy Secretary, provides opening remarks on Mission Innovation and the role of regional partnerships during the Southern California Clean Energy Innovation Ecosystem Roundtable, which was hosted by UCLA on May 10, 2016. (John Vande Wege)

revenues. This will, in turn, result in increased investment and accelerated implementation of clean energy. The interconnection rules and tariffs implemented by local utilities were developed and implemented based on increasingly obsolete rules.…These largely arcane paradigms need to be modified and streamlined to allow the ability to install new clean energy technologies without waiting months to years to follow through the filings and process required for interconnection by local utilities." The group agreed that "California needs continued solar subsidies to level the playing field against subsidized fossil fuels and to facilitate utility-scale solar and wind development."[62]

Regulatory constraints leading to barriers to venture capital were discussed at the University of Washington. Scott Forbes, Director of Computer Science and Engineering at FedIMPACT, further noted how "the energy sector is not conducive to venture capital due to the high failure rates of start-ups and the long lead time to products due to regulatory constraints."[63]

Opportunities to collaborate to address regulatory issues were highlighted in Tennessee. Nick Irvin, Program Manager for Advanced Energy Systems at Southern Company, said that "there are opportunities to collaborate on technology development and regulatory issues." He noted that "TVA and Southern Company have worked on carbon capture technologies together." Dan Stout, Senior Manager for Small Modular Reactors at Tennessee Valley Authority (TVA), said that "the whole Southeast energy industry is collaborating through EPRI [Electric Power Research Institute], sharing resources in a regulatory environment," though he notes, "deregulation makes sharing more difficult."[64]

4. Other Challenges

Unique challenges were raised across the regions from various perspectives ranging from, but not limited to, the need for new business models for the utilities—in Pittsburgh's case—to address flat throughput due to efficiency gains; the need for transmission lines in Texas to enable expanded utilization of renewables; the necessity for reuse and recycling of water in Arizona; the need for infrastructure associated with the introduction of

hydrogen fuel in New Mexico; the need to make biofuels and bioproducts more competitive in Delaware; and market changes and customer demands in Washington. Examples follow.

Richard Riazzi, President and Chief Executive Officer of the Duquesne Light Company, said that Duquesne Light has experienced flat throughput for five years as efficiency gains have offset growth in demand, and he expects throughput to decline by 1% per year over the next five years. To meet these numerous challenges, Duquesne Light continues to increase its operating efficiencies and to look to new revenue opportunities in batteries, renewables, microgrids, and electric vehicles.[65]

The report on the roundtable discussion at the University of Texas at Austin states, "The locations of the best wind and solar resources are often geographically distant from the primary load centers across the United States. Such is true within the SXSWUS region, as well. Expanding the nation's transmission infrastructure could enable expanded utilization of some of the best renewable resources across the country."[66]

Panelists at Arizona State University observed, "Because southwestern water sources are limited, reuse and recycling is not just important, but necessary for fast-growing cities in arid and semi-arid climates. While some metropolitan areas, such as Las Vegas and Phoenix, have maximized wastewater reuse, they still need funds to build infrastructure and implement existing technologies. New technologies and campaigns must also be developed to keep up with demand and increase water quality, particularly since the public and policymakers are resistant to the idea of drinking water that once flowed through a sewer. People need to be educated in order to be open to change in this arena."[67] While discussing renewables, it was noted that because of the variability of their resources (sunlight, water, and wind), renewable technologies are not being fully used. "Disruptive technology, on the order of a 'Wright brothers event,' must take place for us to fully use existing water reserves and fully leverage existing renewable technologies in order to maintain successful population centers in this arid climate."[68]

Catalysis Center for Energy Innovation (CCEI) researcher Kostas Goulas (far right) had a high-level audience with a great deal of scientific expertise on National Lab Day in Delaware (May 13, 2016), when he was joined by (left to right) University of Delaware President Dennis Assanis, Senator Chris Coons (DE), and U.S. DOE Secretary of Energy Ernest J. Moniz. (Kathy F. Atkinson)

Challenges with the broader introduction of hydrogen were discussed at the University of New Mexico. "An important consideration in the broader introduction of hydrogen is the further development of the hydrogen infrastructure. In terms of hydrogen distribution, natural gas pipelines can move hydrogen at concentrations of about 10% without requiring substantial improvements to the existing infrastructure. But additional product development and the need to build hydrogen fueling stations, for example, raise questions regarding the valuation of system and infrastructure costs that may be incurred, and the policy implications and incentives necessary to determine what the value might be of more broadly introducing new energy resources."[69]

Biomass is important to many regions, but the conversion process that turns agricultural waste into fuels, electricity, and chemicals is expensive and complicated, especially when compared to oil and natural gas production. Researchers, such as those at the University of Delaware-based Catalysis Center for Energy Innovation (CCEI) and dozens of investigators from its nine partner institutions, are working to make biorefined fuels and chemicals cheaper by enhancing the processing and conversion of non-food biomass (such as trees and grasses), providing improved intermediate feedstocks for biorefinery product synthesis.

In discussing customer demands at the University of Washington, panelists noted, "Customer demands and markets pose challenges as regional energy solutions 'dramatically change, as old paradigms are challenged by new technologies, the cost burdens of maintaining aging infrastructure, regional market forces driven by shifting customer demand, changing and complex regulatory regimes as well as the consolidation and reorganization of markets.'"[70]

Additional challenges and potential pathways to address them where discussed, as documented in the university reports in Volume 2.

4 Insights on Regional Clean Energy Technology Innovation

Discussions at the regional events covered a wide range of research, development, demonstration, and deployment (RDD&D) topics, summarized here, with illustrative examples, using the overarching themes and energy sectors of the U.S. Department of Energy's (DOE) 2015 Quadrennial Technology Review (QTR)[71] as a framework. The variation in the discussion of each RDD&D topic was aligned with the differences in needs and capabilities across the regions.

A. Overarching Themes

1. Increasing Interdependence (Convergence) of Energy Sectors

The QTR states that "the convergence of many energy sectors—such as the electric grid, electricity production, buildings, manufacturing, fuels, and transportation—into systems linked through information and communications technologies (ICT), advanced modeling and simulation, and controls, has the potential to revolutionize energy services throughout the economy at the component, device, and system levels."[72] This increasing interdependence of all sectors of the energy system and the coupling of energy to water systems, materials flows, waste products, and energy financial markets were reflected in discussions of opportunities for understanding, predicting, designing, and controlling integrated energy systems, at levels ranging from individual buildings to cities and regions. The need for sophisticated energy planning to be part of urban planning and smart cities was discussed in Seattle, Pittsburgh, and Los Angeles.

Discussions of smart cities ranged from the agreements among institutions to work together to modernize the grid and the internet of things [(IoT) – the network of physical objects—devices, vehicles, buildings and other items—embedded with electronics, software, sensors, and network connectivity that enables these objects to collect and exchange data] to a 5-year work plan that exemplifies the increasing interdisciplinary nature of clean energy challenges. Smart buildings (structures that optimize, record, and transmit their energy profiles) and an IoT approach are key building blocks for smart cities. In addition to an IoT approach and smart buildings, the interplay among communications, transportation, and energy systems was highlighted as integral to smart cities.

Discussants at the University of Washington noted that "Microsoft is investing in internet of things [(IoT)—Internet-connected objects, sensors, and equipment (including buildings, vehicles, appliances, and commercial/industrial equipment) that can exchange data and instructions among themselves and with external computers] technologies for smart buildings and smart cities." When speaking to challenges with convergence, it was observed, "The interface between buildings and the grid is one of our [Northwest] key challenges, which has

motivated the campus [University of Washington] transactive project to demonstrate what new technologies can be incorporated into buildings." The connectivity themes, such as enhancing grid-to-building integration, energy storage, and smart-buildings/IoT monitoring was integral to the discussion with participants who recognized that "in the future, the core operational infrastructure for buildings will link to smart agents in the building. The smart building, or more generally, smart energy components will be considered as integrated components in the future energy system. Such devices will bring physical sensors into data models that will provide new abilities to adapt energy usage to building occupants."[73]

Pittsburgh participants "highlighted powerful opportunities to impact future infrastructure in three highly interconnected systems: information and communications technologies, transportation, and energy."[74] Examples of how Pittsburgh is addressing convergence are described in the University of Pittsburgh report:

"Understanding the interplay among communications, transportation, and energy systems, and how to optimize and develop them at a city-wide scale for the future, requires a high level of technical understanding from policy makers. A century ago, Pittsburgh built the first drive-through gas station in the East Liberty neighborhood. For the 21st century, the challenge is to combine DC [direct current] architecture with solar, storage, and rechargeable vehicles in a solution that can be replicated worldwide. The Smart Pittsburgh initiative is one of many energy-related projects in which the City has an active role. It is working with university, industry, business, foundation, and nonprofit partners as it builds toward its goal of a 50% reduction in energy and transportation emissions and water use by 2030. The City's Clean Tech initiative is looking to expand and strengthen sectors developing water, energy-efficient building, and renewable energy technologies. Under its memorandum of understanding with DOE, the City is working with university and utility partners to support the development of advanced energy infrastructure. This includes plans for a 'grid of microgrids' at seven sites across the city that will provide a critical testbed for modern grid technologies and help accelerate the process of transitioning these technologies from research to commercialization."[75]

Energy research discussed at the University of California, Los Angeles (UCLA) by William Torre, Program Director for Energy Storage Systems at the University of California, San Diego (UC San Diego), "involves electric

Attendees view posters on grid modernization and other clean energy topics at the Mission Innovation Workshop on Grid Modernization, held at the University of Pittsburgh's Center for Energy in Pittsburgh, Pennsylvania, on June 24, 2016.

transportation and utilization of automated demand response and vehicle-to-grid control to optimize overall microgrid operation and efficiency."[76]

While speaking at Pittsburgh about the need for sophisticated planning, Mark McGranaghan of the Electric Power Research Institute (EPRI) cited a need for research and collaboration in planning and design as "we go green and modernize."[77] He described Chattanooga, Tennessee, as a bellwether, where fiber optic lines are available in all homes, creating a system that is efficient and that also collects and communicates data. Demand response and distribution management depend on such systems, and he stated that he believes the cybersecurity risks are manageable.[78] Grant Ervin, Pittsburgh's Chief Resiliency Officer, noted that in 2015, Pittsburgh and DOE's National Energy Technology Laboratory (NETL) signed a memorandum of understanding to pursue advanced grid infrastructure, based on a district energy approach. Following a similar line of thought, UCLA's "Sustainable LA [Los Angeles] Grand Challenge" released the Sustainable LA Five-Year Work Plan in December 2015, which summarizes the challenges unique to LA County. This plan exemplifies the increasingly interdisciplinary nature of clean-energy challenges.[79]

Participates at multiple events concluded that additional research is needed to identify the best strategies for integrating smart buildings, transportation, and the grid so smart cities can take maximum advantage of connections among the energy, buildings, and transportation sectors while minimizing their emissions. Sophisticated planning and design are paramount to the success of smart cities.

2. Diversification in Energy Production

The challenges and opportunities for energy infrastructure that are being created by increasing diversification across energy sectors were reflected in discussions of the expanding role of electricity, hydrogen, natural gas, and biofuels in the transportation sector; the transition of the power sector from coal to natural gas and renewables; and the plans for deployment of small modular reactors. Speakers at the events in California, Colorado, Indiana, Rhode Island, and Washington placed emphasis on renewable resources for electricity and fuel.

A significant challenge that was often discussed is balancing the policy, political, and economic considerations of diverse energy resources. Regional strategies in particular may need to balance the interests of subregions. An example was discussed in Seattle: "Of importance to the NW [Northwest] energy dynamic and associated policy making are the geopolitical relationships between the less populated NW interior and the growing metropolitan centers of the Emerald Corridor; between hydropower rich vs fossil energy rich regions. In addition, it is important to recognize and address policy relationships between the Northwest and adjoining Canadian provinces, given the increasing bi-national regional energy (and water) flows. The NW clean energy vision also necessarily must leverage cross-border energy resources and infrastructure, i.e., electrical transmission, pipeline, waterways, rail."[80]

Please see sections C.2. on Electricity Production and C.5. on Fuels, below, for additional discussion on the increasing diversity of energy resources.

3. Role of Scientific Facilities and Computing to Enable Innovation

Scientific facilities and the role of computation in innovation were a key part of the discussion at most of the regional meetings. The availability of scientific user facilities and the resources of the national laboratories and universities are an integral part of the path forward on energy innovation. The confluence of advances in computing power and software, theory, modeling, synthesis, and characterization is enabling "systems by design" for materials, chemicals, and biological science. Integrating data sets from public and private resources can result in better, more relevant research efforts, but the immense amount of data and technology available can pose challenges when decisions must be made quickly, especially when complex systems are involved.

The panel on Materials for Advanced Nuclear Energy Solutions at the University of New Mexico spoke to the interaction of computational modeling and advanced scientific user facilities at national laboratories, and the

"need for integration and coordination of experimental and computational modeling efforts throughout the materials development and demonstration process."[81] "[There is] fundamental difficulty related to assessment of evolving materials behavior in conditions that make direct observation difficult, if not impossible. … The ability to predict these effects begins with fundamental studies of the interaction of radiation with matter. This will lead to improved models that will provide better fundamental understanding, serve as the foundation for the design of new materials with enhanced performance and perhaps shift the life-cycle/licensing for nuclear systems, structures and components to allow for shorter time scales for component replacement." "Helping to meet these and other challenges, the DOE has a variety of experimental facilities across several national laboratories. One example includes the Materials and Fuels Complex (MFC) at Idaho National Laboratory, which has as its mission developing advanced fuels and materials, including nuclear waste. ... LANL [Los Alamos National Laboratory] and SNL [Sandia National Laboratories] also have key experimental facilities that are capable of investigating advanced materials, including the Los Alamos Neutron Science Center (LANSCE) at LANL and the Ion Beam Laboratory (IBL) at SNL."[82]

The ability of DOE's national labs to integrate computational and experimental capabilities to support innovation was echoed in West Virginia and Tennessee: "Our [NETL's] advanced computational and laboratory assets can help advance technologies toward commercialization. NETL has core capabilities that allow us to look at technology in its discovery state and help colleges and industry mature technology to commercialization."[83] "Together, [Oak Ridge National Laboratory's] SNS [Spallation Neutron Source] and HFIR [High Flux Isotope Reactor] are leading neutron scattering facilities in the country and are used to characterize a wide variety of materials including structural and functional materials, polymers and even in structural biology. … The Center for Nanophase Materials Science is another user facility that offers collaborative opportunities with the center's experts in material synthesis, nano fabrication, materials characterization and theory. … Finally, the Oak Ridge Leadership Computing Facility (OLCF) is the fourth DOE SC (Office of Science) user facility that provides world-class leadership high-performance computing to the nation's scientific community."[84]

U.S. Representative Chuck Fleischmann (TN-03) speaks to participants during a welcome panel at the Southeast Regional Energy Innovation Workshop, hosted by The University of Tennessee at Chattanooga, Tennessee, on May 23, 2016. (University of Tennessee at Chattanooga)

Discussions at several events revealed that the integration of unique research facilities and computational capabilities is not—and should not be—confined to national laboratories. This was explored in a panel discussion on Energy Innovation at Northwest Research Institutions at the University of Washington: "The energy ecosystem in the Northwest is a very collaborative group. We have a critical mass of all the pieces you need in a region to do something special. Northwestern universities are both locally and internationally known, the three national laboratories in the Northwest are incentivized to be outwardly focused, and we have a policy and a culture that truly wants to develop technologies that create a clean energy future."[85] In addition, "the Northwest region has a huge software development community. The 'hackathon,' or rapid iteration model, may be a model that would be useful to adopt in specific areas in energy such as transactional controls and IoT. Some start-ups are working with the national laboratories to get support; for example, in leveraging their supercomputer capabilities."[86]

More general applications of high-performance computing were also raised at UCLA and the University of Colorado. Doug Rotman, Energy Program Manager at Lawrence Livermore National Laboratory, stated that "we are only beginning to tap the power of high-performance computing (HPC) to enable greater innovation. HPC does not take the place of experiments, testing, and demonstrations—but much broader use of HPC can help explore areas of new thinking and can enable thinking 'beyond what we think is possible.' An emphasis should be placed on enabling small businesses, not just multinational companies."[87] A discussion of the energy-water nexus partnership in Colorado identified decision support tools as a research priority: development of decision support tools to improve integrated water and energy resource planning through regional climate and geospatial analysis, data integration, water and energy infrastructure, "big data" analysis, and regulatory and policy changes to support sustainable energy and water use.[88]

4. Energy Efficiency

The topic of energy efficiency came up repeatedly at every event. Regional stakeholders expressed interest in addressing the efficient use of resources linked to energy, including water, agricultural products, land, and rare earth materials. Examples included more efficient water treatment and desalination processes; new feedstocks, farming and processing techniques, and logistics that reduce water, land, fuel, and cost requirements of biofuel/bioproduct supply chains; more efficient solar panels to reduce space requirements for distributed solar generation; and designing products for recyclability. The discussions made it clear that the need for efficiency permeates our economy and depends on a wide range of technologies. Panelists spoke to constraints on moving to greater efficiency, greater efficiency through smart grids, and efficiency as a resource.

Deborah Stein of Carnegie Mellon University pointed out that "in this region [Pittsburgh], many small and medium-sized manufacturers could benefit from efficiency, but may lack the capital investment. The result is that even if they know how to implement efficiency measures, they often experience constraints that prevent them from doing so."[89] At the same event, Richard Riazzi, Chief Executive Officer of Duquesne Light Company, identified sustainability as one of the three priorities for grid modernization, and said that providing energy-efficiency tools for their customers is one of their sustainability goals.[90]

The IACMI [Institute for Advanced Composites Manufacturing Innovation] regional composites-manufacturing partnership was discussed at the University of Kentucky where panelists identified three active areas of research in conjunction with DOE's Advanced Manufacturing Office, one of which is vehicle fuel efficiency and light-weighting.[91] Part of the auto industry's current progress in reducing vehicle weight has been through increasing use of aluminum, and Joe Quinn of the Aluminum Association noted that the aluminum industry itself has been increasing its energy efficiency.[92] At Purdue, U.S. Senator James Merritt, Jr., of Indiana completed this vehicle-materials-manufacturing triangle of efficiency by noting that in his state, Subaru has significantly improved the energy efficiency of its auto-manufacturing plant in Lafayette and serves as an example of what can be done with efficiency in manufacturing. Senator Merritt also observed that "saving energy is bipartisan."[93]

The need for both large-scale and small-scale energy storage solutions was discussed by roundtable participants at UCLA, who concluded that "as the technology does not exist yet, smart grids are the place to start in terms of efficiency."[94] A question posed to panelists at UCLA was to identify feasible pathways to double the energy efficiency of existing buildings by 2030. Panelist answers included addressing heating and cooling equipment and requirements simultaneously, combined heat-and-power, fuel cells, systems-thinking (use the heat from a fuel cell to power an absorption-chiller), improved equipment maintenance and IoT monitoring, open energy data and energy audits, and consumer behavioral changes.[95] Along similar lines, speakers in Seattle noted that the Northwest region has met half of the estimated load growth since 1978 through increased efficiency. "Efficiency is the second-largest resource for the region after hydropower." They also emphasized a high-tech approach to building efficiency in which Northwestern research institutions "are partnering with utilities to implement transactive controls between the grid and buildings...."[96]

5. Energy-Water-Food

The energy-water-food nexus is critical to the Southwest and was a main focus of the event held in Colorado. Energy-water was also a main theme at Arizona, one of the themes for the event held in Texas, and was noted as being very important to California and Washington. Discussants focused on optimizing water utilization and energy use with agricultural irrigation, integrated management of resources, regional decision making, and increased pressure on regional energy systems. For example, participants at Arizona State University stressed the importance of addressing the large amounts of energy used to deliver water over long distances to different types of consumers.

Energy, water, and food were discussed as a breakout topic at the Colorado Energy Research Collaboratory. A key area of shared interest was optimizing water utilization and energy use with agricultural irrigation, especially for biofuel crops. Several projects of interest for the region were mentioned: "Development and permitting of unconventional water sources (e.g., oilfield produced water, industrial wastewater, domestic wastewater) for irrigation. Modeling efforts to identify and quantify these sources, determine wastewater qualities, understanding treatment requirements and developing cost/benefit analyses that include the full life-cycle (including transportation)." Participants discussed technology for irrigated cropland and transitioning land from food to biofuel crops:[97]

- "Additional technology that should be evaluated and demonstrated to enhance irrigated cropland includes advanced monitoring techniques for nutrient and water application, biotechnology for genetically modifying plants for drought tolerance, soil supplements to improve the microbial communities that plants require, and remote plant health monitoring."
- "Agriculture to support the production of biofuels is of great interest in the region. In addition to the topics discussed above for optimizing water utilization in irrigated croplands, there is ongoing research to model the impacts of transitioning land from food to biofuel crops in terms of climate change, food security, biodiversity, ecosystems and other potential effects."

While speaking at the University of Texas, Secretary Moniz conveyed that the intersections of energy and water will become increasingly important, raising the need for integrated management of resources and enabling infrastructures.

- During the roundtable discussion, it was noted that the energy-water nexus is particularly relevant in the SXSWUS region (south by southwest region of the United States) because of strained water supplies, active energy production, and population growth. The discussion identified the topic as one where the region could be used as a testbed to develop solutions and establish national leadership on how to use the energy sector to improve the water sector and vice versa. Solutions were identified, such as creating regional wastewater gathering systems for oil and gas operations, using off-peak renewable electricity from wind or solar to desalinate water for communities, or implementing dry cooling technologies at new thermoelectric power plants to decrease the water intensity of electricity generation.[98]

U.S. DOE Secretary of Energy Ernest J. Moniz discusses the importance of the intersection of energy and water policies as part of the Integrating People, Technology, and Natural Resources for a Clean Energy Future: Roundtable Discussion on Mission Innovation at the University of Texas at Austin on May 9, 2016. (University of Texas at Austin)

- The interdependence of electricity generation and water was part of the roundtable discussion at the University of Texas, and panelists advocated a need for dry-cooling technologies at new thermoelectric power plants to decrease the water intensity of electricity generation.

Regional decision making was the focus of discussion at the University of Washington:

- "The focus on energy-water nexus factors heavily into regional decision making due to the Northwest's economic reliance on agriculture, fishing, and hydropower. Therefore, the environmental focus of the Northwest has stimulated a healthy debate over the years about the benefits and consequences of clean energy, most notably the impact of hydropower on salmon migration and survival rates. The region is experienced in grappling with complex energy issues and seeks diverse perspectives, such as those from its Indian tribes, in evaluating potential energy options."[99]

Implications for water over the coming decades, due to population growth, rising temperatures, electrified transportation, and water needs that will put increased pressure on the region's energy system were explored in Southern California.

- UCLA Dean Jayathi Murthy described UCLA's concerted effort to address the energy challenges of the region through their Sustainable LA Grand Challenge, which was launched in 2013 with the goals of reaching 100% renewable energy, 100% locally sourced water, and enhanced ecosystem and human health in LA County by 2050.[100]
- In reference to the state of energy technologies in California, UCLA Professor Eric Hoek briefly spoke about his research focusing on the energy-water nexus, on water reuse, treatment of wastewater, and desalination. Water Planet, a start-up stemming from Hoek's research, is a company working to cut energy use through more efficient water purifying membranes.[101]

Many regional events discussed the regional impact of the energy-water-food nexus, both as an area where innovation and initiative can make a substantial impact and as a regional issue where coordination and cooperation will be vital to success.

B. RD&D Areas Affecting Multiple Energy Sectors

A vast and complex array of systems and associated technologies extract energy resources, convert them into usable forms of energy, and deliver them to end users to provide desired services such as manufactured goods, thermal comfort, lighting, and mobility.[102] The Department's QTR describes the national energy system as comprising six individual sectors: (1) the electric grid, (2) electricity production [power], (3) buildings [residential and commercial], (4) manufacturing [the majority of the larger industrial sector], (5) fuels [with an emphasis on fuels for transportation], and (6) transportation. Each of these sectors comprises numerous technical systems, subsystems, and component technologies.[103] Many important research, development, and demonstration (RD&D) areas affect multiple energy sectors. The differences in capabilities and needs among the regions drive the RDD&D areas on which the various regions focus. The forums provided an avenue for participants to become better aware of RDD&D activities in their area and to explore ways to better leverage those activities. Popular topics were systems integration; carbon management and carbon capture, utilization, and storage (CCUS); advances in materials; and energy storage.

1. Systems Integration

Participants discussed the need for an integrated systems approach to address complexity across multiple sectors from a number of different directions, including grid modernization, communications, infrastructure, and power electronics at Pittsburgh; decentralized infrastructure, including microgrids and bidirectional energy flows as essential parts of grid modernization, at the University of Washington; and the interconnectedness of renewable energy, distributed energy, water storage, and desalination at UCLA.

The bidirectional communication and energy flows required to integrate storage with decentralized infrastructure and microgrids were discussed by multiple speakers in Pittsburgh and Seattle. Communications infrastructure will be crucial to making the modern grid work, according to panelists at the University of Pittsburgh.[104] A panel in Seattle summarized the system integration and modeling challenges: "The energy infrastructure of the future will be bidirectional. The transition to a decentralized infrastructure will bring significant challenges as it will break down services that utilities have traditionally provided based on a centralized model...We will need an energy infrastructure and service models that will help the utilities manage this transition in the future... With distributed energy resources, the key will be to develop new economic methodologies that capture locational resources, or the 'uberization' of energy."[105]

Gregory Reed, professor and director of the Center for Energy and Electric Power Lab at the University of Pittsburgh, commented, "When thinking about enabling technologies, including storage, think about the integration of all of those resources. This also highlights the role of power electronics. A few years ago, DOE estimated that 30 percent of all electricity passes through an inverter, but by 2030 that number is projected to be 80 percent. Not many programs focus on power electronics development though they should."[106, 107]

The heavy reliance on communication between generation, transmission and control, and demand assets also underlies discussions of "transactional controls" and the blending of the grid and the internet of things.[108] This transactional and communicative nature of the future grid will also place a premium on cybersecurity. At Purdue, a panelist suggested that a cybersecurity course be required for all electrical engineering students. The panelist stated that "since digital control and cybersecurity will be critical for stable operation of a grid and many other types of power generation, this should be a high priority."[109]

2. Carbon Management and Carbon Capture, Utilization, and Storage Technology

The need for investment and innovation to enable sustainable fossil energy technologies, including carbon capture, utilization, and storage was a substantial focus of discussions in regions with large coal, oil, or natural gas industries, such as Kentucky, West Virginia, Tennessee, and Texas. Carbon management was also a topic of interest in other regions interested in the deep decarbonization of energy production and utilization, including Washington and Colorado.

Emerging opportunities in technology innovation for supercritical CO_2 cycles, chemical looping, and oxy combustion that can substantially boost conversion efficiencies, as well as advanced carbon capture and storage technologies, were highlighted at the University of Kentucky and West Virginia University. Both explored the potential for creating new markets for coal and coal by-products, through the extraction of rare earth elements, conversion of captured CO_2 to chemicals and liquid fuels, and conversion of coal to high-value carbon products.[110]

Addressing the importance of carbon capture technology to reducing carbon dioxide emissions from coal-fired power generation plants, Roxann Laird, Director of the National Carbon Capture Center, commented at the University of Kentucky that "current technologies have higher capital and operating costs as well as lower efficiencies than conventional power plants without capture." She further noted that "capture technologies separate carbon dioxide from gases produced in electricity generation by one of three methods—pre-combustion capture, post-combustion capture, and oxy-fuel combustion"—and spoke to post-combustion accomplishments.[111] While addressing underground CO_2 storage and subsurface technologies, George Koperna, Vice President of Advanced Resources International, noted the following:

- Traditional storage reservoirs have high porosity or are depleted oil and gas reservoirs, which are not uniformly distributed across the United States. Some nontraditional reservoirs are on the horizon and have the potential to substantially increase storage opportunities.
- Carbon capture and storage (CCS) efforts have taken advantage of decades of CO_2-EOR (enhanced oil recovery) experience in industry as well as natural gas storage.
- A great deal of work has gone into the geologic assessment of reservoirs for CO_2 storage. However, most projects that have advanced are connected with the economic benefits of CO_2-EOR. Ultimately, a portfolio approach will be required to meet long-term storage needs.
- There are a number of next-generation technologies that are available for tracking the CO_2 in the subsurface.

According to Don Stevenson, Executive Director of the Gas Technology Institute, "transformational technologies are emerging, with great hope in modularization, advanced gasification, oxy, and super-critical CO_2 power cycles."[112]

"Coal will be an important fuel internationally and domestically for a long period of time," according to panelists at West Virginia University (WVU). Other observations were also noted at WVU:

- In the absence of market drivers, continued federal support of clean coal research and development (R&D) is critical. For example, incentives to replace existing coal with ultra-supercritical coal combustion instead of only natural gas, emphasis on adoption of technologies, and agreement with the CURC (Coal Utilization Research Council) CCS technology road map, and the public-private cost share model are important.
- Adoption of CCS technologies will require successful large-scale integration demonstrations because CCS technologies are still too immature for full commercialization, and corporate investments are not possible without a near-term market beyond enhanced oil recovery.
- Oxy-combustion technology and chemical looping technologies are promising and progressing well. High-temperature USC [ultra-supercritical] materials expertise feeds directly to supercritical carbon dioxide cycles.

- To address these issues "a Midwest Regional Carbon Storage Partnership [MRCSP] consists of 10 states in partnership and includes members from geology companies, universities, and other industries."[113]

Participants at other university forums made similar observations about the continuing importance of fossil fuels:

- Due to the legacy of oil and gas operations in Texas, it was noted that "as a region that pioneered the use of CO_2 for enhanced oil recovery, and has the largest installed capacity of CO_2 pipelines, the SXSWUS region is well poised to develop and demonstrate a low-carbon path for the nation through carbon capture and sequestration. Large-scale research programs are already underway along the Gulf coast, and large-scale industrial activity is in place in west Texas oil fields. As carbon management grows as a priority, regional innovation will be critical for developing new solutions."
- Timothy Lieuwen, speaking at the University of Tennessee, "emphasized hydrocarbon from natural gas is a good opportunity" and noted that "this makes a lot of sense for the Southeast, because there is an existing R&D powerhouse already in existence, as well as carbon capture sequestration sites." He also noted that "General Electric is experimenting with hydrocarbon from natural gas."
- The strong research capabilities in the Northwest region to address carbon capture and sequestration was recognized at the University of Washington. It was also noted that the need for such innovation is immediate, as new pollution controls and tougher emission standards are forcing older coal-fired power plants to shut down. CCS technology can help address some of the associated challenges, and "Montana is hosting a test of carbon sequestration in a formation near the Canadian border, which could help coal-fired power plants reduce the impact of carbon emissions."[114]

Panelists discuss regional energy needs in renewables, fossil fuels and carbon capture, water, and electric grid and transmission during the North Central/Inter-Mountain West Regional Clean Energy Innovation Summit, hosted by the Colorado Energy Research Collaboratory and held at the University of Colorado, Boulder, on September 19, 2016. (University of Colorado Boulder)

- At the Colorado Energy Research Collaboratory event, it was noted that CCUS can play an important role in decarbonization of the energy sector across the Intermountain West region. All the states in the region rely on fossil fuels for both electricity generation and export potential, and Wyoming is the largest coal-producing state in the United States. There are ample opportunities for CO_2 utilization in the region, including CO_2–EOR in the Bakken fields in North Dakota. Innovation opportunities exist for technologies that can enable CO_2 utilization, affordable advanced carbon capture, and safe and permanent carbon storage.

3. Advances in Materials

A recurring theme in the regional meetings was the need for advances in materials at every stage of the value chain, from innovating new advanced materials to improvements in the way that commodities are produced and utilized. Participants were concerned about vulnerability to the supply of critical materials and a need to find substitutes and to use these materials more efficiently. Post-workshop reports also suggested that there is a need to examine the potential for by-products/co-products, especially from energy commodities such as coal, as these can represent additional revenue streams for the firms and regions that benefit from them. Materials research is needed to develop high-efficiency solar cells, radiation-resistant materials for nuclear reactors, and high-temperature alloys for a variety of industrial applications. The discussion groups also recommended examining opportunities for process innovation in advanced materials manufacturing, as they felt that there are opportunities to improve efficiency, reduce emissions, and decrease businesses' energy costs.

The University of New Mexico decided to host its Southwest Regional Energy Innovation Forum specifically "to explore how new materials technologies can enable clean energy devices and processes and bring transformative low-carbon energy solutions to market."[115] The discussions covered new materials technologies for hydrogen, photovoltaics, energy storage, and advanced nuclear energy systems, among others. Panelists at the University of Washington were interested in innovation in functional and structural materials to enable emerging clean energy technologies, supply-chain considerations for key materials, and looking beyond energy production. For example, the transportation sector is an area where advanced alloys and welding agents are key to lightweighting vehicles and aircraft for increased energy efficiency. Panelists noted that "for every 10% reduction in the weight of a vehicle, you gain 6%–8% in efficiency improvements."[116] Advanced materials, such as high-temperature materials for combustion and heat exchangers, and coal as a source of non-fuel materials (e.g., rare earth elements embedded in coal, and carbon-based materials that can be derived from coal) were explored at the University of Kentucky:

- Jeff Phillips of the EPRI noted that the thermodynamic cycles used in coal combustion reach the temperature limits of ferritic steels, limiting the efficiency of combustion; higher-temperature materials could raise that efficiency.[117]
- In addition, advanced materials are important for developing compact and efficient heat exchangers that facilitate the use of supercritical CO_2 as a working fluid in a closed Brayton cycle plant. Rare earth materials are critical to a number of clean energy applications, and additional RD&D is needed to diversify supplies, develop substitutes, and use available materials more efficiently.
- Also at that meeting, the University of Wyoming introduced their three-pronged Research & Technology Development Plan for a broad range of carbon-based materials that can potentially be derived from coal:[118]
    - "converting Wyoming coal to intermediate liquids and solids,"
    - "identifying products that can be made from coal intermediates and derivatives," and
    - "establishing commercial and techno-economic viability of coal refinery."

In conclusion, across all energy sectors, advances in materials could dramatically accelerate the deployment and reduce the cost of new energy technologies.

4. Energy Storage

With a variation in focus, energy storage was raised at multiple events, both as a critical component of the electrification of transportation and as a major enabler of grid diversification and modernization. Arizona State University, Washington University, and UCLA panelists discussed the importance of combining storage with renewable energy technologies. This combination can assist states in meeting their clean energy goals. It was noted that the Washington Clean Energy Fund provided $14 million in grid modernization funding to deploy four batteries at three utilities, providing nearly 15 megawatt-hours of utility-grade storage.

Panelists discuss the importance of American Indian tribal lands to next-generation clean energy and efficient water use as part of the "Water-Energy from the Tribal Perspective" panel at the Southwestern Regional Water-Energy Nexus Event, held at Arizona State University in Tempe, Arizona, on September 8, 2016. (Arizona State University)

Observations were made at the Arizona State University that "the most significant obstacle to maximizing renewable energy sources is storage. As it currently stands, wind farms must be shut down if we have a surplus of solar energy. Hydroelectric generators go to waste without a method of storing excess power. Power companies, cooperatives, and administrators should not have to take generators offline because there is no way to store the energy."[119]

Similar points were made by speakers at UCLA, but they also discussed possible use of electric-vehicle (EV) batteries for distributed storage, stating, "The only classic 'renewable technologies' that can meet this demand are solar and wind, and the generation technologies are well developed. But these technologies will not suffice without utility scale storage. The only utility scale storage developed to date is concentrating solar power using 'power towers' or 'troughs' with large-scale thermal fluid bulk heat storage. Two large-scale plants have been developed in California, but have gained little traction with environmentalists or investors." Similar to Pittsburgh, the use of EVs as batteries for distributed energy storage was explored. Currently, "the UCLA campus serves as a living laboratory for this work, and hosts 217 prototype EV chargers for this project."[120]

While the discussions about the need for energy storage was consistent with UCLA and the University of Washington, participants at the University of Pittsburgh focused even more on the possibility of using EVs as a sort of mobile grid-storage capability:[121]

- Storage was viewed as a breakthrough technology, because of its ability to buffer the intermittency of wind and solar and to help integrate renewables into the grid. EVs, for example, generate interest for their ability to provide both transportation and mobile backup power during outages. The costs, benefits, and applications of different battery choices were a central topic of debate. Many promising storage options exist but have yet to find widespread use.
- Adam Rossi of Adam Solar Resources commented he thinks the EV market is taking off and that energy storage should be focused there. Instead of having a stationary battery bank, there could be a mobile battery bank that could be dispatched where it is needed.

- Mark McGranaghan, Vice President of Power Delivery & Utilization at EPRI, briefly touched on ten core priorities for grid modernization with one being in energy storage: Energy storage technology—including thermal storage—needs to be improved. While not currently economic in all areas, it will be very important in the future, especially at the customer level. In certain cases today, it can have unique value in meeting capacity needs and presenting a new value stream for customers.

Moving from the need for storage to materials for storage, discussions at the University of New Mexico included hydrogen as a storage medium as well as batteries. In addition to hydrogen, panelists discussed needed critical technology breakthroughs, and the need to understand materials degradation:[122]

- "…hydrogen has been identified as a zero-emission energy carrier with high potential for impact in the transportation sector and in energy storage applications. … Electrolyzer technology could be a solution that allows for greater value of hydrogen to be captured by storing it during periods of low usage and returning it to the grid during peak need."
- "Critical technology breakthroughs that are necessary today are advancements in battery materials to enable greater storage of electricity during non-peak periods; and in electrolyzer materials. … Despite substantial progress in the last 10–20 years, large-scale battery storage lags behind the rapid technological and cost improvements driving the deployment of solar and wind energy technologies. High current cost (> $100 per kilowatt-hour) coupled with low energy density and short cycle life limit the impact of batteries to accommodate the projected 1 terawatt renewable power to be integrated into the national base load. Innovations in materials used for electrodes and electrolytes are needed to create better batteries."
- "An understanding of materials degradation during battery operation and its impact on performance and lifetime is needed. The capability to analyze systems beyond electrochemical parameters is also needed to better understand how the storage system evolves. Such an advance may also inform fuel cells and photovoltaic technologies. Lastly, 'green' disposal methods and recycling of battery materials was also identified as a critical need for large-scale storage."

While the same themes for the need for batteries were echoed at Purdue University, manufacturing methods were the emphasis of the discussion.[123]

- "Energy storage is critical for expanding the generation of electrical energy and for grid and transportation applications. The development of batteries with higher power density will facilitate more efficient capture of energy from wind and solar by providing ways to store power until it is needed."
- "The production of batteries will need to be less costly and the adaptation of older technologies (such as Kodak's mass manufacture of photographic films) could serve as a model in the manufacture of batteries and other large volume energy storage products. Given the need to reduce the cost, this approach should enhance utilization of batteries. Renewable electrical energy harvested from the wind and the sun will need to be stored in a cost-effective and robust manner with a number of different configurations."

In conclusion, RD&D to enable low-cost, high-performance energy storage could enable transformational change across multiple sectors, including transportation and electricity production.

C. Sector-Specific Technology Innovation Issues

1. Electric Power Sector

Participants agreed with the need to decarbonize the electricity sector as well as modernize the grid, and many were already beginning to do so in their respective organizations and regions. There are huge opportunities—and interest in pursuing them—to incorporate more renewables, both distributed and centralized, as well as

a corresponding need for advancements in the technologies that enable this transition, such as energy storage and power electronics. In particular, discussions highlighted a need for advanced materials that increase the efficiency of photovoltaic cells, density and lifetime of batteries, and performance of power electronics, as well as innovations in advanced manufacturing that would allow these technologies to be produced cost-effectively at scale.

As documented in the Quadrennial Energy Review, "…the grid of the future will have to accommodate and rely on an increasingly wide mix of resources including central station and distributed generation (some of it variable in nature), energy storage and responsive load" … "The grid of the future should seamlessly integrate generation, storage, and flexible end use."[124] The forum discussions amplified this message and demonstrated that modernizing the electric power grid is a concern shared by decision-makers across the United States, though the priorities and approaches for modernization vary among regions.

The meetings in California, Delaware, Indiana, Pennsylvania, Tennessee, and Washington each included discussion of different aspects of the shifting technological, market, and regulatory landscapes.

Modernizing the grid was the primary focus of the event held at the University of Pittsburgh where panelists discussed the transmission and distribution infrastructure, integrated energy networks, microgrids, physical and cyber security, integration of distributed and clean energy resources, and core technologies such as energy storage, power electronics, direct current power, and others:

- "Pittsburgh, similar to much of our nation, is confronting aging, legacy-based infrastructure and the need to integrate new technologies such as renewable and distributed resources, energy storage, electric vehicles, and the internet of things. Workshop topics included the interplay of grid technologies, system design, communication and control, integrated energy networks, system operations, regulation, and its influence on markets and policy. Participants discussed strategies, initiatives, and collaborations that will help to drive regional innovation, facilitate solutions, and advance progress toward a modern grid that will have national and international impact."[125]
- Mr. Riazzi, President and Chief Executive Officer of Duquesne Light Company, cited several trends that are converging to drive change and create new uncertainties for utilities and the electric grid, including changing business models, new technologies, environmental objectives, and "the need to continue to provide reliable and affordable power to consumers, especially low-income customers."[126]
- Electric vehicles generated interest for their ability to provide both transportation and mobile backup power during outages.

The technological needs presented by integrating distributed and renewable generation into the electric grid to meet California's renewable portfolio standards were discussed at UCLA.

- Professor J.R. DeShazo from the UCLA Luskin Center for Innovation facilitated the roundtable discussion on identifying the region's immediate and long-term clean energy needs and challenges and laying the foundation for future collaborations between the participants and their associated institutions.[127]

The increasing interest of the community in data connectivity and integrating systems as well as the need for testbeds to prove-out technologies were explored at the University of Washington:

- Participants noted that "utilities have embraced 'big data' and have avoided outages due to new grid analytics control tools, but the decentralization of the future energy system will require them to move decision making out to the edge of their energy system. Connected devices are doing analytics now to create 'on premise' solutions."[128]
- Discussants also highlighted how "the Northwest region is integrating core competencies in smart grid and smart building concepts with the internet of things (IoT) to increase grid flexibility, reliability, resiliency and cyber security. The Pacific Northwest Smart Grid Demonstration deployed over 55,000 advanced meters and automated distribution across over 5 states and 11 utilities."[129]

A self-healing grid and stability of the grid, and cyber security were examined at Purdue. Doug Esamann, Executive Vice President at Duke Energy, said that "a key area for efficient use of electrical energy is the grid. One of the concepts currently being examined is a self-healing grid that will implement, divert, or redirect electrical power in response to extreme events. The discussion also focused on cyber-physical security of the grid. According to John McDonald of GE Grid Solutions, "a smart grid will need to be optimized on a regional basis; hence, a Regional Clean Energy Innovation Center could play a role, and could facilitate coordination on a larger national basis. Some questions to be addressed relative to cyber security include the close link of physical operations and computer control, and achieving a stable grid. There needs to be clear understanding of the risks that are involved."[130]

Maintaining grid stability was of interest at the University of New Mexico.

- Panelists noted that "one solution is to take the excess renewable energy generated on the grid and produce value-added products such as hydrogen for other uses including biofuels, metal refining and synthesizing ammonia for fertilizer, which renders these industries low carbon dioxide generating, as well."[131]

Panelists discuss materials solutions for electrical energy storage at the Southwest Regional Energy Innovation Forum: Materials Technology for Clean Energy, hosted by the University of New Mexico in Albuquerque on July 5, 2016. (University of New Mexico)

- "In the U.S., as more than 20% of renewable energy is added to the grid, it is either going to have to be stored, used in the transportation sector, or converted to value-added products, such as hydrogen. Hydrogen-fueled turbines could be a solution to this, creating hydrogen during load slumps for later use in energy ramps."[132]

The role of grid storage was placed in the context of bidirectional communication between sources and user/loads at the University of Tennessee.

- "David Wade (Electric Power Board of Chattanooga – EPB) said [grid modernization research] is extremely important, and that it needs a two-way model. This model would allow communication between different energy sources, storage capacity, and demand. He said that if limited to a one-way system, the grid cannot be fully integrated and has limited interconnectedness, sustainability, and adaptability. Tom King (ORNL) [Oak Ridge National Laboratory] noted that two-way communication provides the ability to change demand to fit supply—a huge paradigm shift. Passive loads would be replaced with a more dynamic and changing load."[133]

In conclusion, grid technologies that can integrate clean and distributed energy resources and new demand loads, advanced sensors and controls, real-time data analytics, and emerging information and communications technologies can respond to changing conditions, enable new technologies, improve energy and water efficiency, and improve the reliability and controllability of the U.S. energy system.

2. Electricity Production

The Quadrennial Technology Review (QTR) summarizes the current portfolio of electricity production as including a combination of reliable but aging base-load generation, evolving renewable resources, new natural gas plants, and new and pending nuclear and clean coal facilities. As the industry evolves to meet growing electrification and greenhouse gas reduction goals, challenges arise in optimizing the system, minimizing risks, and maintaining reasonable cost. Future developments will likely include a mix of three broad categories: (1) fossil-based generation with CCS, (2) nuclear energy, and (3) renewables, such as solar and wind. Technologies that enable higher efficiencies and effective pollution control are an essential complement to this evolving generation mix.[134]

Large regions with diverse energy resources, such as the Great Plains, the Midwest, the Mid-Atlantic, and the Northwest, which have significant access to fossil fuels, renewables, and nuclear power, have the potential to be "all-of-the-above" clean energy ecosystems, incorporating all three of the broad categories the QTR describes. Participants in Seattle, for instance, noted their range of resources from coal and oil to wind and hydro, and even Idaho's intent to host the nation's first-ever deployment of a small modular nuclear reactor.[135]

Electricity production options vary predicated on a region's energy resources and strategies, including policy, political, and economic considerations. In the Mid-Atlantic, for example, coal-fired electric power plants accounted for 94 percent of West Virginia's net electricity generation in 2015. In contrast, Delaware has ample access to natural gas, and natural gas-fired power plants provided 85 percent of the state's net electricity in 2015, but as a matter of policy, the state's renewable portfolio standard will require 25 percent of electricity to come from renewable resources starting in 2025.[136]

Similarly, Lieutenant Governor Eric Holcomb of Indiana noted the Midwest's hundreds of wind turbines, a solar (photovoltaic) farm at the Indianapolis International airport, and biofuel production facilities currently producing ethanol for fuel use, and added that coal and nuclear energy are also important and will make continuing contributions.[137] Secretary Moniz also addressed the need to make use of both fossil and renewable energy resources while discussing marine energy and ocean resources in the Northeast: "There are a lot of ocean resources, but we also have hydrocarbons here. It could be good to twine them both together."[138]

Other regions may focus on a subset of the power categories mentioned in the QTR; in some cases, electricity production choices are affected by grid availability and grid-technology advances. For instance, the UCLA event noted that "with abundant sunlight and wind resources, and a mild climate year-round, southern California is well positioned for a transition to renewable energy."[139] Conversely, discussions in fossil-fuel rich regions, such as Texas and West Virginia, emphasized the benefits of extraction innovations such as fracking, the need for continued research, the importance of competing globally, and the need for expanded transmission capabilities if those regions are to make use of their renewable resources, particularly wind.[140]

Discussions across the many regions of the United States made it clear that a combination of electricity generation options, supported by an increasingly flexible and interconnected grid, will be required to meet increasing power needs and the security, economic, and environmental challenges facing the country. The grid and the mix of generation options must be able to respond to variations not only in demand but also in current availability and pricing *within* the generating mix.

3. Buildings Technology

Advances in building technologies represent significant potential for energy savings and greenhouse gas reductions. The meetings at UCLA, University of Tennessee, Knoxville, and the University of Washington touched on aspects of efficiency improvements, new materials and manufacturing approaches, and integrated systems in smart buildings.

UCLA panelists were exploring "feasible pathways for doubling the efficiency of existing buildings by 2030":[141]

- William Torre, from the University of California at San Diego, commented that "the population of built environments in California is highly diversified.…In general, retrofits focused on these earlier generations of buildings have the potential to yield a large portion of this statewide goal to double efficiency...A holistic approach to energy supply and consumption needs to be considered including both the electric power consumption and heating and air conditioning requirements. Much greater efficiencies can be achieved through combined heat and power applications."

The buildings discussions in Tennessee focused on the potential impact of advanced materials and manufacturing, and particularly 3D/additive manufacturing. Platt Boyd, founder and Chief Executive Officer of Branch Technology, said, "Modification and design of buildings to save energy is a huge opportunity." He said that "3D printing building components can save up to 50% in small-scale construction." He also said that "39% of landfill waste is produced by the construction industry."

New types of partnerships were again noted as very important for the advancement of building technologies. As an example, ORNL has worked with a local start-up (Branch Technology) on the technology of 3D printing of building structural elements, and ORNL also operates the Buildings Technology Research and Integration Center user facility.

In sum, discussions in multiple forums and workshops indicated that while current technologies can improve the efficiency of buildings, further RD&D can deliver technologies to increase the efficiency of both new and existing buildings. In particular, smart buildings (structures that record, transmit, and optimize their energy

Speakers on the "Innovation, Combustion and CCS Panel" took questions from the audience at the Regional Energy Innovation Forum, hosted by the University of Kentucky in Lexington, Kentucky, on April 21, 2016. (University of Kentucky)

profile) are a key building block for smart cities. Additional research is needed to identify the best strategies for integrating smart buildings into the smart grid.

4. Manufacturing Technology

Manufacturing was a frequent topic of discussion as it is considered a driver of economic growth and, in particular, a pathway that leverages the unique human resources of regions seeing a downturn in certain industry sectors. For example, manufacturing was featured prominently in discussions in Indiana, Kentucky, New Mexico, Tennessee, Washington, and West Virginia. Topics were as varied as metals development, additive manufacturing for nuclear fuels and automotive/aerospace applications, batteries, scalability of bio-based materials and nanotechnology, optimizing operations through hardware and software, and the challenges of matching companies' capabilities across a supply chain.

Challenges faced by bio-derived materials and the issue of scalability for new materials and nanotechnology were discussed at Purdue. For bioproducts, challenges include, but are not limited to, "transportation of biomass from the point at which it is generated (i.e., the farm) to the point of where it is processed (i.e., fermentation facility). … A key impediment is the need for massive scale-up of process technologies and manufacturing capabilities for bioproducts derived through biological, biochemical, and chemical catalysis and separations. The correct cost and price points will need to be defined and the quality of products will need to be better than existing products derived from less expensive petroleum. Life cycle analysis will be needed to guide choices for smart designs of production facilities and generation of renewable feedstocks in a sustainable manner."[142] While discussing the interplay of new materials with manufacturing, participants noted, "The development of new materials, and manufacturing of these materials in new ways, will impact clean energy through improving efficiency (and therefore generating less CO_2), as well as by providing materials that can be used in aviation, transportation systems, and for energy generation and storage."[143]

The importance of manufacturing to the Kentucky economy, and particularly aluminum production and fabrication, was reinforced by panelists from the Aluminum Association and ORNL who discussed examples of innovation in development of new materials and alloys and technologies for multi-material welding, as well as ORNL's work on additive manufacturing.

The potential application of additive manufacturing to nuclear fuels was of interest to speakers at the University of New Mexico.

Advanced and efficient manufacturing techniques (including additive manufacturing), particularly for the automotive and aerospace industries, were discussed at the University of Tennessee. Panelists noted that "conventional manufacturing and engineering processes are adapting at an unprecedented rate to improve, [by] reducing production times and increase[ing] energy efficiency. Efficient manufacturing techniques and clean energy sources are proving themselves a very strong and ever-increasing economic driver in the region."[144] Peter Hoffman of Boeing said that "their production rates are very high for aerospace standards and going higher. So, the ability to work in a facility doing high-level work, underpinned by good theory (and de-risking these new processes before they show up on the floor) is highly valuable."[145] It was observed that advanced manufacturing and aerospace industry research is a critical investment.

Discussion of manufacturing often turned to batteries at the University of Washington, and the related "ecosystem" issues (e.g., supply chain) of the relationships between large companies and start-ups were also addressed. For example, when discussing challenges of a former start-up company, known as EnerG2, supply chain was at the top of the list. "A start-up cannot sell battery materials to manufacturers because the supply chain is too vulnerable. BASF [which bought the start-up EnerG2] was therefore a big factor in EnerG2's success."[146]

At West Virginia, several speakers addressed the need for advances in manufacturing on a number of fronts:[147]

- Denise Swink of the Smart Manufacturing Leadership Coalition discussed intelligent manufacturing and a systems approach to manufacturing technologies and plant/business operations at West Virginia University noting, "By building a smart manufacturing database of hardware and software, companies can pay for what they need when they need it, rather than being locked into one technology. She added that most manufacturing is designed to an energy efficiency level only after the utility bills are paid. A systems integration approach would give them the tools and capabilities to drive down the risk of trying new technology." She noted that opportunities exist to invigorate a better supply chain; shared manufacturing challenges and innovation approaches on the enterprise level; and noted that her organization infuses more intelligence in manufacturing, commenting that
    - the majority of manufacturing is still not technologically sound and needs to increase focus;
    - a group of companies has collaborated to build a prototype for a smart manufacturing database of hardware and software to solve manufacturing problems while creating a lively marketplace; and
    - if you pay for what you need when you need it, you're not locked into one technology, and you can grow where you want to. It eliminates non-integration in a plant, and a cloud-based platform can be used to knit together these things.
    - most manufacturing is designed to an energy efficiency level only after the utility bills are paid. Give them the tools and capabilities that drive down the risk of trying new technology.
- Edward Herderick, of GE Corporate Supply Chain and Operation, noted that "there is an opportunity for all industry in West Virginia for manufacturing and supply chain and he spoke to the industrial revolution between information technology and physical assets and how additive manufacturing fits into place."

In conclusion, several RD&D needs related to advanced manufacturing were identified, including the need to expand advanced manufacturing across multiple industrial sectors. Examination of opportunities for process innovation in advanced materials manufacturing was suggested as a pathway to improving efficiency, reducing emissions, and decreasing energy costs for businesses. In the long term, industry partnerships and "smart" processes will be essential for increasing the scale of advanced clean energy manufacturing.

5. Fuels

A number of regionally focused opportunities for innovation in fuels conversion technologies were discussed at events in California, New Mexico, Indiana, Texas, and Washington, with technologies ranging from both agricultural and nonagricultural biofuels and bio-based products, hydrogen production, transportation and use, to the importance of partnerships in testing new products and supply chain innovations.

Nonagricultural biofuels (such as algal strains) were discussed at UCLA, and participants commented that "other fuel sources may include biomethane capture, and power-to-gas (P2G) technologies."[148] George Minter, of SoCalGas, noted that "power to gas technology … uses excess renewable electricity produced during times of low demand, which can be directed through water in an electrolysis process to produce hydrogen, which is essentially stored energy that can be blended into the gas pipeline system or 'methanated' … and delivered as gas for heat, or for power at a later point in time. This adds additional renewable gas volumes to continue the 'decarbonization of the pipeline.' P2G is a promising electric-to-gas storage technology that has a broader application and potential than mere battery storage."[149]

Hydrogen, as a fuel for fuel-cell vehicles, was explored at the universities of New Mexico and Texas, with participants at both sharing observations about the hydrogen infrastructure. Renewably produced hydrogen can provide "value-added products such as hydrogen for other uses including biofuels, metal refining and synthesizing ammonia for fertilizer, which renders these industries low carbon dioxide generating, as well" according to participants at the University of New Mexico. When discussing hydrogen technology

and infrastructure, they noted that "hydrogen is an enabler of green processes and has the capacity to deeply decarbonize the energy system, including industrial processes and transportation. … An important consideration in the broader introduction of hydrogen is the further development of the hydrogen infrastructure."[150] Participants at the University of Texas stated that "the vast majority of existing hydrogen infrastructure lies along the Texas coastline to support industrial customers" and that "hydrogen could solve multiple problems—such as using variable wind and solar for its production, which firms up grid reliability and reduces emissions while serving multiple customers, such as steel mills, refineries, and transportation hubs."[151]

The economics of biofuels as well as the opportunity to coproduce other bioproducts along with the biofuels were explored at Purdue where the panel on biomass emphasized that "a sustainable supply of biomass feedstock must be available. However, low oil prices make it difficult to keep biofuels competitive."[152] "The coproducts may find use in the manufacture of plastics, coatings, and other chemical products for which an oxygenated … molecule may have superior properties."[153]

The strong Northwest interest in both electric vehicles and in biofuels and its focus on aviation biofuels were discussed at the University of Washington. It was noted that "liquid fuel production from renewable sources is strategic for decarbonizing commercial aviation, an area of historic strength in the Northwestern region."[154] Partnerships that form based on the regional interests and strengths were identified as important to the success of advancements in technologies and fuels. For example, it was stated that "the strong regional focus in aviation biofuels has led to several partnerships—one between WSU [Washington State University] and MIT [Massachusetts Institute of Technology] to lead a new FAA [Federal Aviation Administration] Center of Excellence called ASCENT (alternative jet fuels and environment), and the other between PNNL [Pacific Northwest National Laboratory] and WSU to found a joint laboratory located at the WSU Tri-Cities campus called BSEL – the Bioproducts, Sciences, and Engineering Laboratory."[155]

In conclusion, accelerating the transition from a high-carbon to a low-carbon economy calls for RD&D to balance a mix of fossil fuels, bioenergy fuels, and hydrogen fuels. Liquid fuel and hydrogen production from renewable resources is a strategic resource for decarbonization.

6. Transportation

Panelists recognized the need for continued technological advancement inside and outside the vehicle, and both evolutionary (such as improved vehicle efficiency and cleaner fuels) and revolutionary (such as autonomous vehicles and connected transportation systems) technologies were addressed. Infrastructure needs such as hydrogen pipelines, a sustainable supply of cost-competitive biomass to form clean liquid fuels, and electric vehicle charging stations were recognized. Electric vehicles can be used to reduce emissions in the transportation sector while also acting as electricity storage to help grid reliability. Advancements in materials technologies are critical to success in the transportation sector. Advanced alloys and welding agents are key to light-weighting vehicles and aircraft; catalysts need to be cheaper and scalable to help the competitiveness of fuel cell vehicles; and reaction chemistry must be studied to commercialize the next generation of electric batteries. Beyond the vehicle, smart transportation systems can integrate vehicles, and public-private partnerships (PPPs) can assist the adoption of clean shared vehicles.

To this end, participants focused on a broad range of opportunities and pathways for transitioning the transportation sector to an integrated system that is interconnected with other energy systems (e.g., vehicle-to-grid capability), accelerating adoption of electric vehicles, innovating energy and manufacturing technologies for transportation, developing new materials, improving energy storage capabilities, and exploring hydrogen as a zero emissions carrier. Based on the transportation needs or goals and the research capabilities unique to the regions, panelists explored aspects of these topics in California, Indiana, New Mexico, Pennsylvania, Texas, and Washington.

Challenges to how southern California will reduce petroleum use in cars and trucks by 50% by 2030 were explored at UCLA:

- William Torre, from the University of California at San Diego, noted that "more convenient and efficient charging infrastructure, associated control systems, and regulatory reform is needed to foster higher penetration of EVs. Development of smart charging and vehicle-to-grid (V2G) capability in EVs and associated electric charging infrastructure in addition to making charging more available and affordable will also help to meet the renewable generation goals…"
- Bob Musselman, on behalf of LA Cleantech Incubator, stated that "the obvious answer is accelerated adoption of EVs. EV adoption requires the following: (1) Continued subsidies at the federal and state level, along with perks such as high-occupancy vehicle (HOV) lane access; and (2) As EV battery technology improves and charging times are shortened, the demand for very high charge rates at charging stations will put pressure on higher amperage delivery at local charging stations, a challenge for local utilities for which there is little compensation for infrastructure (larger local transformers) improvements."[156]
- The Angeleno Group noted that they have "seen a trend of smarter transportation practices that can play a promising role in reducing petroleum usage of cars and trucks in southern California. From applying data analytics to traffic signals in Los Angeles, to enterprises partnering with fleet logistics companies and the proliferation of crowd-sourced cars and trucks, southern California is on the road towards better transportation efficiency...."[157]

Transportation was discussed in the context of energy storage, the development and manufacturing of new materials that can be used in aviation and transportation systems, energy systems networks (e.g., a partnership of utilities and automotive transportation currently being developed through shared-ride vehicles), and improving adoption of electric vehicles at Purdue. According to panelists, Indianapolis is indeed testing a "shared-ride basis" to improve the adoption of electric vehicles.

Innovation in energy and manufacturing technologies that have reduced energy consumption in motor vehicles through development of new materials and alloys and technologies for multi-material welding was an important topic at the University of Kentucky.[158]

Hydrogen as a "zero-emission energy carrier with high potential for impact in the transportation sector and in energy storage applications" and "materials innovations that are being made by exploring alternate battery chemistries and concepts" were highlighted at the University of New Mexico (UNM):

- "Hydrogen is an enabler of green processes and has the capacity to deeply decarbonize the energy system, including industrial processes and transportation, which are responsible for over 50% of carbon dioxide emissions."
- Speakers noted that "innovations in materials used for electrodes and electrolytes are needed to create better batteries" and that "renewable energy placed on the grid using scaled nonaqueous redox flow batteries could recharge the U.S. fleet of electric vehicles powered by Li-S [lithium-sulfur] batteries."
- Participants at UNM noted that catalysts need to be cheaper and scalable to help the competitiveness of fuel cell vehicles. UNM pioneered a method for synthesis of platinum group metal-free (PGM-free) catalysts for fuel cells and electrolyzers. This UNM PGM-free catalysts technology was scaled-up and developed for various markets by Pajarito Powder, LLC, an Albuquerque start-up."[159]

Electric avenues as part of "Smart Pittsburgh," electrifying transportation, and the use of electric vehicle batteries were central to a discussion at the University of Pittsburgh:

- The "Smart Pittsburgh" proposal laid out an ambitious plan to develop "electric avenues" pairing DC power infrastructure, solar generation, battery storage, and electric vehicle charging stations.
- The "Core Technologies" panel at the University of Pittsburgh noted that "unlike stationary batteries that might sit stagnant until there is a problem with the grid, electric vehicle batteries let people drive their cars around throughout the day and still have a battery backup for a grid-down scenario."[160]

Panelists at other events noted that "advancements in materials technologies are critical to success in the transportation sector. Jason Swager from Volkswagen Group of America noted that a Southeast energy innovation agenda should include lightweight materials, carbon-fiber research, and manufacturing cost-reductions in its materials portfolio."[161] While discussing decarbonizing and electrifying transportation, panelists at the University of Texas explored "proxies for electrification" such as electrically produced hydrogen. They observed, "With an abundance of low-carbon solar and wind resources, the [Southwest] region makes an interesting test case for electrifying and decarbonizing transportation."[162]

In conclusion, the transportation sector was widely recognized as being an important component of an integrated energy system and in moving to a clean energy economy, with both electric vehicles and hydrogen technology playing a key role. Opportunities for improving the transportation system are huge, with many RD&D needs. PPPs and energy systems networks such as the partnership of utilities and automotive transportation discussed at Purdue are recognized as essential to enabling the transition of the transportation sector.

5 Moving Forward

The regional events serve not only as a forum for the exchange of ideas, but also as a catalyst for further action to expand regional innovation ecosystems. For example, panelists at the University of California at Los Angeles noted that "accelerating clean energy innovation will require two major accomplishments: (1) increased level of energy-related research and demonstration projects, and (2) support for accelerating the transition of innovations developed in research environments toward commercialization."[163] To achieve the state, federal, and international goals in southern California and nationwide, for that matter, requires a drastic emphasis on innovation, which, in turn, will require additional investment in feasibility assessments, road-mapping, and core-focused research. Studies have shown that the energy sector has received a small portion of the overall investment in research. Acceleration of the clean energy sector will require renewed emphasis on research and demonstration projects.[164]

The Institute for Advanced Composites Manufacturing Innovation, a U.S. Department of Energy (DOE)-sponsored Manufacturing Innovation Institute that is part of the National Network for Manufacturing Innovation (NNMI, recently renamed *Manufacturing USA*), was offered as a regional partnership model for consideration at the Southeast forum. Their report notes that "strategies for how the region can contribute to breakthrough innovations in materials technologies for clean energy are being developed in the wake of the forum and will continue to take shape as the partnership develops."[165] Nick Irvin, Program Manager for Advanced Energy Systems at Southern Company, said that "collaborative efforts tend to start small, and grow with successes. DOE could foster a staged collaboration approach with the intent to grow over time. He noted that there is a need to be agile in support of collaboration, which can be messy at times. DOE could develop targets for energy and industry sectors, built around a staged approach. This would accommodate a variety of activities through the innovation life cycle."[166] As a key priority for an energy technology innovation agenda, Dan Stout, Senior Manager for Small Modular Reactors at Tennessee Valley Authority, noted, "The Southeast should have a strengths and weaknesses assessment done, before determining the course of action." He further noted that there is significant nuclear expertise in the region and that there is a growing need for clean, reliable, sustainable electricity. Adding to the conversation, Jason Swager, Manager of Electrical Research and Development at Volkswagen (VW) Group of America said that "from the automotive side, a Southeast energy innovation agenda should include lightweight materials, energy storage, smart vehicles, and smart cities;" and that "increasing carbon fiber research and reducing the cost of the manufacturing is important."

Panelists at the Regional Clean Energy Innovation Forum hosted by Purdue University concluded that the university and its partners "could act as a lens to focus regional activities on robust and internationally relevant solutions in clean energy," with the Midwest having the

potential to become a role model for other centers.[167] The report from the Midwest forum noted a consistent message from their five panels that "the time has come to address clean energy that is most appropriate for a given geographical area, and for which solutions and living laboratories to test and prove the solutions, is best done on a regional basis."[168]

A group of regional research and business stakeholders who participated in the Northwest Regional Clean Energy Innovation Partnership Workshop made a commitment to collaborate in developing a regional road map for clean energy innovation.[169]

Across the events, the participants highlighted that the rationale for taking a regional approach to clean energy technology innovation is strong, and the use of regional partnerships to coordinate research, development, and demonstration (RD&D) efforts affords a diversity of opportunities to address climate concerns, energy security, air and water quality, economic competitiveness, and workforce development on a regional scale. By initiating the regional dialogue, the major research universities have highlighted the importance of getting a better understanding of the similarities and differences among regions to inform the shaping of partnerships that could maximize synergies and resulting impacts for clean energy innovation.

These forums informed key stakeholders within and among regions about the vast array of opportunities and challenges in moving to a clean energy economy as well as capabilities and activities that are well underway that could collectively accelerate innovation and positively impact economic and workforce development if synergies are maximized. They highlighted the need for regional partnerships, envisioned as cost-shared, public-private partnerships that will develop regional RD&D portfolios tailored to the characteristics of the regions that they serve. Many forums closed with a commitment to regularly convene to continue to explore how to understand and improve their energy innovation ecosystems.

Appendix A

Summaries of Events and Agendas for University-Hosted Events

Arizona State University, September 8, 2016

Brown University, April 18, 2016

Colorado Energy Research Collaboratory at Boulder, September 19, 2016

Purdue University, June 9, 2016

Tuskegee University, September 8, 2016

University of California at Los Angeles, May 10, 2016

University of Delaware, May 13, 2016

University of Kentucky, April 21, 2016

University of New Mexico, July 5, 2016

University of Pittsburgh, June 24, 2016

University of Tennessee, May 23, 2016

University of Texas at Austin, May 9, 2016

University of Washington, August 15, 2016

West Virginia University, September 12, 2016

- Arizona State University hosted a full-day event entitled "ASU Water-Energy Nexus Event" that included approximately 75 participants from six states (Arizona, California, Colorado, New Mexico, Utah, and Nevada) and focused on the "Southwest" regional innovation ecosystem and technologies at the water-energy nexus. Attendees included seven regional universities, four national laboratories, and major corporations, including Coca Cola and Intel. Two main components included enhancing research and development (R&D) capacity in the Southwest for regional challenges and the critical role of regional entrepreneurship, start-up development, and economic development. Four panels were held on the Southwestern challenges and opportunities in water-energy, de-risking the value chain for early adopters of clean related tech innovation, water-energy from a tribal perspective, and university research initiatives at the water-energy frontier. Additionally, a "lightning round" was held on envisioning the future of water-energy governance. Themes were related to regional energy challenges including governance of existing water resources, wastewater treatment, etc.; water technology R&D (including enhanced water recovery); and industrial value chain for water from basic research to university testbeds and policy challenges for early adopters.
- Brown University hosted a two-hour roundtable discussion entitled the "Rhode Island Energy Innovation Roundtable" that included approximately 35 active participants and then additional students, faculty, press, and staff present but not participating, representing three states (Rhode Island, Connecticut, and Massachusetts) for the "Northeast" region. The discussion covered a variety of topics including offshore wind energy, ocean energy, natural gas, and energy efficiency. Participants also discussed the regional partnership concept and suggested regional topics of interest.
- The Colorado Energy Research Collaboratory at Boulder hosted a full-day event entitled "Regional Clean Energy Innovation Summit" for the "North Central/Inter-Mountain West" region among four research institutions—the Colorado School of Mines, Colorado State University, National Renewable Energy Laboratory, and the University of Colorado at Boulder. The event included approximately 195 representatives (163 in-person attendees and 32 on the live stream) from ten states (Colorado, Idaho, Kansas, Montana, Nebraska, New Mexico, North Dakota, South Dakota, Utah, and Wyoming) spanning from Colorado to the Dakotas in the North Central and Inter-mountain West region. The opening remarks focused on how local, regional, and national innovation clusters and multistate collaboration can help solve energy challenges in the 21st century. The event featured a panel on "Regional Energy Needs." Keynotes on "Federal and State Government Perspectives" and "Federal Perspectives on Regional Clean Energy Innovation" were provided. Additionally, four facilitated topic breakout sessions were held on grid storage; energy-water-food nexus, energy and climate, and renewables, with outcomes reported out during a plenary session. A final session that summarized the outcomes of the discussions for clean energy innovation in the region concluded the event.
- Purdue University hosted a full-day event for the "Midwest" region entitled "Regional Clean Energy Innovation Forum" that included approximately 195 people from eight states (Minnesota, Illinois, Indiana, Iowa, Michigan, Missouri, Ohio, and Wisconsin). The event held four panels that focused on energy storage, biomass/synthetic biology, wind and grid integration, and critical materials and sustainable manufacturing. The panels focused on current status, future opportunities, and technology innovation as a driver for regional energy and economic development. The event concluded with planning for next steps to accelerate energy technology innovation in the region. Threading themes were that efficient energy generation and utilization have both a regional and national basis; a Purdue University-led regional energy center would focus its scientific and engineering basis to address the bio-economy, wind and solar energy, grid integration, advanced materials energy storage technology, and PPPs in the Midwest; and staffing of high technology activities in clean energy will require an appropriately educated and trained workforce.
- Tuskegee University hosted a full-day event entitled "Advancing Minorities' Interest in Engineering College Opportunity Summit" with over 300 participants from eleven states (Alabama, Delaware, Florida, Georgia, Mississippi, Maryland, North Carolina, Tennessee, Texas, and Virginia) and

the District of Columbia. The summit convened presidents from Historically Black Colleges and Universities (HBCU), industry leaders, members of Advancing Minorities' Interest in Engineering (AMIE), college students, non-governmental organizations, and state, local, and federal officials to discuss regional innovation opportunities. Additionally, this event sought to encourage college presidents, industry leaders, and government agencies to make new commitments to improve sustainable community partnerships and ecosystems that increase college admittance and degree completion and equitable access to high quality science, technology, engineering, and math (STEM) programs by diverse populations.

- The University of California, Los Angeles, hosted a 3.25-hour roundtable event entitled "Southern California Clean Energy Innovation Ecosystem" for the "southern California" region that included approximately 30 participants from California. The event focused on how southern California will meet California's goal of getting 33% of its energy from renewable resources by 2030 and 50% by 2030; reduce petroleum use in cars and trucks by 50% by 2030; double building efficiency and make heating fuels cleaner; accelerate clean energy innovation; transition human resources to a clean energy economy; include and encourage all southern Californians to engage in energy innovation and new energy technology development; and explore the role that relevant research organizations might play in Mission Innovation.
- The University of Delaware hosted a full-day event entitled, "National Lab Day in Delaware." The event convened over 200 university faculty, staff, and students, as well as top leadership from the national laboratories and industry, and government representatives from Delaware and New York. The event's theme was clean energy challenges and opportunities and featured an overview of the energy, science, cyber security, and grid resiliency research, development, demonstration, and deployment activities at the national laboratories. It included a fireside chat with the U.S. Energy Secretary, Ernest J. Moniz, and Senator Chris Coons moderated by Dennis Assanis, President-Elect of the University of Delaware. Concurrent sessions were held on clean energy technology innovation in energy generation, storage, the grid, and cyber and grid security.
- The University of Kentucky hosted a full-day event entitled the "Regional Energy Innovation Forum" that included approximately 90 people from nine states (Illinois, Indiana, Kentucky, Missouri, Pennsylvania, Tennessee, Virginia, West Virginia, and Wyoming) for the "Appalachian" region. Throughout the day, speakers highlighted the role of innovation in coal with panels on innovation, combustion, and carbon capture and storage, new value creation from coal, and technology innovation as a driver for regional energy and economic development. The panel discussions focused on future directions for coal utilization technology research, such as carbon capture storage and utilization, rare earth elements, advanced manufacturing, advanced materials, and chemicals.
- The University of New Mexico hosted a full-day event entitled the "Southwest Regional Energy Innovation Forum: Materials Technology for Clean Energy" that included approximately 120 people from five states (Arizona, Colorado, New Mexico, Utah, and Idaho) for the "Southwest" region. The event was focused on the theme of materials technologies for clean energy, and panel members discussed the state of materials technology and the greatest challenges in hydrogen technology, solar conversion, electrical storage and nuclear energy. Panelists highlighted the latest commercialized and emerging technologies in each of the four areas from the standpoint of materials-enabling breakthroughs, and presented potential revolutionary new approaches to clean energy production and utilization that can be enabled by advances in new materials technologies. The need for critical experimental research, in conjunction with predictive modeling for materials properties, and emerging modes of collaboration between academia, the national laboratories, and industry were detailed and explored.

- The University of Pittsburgh hosted a full-day event entitled the "Mission Innovation Workshop on Grid Modernization" that included approximately 80 people from four states (Ohio, Pennsylvania, Virginia, and West Virginia) for the "Pittsburgh" region. The event was focused on modernizing the nation's vast and complex electric power delivery system. Workshop topics included the interplay of grid technologies, system design, communication and control, integrated energy networks, system operations, regulation, and its influence on markets and policy. Participants discussed strategies, initiatives, and collaborations that will help to drive regional innovation, facilitate solutions, and advance progress toward a modern grid that will have national and international impact.
- The University of Tennessee, Knoxville, hosted a full-day event entitled "Southeast Regional Energy Innovation Workshop" for the "Southeast" region that included approximately 150 representatives from seven states (Tennessee, Alabama, Florida, Georgia, Mississippi, North Carolina, and South Carolina). The event featured three roundtable discussions on the regional energy innovation industry, regional energy innovation with perspectives of university presidents in Tennessee and the surrounding states, and innovation-graduate education. The event also included two panels on Department of Energy capabilities to deliver innovation to industry and tech to market innovations (with focus on the National Network for Manufacturing Innovation [NNMI] Power America at North Carolina State University and NNMI Institute for Advanced Composites Manufacturing Innovation [IACMI] at University of Tennessee and Oak Ridge National Laboratory [ORNL]). Threading themes were related to strengthening the capabilities for advanced materials and manufacturing for the automotive and aerospace industries and the role of scientific facilities and computing in enabling innovation.
- The University of Texas at Austin hosted a 2.5-hour roundtable discussion entitled "Integrating People, Technology, and Natural Resources for a Clean Energy Future" with approximately 30 people from two states (Texas and New Mexico) for the "south by southwest region of the United States." This discussion was motivated by the desire to explore the ways by which regional PPPs can be leveraged to achieve significant advances towards a cleaner, more resilient, secure, reliable, and affordable energy future. The areas of regional excellence that received the most discussion were oil and gas, clean energy entrepreneurship, and integrated energy-water management.
- The University of Washington hosted a full-day event entitled "The Northwest (NW) Regional Clean Energy Innovation Partnership Workshop" that included approximately 120 participants from four states (Washington, Idaho, Montana, and Oregon) for the "Northwest" region. The event was focused on the future of clean energy and ways the Northwest innovation ecosystem can accelerate the development and deployment of clean energy technologies that meet regional, national, and international goals for decarbonization while also stimulating regional economic development and advancing U.S. industrial competitiveness globally.
- West Virginia University hosted a full-day event entitled "Innovation Workshop for the Mid-Atlantic and Appalachian Region" that included approximately 80 representatives from seven states (West Virginia, Delaware, Maryland, Kentucky, Ohio, Pennsylvania, and Virginia). Six panel discussions were held on the future of clean energy, regional challenges and opportunities, innovation opportunities for fossil fuels in a future low-carbon economy, innovation opportunities in other clean energy technologies, policies facilitating sustainable clean energy development, and regional innovation investment and commercialization. There was also a session on the Tri-state Governors' Regional Cooperation. The threading themes were of an energy strategy for the 21st century, advances in and decarbonization of fossil fuel power production, advanced manufacturing, policy support for sustaining clean energy development, and innovation investment and commercialization in the region.

Agendas from the events follow.

Arizona State University Water-Energy Nexus Event

Tempe, Arizona • September 8, 2016

AGENDA

10:00-10:15	Welcome and ASU Water R&D: Panch and Betsy
10:15-10:45	Framing the Water-Energy Nexus in the Southwest
	Jon Sabo to introduce regional congressional representatives (likely videos) and other leaders
10:45-11:45	Municipal Panel: Regional Energy Challenges
	Moderator: Jim Lochhead, CEO/Manager, Denver Water or James Eklund, Colorado Water Conservation Board Panelists: Governor Lewis of the Gila River Community; Pat Mulroy of Brookings (formerly GM of Southern Nevada Water Authority for 25 years); Rob Oglesby, Director of the California Energy Commission; Steve Johnson | Energy Management and Marketing Office Manager Western Area Power Administration, Western Area Power Administration (WAPA); Greg Stanton, Mayor of Phoenix
11:45-12:15	Lunch Buffet
12:15-1:30	De-risking the Value Chain for Early Adopters of Clean Tech Innovation
	Moderator: Robin L. Newmark Associate Laboratory Director, Energy Analysis and Decision Support, National Renewable Energy Laboratory Panelists: Donald E. Brandt, APS; Jonathan Friedman, GE; Kris Mayes, Blue Ribbon Panel on Energy Water Nexus; Kerry McCalman , Advisor, US Bureau of Rec Senior Hydropower; Anna Ewing, CEO of Colorado Office of Economic Development and International Trade (OEDIT) and Executive Director of the Colorado Innovation Network; Theodore "Ted" C. Cooke, Deputy General Manager, Finance and Administration at the Central Arizona Project, (CAP)
1:30-2:30	Spotlight Panel: Water-Energy and Irrigation from the Tribal Perspective
2:30-3:00	ASU Leadership introduction and DOE Deputy Secretary Keynote: Mission Innovation and Regional Partnerships
3:00-4:15	Regional University VPR Panel: Unmet R&D Needs at the Water-Energy Nexus
	Moderator: Jan Dell, formerly VP CH2M OR Dr. Kristina M. Johnson, former U.S. Under Secretary of Energy, Cube Hydro Partners Panelists: Dr. Paul Alivisatos, Vice Chancellor for Research, Berkeley; Dr. Anthony Dean, Senior Vice President for Research and Technology Transfer (or Paul Johnson), Colorado School of Mines; Dr. Van D. Romero, VPR, New Mexico Tech; Dr. Betsy Cantwell or Dr. Panchanathan, VPR/SRO, Arizona State University
4:30-5:30	Reception

Roundtable Conversation on Clean Energy Innovation

Institute for Computational and Experimental Research in Mathematics

Brown University • Providence, Rhode Island • April 18, 2016

10:30 a.m. **Welcome**
Dr. Richard Locke, Provost, Brown University

10:35 a.m. **Opening remarks**
Senator Sheldon Whitehouse
Congressman Langevin
Congressman Cicilline

10:45 a.m. **Mission Innovation**
Dr. Ernest Moniz, Secretary of Energy

11:00 a.m. **Commerce Rhode Island**
Christine Smith, Executive Director, Rhode Island Science and Technology Advisory Council, and Director of Innovation Programs, Commerce Rhode Island

11:05 a.m. **Investments in Clean Energy Technology**
Thorne Sparkman, Managing Director, Slater Technology Fund

11:10 a.m. **VoltServer**
Steve Eaves, CEO, VoltServer

11:15 a.m. **Discussion: Rhode Island's Potential Role in Mission Innovation**
(led by Senator Whitehouse)

11:40 a.m. **Closing remarks**
Senator Whitehouse
Secretary Moniz

11:45 a.m. End

Regional Clean Energy Innovation Summit

University of Colorado Boulder Sustainability, Environment, Energy Complex

Boulder, Colorado • September 19, 2016

APPENDIX C -- Agenda

Regional Clean Energy Innovation Summit

Date: Sept. 19, 2016
Schedule: 9:30 am – 5:30 pm MST; Reception following until 7:00pm MST
Location: University of Colorado Boulder - Sustainability, Environment, Energy Complex (SEEC)
4001 Discovery Drive, Boulder, CO 80303

9:30 – 10:00 am	Check in and networking
10:00 – 10:05 am	Welcome: Peter Green, Deputy Laboratory Director, National Renewable Energy Laboratory
10:05 – 10:30 am	Keynote/Opening remarks – Former Colorado Governor Bill Ritter, Jr., now Director, Center for the New Energy Economy, Colorado State University --- High level points from Collaboratory economic impact report & 9 state North Central and Inter-mountain West region description (MT, ND, SD, NE, KS, CO, WY, UT, ID). Discuss how local, regional and national innovation clusters and multi-state collaborations can help solve energy challenges in the 21st Century.
10:30 – 11:30 am	Panel Session #1: Regional energy needs **Moderator:** Bill Ritter, Director, Center for the New Energy Economy, Colorado State University **Panelist #1:** Martin Keller, Director, NREL (regional needs in renewables) **Panelist #2:** Mark Northam, Executive Director, School of Energy Resources, University of Wyoming (regional needs in fossil fuels and carbon capture) **Panelist #3**: Robert Simm, Senior Vice President, MWH/Stantec (regional needs in water) **Panelist #4:** Frank Prager, VP for Environmental Affairs, Xcel Energy (regional needs in electric grid and transmission)
11:30 – 12:15 pm	Lunch and networking
12:15 – 12:45 pm	Session #2: Federal and state government perspectives **Moderator:** Paul Johnson, President, Colorado School of Mines **Keynote:** Colorado Governor John Hickenlooper
1:00 – 1:45 pm	Session #3: Federal perspectives on regional clean energy innovation partnerships followed by Q&A Introduction -- Chancellor Phil DiStefano, University of Colorado Boulder Keynote – Franklin (Lynn) Orr, Under Secretary for Science and Energy, United States Department of Energy
2:00 – 3:30 pm	Session #4: Facilitated topic area breakout session discussions Introduction and format for breakout sessions: Terri Fiez, Vice Chancellor for Research, University of Colorado Boulder Breakout session A: Grid and Storage Facilitator: Tony Dean, Vice President of Research and Technology, Colorado School of Mines Session leaders: Bryan Hannegan, National Renewable Energy Lab and Dan Zimmerle, CSU

	Breakout session B: Food/Energy/Water Facilitator: Jeff Muhs, Associate Director, Energy Institute at Colorado State University Session leaders: Ken Carlson, Colorado State University and Tzahi Cath, Colorado School of Mines Breakout session C: Energy/Climate/Efficiency Facilitator: Terri Fiez, Vice Chancellor for Research, University of Colorado- Boulder Session leaders: Dag Nummedal, Colorado School of Mines and Bob McGrath, University of Colorado-Boulder Breakout session D: Renewable sources **Facilitator:** Barbara Goodman, Executive Director | Institutional Planning, Integration & Development, NREL **Session leaders:** Bryan Willson, Colorado State University and Ryan Gill, University of Colorado-Boulder
3:45 – 4:30 pm	Session #5: Breakout session reports Moderator: Tony Dean, Vice President of Research & Technology, Colorado School of Mines Each breakout session will summarize highlights to the full group
4:30 – 5:30 pm	Session #6: Summary for a clean energy innovation region **Moderator:** Alan Rudolph, Vice President for Research, Colorado State University Entire group will discuss information covered by speakers and breakout sessions. Open discussion on framework for a regional partnership with next steps. Note: A portal will be open until Sept 22, 2016 at www.regionalsummit.org to accumulate feedback and additional ideas. Feedback from the Sept 19, 2016 meeting and the portal will be summarized in a full report and sent to U.S. Department of Energy by Sept 23, 2016.
5:30 pm	Meeting adjournment followed by a networking reception ending at 7:00pm

Breakout session questions:

1. To facilitate today's activities, four topic areas have been proposed (Grid and Storage; Food/Energy/Water; Energy/Climate; Renewable Sources). These are not meant to be exclusive of the regional needs. Are there additional focus areas that should be added to the list?
2. What are the regional strengths and opportunities in the four proposed topic areas and any topic areas added? Is there an overarching theme for this region that should be pursued? If so, please summarize.
3. Commercial deployment of energy technologies is required to have impact at a large scale. What are the opportunities for industry and research communities in developing and deploying next generation energy innovations at a large scale in our region?
4. How can we align anticipated research topics with state policies that become key drivers of deployment?
5. Building on the idea of regional innovation partnerships based on the RPSEA model (www.RPSEA.org), what are additional inputs to the process and governance that should be considered? How can we structure the regional entity in order to receive effective collaboration across the multi-state region?

Regional Clean Energy Innovation Forum

Purdue University

West Lafayette, Indiana • June 8-10, 2016

AGENDA

Wednesday June 8	**Reception and Posters**	**Page**
Thursday, June 9		
8:45-9:30 a.m.	**Welcome (Objective of Forum and Summary of Findings)**	**4**
	Tómas Díaz de la Rubia, Chief Scientist and Executive Director, Discovery Park, Purdue University **Mitchell E. Daniels**, President, Purdue University **Franklin (Lynn) Orr**, Under Secretary for Science and Energy, Department of Energy **Eric Holcomb**, Lieutenant Governor of Indiana **Jim Merritt**, State Senator, Indiana; Chairman of the Senate Utilities Committee	
	Overall Findings of the Panels	**7**
9:30-10:45 a.m.	**Panel #1: Energy Storage** Moderator: **George Crabtree**, Director, Joint Center for Energy Storage, Argonne National Laboratory Panelists: **David Roberts**, President, Battery Innovation Center **Mark Johnson**, Director, Advanced Manufacturing Office, Office of Energy Efficiency and Renewable Energy, Department of Energy **Joaquín Rodríguez-López**, Assistant Professor of Chemistry, University of Illinois at Urbana-Champaign **Thomas Golab**, Vice President and Chief Financial Officer, Navitas Systems	**8**

11:00-12:15 p.m.	**Panel #2: Biomass/Synthetic Biology** Moderator: **Michael Ladisch**, Director, Laboratory of Renewable Resources Engineering; Distinguished Professor of Agricultural and Biological Engineering, Purdue University Panelists: **Kent Peters**, Program Manager for the Bioenergy Research Centers, Biological and Environmental Research, Office of Science, Department of Energy **Jennifer Dunn**, Biofuel Life Cycle Analysis Team Leader and Environmental Analyst, Energy Systems, Argonne National Laboratory **Bruce Dale**, University Distinguished Professor of AgBio Research, Department of Chemical Engineering and Materials Science, Michigan State University **Peter Keeling**, Innovation Director, NSF Engineering Research Center for Biorenewable Chemicals, Iowa State University **Nancy Heimann**, President and CEO, Enginuity Worldwide	**10**
12:30-1:30 p.m.	**Lunch**	
1:45-3:00 p.m.	**Panel #3: Critical Materials/Advanced Manufacturing** Moderator: **Thomas Lograsso**, Director, Division of Materials Science and Engineering Panelists: **Carol Handwerker**, Reinhardt Schuhmann, Jr. Professor of Materials Engineering and Environmental and Ecological Engineering, Purdue University **Chenn Zhou**, Director, Steel Manufacturing Simulation and Visualization Consortium; Professor and Director, Center for Innovation through Visualization and Simulation, Purdue University Calumet **John Barnes**, Vice President, Advanced Manufacturing & Strategy, Alcoa Titanium & Engineered Products	**11**
3:00-3:15 p.m.	**Break**	
3:15-4:30 p.m.	**Panel #4: Wind Energy/Grid Integration** Moderator: **John Bear**, President and Chief Executive Officer, MISO Energy Panelists: **Doug Esamann**, Executive Vice President and President of Duke Energy's Midwest and Florida Regions, Duke Energy **Juan Torres**, Manager, Energy Systems Analysis, Sandia National Laboratory **Lian Shen**, Benjamin Mayhugh Associate Professor of Mechanical Engineering and Associate Director for Research, St. Anthony Falls Laboratory, University of Minnesota **John McDonald**, SmartGrid Business Development Leader, North America; Global SmartGrid Strategy Group, GE Grid Solutions	**14**

6:00 p.m.	**Reception and poster session**	
7:00 p.m.	**Dinner: Remarks** by **Jay Gore**, Vincent P. Reilly Professor in Mechanical Engineering, Purdue University	
Friday, June 10		
7:45-8:30 a.m.	**Breakfast and registration** Discovery Learning Research Center in Discovery Park, 298 Nimitz Dr., West Lafayette	
8:30-9:45 a.m.	**Panel #5: Public-Private Partnerships** Moderator: **Mark Johnson**, Director, Advanced Manufacturing Office, Office of Energy Efficiency and Renewable Energy, Department of Energy Panelists: **Alfred Sattelberger**, Deputy Laboratory Director for Programs, Argonne National Laboratory **Marcey Hoover**, Chief Operating Officer for the Energy and Climate Program, Sandia National Laboratory **Duane Johnson**, Chief Research Officer, AMES Laboratory **Byron Pipes**, John Leighton Bray Distinguished Professor of Engineering, Purdue University **Paul Mitchell**, President and CEO, Energy Systems Network **Justin Hage**, Director for Strategic Planning and Performance Management, Indiana Economic Development Corporation (IEDC)	**15**
9:45-10:45 a.m.	**Breakout sessions: Clean Energy Innovation Midwest Assets** Facilitator: **Ed Morrison**, Director, Agile Strategy Lab, Purdue University	
10:45-11:30 a.m.	**Reports**	
11:30-11:45 a.m.	**Closing remarks** **Tómas Díaz de la Rubia**, Chief Scientist and Executive Director, Discovery Park, Purdue University	

White House Initiative on Historically Black Colleges and Universities and Advancing Minorities' Interest in Engineering HBCU Partnerships in STEM

Tuskegee University

Tuskegee, Alabama • September 8, 2016

White House Initiative on Historically Black Colleges and Universities and Advancing Minorities' Interest in Engineering

HBCU Partnerships in STEM

AGENDA

Thursday, September 8, 2016
On the Historic Campus of Tuskegee University
Kellogg Hotel and Conference Center

8:30AM	Begin arriving, Kellogg Hotel and Conference Center
	Tour George Washington Carver Museum (optional) Booker T. Washington Home (optional)
	Kellogg Conference Center, Booker T. Washington Board Room
9:45AM	Fishbowl Discussion I: Administration and HBCU Leadership Moderator: Dr. Kim Hunter Reed, Deputy Under Secretary of Education and Acting Executive Director, White House Initiative on Historically Black Colleges and Universities
10:30AM	Fishbowl Discussion II: Administration and Industry Executives Moderator: Dr. Kim Hunter Reed
11:15AM	Wrap up
11:45 AM	BREAK
12:00 PM	Lunch, Booker T. Washington Board Room

Kellogg Conference Center Auditorium

1:00 PM	Welcome – Darryl Stokes, VP - Electric Transmission & Substations Baltimore Gas & Electric Company and Chairman, AMIE
1:10PM	Fireside Chat with the Administration Building Sustainable Partnerships Moderator: Rania Washington, Vice President Global Diversity & Inclusion, Lockheed Martin
2:00 PM	Roundtable Discussion Innovative STEM Strategies in Learning & Preparation Moderator: Dr. Christopher Jones, Corporate Vice President and President, Northrop Grumman Corporation Technology Services, 2016 Black Engineer of the Year Panelists: HBCU Presidents and HBCU Engineering Deans
2:30 PM	Panel Discussion Enrichment Programs for Students in STEM Moderator: Norma Clayton, Vice President for Learning, Training & Development, The Boeing Company Panelists: Industry Representatives; Students in STEM
3:00 PM	Closing Remarks Dr. Brian Johnson, President, Tuskegee University
3:10 PM	Press Availability
3:30 PM	Speed Mentoring Session College and secondary students will have an opportunity to speak with corporate, government agency, and academia representatives on their experiences & knowledge in a series of short, focused conversations relating to STEM.
4:45 PM	Group Photo
5:00 PM	Depart Tuskegee University

Southern California Clean Energy Innovation Ecosystem Roundtable

Kerckhoff Hall State Rooms, UCLA Campus

Los Angeles • May 10, 2016

Hosts: UCLA Dean, Henry Samueli School of Engineering and Applied Science, Dr. Jayathi Murthy and Associate Vice Chancellor for Environment & Sustainability, Dr. Mark Gold

Special Guest: Department of Energy Deputy Secretary, Dr. Elizabeth Sherwood-Randall

Moderator: Director of the Luskin Center for Innovation, Dr. J.R. DeShazo

11:45 am	Lunch
12:30 pm	Convening of the Roundtable, UCLA Dean, Henry Samueli School of Engineering and Applied Science, Dr. Jayathi Murthy
12:40 pm	Introduction to Mission Innovation and Regional Partnerships, Department of Energy Deputy Secretary, Dr. Elizabeth Sherwood-Randall
12:50 pm	State of Energy in LA, Chief Sustainability Officer, City of LA, Matt Petersen
1:00 pm	State of Energy in California, Member, California Independent System Operator Board of Governors, Angelina Galiteva
1:10 pm	State of Clean Energy Technologies, Professors Eric Hoek, Rajit Gadh & James Liao
1:20 pm	Moderated Roundtable Discussion, led by Dr. J.R. DeShazo
	Participant Introductions

Goals: Identifying the region's immediate and long-term clean energy needs and challenges*, and laying the foundation for future collaborations between roundtable participants and their associated institutions.

Sample questions leading the discussion:

- What are our immediate clean energy needs to meet California's goal of getting 33% of our energy from renewable sources by 2020 and 50% by 2030? What unique challenges do we face in the Southern California region in meeting these goals?
- How will Southern California reduce petroleum use in cars and trucks by 50% by 2030? What are the challenges specific to Southern California in reaching this goal?

- What are some of the feasible pathways for doubling the efficiency of existing buildings by 2030 and making heating fuels cleaner? What are the challenges specific to the Southern California region in reaching this goal?
- How can we accelerate clean energy innovation in Southern California? What are the major obstacles to providing affordable clean energy to consumers and creating additional commercial opportunities in clean energy?
- What are some of the human resources that we have/need to transition to a clean energy economy in LA? What is needed in terms of workforce development?
- How do we ensure that energy innovation and new energy technology development initiatives are inclusive and encourage all southern Californians to engage?

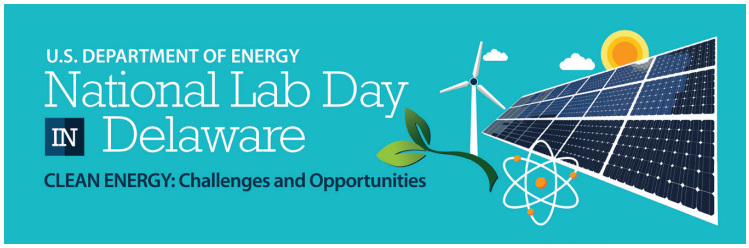
2:30 pm	Next steps: summation of discussion and discussion of potential future collaborations moving forward
3:00 pm	Roundtable Ends

* Note: Challenges may be related to governance, costs, inertia, regulatory and legal restrictions, available land, technology transfer, and more.

U.S. Department of Energy National Lab Day Delaware
Clean Energy: Challenges and Opportunities

University of Delaware

May 13, 2016



AGENDA

MAY 13, 2016

TIME	SESSION	LOCATION
8:00 a.m.	REGISTRATION	Front Desk
8:30 a.m.	WELCOME *Nancy M. Targett,* Acting President, University of Delaware *Mark Brainard,* President, Delaware Technical Community College	Auditorium
8:45 a.m.	MORNING KEYNOTES *The Honorable Tom Carper,* U.S. Senator *The Honorable Jack Markell,* Governor of Delaware	Auditorium
9:00 a.m.	OVERVIEW OF THE NATIONAL LABS: ENERGY AND SCIENCE **MODERATOR:** *Charlie Riordan,* Deputy Provost for Research and Scholarship, University of Delaware	Auditorium
10:00 a.m.	BREAK	Lobby
10:30 a.m.	OVERVIEW OF THE NATIONAL LABS: CYBERSECURITY AND GRID RESILIENCY **MODERATOR:** *Charlie Riordan,* Deputy Provost for Research and Scholarship, University of Delaware	Auditorium
11:45 a.m.	LUNCHEON KEYNOTE, *"Fireside Chat"* **MODERATOR:** *Dennis Assanis,* President-Elect, University of Delaware *The Honorable Ernest J. Moniz,* Secretary, U.S. Department of Energy *The Honorable Chris Coons,* U.S. Senator	Room 101A
1:30 p.m.	CLEAN ENERGY CONCURRENT SESSIONS	
	GENERATION	Auditorium
	STORAGE	Room 123
	THE GRID	Room 121
	CYBER AND GRID SECURITY	Room 119
2:30 p.m. – 3:15 p.m.	WORKING WITH THE NATIONAL LABS AND NETWORKING RECEPTION *Jetta Wong,* Director, Office of Technology Transition, Dept. of Energy	Room 101B

UNIVERSITY OF DELAWARE

Regional Energy Innovation Forum

University of Kentucky Center for Applied Energy Research

Lexington, Kentucky • April 21, 2016

Introduction and Welcome

8:30 AM - 9:30 AM

Ernest Moniz
U.S. Secretary of Energy

Eli Capilouto
President, University of Kentucky

Panel Session I

9:30 AM - 10:45 AM

Innovation, Combustion and CCS

Moderator: David Mohler
Deputy Assistant Secretary for Clean Coal and Carbon Management

Jeffrey Phillips
Senior Program Manager, Electric Power Research Institute

Kunlei Liu
Associate Director for Research, UK Center for Applied Energy Research

Roxann Laird
Director, National Carbon Capture Center

George Koperna
Vice President, Advanced Resources International, Inc.

10:45 AM - 11:00 AM

Break

Panel Session II

11:00 AM - 12:15 PM

New Value Creation from Coal

Moderator: Grace M. Bochenek
Director of the National Energy Technology Laboratory (NETL)

Rick Honaker
Chair of Mining Engineering, UK College of Engineering

Sallie Greenberg
Associate Director, Advanced Energy Technology Initiative, Illinois State Geological Survey

Kipp Coddington
Director, University of Wyoming Carbon Management Institute

Don Stevenson
Executive Director, Gas Technology Institute

12:15 PM - 1:15 PM

Lunch and Poster Session

Panel Session III

1:15 PM - 2:30 PM — Technology Innovation as a Driver for Regional Energy and Economic Development

Moderator: David Foster
Senior Advisor on Industrial and Economic Policy

Earl Gohl
Federal Co-Chair, Appalachian Regional Commission

Thom Mason
Laboratory Director, Oak Ridge National Laboratory

Joe Quinn
Vice President of Public Affairs, Aluminum Association

2:30 PM - 3:00 PM — *Wrap up and Rapporteur*

Southwest Regional Clean Energy Innovation Forum: Materials Technology for Clean Energy

The University of New Mexico

Albuquerque, New Mexico • July 5. 2016

BALLROOM C

11:30 AM

Master of Ceremonies Introductory Remarks by Gabriel P. López, Vice President for Research, The University of New Mexico & 2016 STC.UNM Innovation Fellow

Welcome & Opening Remarks by Robert G. Frank, President, The University of New Mexico

Congressional Remarks by the Honorable Tom Udall, US Senate & the Honorable Martin Heinrich, US Senate

Forum Address by the Honorable Ernest Moniz, Secretary, US Department of Energy

BALLROOM B

12:30 PM

Buffet Lunch Line

BALLROOM C

12:40 PM

Luncheon Discussion with Panel I - Enabling Materials for Hydrogen Technology & Infrastructure moderated by Bryan Pivovar, Program Manager, National Renewable Energy Laboratory

Panelists include: Rod Borup, Program Manager for Fuel Cells, Los Alamos National Laboratory | Plamen Atanassov, Distinguished Professor & Director, Center for Mirco-Engineered Materials, The University of New Mexico | Tom Stephenson, Chairman & CEO, Parajito Powder, LLC, Albuquerque, New Mexico

BALLROOM C

1:41 PM	**Panel II - Materials for Improving Efficiency & Lowering Manufacturing Costs for Photovoltaics** moderated by Kevin Malloy, Professor Emeritus of Physics & Astronomy, Special Assistant to the VPR for Science & Engineering, The University of New Mexico Panelists include: Nancy Haegel, Center Director of the Materials Science Center, National Renewable Energy Laboratory | Christiana Honsberg, Director, Quantum Energy & Sustainable Solar Technologies Engineering Research Center, Arizona State University | Pete Atherton, COO of mPower Technology, Former Senior Manager of Industry Partnerships, Sandia National Laboratories, Albuquerque, New Mexico
2:42 PM	*Break*
2:52 PM	**Panel III - Materials Solutions for Electrical Energy Storage** moderated by Babu Chalamala, Manager of the Energy Storage Technology & Systems Department, Sandia National Laboratories Panelists include: Kevin Zavadil, Distinguished Member of Technical Staff, Sandia National Laboratories | Shelley Minteer, USTAR Professor, University of Utah | Cody Friesen, CEO, Zero Mass Water, Phoeniz, Arizona
3:53 PM	**Panel IV - Materials for Advanced Nuclear Energy Systems** moderated by Chris Stanek, NEAMS National Technical Director, Los Alamos National Laboratory Panelists include: John Wagner, Chief Scientist, Idaho National Laboratory | Edward Blanford, Assistant Professor, Nuclear Engineering, The University of New Mexico | Tiangan Lian, Program Manager, Electric Power Research Institute, Palo Alto, California
4:54 PM	**Closing Remarks** by Gabriel P. López, Vice President for Research, The University of New Mexico & 2016 STC.UNM Innovation Fellow

BALLROOM B

5:10 PM	**Networking Reception**

U.S. Department of Energy - Mission Innovation Workshop on Grid Modernization

The University of Pittsburgh, Center for Energy

Pittsburgh, Pennsylvania • June 24, 2016

10:00 AM **Registration and Networking**

11:00 AM **Welcome: University of Pittsburgh**

Dr. Gerald Holder – U.S. Steel Dean, Swanson School of Engineering

Dr. Gregory Reed – Professor and Director, Center for Energy and Electric Power Lab

11:15 AM **Opening Remarks:**

Grant Ervin – Chief Resiliency Officer
City of Pittsburgh, Office of the Mayor

11:40 AM **Panel Session: "Regional and National Grid Modernization Priorities"**

Richard Riazzi – President and CEO
Duquesne Light Co.

Mark McGranaghan – Vice President, Power Delivery and Utilization
Electric Power Research Institute (EPRI)

Alexis Abramson – Director, Great Lakes Energy Institute
Case Western Reserve University

Michael Pesin – Deputy Assistant Secretary
Office of Electricity Delivery & Energy Reliability., U.S. Dept. of Energy

1:00 PM **Lunch**

1:30 PM **Luncheon Keynote Address:**

Dr. Cynthia Powell – Acting Deputy Director, Science & Technology
National Energy Technology Laboratory, U.S. Department of Energy

Dr. Franklin (Lynn) Orr – Under Secretary for Science and Energy
U.S. Department of Energy

2:00 PM **Moderated Discussion – Subtopic 1**

"T&D Infrastructure, Distributed and Clean Energy Resource Integration"

Moderator:

Benjamin Morris – Senior Manager, Strategic Planning & Operational Analytics
Duquesne Light Company

2:35 PM **Moderated Discussion – Subtopic 2**

"Integrated Energy Networks, Microgrids, Physical and Cyber Security"

Moderator:

Aimee Curtright – Senior Physical Scientist
RAND Corporation

3:10 PM **Moderated Discussion – Subtopic 3**

"Core Technologies: Energy Storage, Power Electronics, DC, other"

Moderator:

Thomas Feeley – Local and Regional Partnerships Manager
National Energy Technology Laboratory

Discussion Session Rapporteurs:

Barbara Granito – Strategic Director, Science & Engineering Ambassadors Program
National Academy of Sciences and National Academy of Engineering

Ann Merchant – Deputy Executive Director, Office of Communications
National Academies of Science, Engineering, and Medicine

3:45 PM **Wrap-Up, Next Steps, and Closing Remarks**

4:00 PM **Dessert and Coffee Reception**

Optional: Tours of EIC facility and current construction of the Pitt Center for Energy / Energy GRID Institute space

Southeast Regional Energy Innovation Workshop

University of Tennessee, Knoxville and Oak Ridge National Laboratory

Chattanooga, Tennessee

8:00 a.m. **Arrivals and Registration**

9:00-9:45 a.m. **WELCOME**

Dr. Thom Mason, Director, ORNL, *Convener*
Mayor Andy Berke, City of Chattanooga
Dr. Joe DiPietro, President, University of Tennessee
Dr. Elizabeth Sherwood-Randall, Deputy Secretary, U.S. DOE
Congressman Chuck Fleischmann, 3rd District of Tennessee

9:45-10:45 a.m. **ENERGY INNOVATION INDUSTRY ROUNDTABLE**

Joe Hezir, Chief Financial Officer, U.S. DOE, *Moderator*
Dr. Mo Khaleel, Director of Planning, ORNL, *Rapporteur*

- **Peter Hoffman**, Vice President, Intellectual Property Management, Boeing Co.
- **Dan Stout**, Senior Manager, Small Modular Reactors, TVA
- **Jason Swager**, Manager R&D Electrical, VW Americas
- **Nick Irvin**, Program Manager, Advanced Energy Systems, Southern Company

10:45-11:45 a.m. ENERGY INNOVATION UNIVERSITY ROUNDTABLE

Dr. Stacey Patterson, Associate Vice President for Research, University of Tennessee, *Moderator*
Susanna Sutherland, PhD Candidate, The Bredesen Center, University of Tennessee, Knoxville *Rapporteur*

- **Dr. Jimmy Cheek**, Chancellor, University of Tennessee, Knoxville
- **Dr. Joanne Romagni**, Vice Chancellor for Research and Dean of the Graduate School, University of Tennessee, Chattanooga
- **Dr. Timothy Lieuwen**, Executive Director, Strategic Energy Insitite, Georgia Institute of Technology
- **Dr. Tanju Karanfil**, Vice President for Research, Clemson University
- **Dr. Ray Vaughn**, Vice President for Research and Economic Development, University of Alabama, Huntsville
- **Dr. David Kosson**, Cornelius Vanderbilt Professor of Engineering, Department of Civil and Environmental Engineering, Director of CRESP, Vanderbilt University

11:45-12:30 p.m. LUNCH

12:30-12:45 p.m. BREAK

12:45-1:30 p.m. **PANEL 1: ENTREPRENEURSHIP & GRADUATE EDUCATION TO DRIVE INNOVATION**

Dr. Lee Riedinger, Director, The Bredesen Center, University of Tennessee, Knoxville, *Moderator*
Victoria DiStefano, PhD Candidate, The Bredesen Center, University of Tennessee, Knoxville, *Rapporteur*

- **Dr. Franklin (Lynn) Orr**, Undersecretary for Science & Energy, U.S. DOE
- **Mallory Ladd**, PhD candidate, The Bredesen Center, University of Tennessee, Knoxville

- **Jeff Beegle**, PhD Candidate, The Bredesen Center, University of Tennessee, Knoxville
- **David Colloa**, PhD Candidate, University of Tennessee, Chattanooga
- **Anne Mallow**, PhD Candidate, Georgia Institute of Technology
- **Annette Bodenheimer**, PhD Candidate, North Carolina State University

1:30-2:30 p.m. **PANEL 2: CLEAN ENERGY INNOVATIONS**

Cortney Piper, Tennessee Advanced Energy Business Council, *Moderator*
Guin Shaw, PhD Candidate, The Bredesen Center, University of Tennessee, Knoxville, *Rapporteur*

- **Dr. Tom King**, Director, Energy Efficiency and Electricity Programs, ORNL
- **Dr. Ajeet Rohatgi**, Georgia Tech University Center of Excellence for Photovoltaics
- **David Wade**, Executive Vice-President and Chief Operating Officer

2:30-3:30 p.m. **PANEL 3: LEVERAGING DOE CAPABILITIES TO DELIVER INNOVATION**

Dr. Jim Roberto, Associate Lab Director, Science and Technology Partnerships, ORNL, *Moderator*
Suzy Tichenor, Director, Industrial Partnerships Program, Computing & Computational Sciences, ORNL, *Rapporteur*

- **Dr. Jeff Nichols**, Associate Laboratory Director, Computing and Computational Sciences, ORNL
- **Dr. Michelle Buchanan**, Associate Laboratory Director, Physical Sciences, ORNL
- **Dr. Bill Peter**, Director, Manufacturing Demonstration Facility, ORNL
- **Dr. Roderick Jackson**, Group Leader, Building Envelope Systems, ORNL

3:30-3:45 p.m. **BREAK**

3:45-4:45 p.m. **PANEL 4: TECH TO MARKET INNOVATIONS**

Dr. Mark Johnson, Director, Advanced Manufacturing Office, U.S. DOE, *Moderator*
Emily Clark, PhD Candidate, The Bredesen Center, University of Tennessee, Knoxville, *Rapporteur*

- **Major General Nick Justice**, Executive Director, NNMI Power America at North Carolina State University
- **Dr. Craig Blue**, Director, NNMI IACMI at University of Tennessee/ ORNL
- **Fred Cartwright**, Executive Director, CU-ICAR
- **Dr. Johney Green**, Director, Energy and Transportation Science, ORNL
- **Jay Rogers,** CEO and Co-Founder, Local Motors

4:45-5:15 p.m. **CLOSING REMARKS**

Dr. Taylor Eighmy, Vice Chancellor for Research & Engagement, University of Tennessee, Knoxville

Roundtable Discussion on Mission Innovation

The University of Texas at Austin

Austin, Texas • May 9, 2016

Thursday, May 05, 2016

Agenda for Clean Energy Innovation Roundtable
Monday, May 9th 2016
12:00pm-2:30pm
Barrow Conference Room, JGB 4.102

Moderator	*Dale Klein, UT System, Vice Chancellor for Research*
11:30am	Attendees may arrive prior to noon to begin settling in for lunch
12:00pm-12:45pm	Each participant will have one minute to introduce him/herself and describe their work
12:45pm-12:55pm	Introductory remarks by Secretary Moniz
12:55-1:15pm	4-6 pre-selected individuals will speak more in depth based upon the following agreed upon topics: · Innovation in Oil & Gas · Innovation in the Energy-Water Nexus · How to Build a Regional Innovation Ecosystem
1:15pm-2:30pm	Open up the table to Secretary Moniz to participate in a more all-inclusive discussion

Northwest Regional Clean Energy Innovation Partnership Workshop

The Lyceum, Husky Union Building • University of Washington, Seattle

Seattle Washington • August 15. 2016

Agenda

7:30 - 8:00 a.m. Registration

8:00 - 8:05 a.m. Welcome

Gerald Baldasty
Provost, University of Washington

8:05 - 8:15 a.m. Mission: Innovation

Mary Lidstrom --*Introduction by Jerry Baldasty*
Vice Provost for Research, University of Washington

8:15 - 8:35 a.m. The Northwest as a Clean Energy Leader

Derek Kilmer --*Introduction by Mary Lidstrom*
U.S. Representative, State of Washington

Daniel T. Schwartz – *introduction by Mary Lidstrom*
Director, Clean Energy Institute

8:35 - 8:45 a.m. Emerging Opportunities & Challenges for Clean Energy

Thomas J. Ranken -- *introduction by Dan Schwartz*
President and Chief Executive Officer, CleanTech Alliance

8:45 - 9:45 a.m. Panel 1: Emerging Opportunities to Accelerate Clean Energy

Moderator: Thomas J. Ranken
President and Chief Executive Officer, CleanTech Alliance

Panelists: Steve Ashby
Director, Pacific Northwest National Laboratory

Kelly Beierschmitt
Chief Research Officer, Idaho National Laboratory

Grace Bochenek
Director, National Energy Technology Laboratory

Cynthia Sagers
Vice President for Research, Oregon State University

Chuck Staben
President, University of Idaho

9:45 - 10:00 a.m.	Break
10:00 - 11:00 a.m.	Panel 2: Policies and Activities to Accelerate Regional Leadership
	Moderator: David Kenney -- *introduction by Dan Schwartz* Director, Oregon BEST
	Panelists: Brian Bonlender Director, Washington State Department of Commerce
	Christopher C. Deschene Director, U.S. Department of Energy Office of Indian Energy Policy and Programs
	Michael Hagood Program Development Director, Center for Advanced Energy Studies and Idaho National Laboratory
	Fawn Sharp President, Quinault Indian Nation
	Elliot Mainzer Administrator, Bonneville Power Administration
11:00 a.m.- 12:00 p.m.	Panel 3: Energy Innovation at Northwest Research Institutions
	Moderator: Malin Young -- *introduction by Dan Schwartz* Chief Research Officer, Pacific Northwest National Laboratory
	Panelists: Cynthia Powell Chief Research Officer, National Energy Technology Laboratory
	Daniel Schwartz Director, Clean Energy Institute, University of Washington
	Jud Virden Associate Laboratory Director — Energy & Environment, Pacific Northwest National Laboratory
	Michael Wolcott Regents Professor, Louisiana-Pacific Distinguished Professor, and Director, Institute for Sustainable Design, Washington State University

12:00 - 1:00 p.m. Lunch

1:00 - 2:00 p.m. Panel 4: Industry for Regional-to-Global Impact

Moderator: Jud Virden-- *introduction by Dan Schwartz*
Associate Laboratory Director — Energy & Environment,
Pacific Northwest National Laboratory

Panelists: Michael Atkinson
North American Region General Manager, GE Grid Solutions

Curt Kirkeby
Fellow Technology Strategy, Avista Utilities

Bert Van Hoof
Group Program Manager, Microsoft Corporation

Dave Cuthbert
Senior Solutions Architect, Amazon Web Services

2:00 - 2:15 p.m. Break

2:15 - 3:15 p.m. Panel 5: The Innovation Ecosystem - From Research to Startup

Moderator: Brian Young-- *introduction by Dan Schwartz*
Director, Economic Development for the Clean Technology Sector, State of Washington

Panelists: Scott Forbes
Director, Computer Science & Engineering, FedImpact

John Hopkins
Chairman and Chief Executive Officer, NuScale Power

Eric "Rick" Luebbe
Chief Executive Officer, EnerG2

Gary Yang
Chief Executive Officer, UniEnergy Technologies

3:15 - 5:00 p.m. Leadership Speaker Series – The Future of Clean Energy

Jay Inslee –*Introduction by Steve Ashby*
Governor, State of Washington

Ernest J. Moniz—*Introduction by Grace Bochenek*
U.S. Energy Secretary
Q&A moderated by Jaime Shimek

Maria Cantwell--*Introduction by Dan Schwartz*
U.S. Senator, State of Washington

Mid-Atlantic Region Energy Innovation Forum

West Virginia University

Morgantown, West Virginia • September 12, 2016

WEST VIRGINIA UNIVERSITY

C. Agenda

Mid-Atlantic Region Energy Innovation Forum

Mid-Atlantic Region Energy Innovation Forum
Hosted by
West Virginia University
Morgantown, WV
September 12, 2016

WVU College of Law Event Center
101 Law School Drive
Morgantown, WV 26506

This Innovation Forum hosted by West Virginia University will bring together leaders from state government, academia and industry to discuss solutions and create a path for accelerating innovation in the Mid-Atlantic Region.

8:30 – 9:00 a.m. **Registration and Networking**

9:00 – 9:05 a.m. **Welcome**
E. Gordon Gee
President, West Virginia University

9:05 – 9:45 a.m. **Panel 1: Regional Challenges and Opportunities**
Moderator: Brian J. Anderson
Director, Energy Institute
West Virginia University

Panelists: Grace Bochenek
Director, National Energy Technology Laboratory
U.S. Department of Energy

Steven Winberg
Program Manager, Battelle

Andrew Gellman
Co-Director, Wilton E. Scott Institute for Energy Innovation
Carnegie Mellon University

William Getty
President, Claude Worthington Benedum Foundation
Co-Chair, Power of 32

9:45 – 11:00 a.m. **The Future of Clean Energy**
Joe Manchin, III
U.S. Senator, West Virginia

David B. McKinley, P.E.
U.S. Representative, West Virginia's 1st Congressional District

Ernest J. Moniz
U.S. Energy Secretary

11:00 – 11:15 a.m. Break

WestVirginiaUniversity

Mid-Atlantic Region Energy Innovation Forum

11:15 – 11:45 a.m. **The Tri-State Governor's Regional Cooperation**
Chris Stadelman
Chief of Staff for the Governor, State of West Virginia

Dennis Davin
Secretary, Department of Community and Economic Development, Commonwealth of Pennsylvania

11:45 – 12:15 p.m. Lunch

12:15 – 1:15 p.m. **Panel 2: Innovation opportunities for fossil fuels in a future low carbon economy**
Moderator: Sean Plasynski
Executive Director, Technology Development & Integration Center, NETL

Panelists: James Bielenberg
Corporate Strategic Research, ExxonMobil Research and Engineering

Neeraj Gupta
Senior Research Leader, Battelle

Dave van der Wiel
Director, Babcock & Wilcox Research Center

David Zaziski
Vice President, Siluria

This panel will discuss the technical challenges and opportunities for innovation in the utilization of coal and gas. Recognizing the technical challenges associated from coal and gas utilization for electric power generation, this panel will focus comments on opportunities to significantly improve power generation processes, such as novel approaches to conversion and combustion via application of chemical looping and oxy-combustion technologies as well as the materials needed for ultra-supercritical steam conditions at coal-fired power plants. As these technologies still result in significant amounts of CO_2 emissions, CO_2 capture and storage innovation opportunities will also be discussed. Additionally, the potential for technology innovations in the utilization of natural gas will be explored. Topics will span new conversion pathways of natural gas and natural gas liquids. The development of shale gas resources in the region have spurred increased interest in new products, processes, and use of natural gas.

WestVirginiaUniversity

Mid-Atlantic Region Energy Innovation Forum

1:15 – 2:00 p.m. **Panel 3: Innovation opportunities in other clean energy technologies**

Moderator: Court Gould
Executive Director, Sustainable Pittsburgh

Panelists: Stewart Prager
Director, Princeton Plasma Physics Laboratory

Edward Herderick
GE Corporate Supply Chain and Operations

Denise Swink
Chair, Smart Manufacturing Leadership Coalition

This panel will discuss potential opportunities for identifying and creating new low-carbon pathways to drive economic growth in the region. Perspectives from both the creation of new, valuable products and from the creation of a nexus of innovation that creates and sustains itself on a critical mass of technical capabilities to serve both domestic and international markets. The potential for advances in manufacturing techniques to both raise the advantage of U.S. manufacturers to produce both conventional technologies as well as create the market advantage for those manufacturers to produce technology products of a specification not previously possible through traditional manufacturing techniques.

2:00 – 2:15 p.m. **Break**

2:15 – 3:15 p.m. **Panel 4: Policies Facilitating Sustainable Clean Energy Development**

Moderator: Scott Rotruck
Director of Energy & Transportation Services, Spilman Thomas & Battle

Panelists: Jan Mares
Senior Policy Advisor, Resources for the Future

Gary Helm
Lead Market Strategist, PJM Interconnection

Mike Casper
Senior Manager, Generation and Fuels, National Rural Electric Cooperative Association

3:15 – 4:00 p.m. **Panel 5: Regional Innovation Investment and Commercialization**

Moderator: Mike Green
Chairman, West Virginia Growth Investment Fund

Panelists: Jeffrey McDaniel
Executive-in-Residence, Innovation Works

Joseph Hezir
Chief Financial Officer, U.S. Department of Energy

Mark Nydam
Principal, HarbourVest Partners, Executive Chairman Accordant Energy

4:00 – 4:15 p.m. **Closing Remarks – Mission: Innovation**

Fred King
Vice President for Research, West Virginia University

WestVirginiaUniversity

Appendix B

Clean Energy RD&D Focus Areas

The clean energy research, development, and demonstration (RD&D) focus areas identified in the U.S. Mission Innovation portfolio are well aligned with the Department of Energy's (DOE or Department) current investments in basic and applied RD&D, as briefly outlined below. The Department's portfolio also includes the deployment of innovative technologies, which is not part of Mission Innovation.

1. Industry and Buildings

The industry and buildings focus area identified in the U.S. Mission Innovation portfolio spans two major energy sectors identified in the 2015 Quadrennial Technology Review (QTR): manufacturing (representing the majority of the larger industrial sector) and buildings.

In 2014, the industry sector consumed 32% of U.S. primary energy. Transformative manufacturing processes, materials, and technologies can provide advantages over current practices, and they can also accelerate the fabrication of innovative clean energy products. Two questions raised in the QTR could profitably be addressed by the regional clean energy innovation partnerships (RCEIPs) proposed in the FY2017 President's Budget:

- What manufacturing R&D opportunities can be developed to drive down energy intensity, carbon intensity, and use intensity?
- What innovative manufacturing technology and system improvements and innovations might result in the greatest economy-wide impacts?

The buildings sector accounts for about 76% of U.S. electricity use and 40% of all U.S. primary energy use and associated greenhouse gas (GHG) emissions. Substantial reductions in building energy use (and in costs to building owners and tenants) could be obtained simply by increased deployment of existing technologies; even greater savings can be realized by research, development, and demonstration (RD&D) focused on improving (1) the performance of system components (e.g., lighting, appliances, air conditioners) and (2) the interactions of these components as elements of integrated building systems. The proposed RCEIPs can be structured to address these opportunities.

Within DOE's Office of Energy Efficiency and Renewable Energy (EERE), the Advanced Manufacturing Office supports the development and application of better manufacturing technology and materials. The EERE Buildings Technology Office is engaged in a variety of RD&D activities aimed at improving the efficiency of residential and commercial buildings.

2. Vehicles and Transportation

Transportation represents 70% of all U.S. petroleum use and 27% of U.S. GHG emissions. Multiple opportunities exist for RD&D to improve vehicle efficiency and reduce the use of petroleum-based fuels, providing a pathway to reducing the cost of fuel, supporting domestic industry, minimizing carbon emissions and other pollutants, and increasing the nation's energy security. In addition, the proposed RCEIPs could be positioned to build the systems perspective on transportation that is needed to enable optimization of future energy use through smarter transportation systems and technologies.

The EERE Vehicle Technologies Office supports R&D and deployment of efficient and sustainable highway transportation technologies.

3. Bio-Based Fuels and Energy

The creation of a robust, next-generation domestic bioenergy industry is an important step toward providing Americans with sustainable, renewable energy alternatives. The QTR notes that biofuels can benefit from RD&D across the entire value chain, from resources through conversion to a variety of refined products, and identifies five key research priorities:

- terrestrial feedstocks,
- algae,

- biochemical conversion,
- thermochemical conversion, and
- bioproducts.

In addition, research is still required to break down the remaining basic science barriers to establishing a commercially viable and sustainable specialty biofuels and bioproducts industry in the United States.

The EERE Bioenergy Technologies Office establishes partnerships with key public and private stakeholders to develop and demonstrate technologies for producing cost-competitive advanced biofuels from non-food biomass resources. The Office of Biological and Environmental Research (BER) within DOE's Office of Science sponsors a Genomic Sciences Program that seeks to develop the fundamental science, research technologies, and knowledge base necessary to enable the cost-effective, sustainable production of biofuels and bioproducts from plant biomass. The three Bioenergy Research Centers established by BER in 2007, which are located in three geographically distinct regions, offer a model for coordinating multi-institutional biofuels RD&D.

4. Solar, Wind, and Other Renewables

The United States has abundant solar, wind, water, and geothermal energy resources, and many U.S. companies are now developing, manufacturing, and installing cutting-edge, high-tech renewable energy systems. Regional variations in resource availability make this a particularly appropriate focus area for RCEIPs, which can select the best options for a region and then work to accelerate the deployment of existing technologies, facilitate their integration into the electricity grid, and coordinate the RD&D needed to improve efficiency and reduce the cost of advanced renewable energy innovations.

Within EERE, the Solar Energy Technologies Office, the Wind Energy Technologies Office, Water Power Technologies Office, and the Geothermal Technologies Office work with a large network of researchers and other partners to develop and deploy innovative technologies for clean power generation.

5. Nuclear Energy

Nuclear power represents a zero-emissions energy source that currently accounts for 19% of U.S. electricity overall and 60% of the nation's carbon-free electricity. Because of its ability to provide significant quantities of baseload electricity, nuclear power is expected to be a significant contributor to a low-carbon electricity system. RD&D opportunities include reducing the cost of the large light water reactors now being constructed, bringing small modular reactors into commercial operation by the mid-2020s, developing advanced reactor designs that will enable new fuel cycles and widen the range of commercial applications for nuclear power, focusing on the nuclear fuel cycle to facilitate the management of nuclear waste and address concerns about proliferation, and developing and applying new approaches to integrating nuclear power to allow better alignment with variable generation through more flexible operations.

DOE's Office of Nuclear Energy sponsors a broad RD&D program guided by four objectives:

- Develop technologies and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors.
- Develop improvements in the affordability of new reactors to enable nuclear energy to help meet energy security and climate change goals.
- Develop sustainable fuel cycles.
- Understand and minimize the risks of nuclear proliferation and terrorism.

The Gateway for Accelerated Innovation in Nuclear (GAIN) initiative provides the nuclear energy community with a single point of access to the broad range of capabilities—people, facilities, materials, and data—available at DOE national laboratories and other locations.

6. Hydrogen and Fuel Cells

Hydrogen offers important long-term value as an energy carrier. It can be used in highly efficient fuel cells for transportation and stationary power applications, in internal combustion engines, and as an energy carrier and storage medium in grid modernization and other applications. Hydrogen can be produced via a variety of industrially proven technologies from fossil sources such as natural gas, but further RD&D for producing hydrogen from renewables could lower costs and risks. Other challenges include storage, transmission, and distribution infrastructure; fuel cell cost and durability; and economic scale-up.

The EERE Fuel Cells Technologies Office manages a comprehensive portfolio of activities that address the full range of barriers facing the development and deployment of hydrogen and fuel cells.

7. Cleaner Fossil Energy

Fossil fuels supply about 82% of primary energy consumption in the United States. Innovations that increase the efficiency and reduce the carbon emissions of coal, oil, and natural gas will make it possible to continue using these traditional resources to provide clean, secure, and affordable energy.

DOE's Office of Fossil Energy sponsors an extensive RD&D portfolio aimed at enabling cost-competitive, fossil fuel–based power generation with near-zero emissions.

8. Carbon Capture, Utilization, and Storage

Carbon capture, utilization, and storage is a key component of efforts to reduce GHG emissions and mitigate climate change. RD&D is needed to deliver cost-effective technology, infrastructure, and regulations that will ensure the safe and permanent storage and/or utilization of carbon dioxide (CO_2) captured from point sources, from coal-fired power plants to industrial sources such as cement plants and paper mills.

DOE's Office of Fossil Energy leads RD&D and demonstration efforts on advanced technologies for carbon capture, utilization, and storage.

9. Electricity Grid

A resilient, secure, reliable, and flexible electricity system is a vital asset for the United States. Advanced grid technologies are needed to improve the agility and flexibility of the system to better integrate the changing characteristics of devices and technology systems on both the supply side and the demand side. In addition, RD&D is urgently needed to enhance the cyber and physical security of the national electricity grid.

DOE's Office of Electricity Delivery and Energy Reliability leads the Department's efforts to ensure a resilient and flexible electricity system in the United States.

In November 2014, DOE launched the Grid Modernization Initiative. This multiyear collaborative initiative is coordinating a broad portfolio of R&D programs and analytical efforts focused on

- developing new architectural concepts, tools, and technologies that measure, analyze, predict, protect, and control the grid of the future, and
- enabling the institutional conditions that allow for more rapid development and widespread adoption of these tools and technologies.

The initiative is engaging public- and private-sector energy stakeholders, including the DOE national laboratories, utilities, regulators, equipment manufacturers, vendors, developers, universities, associations, and others.

10. Energy Storage

Energy storage is a critical element of a clean energy future. Expansion of the electric vehicle industry, large-scale deployment of renewable energy systems, and rising demand for reliable energy all create the need for efficient and cost-effective energy storage systems.

Within DOE's Office of Science, the Office of Basic Energy Sciences sponsors research to explore fundamental processes in batteries and fuel cells and apply the resulting understanding to deliver major improvements in performance. The Office of Electricity Delivery and Energy Reliability supports R&D on materials used in energy storage systems, as well as advanced component development and field testing of storage systems in diverse applications, with the goal of lowering life-cycle costs, improving performance, and overcoming siting issues by reducing the size and environmental impacts of energy storage technology.

11. Basic Energy Research

Chapter 9 of the QTR explains the need for basic energy research to underpin advances in clean energy technologies: "Basic science, including the tools needed to facilitate discovery, expands our understanding of the natural world and forms the foundation for future technology."[170] For example, basic scientific research is necessary both to enable the creation of new materials with the specific characteristics needed for next-generation energy technologies and to develop a predictive understanding of energy-relevant biological and environmental systems. With respect to tools, dramatic advances in computation are making it possible to model and simulate real-world phenomena at very high spatial and temporal fidelity, accelerating the pace of discovery in materials science, combustion, nuclear energy, and other energy-related fields.[171]

Programs sponsored by DOE's Office of Science would offer a number of opportunities for the proposed RCEIPs to connect with and capitalize on basic energy research.

Appendix C

DOE R&D Assets

1. National Laboratories

The 17 U.S. Department of Energy (DOE) National Laboratories, particularly those with substantial clean energy research, development, and demonstration (RD&D) portfolios, will be a vital resource for proposed regional clean energy innovation partnerships (RCEIPs). The national laboratories occupy a distinctive space in the national innovation ecosystem, deploying multidisciplinary teams to tackle large-scale, long-term, high-risk research and development (R&D) challenges that are generally beyond the scope of industry or universities. They also

- design, construct, and operate specialized R&D facilities that are available for external use, as discussed in Section 4.A.3;
- work to transfer the knowledge and technology that are the products of their R&D to the marketplace[172]; and
- support the education and training of the workforce of the future.

The proposed RCEIPs could be structured to take advantage of these activities and of the geographic distribution and distinctive missions of the national laboratories.

Students from the University of Tennessee, Knoxville, Bredesen Center for Interdisciplinary Research and Graduate Education identify themselves in the audience at the Southeast Regional Energy Innovation Workshop in Chattanooga, Tennessee, on May 23, 2016. At the workshop, about 150 representatives from universities, industry, and federal agencies participated in a forum on how to bring together private and public sectors in an effort to grow new initiatives and create stronger regional collaborations to advance clean energy technologies and applications. (Billy Weeks/University of Tennessee)

2. Specialized R&D Facilities

The cutting-edge experimental and computational facilities supported by DOE provide unique opportunities for the development and testing of innovative clean energy technologies.[173] Nearly all of these facilities are located at national laboratories. While arrangements for external use vary, partnership agreements can be developed to meet the needs of external users.

The national scientific user facilities supported by DOE's Office of Science (SC) provide researchers with the most advanced tools of modern science, including

- the x-ray light sources, neutron sources, and Nanoscale Science Research Centers supported by the SC Basic Energy Sciences program;
- the high-performance computing and networking resources supported by the SC Advanced Scientific Computing Research program; and
- the Environmental Molecular Sciences Laboratory at Pacific Northwest National Laboratory and the Joint Genome Institute at Lawrence Berkeley National Laboratory, both supported by the SC Biological and Environmental Research program.

The Nuclear Science User Facilities (NSUF) program sponsored by DOE's Office of Nuclear Energy provides research teams with access to reactors, accelerators, post-irradiation examination capabilities, and computing resources at national laboratories, universities, and industry facilities across the country.

Shared R&D facilities provide external partners with access to a wide range of capabilities for testing processes, technologies, and equipment. Examples of interest for the proposed RCEIPs include

- the Integrated Biorefinery Research Facility at the National Renewable Energy Laboratory, which is taking early-stage biofuel development to pilot scale by enabling partners to test conversion technologies on up to 1 ton of biomass material a day;
- the Manufacturing Demonstration Facility at Oak Ridge National Laboratory, which is strengthening the nation's manufacturing enterprise assisting industry in the development and deployment of additive manufacturing and materials technologies and processes;
- the Materials Engineering Research Facility at Argonne National Laboratory, which enables engineers to develop manufacturing processes for producing advanced battery materials in sufficient quantity for industrial testing;
- the Northeast Solar Energy Research Center at Brookhaven National Laboratory, which provides the solar industry with a research and test facility that features laboratories for standardized testing and a solar photovoltaic research array for field testing technologies under actual northeastern weather conditions; and
- the Combustion Research Facility at Sandia National Laboratories, which has worked closely with U.S. engine manufacturers for more than 30 years to increase scientific understanding of internal combustion engine processes affecting efficiency and emissions.

Endnotes

These endnotes reference external sources or university reports contained in Volume 2 of this report. Volume 2 is a more detailed compilation of reports from the university workshops on clean energy technology innovation held during the spring and summer of 2016. Any reference to the Volume 2 reports will reflect both section and page numbers (e.g. pg 10-33).

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