THE NATIONAL ACADEMIES
MEETING IN BRIEF

THE CROSS-SECTOR IMPACT OF THE SMART GRID

Government-University-Industry Research Roundtable
February 9-10, 2015

New players and the demand for new technologies have emerged in the power supply industry. A meeting of the Government-University-Industry Research Roundtable explored the successes and challenges that the energy sector has encountered as it works to implement smart grid technologies (technologies that allow for greater data transparency and automation), develop new ways to store energy, and protect existing and emerging systems from cyberattacks. Participants of the Roundtable also discussed ways that public−private partnerships can help meet these challenges.

The keynote address on February 9 was offered by **Harold DePriest,** President and CEO of Electric Power Board (EPB) of Chattanooga, Tennessee. DePriest opened his presentation by saying that he views it as his job to give ordinary people the chance to do extraordinary things with technology.

Chattanooga has evolved from an industrial city in deep decline to one of the more livable cities in the United States. The city's economy was based on foundries and heavy industry, and in 1969 it had the dirtiest air in the nation.[1] Chattanooga cleaned up the air over the years, said DePriest, showing images of sections of the city before and after its transformation. Chattanooga's transformation may be a metaphor for what we need to do with the smart grid.

Right now people only think about electricity if it fails, but the smart grid provides the opportunity for electricity to be part of people's lives in a way that doesn't exist today, DePriest continued. EPB has taken five steps to improve the culture and operations in the region, including 1) focusing people on the future and communicating the organization's strategy to everyone within it; 2) requiring teamwork and collaboration; 3) recognizing the power of processes and working to improve them, which has often meant automating them; 4) learning to measure things that are important to measure rather than just those that are easy to measure; and 5) building a new culture, one where people are free to work on things they are passionate about and where they do not fear hierarchy.

EPB got into the communications business about 15 years ago by building a small phone company. The utility now has about 9,000 miles of fiber, including lots of ring fiber, which increases reliability. EPB has also installed about 1,200 intelligent switches on the electric system—on poles, high-voltage lines, and fiber—and they communicate with each other.

[1] In October of 1969, on an evening news broadcast, Walter Cronkite announced to the country that Chattanooga, Tennessee had been named the "Dirtiest City in America."

The power company can control them and can change their characteristics in a matter of minutes, explained DePriest. They also use smart meters with a communications device that speaks for 5 milliseconds every 15 minutes, totaling about 1 second a day.

The meters give fast readings of electrical usage along with voltage profiles across the whole system, and they let the utility know when the meter is on or off—important information for when the company is working on restoring power during an outage. EPB's systems have 100 different dashboards that give employees real-time information about the electric system, allowing them to see whether someone has been assigned to work on a problem, if they are in route, and the location of critical customers, such as those on life support. The company has seen an increase in productivity of about 20 percent since starting to monitor crew locations using the dashboard maps. The systems let EPB manage a large number of crews and match the crews with the right skills to the right job.

DePriest showed an animation that demonstrated how quickly automation let EPB restore power after a heavy windstorm. Without the smart grid, about 85,000 customers would have lost power, he said. With the smart grid, a little under 40,000 customers lost power.

Many people who previously would have lost power for hours or possibly days were without power for less than 15 seconds. If EPB had restored power manually as they did three years ago, it would have taken 1.5 days to get everyone's lights back on; instead, they were able to do 17 hours of switching automatically in 15 minutes. Chattanooga's businesses are seeing roughly $50 million to $60 million per year in savings from reduced power outage costs.

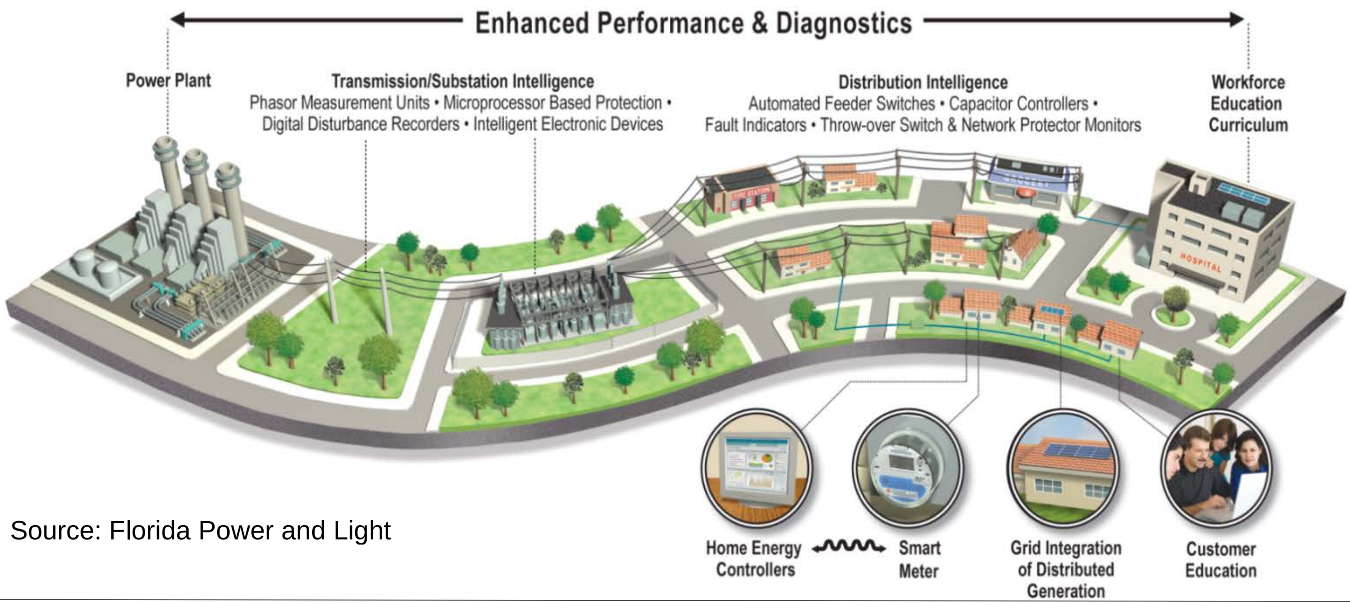
The first presentation on February 10 was offered by **Henry Kenchington** of the Department of Energy's Office of Electricity Delivery and Energy Reliability (DOE OE), who spoke about DOE's efforts to deploy and assess smart grid technologies over the past four years in partnership with utilities, equipment manufacturers, universities, and other industry participants as a part of the Smart Grid Investment Grant and Demonstration Programs. These initiatives, which were funded under the American Recovery and Reinvestment Act (ARRA) of 2009, involved new technologies and programs such as synchrophasors for electric transmission, distribution, automation, advanced metering infrastructure, and consumer systems like in-home displays, time-based rates, and web portals. Over $10 billion of public and private funds were invested in these programs to modernize the nation's electric grid, including a one-time $4.5 billion appropriation through ARRA. With the programs nearly complete, he said, DOE is seeing advances in areas such as cybersecurity, interoperability, and business case analysis that could not have happened otherwise.

Generally speaking, the term "smart grid" refers to the application of digital communications and control technologies to improve efficiency and optimize performance of electric delivery systems. It also includes tools and techniques that enable customers to better manage their power consumption, costs, and bills. DOE's smart grid efforts include analysis, outreach, and coordination activities with utilities, other federal and state agencies, national laboratories, universities, and other electric power systems, and produce benefits such as fewer and shorter outages, reductions in peak demands, and integration of clean distributed and renewable energy resources, Kenchington explained.

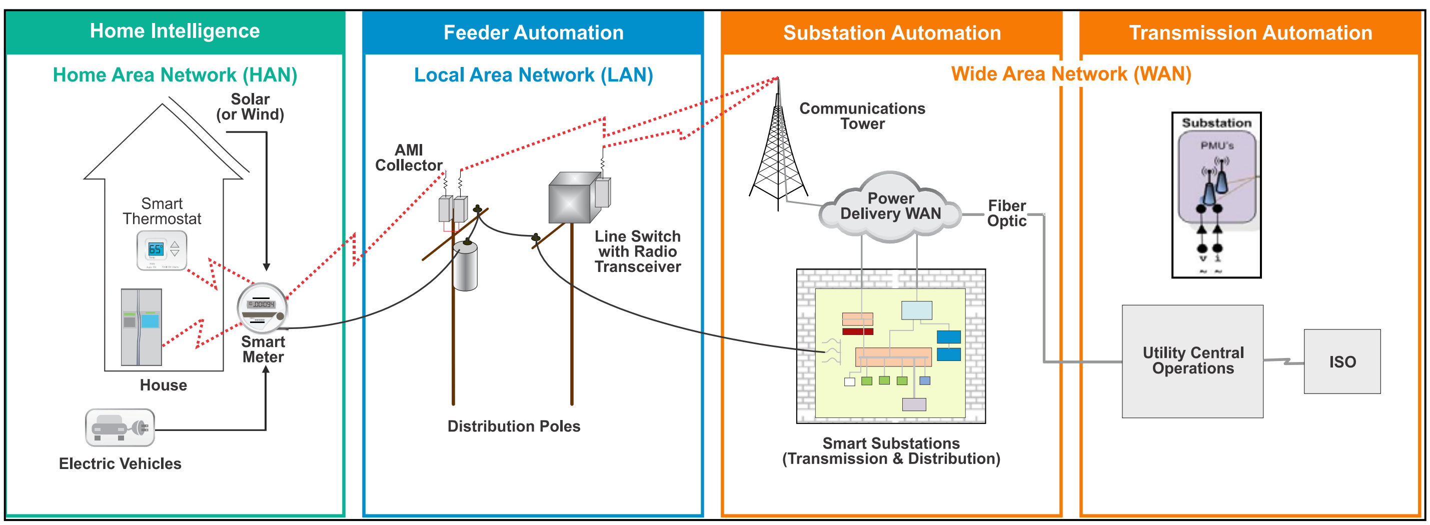
DOE is working with the participating utilities and other project participants to evaluate the impact of the smart grid investments and provide decision makers and policy officials with information on grid impacts, costs, benefits, and lessons learned. For example, there are about 146 million customers in the United States today, about 7 million of whom had smart meters before the ARRA smart grid projects were launched in 2009. Now, according to industry estimates, there are approximately 50 million smart meters installed in homes and businesses across the United States, helping people better manage their electricity use—a significant advance in just six years.

Project results show tangible benefits, Kenchington said. For example, Oklahoma Gas and Electric deployed variable peak pricing and programmable communicating thermostats, which reduced demand during peak times by as much as 30 percent. Benefits for electric transmission are also being realized from using synchrophasors to improve wide-area visibility into power flows and to detect oscillations and disturbances before they cascade into larger problems or regional outages.

DOE expects to continue evaluation of these smart grid efforts and hopes to issue one or more new solicitations in 2015, along with announcing a new university-led consortium, said Kenchington. In 2016, depending on Congressional appropriations the Office expects to issue a competitive solicitation for research in advanced computational tools that can take advantage of the new data produced by smart grid deployments to improve electric power system planning and operations. Information about these solicitations is available at www.oe.energy.gov.



Source: Florida Power and Light



Generic Smart Communications Architecture

Figure 1 Smart Grid Enables Grid Modernization with Advanced Communications and Controls.
Source: Kenchington, H. 2015. Smart Grids Need Smart People. Presentation at the February 10, 2015 Government-University-Industry Research Roundtable workshop, The Cross Sector Impact of the Smart Grid.

The next presentation was offered by **Gregory Reed** of the University of Pittsburgh's Center for Energy and the Electric Power Initiative (EPI) in Pittsburgh, Pennsylvania, who spoke about opportunities for the power grid in the emerging energy economy. Electricity is the lifeblood of modern society, said Reed. But electricity in our country remains terribly inefficient, and research at the EPI is trying to improve this efficiency.

Today's power grid infrastructure is a vast, complex, highly integrated machine that operates quite reliably 365 days of the year, 24 hours a day, said Reed. But, that reliability is beginning to be threatened. The vast majority of our infrastructure was built from the 1930s to the 1970s, and not much investment has been made since then. The main components of today's electric power systems are large-generation facilities and long distance, high voltage transmission networks which connect to low voltage distribution networks, and then to our homes and businesses. People are accustomed to plugging into a 120-volt alternating current (AC) outlet at 60 hertz. This is still largely a one-way flow from large, centralized generation to the consumer, a system that is also being challenged. The greatest density of power grid infrastructure is where most of the population is—along the East Coast, West

Example of energy lost during conversion and transmission. Imagine that the coal needed to illuminate an incandescent light bulb contains 100 units of energy when it enters the power plant. Only two units of energy eventually light the bulb. The remaining 98 units are lost along the way, primarily as heat.

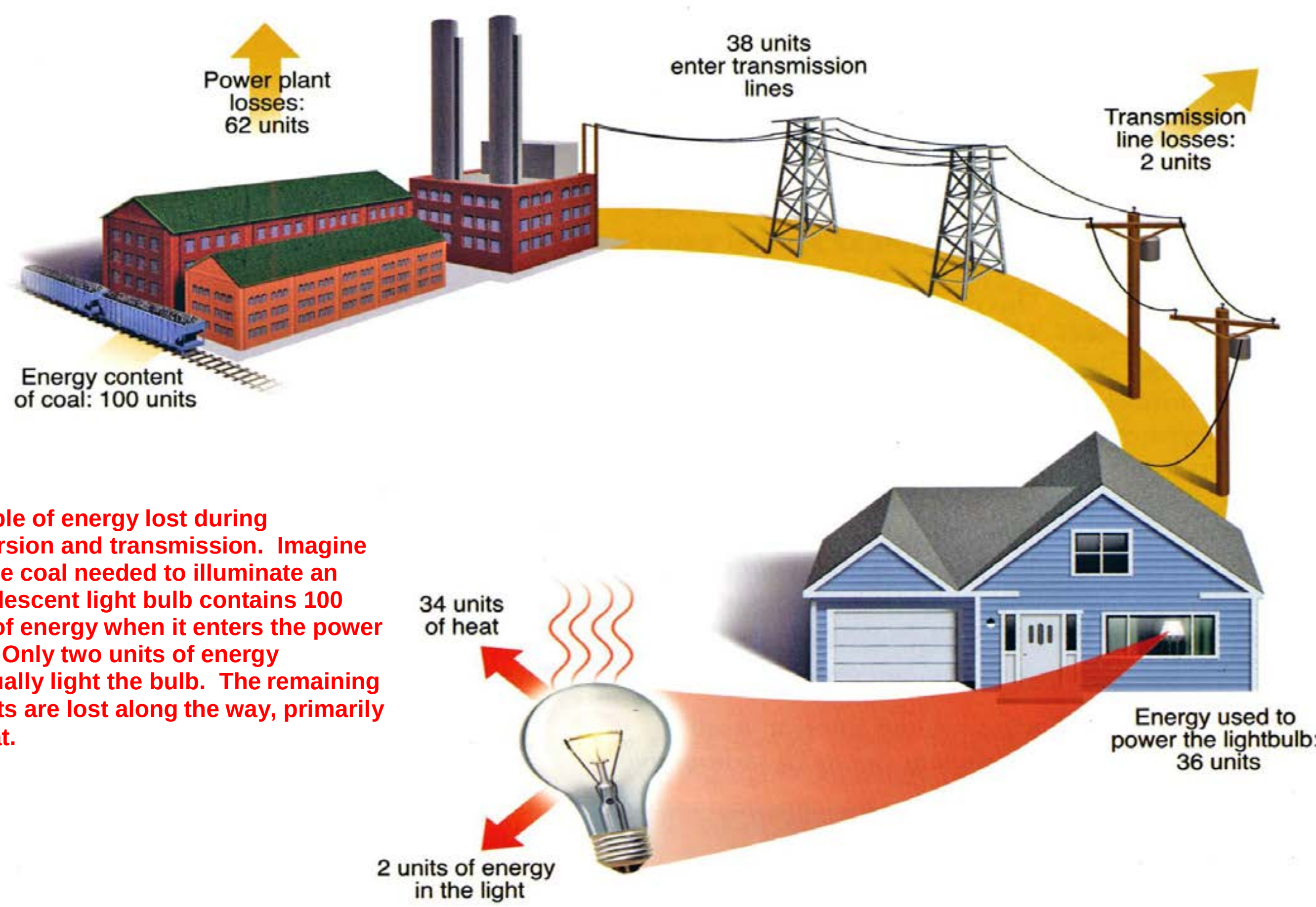


Figure 2 Energy and Electricity (In)Efficiency – Losses
Source: Reed, G. 2015. Opportunities for the Power Grid in the Changing Energy Economy. Presentation at the February 10, 2015 Government-University-Industry Research Roundtable workshop, The Cross Sector Impact of the Smart Grid.

Coast, Gulf Coast, and Great Lakes. The United States has over 400,000 miles of high-voltage transmission lines and 16,000 substations across the country, and lower voltage distribution networks that represent an additional ten times that amount of infrastructure. Modernization cannot readily be achieved by dismantling and replacing existing infrastructure, Reed explained, but we can integrate new technologies to make this infrastructure more efficient and allow it to continue to serve us in a reliable way. One challenge is that many of the new resources that are starting to be put into the grid—wind in the Texas panhandle, remote parts of California, and central plains states, for example, and solar in the Southwest and in many other parts of the country—are located far from where the highest power capacity needs and power infrastructure are located. We need to build that infrastructure, and we need to build it in a smarter and better way than we've done in the past, said Reed. Consumers are changing the game as well, perhaps even more dramatically, according to Reed. There is a mismatch between how we supply our electricity and how we use most of it, which is low voltage direct current (DC). Many electronic devices do not require 120 volts AC, so people carry around adapters to convert that 120 volts AC to a few volts DC. That causes a lot of inefficiency and lost energy. Consumers want to get more involved—for example, by putting solar panels on their roofs. In addition, many people want microgrids for greater self-reliance and resiliency.

Couple the use of DC power with the growth in renewables and private energy storage, and we are creating a new economy that is challenging the structure of the grid, because traditional consumers are now generating power that flows back into the grid infrastructure. Now, energy is being produced on the consumer side, and our power systems weren't designed for that, said Reed. The grid of tomorrow needs to be able to handle multiple-flows, not just one-way or even two-way flows, with a lot of it coming from DC sources, said Reed.

Reed proposed a move toward more DC infrastructure as we modernize the grid, in order to better match supply and demand and drive some inefficiency out of the system. Advantages of DC include greater capacity per right-of-way and better controllability of transmission and distribution networks compared to AC; the power electronics operate like valves that one can turn on and off rapidly, which can eliminate the prospect of cascading blackouts. DC also offers some cost advantages over AC, which requires three phases and a lot of heavy infrastructure. The advanced power controls and valves needed for DC are fairly costly right now, but the overall infrastructure costs between two-thirds and one-half the cost of AC infrastructure.

In addition, DC solutions and the power converters or power electronics technologies needed represent a tremendous opportunity for our nation to regain our technological leadership in the energy sector, creating opportunities for economic development and growth, as well as high-end jobs, said Reed.

Next, **William Sanders** of the University of Illinois at Urbana-Champaign offered a presentation on cybersecurity of the power grid. In the simplest sense, the challenge is to keep the lights on, he said. A 1999 National Research Council report, *Trust in Cyberspace*,[2] defined "trustworthy" as a system that does what it is supposed to do and nothing else. The "nothing else" is just as important as the "what it is supposed to do," particularly in thinking about cybersecurity.

The power grid today is a cyber-physical system, and in the past 10 years there has been a dramatic change in how the cyber parts of the grid interact with the physical side, said Sanders; all of these parts need to be considered in developing trustworthy systems. We need protection that uses classical cybersecurity approaches tailored to the cyber-physical nature of the grid. We also need to be able to detect and respond to intrusions; the concept of resiliency will help us move forward to achieve trustworthiness. Sanders leads a program called Trustworthy Cyber Infrastructure for the Power Grid (TCIPG), a collaboration of four universities, involving both power system engineers and cybersecurity experts. The program focuses on the cyber side of the grid, striving to understand the unique aspects of power systems and to build a cyber-structure that can help the power system operate through inevitable attacks.

The program involves not only university faculty and students but also full-time technical staff at power plants—power system engineers, cybersecurity auditors, and programmers—to build and implement the innovations that are developed. The program organizes its activities around four areas corresponding to the four cybersecurity challenges: 1) trustworthy technologies for wide-area monitoring and control; 2) trustworthy technologies for local-area monitoring and control; 3) detecting and managing attacks; and 4) trust assessment. TCIPG does fundamental research but also strives for major impact on the industry itself, said Sanders. TCIPG has also created educational materials for students and the general public, as well as hands-on training opportunities for staff at power companies.

Patrick McDonnell of the Pennsylvania Public Utility Commission spoke about cybersecurity from a policy perspective. Pennsylvania has a regulatory requirement that all utilities have plans for cyber security, physical security, emergency response, and continuity of operations. Utilities self-certify these plans on an annual basis, and they are subject to audit. Utilities also must report physical or cyber incidents that result in a service interruption resulting in over $50,000 in damage. So far, no cyber incident has met that threshold.

The commission started a cybersecurity team three years ago, and much of its activity has been non-regulatory and in collaboration with industry. Most utilities are fairly sophisticated in their approach to cybersecurity, not necessarily because they are afraid of regulators but because of their responsibility to shareholders, said McDonnell; the worst thing that can happen to them is an interruption in service, whatever the cause.

Pennsylvania House Bill 2200, Act 129 of 2008 required the seven largest utilities—those with over 100,000 customers—to install smart meters over a 15-year period. Most of the utilities have just begun to roll out their meters. The law requires smart meters to be bi-directional (providing information to the consumer and to the power company), to record use on at least an hourly basis, to provide direct customer access to price and consumption data, and to enable time-of-use or real-time pricing. The meters also must support the automatic control of customer consumption by the customer, utility, or a

[2] Trust in Cyberspace 1999. National Research Council. Committee on Trustworthiness, Commission on Physical Sciences, Mathematics and Application. Fred B. Schneider, Editor. National Academy Press; Washington, DC.

third party chosen by either—a significant matter in the context of cybersecurity and privacy.

The seven largest utilities in Pennsylvania are generally already responsible in terms of cybersecurity, so the smart grid fits into an existing, larger cybersecurity structure, as opposed to something they have to protect completely separately. The utilities are actively testing their systems and hiring third parties to try to break in and identify vulnerabilities. One of the ways the commission protects at the meter level is through encryption, McDonnell said; the meters themselves do not collect personal data (the address or identity of the customer). The information collected/stored by smart meters includes: meter number, how much energy is used, and maybe some pricing information—all of which is encrypted.

Utilities may do everything they can to secure data, but by law customers need to be able to get their data directly from the meter, which creates a huge potential vulnerability, noted McDonnell. Customers could place their data on their desktop at home, possibly with little protection.

Next, a presentation by **George Crabtree** from Argonne National Laboratory explained the work of the two-year-old Joint Center for Energy Storage Research (JCESR), a public-private organization that he directs.

Crabtree spoke about energy storage challenges, noting that there are two big energy uses waiting for transformational change: transportation and electricity. For its 125-year history, the grid has been operating under a serious constraint: it is necessary to generate electricity at the exact rate at which it is being used. If instead there were cheap ways to store energy, that paradigm could be broken. Suddenly, there would be new ways to operate the grid, and that could be a game-changer in terms of resiliency, flexibility, and efficiency. For example, storage will help the shift to variable sources like wind and solar.

JCESR's long-term vision is to transform transportation and the electricity grid with high-performance, low-cost energy storage. The organization's ambitious five-year goal is to deliver electrical energy storage with five times the energy storage capacity at one-fifth the cost of today's batteries. The legacies JCESR would like to produce are: 1) a library of the fundamental science of the materials and phenomena of energy storage at the atomic and molecular level, to help the R&D community move away from simple trial and error to a better understanding of why possible solutions work or fail; 2) two prototype batteries, one for the car and one for the grid; and 3) a new paradigm for battery R&D, one that integrates discovery science, battery design, research prototyping, and manufacturing collaboration—all in one highly interactive organization.

Crabtree raised the possibility that the organization's public-private model might work to bring high-risk opportunities to the market in areas beyond battery storage. He also offered criteria for when public-private organizations can be helpful and appropriate, such as when challenges require capacity beyond that of existing organizations and when there is clear public good.

A second presentation on energy storage was offered by **Jay Whitacre** of Carnegie Mellon University and Aquion Energy, who explained the genesis of Aquion and the technologies under development. There is a tremendous need for grid-level storage, and good low-cost storage would change the way we think about electricity, said Whitacre. However, current generation lithium ion batteries would have safety issues if used on a large scale.

In 2008, Whitacre founded Aquion with the goal of developing low-cost batteries with sufficient energy density. Any solution would need to use cheap materials (less than $4/kg) and a simple manufacturing approach. The company was founded with venture capital and incubated at Carnegie Mellon, explained Whitacre. Since its founding, Aquion has received over $120 million in support from a wide range of parties, including DOE, Carnegie Mellon, Bill Gates, and Shell Technology Ventures.

Whitacre described the technology Aquion is developing. The company finished its battery prototype a year ahead of time, and the batteries exceeded expectations; they were capable of storing 50 watt hours and were remarkably stable. Aquion now rents part of a factory in Pennsylvania, where employees assemble batteries by hand. In 2013, the first assembly line was finished, and 2014 saw the launch of the first product, a 2.4 kilowatt hour battery stack. Batteries have been sold and shipped to buyers in North America, Europe, and Asia. The company is currently working to identify places that have solar capability and that don't want diesel generation, such as the Philippines and Malaysia.

The batteries are estimated to last five years, and they will be the first green-certified battery, as they contain nothing toxic. Aquion's battery was identified by *Popular Science* as one of the 100 greatest innovations of the year. Anyone can buy them now, but most homeowners are not sophisticated enough or have the capability to integrate one into their energy use, noted Whitacre. They are continuing to improve the batteries, and going forward they are working on grid-level solutions for 2017.

A panel discussion on transitioning to the grid of the future opened with a presentation by **Rebecca Harrison** of the GridWise Alliance. The Alliance is a nonprofit consortium of passionate stakeholders focused on the modernization of the electric system for a sustainable energy future, said Harrison. The consortium is a public-private effort that includes a real range of parties—national labs, utilities, universities, and companies.

Harrison explained the findings of the organization's December 2014 report, "The Future of the Grid: Evolving to Meet America's Needs."[3] Developed at regional workshops and a national summit sponsored by GridWise and DOE, the report explains the industry's view of the grid of the future. At these events, participants discussed what the electrical system of the future might look like and how to transition the business model and the regulatory model to reach the system envisioned.

Based on discussions at these events, the GridWise Alliance report presents the following vision of the future electric system:

- Consumers will use the grid in different ways and they will produce as well as consume energy.
- There will be both centralized and distributed generation sources with a mix of dispatchable and non-dispatchable generation.
- Multi-consumer and single-consumer microgrid operations will complement the future grid.
- Energy storage will be a key component but will not replace the need for dispatchable generation.
- Balancing supply and demand will become increasingly complex and increasingly important.
- A retail market will develop, and it will be essential to figure out how wholesale and retail markets work together.
- Third-party competitive non-regulated parties will play an increasingly bigger role.

The vision for the future grid is very much the same across regions and types of utilities: we will still need and want a grid—the network effect will continue to have value—but it will no longer be a delivery pipe; there will be multi-way power flow. The grid needs to be agile and fractal, able to operate in both connected and disconnected states, and to switch between those states easily. The grid is envisioned as a dynamic enabling platform.

When industry participants were asked about the most critical technology challenge in the next 15 years, Harrison reported, the top vote-getters were incorporating and managing distributed energy resources and achieving cost-effective storage. When asked about the most critical technology challenge today, the top answers were dealing with the intermittency of renewable generation and dealing with big data. According to the industry participants, the highest risk scenario is continuing to debate change but keeping to the status quo. When asked how many years it will take for utilities to implement the systems they need to effectively manage significant distributed energy resources, most participants said 6 to 8 years or more than 8 years.

The report also offers recommendations, Harrison said, such as developing a unifying architecture that ensures that the grid can keep working across state and regional boundaries and a framework that states can use to help guide their investments going forward. According to Harrison, uncertainty in regulation stops investments in their tracks, and that is mostly happening at the state level. Providing regulatory clarity in times of significant change is important.

The final presentation was offered by **Carl Imhoff** from Pacific Northwest National Laboratory. There is a substantial change already underway, he said, including a lot of *ad hoc*, bottom-up activity in the grid modernization agenda. We have 3,500 utilities in 50 states, none of whom trust the federal

[3] *The Future of the Grid: Evolving to Meet America's Needs,* December 20014. Final report on an Industry-Driven Vision of the 2030 Grid and Recommendations for a Path Forward. GridWise Alliance and the Department of Energy.

government in terms of regulatory activities—a big challenge and barrier in terms of modernizing the grid. There is a great opportunity for public-private partnerships in this area.

Imhoff noted a few challenges and areas for development. Few people foresaw the natural gas bubble and the oil bubble 3-5 years ago, so the energy industry needs to consider potential bubbles when developing a long-term 30- to 50-year framework. Right now, the science to solutions pipeline moves too slowly. Groups need to look at how we federate across the innovation assets we have at universities, industry, and laboratories in order to move science more quickly to implementation. But the biggest hurdle is policy and regulation, which is where engagement with the states through public-private activities like GUIRR will be important.

The grid is under a lot of challenge, and grid modernization will be more strategic to us as a nation as we try to achieve our economic, policy, and national security goals going forward, along with the climate action plan. Some phenomenal transitions are already under way that the average consumer may not fully understand, said Imhoff. For example, California is looking at higher standards for reliability on that system. The new trends are pushing out the old business model and the traditional ways of controlling the system.

The transformation has been substantial, said Imhoff. After the great blackout in 2003, it was thought to be great progress to have 300 time-synchronized phasor measurement units (PMUs) to provide for wide-area situational awareness. At the end of this past year, we had 1,300 phasor measurement units networked and interacting, giving us a phenomenal ability to see the system as never before. The biggest target for a revolution now is the distribution system. Only about 20 percent of distribution feeders have high-end distribution management system software tools; many utilities still wait for the phone to ring to find out where they have outages.

"The nation would be well-served with a public-private agenda to help identify some key aiming stakes 10, 20, and 30 years into the future," said Imhoff. Such an agenda could help us envision the future grid and identify the architectural changes needed to accomplish a lot of the new possibilities—in terms of consumer engagement, distributed generation, cleaner portfolios, and so on—while still maintaining the fundamentals of affordability, reliability, and resilience.

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DISCLAIMER: This meeting summary has been prepared by **Sara Frueh** as a factual summary of what occurred at the meeting. The committee's role was limited to planning the meeting. The statements made are those of the author or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, GUIRR, or the National Academies.

The summary was reviewed in draft form by **Celia Merzbacher**, Semiconductor Research Corporation, and **Galen Rasche**, Electric Power Research Institute, to ensure that it meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

ABOUT THE GOVERNMENT-UNIVERSITY-INDUSTRY RESEARCH ROUNDTABLE (GUIRR)

GUIRR's formal mission is to convene senior-most representatives from government, universities, and industry to define and explore critical issues related to the national and global science and technology agenda that are of shared interest; to frame the next critical question stemming from current debate and analysis; and to incubate activities of on-going value to the stakeholders. The forum is designed to facilitate candid dialogue among participants, foster self-implementing activities, and, where appropriate, carry awareness of consequences to the wider public.