Electricity Use in Rural and Islanded Communities: Summary of a Workshop

DETAILS

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Electricity Use in Rural and Islanded Communities

SUMMARY OF A WORKSHOP

Ben A. Wender, *Rapporteur*

Board on Energy and Environmental Systems

Division on Engineering and Physical Sciences

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

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Acknowledgement of Reviewers

This summary has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published summary as sound as possible and to ensure that the summary meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Gary Connett, Great River Energy,
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Pam Silberstein, National Rural Electric Cooperative Association, and
Richard Tabors, Tabors Caramanis Rudkevich.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the views presented at the workshop, nor did they see the final draft of the workshop summary before its release. The review of this workshop summary was overseen by Thomas Overbye, University Illinois, Urbana-Champaign, who was responsible for making certain that an independent examination of this workshop summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the author and the institution.

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Workshop Introduction: Welcome and Meeting Objectives

On behalf of the Quadrennial Energy Review (QER) Task Force, the National Academies of Sciences, Engineering, and Medicine hosted a workshop on February 8-9, 2016, titled "Electricity Use in Rural and Islanded Communities." The objective of the workshop was to help the QER Task Force public outreach efforts by focusing on communities with unique electricity challenges. The workshop explored challenges and opportunities for reducing electricity use and associated greenhouse gas emissions while improving electricity system reliability and resilience in rural and islanded communities. Although the statement of task (Appendix A) mentioned design of microgrids for hospitals, universities, military bases, and other unified load centers, presenters covering microgrids were encouraged to describe potential applications serving isolated communities and towns in keeping with the theme of the workshop. Speakers were assembled from diverse locations, including Hawaii, Alaska, North Carolina, and Vermont, and with expertise in many facets of electricity system design and operation. Speakers were encouraged to do the following: (1) identify and share best practices between rural and islanded electricity system users and operators and (2) provide suggestions for federal policies and research and development investments that could be implemented in both the near- and long-term time frames. This report has been prepared by a rapporteur as a factual summary of what occurred at the workshop. The planning committee's role was limited to organizing and convening the workshop. The views contained in the report are those of individual participants and do not necessarily represent the views of all workshop participants, the planning committee, or the Academies. Appendix B contains the full list of participants and attendees, and Appendix C presents the 2-day agenda. In addition to the written summary provided here, materials related to the workshop can be found at the website of the Board on Energy and Environmental Systems (http://www.nas.edu/bees), including speaker presentations.

Welcoming remarks given by Karen Wayland, deputy director for state and local cooperation in the Office of Energy Policy and Systems Analysis at the Department of Energy (DOE), provided speakers and attendees with an overview of the QER. The first installment focused broadly on transmission, storage, and distribution infrastructure for all forms of energy—electricity, natural gas, and liquid fuels. The second installment of the QER (QER 1.2) currently in preparation will focus specifically on electricity generation, transmission, distribution, and end use, as shown in Figure 1, because of the central importance of electricity systems to the nation. Amidst a backdrop of rapid and foundational changes in the electricity sector over the past 5 years, Wayland emphasized the importance of recognizing operational and historical differences across the United States: "You can't develop national electricity policy without really understanding the regional differences. And not just regional differences, but the differences within regions, which is the reason for this workshop."

K. John Holmes, Academies' study director, explained that the workshop planning committee assembled experts with experience deploying innovative strategies to improve electricity system performance in rural and islanded communities. This focus on rural and islanded communities adds a unique perspective to the public outreach efforts of the QER Task Force, and hearing from practitioners implementing these strategies can help inform federal decisions in the near and long term. The first day of the workshop provided context on rural and islanded electricity systems and presented approaches that could be implemented in the 0- to 5-year time frame. The second day focused on more distant solutions that could transform the electricity system in a 5- to 30-year period.

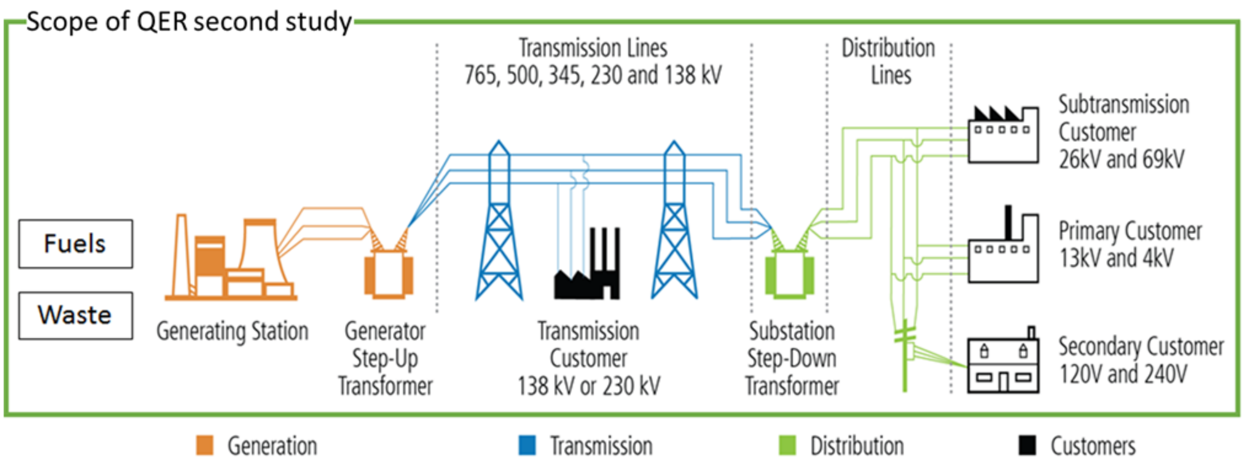

FIGURE 1 Quadrennial Energy Review (QER) 1.2 will focus exclusively on the U.S. infrastructure for electricity generation, transmission, distribution, and end use. SOURCE: Karen Wayland, Department of Energy, "Quadrennial Energy Review 1.2: An Integrated Study of the Electricity System," presentation to the workshop, February 8, 2016.

Summary of Workshop Presentations and Discussions

UNDERSTANDING ELECTRICITY SYSTEMS IN RURAL AND ISLANDED COMMUNITIES

In its 80th anniversary year, the Rural Utility Service (RUS)[1] is celebrating a long history of helping to bring electricity infrastructure—spanning generation, transmission, distribution, and end-user engagement—to rural communities, said Chris McLean, assistant administrator for the RUS Electric Program at the U.S. Department of Agriculture. One salient characteristic of rural communities is that they include nearly 93 percent of the persistently impoverished counties in the United States. Furthermore, the cost of expanding electricity access to rural communities may be prohibitively high for traditional investor-owned utilities whose fiduciary responsibility is the creation of dividends for investor-owners. Thus, RUS partners predominantly with customer-owned rural electric cooperatives to finance infrastructure improvements that generate wealth in local communities. To date, more than 40 percent of U.S. electricity infrastructure (as measured by miles of line) has been funded by RUS-affiliated programs with a loan delinquency rate less than 0.05 percent. McLean described recent RUS efforts to make aging rural infrastructure cleaner, greener, smarter, and stronger by investing in emissions mitigation technologies, fuel switching from coal, distributed and centralized renewables, and smart grid technologies. "If you look at the wind corridors, the solar corridors, the biomass corridors, they are all in rural America. And if you look at all of the transmission needs, they are all in rural America. . . This is the time to invest in rural electric infrastructure," McLean concluded.

Electricity infrastructure challenges facing island communities such as Hawaii are different from those of rural areas in the continental United States because of both policy and geographic considerations, explained Chris Yunker, who is the energy systems and planning program manager at the Hawaii State Energy Office. Motivated by high electricity costs and fuel supply chain risks, Hawaii is striving to increase its energy security and affordability. "To understand Hawaii's perspective," he said, "you need to understand that we recently passed a 100 percent RPS [renewable portfolio standard] law by 2045 . . . and [are] look[ing] at getting off imported fuels for Hawaii both in the electric sector and in the ground transportation sector." Yunker stressed that this longer-term goal underlies all planning and investment decisions being made today. There are many ways to get to 40 or 50 percent renewables, but the pathway must be in support of this 100 percent goal. Yunker also emphasized the importance of considering Hawaii's energy system holistically. Hawaii's pursuit of energy independence through electrification of the transportation sector will have significant implications for the grid—potentially positive or negative depending on vehicle charging habits—so considering these systems together can illuminate innovative strategies to reach Hawaii's long-term goals. There is also a lot of diversity in resources and electricity system characteristics across the separate Hawaiian islands (Figure 2), which provides an opportunity to experiment with multiple approaches to improving electricity systems. Yunker concluded that islands "provide a rich opportunity for innovative solutions that . . . will help build a toolbox that can be utilized not only by the island and rural communities, but can also be utilized by mainland grids, because at some point we will all be dealing with some of the issues that we're seeing here."

[1] U.S. Department of Agriculture, "Rural Utilities Service," http://www.rd.usda.gov/about-rd/agencies/rural-utilities-service, accessed June 14, 2016.

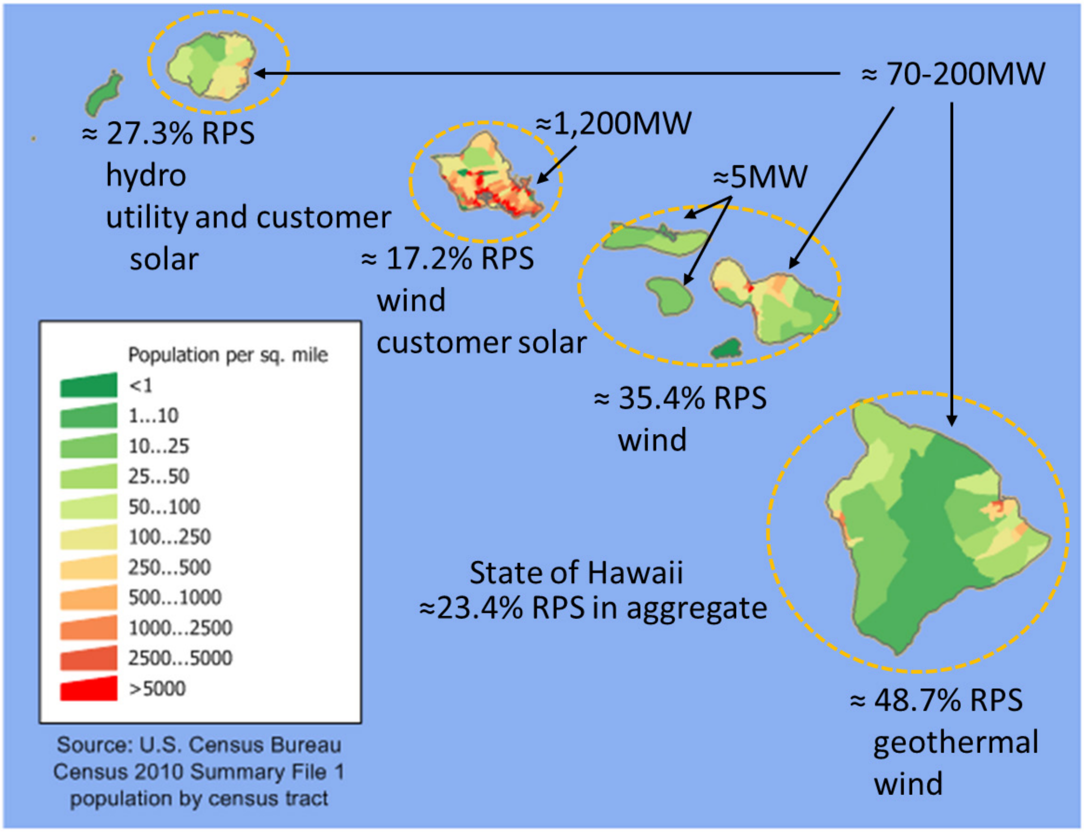

FIGURE 2 The Hawaiian Islands have diverse population densities and electricity system characteristics, with isolated grids ranging from 5 megawatts (MW) up to 1,200 MW. Each island has different renewable portfolio standards (RPS) and resource mixes. Data shown for calendar year end of 2015. NOTE: 2015 Renewable Portfolio Standard Status Reports are available from http://puc.hawaii.gov/wp-content/uploads/2013/07/RPS-KIUC-2015.pdf; http://puc.hawaii.gov/wp-content/uploads/2013/07/RPS-HECO-2015.pdf; and http://puc.hawaii.gov/wp-content/uploads/2015/04/Adequacy-of-Supply-KIUC-2015.pdf. SOURCE: Modified from Chris Yunker, Hawaii State Energy Office, "Islanded Communities: Issues and Differences," presentation to the workshop, February 8, 2016. Population density map © Jim Irwin, licensed under creative commons 3.0 (CC-BY SA 3.0).

Although not necessarily on physical islands, rural Alaskan communities are electrically islanded in that they are not connected to the large mainland transmission grid. Meera Kohler, president and CEO of the Alaska Village Electric Cooperative (AVEC), noted that Alaska covers a gigantic area with rugged terrain throughout which small populations are spread out. Outside of the few larger cities, Alaskans face similarly high fuel and electricity costs but different challenges than communities in Hawaii. For the 30,000 individuals in 56 rural communities served by AVEC, the pervasive reliance on imported diesel fuel contributes to electricity prices between $0.50 and $0.80 per kilowatt hour (kWh), which is approximately 5 times the national average (Figure 3). Capital investment costs are similarly exaggerated in rural Alaska—between 3 and 5 times the national average—in part because of the small-scale, large transportation costs, and the need to build in redundancy in generation. The average AVEC customer consumes less than 400 kWh per month, so there is little potential for energy savings through increased end-use efficiency. These villages already conserve as much as possible. Kohler remarked, "I have a grocery store a quarter of a mile from my house in Anchorage [the largest city in Alaska] that uses twice as much [energy] as our average village." Alaska's villages have highly seasonal demand, with

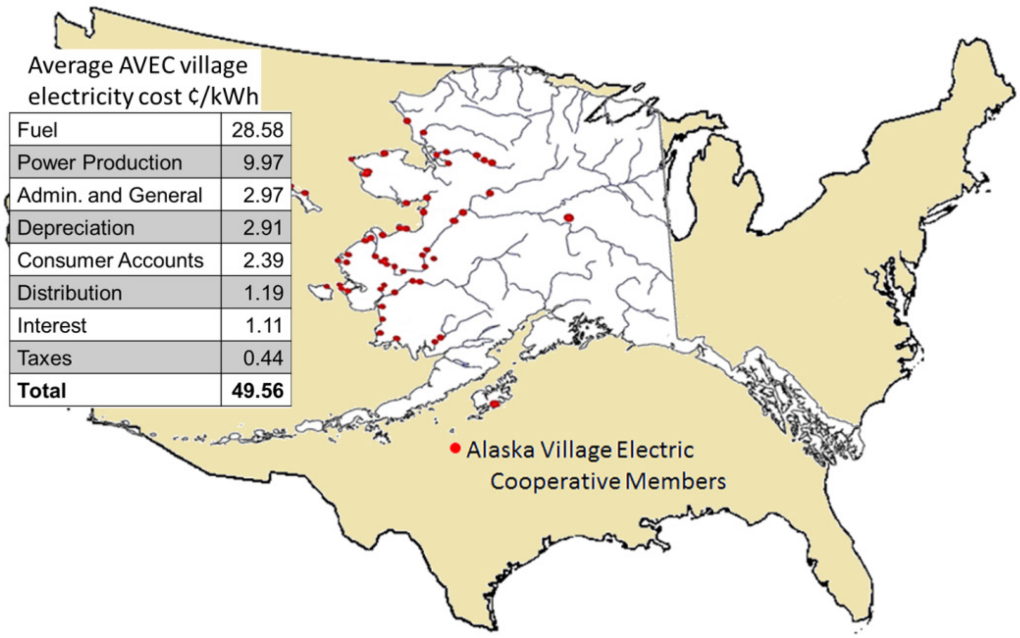

FIGURE 3 As of 2015, the Alaska Village Electric Cooperative serves more than 50 small communities dispersed across large distances and in remote regions with harsh climatic conditions. All of these factors contribute to average electricity prices approximately 5 times the U.S. national average. SOURCE: Modified from Meera Kohler, Alaska Village Electric Cooperative, "Alaska Village Electric Cooperative," presentation to the workshop, February 8, 2016.

consumption peaking in the winter as heating and lighting are required almost constantly, whereas summer load is nearly zero. Rural Alaska is largely reliant on diesel generators; nonetheless, AVEC is the state's largest owner of wind turbines, with more than 30 installed in high resource areas. Kohler concluded with a series of suggestions for research and efforts to improve electricity system performance in rural Alaskan villages, including the following: (1) greater interconnection between communities through small- and medium-voltage direct current cables and inverter systems; (2) practical, cost-effective electricity storage solutions and "grid bridging" capacitor systems that allow 10 to 15 seconds for diesel generators to come online; (3) technical training in new technologies so they become as familiar as diesel generators; and (4) technical support to operate advanced metering infrastructure and virtual supervisory control and data acquisition (SCADA) systems in spite of poor communications infrastructure.

INCORPORATING EFFICIENCY

According to R. Neal Elliott, senior director for research at the American Council for an Energy Efficient Economy (ACEEE), reducing end-use electricity consumption by increasing the efficiency of homes and businesses in rural communities is a more cost-effective strategy than building more generation, transmission, or distribution infrastructure. However, energy efficiency programs in rural communities face unique challenges for several reasons: (1) rural communities contain a greater proportion of low-to-moderate-income individuals with greater difficulty accessing credit or capital necessary to invest in home improvements; (2) a disproportionate amount of agricultural activities occur in rural areas, which often have seasonal processing loads that increase the payback time of efficiency investments; and (3) electric cooperatives serving rural communities may have access to fewer financial and technical resources than large investor-owned utilities. Rural communities also have unique resources—for example, strong community organizations, local banks, extension services, and ties to the

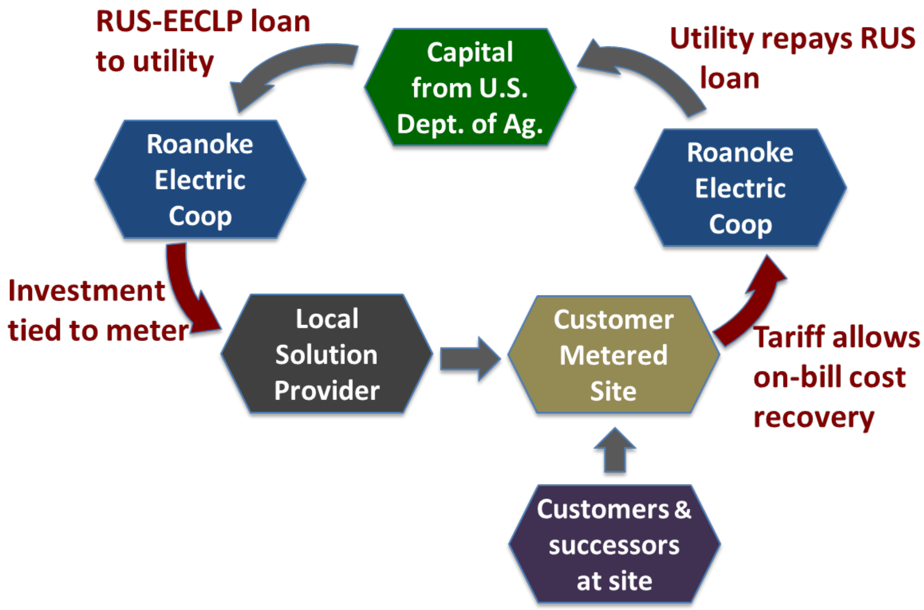

FIGURE 4 Roanoke Electric Cooperative uses a U.S. Department of Agriculture Rural Utility Service Energy Efficiency and Conservation Loan Program (RUS-EECLP) loan to finance meter-tied efficiency improvements installed by local contractors and recovers this investment via an on-bill tariff to repay the original RUS loan. SOURCE: Modified from Curtis Wynn, Roanoke Electric Cooperative, "Upgrade to $ave," presentation to the workshop, February 8, 2016.

U.S. Department of Agriculture—and it is important for energy efficiency programs to take advantage of this unique rural infrastructure to improve program organization and dissemination of information. He added that energy efficiency measures complement installation of distributed generation (DG) systems by lowering end-use electricity demand, thereby reducing the size and cost of DG projects. This synergy may be particularly beneficial for rural customers at the end of distribution systems where DG resources can improve power quality and avoid significant investments in distribution infrastructure. Elliott suggested there is a need for better data collection and analysis regarding electricity use in rural communities, which can help develop rural-specific energy efficiency strategies. He concluded by citing the lack of energy efficiency measures available for mobile homes, which are aging and constitute an important component of the housing stock in the rural United States, and urged the creation of energy efficiency measures for mobile homes.

Curtis Wynn, CEO of Roanoke Electric Cooperative, described energy efficiency programs currently being implemented by his organization with support from the RUS Energy Efficiency and Conservation Loan Program (RUS-EECLP). Wynn reinforced several of the points raised in the preceding presentation—specifically, that the community served by Roanoke Electric Cooperative is economically distressed and contains more than twice the number of mobile homes compared to national benchmarks. More than 30 percent of community members report having an average electricity bill in excess of $250 per month. However, the large upfront capital investment required for energy efficiency upgrades—which could reduce electricity consumption and expenditures—is generally prohibitive because of the high fraction of renters, reluctance to incur additional debt, and limited access to credit. To address this cycle, Wynn sought a more inclusive solution by financing meter-tied efficiency investments with an RUS-EECLP loan. The utility recovers this investment through a tariff collected from the occupant at the metered site (Figure 4), who in turn benefits from reduced bills and net savings because the tariff is less than the gross cost savings. The primary efficiency improvements are in better insulation, duct and air sealing, heat and water pump upgrades, and higher-efficiency lighting. After making efficiency upgrades, the average monthly savings at a site are approximately $120, and the average monthly tariffs collected by the cooperative are approximately $60 with the balance kept as savings by the customer. With an average upgrade cost of $6,900 per site, the cooperative recovers its initial investment in less than 10 years. Additionally, local contractors benefit from consistent business, which creates jobs and wealth that stay in the community. In the future, Roanoke Electric Cooperative is looking to incorporate smart appliances and thermostats into its efficiency offerings but currently is limited by patchwork broadband access in its service community. Regardless, Wynn argued that energy efficiency investments make a strong business case for the cooperative, despite leading to a decrease in electricity sales, because the cooperative has lower wholesale power expenditures in a rising-cost environment. The upgrades can also offset the costs of state-mandated energy efficiency credits: “All said and done, we are experiencing about a 6 to 10 percent net present value internal rate of return for every measure we are doing. Folks, that’s huge.”

INCREASING SYSTEM RESILIENCE AND RELIABILITY

David Wade, executive vice president and chief operating officer for the Electric Power Board (EPB) in Chattanooga, Tennessee, reminded the audience of the strong connection between economic productivity and electric power and that reducing power outage frequency and duration translates into economic gains in the community. In pursuing an electricity system that was “intelligent, interactive, and self-healing,” EPB realized that throughout its service territory the missing link was communications infrastructure. EPB installed a fiber optic network everywhere there were roads in its territory, including rural areas at the end of distribution lines, which enabled EPB to automate control of the distribution and sub-transmission systems. Wade presented data visualizations from two outage events in which automation rapidly restored power to thousands of users, helped system operators prioritize restoration responses, and saved millions of dollars for the community and EPB. Other anecdotes demonstrated the ability for improved sensing and analytics to detect faults in grid-connected equipment—for example, aging transformers or home heating and air conditioning systems—that improve efficiency, enhance reliability, and save money. Wade suggested that a resilient distribution system must have multiple sources of power from the larger transmission grid. Where additional connections to the transmission grid are not available, EPB is exploring the potential for DG and electricity storage devices to provide this redundancy for rural areas located at the end of distribution lines. Wade reinforced the importance of building communications infrastructure that anticipates future needs and developments, to which a network of sensors and automation controls can be added. In turn, this requires development of data processing and analysis capabilities that generate value for customers and the utility from this large flow of data. In processing this data, Wade emphasized that there is a need to anonymize data collected from homes and businesses to address customer privacy concerns while allowing data sharing with other utilities and researchers.

Henri Dale, of Henri Dale, LLC, and retired power systems manager from the Golden Valley Electric Association, introduced participants to the Alaska Railbelt Electric System, which connects the Kenai Peninsula, South Central (Anchorage), and the Interior Region (Fairbanks) and is served by six vertically integrated utilities, as shown in Figure 5. Although interconnected, the 800 MW-peak system is islanded from the continental North American grid and faces high electricity prices due to the relatively small scale of operations, large construction costs, and long transportation distances for fuel. The Railbelt system employs a variety of techniques to maintain power quality and reliability across the system, which is a challenge because of the system’s small size and ongoing replacement of old larger turbines with lighter aeroderivative turbines that provide less spinning inertia. One technological solution in place is the Battery Energy Storage System (BESS), which is a large nickel-cadmium battery system that provides 27 MW of power for approximately 15 minutes—roughly the amount of time required for operators to bring a new generator onto the Railbelt grid. Since adding the BESS, the Interior Region utilities no longer have

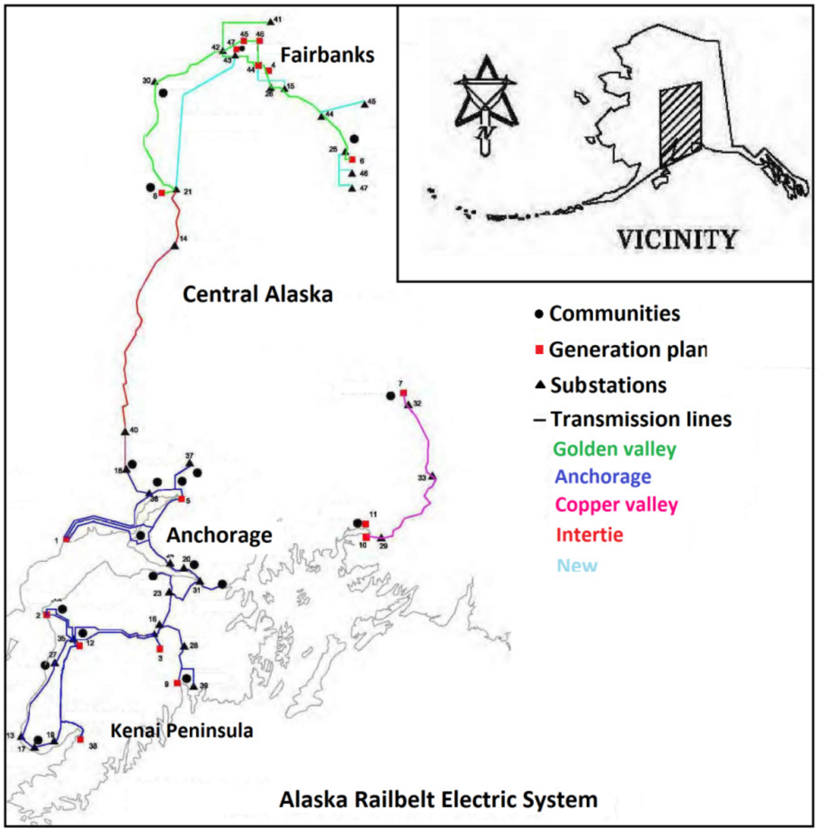

FIGURE 5 The Alaska Railbelt Electric System is a large, 800 MW-peak system connecting Alaskan population centers in Fairbanks and Anchorage, which is served by six vertically integrated utilities. SOURCE: Modified from Henri Dale, Henri Dale, LLC, "Alaska Railbelt Electric Systems," presentation to the workshop, February 8, 2016.

to shed customer load in lieu of keeping high-cost reserve generation available. Dale also described how the BESS is used to modulate system voltage and frequency and that its addition to the Railbelt system makes operators more confident in operating the system closer to technical limits, thereby improving economic efficiency. Unfortunately, Dale said, the BESS was not particularly helpful in addressing the intermittency of installed wind turbines because of the relatively small storage capacity compared to the long period of time between wind peaks. Nonetheless, the Railbelt system's long-term plans include addition of a second BESS in the South Central service area based on the benefits realized to date.

UTILIZING RATE DESIGN

Many utilities facing flat or declining electricity demand and growing penetration of DG resources are considering increased fixed cost charges within their tariffs to maintain revenue for operations and service. According to Ken Colburn, a principal at the Regulatory Assistance Project who also serves on the board of directors of the New Hampshire Electric Cooperative (NHEC)—sharing his personal opinion and not speaking on behalf of either organization, this is not an optimal solution. Prominent media coverage of disputes between utilities and customers or solar advocates over large fixed fees imposed on net metering customers reflects poorly on power companies because they appear anti-competitive, and local non-polluting solar power is popular with the public. Colburn suggested a better approach is to develop rate structures that simultaneously promote growth of solar DG and provide sufficient funds for operation, administration, and maintenance of the electrical distribution system. Through his work with the Regulatory Assistance Project, Colburn offered three principles that should underlie rate design today: (1) a customer should be able to connect to the grid for no more than the cost of connection, (2) a customer should pay for grid service and power in proportion to how much he/she uses those services and consumes power, and (3) a customer who supplies power to the grid should be fairly compensated for the value of power supplied. When NHEC approached the statuary "cap" on net metered customers in its service territory, the board applied these principles and worked with its members and stakeholders to develop a new rate structure. Net metering customers joining after reaching the cap receive the majority of the full retail price of power (e.g., approximately 70-85 percent of the full retail charge in cents per kilowatt hour) while the cooperative retains a smaller fraction of this amount (e.g., the remaining 15-30 percent of the full retail price). The exact percentages returned for previously existing net metering accounts ("below-the-cap") and new accounts ("above-the-cap") differ based on the size of the solar installation, as shown in Figure 6. With the cooperative made whole for the cost of maintaining the distribution system, NHEC determined that there was no need to artificially cap the amount of net metering allowed and thus eliminated any DG cap whatsoever. The new rate structure was introduced in early 2015 and has not negatively impacted the growth of distributed solar. Based on the success of this program, Colburn continued, New Hampshire legislators, the state public utility commission, and other utilities are considering adopting a similar approach: "Just as states are the laboratory of democracy, cooperatives are the laboratories for electricity." Colburn suggested that federal agencies work to identify and compile best practices from regionally diverse electric cooperatives and municipal utilities, run thorough analyses on these programs, and take an active role disseminating best practices and their results to the broader electricity community.

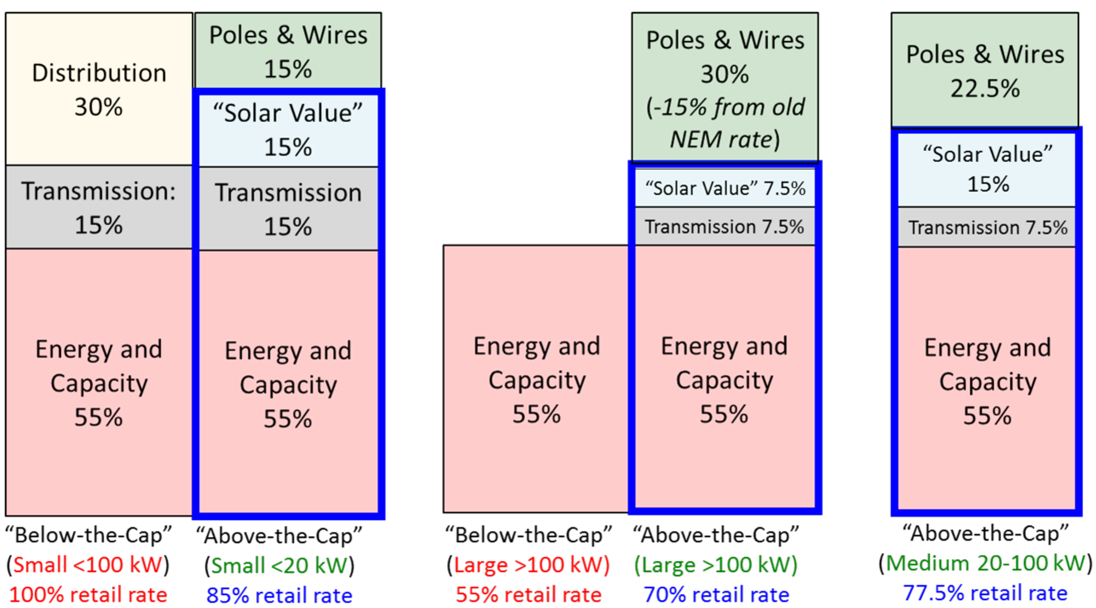

FIGURE 6 New ("above-the-cap") net metering rate structures compensate customers with a variable percentage of the full retail cost for power based on the size of installation, while allowing the New Hampshire Electric Cooperative to collect the remaining amount for costs associated with grid maintenance and administration. Customers who established net metering accounts prior to reaching the statutory cap ("below-the-cap") retain original rates. NOTE: Percentages shown are illustrative and actual values vary. SOURCE: Modified from Ken Colburn, Regulatory Assistance Project, "Rate Design: New Times Warrant New Approaches," presentation to the workshop, February 8, 2016.

Ron Meier, manager of engineering at La Plata Electric Association serving southwestern Colorado, discussed the potential for variable prices depending on the time-of-use (TOU) to help the cooperative manage its load profile and improve overall system efficiency. Meier presented daily load curves for two high-demand days—with and without TOU on peak price signals—and showed that TOU resulted in lower peak power demand despite increased energy consumption, thereby improving the load factor. When high rates begin for peak hours, electrothermal storage units switch off, causing a notable decrease in load. Likewise, as peak rates end and storage units switch on to recharge, load increases rapidly (Figure 7). One unintended consequence of the success of La Plata's TOU rates was that these large ramp rates would cause circuits to have nuisance trips and overload the capacity of the lines in certain areas of the grid. Meier described several approaches taken to remedy this action, including the following: (1) moving the beginning of off-peak rates later in the night when baseload demand is lower and (2) randomizing the start time of thermal storage units so they did not all turn on at once. In addition to technical challenges, TOU rates are affected by economic and policy decisions—for example, when the generation company serving La Plata changed its rate structure to be based solely on total energy consumption as opposed to peak power use. With no economic incentive to reduce peak power consumption, La Plata modified its TOU rates such that there was less of a difference between on- and off-peak pricing, which reduced consumer participation in the TOU program by more than a factor of two. Meier suggested that utilities considering TOU rates pay close attention to the ratio of on- and off-peak rates, as this is the primary signal to consumers and significantly affects customer participation. La Plata also learned that TOU programs benefit from wider implementation of smart meters, which facilitates reprogramming and allows prospective comparison of potential savings associated with switching to TOU rates. However, Meier cautioned that utilities invest in data management systems alongside smart meters to be better prepared to sort and analyze the large amount of incoming data into useable information.

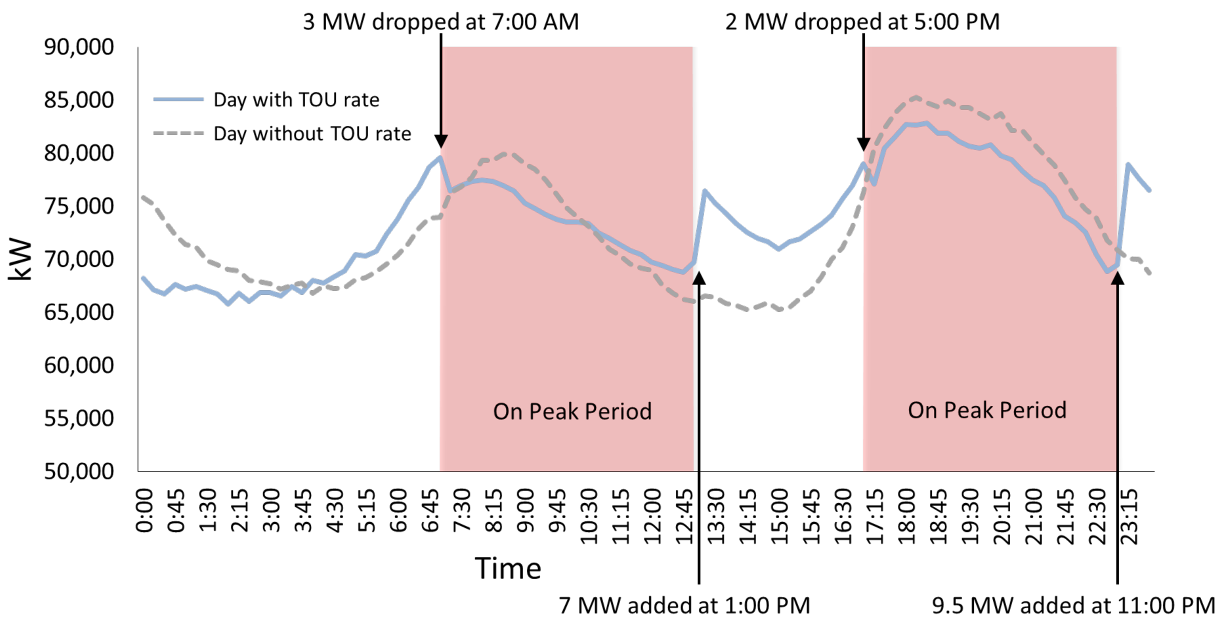

FIGURE 7 La Plata Electric Cooperative reduced peak power consumption with its time-of-use (TOU) program but had to develop strategies to address the large ramp rates occurring at the end-of-the-peak billing period when thermal storage units all switch on. SOURCE: Modified from Ron Meier, La Plata Electric Association, "Time-of-Use Rates: The Policy, Economics, and Physics," presentation to the workshop, February 8, 2016.

GENERATION ALTERNATIVES FOR GREENHOUSE GAS REDUCTIONS

The remote and isolated conditions faced by Alaskan electricity systems underlies the mission of the Alaska Center for Energy and Power (ACEP) to develop practical and cost-effective energy solutions, said Marc Mueller-Stoffels, director of Power Systems Integration at ACEP. Despite high fuel costs, diesel generators are ubiquitous in Alaska because they serve important functions beyond electricity generation, such as production of waste heat, maintenance of sufficient inertia to withstand minor disturbances, and creation of a voltage and frequency reference. For these reasons, it is difficult to move away from diesel generators entirely, despite sustained interest in incorporating more renewable energy generation, energy storage, and demand response programs. Mueller-Stoffels noted that intermittent renewables could not be the sole energy source without oversizing the system capacity by 300 to 900 percent of peak power demand. Describing a recent project done with the community of Nome, Alaska, Mueller-Stoffels acknowledged that the inclusion of *some* renewable generation and energy storage systems can result in substantial fuel savings. This type of system is significantly more complex than directly connecting a diesel powerhouse to customer load, and it requires some form of central coordination to manage variable generation, load, storage, and traditional diesel generators. Furthermore, control systems have to be flexible enough to accommodate multiple, often changing, objectives. This necessitates management of large data streams, and Muller-Stoffels emphasized that Alaska will need significant help to develop broadband capability because of limited access to cloud-computing resources.

David Dunn of the Energy Innovation Center at Green Mountain Power (GMP) in Vermont described a program "affectionately called Cow Power" (Figure 8), which is based on the anaerobic digestion of animal waste to produce biogas that can be combusted in an engine or generator. Dairy farms, present in many rural areas, are a significant part of Vermont's economy and provide a large, consistent source of animal waste that can be used as a resource. This waste is collected at each of 13 digesters located on dairy farms across Vermont. These projects were developed through the Cow Power program and GMP's renewable development fund, and they produce renewable baseload electricity. Furthermore, biogas may be stored more cost effectively than electricity, so building storage facilities offers a cost-effective strategy to meet peak load demands with a renewable resource. The climate benefits of anaerobic digestion of animal waste exceed simple offsets of electricity produced from conventional sources, because digestion of animal waste also reduces direct methane emissions from manure storage. Dunn estimates that more than 40,000 metric tons of CO_2 equivalents of methane have been avoided through the Cow Power program. Additionally, the digestion process creates useful byproducts, such as a recovered fiber that is used as animal bedding and liquid fertilizers that are easier to incorporate into crop land, which can reduce eutrophication-causing nutrient runoff into surface waters and improve water quality. Cow Power grew from several small grants, and Dunn stressed the importance of government funding to support scale-up of innovative concepts as well as funding for research to optimize the microbial communities found in digesters. Finally, Dunn encouraged holistic consideration of energy-climate-health systems, as opposed to optimizing each separately, to develop solutions that address multiple challenges simultaneously.

TECHNOLOGICAL AND OPERATIONAL INNOVATIONS

For more than 40 years working at the Minnesota generation and transmission cooperative Great River Energy, Gary Connett managed generation assets precisely to match variable demand. Recently, with greater penetration of distributed and variable energy resources, utilities now have to manage both variable load and variable generation. As director of demand response programs at Great River, he described an approach to controlling load to meet generation capacity using the "battery in the basement"—domestic water heaters. Great River has more than 110,000 water heaters under some form of control, which they charge during off-peak hours to store approximately 1 gigawatt hour (GWh) every

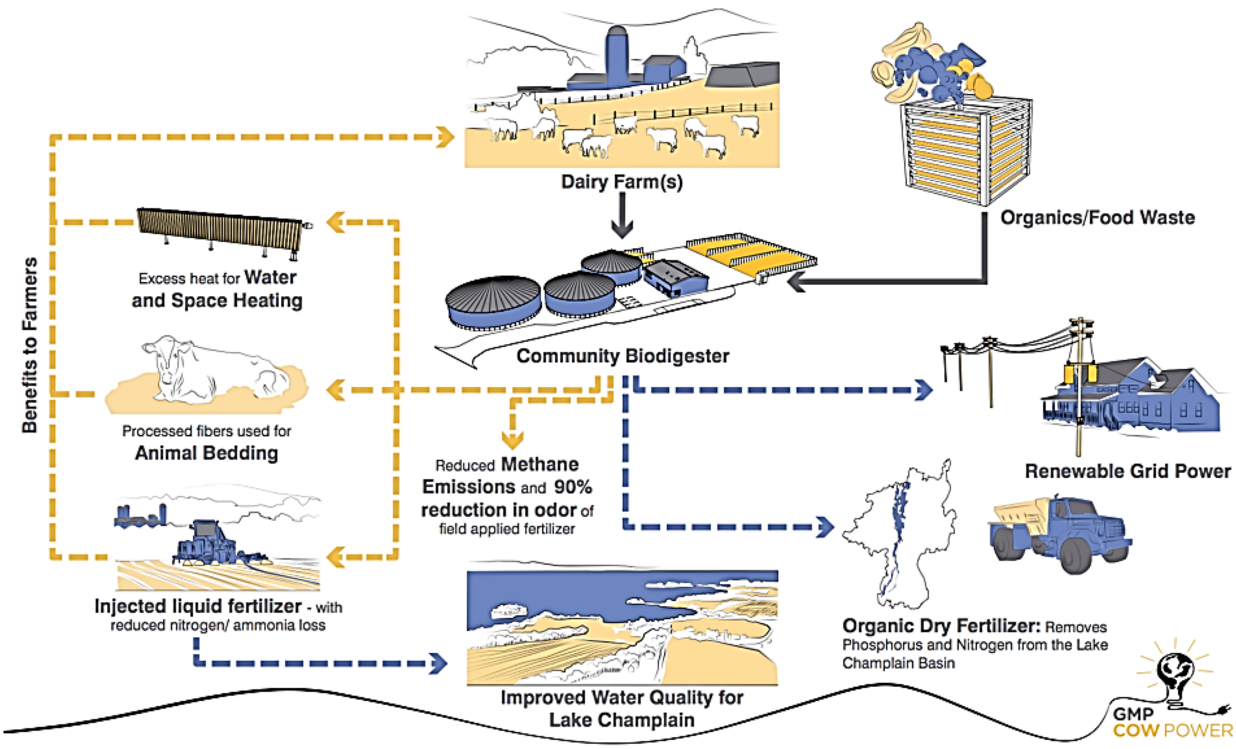

FIGURE 8 Green Mountain Power's Cow Power program uses anaerobic digestion of animal and agricultural waste to produce biogas for baseload renewable power as well as fertilizer, animal bedding, and waste heat coproducts that create additional benefits. SOURCE: David Dunn, Green Mountain Power, "GMP's Clean Energy & Clean Water Projects in Vermont," presentation to the workshop, February 8, 2016.

night. This community storage program helps utilities become more efficient and is one operational innovation emerging from cooperatives with great potential for wider adoption. Under a pilot program, Great River Energy also operates a handful of grid-interactive water heaters that adjust their heating rate every 5 seconds based on real-time market conditions, with the hope of ultimately offering these water heaters and others into the ancillary services market. Connett also reviewed ongoing community and utility-scale solar projects in their service area, emphasizing the potential to couple community solar with community storage initiatives. For example, one project offers residents a free electrothermal storage tank with the purchase of a solar panel, giving distribution utilities greater control of demand and encouraging greater penetration of renewables. Connett concluded that the future grid will require distributed energy resource management systems, which go beyond switching water heaters and air conditioners off and on and would allow dynamic balancing of variable generation and load.

Rich Silkman, founder and co-manager of Grid Solar, LLC, described how innovative combinations of technology and demand response strategies can improve grid reliability in rural areas without making large investments to expand transmission or generation capacity. Approximately $10 billion of transmission system improvements are planned for the New England area to improve reliability during the relatively few hours of peak load in which the system is stressed each year, Silkman said. This is analogous to building a second Maine Turnpike because local secondary roads could not accommodate all traffic on Labor Day or Memorial Day weekend if a catastrophic accident occurs. Silkman emphasized that building new transmission capacity was an inefficient solution to peak load problems, and instead, non-transmission alternatives such as distributed generation and demand response could be used to reduce the amount of power needed at the place of demand. A pilot project in Boothbay Harbor, Maine, demonstrated that a portfolio of alternatives could maintain service and grid reliability in this rural community while avoiding a costly investment in additional transmission capacity. Silkman described a portfolio that included solar distributed generation, backup diesel generators, demand response, on-peak efficiency measures, and 500 kilowatts (kW) of battery storage for a total capacity of 1.8 MW of non-transmission alternatives. Monitoring grid conditions and dispatching these resources when the distribution system is approaching critical thresholds solves Boothbay's peak load reliability problems at less than one-third of the cost of new transmission capacity over the lifetime of the project, which benefits the utility and ratepayers, Silkman explained. However, there are technical and institutional barriers to wider adoption of this approach. Regarding technology, today's distribution system is not designed to accommodate two-way power flows that become more significant with greater penetration of DG resources. Specifically, electricity fed back onto the distribution grid may be stopped at the substation where relays designed to accommodate one-way power flow can shut down the system. Thus, Silkman concluded, there is a critical need to better understand and design for two-way power flow. Regarding institutional barriers, no independent organization manages distributed resources and utility power flows at the distribution scale. Similar to independent system operators (ISOs) managing the system at the transmission level, Silkman suggested that we think carefully about the formation of distribution-level ISOs to perform analogous balancing and oversight services on the distribution level. Finally, ISO rules and tariffs regarding the recovery of transmission-related expenses are different and much more favorable to utilities than are the rules governing the recovery of distributed generation resources that are used solely for providing grid reliability and not for participating in energy markets. Silkman said this is an important barrier that needs to be addressed by the Federal Energy Regulatory Commission if the full advantages of a smart electric grid are to be realized by ratepayers.

At roughly 20 percent of capacity in aggregate, solar electricity is now the single largest generator of peak power in the summer in the state of Vermont, said Kerrick Johnson, vice president of strategy and communication at Vermont Electric Power Company (VELCO). The local weather has a large influence on generation from wind and solar resources, and a long history of research shows that weather also influences demand for electricity. VELCO developed a coupled-model framework that links IBM's high-resolution weather forecasting model Deep Thunder, a demand forecast model, and a renewable generation forecast model to generate actionable information through a renewable integration stochastic engine. Johnson said that integrating the results from each of these components through this optimization engine can help VELCO improve utilization of renewable generation resources, increase grid reliability, and decrease operational costs associated with weather-related incidents. To a large extent, the value of the model is derived from connecting disparate data streams—collected through local weather stations, installed smart meters, network telemetry, and other data sources—and inputting them into models that had not previously been connected, he said. Although the coupled models remain under continual development, the approach has already been used by VELCO to predict the locations of power outages, which correlate closely with predicted wind maximums, as shown in Figure 9, and dispatch service crews to affected areas more efficiently. Results have also been used to forecast wind generation based on wind speed modeled at the hub height with greater accuracy than any other models currently available in the world. Data collection for the model required foundational investments in communication infrastructure, and Johnson called for greater coordination between federal regulators and research organizations to remove barriers to widespread deployment of fiber optic infrastructure. Looking forward, Johnson urged people to think more holistically about planning, investing, and expanding generation, transmission, and distribution resources because "it's not always a wire that is a perfect fix." Johnson noted that the research undertaken in cooperatives can get operationalized in the field quickly, in part due to strong stakeholder alignment, pointing to another example of how rural electric cooperatives can lead innovation in the electric sector.

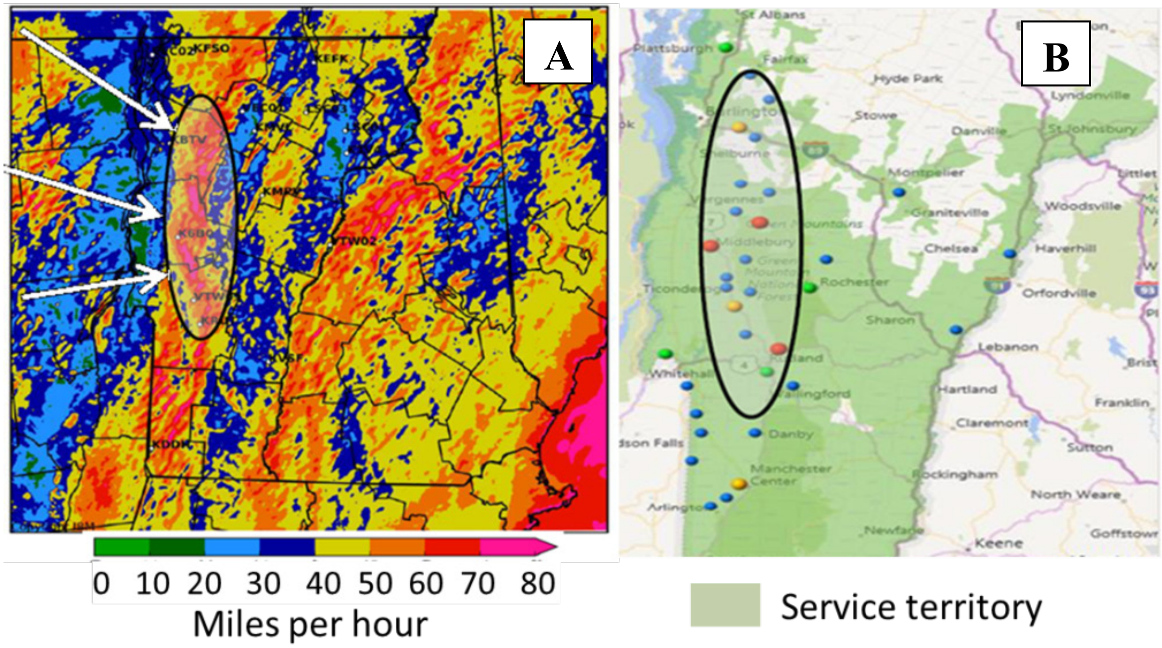

FIGURE 9 The Vermont Electric Power Company's (VELCO's) high-resolution weather forecasting models predicted the location of wind speed peaks, shown in A, which corresponded closely to outage locations, shown in B, and helped VELCO to dispatch repair crews efficiently. SOURCE: Modified from Kerrick Johnson, VELCO, "Power Connection: Vermont Weather Analytics Center Project," presentation to the workshop, February 8, 2016.

TURNING SMART TECHNOLOGIES INTO SMART GRIDS

Insufficient attention is afforded to the social, behavioral, cultural, and institutional change that needs to accompany the upcoming energy transition, argued Jennie Stephens, Blittersdorf Professor of Sustainability Science and Policy at the University of Vermont. If these broader considerations were appreciated, the heterogeneity of rural and islanded communities would be integrated more meaningfully into policy formulation and technology development. Stephens described the complex interactions among political, cultural, economic, regulatory, and technical factors that influence energy technology deployment and large-scale energy transitions. Using these diverse lenses, Stephens elicited multiple stakeholder perspectives through targeted focus groups across seven locations in the United States, calling attention to different priorities held by each group. Her work identifies inherent tensions among these competing priorities—for example, among affordability valued by consumers, reliability prioritized by utilities, and environmental sustainability desired by advocacy groups. Another important tension exists between centralized and decentralized generation, where decentralized energy may have greater potential to foster economic independence and resilience in rural and islanded communities. Stephens went on to note how decentralized energy systems offer broader societal co-benefits, including decentralization of influence as well as greater engagement by end users. To facilitate identification of these societal values, there is a critical need for broader social science research and civic engagement in energy research and education. Many of the assumptions and projections made in energy models are no longer valid and change is happening fast, concluded Stephens, which means new and different kinds of analyses are needed to identify key trends and policy opportunities.

LOOKING OUT: 5- TO 25-YEAR SOLUTIONS

Joe Brannan, executive vice president and CEO of North Carolina Electric Membership Corporation, opened the second day of the workshop by describing the rapid pace of technological innovation and the potential for new consumer products to drive disruptive change in the utility industry. Individual devices such as thermostats and light bulbs no longer offer a simple service, but rather are increasingly smart, interconnected, and under real-time control by consumers. Although the service offered by a single device may be limited, when viewed as a managed portfolio of network devices, it begins to create new value, said Brannan. Nonetheless, the proliferation of smart interconnected devices will be incredibly challenging for utilities because of dispersed intelligence behind meters throughout the electricity system, where utilities historically had limited access and interest. Brannan envisioned consumers using this information to manage home energy systems—for example, by monitoring and changing their thermostats with smartphone applications—in a way that will be disruptive for the electric power industry. Brannan asked the participants to consider how few utilities make efforts to truly understand customer needs and values. He emphasized the importance and need for honest and frequent communication with the consumer beyond a monthly bill and yearly newsletter. In addition to improved communication and customer engagement, Brannan suggested that the electricity system should be able to accommodate new ideas despite incredible technological, financial, and institutional complexity. The appropriate strategy is to take small steps that demonstrate both technical feasibility and creation of value for customers, and rural areas are well-suited to lead the way. For example, coastal North Carolina beach communities have the willingness and technical characteristics—such as highly seasonal load profiles and long-exposed transmission infrastructure—to test the efficacy of portfolio management strategies for distributed resources on the distribution scale. Brannan concluded with several suggestions for federal organizations, including: (1) ensure and facilitate robust broadband connectivity in rural and islanded communities and (2) help to develop open standards and protocols for device interconnection and operation within the home and between homes and the utility.

MODERNIZING THE PLANNING PARADIGM

James Connaughton, executive vice president of C3 IoT, presented an ongoing project with the state of Hawaii in which they are developing a platform for data aggregation and analysis tools to help energy system planners and operators. Currently, Hawaii spends more than 10 percent of its gross domestic product on fuel imports, making it the most petroleum-dependent state in the United States. In trying to reduce petroleum imports, the state is facing numerous grid modernization challenges related to high penetration of distributed renewables and is uniquely positioned to teach other utilities lessons as the "canary in the coal mine," said Connaughton. In Hawaii and across the nation, there will be more and more smart devices added to the grid; however, there is no central platform that curates and analyzes data from these devices to provide actionable information to decision makers at the right time. Nonetheless, Connaughton remains optimistic because the necessary tools are already being used in other industries, such as financial services, telecommunications, and social media, and the challenge now is to adapt these to a more complex electricity system. C3 IoT is creating an operating system that collects data from dispersed sensors, each tracking different system metrics, and configures applications that parse these data to answer specific questions. Connaughton described today's situation in grid management as analogous to carrying a pager, BlackBerry, PalmPilot, and pocket calculator. The future will look more like the smartphone, which replaced all of these devices and offered even more functionality than stand-alone "point solution" applications. Just as new services proliferated for smartphone users, the creation of a common operating system for grid analytics will enable new applications spanning the entire value chain, from customers up to generators, said Connaughton. For example, distribution utilities that operate and maintain dynamic grids could be better able to improve operational efficiency and reliability by aggregating sensor data, maintenance data, asset data, and customer data and predicting asset failure (i.e., when and where the next fault is likely to occur). Predictive maintenance is one of many examples of new applications under development that can help customers and operators understand and manage the electricity grid while saving hundreds of millions of dollars for utilities and customers in the state of Hawaii alone. Connaughton suggested that the federal government and industry actors continue to work toward standardization of data exchange protocols as a necessary next step to develop a truly smart grid, as opposed to a dumb grid with smart components.

There is an important distinction between planning for a 100 percent renewable grid and planning to *transition an existing system* to 100 percent renewables, said Chris Yunker, program manager for energy systems and planning in the Hawaii State Energy Office. Before making transformational investments, energy systems planners must consider what resources are available and be cognizant of how the constraints of the existing system will be tested through long-term change by anticipating potential disruptions. Furthermore, planning decisions must be flexible enough to accommodate uncertain future technological breakthroughs—for example, if hydrogen becomes a viable transportation fuel or ocean thermal energy technologies provide baseload renewable power—that are necessary to enable the long-term goal. Yunker described the challenge of focusing on a long-term objective of 100 percent renewables while making sure that each successive 5-year investment plan supports multiple technological pathways. He showed scenarios considering alternative generation mixes that result in different hypothetical net load profiles (Figure 10), each with a varying amount of curtailed renewable generation and power ramp rate constraints. These illustrate that the grid management strategies differ for each generation mix. Furthermore, these large-scale investments impacting the public and energy planning decisions are increasingly scrutinized, so the Hawaii State Energy Office is actively engaging a broad set of stakeholders to solicit input and improve customer acceptance. Utilities should be central to these efforts, urged Yunker, who went on to describe that big data, advanced analytics, and visualization techniques can potentially be used to make complex planning decisions more widely accessible to the public. Yunker suggested that federal investments be made to help states develop data analysis and visualization tools that energy planners can use to engage the public. These tools should be applicable to interdependent energy systems, robust under technological and market uncertainty, and adaptable to different regions so that planners can more effectively engage the public in energy system investment decisions.

Terry Surles, program lead for Clean Energy Solutions in the Hawaii Natural Energy Institute at the University of Hawaii and senior advisor at the University of California Institute for Energy and Environment, stated that the challenges currently arising in Hawaii will soon be faced by regions in the continental United States, and therefore the islands provide a substantial learning opportunity. Legislation is often aspirational and gets passed with little thought regarding how it will actually be implemented or regulated, Surles explained, making reference to Hawaii’s 100 percent renewable portfolio standard and goals for complete electrification of transportation. Conversely, utilities and regulatory agencies—because of a variety of other requirements placed on them—tend to be conservative in implementation and enforcement. Nonetheless, legislation can effectively drive growth. Many locations in Hawaii have high percentages of distributed renewables, some more than 250 percent of minimum daily load, that impact individual distribution circuits. Two-way electricity flows caused by these high percentages, in turn, feed back into the transmission system, said Surles. There is a critical need for smart grid solutions that will connect new opportunities from information and communication technology with the legacy electric infrastructure, much of which is aging and not designed to handle two-way power flows associated with increased customer generation. As one example, Surles described an ongoing collaboration between the Hawaiian Electric Company and the National Renewable Energy Laboratory developing smart inverters that should allow for safer integration of higher levels of distributed renewables while maintaining grid stability, reliability, and resilience. However, it can take years between technology research and development and utility and consumer implementation, as evidenced by the long timeline for wider approval of automated demand response in California. Surles suggested that DOE undertake efforts to close the gap between studying new technologies and actually implementing them on the grid.

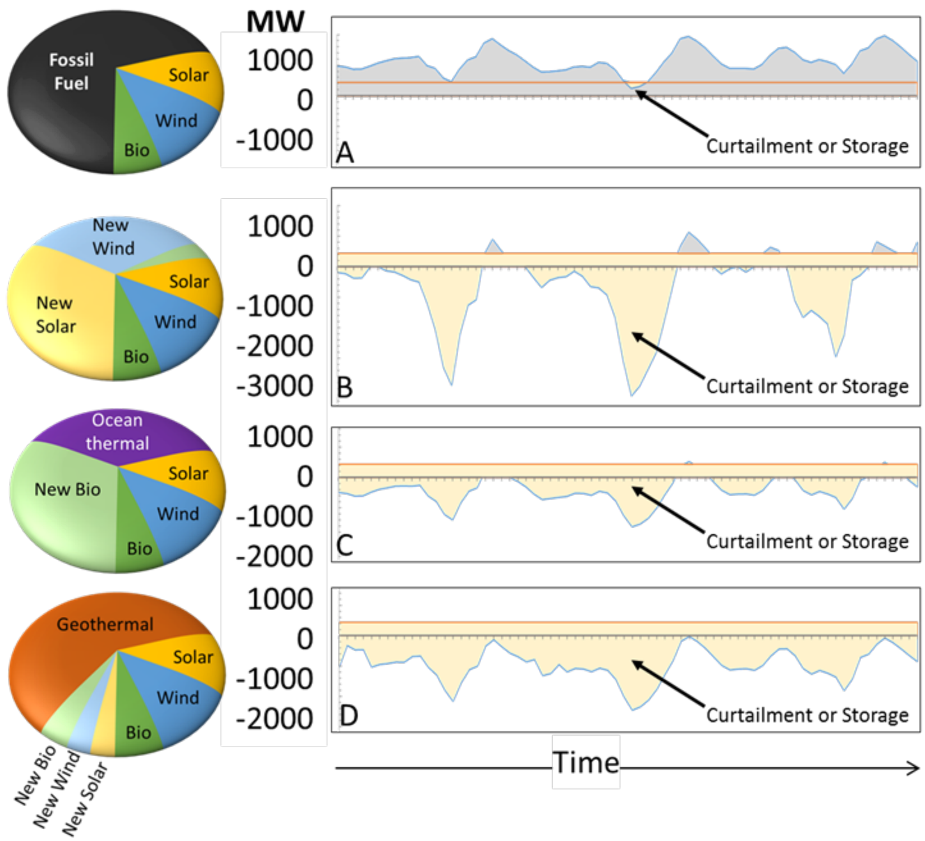

FIGURE 10 Hypothetical 72-hour net load profiles for the State of Hawaii, assuming alternative future resource mixes from the baseline scenario representing 70 percent fossil fuels shown in Scenario A. Although purely illustrative, these scenarios demonstrate that different levels of curtailment, storage, ramp rates, and grid management strategies are required for different mixes of generation resources. Scenario B shows replacement of all fossil fuels with variable wind and solar; Scenario C assumes a breakthrough in baseload renewable power provided by ocean thermal generation; and Scenario D considers interconnected island grids that can accommodate a larger share of geothermal power. Charts are for illustrative purposes to demonstrate the technical requirements of different renewable portfolio mixes and do not represent current or future, actual or proposed resource portfolios. SOURCE: Modified from Chris Yunker, Hawaii State Energy Office, “Getting to 100% by 2045: Planning Holistically,” presentation to the workshop, February 9, 2016.

Hawaii is addressing essential questions for moving forward with greater penetration of distributed renewables, but there are some significant scale issues that will be encountered en route to reaching 100 percent renewables, said Richard Rocheleau, director of the Hawaii Natural Energy Institute at the University of Hawaii, in a short commentary at the end of the session. In a back-of-the-envelope calculation, Rocheleau estimated that the state of Hawaii would need approximately 1,000 2.5 MW wind turbines or 5,000 MW of solar, with battery storage, to meet the 100 percent renewables goal. Furthermore, neither of these estimates account for electrification of transportation, which would double the required number of wind turbines or solar panels if Hawaii achieves 100 percent electric vehicles. Installations on this scale are likely to raise serious issues with siting and public acceptance, beyond the technical challenges associated with maintaining grid reliability in both periods with high renewable resource and excess generation as well as during days with no generation. In later discussions, Rocheleau commented on the magnitude and variability of curtailment, storage, and ramp rates for

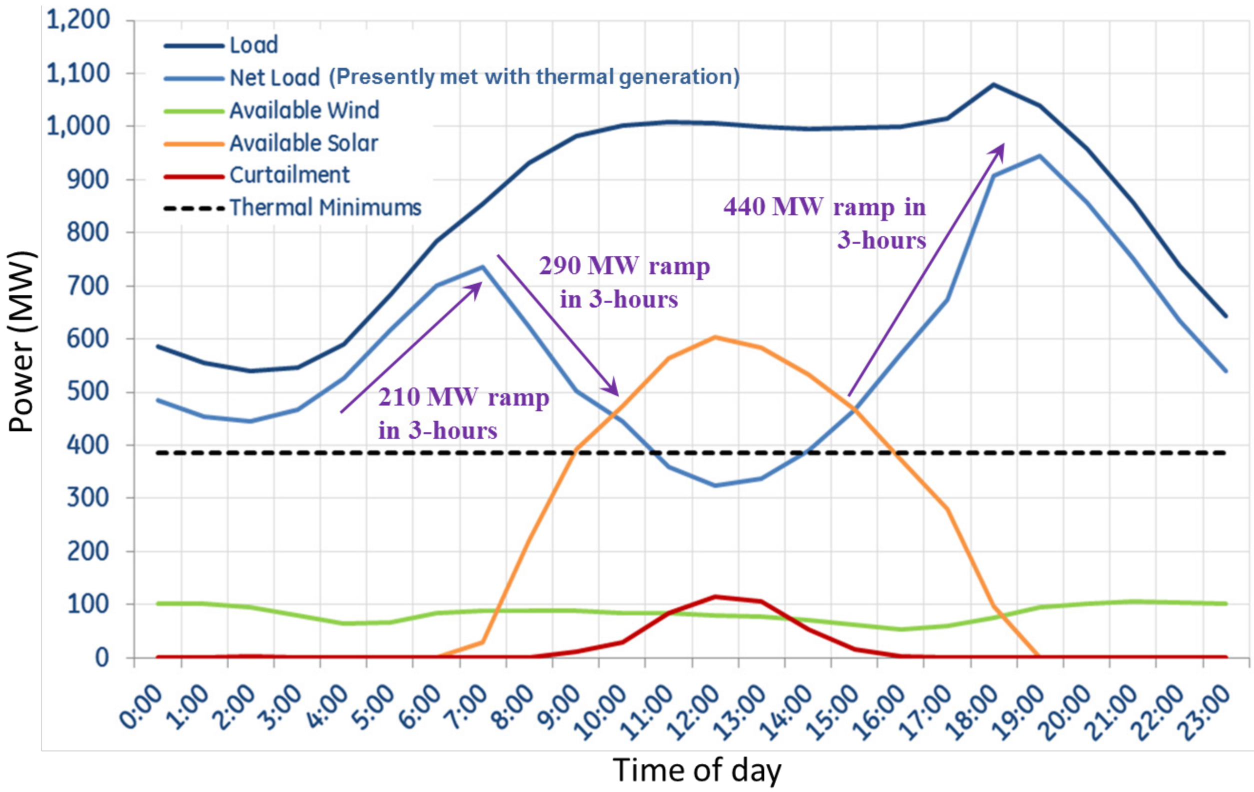

FIGURE 11 High deployments of solar photovoltaics and associated power production in the middle of the day (orange line) create a need for curtailment (red line), storage, or other load management strategies. This presents grid operators with challenges related to large power ramp rates (identified in purple) for thermal generation plants necessary to match net load (light blue). SOURCE: Modified from Richard Rocheleau, Hawaii Natural Energy Institute, "Impact of Distributed Energy Resources on Small Systems is Significant," presentation to the workshop, February 9, 2016.

thermal generation plants necessary to match net load in grids with high fractions of renewable generation, illustrated in Figure 11, and encouraged planners and operators to closely consider these factors in electricity system design. Although Hawaii is leading the way and solving challenges one step at a time, Rocheleau asserted that the state has to communicate more honestly and clearly how these goals will be achieved as well as the unintended costs of doing so.

LINKING TRANSPORTATION TO THE ELECTRICITY SYSTEM

Richard Rocheleau described Maui as an ideal testbed to evaluate potential synergies between variable renewables and high deployment of plug-in electric vehicles (PEVs) because of the following: (1) drivers are less constrained by PEV range given the small traveling distances on the island, (2) the Maui grid has 72 MW of wind operational and nearly 120 MW of distributed solar installed or approved in 2015 with a peak load of only 200 MW, and (3) the intermediate-sized grid allows creation of pilot studies with relatively modest investment. JumpSmart Maui is one of several ongoing collaborations between the Hawaii Natural Energy Institute and an international cohort of government and industry partners researching and demonstrating the use of PEVs to provide energy storage and auxiliary services to an electric grid with high penetration of distributed renewables. With more than 100 vehicle charging stations installed in volunteers' homes and public locations, one-third of which are Level 3 direct current

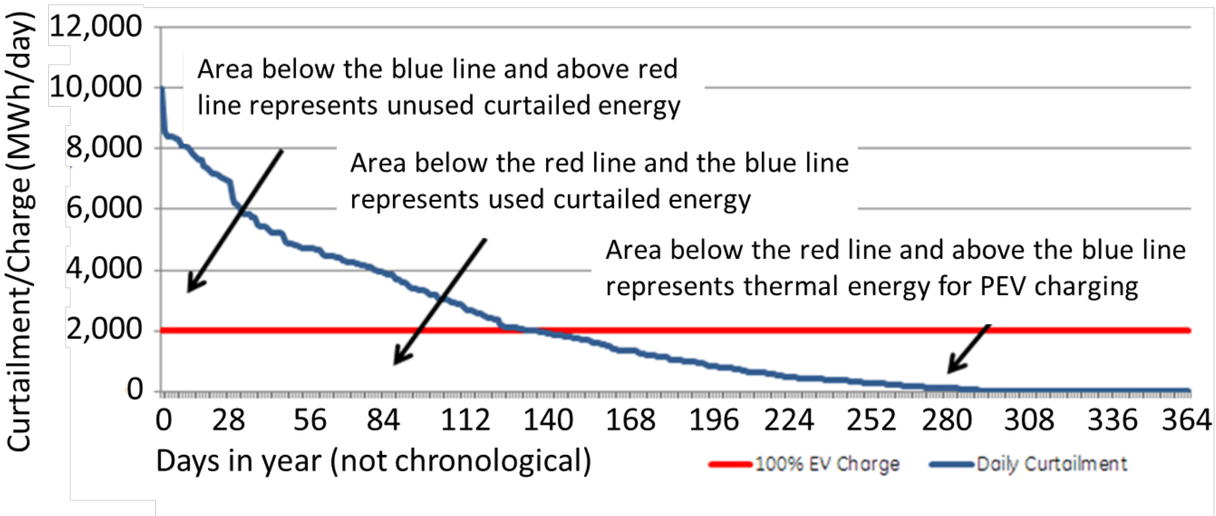

FIGURE 12 Modeled scenarios assuming availability of 2 GWh of storage capacity in PEV batteries—equivalent to the average magnitude of curtailed renewables—suggest large fractions of the year will require additional thermal generation to charge plug-in electric vehicle (PEV) batteries or additional storage or curtailment beyond PEV battery capacity. SOURCE: Richard Rocheleau, Hawaii Natural Energy Institute, "Electric Vehicles for Hawaii's Clean Energy Future," presentation to the workshop, February 9, 2016.

fast chargers, the project had some success in reducing peak demand and curtailment of renewable generation. This required investment in smart grid components, appropriate controls, and engagement strategies to change people's charging behavior, said Rocheleau. The project also developed the communications, analytics, and control networks necessary to help integrate vehicle and electricity systems across individual distribution circuits, and to connect distribution-level impacts to the performance of the larger transmission system and inform operational decisions. The more ambitious second phase of the project is currently recruiting volunteers and installing a number of two-way power flow charging stations to collect data on the potential benefits and impacts to grid and vehicle performance and cost. In the future, the project may expand island-wide as part of the long-term vision to operate Maui as a virtual power plant. However, developing the communications, analytics, and control systems necessary to enable this transition already presents a substantial challenge at current renewable levels near 30 percent, which is still far below the ultimate goal of 100 percent renewable generation, Rocheleau noted. The curtailment and storage requirements associated with such high levels of renewables are large in magnitude and variable from day to day, and PEVs may not be able to address this. Rocheleau presented scenarios assuming 2 GWh of storage capacity available per day in PEV batteries, which showed a substantial fraction of the year during which the PEVs are full and unavailable to store additional curtailed energy or empty with insufficient renewable power from the grid to charge (Figure 12). Rocheleau concluded with suggestions for further work on developing standards and protocols that facilitate communication between grid components and vehicles, as well as for better definition of situations in which PEVs can provide high-value services to the grid.

Electric vehicles are good for utilities, consumers, and the environment, said Gary Connett, director of member services at the Minnesota cooperative Great River Energy, and utilities should be actively promoting beneficial electrification of transportation. The utility is now part of vehicle purchasing decisions, and Great River Energy has convened focus groups and engaged stakeholders to better understand the motivations, decision variables, and expectations of potential PEV owners. These activities informed a program called the ReVolt Campaign that is being adopted across the state of Minnesota to promote adoption of PEVs. Connett described ReVolt's three pillars to PEV growth: (1)

helping to establish a charging infrastructure for customers, (2) stimulating market growth by collaborating with automobile dealers and manufacturers, and (3) offering cooperative members retail initiatives that include renewable energy credits for the electricity used over the lifetime of the car and rebates to offset expenses of installing home charging equipment. PEVs can impact a utility's load profile, so as a residential-serving utility with peak use in the evening, Great River Energy developed a TOU rate structure to encourage charging after 10:00 p.m., which benefits both the utility and the customer. In this way, Connett encouraged utilities to consider PEVs as another opportunity to control and shape their load profiles, which will become increasingly important with increasing amounts of variable renewables. Great River Energy is thinking systematically about increasing PEV adoption—for example, by considering bulk purchases of PEVs with its members and encouraging building standard developers and housing companies to consider PEV charging needs in future designs. Nonetheless, Connett reiterated, PEVs are a long-term strategy for utilities, particularly given recent low fuel prices, but "if you're not planning for the future, someone else will plan it for you."

San Diego Gas and Electric (SDG&E) already serves approximately 19,000 PEVs with more than 1,000 public charging stations and 67 Level 3 direct current fast chargers, said Tom Bialek, chief engineer at SDG&E, a Sempra Energy utility. For some consumers, TOU rates are very effective price signals to influence charging behavior; however, less than half of the PEVs in the SDG&E service territory are enrolled in the vehicle TOU program. Anecdotally, there are a number of PEV owners with photovoltaic panels installed at their homes, said Bialek, and these customers seem less concerned with the time of day at which they use energy. Nonetheless, effective rate design to incentivize charging behavior that is beneficial for the grid is critical for areas with significant adoption of PEVs. In California, the lack of public charging infrastructure and concerns about PEV driving range limitations are critical barriers to reaching the state's goal of having 1.5 million electric vehicles on the road by 2025. Bialek presented a demonstration workplace-charging station using solar panels and battery storage with an associated kiosk and cellphone application that housed all analytics and allowed users to pick charging times based on the rate. The market for third-party charging providers has not grown at the rate expected by the state, and the utility can play an important role in providing this infrastructure to help reach transportation emission-reduction targets, said Bialek. The California utility commission recently approved a proposal for SDG&E to install 350 charging facilities in multifamily communities and workplaces—locations that may be underserved by third-party providers—and recover the cost through customer rates. The program allows for day-ahead hourly rates based on the local grid conditions, which can be used to encourage charging during off-peak times and incentivize grid-beneficial charging. Responding to participant questions, Bialek described charging infrastructure installation costs as variable based on the necessary equipment upgrades required on the circuit, although to date no major modifications have been required to date even on circuits serving multiple PEVs.

DESIGNING MICROGRIDS

A microgrid is a local network that can be operated autonomously—that is, disconnected from the larger commercial grid. It can consist of a single entity with a backup generator, such as a hospital, or a more extensive aggregation of distributed resources, such as batteries, wind, and solar. Tom Bialek reiterated that microgrids are not new and that the shrinking in scale of analysis and operations was a return to the historical roots of the grid. However, advances in supporting technologies and information and communication infrastructure enable utilities to consider using microgrids as an alternative service-delivery model. There are places in the SDG&E service territory where microgrids offer an appealing alternative to costly investments in transmission lines—for example, if new lines must cross National Park Service or Bureau of Land Management property, said Bialek. Microgrids can also improve system reliability and resilience and, in some instances, are a better solution than installing a redundant service line for customers willing to pay for higher reliability. Microgrids can be designed to help utilities accommodate higher fractions of renewables; with appropriate equipment, microgrids can operate as

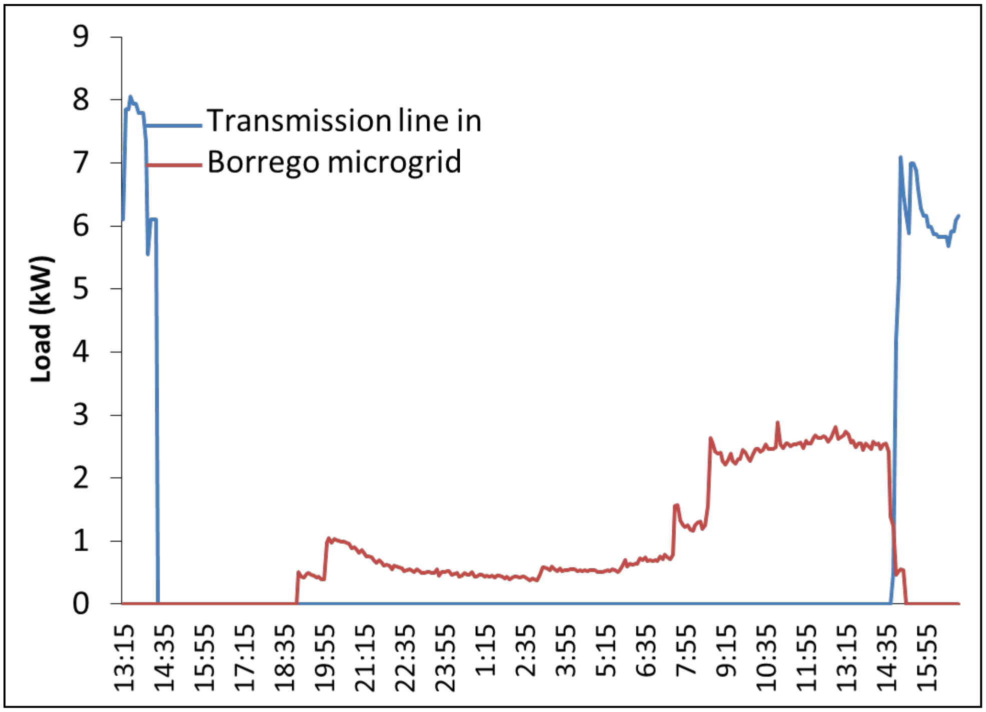

FIGURE 13 Power provided by the microgrid in a step restoration process after severe thunderstorms. From the beginning of the outage (14:35) it took approximately 4 hours to access the area and ensure lines were not energized, and only then (18:35) could the microgrid begin providing power to affected customers. SOURCE: Tom Bialek, San Diego Gas and Electric, a Sempra Utility, "Utility Role in Microgrids," presentation to the workshop, February 9, 2016.

dispatchable virtual power plants that one day may help utilities manage customer-owned distributed energy resources to improve grid conditions, Bialek explained. Microgrids are beginning to take hold in rural and islanded locations, on military installations that require energy assurance, and at some universities trying to optimize campus energy use. Bialek presented data from intentional and unintentional electrical islanding events at the Borrego Spring Microgrid, which serves approximately 2,800 customers with a peak load of 15 MW over three distribution circuits. The substation is fed by one transmission line and has two 1.8 MW diesel generators, as well as 1.5 MW for 3 hours of storage in lithium-ion batteries. In one example, the microgrid provided power to more than 1,000 customers in a step restoration process (Figure 13) after a particularly severe thunderstorm damaged 9 transmission and 11 distribution poles. Some customers with distributed energy sources and a community storage device never saw an outage over the entire 25-hour restoration process, said Bialek. In the second phase of the Borrego Springs Microgrid project, the utility connected a 26 MW photovoltaic array with smart inverters and increased automation to improve emergency readiness, operational flexibility, and grid resilience with 100 percent renewable resources.

Microgrids can improve reliability and reduce energy costs in remote and islanded areas with high reliance on diesel generators by maximizing use of renewable energy sources, according to Steven Rowe, senior services manager at General Electric (GE) Digital Energy. As part of a consortium effort, GE helped develop controls and optimization strategies for a microgrid serving the remote, off-grid community of Bella Coola, approximately 250 miles north of Vancouver, British Columbia. The Bella Coola site has two hydro and eight diesel generators serving a predominately residential load with 4.7 MW seasonal peak. One of the principal objectives for the project was to increase the utilization of hydro power to reduce diesel consumption. The project included additional battery storage and a hydrogen fuel cell, and Rowe emphasized the importance of developing a communications architecture that allows monitoring and control of diverse assets. At the Bella Coola site, the communication and control system used both Ethernet and wireless radio to connect all microgrid components to a centralized controller, as well as one remote monitoring and control station provided for the regional utility, to support optimal dispatch of generating resources to meet load. Rowe described the challenges faced in integrating microgrid components, many of which use different protocols and languages, and therefore require substantial efforts in protocol conversion. Furthermore, concerns about cybersecurity also have to be considered in communications system design, particularly given recent utility compliance standards issued by the North American Electric Reliability Corporation. In the future, microgrids will be able to participate in power and ancillary services markets through day-ahead bidding, said Rowe, who concluded with a brief description of two new GE-affiliated projects in New York that will apply the communication and control techniques pioneered at Bella Coola.

Aloke Gupta, senior director of policy and market development at Imergy Power Systems, presented on the use of vanadium flow batteries to provide electricity storage for microgrids in emerging markets, where the majority of new electricity demand will be concentrated. Many of these areas lack access to large power generation and transmission systems and are pursuing a strategy of distributed community microgrids, as opposed to waiting years for the establishment of a centralized grid. There are both financial and technical barriers to wider adoption of microgrids in emerging and established markets alike, said Gupta, and robust affordable batteries for energy storage are central to overcoming these. Although vanadium flow batteries have been available for more than 20 years, Imergy uses recycled vanadium, which substantially reduces battery cost. In addition to affordability, Gupta argued that batteries used in microgrids must be able to provide energy over a long duration, maintain performance over a long calendar life with a high number of cycles, and operate properly in harsh environments with minimal maintenance. These technical requirements rule out conventional alternatives such as lead acid and lithium-ion batteries, whereas vanadium flow batteries require no thermal management system, have a long lifetime because they do not degrade with increased cycles, and offer the lowest total cost of ownership. Imergy batteries have been used in microgrids across Africa, India, and Europe, demonstrating sustained performance across an ambient temperature range from −10°C to 55°C for more than 10,000 cycles. Data from one installation are shown in Figure 14. Gupta suggested that the federal government do the following: (1) expand awareness of vanadium flow batteries to international aid agencies and programs within the U.S. Department of Agriculture as a proven component of microgrids as opposed to an experimental technology, (2) decrease the size threshold and transaction costs associated with microgrid financing programs, and (3) facilitate communication and interaction between technology suppliers and rural cooperatives or smaller utilities.

Combining distributed generation, sensors, and scalable control platforms supports the transformation of the electricity industry from centralized generation to a new paradigm of decentralized producer-consumers, said Andrew Merton a system analyst at Spirae, LLC. Spirae employs a bottom-up architecture for identifying and controlling individual energy assets on a sub-cycle time scale, and then aggregating the control and services of these assets into higher substation and distribution network levels that operate on the hour-to-day time scale (Figure 15). This general framework can be adapted to achieve specific power system objectives, and Merton presented two case studies using this approach. The first case study described the development of a 350 kW peak island microgrid with the objective of reducing diesel consumption by at least 75 percent through integration of 320 kW of solar, 900 kW of wind, 1 megawatt hour (MWh) of battery storage, and a small amount of demand response. The operating constraints for the microgrid include the ability to provide black start services, curtailment of renewables when all load is met and the battery is charged, and compliance with minimum run time and load requirements for diesel generators. According to Merton, all of these factors influence the design and utilization of the control system, which is constantly monitoring and refining the state of all assets to reduce diesel consumption within these constraints. For example, for the battery energy storage system to provide voltage and frequency support, the system maintains a state of charge between 50 and 60 percent so that it has room to move in both directions as load increases or decreases. Merton contrasted the island

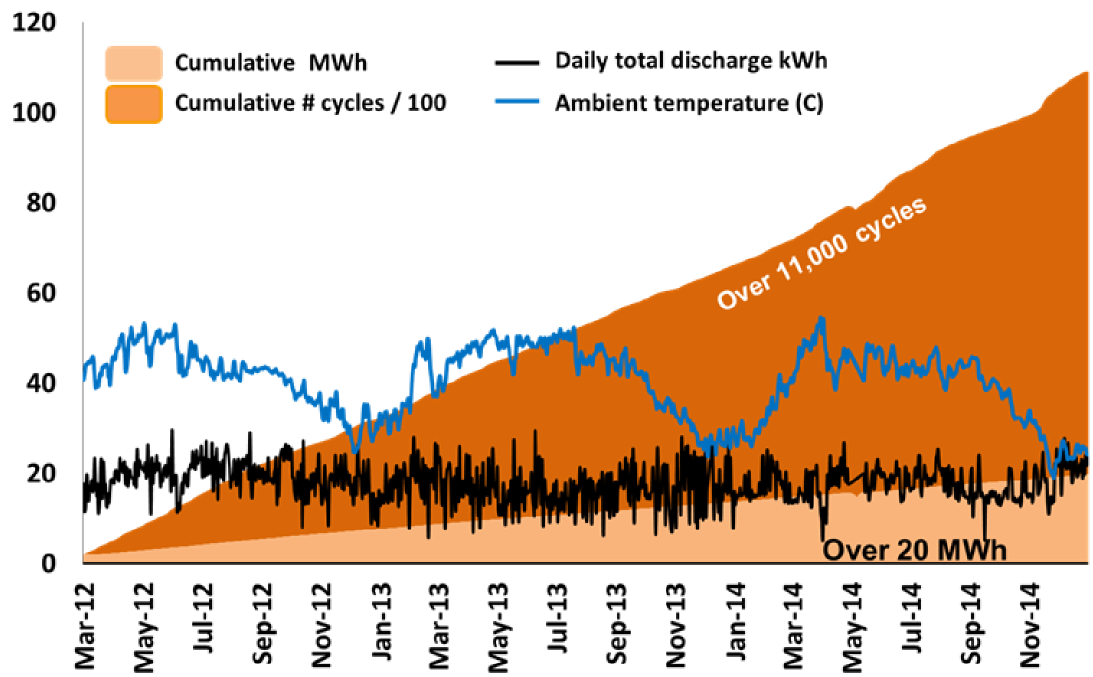

FIGURE 14 In-field performance data illustrating vanadium flow battery cycling (black line) over a large temperature range (blue line) and cumulative number of cycles (dark orange) and delivered power (tan). SOURCE: Aloke Gupta, Imergy Power Systems, "QER/National Academy of Sciences," presentation to the workshop, February 9, 2016.

case study to an ongoing project with the Flathead Electric Cooperative in which the objective is to reduce peak demand through coordinated dispatch of electric water heaters. Whereas the island microgrid requires high-speed monitoring, controls, and on-site management, the dispatch of electric water heaters can be scheduled ahead of time, operated on a relatively slow time period, and coordinated off-site with cloud storage. Merton suggested that (1) power system designers develop goals within the constraints of generation assets and communication infrastructure and (2) the federal government provide more funding mechanisms to reduce the up-front implementation costs of microgrids.

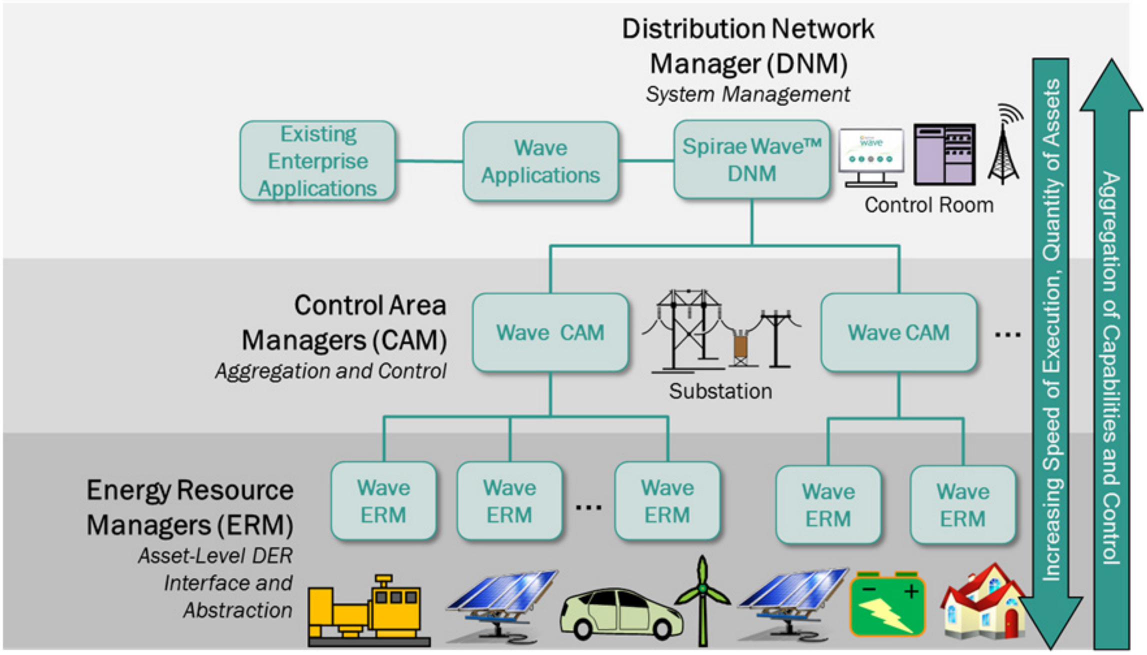

FIGURE 15 Spirae's Wave™ architecture for management of distributed resources and aggregation of information and control from the individual asset level to the substation and distribution network levels. SOURCE: Andrew Merton, Spirae, LLC, "Microgrids: Distributed Controls Perspective," presentation to the workshop, February 9, 2016.

Appendixes

A

Workshop Statement of Task

An ad hoc committee will convene a 2-day public workshop to look at the challenges and opportunities for lowering end-use electricity use, reducing electricity-related GHG emissions and improving electricity resiliency in rural communities, isolated/islanded locations, and large users that can operate as microgrids (military installations, other large federal facilities, hospitals/universities, other unified demand centers). The objective is to help the Quadrennial Energy Review's public outreach by focusing on communities that have unique challenges and focusing on electricity end use, edge of grid, and the distribution network. The NRC will appoint a workshop planning committee of 3-6 people to develop a proposed agenda and invitees. The discussion would focus on improving electricity efficiency and resiliency and the technologies, strategies, and policies that offer opportunities for addressing these for rural and islanded communities.

Though the planning committee will be responsible for setting the goals of the workshop, major themes likely to be considered include:

(1) Attributes of electricity use and distribution systems associated with rural electricity users, islanded residents, and isolated demand centers;
(2) Challenges and opportunities for increasing efficiency, reducing emissions and costs, or improving resiliency in such locations;
(3) Innovative clean energy strategies being undertaken in such locations.

B

Registered Workshop Participants

Chandler Allen, U.S. Department of Interior, Indian Energy and Economic Development
Tom Bialek, San Diego Gas and Electric, a Sempra Utility
Celina Bonugli, Worldwatch Institute
Joe Brannan, North Carolina Electric Membership Corporation
Alamelu Brooks, ICF International
James Buttles, Oceanic Evergreen Technologies, Inc.
John Caldwell, Edison Electric Institute
Jorge Camacho, District of Columbia Public Service Commission
Chad Campbell, The EOP Group
Ken Colburn, New Hampshire Electric Cooperative Board
James Connaughton, C3 Energy/IoT
Gary Connett, Great River Energy
Henri Dale, Henri Dale, LLC, and Golden Valley Electric Association (retired)
David Dunn, Green Mountain Power
Michael Dworkin, Vermont Law School
Aurora Edington, U.S. Department of Energy
R. Neal Elliott, American Council for an Energy Efficient Economy
Caterina Fox, U.S. Department of Energy (Contractor)
Lindsey Griffith, U.S. Department of Energy
Aloke Gupta, Imergy Power Systems
Robert Hershey, Robert L. Hershey, P.E.
Terry Hill, PHIUS
K. John Holmes, National Academies of Sciences, Engineering, and Medicine
Vieda White Hubbard, U.S. Department of Agriculture, Rural Utilities Service
Kerrick Johnson, Vermont Electric Power Company
Sydney Kaufman, U.S. Department of State
K. Kaufmann, Solar Electric Power Association
Meera Kohler, Alaska Village Electric Cooperative
Krystal Laymon, U.S. Department of Energy
Debora Ley, Regional Clean Energy Initiative
Arthur Lord, U.S. Department of Defense
Joe McGarvey, Senior Policy Advisor U.S. Senator Mazie K. Hirono
Chris McLean, U.S. Department of Agriculture, Rural Utilities Service
Ron Meier, La Plata Electric Cooperative
Andrew Merton, Spirae, Inc.
Marc Mueller-Stoffels, University of Alaska, Alaska Center for Energy and Power
Caitlin Murphy, U.S. Department of Energy/American Association for the Advancement of Science

Brent Nelson, U.S. Department of Energy/Northern Arizona University
Rick Northrop, FIND - Media
Titilayo Ogunyale, U.S. Department of Agriculture, Rural Utilities Service
Chinyere Osuala, Earthjustice
Jeanette Pablo, U.S. Department of Energy
John Parry, The EOP Group
Steven Piccirillo, U.S. Department of Agriculture, Rural Utilities Service
James Bradford Ramsay, National Association of Regulatory Utility Commissioners
Jason Reott, Assistant to U.S. Senator Bernie Sanders
Richard Rocheleau, University of Hawaii, Hawaii Natural Energy Institute
Steven Rowe, General Electric
Pam Silberstein, National Rural Electric Cooperative Association
Rich Silkman, Grid Solar, LLC
James Slutz, National Petroleum Council
Ben Steinberg, U.S. Department of Energy
Jennie Stephens, University of Vermont
Terry Surles, University of Hawaii, Hawaii Natural Energy Institute
Anthony Triplin, U.S. Department of Energy
David Wade, EPB Electric Power
Sandra Waldstein, Federal Energy Regulatory Commission
Stephen Walls, U.S. Department of Energy
Karen Wayland, U.S. Department of Energy
Ben A. Wender, National Academies of Sciences, Engineering, and Medicine
Carol Werner, Environmental and Energy Study Institute
Devon Wilson, K&L Gates
Curtis Wynn, Roanoke Electric Cooperative
Miguel Yanez, Environmental and Energy Study Institute
Chris Yunker, Hawaii State Energy Office
Craig Zamuda, U.S. Department of Energy
Elizabeth Zeitler, Millennium Challenge Corporation
James Zucchetto, National Academies of Sciences, Engineering, and Medicine

C

Workshop Agenda

FEBRUARY 8-9, 2016
KECK CENTER, WASHINGTON, D.C.

Workshop Objective: Speakers will be encouraged to identify challenges and opportunities for increasing efficiency, reducing emissions and costs, and improving resiliency, as well as to discuss innovative clean energy strategies being implemented in rural and islanded communities. Speakers will also be encouraged to offer to the QER Task Force insights on research needs and state and local policies, in addition to recommendations on federal policies (examples of federal policies include executive actions, legislation, R&D initiatives, and/or funding distributions that can be implemented in both the short and the long term).

February 8, 2016

Welcome and Opening Presentations

8:00 a.m. Continental Breakfast

8:30 **Introduction to QER—**For the second installment of the Quadrennial Energy Review, the QER Task Force will conduct an integrated study of the U.S. electricity system from generation through end use. The Task Force will produce a report offering recommendations on executive or legislative actions to address the energy challenges and opportunities facing the Nation. In this workshop, the QER Task Force is interested in your expertise on electricity use in rural and islanded communities.

Karen Wayland, Department of Energy

8:50 Q&A with Karen Wayland

9:05 **Introduction to Workshop Structure and Planning Committee**

K. John Holmes, National Academies of Sciences, Engineering, and Medicine

9:15 **Describe characteristics of electricity use in rural communities. Identify salient differences from other communities.**

Chris McLean, U.S. Department of Agriculture, Rural Development

9:30 Q&A with Chis McLean

9:45 **Introduce Critical Electricity Issues for Islanded Communities—**Compare challenges across different islanded communities.

Chris Yunker, Hawaii State Energy Office
Meera Kohler, Alaska Village Electric Cooperative

10:05 Q&A with Speakers

10:15 Break

Topical Sessions

10:30 **Incorporating Efficiency—**Survey implemented strategies for improving end-use efficiency. Consider benefits to rural and agricultural communities.

Curtis Wynn, Roanoke Electric Cooperative
R. Neal Elliott, American Council for an Energy-Efficient Economy

11:30 **Increasing Resilience/Reliability—**Describe methods to improve electricity system resilience and reliability. Discuss how technology and automation can benefit rural communities.

David Wade, EPB Electric Power
Henri Dale, H Dale, LLC

12:30 p.m. Lunch

1:30 **Rate Design—**Consider time-of-use and other rate designs as strategies to manage demand, account for grid maintenance costs, and address potential consumer privacy concerns.

Ken Colburn, New Hampshire Electric Cooperative Board
Ron Meier, La Plata Electric Association

2:30 **Generation Alternatives for CO_2 Reduction**—Review technology alternatives including renewables with grid storage. Identify barriers and enablers for bringing distributed generation into rural systems.

Marc Mueller-Stoffels, University of Alaska, Alaska Center for Energy and Power
David Dunn, Green Mountain Power

3:30 Break

3:45 **Technological and Operational Innovation**—Discuss technologies deployed to improve electricity service and reduce costs in rural areas. Identify operational strategies to increase system performance.

Gary Connett, Great River Energy
Rich Silkman, GridSolar
Kerrick Johnson, Vermont Electric Power Company

5:00 **Turning Smart Technology into Smart Grids**—Introduce social, technological, and legal dimensions of smart grid deployment. Identify alternative paths forward and implications for rural electricity users.

Jennie C. Stephens, University of Vermont

February 9, 2016

Welcome and Keynote Presentation

8:00 a.m. Continental Breakfast

8:30 **Opening Keynote**—Anticipate developments in new technologies, planning paradigms, and business models that will impact rural electricity systems over the next 5 to 25 years. Point to steps the federal government and others could take over this time frame that direct towards desired outcomes.

Joe Brannan, North Carolina Electric Membership Corporation

9:00 Q&A with Joe Brannan

Topical Sessions: Modernizing the Rural & Islanded Electricity Systems through Emerging Technologies and Planning Paradigms

9:30 **Modernization of Planning Paradigm**—Consider Hawaii as an example of alternative planning strategies using big data and emerging technologies to strive for a 100% renewable grid.

Jim Connaughton, C3 Energy
Chris Yunker, Hawaii State Energy Office
Terry Surles, University of Hawaii
Richard Rocheleau, short commentary, Hawaii Natural Energy Institute

11:00 **Transportation Linkage to Electricity System**—Discuss influence of, and possible synergies between, electric vehicles and the grid.

Richard Rocheleau, Hawaii Natural Energy Institute
Gary Connett, Great River Energy
Tom Bialek, Sempra Energy

12:00 p.m. Lunch

1:00 **Microgrids**—Discuss the potential for microgrids to improve resilience and operations. Consider new technologies and business models for decentralized generation and their implications for rural and islanded communities.

Tom Bialek, Sempra Energy
Steven Rowe, General Electric
Aloke Gupta, Imergy
Andrew Merton, Spirae

D

Acronyms

ACEEE	American Council for an Energy Efficient Economy
ACEP	Alaska Center for Energy and Power
AVEC	Alaska Village Electric Cooperative
BESS	Battery Energy Storage System
DG	distributed generation
DOE	Department of Energy
EPB	Electric Power Board
GE	General Electric
GMP	Green Mountain Power
GWh	gigawatt hour
ISO	independent system operator
kW	kilowatt
kWh	kilowatt hour
MW	megawatt
MWh	megawatt hour
NHEC	New Hampshire Electric Cooperative
PEV	plug-in electric vehicle
QER	Quadrennial Energy Review
SCADA	supervisory control and data acquisition
SDG&E	San Diego Gas and Electric
RPS	renewable portfolio standard
RUS	Rural Utilities Service
RUS-EECLP	Rural Utilities Service Energy Efficiency and Conservation Loan Program
TOU	time-of-use
VELCO	Vermont Electric Power Company