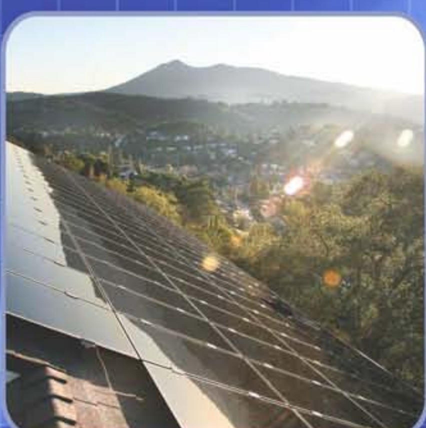
Technology, Measurement, and Standards Challenges for the Smart Grid



March 2013 (Final Version)

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Workshop on Technology, Measurement, and Standards Challenges for the Smart Grid

August 13–14, 2012

Boulder, Colorado

SUMMARY REPORT

March 2013 (Final Version)

Co-hosted by the
National Institute of Standards and Technology

and

The Renewable and Sustainable Energy Institute, a joint institute of the University of Colorado at Boulder and the National Renewable Energy Laboratory

Acknowledgments

This report summarizes the results of the *NIST-RASEI Smart Grid Workshop* held August 13–14, 2012, in Boulder, Colorado. The workshop was a collaborative effort of the National Institute of Standards and Technology (NIST), an agency of the U.S. Department of Commerce, and the Renewable and Sustainable Energy Institute (RASEI), a joint institute of the University of Colorado Boulder and the National Renewable Energy Laboratory (NREL).

We would like to extend our gratitude to the Steering Committee co-chairs and Working Group Chairs for their considerable effort in guiding this workshop toward a successful outcome. We also appreciate our co-hosts at RASEI for their tremendous efforts in handling all the many logistical details both before and during the workshop. Finally, we wish to thank the Energetics Incorporated team for their assistance in facilitating the workshop and preparing this report.

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EXECUTIVE SUMMARY

The U.S. electricity system is a vital national asset, ensuring domestic safety and security, powering the economy, and making possible many of the technologies that Americans depend on every day. The power "grid" is a vast network of interconnected systems—wires, substations, transformers, switches, and other devices—used to transmit and deliver power to consumers. This complex infrastructure is composed of centralized and independent power plants, transmission lines, and distribution systems that have been constructed over the past century.

Today's electricity system is composed of disparate technologies that vary widely in age, condition, and capacity. Some of the technologies within this massive infrastructure are reaching the end of their useful life or becoming obsolete, while others are proving inadequate to support expanded use of new energy sources, such as wind and solar. Aging equipment also contributes to system failures—leading to fluctuations in power quality and availability.

The power grid must be modernized to meet the needs of our 21st century society and economy, which increasingly rely on digital and electronic technologies. Creating a smart grid is an essential step; it will provide new capabilities that increase the efficiency, reliability, interoperability, and security of the U.S. electric system.

Smart grid tools and technologies implemented in the electrical grid infrastructure enable bidirectional flows of energy and energy-related communications. This fundamental attribute is vital for integrating widespread renewables, such as solar photovoltaic (PV) and wind, and incorporating the large-scale electric energy storage needed to support these variable energy resources. A smart grid will also better support widespread plug-in electric vehicles and distributed energy and storage and take advantage of demand response, energy efficiency, and load control. Near-real-time awareness of system status possible through a smart grid will enable power companies to greatly improve system reliability and redundancy.

Smart grid technologies will give individual users the ability to have an interactive role in their use of electrical power. Such a system requires sophisticated, wireless, self-powered sensors and communication throughout the grid environment. Inherent in the smart grid is the need for cyber security for both energy producers and energy users. An early example of smart grid infrastructure is the accelerating installation of cyber-based smart meters on homes and businesses now underway throughout the United States.

Smart grid-related technology and services have been growing rapidly and are forecasted to reach nearly $43 billion in the United States by 2014 and more than $171 billion globally. While the conventional electric grid was arguably the largest engineering project of the 20th century, the smart grid will likely be one of the largest (if not the largest) engineering projects of the present century. Recent reports suggest that substantial investments are needed to modernize the electricity system through new technology and other improvements.

Significant progress is being made toward the development and implementation of a smart grid, but there are many challenges that still need to be addressed. A number of roadmaps and reports have outlined the technical issues and potential approaches for overcoming them, from the federal, state, industry, and even global perspectives. The National Institute of Standards and Technology (NIST) has a unique role in the smart grid arena.[1] In the 2007 Energy Independence and Security Act (EISA 2007), Congress charged NIST with facilitating the development of interoperability standards for the smart grid. The primary tool for achieving this task has been developing a public/private partnership known

[1] National Institute of Standards and Technology, "Smart Grid," http://www.nist.gov/smartgrid/.

as the Smart Grid Interoperability Panel[2] (SGIP) that brings together electrical manufacturers, researchers in academia and national laboratories, utility technology and business experts, and related interested parties.

Workshop Overview

The National Institute of Standards and Technology and the Renewable and Sustainable Energy Institute[3] (RASEI)—a joint institute of the University of Colorado and the National Renewable Energy Institute (NREL)—co-sponsored the *Workshop on Technology, Measurement, and Standards Challenges for the Smart Grid* on August 13 and 14, 2012, in Boulder, Colorado. Key stakeholders from industry, academia, and government participated and provided expert views on the current state, future characteristics and goals, technological and measurement science challenges, and research and measurement science priorities for the smart grid within the following four topical areas:

- Integration of large, utility-scale renewable energy onto the grid
- Integration of distributed generation (including renewables) and energy storage with the grid (including microgrids and local energy control systems)
- Energy efficiency, demand response, and load control (including impact of electric transportation)—residential, commercial, industrial
- Efficiency, reliability, security, and stability of the grid (including advanced transmission and distribution management applications)

Crosscutting issues such as cyber security, privacy of information, industry standards, communications infrastructure (requirements for response, bandwidth, latency), and information infrastructure were also considered.

This report summarizes the outputs from the workshop. The ideas presented reflect the attendees' opinions and are not necessarily the views of the entire industry; they should be considered a snapshot of the important perspectives, but not an all-inclusive representation. Note that participants were carefully selected for their high level of knowledge and expertise in the many technical fields related to the smart grid.

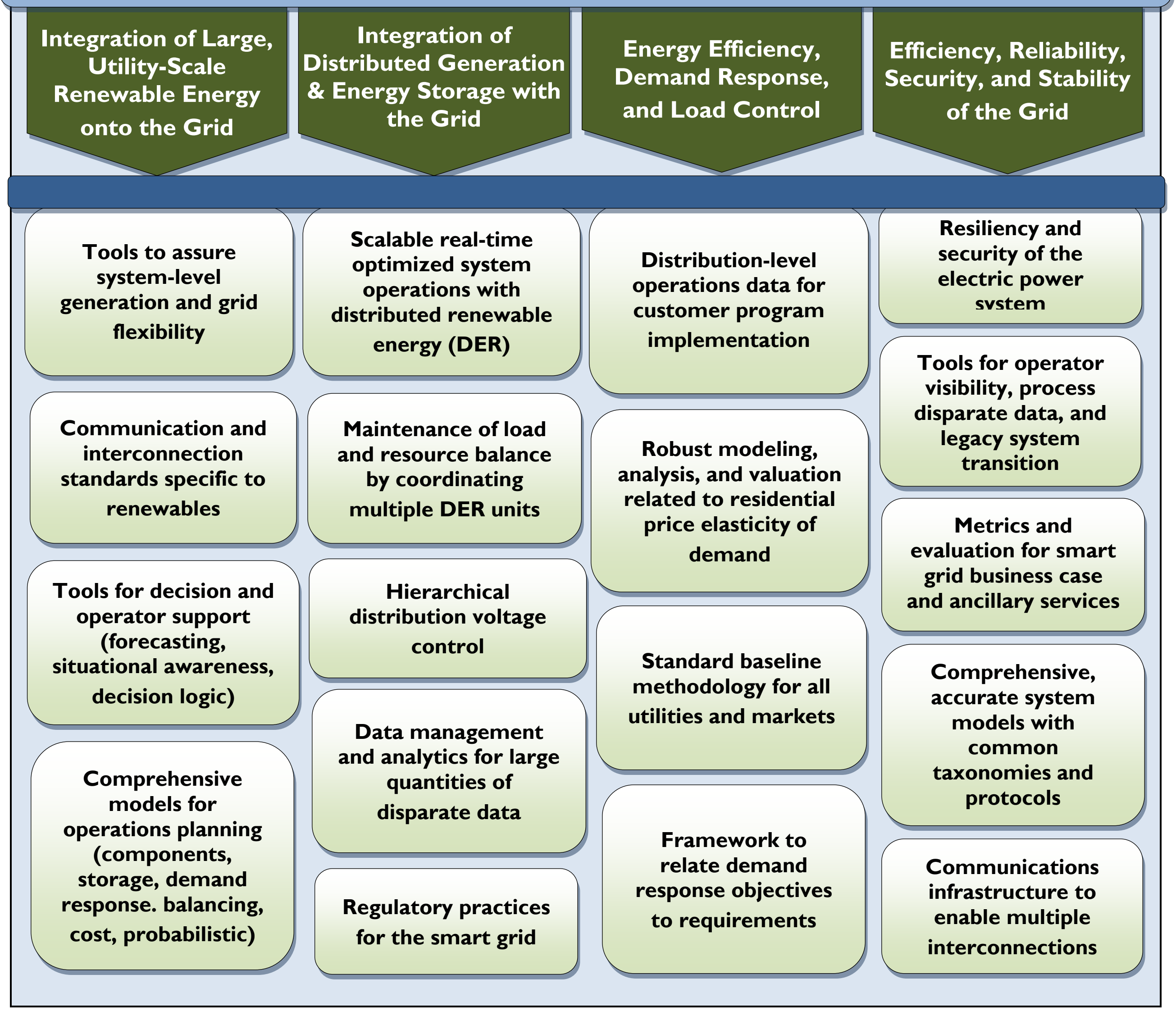
This report will help to (i) build a coordinated smart grid research program for industry, government, and academia, including NIST, the national laboratories, and the participants in the SGIP; (ii) identify and remediate strategic gaps in smart grid research and measurement science that could impede progress in manufacturing and deployment of smart grid infrastructure; and (iii) create an integrated vision and development strategy for the smart grid environment.

Priority Challenges

Figure E-1 lists the technical and measurement challenges that were identified as priorities within each topical area. These cover a wide range of technological and measurement science issues.

[2] Smart Grid Interoperability Panel, "Shape the Smart Grid Standards," http://www.sgip.org./.
[3] The Renewable and Sustainable Energy Institute, A Joint Institute of the University of Colorado Boulder & the National Renewable Energy Laboratory, "RASEI," http://rasei.colorado.edu/.

Figure E-1
Prioritized Technical, Measurement, and Standards Challenges



A number of cross-cutting technical challenges were identified that impact all four topical areas, including the following:

- **Robust operational and business models**, which incorporate diverse generation sources, storage options, and models for flexibility, to enable effective operations and planning
- **Technologies and tools to enable use of demand response, load control, and energy efficiency**, including measurement and evaluation methods
- **Better decision tools for operators** to increase visibility and situational awareness, enable planning and forecasting, and provide logic for decision making

- **Communications infrastructure** to enable interconnections and data flow among various components and systems, public networks, and devices, as well as operations and planning functions
- **Infrastructure to assure cyber security and resilience**, including flexible topologies, cyber-physical design methods, and metrics
- **Cost-benefit and life cycle models** to support better business models, encourage investment, and inform regulation

Follow-On Document

This report summarizes the major impediments to smart grid development and deployment that were discussed during the August workshop. It indicates the participants' prioritization of technological and measurement science challenges, as well as a number of non-technical challenges. A follow-on document, *Strategic R&D Opportunities for the 21st Century Smart Grid*, provides a higher level discussion of these impediments. It will be of value to decision makers in the public and private sector with an interest in pursuing research and development (R&D), standards development, or other activities needed to achieve the potential of the smart grid.

1 INTRODUCTION

1.1 Overview

Smart grid tools and technologies implemented in the electrical grid infrastructure enable bidirectional flows of energy and communication. These new capabilities can lead to improved efficiency, reliability, interoperability, and security. Smart-grid-related technology and services have been growing rapidly and are forecasted to double between 2009 and 2014 to nearly $43 billion in the United States and to more than $171 billion globally.[4]

EISA 2007 outlines a strategy for developing a domestic smart electric grid through modernization of the U.S. electricity transmission and distribution system.[5] A public investment of $4.5 billion was later authorized by the American Recovery and Reinvestment Act of 2009 (ARRA) for electricity delivery and energy reliability activities to modernize the electric grid and implement demonstration and deployment programs (as authorized under Title XIII of EISA).[6] Private entities were to match this public investment with a 50% cost share.

EISA outlined a number of important smart grid characteristics, ranging from increased use of digital information and controls to integration of renewable and distributed energy resources (DERs) and deployment of smart technologies for communications, metering, and consumer devices.[7]

Recent reports suggest that substantial investments are needed to modernize the electricity system through new technology and other improvements. Between 2010 and 2030, estimated costs for modernization range from $340–$480 billion.[8] However, benefits are estimated at $1.3–$2 trillion over 20 years—roughly three to five times the investment. Despite the projected value, expenditures for improvements are expected to fall about $107 billion short by 2020 (ASCE 2011).[9] This growing investment gap is likely to increase the potential for electricity interruptions due to aging equipment and capacity bottlenecks.

Significant progress is being made toward the development and implementation of a smart grid, but there are many challenges that still need to be addressed. A number of roadmaps and reports have

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[4] Zpryme Research and Consulting, "Smart Grid: United States and Global Hardware and Software Companies Should Prepare to Capitalize on This Technology," December 14, 2009, http://zpryme.com/news-room/smart-grid-united-states-and-global-hardware-and-software-companies-should-prepare-to-capitalize-on-this-technology.html.
[5] Energy Independence and Security Act of 2007 [Public Law No: 110-140].
[6] The White House, "American Recovery and Reinvestment Act: Moving America Toward a Clean Energy Future," February 17, 2009, http://www.whitehouse.gov/assets/documents/Recovery_Act_Energy_2-17.pdf.
[7] Energy Independence and Security Act of 2007 [Public Law No: 110-140] Title XIII, Sec. 1301.
[8] EPRI 2011, "Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid," Electric Power Research Institute, 2011, accessed January 3, 2012, www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001022519.
[9] ASCE 2011, "Failure to Act: The Economic Impact of Current Investment Trends in Electricity Infrastructure," Economic Development Research Group, Inc., in association with La Capra Associates, for the American Society of Civil Engineers, 2011, accessed December 21, 2012, www.asce.org/uploadedFiles/Infrastructure/Failure_to_Act/SCE41%20report_Final-lores.pdf.

outlined the technical issues and potential approaches for overcoming them, from the federal, state, industry, and even global perspectives.[10,11,12,13,14,15]

1.2 Role of Measurements and Standards

Measurement science and standards play a key role in many of the technical challenges related to the smart grid, for example, they support effective communication and interoperability of the equipment connected to the grid and the infrastructure that serves the grid. There are also numerous measurement and standards challenges related to the key technologies that support the grid, such as power electronics, power metering, and energy storage.

NIST has two broad roles relating to the smart grid—standards coordination as mandated by EISA and relevant measurement science research that falls within its core mission. The EISA legislation charges NIST with the facilitation of interoperability standards for the smart grid. The primary organizational tool for addressing this task has been the formation and coordination of the SGIP, a public/private partnership founded in 2009. With regard to in-house, measurement-oriented core research, NIST supports several smart-grid-related projects dealing with electric power metering, power electronics, synchrophasor measurements, precision timing, modeling, and evaluation of intra-grid communications, building control system interfaces, sensor network interfaces, advanced power metering, electromagnetic compatibility, and cyber security.

1.3 Workshop Objectives and Methodology

To successfully conduct its efforts in this area, NIST needs a better understanding of the major technological and measurement challenges that present obstacles to the successful deployment and operation of the smart grid by the industrial sector. To this end, NIST and the Renewable and Sustainable Energy Institute (RASEI) co-sponsored the *Workshop on Technology, Measurement, and Standards Challenges for the Smart Grid* on August 13 and 14, 2012, in Boulder, Colorado.

Key stakeholders from industry, utilities, academia, and the national laboratories were invited to participate in the workshop and provide their expert views. Each of the participants served on one of four working groups:

- **Working Group 1**: Integration of large, utility-scale renewable energy onto the grid
- **Working Group 2**: Integration of distributed generation (including renewables) and energy storage with the grid (including microgrids and local energy control systems)
- **Working Group 3**: Energy efficiency, demand response, and load control (including impact of electric transportation)—residential, commercial, and industrial
- **Working Group 4:** Efficiency, reliability, security, and stability of the grid (including advanced transmission and distribution management applications)

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[10] National Academy of Engineering, *The Smart Grid: A Bridge between Emerging Technologies, Society, and the Environment*, 2010, http://www.nae.edu/Publications/Bridge/TheElectricityGrid/18895.aspx.

[11] National Institute of Standards and Technology, *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0*, February 2012. http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf.

[12] California ISO, *Smart Grid Roadmap and Architecture*, 2010, http://www.smartgrid.epri.com/doc/cal%20iso%20roadmap_public.pdf.

[13] New York State Smart Grid Consortium, *Smart Grid Roadmap for the State of New York*, 2010, http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/NYSSGC_Attachment.pdf.

[14] International Electrotechnical Commission, *Smart Grid Roadmap*, 2012, http://www.iec.ch/smartgrid/roadmap/.

[15] Zpryme and Clasma, *Energy 2.0: 2012 to 2022 Smart Grid Roadmap*, 2012, http://en.calameo.com/read/000414633706521e203b1.

In several teleconferences before the workshop and in breakout sessions during the workshop, each working group considered the issues of (i) the current state of the smart grid, (ii) future goals and visions for the smart grid, (iii) major technological and other challenges, and (iv) research and measurement science priorities. During the fourth breakout session, each working group voted on a prioritized list of research and measurement science challenges, as indicated in the tables that follow.

By design, the workshop was consensus seeking rather than tutorial. The considerable discussions that occurred within each working group for the several months before the actual workshop allowed the workshop to achieve a certain degree of consensus.

In addition to specific working group topics, the following crosscutting issues were discussed in all working groups: cyber security, privacy of information, industry standards, policy and regulation, communications infrastructure (requirements for response, bandwidth, latency), and information infrastructure (enterprise data management requirements).

The primary technical output of the workshop is a list of challenges within each topic area that the group considered to be a priority. Note that the ideas presented here are a reflection of the attendees and not necessarily the entire industry. As such, they should be viewed as a good snapshot of the important perspectives but not all-inclusive. The workshop participants were carefully selected based on their high level of technical knowledge related to smart grid technologies and systems and are considered experts in the field.

The results of the workshop will help to (i) build a coordinated smart grid research program for industry, government, and academia; (ii) identify and remediate strategic gaps in smart grid efforts that could impede progress; and (iii) create an integrated vision and development strategy for smart grid.

The workshop accomplished a dynamic forum for viewpoints on technology and measurement science impediments to the successful development of the smart grid in the United States. A follow-on document, *Strategic R&D Opportunities for the 21st Century Smart Grid*, will be available to the public in early 2013, which will be particularly useful to smart grid planners and research directors. This document will provide a high-level summary and discussion of the opportunities identified for smart grid development.

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2

INTEGRATION OF LARGE, UTILITY-SCALE RENEWABLE ENERGY ONTO THE GRID

2.1 Overview

Large, utility-scale renewable energy (RE) systems (~50 MW or larger) have the potential to make a substantial contribution to future domestic power supplies. A wide range of renewable sources can be considered for large-scale grid integration, including solar, wind, geothermal, and hydropower. While progress is being made in deployment of renewable power technologies, there are unique challenges associated with integrating these sources at larger scales.

Some challenges arise when integrating these non-traditional, variable, non-baseload power sources onto the grid. The variable nature of the output must be taken into account in order to optimize the operation of the entire system. Existing conventional power plants and other system assets will need to be operated differently. It is envisioned that the smart grid will be particularly capable of integrating renewable resources on a much larger scale, but a number of technical issues must be addressed before this becomes a reality. Some of the important factors impacting integration of renewable energy at utility scale are related to the following:

- Improved operator visibility of renewable resources
- Utilization of advanced forecasting methods and integration with system operations
- Planning methods that are robust in scenarios with high penetration of renewable energy
- Effective use of demand response (DR), economic large-scale energy storage, and other sources of flexibility
- Incorporation of better supervisory control and data acquisition (SCADA)/energy management systems (EMS)
- Incorporation of renewable generation controls into traditional system operation
- Phasor measurement units (PMUs) and networks used in wide area measurement systems
- More ubiquitous use of high voltage power electronics (e.g., flexible alternating current transmission system (FACTS), static synchronous compensator (STATCOM), variable frequency transformer)
- Adoption of appropriate interconnection requirements for large renewable energy (e.g., fault ride through,[16] volt and volt-ampere reactive [VAR] control[17])

2.2 Current State

Integration of Renewable Energy: The impacts of renewable energy on system operations and planning are fairly well understood. However, existing smart grid capabilities (e.g., renewable portfolio standards and communication and controls) for handling the impacts of integration and optimizing the future power system with high levels of wind and solar energy have not been sufficiently studied.

State incentives for using renewable energy and environmental policies (e.g., restrictions on emissions) are helping accelerate deployment of renewable generation. However, complex jurisdictional and

[16] Ride through capability enables power source to deliver usable power for a limited time during a power loss.
[17] Volt and VAR control reduces electricity consumption by reducing energy load through voltage optimization and by reducing losses on the electric grid.

policy issues; permitting; and differences among state, federal, and interstate policies, as well as cost, continue to challenge widespread deployment of large-scale renewables. Studies analyzing large-scale wind and solar integration are available and help to provide information support for both policies and implementation. Simulation models for wind and solar generation are developing, but need improvement, which makes grid planning and generator interconnection more difficult. The means for integrating renewable energy—system operators, consistent policy and regulatory environment, standards/protocols, and market incentives—could all be improved. While cheap natural gas currently creates a competitive situation for new power plant construction, renewables offer long-term energy at a known price (without uncertainty around future fuel prices) with a very low marginal operating cost. Therefore, utilities are procuring renewables for both economic and diversity reasons.

Communication Standards: Communication standards for utility-scale renewable power plants, such as International Electrotechnical Commission (IEC) 61400-25 and NIST PAP 16 related to wind plant communications, are being considered, as are efforts to develop standards for smart grid communications in general.[18] However, gaps in communications standards remain significant. Standards for interoperability and security of communication systems are also an issue, although significant work is being done in this area.

Infrastructure: The grid infrastructure is composed of disparate technologies that vary widely in age, condition, and capacity. Some of the technologies within this massive infrastructure are reaching the end of their useful life or becoming obsolete, while others are proving inadequate to support expanded use of new energy sources, such as wind and solar. The entry of new technologies and energy resources is challenged by factors such as cost, perceived technical risk, and significant learning curves. Efforts are underway to expand the grid measurement infrastructure (e.g., smart meters, PMUs), but it is still uncertain how this new infrastructure can be best leveraged to support transmission operations and how these capabilities can be taken into account in the system planning process. A clear direction for future grid architectures has yet to be defined. There is a trend toward increasing application of power electronics, such as FACTS (STATCOMs, voltage source converters) and inverter-based renewable generation.

Scheduling and Dispatch: Today's operating practices do not adequately support voltage scheduling and real power generation with renewables in the mix. Recent large-scale renewable integration studies have increased our understanding of best practices for scheduling and dispatch best practices. The market mechanisms and reliability standards that frame existing operational practices are evolving rapidly. Grid compatibility standards or grid codes (e.g., electromagnetic compatibility) vary greatly and are being revised (through organizations such as the North American Electric Reliability Corporation (NERC) and the Integration of Variable Generation Task Force) to address specific issues, such as the management of inverter-based renewable generation versus conventional generation. Today, most operational paradigms are based on preventative action. If operators could more actively respond to signals from variable resources the power system would operate more effectively.

While forecasting of renewable resources has improved and is widely used, some system operators are not applying it to generator scheduling and dispatch in an optimal way. In many cases, forecasts are customized for individual customers. Standard forecasting definitions and formats that could be applied to different uses or time granularity, for example, would be useful.

Regional Planning and Coordination: Market agility varies widely by region. For example, in some regions, intra-hour transactions are not supported, which requires balancing with more expensive generation sources. While many regions are beginning to coordinate operational scheduling of resources and cross-state transmission planning, regional coordination is not advancing as rapidly as

[18] National Institute of Science and Technology, "Smart Grid Panel Agrees on Standards and Guidelines for Wireless Communication, Meter Upgrades," April 19, 2011, http://www.nist.gov/smartgrid/smartgrid-041911.cfm.

the growth of wind and solar generation. In some cases, areas that have great potential for large-scale deployment of renewable resources have limited access to fluid flexible markets.

Reliability: The reliability of power supply is assumed to be an essential requirement. Reliability assessments are currently performed, but the metrics used may not be appropriate for a changing operational environment that includes renewable resources, which are intermittent. As the generation mix changes and distributed options become more prevalent, greater emphasis will need to be placed on reliability metrics that take into account a wider variety of controllable resources, including variable generation and load.

Enabling Technologies: New technologies provide many benefits, including generation and delivery flexibility, better operational visibility, and more sophisticated planning and operation support tools. However, their adoption is hindered by a number of factors: (i) the current and future features of enabling technology, such as smart meters, are underutilized and not well understood; (ii) the ability of new technologies to enable supply and demand to more efficiently provide services to the grid is not well understood or implemented, and (iii) methodologies for quantifying the value of these new technologies are immature or not widely understood or employed. More extensive and coordinated monitoring and communication could lead to greater system visibility of new technology and resources across control areas.

Data Mining and Sharing: The amount of data generated and managed has exploded and will continue to grow in the future. Computational resources for planning and operations, such as central sharing of best practices, data repositories, data usage information, and applicability of data, increases each year; however, compatibility of data sets continue to be an issue. Uncertainty in the security and privacy of data as well as information access (e.g., data access rights) hinders the adoption of smart grid solutions. The smart grid information technology (IT) perimeter has expanded to include systems previously outside the grid, generating beneficial data but also creating new security issues. Good security foundations and models must be in place to ensure data security, grid safety, and advancement of smart grid technologies.

2.3 Future Goals and Capabilities

The goal for the future is to rapidly increase integration of renewable resources. This will be driven predominantly by favorable policies, incentives, and cost improvements. Incorporating renewable resources at utility scale will require enabling technologies in areas such as communication, generation, optimization, and scheduling, as shown by the future capabilities identified in Table 2-1.

Table 2-1: Future Capabilities to Support Integration of Renewables at Utility Scale
Enabling Technologies
Smart Grid Technologies
• Smart grid technology and capabilities that take full advantage of wind/solar resources and take into account the impacts of integrating large-scale renewables
Transmission and Distribution
• Wider range of frequency support and active power control capability for solar/wind integration
• Communication system that allows self-organizing interconnections between grids and microgrids
• Real-time sensing, customer-controllable load, and on-site controls for distributed generation (DG) for targeted DR
Energy Storage
• Economic energy storage as transmission or system assets for managing system operation

Table 2-1: Future Capabilities to Support Integration of Renewables at Utility Scale

Planning and Operation Protocols

Dispatch and Optimization

- More flexible dispatch and optimization for generation and operations; flexibility beyond generation (e.g., communication systems, networks, system-level thinking)
- Definition of resource-specific targets and value-based needs with clear pathway and options for achieving the targets
- Integration of a distribution energy management system (DEMS) into the DR loop
- Tighter, more transparent link between transmission and distribution (particularly for voltage support)
- Full-integration and co-optimization of all controllable resources (e.g., generation, demand, storage, transmission, distribution)
- Dispatchable renewables via close-to-real-time schedule updates and dispatch; dispatchable transmission for economic efficiency

Planning Information and Tools

- Seamless and harmonized information exchange between operations and planning, with clear understanding of what information needs to be exchanged
- Planning models for wind, solar, and new DG technology (within five years)
- Widely adopted probabilistic operations and planning tools with integrated risk factors

Market Structures

Market and Rate Structures

- New market structures that incentivize grid flexibility
- Reconciliation and revenue billing/rate structures to accommodate higher penetration of renewable sources
- Normalized sub-level scheduling/settlement processing capabilities that communicate transparently across regions and accept bids from all supply and demand resources

Market Forecasting

- Forecasting to support inter-hour scheduling in balancing areas and markets, often coordinated by independent system operators with support for regional, type-specific attributes
- Clarification of the business model for generating, improving, and sharing wind and solar forecasts
- Coordinated forecast for balancing authorities that have common inter-ties to address *seams*

Resource Planning

- Increased renewable islanding supplies
- Ways to handle increasing integration levels of renewables (e.g., 20%, 50%, and more)
- Better reconciliation of markets and resource planning
- DR tied to supply and managed as a resource through markets
- Homogenized integration methods, increasing the understanding of methods and reception of initialization data
- Defined attributes for real-time markets

Table 2-1: Future Capabilities to Support Integration of Renewables at Utility Scale
Policy and Regulation
Codes and Standards • Clear, consistent grid codes to address renewable generation (e.g., interconnections, types of information required for operators) • Engineering support to assess appropriate standards for frequency ***Future Policies*** • Alignment of value proposition with incentives and policy structures • Integrated policy and planning processes for RE, transmission, DR, and systems operations, all driven by data and analysis feedbacks • Reduced policy uncertainty for renewables and climate change to facilitate mid- to long-term grid planning and development • Policies to incentivize zero-pollution, low-cost, green electric service • Policy for large energy storage use and other sources of flexibility to anticipate high penetration of renewables

2.4 Non-Technical Challenges

Several non-technical challenges were identified as impeding the integration of utility-scale renewable energy. Some of the major non-technical challenges identified by workshop participants are outlined below.

Conservatism of the Utility Sector: The utility sector is historically conservative and a relatively low-competition market. The decisions that utilities make regarding capital assets can last for 40 years due to the exceedingly long life of equipment, so large investments in R&D and new technology are not common. Stimulus funds provided some impetus for investments related to the smart grid, but post-stimulus, significant challenges exist to incentivizing R&D when potential benefits do not clearly favor the utility's current business model.

Public Perspectives: Consumers are reluctant to accept smart grid technologies due to real or perceived issues. One is the privacy factor, which is manifested in the desire to protect or have a say in the release of what may be perceived as personal information about behavior or habits. Another is the uncertain security of data flows.

Return on Investment (ROI): New technology can be costly to implement, and has led to a debate over who should pay for upgrades at the utility and how and when these costs will be recouped. The distribution of benefits (e.g., cost savings from smarter electricity) has not been clearly defined. The ability to recover costs is still uncertain in the U.S. market; a lack of clear incentives can limit the motivation to invest.

Unconsolidated Operations: There are many small balancing authorities across large areas that can delay operational optimization. The lack of communication and protocols information exchange for use among balancing authorities also hinders optimization. Each entity operates its own infrastructure, which in the short run is easier to maintain but more costly overall.

2.5 Technological and Measurement Challenges

A number of technical and measurement challenges to utility-scale integration of renewables were identified. One major issue is the lack of adequate modeling tools for operations and planning for the use of bulk renewable resources. These tools could drive many of the advances that are needed to fully optimize the use of renewable resources at utility scale. They are also critical to the development of the effective policies and regulations needed to support greater integration of renewables.

Attaining system-level flexibility in generation as well as the grid is another major issue. Flexibility needs to be well defined and incorporated through novel technologies (e.g., DR, flexible generation, economic energy storage,). There also needs to be a greater understanding of issues, such as the transition from central control to loosely coupled systems. Operators must be able to make informed decisions about how to effectively schedule and dispatch renewable sources.

Some of these challenges will require a nominal effort to overcome, while others represent step-change improvements that are difficult but critical to future integration. The challenges identified are listed in Table 2-2, organized by four major categories: enabling technologies, planning and operations protocols, market structures, and policy and regulation. Those that are the most critical and would have the greatest impact if overcome are categorized as high priority.

Table 2-2: Prioritized Challenges—Technological and Measurement—for Utility-Scale Integration of Renewables (● = one vote)	
Models for Operations and Planning	
Higher Priority	• Models and tools to support operations and planning as well as policy and regulation ●●●●●●●●● (9) – Lack of system-level performance metrics for renewables, DERs, and smart grid – Inability to determine whether adequate frequency response is measurable and appropriate metrics – Inability of models to resolve temporal and spatial details while incorporating production, cost, planning, and probabilistic data – Lack of integrated production cost models that cover DR, distribution, storage, smart grid operation, and wind/solar (e.g., handling net load issues), with balance of system (BOS) capability to provide a plant-wide view – Developing closed loop models with updated data ability to represent effects of local automation
Medium Priority	• Limited operational models for bulk renewable resources (short-term dynamic and short-term forecasting) and for online security assessment ●●●●● (5) • Lack of standard methods (e.g., algorithms) for quantifying and applying the value of new technologies at scale ●●●● (4) – Lack of clear federal and state guidance on cost allocation and recovery of expensive technical upgrades (e.g., socialized cost, burden shared by ratepayers or shareholders) – Lack of models to quantify benefits – Need to determine who benefits from new technologies
Lower Priority	• Lack of standardized models for control design (rather than analysis) • Inability of existing tools to easily share data and models (e.g., using EMS for transmission planning)

Table 2-2: Prioritized Challenges—Technological and Measurement—for Utility-Scale Integration of Renewables (● = one vote)	
System and Operational Flexibility	
Higher Priority	• Lack of system-level flexibility for generation and the grid ●●●●●●●●●●● (11) – No clear definition of flexibility and means for quantifying flexibility – Lack of metrics for reliability and flexibility • Lack of grid architecture to support flexibility ●●●●●●●● (8) – Inadequate control architectures for massive DER participation – Developing control logic to self heal and self operate – Inability to transition from central control to loosely coupled or decentralized systems • Inability to utilize demand and network flexibility and take full advantage of renewable resources ●●●●●●●● (8) – Developing faster and more dynamic access to generation capabilities and flexibility, even for legacy generation – Incorporating a more dynamic view of operational changes and power outputs – Better utilizing demand side and EMS as high-value tools for operators – Lack of tools to dispatch, plan, optimize, control complexity, and ensure reliability with new systems that differ considerably from past systems – Lack of systematic way to schedule voltage support on automatic voltage regulators to support delivery of renewable power – Understanding how to handle impacts of large-scale renewables in operational practices and planning – Lack of standardized market and operational solutions for renewable integration
Medium Priority	• Lack of breakthrough power storage technology ●●●●● (5) – Complexity, cost, and difficulty of developing large bulk storage – Lack of consensus on best storage concepts (e.g., transmission can be an alternative to storage), which is further complicated by major jurisdictional issues
Lower Priority	• Cost of bandwidth and legacy infrastructure; difficulty justifying replacement of legacy systems with new technology and/or gadgets • Interoperability of legacy and new systems • Lack of transmission capabilities and load transmission for wind • Inability to connect Eastern and Western grids or achieve globalized integration across the continent • Difficulties in reconciling very different lifetimes for a range of technologies (e.g., transformers vs. IT and communications) • Difficulties of using high voltage direct current (HVDC) to remake the grid (e.g., hardware cost, system controls)
Measurement and Decision Tools and Methods	
Higher Priority	• Lack of high fidelity forecasting and other elements for dispatch decisions ●●●●●●●● (8) – Insufficient forecasting of renewables – Lack of innovation in forecasting methods – Lack of secure data collection and real data for scenario planning – Limited ability to correlate various characteristics impacting renewables generation • Insufficient operator visibility of situational awareness ●●●●●●●● (8) – Lack of probabilistic planning operations and tools

Table 2-2: Prioritized Challenges—Technological and Measurement—for Utility-Scale Integration of Renewables (● = one vote)	
	– Insufficient data management capability (e.g., from PMUs) particularly for large amounts of incoming systems data – Limited ability to provide control room operators with useful data for decision making. (i.e., just enough data rather than too much data) – Lack of centralized EMS and data capture or decision support • Inability to adjust decision logic based on dynamic conditions and multiple resource options ●●●●●●● (7) – Limited advanced decision support for operators – Developing predictive algorithms (proactive and reactive) with more granular/broad measurement – Lack of methods (e.g., predictive algorithms) to use the measurements – Adopting auto control over human-based action decision support – Inadequate device behavior data to simulate/predict performance, including extreme conditions – Integration of sensors and fusion of data in a useful way
Medium Priority	• Inadequate understanding of the value of faster measurements or faster response (i.e., what is gained by gathering data faster, how fast is better, and when is value added) ●●●● (4)
Lower Priority	• Developing measurement systems that provide short-term prediction of transients in wind and solar energy and make data available in time to activate back-up systems (e.g., seconds or minutes) • Dealing with the greater complexity of decentralized controls and markets and their effect on the stability of power systems in the future
Standards and Protocols for Large-Scale Renewables	
Higher Priority	• Methods and tools for testing and compliance to meet interconnection standards and dynamic response ●●●●●● (6) – Lack of tests for reliability and equipment lifetime – Lack of clear and consistent grid codes for renewable generation in terms of interconnections, types of information required by operators, and generation technologies – No clear technical standards for communication (e.g., formats, data interfaces, and exchange) – Limited rules for the interoperability of software and hardware – Lack of established communication test protocols – Ensuring interconnections and interoperability with legacy equipment
Medium Priority	• Complexity of coordinating roadmaps, standards development, and master plans ●●● (3)
Lower Priority	• Ability to develop technology-neutral standards • Lack of clear standards for cyber security, privacy and protecting proprietary information; limited protocols for sharing information related to cyber security • Slow and cumbersome process for developing new standards • Lack of standards for provable dynamics • More complex EMS and contingency analysis with high renewable penetration and relaxed frequency standards

2.6 Prioritized Challenges Summary

Several of the technical challenges were identified by the working group as priority impediments to the successful integration of utility-scale renewables. These priority challenges are summarized below and described in more detail in Figures 2-1 through 2-4.

Tools to Assure System-Level Generation and Grid Flexibility: The flexibility of system-level operations, generation, and the grid needs to be clearly defined (Figure 2-1). A clear definition will aid in developing methods for quantifying what constitutes flexibility and incorporating flexibility into future grid architecture plans. The overall objectives are to enable simulation and evaluation of the flexibility embedded in current systems, alternative architectures, and flexible sources. New tools would also allow for greater utilization of demand and network flexibility.

Communication and Interconnection Standards Specific to Renewables: Current communication and interconnection standards and regulations are inadequate to address data interfacing requirements (Figure 2-2). Regulations for grid support functions are relatively undefined and data exchange rules among enterprise applications are lacking. Addressing these issues would lead to seamless data exchange between distribution, transmission, generation, and customer applications via established communication protocols. Easier data translation and better utilization of system assets would increase system efficiency. Standard interconnection protocols would reduce operator error and increase detection of system problems, thereby increasing system assurance and security.

Tools for Decision and Operator Support: High-fidelity forecasting capability is needed for improving dispatch decisions (Figure 2-3). The objective is to create tools that are capable of using improved weather observations, computational methods, and renewable generation characteristics. Operators lack sufficient visibility and situational awareness; increasing visibility, including uncertainties, would improve operational decisions while ensuring reliability and optimization. The ability to forecast operating conditions and understand the options in advance (e.g., one day ahead) for achieving operating objectives would increase efficiency and improve DR. Operators are unable to adjust decision logic based on changing conditions created by dynamic data and in step with rapid responses required by the increased resource choices. Advanced decision support for operators, such as better control architectures and fusion of advanced data (e.g., EMS, DR), could help to improve decision logic. Automatic logic approaches should also be explored (e.g., automatic activation of remedial action schemes (RAS) or other control schemes).

Comprehensive Models for Operations and Planning: Performance metrics are needed to evaluate the impacts of renewables, DERs, and smart grid performance based on quantifiable responses (Figure 2-4). Performance metrics would require consensus among stakeholders as well as policymakers to be effective and gain widespread use. Another issue is that operational and planning models available today are unable to resolve different spatial and temporal detail while incorporating key production, cost, balancing, and planning data. Commercial models are needed that are acceptable to the industry for assessing the dynamics of operations and performance. Integrated models are also needed to simulate various system components (performance, storage, DR, renewable characteristics). New measurement approaches are needed to guide efforts to collect, simulate, and verify data for use in model validation approaches. Models are needed to provide a full plant perspective; models are available for wind turbines and solar cells, but not for the BOS.

Figure 2-1:

Tools to Assure System-Level Generation and Grid Flexibility

Technology/Measurement Barrier
Lack of a clear definition for and quantification of methods of flexibility

Technology/Measurement Barrier
Lack of future grid architecture that considers flexibility

Technology/Measurement Barrier
Inability to utilize demand and network flexibility and operator reluctance to implement flexible resources

Technologies/Decision Tools to be Developed

- General classification of flexibility as a concept
- Mathematical formulation of flexibility

- Planning tools, testing methods, operations tools, and market designs that specifically incorporate flexibility

- Communications and operational tools that dispatch and utilize flexibility through automated controls

Key R&D Activities

- Analyze current system flexibility embedded in business processes, market designs, and operating practices
- Modify and re-think reliability metrics

- Simulate alternative architectures
  - Fully centralized vs. fully decentralized
  - Hybrids
- Simulate new flexibility sources (e.g., a real-time digital simulator [RTDS])

- Standardize "transactive energy"
- Develop flexible supply curve
- Correct action-based controls incorporating all flexibility sources
- Implement inter-hour scheduling
- Build power flow control hardware

Performance Targets

- Evaluation of embedded flexibility in current systems
- Revised reliability metrics

- Simulation of alternative architectures
- Simulation of new flexibility sources

- Smart load shedding/dumping
- Flexible market designs
- New market products like non-generator resource/ regulation energy management (NGR/REM)
- Inter-area cooperation schemes
- Improved flexibility in gas power plants

Stakeholders and Roles

Industry: Guide, review, test, data supply/provision, industry R&D (1/2 of 1% of revenue)

National Labs: Convene and collaborate, provide simulation hub, provide computational resources, facilitate international coordination

Academia: Conduct fundamental research on sources of flexibility

Trade Organizations: (American Wind Energy Association): Provide harmonization of flexibility

Standards Organizations: (IEEE, IEC): Provide international coordination, harmonization

Government: Guide research programs, convene public/private collaboration

Potential Impacts

Reliability: Improvement of reliability

Operation or Installation Cost: Reduction of cost of integrating renewables

Efficiency/Usability: Improvement of efficiency/usability

System Assurance and Security: Increase of system resilience to all types of threats and instabilities

Load or Demand Response: Improvement of utilization

Other: N/A

Milestones

2013-14: Utilize/leverage existing equipment

2017: Alternate methods of system utilization

2020 and beyond: Total re-development of existing electric industry

Figure 2-2:

Communication and Interconnection Standards Specific to Renewables

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Inadequate interconnection requirements to address data interfacing requirements (e.g., time intervals)	Lack of data exchange rules among enterprise applications	Limited communication capability in legacy equipment	Undefined performance regulations for grid support functions; discrepancies between multiple communication protocols and data models

Technologies/Decision Tools to be Developed

• Interfaces between legacy systems and new	• Data exchange rules	• Communication protocols	• Standards for communication interfaces

Key R&D Activities

• Define a robust data structure for both real-time communication and application interfacing • Identify data to be transmitted locally and centrally so data is available when needed	• Create rules and protocols on data exchange for privacy and security	• Create rules and protocols for connection with legacy systems	• Define grid support functions • Identify gaps and issues in communication protocols and data interfaces

Performance Targets

• Seamless data exchange between distribution, transmission, generation, and customer applications	• Accepted data rules and protocols	• Established communication test protocols	• Standards and protocols for communication interfaces • Compliance testing for interfaces

Stakeholders and Roles

Industry: Develop software, technology, and innovation

National Laboratories: Provide laboratory demonstrations, conformance evaluations, and protocols

Trade Organizations: Help define target, vision, and objectives

Standards Organizations: Develop consensus, standards, and test methods

Government: Identify gaps and priorities

Potential Impacts

Reliability: Access to actionable data for decisions and corrective action

Operation or Installation Cost: Less custom engineering

Efficiency/Usability: Easier data translation; better utilization of system assets

System Assurance and Security: Reduced operator error; detection of system problems

Load or Demand Response: Enables DR, load

Other: N/A

Milestones

2013: Systematically derive communication/interface needs across classes of stakeholders, vet widely

2015: Establish standards development project under appropriate standards development organization

2017: Create compliance testing protocols; begin deployment

2020: Review and update protocols

Figure 2-3:

Tools for Decision and Operator Support

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Lack of high-fidelity forecasting capability for renewables and other elements for improved dispatch decisions	Limited operator situational awareness	Inability to adjust decision logic in response to changing conditions created by dynamic data and rapid response resource choices

Technologies/Decision Tools to be Developed

- Models correlating a greater density of weather sensors, improved computation methods, and renewable generation characteristics

- Probabilistic tools/models
- High-speed aggregation of PMU data and other data
- Forecasts of grid behavior

- Control architectures (i.e., distributed, central, and the coordination thereof)
- Fusion of advanced data

Key R&D Activities

- Create high-resolution, localized, meteorological forecasts (e.g., wind, cloud cover) for events that result in power ramp-ups

- Increase understanding of human factors to ensure information can be consistently processed and acted upon using probabilistic methods
- Determine how to integrate tools and methods to provide grid behavior forecasts

- Determine extent of human participation and feasibility of automatic logic to operate completely anonymously
- Develop advanced decision support for operators

Performance Targets

- Achievement of pay ahead forecast of renewable contribution, which is similar to the certainty of the load

- Ability to forecast the operating conditions and provide options in advance (e.g., one day ahead) that achieve operating objectives
- Increased situational visibility, including uncertainties, to improve operator decisions while ensuring reliability and optimization

- Capacity to automatically activate RAS or other control schemes
- Ability to switch between control schemes quickly for more resiliency and flexibility (RAS voltage variability needs)

Stakeholders and Roles

Industry (Utility, ISO, vendors): Contribute to standards making; develop, deliver, and use the technology

National Laboratories: Perform research; validate technology

Academia: Develop algorithms and new sensors

Trade Organizations: Establish guidelines, agreed practices, and performance targets

Standards Organizations: Create standards and protocols; determine measurements

Government: Conduct programs in technology evaluation; drive consensus; communicate best practices

Potential Impacts

Reliability: Improved awareness; better decision making tools

Operation or Installation Cost: Improved optimization of resource choices and reduced market cost

Efficiency/Usability: Better coordination with planning; improved capability utilization of transmission; more efficient use of renewables

System Assurance and Security: Enhanced via increased automation considering dynamic characteristics

Load or Demand Response: Increased use of load as a system resource

Milestones

2015: Forecasting capabilities achieved for advance operational planning and control

2017: Automatic activation of RAS or other schemes

Figure 2-4:
Comprehensive Models for Operations and Planning

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Lack of performance metrics (e.g., component-level, interconnection level) to evaluate the effect of renewables, DERs, and smart grid on system performance	Inability of models to resolve different spatial and temporal detail while incorporating dynamic, production, cost, balancing, and planning data; limited probabilistic capabilities	Lack of component model and performance data, energy storage, and DR data for wind and renewables balancing decisions
Technologies/Decision Tools to be Developed		
• Methods for defining performance objectives (e.g., component and system level) • Clarification/definition of multiple objectives (e.g., efficiency, environment)	• Tools for representing different effects (e.g., wind, DER, storage) • Tools to represent effects of local automation	• Measurement approaches to collect, simulate, and verify necessary data • Model validation approaches
Key R&D Activities		
• Develop grid-level performance metrics for quantifiable response (e.g., temporal, spatial) given a percentage of renewable penetration	• Create models to assess performance and compliance over all time scales and granularity	• Build control designs for meeting pre-specific performance • Develop algorithms for co-optimizing supply and demand options
Performance Targets		
• Agreement on performance metrics by stakeholders, including policymakers • Flexible performance metrics to serve differing needs	• Commercial models acceptable to the industry for assessing dynamics of operational performance metrics	• Acceptance of probabilistic tools for enabling a percentage of wind integration • Validation of component and system models and performance data

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Provide system data and component data; materials to researchers **National Laboratories:** Produce sanitized raw data for academic use; work on model scalability and validation **Academia:** Develop models and tool performance metrics; conduct simulations **Trade Organizations:** Facilitate support for research via industry data **Standards Organizations:** Work on performance metrics **Government:** Facilitate RD&D; bring stakeholders together	**Reliability:** Better decision making tools **Operation or Installation Cost:** Improved resource optimization **Efficiency/Usability:** Better use of renewables	**2014**: Performance metrics **2015:** Early planning models developed **2018:** Commercial models

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3

Integration Of Distributed Generation And Energy Storage With The Grid

3.1 Overview

Integrating significant distributed generation capacity and energy storage with the grid can enable a cleaner, reliable, and more efficient power generation and delivery system. DG and energy storage, collectively referred to as distributed energy resources, are capable of increasing the efficiency of the transportation sector, reducing peak power requirements, reducing the carbon intensity of grid-supplied electricity, and providing a more resilient energy supply. DERs can also relieve transmission congestion by reducing the amount of electricity delivered by long-distance power lines.

DG includes renewable generation, such as photovoltaic arrays and wind turbines, as well as fossil-based, small-scale power sources, such as private electric generating units and microturbines. Energy storage devices include batteries, compressed air, flywheels, and super capacitors, and many alternatives are based on new or emerging technologies. Integrating energy storage in tandem with DG increases dispatchability of power flows and can optimize the benefits of using DG.

While progress is being made in the accommodation and deployment of DER technologies, there are unique challenges associated with integrating these resources. Technical, economic, and regulatory issues are inhibiting greater integration of DER. For example, communication between DER, loads, utilities, and dispatchers is broadly insufficient for an optimized smart grid. In general, new technologies and devices are outpacing the ability to integrate them into the grid and incorporate their full functionality.

Following are examples of important topics associated with integrating DER with the grid:

- Integration of distributed and local controls into DEMS (e.g., smart inverters)
- Field area network communications infrastructure
- SCADA/DEMS applications (e.g., fault diagnosis, isolation, and recovery (FDIR) and integrated volt-VAR control (IVVC))—functional requirements with DG, renewables, and storage
- Energy storage and community energy storage (CES)
- Geographic information system (GIS), outage management system (OMS)
- Microgrids
- Rooftop PV panels

3.2 Current State

The current electric grid is reliable, affordable, and easy for consumers to use. The integration of DER technologies, which is still largely nascent, has not altered these core characteristics. DER technologies are being developed and deployed in larger numbers, and significant progress has been made in integrating them into today's electricity infrastructure. However, the interconnection communications, functionalities, and business strategies associated with implementing DER technologies into the existing system are uneven across the United States. In addition, many of the advanced applications and devices are exceeding the ability of legacy systems to accommodate them.

Business Models: Wide-scale implementation of DG will require significant investment. However, significant cost reductions may be possible through recent and future decreases in equipment costs, alternative deployment strategies, and economies of scale in both manufacturing and design/engineering. For example, PV solar panel costs have dropped significantly in the past decade. Gradual deployment, in which storage purchases are distributed over multiple years, can lower storage costs by postponing expenditure, raising equipment pricing competition, and extending asset life. This practice can reduce the cost of distributed storage, such as CES, by 40%–50%, depending partly on the number of years of implementation and parallel reduction in storage cost. As production increases and adoption rates increase, not all installations need to be designed as one-off systems. Good business models are important for implementation of DER as they can provide the justification and rationale for investments into capacity planning and grid operations. While there are limited ancillary services markets and dynamic or time value of energy pricing models, current rate structures and utility revenue models are not designed to promote or capture the value of DER. Price-based DR policies, such as time of use, critical peak pricing, and real-time pricing provide insight into the economics of DER, but may not capture the time-varying value of energy or incorporate its life-cycle cost. As there is little full-scale experience in integrating DER, there is limited data to quantify key business metrics, such as ROI. A closely related issue is the conservative nature of utilities; they are generally hesitant to adopt new practices as their capital decisions last for decades.

System Coordination and Communication: It is critical that all levels of DER (e.g., DG and energy storage) be able to operate both independently and collectively through coordination via networked communication. Smart grid technologies have progressed at different rates, resulting in some systems that employ both new and old technologies with differing communication capabilities. At the local level, DER is being deployed and optimized for reliability and is operating almost exclusively in a local/islanded mode of operation. Existing systems are based on radial operations and coordination of DER at the larger community level is not available. In general, control operations and the required underlying communication infrastructure are not clearly articulated between DER and system grid operation. System operators are generally not familiar with DER dispatch at the system level. They lack visibility of DER operations, which impacts their ability to incorporate large amounts of DER while still accurately forecasting loads and maintaining grid reliability. In addition, utilities currently consider DG as a load reduction technology, rather than a source of generating capacity; therefore, it is not integrated as an alternative in the planning process.

Monitoring and Devices: Technology is progressing as millions of devices are being deployed, although the level of integration of devices currently varies across the United States. Distributed automation expansion is occurring in some instances, notably with the proliferation of SCADA devices, although there is minimal monitoring currently in place. Distributed sensing and monitoring equipment are not commonly used, resulting in little awareness of key measures of power quality and distribution grid stability. Devices such as four quadrant inverters, which can increase the functionality and value of DER, have not yet been piloted.

Tools and Models: Models today are typically based on static load flow, although some transient models are available. There have been some power quality problems; proactive tools to identify and mitigate them are limited.

Standards and Interoperability: Standards are essential for coordinating between all operational levels of DER and the grid, including relevant standards for operation. While standards exist, in some cases their applicability to DER is insufficient or limited. DER interconnected to the system are operated on a local autonomous basis, therefore they do not function in a coordinated way. There is little interaction between electrical or thermal storage and DER. Additional standardization of various levels of energy management systems and their communications are needed to address this. Practical realizations of plug-and-play interoperability do not exist from a technical, economic, and business perspective and are not yet available in demonstrations. Relevant standards do exist that can be used to enable plug-and-play installations, such as IEC 61850-7-420. DEMS are in place but need improved capabilities to effectively simulate the system and evaluate its performance.

Data, Demonstration, and Knowledge Sharing: Understanding smart grid operations and maximizing the potential benefits from new technologies and resources requires a solid foundation of data, demonstration, and knowledge sharing among the community. Experiments, test beds, demonstrations, and projects that utilize DER and renewables are currently generating valuable data and expanding the knowledge base, but the collection, management, and sharing of performance, impact, and other data among stakeholders is limited.

Storage: Energy storage technologies such as lead-acid batteries, pumped hydro storage systems, and compressed air energy storage have been used for years to match central electric supply with demand. DG requires energy storage further out along the distribution system at substations, feeders, and end-user premises. Storage devices, standardized architectures, and techniques for distributed intelligence and smart power systems as well as planning tools and models to aid the integration of energy storage systems are lacking. CES is showing promise for widespread deployment. This is kilowatt (kW)-scale energy storage connected to secondary transformers on feeders serving small commercial buildings or groups of homes. Current storage concepts can also be limited, especially for DG. For example, different control regimes require a range of cycling types that are largely unanticipated by storage manufacturers. As a result, storage devices must be operated in a limited state of charge range, which makes evaluation of storage status and performance difficult and creates implications for guarantees and warranties.

Regulation: Utility regulations currently do not allow private distribution of DG from customer to customer, limiting some uses of this resource.

3.3 Future Goals and Capabilities

In the future, there will be high market penetration of DER in the distribution system. This will maintain or improve the reliability, affordability, and ease of use of today's electric grid while reducing the use of carbon-based fuels. Communications between DER, distribution systems operators and independent system operators (ISOs) will be ubiquitous, secure, and reliable. Advanced devices, such as sensors and meters, will provide secure streaming data links between DERs and utilities that will feed advanced operations dashboards. These interconnections will provide utilities with situational awareness and a constant flow of real-time, actionable information. DER automation will be based on dynamic models that incorporate this data and optimize system operations. Table 3-1 includes further details on the goals and capabilities of a future smart grid integrated with DER.

Table 3-1: Future Goals and Capabilities to Support Integration of Distributed Generation and Energy Storage with the Grid
Secure and Reliable Communication/Coordination
Communication Devices Sharing and Optimizing Data • Automated collection and evaluation of data and a centralized control system to aggregate information throughout the grid, enabling proactive optimization of power quality • Real-time monitoring, advanced sensing, communications, control, and telemetry that accommodates DER and improves forecasting error • Advanced operations dashboards that allow differentiation between ISO and distributed demand • Advanced sensors, data, and controls that maintain and enhance overall system reliability • Easy electric and information and communication technology (ICT) connection and interoperability for DER • Secure distributed control strategies, allowing local and system-wide optimization of all resources (DER,

Table 3-1: Future Goals and Capabilities to Support Integration of Distributed Generation and Energy Storage with the Grid

storage, load)
- Continuous communication of DER status along with control technology in place, enabling utilities to use their distributed assets
- Improved coordination between DER at the transmission and distribution level
- Distribution-system-enabled services from DER shared at community and system levels

ISOs Enabling DER
- ISOs understand state of charge and allow DER to participate in regulation/operation within its range
- ISOs understand costs associated with metering and telemetry
- ISOs provide a secure, reliable, cost-effective framework that allows DER to participate in the wholesale energy market

Customers Actively Participating
- Customer participation in ISO and local markets, enabled by the availability of unbundled and time differentiated price signals (e.g., kW, kWh, kVAR, kVARh)

Appropriate Government Policies and Actions
- Incentives, standards and ratings aligned with a true holistic view that promotes appropriate independent actions
- Cross subsidies are removed; policies support "those who use the grid pay for the grid"

Devices

Commercialization of Advanced Technologies
- Improved inverter technology with VAR control and associated standard for utility/smart grid control of DG inverter VARs
- Reliable, cost-efficient, communication-enabled sensors, local processing (independent or equipment embedded)
- Interoperable customer systems with distribution control infrastructure (customer generation, demand management, and real time)
- Simple key control items to autonomous devices and groups of autonomous devices

Broad Deployment of Advanced Technologies
- Broad application of cost-effective smart meters and sensors
- Greater use of power electronics to integrate more DER
- Scalable technologies are developed to allow incremental deployment of DER
- Improved user perspective (e.g., easy, simple, cost effective) of devices to increase market uptake

Service Capability

More Options for Consumers
- Differentiated levels of reliability offered to end users, with different reliability guarantees and prices, thus avoiding the socialization of high levels of reliability
- A wide range of rate structures offered (including dynamic power flows)

Service Improvements
- Cycle life guaranteed for energy storage
- Easy-to-maintain self-diagnostic smart grid with considerations for future maintenance
- DER treated like a wholesale resource

Models/Framework

Accurate, Dynamic Optimization and Forecasting Models
- Industry-wide, smart grid architecture model that is adaptable to emergence of new device types; achieves coordinated integration of numerous emerging types of intelligent electronic devices (IED)s
- Dynamic models running in utility operations that allow for optimization

Table 3-1: Future Goals and Capabilities to Support Integration of Distributed Generation and Energy Storage with the Grid

- Real-time computational intelligence to dispatch an optimized mix of DR events, energy storage, and DG; resources optimized to load forecast and price
- Investments and policies have a stable, long-term view of costs
- Accurate weather-based stochastic energy forecasts available day ahead and hour ahead

Business Case

Revenue Models to Capture the Value of DER

- Value of time-dependent energy and ancillary services is incorporated into DER business case
- DG sources evaluated by more than levelized cost of energy (LCOE) and dollars/kW; DG elements that provide reliability and smart grid functions are rewarded

Infrastructure

Robust Smart Grid Physical Infrastructure to Support DG

- Distributed control infrastructure reaches first-generation deployment in 5–10 years on a significant scale; multiple device types available:
- Distribution systems absorb DG without major grid upgrades; distribution system easily accommodates variable renewable energy technologies up to substation transformer/line ratings

3.4 Non-Technical Challenges

Non-technical barriers also inhibit advancements of DER integration with the grid in important ways. Non-technical barriers can exacerbate technical challenges, creating an additional layer of complexity and making the development of solutions more difficult. The most important non-technical challenges identified include the following:

- **Regulations:** Regulatory practices for the smart grid do not properly value DER and limit more widespread integration of DG and storage technologies. More flexible regulatory models that incorporate more than just $/kWh, including innovative rate structures and decoupling, would create greater incentives for broader deployment. Incorporation of societal costs and benefits into rate structures would make DER integration investments significantly more favorable.

- **Policy Coordination:** Lack of policy coordination among entities at the federal level and among states and utilities is creating uncertainty, which inhibits investment and growth. With resources and services that are separately guided by multiple regimes, managing the grid involves navigating a complex patchwork of protocols and policies. Coordination of policy making among stakeholders and regions and flexible regulations that support new technologies can ensure that policies promote development of real solutions.

3.5 Technological and Measurement Challenges

There is a clear gap between the status described by the current state and the future vision for a smart grid integrated with DER. Bridging this gap will require overcoming a range of technical and measurement challenges. It will involve addressing challenges such as developing cost-effective measurement devices and data collection techniques and securely sharing and using the data from demonstrations and in-field installations to better understand and improve system operation. Many of these advancements would be enabled by standard practices and platforms for distribution system-level communication and control.

The challenges identified are listed in Table 3-2. Some challenges would advance the state of grid integration of DER incrementally, while others represent step-change improvements. Those challenges highlighted as high priority are the most critical as they would have the greatest impact if overcome.

Table 3-2: Prioritized Challenges—Technological and Measurement—for Integration of Distributed Generation and Energy Storage with the Grid (● = one vote)

Standards	
Higher Priority	• Insufficient development and incorporation of universal standards, regulation, and price signals that are easily available to DER, such as a coordinated universal regulation ●●●●●● (6) – Developing smart inverter input/output standards that do not stifle innovation – Improving business case to enable greater investment and future deployment of DER
Medium Priority	• Insufficient acceleration of development, promulgation, and adoption of standards for electrical, safety, and communications issues that are associated with DER ●●●●● (5) – Adding new information to existing standards (e.g., extension to 1547) and creation of new standards – Overcoming issues of cost, industry motivation, and time to develop • Incorporating a broadly accepted method to evaluate electric storage with other storage mediums; accepted methods to compare thermal and electric storage are lacking ●●● (3) – Avoiding standards that are too restrictive – Developing standards that increase adoption of energy storage
Lower Priority	• Lack of common data architecture that can inform and facilitate automated or operator action • Insufficient development of comprehensive National Electric Code (NEC) sections for DER in residences; lack of sufficient demand to drive standards development
Secure Communications, Coordination, and Control	
Higher Priority	• Lack of hierarchical control architectures, including new voltage control schemes for distribution circuits for DER (Link, LTC, CAPS, VR to DER) ●●●●●●●● (8) – Limited capability for four-quadrant operation and sensing – Insufficient knowledge base to address the challenge • Lack of secure, reliable communications infrastructure to connect DER to on the utility side; high cost of infrastructure ●●●●●● (6) – Gaining consensus among stakeholders regarding needed infrastructure specifications and the associated standards – Addressing current legacy systems that prevent adoption of new standards
Medium Priority	• Insufficient development and deployment of supportive control infrastructure in the utility system and creation of operations control systems to manage resources on the distribution system ●●●● (4) – Incorporating sensors and real-time communications, which is complex and cost prohibitive on a large scale
Lower Priority	• Insufficient coordination of information and settlement exchange between ISO, utility, aggregator of DER resources and owner of DER resources ●● (2)
Devices and Equipment	
Medium Priority	• Insufficient incorporation of cradle-to-grave life cycle cost accounting in evaluating equipment and devices (e.g., accepted methods for verifying recyclability of components) ●●●●● (5)

Table 3-2: Prioritized Challenges—Technological and Measurement—for Integration of Distributed Generation and Energy Storage with the Grid (● = one vote)	
	• Lack of power electronics to be interfaced to the smart grid to perform grid control functions (not necessarily tied to a solar array, battery, or other component) and enable coordinated control of a broad range of devices ●●● (3) – Advancing power electronics capability for interoperability (e.g., solid state transformers)
Lower Priority	• Lack of inexpensive plug-and-play sensors to relay information on status, power quality, and state of charge ●● (2) • Lack of low-cost metering and telemetry that are scalable to enable DER to meet ISO requirements and facilitate deployment of smaller scale DG installations ●● (2) • Insufficient production of universal, mass-produced distribution system RTU with energy harvest radio and current volt sensors and control output (market issue driven by demand for the product) ● (1) • Lack of low-cost and reliable storage equipment to improve overall system reliability and reduce electric power losses ● (1) • Insufficient reduction of capital and operations and maintenance costs for distribution automation and smart grid systems (reliable and secure), relevant to both devices and systems • Inability to monitor overall power quality and to proactively take action to optimize the system based on reliability and cost effectiveness • Lack of a low-cost method for islanding detection or safe islanding microgrid, currently inhibited by existing standards • Inability to ensure long-term hardware and software reliability, safety, and longevity of smart devices (e.g., for hospitals and medical applications)
Model/Frameworks/Methods	
Higher Priority	• Inability to incorporate data management and analytics for large quantities of data received by new devices and communications methods ●●●●●●● (7) – Collection and analysis of the right type of data (not just massive data sets) • Inability to integrate a scalable framework approach to real-time optimized system operations with DER; creating stability and security underpinnings for multi-agent autonomous distributed operations ●●●●●● (6)
Medium Priority	• Inability to determine the time-dependent value of energy and ancillary services for DER participation decisions and to determine which ancillary services for DER have a business case; includes local aspects unique to each utility/region ●●●● (4) • Lack of accurate load forecast tools for distribution networks in the DER environment (advanced system modeling, real time, annual, seasonal) with communication-enabled source and universal time stamp, for more accurate valuation of DER in the system ●●● (3)
Lower Priority	• Lack of evaluation and comparison of two or more grids via metrics to clearly delineate grids and demonstrate progress toward meeting objectives ● (1) • Inability to determine how DER impacts power quality and power system operation, and understanding of how DER interacts (e.g., understanding properties and characteristics of resources) ● (1) • Lack of measurements and metrics for sensing communications and control to mitigate instability of distribution networks and allow more efficient dispatch of DER • Insufficient understanding of customer behavior with respect to behind-the-meter DER

Table 3-2: Prioritized Challenges—Technological and Measurement—for Integration of Distributed Generation and Energy Storage with the Grid (• = one vote)	
	optimization strategies, including what motivates consumers and predicting behavior responses to reduce uncertainty in forecasting and business models • Lack of holistic solutions-based approaches for integrating DER via decision frameworks that incorporate non-energy benefits as well as energy, technical, and economic benefits of investments in DER
Demonstrations and Data	
Medium Priority	• Limited understanding of best practices utilized by stakeholders affected by and influential in integrating DER; models and frameworks with this information could ultimately improve grid performance ••• (3)
Lower Priority	• Lack of demonstrations on what smart grid can accomplish with variable DG to enhance the knowledge base with real data for informed decisions and accurate models – Developing appropriate control schemes and appropriate standards – Creating standard reporting formats based on defined objectives and known uses of the data • Lack of actual and granular measured data and measurements from sensors at demonstrations and field deployments • Lack of benchmarks for performance and sharing data among the community

3.6 Prioritized Challenges Summary

A number of technical challenges were identified as priority impediments to successful integration of distributed energy and storage. In addition, a non-technical challenge concerning regulatory practices was considered important enough to be addressed as a priority. The priority challenges are summarized below and described in more detail in Figures 3-1 through 3-6.

Regulatory Practices for Smart Grid: Reform of regulatory practices for the smart grid is needed to capture the true long-term cost and value of DER and encourage more widespread integration of DG and storage technologies (Figure 3-1). Understanding how regulation and policy impact DER technology deployment is lacking, particularly as it relates to the smart grid. Data is not available to enable rigorous, quantitative comparison of current or alternative regulatory models and outcomes. At a higher level, data is needed to design, assess, and validate economic models that capture all costs and benefits (e.g., societal, environmental, reliability).

Scalable Real-Time Optimized System Operations with DER: Optimizing system operations while enabling wide-scale penetration of DER presents significant challenges (Figure 3-2). For example, advanced control system architectures for distribution networks that enable real-time awareness need to be developed, implemented, and deployed to facilitate automated or operator responses to optimize the system and allow distributed decision making. Both centralized and distributed control models should be evaluated, with attention to issues of scaling and coordination between clustered assets. Interoperability of sensor and communication technologies across all network layers must be addressed. An associated challenge is security and privacy of data.

Maintaining Load and Resource Balance: Currently, a balancing authority manages load and resource dispatch. This regime does not enable or encourage broad deployment of DER. In addition, there is a lack of accurate models and associated analyses for distribution networks that incorporate DER, and there is generally limited understanding of how to optimize power flows among DERs and loads (Figure 3-3). Because DER power flows can be volatile, maintaining power quality and stability while maximizing efficiency is a significant challenge as DER penetration levels increase. A lack of standardized communication and control protocols is an associated issue that, if overcome, would help address this challenge and many others (Table 3-2).

Hierarchical Distribution-Level Voltage Control: The lack of adequate communication and control between DERs, loads, and utilities is an important factor inhibiting large-scale DER integration (Figure 3-4). The lack of proven control methodologies and supporting tools, noted above, increases the challenge of voltage control as DER integration levels increase. Hierarchical approaches to regulation may provide both benefit/cost efficiency and resilience to failures, improving reliability. Hierarchical architectures, along with low-cost, networked sensors could enable higher DER penetration levels.

Communications Infrastructure for DER: There is no single standard to integrate all devices and all communication functionalities (Figure 3-5). The current system is a mixture of legacy devices and new, advanced technologies. Implementing communication and networking infrastructure for both legacy and advanced technologies is a complex but important issue to address. For example, adaptors that translate information between old and new devices are needed for legacy equipment. Standards and practices are needed for devices that ensure secure communication at a low cost.

Data Management and Analytics for Large Quantities of Data: With the pending deployment of billions of networked sensors, an enormous amount of data is available now, and the data volume will increase exponentially. Mining, analyzing, and managing the data can deliver meaningful and actionable information for model inference and state-based control (Figure 3-6). Data analytics can help inform planners, operators, and business units regarding the value and use of DER, in addition to supporting autonomous control of operations. This issue cuts across many smart grid focus areas and is particularly important for DER integration.

Figure 3-1:

Regulatory Practices for Smart Grid

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Poor understanding of regulation and policy impacts on DER and smart grid technology deployment	Inability to capture outcome data on current or alternative regulatory models	Ineffective economic models to capture all cost and benefits of the smart grid (e.g., societal, environmental, reliability)	Undefined metrics and data for smart grid technology and the inability to compare between metrics

Technologies/Decision Tools to be Developed

• Central repository for education and outreach, plus comparison of methods and rate structures	• Ability to synthesize impact o Observational vs. experimental evaluation, measurement, and verification (EM&V) o Performance metrics	• Appropriate models o Impacts on institutions and other stakeholders o Pricing structure alternatives	• Suitable metrics

Key R&D Activities

• Determine current state-of-the-art by performing a literature search • Create an open, flexible searchable database available to all interested parties	• Determine current state-of-the-art by performing a literature search • Create logic models • Develop a dynamic system model based on data	• Determine current state-of-the-art by performing a literature search • Design a theoretical model • Develop new assessment models to determine success	• Determine current state-of-the-art by performing a literature search • Create comparable metrics for technologies

Performance Targets

• Informed regulatory/policy decisions • Educational tools (Regulation 101) • Reduced barriers to innovation	• Identification and implementation of best practices for flexible regulatory models	• Achievement of appropriate levels of smart grid technology deployment • Accomplishment of sustainable energy delivery	• Universally accessible, consistent, applicable, unified, and comparable metrics for a range of technologies

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Provide data, demonstrations, model validation **National Labs:** Conduct model development and analysis, and literature reviews **Academia:** Conduct literature reviews; model development, and analysis **Trade Organizations:** Provide data and model validation **Standards Organizations:** N/A **Government:** Share data and vet efforts	**Reliability:** Differentiated levels of reliability available **Operation or Installation Cost:** Positive impact **Efficiency/Usability:** Positive impact **System Assurance and Security:** Positive impact **Load or Demand Response:** Positive impact: ability to quantify and track **Other:** Facilitates technology development and innovation	**2013:** Literature search; complete, centralized database **2015:** New models; new metrics; analysis tools; assessment protocols available for testing **2020:** Targets achieved

Figure 3-2:

Scalable Real-Time Optimized System Operations with DER

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Inability to analyze and maintain stability with large penetration DER	Difficulties scaling up centralized model or control approach incorporating large DER penetration and necessary sensing and monitoring technology and synchronization	Difficulties securing data integrity for control and coordination; protecting owner/operator information privacy

Technologies/Decision Tools to be Developed

• Control system architecture that is scalable, reliable, and coordinates distributed decision making	• Analysis of system control architecture for real-time situational awareness • Analysis of system operator response for stability and security	• Identification/determination of value of optimization objectives (e.g., energy, voltage, frequency) • Participation of local decisions in optimized system operation

Key R&D Activities

• Develop analysis tools and methods to support safe, reliable, and affordable distributed optimization (e.g., market-based approach)	• Develop distributed agent models and compare with centralized modeling and control	• Research the stability and security of distributed control approaches and fail-safe rules and operation

Performance Targets

• Cost-effective and scalable, reliable, and safe large-scale DER penetration into the grid	• Increased ease and decreased cost of deployment • Cost-effective, optimized maintenance • Safe, reliable, and robust operations • Proven optimized operation considering multiple objectives	• Performance constraints on behavior of distributed controller and their devices • Standards for behavior of decentralized controllers

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Provide business drivers and performance targets, and demos **National Labs:** Conduct analysis, develop models, methods, and simulations; conduct demonstrations **Academia:** Conduct analysis, models, methods, and simulations **Trade Organizations:** Provide input to performance characteristics and capabilities **Standards Organizations:** Standardize electric and IT interfaces; capture best practices and targets **Government:** Facilitate stakeholder coordination	**Reliability:** More robust, higher availability **Operation or Installation Cost:** Ease of installation, integration in system **Efficiency/Usability:** Less coordination with decentralized approaches **System Assurance and Security:** Less information exchange; fail-safe operations **Load or Demand Response:** Incorporates optimized operations with DR **Other:** Framework for multi-party coordination	**2014**: Architecture approaches **2015:** Analysis methods, tools, and simulations; acceleration of standards development **2016:** Demonstration/education to policy makers; simulation and calibration

Figure 3-3:

Maintaining Load and Resource Balance

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Current balancing authority based paradigm inadequate for DER	Poor knowledge about how to determine load/resource balance with DER operating	Inconsistent communications formats and methods

Technologies/Decision Tools to be Developed

• Modeling and analysis of current methods and DER application	• Comprehensive grid model of load resource balancing	• Comprehensive hardware and software that enable a communications path

Key R&D Activities

• Categorize DER by their common performance attributes • Evaluate various architectures of load and resource measurement	• Develop system modeling and control technologies • Evaluate the effect of market forces (i.e., price) versus engineering optimization	• Perform a comparative analysis of alternatives, including field demonstrations

Performance Targets

• DER categories of load (DR) ramp rates, and generation ramp rates • Coordinated universal regulation • Complete balance of load/resource	• Modified model that includes any number, size, and type of load and resource	• Creation of easily accessible, universal standards for regulation (load and resource balance) and price signals

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Conduct real-world evaluations; provide funding; provide open access to data **National Labs:** Conduct testing and demonstrations **Academia:** Carry out modeling and optimization research **Trade Organizations:** Communicate and promote the concept **Standards Organizations:** Evaluate best practices and develop the standard **Government:** Support research and demonstrations	**Reliability:** Improves reliability, drastically **Operation or Installation Cost:** Decreases operation cost due to automation **Efficiency/Usability:** Increases effectiveness of DER **System Assurance and Security:** Increases focus on security; will drive cyber security improvements **Load or Demand Response:** Improves load and resource balancing **Other:** Reduces greenhouse gases; may offset large capital expenses in traditional generation	**2013:** Becomes major research area **2014:** Demonstrations begin **2016:** Evaluations completed and best practices determined **2020:** Adaption begins in niche market **2030:** Widespread adaption

Figure 3-4:

Hierarchical Distribution-Level Voltage Control

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barriers
Lack of standardized object models and control methodologies for all devices	Sensors too expensive for use at multiple points; slow response speed of voltage regulation devices; inadequate communication speed to hierarchical control system	Lack of coordinated, adaptable distributed controls; limited engineering design tools to predict impacts of system changes

Technologies/Decision Tools to be Developed

• Standardized object models for all components (e.g., hardware and controller) • Novel, widely accepted control methodologies that account for DER characteristics	• Low-cost sensors with standardized communication interface • High-speed communication infrastructure and low latency communication • Higher speed voltage regulation devices	• Devices that support all control methodologies noted above • Tools that maximize the DER benefits in the context of voltage control

Key R&D Activities

- Define future objectives and parameters for voltage regulation
- Develop voltage regulation infrastructure that meets the stated technology requirements, starting with a vision for hierarchical control

Performance Targets

- Maintenance of a specified nominal voltage within a specified tolerance range

Stakeholders and Roles	Potential Impacts	Milestones
None provided	None Provided	None provided

Figure 3-5:

Communications Infrastructure for DER

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
No universal standard for device interfacing (i.e., requires full use of IEC 61850 and mappings)	Uncertainty in implementation of new standards and technologies in legacy systems	Lack of secure, reliable, "utility grade" communication hardware and infrastructure at economical cost
Technologies/Decision Tools to be Developed		
• Hardware that utilizes current communication standards and mappings	• Adaptors for legacy systems	• Defined cost targets • Redesigned system that is secure, hardened, and either wireless, power-line carrier (PLC), or fiber based
Key R&D Activities		
• Develop hardware that incorporates all the communications functionality	• Design adaptors that translate information while maintaining security	• Create high-bandwidth PLC • Design hyper-secure wireless
Performance Targets		
• Utilization of a standard communication protocol by all devices in a utility run, hierarchical controlled, plug-and-play environment that manages system operations and markets	• Guaranteed security on connecting legacy systems through the translation between devices	• Definition of current cost needs • Map to show level of cost reduction related to service

Stakeholders and Roles	Potential Impacts	Milestones
Industry: (Device manufacturers, utilities): Prototype development; pilot/deployment projects **National Labs:** Testing communication protocol including cyber security aspects **Academia:** Developing education around new technologies; research linked to industry (internships) **Trade Organizations:** (EPRI, NEMA): Coordinate disparate set of players: help make sure R&D aligns with industry needs **Standards Organizations:** (IEEE, IEC): Build standards **Government:** Coordination of standards; programmatic support	**Reliability:** Increase reliability by allowing disparate systems to work together **Operation or Installation Cost:** Initial increase in capital costs; may decrease operations cost **Efficiency/Usability:** Increases by reducing system losses **System Assurance and Security:** Increased security (if implemented appropriately) **Load or Demand Response:** Easier access to demand controls	**2015:** Demonstration of standard communications protocols and advances in communications hardware **2017:** Secure connection of legacy systems demonstrated via device translation

Figure 3-6:

Data Management and Analytics for Large Quantities of Data

Technology/Measurement Barrier

Difficulty managing and deriving value from large volumes of data (e.g., AM1, 200 billion sensors, 8,000 sensors in the home) with existing systems that are designed for small data volumes

Technologies/Decision Tools to be Developed

- Data concentration and consolidation without losing trends, statistics, and context
- New methods for data application and utilization that incorporate the following:
  - Visualization tools (user interface)
  - Data navigation (user interface)
  - Context application
  - Relational data building
  - Advanced searching

Key R&D Activities

- Develop new methods to improve predictive capability from historical data
- Partner with bulk data management companies (e.g., IBM, Google, Oracle) to define industry problem and requirements

Performance Targets

- Latency targets appropriate to the need of the consumer of data
- New class of sensor data available to planners, operations, and business units as a resource

Stakeholders and Roles

Industry: Provide historical and real time data

National Labs: Determine how to mine and transform data

Academia: Determine how to mine and transform data

Trade Organizations: Utilize data

Standards Organizations: Conduct uniform analysis for data consistency, data quality

Government: Provide program support; provide an application of information for development of better policies and regulations

Potential Impacts

Reliability: Quality of operations and performance

Operation or Installation Cost: Better decisions, improved value of deployments—less waste

Efficiency/Usability: Reduce loss, optimize operations; better asset utilization

System Assurance and Security: Improved analytical tools to reduce risk

Load or Demand Response: Better management and predictability of load

Other: Improved credibility based on new verified data

Milestones

2013: Requirements developed

2014: Data collected; development of industry data context

2015: Visualization tools

2016: Predictive algorithms

2020: Value of data realized

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4

Energy Efficiency, Demand Response, and Load Control

4.1 Overview

Energy efficiency is not simply using less energy, but using energy in a smarter, optimized way. Information technology is allowing customers to make better decisions, and two-way technology communication is changing the way customers use energy. The supply side and the customer side of the meter are mutually significant when considering energy efficiency (EE), DR, and load control (LC) implications of the smart grid. The variance in load type is also an important consideration. The fundamental load types impacting energy efficiency, DR, and load control of the smart grid include residential, commercial, industrial, agricultural, and plug-in electric vehicles.

For EE, DR, and LC to be effective in the future, five key interest areas need to be addressed:

1. Market value and regulatory structure of EE, DR, and LC: How is DR positioned in the market? What technical advancements are needed to unlock ancillary services?
2. Momentum of technology/cultural shift: Utilities are advancing quickly but is adoption keeping pace and considering public attitudes toward smart meters?
3. Modeling and systems planning approach: There are multiple sources for measuring energy efficiency in demand-side management, how can this be captured?
4. Measurement of energy efficiency in deemed savings: Is there a common format for determining energy savings of measures underway? Is the assumed energy efficiency real, will it persist, and do sufficient base-lining and interval energy usage measurements exist to verify it?
5. Information ecosystem and communications: How do they impact EE, DR, and LC?

Examples of important topics which involve EE, DR, and LC include the following:

- Smart meters with advanced metering infrastructure (AMI) two-way communications
- Integration of AMI into distribution operations
  - Advanced load models
  - Outage detection and location
  - Customer response characteristics
  - Meter data management systems (MDMS)
- DR as part of distribution operations
- Demand response management systems (DRMS)
- Home energy management systems (HEMS)
- Facility/community energy management systems
- Electric vehicles (EVs), smart charging
- In-home enabling technology (programmable communicating thermostats [PCTs], smart appliances, energy manager)
- Incorporating EE, DR, electric transportation, and other concepts into distribution planning (e.g., advanced models)

4.2 Current State

The smart grid has started exploration into real-time pricing, real DR, demand bidding, and a tapestry of consumer response programs. The market for these programs today is fragmented, and the lack of a clear vision for policy and technology makes it unclear which direction the smart grid will take. Regulators do support and promote energy efficiency but sometimes the future development, applications, and impacts of technologies are not entirely understood. Below is a summary of the current state of technologies and practices in key areas important to EE, DR, and LC.

Consumer Data and Operations: Improvements in information technology (IT) are allowing residential customers to make better decisions and change the way they use energy. Customers have the ability to access their energy consumption on an hourly or at least daily basis. A tapestry of consumer response programs exist that offer real-time pricing, real DR, and demand bidding. Utilities and ISOs have a tendency to think of AMI as a gateway for customer intelligence and information; while there is control up to the residential meter and growing interest in reliability meters for EE and DR, there are other approaches that are not based on AMI as a gateway. There is also a lack of DR-ready products that consumers can easily buy and equipment retrofits are now commonly needed to enable DR.

Demand Response: The interest of both utilities and ISO in DR is increasing and ancillary services are being provided for DR. Increased interest in DR by the ISO market has been in part driven by a positive regulatory approach by the Federal Energy Regulatory Commission (FERC). DR is being considered for its potential to meet flexible capacity and capability needs for renewable integration. DR is becoming less centralized and there are a multitude of DR systems; new technologies such as EVs will make the DR infrastructure more diverse. There are different needs and impacts for DR in generation and transmission as opposed to distribution. Some technologies are available, but the programs, policies, and integration abilities are lacking. Demand-side resources are increasingly looked at for more than just peak shaving (e.g., for regulation, balance).

Non-Utility Solutions for Energy Management: The largest growth in energy management is in non-utility solutions. Thus, energy management and the definition of the smart grid are being driven not by utilities but by non-utilities such as security, communications, and internet companies. Traditionally, devices have been delivered inside the meter via the utility channel, but there is also a growing interest in trade and retail channels as consumers adopt smart-grid-related devices.

Electricity aggregation: This concept is gaining acceptance particularly in municipalities. Electricity aggregators bundle customers together (e.g., residential and small business electricity customers) and then negotiate with smaller suppliers to get the best possible rate. The objective is buying in bulk at cheaper prices.

Market Fragmentation: The marketplace is very fragmented, especially regarding technology and regulations. There are 3,200 utility companies operating under more than 50 regulatory bodies and rate structures. The lack of a common policy vision between utilities and ISOs for the smart grid and residential sector in particular has led to manufacturers having to address many different solutions. Current utility and ISO requirements are heterogeneous, thus making broad applicability of devices a challenge. No two utilities have the same solution and devices must be able to be integrated into unique systems.

Lack of Vision for Demand Response: The lack of policy vision and direction has also led to a crossroads concerning whether DR should be supply side or demand side in the future. The supply side is dispatchable, meaning that an end user contracts with a provider, a signal is sent, the load is dispatched, and payment is received. The demand side uses pricing rules rather than dispatching tools to realize the same outcome and many smart grid technologies support demand side. Some technologies can handle both supply and demand side; additional modifications in regulatory policies may be needed to take full advantage of this.

Electricity Pricing and Uncertainty: The drop in electricity prices de-emphasizes the use of DR and dynamic pricing. The uncertainty in payback due to low prices makes for a difficult planning environment for businesses that are focused on DR. This also causes uncertainty in investment. Electricity prices are also tied to fuel availability, particularly natural gas, as it is often used in peak demand units. Wholesale electricity prices for commercial and industrial customers are generally reduced; large commercial buildings are migrating toward fixed price contracts as opposed to real-time pricing because they are looking for greater certainty and to hedge risk.

Software Applications: Open automated demand response (ADR) is the standard for provisioning, but there are many types of software (distributed by retail-oriented companies) that provide DR management systems. There is an increase in specific software applications with capabilities that help utilities with activities such as base lining, forecasting DR resources, optimizing dispatch resources, measurement and verification (M&V), and billing/settlement.

Optimization Trends: An increase in localized optimization is the current trend for DR, and DR is also being considered for distributed optimization. Regional transmission operators (RTOs) and ISOs are also offering trends in the integration of localized control while trying to bridge the gap between localized and centralized control. Voltage optimization for EE is starting to interact with load reducing voltage production schemes that were previously in place.

Electric Transportation: The low cost of electricity means that operating an EV is a good deal when compared to a traditional car that runs on gasoline (at nearly $4 a gallon). Yet this could potentially cause problems as it is difficult to structure a rate that would deter people from charging their vehicle during peak demand periods. Also, EVs pose a challenge for utilities because it is a mobile load. They may operate in one service territory today and another tomorrow.

Storage: The potential of storage has barely been investigated in terms of controlling energy resources and storage is still too expensive.

Energy Efficiency: Many state energy efficiency requirements/standards currently exist; for utilities, EE may be a state or federal standard. The strategy of the sector is shifting from mass market to the commercial sector and integrated buildings as they are backing away from robust energy management. Many opportunities for energy efficiency in the commercial sector are currently available.

Load Control: There are many legacy programs for load control. Current technology often involves one-way communication, but there is a trend toward considering two-way communication beyond just the load signal.

4.3 Future Goals and Capabilities

In the future, the consumer will be more engaged in the smart grid and consumer behavior will be better understood. An automated approach with devices that are simple to program will enable increased consumer participation. There are two different types of possible distribution markets: one will change the way the consumer buys and the other involves selling a service. Table 4-1 lists the identified goals and capabilities of the smart grid related to EE, DR, and LC.

Table 4-1: Future Goals and Capabilities to Support Energy Efficiency, Demand Response, and Load Control

Understanding/Influencing Customer Behavior

- Full consumer engagement; benefits to the consumer are clearly defined; customer engagement is simplified by use of an automated approach with uncomplicated programming
- Measurable, sustainable energy efficient consumer behavior
- Behavioral science and techniques integrated to encourage efficiency in residences and increase customer caring, enthusiasm, and participation

Planning, Operations, and Integration

- More granular forecasts by customer type or sector
- Power quality data from AMI and smart devices integrated into distribution and systems planning for energy efficiency
- Wholesale grid conditions connected to consumers and their device response
- Integrated optimization (with many devices) balance integration with the circuits themselves; use of discrete algorithms optimize both the circuit and the system
- Smart end-use devices are default products from manufacturers
- Standardized energy platform structure where applications can run as a single platform and external application programming is allowed, ranging from home area networks to distribution control (e.g., enterprise service bus)

Measurement/Analytics

- Consistent approach to base lining and M&V for EE and DR
- Improved analytics based on meter data (e.g., weather-stripping measurement, insulation measurement)
- Integration of behavioral science and techniques to enable efficiency in residences and increase customer interest, enthusiasm, and participation

Automated Optimization

- Automated local cost-reducing decisions (ideally designed to minimize effect on end user)
- Automated local optimization in commercial buildings without occupant interaction; systems recognize what needs to be done

Storage

- Cost-effective energy storage
- Capital, operations, and maintenance costs that are effective and competitive for energy storage
- Energy efficiency and DR mimic energy storage
- Improved, less-expensive alternatives to battery storage, including electric thermal storage (ETS), compressed air energy storage, superconducting magnetic energy storage (SCMS)

Market Dynamics

- Two different types of possible supply models for a given territory:
  - Supply model A: Open market for EE, DR, LC, and end use where consumers can bid into DR through an auction; ISO looks at dispatchability and energy, capacity, and reserves markets
  - Supply model B: Vertically integrated, dispatchable DR, load control, and electric transportation services (automated) on the supply side where the utility issues a signal and the device responds
- Open market access to the distribution network and utility asset ownership behind the customer side of the meter (e.g., retail competition)
- Wholesale market participation in DR, with flexible capabilities
  - Regulatory treatment for EE and DR investment, equivalent to supply-side model

Table 4-1: Future Goals and Capabilities to Support Energy Efficiency, Demand Response, and Load Control
• Quantified policy choices and benefits to help inform and educate policy makers • Whole home as a DR resource that can bid in open markets – Home energy manager responds to utility's DR signal – Price signal vs. demand load control (DLC) and DR (supply side vs. demand)
Electric Vehicles
• More plug-in hybrids and smart changing stations (both public and workplace locations) • Increased EV penetration into the market due to reduced cost • Vehicle charging algorithms are available to facilitate DR integration

4.4 Non-Technical Challenges

While the focus is on the technological and measurement barriers to achieving improved EE, DR, and LC of the grid, there are also a number of non-technical challenges. These are linked to three key areas: market value and regulatory structure, momentum of technology/cultural shift, and information ecosystem and communications. Non-technical challenges include the following:

Lack of Message for Engagement: A uniform, simple message is lacking for why electric utilities and the industry as a whole are engaging customers and calling for a response.

Resistance to Smart Meters: Some communities are not embracing the use of smart meters and in some cases are banning them. This is a major limitation to the installation of smart meters and their benefits. Without smart meters, consumers will have limited understanding of their energy usage, and utilities will be unable to gather sufficient data on energy consumption.

Business Case: For a company to make a strong business case, information from several places must be brought together, which can be difficult because of the information silo boundary among the many diverse smart grid stakeholders. Organizational information silos can also lead to missed opportunities for improved operational efficiencies.

Industry Culture: Utilities often are not focused on innovation and operational improvements, which is a cultural problem. Innovation must also be part of the business culture and organizational design, as this will encourage deployment of advanced technologies. The utility industry by nature is historically conservative in deploying new technology.

Lack of Acceptance of Experimental Results: Utilities and other companies often view the experimental results of other companies with skepticism. Often they will not accept results as applicable to them and perform the experiment and gather data themselves. This prevents utilities and companies from being able to learn from each other without reproducing results.

4.5 Technological and Measurement Challenges

Many challenges exist in improving EE, DR, and LC of the future grid. The technical and measurement challenges are closely connected to two key areas: (i) modeling and systems planning and (ii) measurement of energy efficiency savings. Modeling, measurement, data availability, and creating baselines are key challenges facing the industry. Although real-time and backhaul energy data is increasingly available, it is the interpretation, application, and availability of the data that presents a real challenge. The challenges identified are listed in Table 4-2. The challenges defined as high priority are the most critical and would have the greatest impact if overcome.

Table 4-2: Prioritized Challenges—Technological and Measurement—for Energy Efficiency, Demand Response, and Load Control (● = one vote)

Customer/Behavior	
Higher Priority	• Lack of robust modeling, analysis, and valuation related to residential price elasticity of demand ●●●●●●● (7) – Inadequate understanding of how to structure dynamic/variable tariffs – Unwillingness to handle peak price increases – Inability to deal with greater complexity
Medium Priority	• Inability to measure and aggregate customer-sited electrical and thermal energy storage ●●●●● (5)
Planning/Architecture	
Higher Priority	• Difficulty in determining the appropriateness of distribution-level operations data for customer program implementation ●●●●●●●●●●●●● (13) – Difficulty in determining what data to collect, who will use it, and what it will be used for – Inability to ensure real-time, reliable visibility of transmission operator to DERs – Lack of visibility (i.e., real-time measurement) of non-generation resources (e.g., DR, EVs, storage) for wholesale market participation (e.g., metering, telemetry) due to a lack of market structure – SCADA intelligence not linked to energy efficiency, DR, and load control programs – Poor visibility of distribution grid operational constraints (i.e., feeder/sub-station level) – Lack of nodal prices (or value) for most of the distribution grid network o Balance, workability, and resolution of information that is provided on the local basis o No reference on whether a value is good or bad or how it compares to other locales • Lack of a framework for relating objectives for DR to requirements, technology enablers ●●●●●●●●● (9)
Medium Priority	• Utilities not accounting for energy efficiency and DR in capacity planning ●●●● (4)
Lower Priority	• Historic view of technology as a means to an end to build generation and not as a standalone value producer (e.g., vertically integrated investor-owned utility perception) • Mismatch in technology lifecycle and expected asset/program duration • Trend toward local control leading to de facto systems that can be difficult to integrate at a large scale
Measurement/Analytics	
Higher Priority	• Lack of standard way to establish a baseline that is consistent across utilities and markets; current M&V lacks credibility and achieving acceptance of new methods is a challenge ●●●●●●●●●● (10)
Lower Priority	• Difficulty determining what to measure, how much should be measured, and how accurately it should be measured ● (1) • Data from smart meters that is not available until the next day for variable generation response, although millions of meters exist ● (1) – Data is not readily available outside the utility – Problems with legacy systems • Lack of an overarching system responsible for measuring and verifying customer DR and

Table 4-2: Prioritized Challenges—Technological and Measurement—for Energy Efficiency, Demand Response, and Load Control (• = one vote)	
	energy efficiency measures and for generating meaningful reports to monitor their activities and resources • Difficulty differentiating between load type or supply side (e.g., carbon footprint) – Limited technologies to disaggregate load • Narrow definitions of energy efficiency
Automated Optimization	
Lower Priority	• Lack of an economically viable, dependable communication path that enables smart devices at the end of the line
Storage	
Lower Priority	• Inconsistent or absent ownership precedent of customer premise energy storage systems, akin to solar programs •• (2) • Lack of metering/measure of direct current power (e.g., PV to EV); sale of direct current power precluded in California • (1) • Non-uniform reporting methods for customer-owned storage capabilities • Discounting thermal mass of buildings as an inexpensive storage medium • Deficient methods for capturing energy storage bundling opportunities • Difficulty determining the optimal location for energy storage
Market Dynamics	
Medium Priority	• Lack of a blueprint for alternative distribution models for energy efficiency and DR (e.g., retail, trade, online, security, internet) ••• (3) – Difficulty in determining options other than direct installation – Difficulty in identifying incentives and stakeholders
Lower Priority	• Lack of clear and concise knowledge of who is accountable for delivering value proposition • Current excess capacity reduces value of load control

4.6 Prioritized Challenges Summary

Based on working group participant voting, several of the identified technical challenges were deemed priority impediments to successful utilization of EE, DR, and LC. These priority challenges are summarized below and in more detail in Figures 4-1 through 4-4.

Distribution-Level Operations Data for Customer Program Implementation: The lack of real-time measurement and visibility of non-generation resources is partially due to the lack of a market structure that is able to react to a response. Incentives are lacking to provide visibility down to the distribution level (Figure 4-1). Data best practices for distribution-level instruments and systems are lacking; it is necessary to determine what types of data should be collected, who will be able to use the data, and for what purposes the data will be used. The appropriate stakeholders should be provided with visibility of data as well as the necessary level of data access in order to implement customer programs. Also, the role of energy efficiency and DR in reliability functions must be fully formed.

Robust Modeling, Analysis, and Valuation Related to Residential Price Elasticity of Demand: There are two main barriers for modeling, analysis, and valuation for residential price elasticity of demand (Figure 4-2): (i) a lack of consistent probabilistic modeling methods for load forecasting under dynamic pricing (which is currently not fully understood) and (ii) the reluctance to accept results from models that draw from external studies. It is necessary to develop a universal method to characterize the load profile for a given service area to overcome these barriers. A universal model along with a methodology that can utilize a utility's unique characteristics to project load profiles will help utilities with their system and resource planning and support decision making under conditions of uncertainty.

Standard Baseline Methodology for All Utilities and Markets: Current methodologies for evaluation, measurement, and verification (EM&V) for energy efficiency, DR, and DLC vary across proponents, markets, organizations, and regulatory bodies and thus lack consistency and credibility (Figure 4-3). The present methods must be analyzed and further developed in order to determine the most appropriate EM&V technologies to utilize. To overcome this challenge, there must eventually be a protocol framework established to help determine the best methodology for EM&V. Also, the baseline method that is developed needs to be widely accepted to be effective and used across the nation.

Framework to Relate Demand Response Objectives to Requirements: No clear unified view or consolidated framework is available that enables the mapping of DR capabilities to the specific DR business needs of utilities and grid operators (Figure 4-4). The barriers of DR need to be better defined to help inform and guide policy. DERs such as storage and DER for various customer sectors also lack the necessary technical capabilities. It is necessary to develop more technologies that can meet business needs and to improve and optimize the dispatch of DR and DER to meet business requirements.

Figure 4-1:

Distribution-Level Operations Data for Customer Program Implementation

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Non-uniform data measurement methods leading to poor distribution level visibility; Non-uniform regulatory standard for distribution operations to feed EE/DR/LC programs	Insufficient data best practices for distribution level instruments or systems (e.g., determining data collection accuracy, frequency, and quantity)	Inconsistent framework for the justification of EE/DR and storage

Technologies/Decision Tools to be Developed

• Low-cost, intelligent sensors integrated into measurement methods • Aggregated sensor data at multiple levels of granularity that is useful to stakeholders	• Assessment of appropriate technologies for measurement practices • Measurement requirements tied to new needs	• Specifications for measurement and instrumentation systems that will provide input to control methodologies for EE/DR

Key R&D Activities

• Pilot regulatory scenarios (both simulation and in-field) for data measurement methods which drive EE/DR algorithms	• Model distribution system to determine key "trouble points" • Determine relevance of measurements and data to various stakeholders	• Identify performance objectives and criteria (POC) including performance targets and the formal EE/DR role in reliability

Performance Targets

• Cost-effectiveness targets • Consistent visibility of data methods available to appropriate EE/DR stakeholders • Determination of appropriate stakeholders and level of data access for implementation of programs	• Data best practices for distribution-level instruments or systems	• Fully formed EE/DR role in reliability function

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Collaborate with all other stakeholders **National Labs:** Continue legacy roles in situational awareness (LBNL, PNNL) **Academia:** Open ADR-LBNL **Trade Organizations:** Consolidate industry needs and perspectives **Standards Organizations:** Develop best practice principles and guide industry toward standards development **Government:** Evaluate revisions to policies which potentiate development and implementation	**Reliability:** New options created for the use of provision in reliability **Operation or Installation Cost:** Reduced; options provided for cost reduction **Efficiency/Usability:** FOCAL **System Assurance and Security:** Uniform environment assured for the development of systems/programs **Load or Demand Response:** FOCAL **Other:** N/A	**2013:** Baseline/scoping study to determine existing practices and gaps; define needs and architectures **2014:** Create scenarios; perform simulations during Q1 and Q2 and pilots and field trials during Q3 and Q4 **2015:** Evaluate trials; develop best practice recommendations **2016:** Reduce best practices to standards **2017:** Implement

Figure 4-2:

Robust Modeling, Analysis, and Valuation Related to Residential Price Elasticity of Demand

Technology/Measurement Barrier	Technology/Measurement Barrier
Inconsistent probabilistic modeling techniques for load forecasting under conditions of dynamic pricing (e.g., quantifying uncertainty)	Unacceptable modeling results using external studies

Technologies/Decision Tools to be Developed

• Incremental improvements of probabilistic modeling for load forecasting under conditions of dynamic pricing	• Incremental improvements to methodologies to project/forecast load profiles based on a utility's unique characteristics (e.g., climate, historical load, demographics)

Key R&D Activities

• Integrate existing bodies of research on dynamic pricing/customer response into a universal model with broad applicability	• Apply the universal model mentioned on the left to specific planning scenarios that incorporate local data and account for associated uncertainties to provide a distribution of expected outcomes

Performance Targets

• Standardized model for characterizing expected load profile in a given territory/service area under conditions of dynamic pricing	• Utilization of outcomes from research for system/resource planning purposes • Support framework for decision making under uncertainty

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Provide data on previous pilots/programs; steering committee engagement; adopt model for system planning **National Labs:** Support model development **Academia:** Support model development **Trade Organizations:** Participate in steering committee; provide guidance on adoption of model for system planning **Standards Organizations:** Support model development (certification) **Government:** Convene steering committee; oversee/direct adoption of model in system/resource planning efforts (integrated resource plan, etc.)	**Reliability:** Greater confidence in the use of price response demand in system planning **Operation or Installation Cost:** Better matching of strategy with desired outcome **Efficiency/Usability:** N/A **System Assurance and Security:** Greater confidence in the use of price response demand in system planning **Load or Demand Response:** Increased understanding of resulting load profile **Other:** N/A	**2013:** Establish steering committee to guide development; gather results from previous studies; develop universal model framework **2014:** Populate and test model; present to steering committee for validation/approval **2014-15:** Steering committee approval for publication **2015:** Incorporate into system planning initiatives

Figure 4-3:

Standard Baseline Methodology for All Utilities and Markets

Technology/Measurement Barrier (EE)	Technology/Measurement Barrier (DR/DLC)
Inconsistent EM&V methodologies for EE (conservation voltage regulation/dynamic voltage regulation) across proponents (e.g., California ISO, Bonneville Power Administration [BPA]), markets, organizations, and regulatory bodies	Inconsistent EM&V methodologies for DR/DLC across proponents (e.g., California ISO, BPA), markets, organizations, and regulatory bodies

Technologies/Decision Tools to be Developed

- EM&V methodologies for EE that are broadly deployed and accepted
- Analysis and development of present methods including econometrics, behavioral science, simulation modeling, field instrumentation, spot measurement, continuous power measurement, calibrated simulation model, and billing analysis

- EM&V methodologies for demand response/demand load control that are broadly deployed and accepted
- Analysis and development of present methods including econometrics, behavioral science, simulation modeling, field instrumentation, spot measurement, continuous power measurement, calibrated simulation model, and billing analysis)

Key R&D Activities

- Identify and categorize resource characteristics that are critical to determining the appropriate EM&V methodologies, where appropriateness is based on a balance of accuracy, precision, and cost
- Identify and categorize data sources (e.g., SCADA, AMI, register) and how to use them in EM&V

- Identify and categorize resource characteristics that are critical to determining the appropriate EM&V methodologies, where appropriateness is based on a balance of accuracy, precision, and cost
- Identify and categorize data sources (e.g., SCADA, AMI) and how to use them in EM&V

Performance Targets

- Development of a protocol framework that is capable of determining the best EM&V methodology for EE based on resource and system attributes

- Development of a protocol framework that is capable of determining the best EM&V methodology for DR/DLC based on resource and system attributes

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Identify data sources; collaborate on methodology development **National Labs:** Provide proving grounds and technical expertise **Academia:** Provide proving grounds; verify results **Trade Organizations:** Recruit participants/resource pool **Standards Organizations:** Act as convener **Government:** Act as convener; provide program support	**Reliability:** Greater confidence in EE/DR from wholesale to distribution **Operation or Installation Cost:** Optimization of existing assets; better understanding of ROI **Efficiency/Usability:** Automated implementations of EM&V; more efficient identification of proper methodology **System Assurance and Security:** Minimal impact **Load or Demand Response:** Lead to greater adoption of programs and reduced volatility of investment **Other:** N/A	**2013:** Convene working group and begin identifying categories and appropriate methodologies and data points involved **2014:** Begin developing standards **2015:** Publish protocol framework; piloting of output, review **2016:** Obtain DOE and/or American National Standards Institute approval/certification; achieve broad industry acceptance **2016+:** Implementation and revision

Figure 4-4:

Framework to Relate Demand Response Objectives to Requirements

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Unclear DR business and customer needs; nonexistent DR taxonomy and technical capabilities (e.g., loads, DER, storage) by customer sector	Inability to map DR capabilities to specific DR business needs of utilities and grid operators (e.g., by loads, DER, storage, PV, personal/plug-in electric vehicle)	Lack of framework to inform policy by identifying DR barriers and additional requirements to fill gaps in system capabilities (e.g., transmission and distribution [T&D])

Technologies/Decision Tools to be Developed

• DR taxonomy • List of DR business and customer needs	• Incremental improvements in the consolidated framework to map DR capabilities and business needs	• Identification of DR barriers and requirements

Key R&D Activities

- Identify and consolidate relevant frameworks/resources
- Build a model using elements of the framework, including additional variables for utility/operator geography and customer differences; understand how to customize models for specific utility/operator needs
- Develop a requirements document for tools that can be developed by third parties to complete smart dispatch of DER/DR

Performance Targets

• Understanding of complete spectrum of DR business and customer needs	• Development of additional technologies that meet business needs • Improved/optimized dispatch of DER/DR to satisfy business requirements	• Established framework for informing policy and connecting barriers and requirements

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Vendors/utilities – work towards Research Activity III **National Labs:** Perform research; work towards Research Activities I and II **Academia/Research Institutes (e.g., EPRI):** Perform research; work towards Research Activities I and II **Trade Organizations:** N/A **Standards Organizations:** N/A **Government:** N/A	**Reliability:** Will be affected **Operation or Installation Cost:** Operation will be affected **Efficiency/Usability:** Will be affected **System Assurance and Security:** N/A **Load or Demand Response:** Will be affected **Other:** N/A	**2013:** End-to-end framework completed **2014-15:** Model to support framework, customized to operator and utility requirements **2016+:** Completion of requirements documents for tools for smart dispatch

5 EFFICIENCY, RELIABILITY, SECURITY, AND STABILITY OF THE GRID

5.1 Overview

The future electricity grid will look very different from today's power system. Large variable renewable energy sources will provide a greater portion of electricity, small DERs and energy storage systems will become more common, and utilities will operate many different kinds of energy efficiency and DR programs. All of these changes will add complexity to the grid and require operators to be able to respond to fast dynamic changes to maintain system stability and security. Thus, comprehensive grid models and system operator tools must be developed and must be able to fully utilize the vast amounts of data being generated by the new technologies and devices being deployed.

To develop the methods and tools needed to maintain the stability and security of the future grid, there must be agreement on the metrics and system measurements used to evaluate and manage the grid. Comprehensive system models that incorporate new technologies and devices need to be developed and validated, and models need to be turned into useful operator tools. For a successful transition to a stable and secure smart grid, numerous non-technical challenges related to policies, regulations, standards, workforce issues, and public education need to be addressed as well.

Important issues regarding grid efficiency, reliability, security, and stability include the following:

- Next generation operational tools
- New, high-speed communications networks to handle increased communications and controls
- Advanced voltage control with DERs, DR, storage, and other components
- Large-scale system modeling and analysis for real-time operations and planning
- Advanced customer business models and DERs incorporated into system operations
- New architectures for DEMS and integration with energy management systems
- Advanced protection schemes that extend current RAS/special protection systems (SPS)
- Closed loop control (taking the operator out of the loop) Advanced sensors and visibility of asset condition
- Distributed intelligence for increased control actions downstream of the control centerDR being used for system reliability and security Workforce issues, including retirements and operator training

5.2 Current State

Different aspects of smart grid technology development and deployment have progressed at varying speeds, resulting in an electric grid made up of both new and old technologies. Once installed, these technologies become legacy equipment. As new, advanced applications and devices are still being developed, it is not clear how these technologies will be integrated with legacy equipment that is a hybrid of old and new technologies. Currently, the regulatory framework, policies, and utility models have not kept pace with the development of new technologies and integration with legacy systems can be problematic.

Technologies and Deployment: While smart grid technologies are being deployed across the country at different rates, smart grid projects and their evaluation are predominantly local in nature, rather than regional. ARRA funding has provided a significant boost to deployment activities. Significant smart meter penetration has enabled a number of different applications; however, not all of these capabilities are being used. Following is an overview of these applications:

- DR applications are being deployed, but they are used to manage peak demand rather than reliability concerns.
- In the distribution system, SCADA monitoring is now ubiquitous, but there are vulnerability and cyber concerns with these networks.
- Deployment of more advanced distribution automation technologies has started, but covers only a small portion of the distribution system at this time.
- New distribution automation applications, such as feeder automation and advanced Volt/VAR control, are being deployed in only a small number of systems.
- While syncrophasor technology is becoming an off-the-shelf technology and its deployment in the transmission system is well underway due to ARRA funding, applications, which need to be designed and demonstrated for optimal interaction with grid operators, are not fully utilizing this data.

There have been advances in other grid technologies, such as microgrids, but their deployment has been lagging.

Cyber Security: While a number of frameworks exist for cyber security, rules vary between different operators, utilities, and regions. NERC, a non-governmental standards organization, supports the Critical Infrastructure Protection Program, and some states have their own regulatory requirements. Other agencies involved with promulgating or developing requirements for cyber security for the grid include the Department of Homeland Security (DHS), Department of Energy (DOE), FERC, and NIST. Organizations receiving ARRA funding for smart grid projects are also required to implement cyber security. In some instances, cyber security concerns are preventing organizations from fully utilizing the capabilities of new smart grid technologies.

Data Management: More and more data is becoming available to system operators as more technologies are being deployed. Better modeling, simulation, and analysis tools are being developed, but much work remains to be done in this area. Grid measurement data and other information sources are becoming available, but are not fully utilized. Solutions for data overload and processing of smart grid data are being pursued, but there is less concern for communication network demands.

Aging Assets and Workforce: Transmission and distribution system assets generally have a very long useful life. As new smart grid technologies are deployed, it is resulting in a hybrid system consisting of both new technologies and very old technologies. Some of the new communication and control technologies are designed for 5–10 year lifetimes, which is not consistent with traditional utility industry practice. Utility sector workers are aging, resulting in a large portion of the workforce retiring in the coming years.

Regulations and Standards: Electric power industry regulatory framework and business models are still geared toward the old grid, and regulatory incentives for reliability, efficiency, and renewables are fragmented. Some standard development processes are in progress (e.g., Institute of Electrical and Electronics Engineers' [IEEE's] 1547 standard for distributed generation integration), other processes are just starting (e.g., IEC 61850 for substation automation).

Policy and Markets: There has been some progress in linking new technologies, relevant policies, and stakeholder expectations. Efficiency gains and other benefits to the system are viewed from the system owner's local perspective, rather than from the broader societal perspective. Applications and technologies are being deployed where there is a fuller understanding of all the benefits. There may be too much focus on the ability of the markets to manage the power grid; regulatory and operational issues may warrant more attention.

5.3 Future Goals and Capabilities

Grid modernization is leading to the development of an electric system that features a mix of new power resources as well as numerous new technologies and devices used to operate and manage the system. The grid of the future will have a higher penetration of renewable energy resources, energy storage devices, electric vehicles, and interconnected microgrids. New technologies and devices extract more granular information about the state of the grid, and new analytical tools and models improve the capability of the system operators to manage the grid. Increasingly, grid stability and reliability will be maintained through automated control schemes and operator tools. Cyber security will be seamlessly embedded in all grid devices and systems. Supportive policies, regulations, and business models will be adopted to enable these developments. Table 5-1 lists the future goals and capabilities identified for an efficient, reliable, secure, and stable smart grid.

Table 5-1: Future Goals and Capabilities for an Efficient, Reliable, Secure, and Stable Smart Grid
New Technologies
• Secure, reliable communication systems that can handle large volumes of data • New, sophisticated control algorithms to manage reliability, efficiency, and demand • Accurate models and forecasting tools • Asset health monitoring capability, including sensor-based analytics to predict/prevent equipment failures • A framework that easily allows for change and interoperability (plug-and-play solutions and devices) • Self-healing and graceful degrading architecture • High penetration of renewable energy, energy storage, distributed generation, and electric vehicles • Intelligent interfaces between end-user devices and the grid • Interconnected microgrids • Transition from baseload coal plants to natural gas • Large-scale deployment of HVDC and medium voltage direct current MVDC
System Operation
• Most decisions related to stability and reliability are made automatically, particularly during dynamic grid changes • System operators have decision support tools that provide them with excellent situational awareness in the whole system and offer fast solutions to operational issues • Integrated systems for real-time asset management and grid operation • Distribution system operated in a networked configuration • Demand is managed through voltage regulation • Increased capacity to predict system performance based upon high-speed simulation • Enhanced system control and tools enable significant increase in transmission throughput capacity • DR, DERs, and microgrids provide energy as well as ancillary services for grid efficiency and reliability
Cyber security
• Cyber security systems fully integrated with other IT systems for grid management • Active compromise detection capability and traceability • Security becomes part of utility culture
Non-Technical Qualities

Table 5-1: Future Goals and Capabilities for an Efficient, Reliable, Secure, and Stable Smart Grid
• Pricing schemes that, when combined with DR capabilities, enable utilities to request ancillary services • Smart grid capabilities that enable consumer engagement and lead to positive outcomes • Shared view by different stakeholders on goals, benefits, and cost effectiveness of new technologies • National energy policy and regulatory framework supportive of smart grid technologies • New entities formed that play significant role in shaping peak and providing ancillary services for the grid, such as aggregators, distributed generation control centers, and outsourced data processors • Information sharing with other entities, such as police, fire departments, and other utilities • Smart grid engineering education will be widely available, including engineers who understand both IT and electric power systems

5.4 Non-Technical Challenges

Discussions focused on technological and measurement barriers to achieving greater efficiency, reliability, security, and stability of the grid, but a number of non-technical challenges were identified as well. These non-technical challenges—related to policies, standards, planning, workforce issues, and public education—need to be addressed for the technical solutions to be implemented successfully. Among the major non-technical challenges identified were the following:

Non-Supportive Policies and Regulations: The current policy and regulatory structure is not supportive of risk taking and innovation. There is a need to develop a less risk-averse environment to test and try new concepts. Policies and regulations can also be inconsistent—a policy or regulation designed to promote a certain goal can be a barrier to the deployment of smart grid technologies.

Slow Standard Adoption Process: There is a need for fast-track standardization, as the normal process for standardization takes a very long time. It is important that end users, such as utilities and customers, are involved in the standard development process, but often it is difficult for these stakeholders to find the time to be involved in the process.

Planning and Change Management in a Dynamic Environment: The generation mix and physical dynamics of the electric grid are continuously evolving, making system development and planning a challenge. External factors, such as climate change and resulting extreme weather impacts, are expected to have a significant impact on the grid. Lack of integrated planning for the electrical and natural gas systems also creates challenges. Change management must be done effectively as the industry transitions from legacy systems to the new technologies.

Mismatched and Inadequate Workforce: The aging utility sector workforce and upcoming wave of retirements are creating challenges for the industry. There is an inadequate supply of smart grid workforce, including positions in cyber security and manufacturing of smart grid devices. New industry leadership coming from financial, legal, and IT backgrounds may not always adequately understand utility sector technologies and operations.

Public Lack of Understanding of Technologies: The concept of the value of the smart grid has not been adequately explained to consumers and policy makers. There is a need to educate policy makers and the general public about smart grid technologies to gain more widespread acceptance and better inform new policies and regulations.

5.5 Technological and Measurement Challenges

A large number of challenges related to greater efficiency, reliability, security, and stability of the grid were identified. While it appears that most of the critical new technologies and devices have been developed and they are currently being deployed, full understanding of the complex interactions between the different system components and devices is lacking. Because of this, holistic system models are not available; new technologies are not fully integrated; and operator tools are not offering the kinds of capabilities envisioned. To support full system functionality, adequate communication systems must be in place. There is also a need to develop metrics to evaluate and manage the new technologies.

The identified challenges are explained in more detail in Table 5-2, including priority ranking as established by working group participants.

Table 5-2: Prioritized Challenges—Technological and Measurement—for Efficiency, Reliability, Security, and Stability of the Grid (● = one vote)	
Modeling and Metrics	
Higher Priority	• Lack of accurate and comprehensive system models ●●●●●●● (7) – Lack of models that account for the complexity of the grid and include predictive capabilities, and are verified with data
Medium Priority	• Lack of metrics for data analysis applications to manage the complex interactions between different system components and data sources, such as DERs, distribution automation, transmission system, weather forecasts, and pricing schemes ●●● (3) • Lack of agreement on the core system measurements that are needed to operate the future power system ●● (2) • Lack of comprehensive distribution system models covering the whole system from end devices to the utility enterprise ●● (2)
Lower Priority	• Lack of sensing and simulation measurements and standards for continental data exchanges ● (1) • Inadequate integration of communication models in system simulations and models ● (1) • Difficulty of going from state estimation to state measurement
Devices	
Medium Priority	• Lack of time-referenced solutions that are calibrated ●●● (3) – Developing a resilient high-resolution time resource to complement and extend GPS
Lower Priority	• Lack of cost effectiveness and availability of many smart grid system components, including DERs, energy storage devices, electric vehicles, and smart appliances ● (1) • Inadequate control technologies for the requirements of the future grid
Communications and IT	
Higher Priority	• Inadequate communications infrastructure and bandwidth for full telemetry ●●●●● (5)
Medium Priority	• Lack of a cost-effective transition plan to industry standard communication protocol ●●● (3)
Lower Priority	• Difficulties associated with IT systems that do not meet utility-grade reliability and longevity requirements
Security	
Medium Priority	• Lack of end-to-end cyber security standards or requirements that identify the desired security results, but do not necessarily mandate specific solutions ●●●● (4)

Table 5-2: Prioritized Challenges—Technological and Measurement—for Efficiency, Reliability, Security, and Stability of the Grid (● = one vote)	
Lower Priority	• Cyber security interoperability between different vendors ● (1) • Difficulty identifying all security vulnerabilities due to the complex interaction between the cyber space and physical systems, including rapid expansion of the attack surface resulting from deployment of consumer devices ● (1) • Industry cyber security fears and concerns
System Design	
Higher Priority	• Inadequate resiliency and security of the electric power system ●●●●●●●●● (9) – Advancing the state of protection schemes, testing, and integration of already developed reliability and stability methods, and volt/VAR control schemes to mitigate PV impacts
Medium Priority	• Lack of virtual microgrid schemes to enable distribution utilities to offer differentiated reliability services to customers ●● (2)
Operations	
Higher Priority	• Lack of operator tools that enable responses to fast dynamic changes in the complex grid to prevent outages and blackouts ●●●●●● (6)
Metrics and Standards	
Higher Priority	• Lack of standards to measure benefits of distribution automation, volt/VAR control, conservation voltage, and other strategies ●●●●●●●● (8) • Lack of metrics and evaluation tools for provision of ancillary services across all market sectors ●●●●● (5)
Lower Priority	• Lack of metrics to guide structured debate and evaluation of the desired long-term control paradigm, which is needed to guide standards and technology development ● (1) • Lack of cross-domain standards ● (1) • Lack of metrics for international benchmarking

5.6 Prioritized Challenges Summary

Based on working group participant voting, several of the identified technical challenges were deemed priority impediments to creating an efficient, reliable, secure, and stable smart grid. These priority challenges are summarized below and in more detail in Figures 5-1 through 5-5.

Resiliency and Security of the Electric Power System: Dependable electricity distribution depends on a resilient power infrastructure. Infrastructure resilience, as defined by the National Infrastructure Advisory Council of DHS, "…is the ability to reduce the magnitude and/or duration of disruptive events."[19] Currently, there is no holistic conceptual framework that incorporates new smart grid technologies; in addition, cyber-physical design and analytical tools are lacking (Figure 5-1). This results in a diminished ability to fully utilize the capabilities of new technologies. Holistic system models and resulting tools would improve grid reliability, security, and throughput capacity.

Tools for Operator Visibility, Data Analytics, and Legacy System Transition: Grid operators do not have visibility of the complete system at appropriate time and spatial resolution, resulting in a diminished capability to respond to sudden changes in the system (Figure 5-2). Data from new grid technologies is becoming available, but there is no integrated approach to process data from

[19] National Infrastructure Advisory Council, *A Framework for Establishing Critical Infrastructure Resilience Goals: Final Report and Recommendations by the Council,* October 19, 2010, http://www.dhs.gov/xlibrary/assets/niac/niac-a-framework-for-establishing-critical-infrastructure-resilience-goals-2010-10-19.pdf.

the different systems. To develop new operator tools will require validated models, high-performance computing, and data with high-precision time stamps. These new tools would enable operators to respond to fast dynamic changes in the complex grid and help prevent outages and blackouts.

Signaling, Performance Metrics, and Evaluation for Smart Grid Business Case and Ancillary Services Provision: Consistent performance metrics are lacking to drive the business case for various smart grid applications (Figure 5-3). There is a need to establish standard methods to quantify the lifecycle benefits for each smart grid application. Having such performance metrics would drive utility investments toward the most cost-effective smart grid solutions. There is also a need to identify metrics and evaluation tools, as well as cost-effective and fast-signaling approaches, for the provision of ancillary services. These advancements would enable better utilization of potential ancillary service providers.

Comprehensive, Accurate System Models with Common Taxonomies and Protocols: Grid models currently in use are not comprehensive but apply separate models for different parts of the system, such as transmission, distribution, and communication system (Figure 5-4). Current models are often inaccurate and are being used for different purposes than their original design and they lack common definitions and taxonomies. There is a need to meld together the models used for the different parts of the grid, and the models and data sets that are being used need to be tested and validated. Being able to use more accurate model output to manage the grid would enhance system reliability.

Communications Infrastructure to Enable Multiple Interconnections: The utility industry needs robust communication solutions to be able to manage and control a large number of interconnected devices. However, different applications being deployed have varying communications needs. Current communication solutions being used do not always meet the requirements of the utility industry and the new smart grid technologies being deployed, and there is a mismatch between available public communication networks and utility communication requirements (Figure 5-5). The many communications solutions that are available need to be evaluated and optimized for different applications. Developing standards for the design and operation of communication networks and reference communication/grid models will enable utilities to adopt cost-effective solutions and leverage significant communications industry infrastructure investment.

Figure 5-1:

Resiliency and Security of the Electric Power System

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Inflexible existing topology of power systems (i.e., legacy technologies and design)	Lack of cyber-physical design and analytical tools	Nonexistent holistic conceptual framework for all stakeholders

Technology/Decision Tools to be Developed

• List of facts about the electric power system • Microgrids • Alternative generation • End-to-end communication models	• Cyber-physical models for simulation, including cyber security simulations	• Holistic conceptual framework that incorporates new smart grid technologies, and cyber-physical design and analytical tools

Key R&D Activities

• Identify alternate topologies • Define metrics to compare alternate topologies • Develop models and include all networks	• Explore new science of cyber-physical models • Develop metrics for cyber-physical models • Perform pilot projects	• Conduct educational demonstrations

Performance Targets

• Development of flexible topologies	• Design of working cyber-physical design methods, metrics, and tools	• Acceptance of holistic mindset and framework

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Operate test platforms, test beds (utilities and other involved industries) **National Labs:** Conduct early tests, simulations **Academia:** Develop new science, metrics, educational approaches **Trade Organizations:** Provide facts; promote efforts **Standards Organizations:** Develop cyber-physical standards, cyber security standards **Government**: Facilitate pro-innovation environment for work	**Reliability:** Enables improvements **Operation or Installation Cost:** N/A **Efficiency/Usability:** Efficiency remains the same; usability improves **System Assurance and Security:** Enables improvements **Load or Demand Response:** More available and more used **Other:** Future-proof	**2013:** Vision document via Industry-Government collaboration **2014:** Roadmap published **2015:** New science, new educational approaches available **2016:** Pilot and demonstration projects **2017:** Early migration

Figure 5-2:

Tools for Operator Visibility, Data Analytics, and Legacy System Transition

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Poor visibility of the complete system at appropriate time and spatial resolution	No integrated approach for processing smart grid data from disparate systems	Legacy system transitioning usually exceeds available capital and time resources

Technology/Decision Tools to be Developed

• Enhanced communications infrastructure • Validated models for operator visibility	• High-performance computing • High-performance graphics and visualization interfaces	• High-precision time stamps across all data sources • Data management tools

Key R&D Activities

• Develop visualization and application analytics to convert smart grid data into action • Develop unified model and data semantics for the complete infrastructure (e.g., T&D, communications)	• Develop new algorithms • Combine advanced computing and parallel processing to use and extract knowledge from smart grid data	• Develop correlation tools for bringing apparently unrelated large data sets into a more relational approach • Utilize new tools for operating uncertainties of generation and/or loads

Performance Targets

• Production of actionable outputs from operational interface	• Autonomous detection and mitigation of cascading events	• Demonstration of state measurement instead of state estimation

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Provide appropriate data and testing scenarios **National Labs:** Promote technologies for development and offer test beds **Academia:** Conduct fundamental, relevant R&D **Trade Organizations:** Promote interoperability and certification of smart grid technologies **Standards Organizations:** Develop new test methods and standards **Government:** Support demonstrations; promote standards	**Reliability:** Improved reliability from decision process improvement **Operation or Installation Cost:** Reduced uncertainty **Efficiency/Usability:** Optimized resources and end use **System Assurance and Security:** Assurance of controllability and correct actionable response **Load or Demand Response:** Tools allow "faster than real time" **Other:** Overall robustness of power system and decision making	**2013:** Data integration **2015:** Advanced analytics demonstrated **2017:** New operating procedures and practices **2020:** Full capability achieved and benefits realized

Figure 5-3:

Signaling, Performance Metrics, and Evaluation for Smart Grid Business Case and Ancillary Services Provision

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Inconsistent performance metrics to drive business case for various smart grid applications (i.e., bottom line benefits)	Inability to quickly signal resolution and spinning reserve needs to devices	Inability to forecast and measure device responses and line to benefits, rewards, or incentives

Technologies/Decision Tools to be Developed

• Standard methods to quantify lifecycle benefits tailored to each smart grid application	• Fast, low-latency, time-synchronized communication technologies	• Devices capable of DR calculations • Ability to measure actual load and compare to model to improve voltage conservation regulation

Key R&D Activities

• Benchmark methods • Analyze best practices • Develop new methods and performance metrics as necessary	• Examine options for high-speed communications of simple regulation and spinning reserve signals • Develop industry consensus on method	• Develop in-meter billing application, test performance, and upgrade meters as needed • Develop model-based methods and validate them in the field

Performance Targets

• Industry consensus on best practices for each smart grid application	• Industry adoption of an approximate four-second latency signal approach	• Attain acceptable level of accuracy (to be defined) • Reach an acceptable level of marginal cost for M&V

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Establish best practices; develop accuracy and other requirements; implement and test methods **National Labs:** Conduct pre-competitive R&D to prove concepts **Academia:** Conduct pre-competitive R&D to prove concepts **Trade Organizations:** Review, support methods and best practices development **Standards Organizations:** Formalize and define performance metrics, signaling methods, and M&V methods **Government:** Establish incentives and approve metrics; provide support for R&D, demonstrations, testing	**Reliability:** Improved ancillary services **Operation or Installation Cost:** Reduced need for power plants and transmission, distribution capacity **Efficiency/Usability:** Conservation voltage—2%–3% of nation's electricity **Load or Demand Response:** DR for ancillary services **Other:** Renewables drives increased need for ancillary services; performance metrics drive business case, which drives investments	**2014**: Best practices for life cycle quantification **2015:** Consensus on high-speed communications; model-based methods for device responses **2017:** Performance metrics, signaling methods, and M&V methods developed

Figure 5-4:
Comprehensive, Accurate System Models with Common Taxonomies and Protocols

Technology/Measurement Barrier	Technology/Measurement Barrier	Technology/Measurement Barrier
Disjointed modeling of power system domains	Inconsistent definitions, vocabulary, and taxonomy for creating models	Inaccurate output from and inappropriate application of models

Technologies/Decision Tools to be Developed

• Connected transmission, distribution, and communication models	• Standard, all-inclusive library models	• Standard test cases, data sets, and metrics for model and data validation

Key R&D Activities

• Fully define model requirements • Develop tools to combine domains for modeling	• Develop common vocabulary and taxonomy for building models • Leverage IEEE Intelligent Grid Coordinating Committee efforts	• Develop a structured approach for model validation • Develop metrics for determining acceptable outputs

Performance Targets

• Robust utility participation and use of standardized and effective model exchange and protocols	• Widespread adoption of vocabulary and taxonomy for building models	• Trustworthy model output used for application purposes • Enterprises driven by the model • Creation of a self-defining database

Stakeholders and Roles	Potential Impacts	Milestones
Industry: Use and validate models **National Labs:** Help provide and drive standards; help validate models; conduct interoperability testing **Academia:** Help provide and drive standards; help validate models **Trade Organizations:** Convene groups **Standards Organizations:** Maintain and hold standards definitions **Government:** Provide financial support, oversight, and guidance	**Reliability:** Direct connection between models and reliability; exercise caution with increased complexity to avoid reliability degradation **Operation or Installation Cost:** More efficient database management **Efficiency/Usability:** More efficient database management **System Assurance and Security:** See "Reliability" above **Load or Demand Response:** See "Reliability" above	**2013:** Articulate needs; gain involvement of appropriate groups **2015:** Definition of gaps in existing standards: usability, coverage, and use cases **2017:** Functional CIM definition that cuts across T&D and can be demonstrated with interoperability, across multiple vendors; standard model libraries for smart grid component **2019:** Interoperable models that are validated with repeatable test cases

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6 Cross-Cutting Challenges

6.1 Common Technical Challenges

A number of technical challenges were identified that cut across all the topic areas, including the following:

- **Decision tools for operators** are needed to increase visibility and situational awareness, enable planning and forecasting, and provide logic for decision making.
- **Communications infrastructure** today is inadequate and must be improved to enable interconnections among various components and systems, public networks, and devices, as well as operations and planning functions.
- **Performance metrics** are lacking to better understand, manage, and control performance, flexibility, and a host of other elements.
- **Data management and analytics** are not sufficient for effectively collecting, storing, and interpreting the massive amounts of data that can potentially be collected.
- **Robust operational and business models** are needed to enable effective operations and planning and that can incorporate diverse generation sources, storage options, and models for flexibility.

6.2 Common Non-Technical Challenges

Common non-technical challenges that impact all topic areas include:

- **Privacy of information** is still uncertain and is needed to assure consumers that personal information is protected and its release is controlled; this will lead to greater acceptance of smart grid technologies.
- **Coordination of policy and regulations** at the federal level and among states and utilities on smart grid policies is insufficient—creating uncertainty and a business environment that is not supportive of risk-taking and innovation.
- **Market fragmentation for smart grid technologies** results, in part, from the lack of a common vision between utilities and ISOs for the smart grid and the residential sector. This has led to manufacturers having to address many different solutions and many types of technologies entering the market.
- **The business case for smart grid technologies** is still uncertain and lacks clarity; investments are complicated by uncertainties over who should pay for upgrades (e.g., consumers, utilities) and how and when these costs will be recouped.

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APPENDIX B: ACRONYMS

ADR	automated demand response
AMI	advanced metering infrastructure
ARRA	American Recovery and Reinvestment Act
BOS	balance of system
BPA	Bonneville Power Administration
CES	community energy storage
DER	distributed energy resource
DG	distributed generation
DHS	U.S. Department of Homeland Security
DLC	direct load control
DEMS	Distribution Energy Management System
DOE	U.S. Department of Energy
DR	demand response
DRMS	demand response management systems
EE	energy efficiency
EISA	Energy Independence and Security Act
EM&V	evaluation, measurement, and verification
EMS	energy management systems
EPRI	Electric Power Research Institute
ETS	electric thermal storage
EV	electric vehicle
FACTS	flexible alternating current transmission system
FERC	Federal Energy Regulatory Commission
FDRI	fault diagnosis, isolation, and recovery
GIS	geographic information system
HEMS	home energy management systems
HVDC	high voltage direct current
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	independent system operator
IPV6	Internet Protocol V.6
IP	Internet Protocol
IT	information technology

IVVC	integrated Volt-VAR control
k	kilo
kW	kilowatt
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LC	load control
M&V	measurement and verification
MVDC	medium voltage direct current
MDMS	meter data management system
NERC	North American Electric Reliability Corporation
NGR/REM	Non Generator Resource - Regulation Energy Management
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
OMS	outage management system
PCT	programmable communicating thermostat
PLC	power line carrier
PMUs	phasor measurement units
PNNL	Pacific Northwest National Laboratory
POC	performance objectives and criteria
PV	photovoltaic
RAS	remedial action schemes
RASEI	Renewable and Sustainable Energy Institute
RE	renewable energy
ROI	return of investment
RTDS	real-time digital simulator
RTO	regional transmission operators
RTU	remote terminal unit
SCADA	supervisory control and data acquisition
SCMS	superconducting magnetic energy storage
SGIP	Smart Grid Interoperability Panel
SPS	special protection systems
STATCOM	static synchronous compensator
T&D	transmission and distribution
VAR	volt-amp-reactive