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Smart Grid Status and Metrics Report

July 2014

PJ Balducci
MR Weimar
H Kirkham

U.S. DEPARTMENT OF
ENERGY

Prepared for the U.S. Department of Energy
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Abstract

A smart grid uses digital power control and communication technology to improve the reliability, security, flexibility, and efficiency of the electric system, from large generation through the delivery systems to electricity consumers and a growing number of distributed generation and storage resources. To convey progress made in achieving the vision of a smart grid, this report uses a set of six characteristics derived from the National Energy Technology Laboratory Modern Grid Strategy. The report defines and examines 21 metrics that collectively provide insight into the grid's capacity to embody these characteristics.

Executive Summary

A smart grid uses digital power control and communication technology to improve the reliability, security, flexibility, and efficiency of the electric system, from large generation through the delivery systems to electricity consumers and a growing number of distributed generation and storage resources. The information networks that are transforming our economy in other areas are also being used to support applications for dynamic optimization of electric system operations, maintenance, and planning. Resources and services that had been separately managed are now being integrated and bundled as we address traditional problems in new ways, adapt the system to tackle new challenges, and discover new benefits that have transformational potential.

Progress in Achieving the Characteristics of a Smart Grid

To convey progress made in achieving the vision of a smart grid, this report uses a set of six characteristics derived from the National Energy Technology Laboratory (NETL) Modern Grid Strategy. The 21 metrics identified in Table ES.1 provide insight into the grid's capacity to embody these characteristics. These metrics were measured through 2012 and compared to similar measurements presented in the 2009 and 2010 Smart Grid System Reports (SGSR) prepared by the U.S. Department of Energy (DOE).[1,2] Note that this is not an SGSR but rather a report designed to provide a status report on the metrics measured previously in past SGSRs. Nearly all of the metrics contribute information to understanding multiple characteristics. Main findings are summarized below:

- Enables Informed Participation by Customers. With bidirectional flows of energy and coordination through communication mechanisms, a smart grid helps balance supply and demand, and enhances reliability by modifying how consumers use electricity. The number of advanced meters [Metric 12] installed in the U.S. reached 36 million in 2012, or 24.2 percent of all U.S. meters.[3] In 2007, there were only 6.7 million advanced meters installed in the U.S. Advanced Metering Infrastructure (AMI) technologies enable the communication of grid conditions, consumption information, and real time pricing data to support dynamic pricing programs. A Federal Energy Regulatory Commission (FERC) study estimated that in 2010, approximately 1.1 million electricity consumers were enrolled in dynamic pricing programs [Metric 1] in the U.S.[4] Lastly, the amount of load participating based on grid conditions is beginning to show a shift from traditional interruptible demand toward demand response programs that either allow an energy service provider to perform direct load control or provide financial incentives for customer-responsive demand at homes and businesses. Potential

[1] DOE – U.S. Department of Energy. 2009. *2009 Smart Grid System Report.* Accessed May 29, 2014, at http://energy.gov/sites/prod/files/2009%20Smart%20Grid%20System%20Report.pdf.
[2] DOE – U.S. Department of Energy. 2012. *2010 Smart Grid System Report.* Accessed May 29, 2014, at http://energy.gov/oe/downloads/2010-smart-grid-system-report-february-2012.
[3] IEE – Institute for Electric Efficiency. 2012. *Utility Scale Smart Meter Deployments, Plans & Proposals.* Washington, D.C. Accessed May 17, 2012 at http://www.edisonfoundation.net/iee/Documents/IEE_SmartMeterRollouts_0512.pdf.
[4] FERC – Federal Energy Regulatory Commission. 2011. *Assessment of Demand Response & Advanced Metering – Staff Report.* Washington, D.C. Accessed June 4, 2012 at http:// www.ferc.gov/legal/staff-reports/11-07-11-demand-response.pdf (undated webpage).

managed load reached 1.20 percent of net summer capacity in 2010, up from a low of 0.96 percent in 2006.[5]

- Accommodates All Generation and Storage Options. Accommodating a range of diverse generation types, including centralized and distributed generation, is a core principle of the smart grid. Distributed generation (DG) systems (10 MVA or less) that can be connected to primary and/or secondary distribution voltages reached 14,273 MW in 2009 [Metric 7]. Actively managed DG represents approximately 1.4 percent of total generating capacity and 89 percent of total DG.[6] Policies to promote installation of such systems are becoming more common at the state level. As of 2012, 43 states plus Washington DC and Puerto Rico had adopted variations of an interconnection policy [Metric 3].[7] The growth of energy storage lags DG with electricity service providers reporting energy storage capacity (e.g., batteries, flywheels, pumped hydro) at 1.3 percent of total grid capacity (Appendix B). Renewable resources [Metric 21] excluding conventional hydro have reached more than 4 percent of total generation, almost double that of 2004 levels.[8] Total output is expected to more than double again by 2035 as states implement renewable portfolio standards. As of 2012, 29 states plus Washington, D.C. had established RPSs.[9]

- Enables New Products, Services, and Markets. A smart grid enables new products and services through automation, communication sharing, facilitating and rewarding shifts in customer behavior in response to changing grid conditions, and its ability to encourage development of new technologies. Examples of grid-responsive equipment includes communicating thermostats, responsive appliances, responsive space conditioning equipment, consumer energy monitors, responsive lighting controls, and controllable wall switches [Metric 9]. The smart grid also supports the deployment of new vehicle technologies. While plug-in electric vehicle (PEV) sales are currently low, reaching 52,835 in 2012 or 0.4 percent of the light-duty vehicle fleet, a number of new vehicle models have recently entered the market and sales are forecast to grow significantly in the coming years [Metric 8].[10] Electricity service providers (ESPs) are experiencing success at building smart grid-related investments into their rate structure [Metric 4]. In 2012, ESPs interviewed for this study estimated they were recovering 59.8 percent of their smart grid investment through rate structures, compared to 23.5 percent in 2010 and 8.1 percent in 2008 (Appendix B). Finally, companies with new smart grid concepts continue to receive a significant injection of capital. Venture capital funding of smart grid

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[5] EIA – U.S. Energy Information Administration. 2011. *Table 9.1: Demand-Side Management Actual Peak Load Reductions by Program Category, 1999 through 2010.* In Electric Power Annual 2010 Data Tables. U.S. Department of Energy, Washington, D.C. Accessed May 31, 2012, at http://205.254.135.7/electricity/annual/.

[6] EIA – U.S. Energy Information Agency. 2011. Table 2.1:A Net Generation by Energy Source by Type of Producer. In Electric Power Annual 2010. U.S. Department of Energy, Washington, D.C. Accessed May 23, 2010, at http://www.eia.gov/electricity/annual/ (last updated November 9, 2010).

[7] DSIRE – Database of State Incentives for Renewable Energy. 2012. *Summary Maps.* Accessed August 14, 2012, at http://www.dsireusa.org/summarymaps/index.cfm?ee=0&RE=0 (last updated June 2012).

[8] EIA – U.S. Energy Information Agency. 2011. Table 2.1:A Net Generation by Energy Source by Type of Producer. In Electric Power Annual 2010. U.S. Department of Energy, Washington, D.C. Accessed May 23, 2010, at http://www.eia.gov/electricity/annual/ (last updated November 9, 2010).

[9] DSIRE – Database of State Incentives for Renewable Energy. 2012. *Summary Maps.* Accessed August 14, 2012, at http://www.dsireusa.org/summarymaps/index.cfm?ee=0&RE=0 (last updated June 2012).

[10] Electric Drive Transport Association. 2013. *Electric Drive Vehicle Sales Figures (U.S. Market) – EV Sales.* Accessed on October 17, 2017, at http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952 (undated webpage).

startups [Metric 20] grew at an average annual rate of 25.7 percent between 2002 ($58.4 million) and 2011 ($455.5 million).[11]

- Provides the Power Quality for the Range of Needs. NETL has estimated that power quality issues cost the U.S. more than $100 billion annually.[12] While power quality has been difficult to quantify, ESPs interviewed for this study estimated that the percentage of customer complaints tied to power quality-related issues (excluding outages) comprised 1.2 percent, 0.4 percent, and 0.1 percent of all customer complaints submitted by residential, commercial, and industrial customers, respectively [Metric 17] (Appendix B). Smart grid solutions range from local control of your power needs in a microgrid [Metric 6] and supporting distributed generation [Metric 7], to more intelligent operation of the delivery system through technology such as is used in transmission and distribution (T&D) automation.
- Optimizes Asset Utilization and Operating Efficiency. The smart grid can enable lower operational costs, lower maintenance costs, and greater flexibility of operational control in the power system. Electricity generation and T&D efficiency rates have improved in recent years. The percentage of total energy consumed to generate electricity that is lost in generation, transmission, and distribution dropped from 67.7 percent in 2007 to 65.6 percent in 2011.[13] The summer peak capacity factor [Metric 14] has declined for several years, falling from 81 percent in 2007 to 72 percent in 2011, but is projected to increase over the next 10 years.[14] Smart grid contributions to these measures include T&D automation and dynamic line ratings. ESPs contacted for this study indicated that 85.7 percent of their substations were automated [Metric 11], a significant increase from the 47.7 percent reported in 2010 SGSR. Dynamic line ratings [Metric 16] have been implemented on a very limited basis to date.
- Operates Resiliently to Disturbances, Attacks, and Natural Disasters. The ability to respond resiliently and adapt to system events is a key function of the smart grid. The national average for reliability indices (outage duration and frequency measures SAIDI, SAIFI and MAIFI) have been flat since 2003 showing a steady level of reliability [Metric 10].[15] Within delivery-system field operations, substation automation is showing progress [Metric 11]. In recent years, significant investments have been made in phasor measurement units (PMUs). PMUs sample voltages and currents to synchronously provide measurement of the state of the electric system and power quality in real time.

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[11] Cleantech Group. 2012. *i3 Platform.* Cleantech Group, LLC, San Francisco. Accessed July 10, 2012, at http://research.cleantech.com/ (undated webpage).

[12] NETL – National Energy Technology Laboratory. 2009. *Smart Grid Principal Characteristics Provides Power Quality for the Digital Economy.* DOE/NETL-2010/1412. Accessed August 15, 2012 at http://www.netl.doe.gov/smartgrid/referenceshelf/whitepapers/Provides%20Power%20Quality%20for%20the%20Digital%20Economy%20%28Oct%202009%29.pdf.

[13] EIA – U.S. Energy Information Administration. 2012. *Electricity Flow Diagram*, 2011. In Annual Energy Review. U.S. Department of Energy, Washington, D.C. Accessed September 13, 2013, at http://www.eia.gov/totalenergy/data/annual/diagram5.cfm.
NERC – North American Electric Reliability Corporation. 2011. *Electricity Supply & Demand (ES&D): Frequently Requested Data.* Accessed June 10, 2012, at http://www.nerc.com/page.php?cid=4|38|41 (undated webpage).

[14] NERC – North American Electric Reliability Corporation. 2011. *Electricity Supply & Demand (ES&D): Frequently Requested Data.* Accessed June 10, 2012, at http://www.nerc.com/page.php?cid=4|38|41 (undated webpage).

[15] IEEE – Institute of Electrical and Electronics Engineers. 2012. IEEE Benchmarking 2011 Results. Presented at the Distribution Reliability Working Group Meeting, San Diego, California.

Due to investments made under the American Recovery and Reinvestment Act (ARRA), the number of networked PMUs grew from 140 in 2009 to nearly 1,700 by December 2013.[16] Non-generating demand response equipment such as smart appliances [Metric 9] remains in its commercialization infancy, though programmable communicating thermostats are a near-term success.

The State of Smart Grid Deployments

This report looks across a spectrum of smart grid concerns to measure the status of smart grid deployment and impacts. Across the vast scope of smart grid deployments, a number of advancements have taken place since the 2010 SGSR was published. ARRA funded two major technology deployment initiatives: the Smart Grid Investment Grant (SGIG) Program and the Smart Grid Demonstration Program (SGDP). These programs are currently implementing 131 deployment and demonstration projects. As of September 30, 2012, investments made under these programs include deployment of the following: 12.1 million advanced meters, 569 phasor measurement units, 7,269 automated feeder switches, 10,749 automated capacitors, 15,376 substation monitors, 775 electric vehicle charging stations and 186,687 programmable communicating thermostats.[17, 18]

The SGIG program, which received $3.4 billion under ARRA, has authorized 99 projects at a total cost of $8 billion. Figure ES.1 presents the status of SGIG investments made through September 30, 2012.[19] These values represent total costs, which are the sum of the federal investment and cost share of the recipient. The recipient cost share under ARRA must be at least 50 percent of the total overall project cost.

[16] Silverstein, A. 2013. *NASPI and Synchrophasor Technology Program.* Presented at NERC OC-PC Meetings. December 2013. Atlanta, GA.
[17] DOE – U.S. Department of Energy. 2012. *Recovery Act Smart Grid Programs.* SmartGrid.gov, Washington, D.C. Accessed November 28, 2012, at http://www.smartgrid.gov/ (undated web page).
[18] Wang, W. 2013. Personal Communication. *Data Compiled from ARRA Recipient's Federal Financial Reports (FFR) SF-435.* May 31, 2013.
[19] DOE – U.S. Department of Energy. 2012. *Recovery Act Smart Grid Programs.* SmartGrid.gov, Washington, D.C. Accessed November 28, 2012, at http://www.smartgrid.gov/ (undated web page).

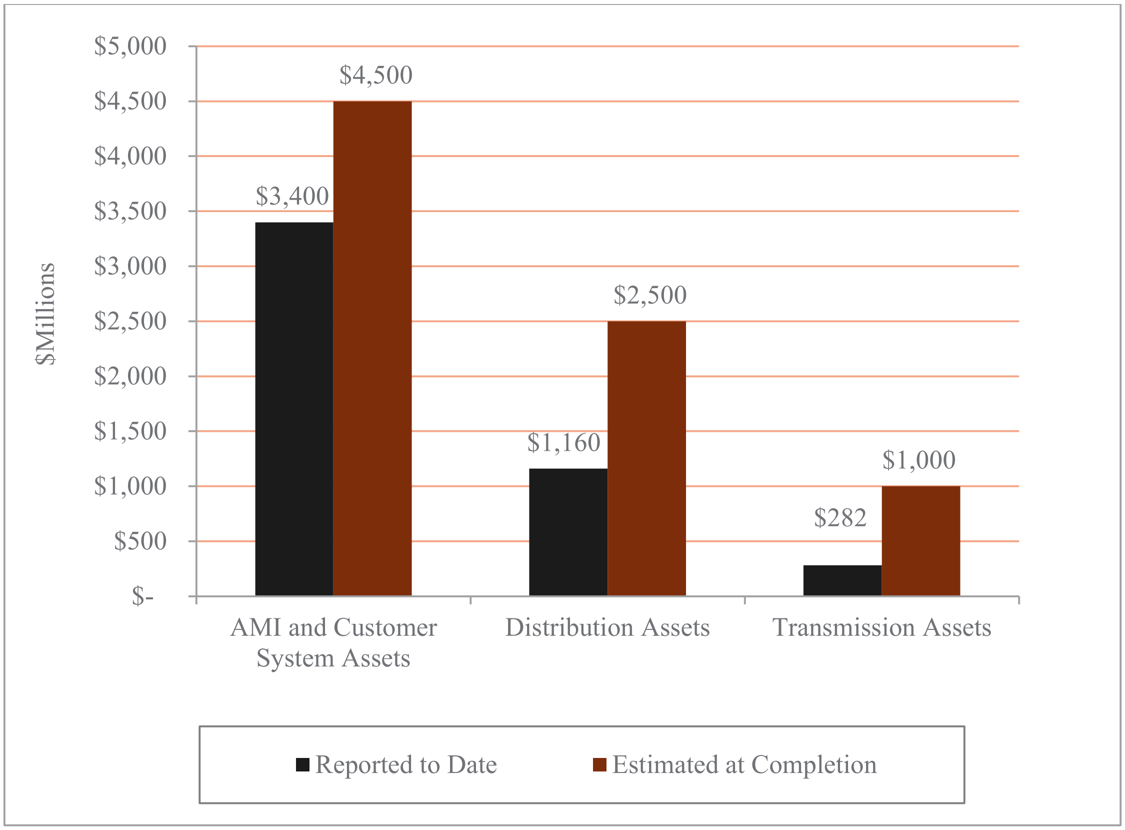

Figure ES.1. SGIG Total Investments Deployed as of September 30, 2012

The second major technology deployment initiative funded under ARRA, the SGDP, consists of 32 projects in two areas: smart grid regional demonstrations (16 projects) and energy storage demonstrations (16 projects). ARRA provided significant investment for DG and storage under the SGDP, awarding $185 million in support of 16 energy storage projects valued at $777 million [Metric 7 – Grid Connected Distributed Generation]. These energy storage projects are focused on grid-scale applications of energy storage involving a variety of technologies, including advanced batteries, flywheels, and underground compressed air systems. DOE also awarded $435 million for 16 smart grid regional demonstration projects collectively valued at $874 million.[20] These regional demonstrations are focused on advanced technologies for use in power system sensing, communications, analysis, and power flow controls, and are assessing the integration of advanced technologies with existing power systems, including those involving renewable and distributed energy systems and demand response programs.

In addition to the technology deployment programs, ARRA funded workforce training and development programs, as well as standards and interoperability activities. One outcome of these investments was the National Institute of Standards and Technology's Release 2.0 of the *Framework and Roadmap for Smart Grid Interoperability Standards,* which lays out a plan for transforming the nation's electric power system into an interoperable smart grid.[21]

[20] Bossart, S. 2013. Personal Communication. *Data Compiled from ARRA Recipients Federal Financial Reports (FFR) SF-435.* April 26, 2013.

[21] NIST – National Institute of Standards and Technology. 2012. *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0.* Washington, D.C. Accessed July 24, 2012, at http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf (undated webpage).

Assessing the Smart Grid Metrics

Table ES.1 lists the 21 metrics used in this report. The table indicates each metric's status (penetration level/maturity) and trend. The intent is to provide a high-level, simplified perspective of a complicated picture. If it is a build metric, the penetration level is indicated as being nascent (very low and just emerging), low, moderate, or high. Because smart grid activity is relatively new, there are no high penetration levels to report on these metrics at the present time. The maturity of the system with respect to value metrics is indicated as being either nascent or mature. The trend is indicated for value metrics as worsening, flat, or improving. For build metrics, trends are indicated as being at nascent, low, moderate, or high levels. An investigation of the measurements for each metric is presented in Appendix A.

In this report, the following changes have been made to the status of metrics reported in Table 2.1 compared to those reported in the 2010 SGSR:

- Metric 4 – ESPs interviewed for this report indicated that, on average (weighted), they are recovering 59.8 percent of their investment through rate structures, compared to 23.5 percent in the 2010 SGSR and 8.1 percent estimated for the 2009 SGSR (Appendix B). Thus, the current penetration/maturity level assigned to policy/regulatory progress was changed from low to moderate. The long-term trend was adjusted to high.
- Metric 6 – Microgrids may become more prevalent with the adoption of the Institute of Electrical and Electronics Engineers (IEEE) Standard 1547.4-2011.[22] Microgrids currently provide 575 megawatts (MW) of capacity in the United States out of total capacity of 1 terawatt and have the potential to reach 1,500 MW by 2017, according to Pike Research.[23] Thus, the current penetration/maturity level assigned to this metric was changed from nascent to low, while the long-term trend remained low.
- Metric 10 – From 2003 through 2011, transmission and distribution reliability, as measured in the IEEE benchmarking studies, was flat in the United States. From 2003 through 2011, there was no change in the Customer Average Interruption Duration Index (CAIDI) and a slight increase in the System Average Interruption Frequency Index (SAIFI).[24] Thus, the trend is now flat.
- Metric 20 – Venture capital funding of smart grid startups topped $878 million during the 2010–2011 timeframe.[25] The current penetration/maturity level for this metric was changed from nascent to low, while the long-term trend remained high.

[22] IEEE Standard 1547.4-2011. 2011 *IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems.* IEEE Standards Coordinating Committee 21, IEEE, New York. Accessed March 14, 2012, at http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5960751 (updated July 20, 2011).
[23] Asmus P and C Wheelock. 2012. Distributed Energy Systems for Campus, Military, Remote, Community, and Commercial & Industrial Power Applications: Market Analysis and Forecasts. Pike Research, Boulder, Colorado. Accessed July 26, 2012, at http://www.pikeresearch.com/research/smart-grid/microgrids (undated webpage).
[24] IEEE – Institute of Electrical and Electronics Engineers. 2012. *IEEE Benchmarking 2011 Results.* Presented at the Distribution Reliability Working Group Meeting, San Diego, California.
[25] Cleantech Group. 2012. *i3 Platform.* Cleantech Group, LLC, San Francisco. Accessed July 10, 2012, at http://research.cleantech.com/ (undated webpage).

Table ES.1. Summary of Smart Grid Metrics and Status

#	**Metric Title** (*Type: build or value*)	**Penetration/ Maturity**	**Trend**
1	Dynamic Pricing (*build*): fraction of customers and total load served by RTP, CPP, and TOU tariffs*	low	moderate
2	Real-Time System Operations Data Sharing (*build*): total SCADA points shared and fraction of phasor measurement points shared*	moderate	high
3	Distributed-Resource Interconnection Policy (*build*): percentage of electricity service providers with standard distributed-resource interconnection policies and commonality of such policies across electricity service providers	moderate	high
4	Policy/Regulatory Recovery Progress (*build*): weighted-average percentage of smart grid investment recovered through rates (respondents' input weighted based on total customer share)	moderate	high
5	Load Participation Based on Grid Conditions (*build*): fraction of load served by interruptible tariffs, direct load control, and consumer load control with incentives	low	low
6	Load Served by Microgrids (*build*): percentage of total summer grid capacity	low	low
7	Grid-Connected Distributed Generation (renewable and non-renewable) and Storage (*build*): percentage of distributed generation and storage	low	high
8	EVs and PHEVs (*build*): percentage shares of on-road light-duty vehicles comprising EVs and PHEVs*	nascent	low
9	Non-Generating Demand Response Equipment (*build*): total load served by smart, grid-responsive equipment	nascent	low
10	T&D System Reliability (*value*): CAIDI, SAIDI, SAIFI, MAIFI*	mature	flat
11	T&D Automation (*build*): percentage of substations having automation	moderate	high
12	Advanced Meters (*build*): percentage of total demand served by AMI customers	low	high
13	Advanced Measurement Systems (*build*): percentage of substations possessing advanced measurement technology	moderate	high
14	Capacity Factors (*value*): yearly average and peak-generation capacity factor	mature	flat
15	Generation and T&D Efficiencies (*value*): percentage of energy consumed to generate electricity that is not lost	mature	improving
16	Dynamic Line Ratings (*build*): percentage of miles of transmission circuits being operated under dynamic line ratings	nascent	low
17	Power Quality (*value*): percentage of customer complaints related to power quality issues, excluding outages	mature	worsening
18	Cybersecurity (*build*): percentage of total generation capacity under companies in compliance with the NERC critical infrastructure protection standards	low	low
19	Open Architecture/Standards (*build*): interoperability maturity level – weighted-average maturity level of interoperability realized between electricity system stakeholders	nascent	low
20	Venture Capital Funding (*build*): total annual venture capital funding of smart grid startups located in the United States.	low	high
21	Grid-Connected Renewable Resources (*build*): percentage of renewable electricity, in terms of both generation and capacity	low	moderate

*RTP = real time pricing; CPP = critical peak pricing; TOU = time-of-use pricing; SCADA = supervisory control and data acquisition; EV = electric vehicle; PHEV = plug-in hybrid electric vehicle; CAIDI = customer average interruption duration index; SAIDI = system average interruption duration index; SAIFI = system average interruption frequency index; MAIFI = momentary average interruption frequency index; NERC = North American Electric Reliability Corporation

Challenges to Smart Grid Deployments

With the aforementioned progress noted, significant challenges to realizing smart grid capabilities persist. Foremost among these are the challenges associated with finding a clear pathway to the value proposition, interoperability standards, cybersecurity and education of smart grid stakeholders.

In finding a clear pathway to a value proposition, stakeholders such as industry groups and regulators, cooperative boards, and city councils/boards need to be educated on costs/benefits even though ARRA significantly advanced the knowledge base. Further, state legislation, regulations, and industry strategies are not necessarily aligned currently. Investment is contingent on asset investment strategies and the capacity of industry and its stakeholders to absorb costs. To move from pilot projects to full-scale deployment requires taking risks that stakeholders may be reluctant to take.

Interoperability and systems integration challenges are new to the industry. Smart grid technologies require significant systems integration with careful planning to avoid future stranded assets. Interoperability standards are being advanced, yet industry is advancing ahead of them. Cybersecurity for smart grid components and systems presents new challenges that must be addressed. While the ARRA smart grid projects have enhanced the adoption of cyber practices, advancement in this space will be continual. Technology adoption sometimes occurs ahead of cybersecurity standards, which could make certain technologies harder to protect. Consumer education needs greater emphasis as consumers become more involved (potentially as partners) in the management of electricity.

Acronyms and Abbreviations

AEO	Annual Energy Outlook
AMI	advanced metering infrastructure
ARPA-E	Advanced Research Projects Agency-Energy
ARRA	*American Recovery and Reinvestment Act of 2009*
ATVM	Advanced Technology Vehicle Manufacturing
BPA	Bonneville Power Administration
CAES	compressed air energy storage
CAIDI	customer average interruption duration index
CERTS	Consortium for Electric Reliability Technology Solutions
CIP	critical infrastructure protection
CPP	critical-peak pricing
DER	distributed energy resource
DG	distributed generation
DLR	dynamic line rating
DMS	distribution management system
DOD	United States Department of Defense
DOE	United States Department of Energy
DSIRE	Database of State Incentives for Renewable Energy
EIA	Energy Information Administration
EISA	*Energy Independence and Security Act of 2007*
EMS	energy management system
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ES-C2M2	Energy Sector − Cybersecurity Capability Maturity Model
ESP	Electric service provider
EV	electric vehicle
FERC	Federal Energy Regulatory Commission
GW	gigawatt(s)
GWh	gigawatt hour(s)
GWAC	GridWise® Architecture Council
HEV	hybrid electric vehicle
IEEE	Institute of Electrical and Electronics Engineers
IT	information technology
LBNL	Lawrence Berkeley National Laboratory
LRAM	lost revenue adjustment mechanism

MAIFI	Momentary Average Interruption Frequency Index
MW	megawatt(s)
MVA	megavolt-ampere
NARUC	National Association of Regulatory Utility Commissioners
NASPI	North American Synchrophasor Initiative
NBISE	National Board of Information Security Examiners
NERC	North American Electric Reliability Corporation
NETL	National Energy Technology Laboratory
NIST	National Institute of Standards and Technology
NNEC	Network for New Energy Choices
NOPR	notice of proposed rulemaking
NSTC	National Science and Technology Council
OG&E	Oklahoma Gas and Electric
ORNL	Oak Ridge National Laboratory
PAP	priority action plan
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicle
PMU	phasor measurement unit
PNNL	Pacific Northwest National Laboratory
PQ	power quality
R&D	research and development
RDSI	renewable and distributed systems integration
RMP	risk management process
ROI	return on investment
RPS	renewable portfolio standards
RTP	real-time pricing
RUS	Rural Utility Service
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	supervisory control and data acquisition
SGDP	Smart Grid Demonstration Program
SGIG	Smart Grid Investment Grant
SGIMM	Smart Grid Interoperability Maturity Model
SGIP	Smart Grid Interoperability Panel
SGMM	Smart Grid Maturity Model
SGSR	Smart Grid System Report
T&D	transmission and distribution
TOU	time-of-use pricing

TWh	terawatt-hour(s)
WECC	Western Electricity Coordinating Council

Contents

Figures

Tables

1.0 Introduction

In 2013, global investment in smart grid technologies reached $14.9 billion, with approximately 24 percent ($3.6 billion) spent in the U.S. (BNEF 2014). This included investments made under the American Recovery and Reinvestment Act (ARRA) of 2009. Forecasts of the additional monetary investments required to modernize the grid over the 2010-2030 time horizon range from $340 to $880 billion (EPRI 2011, Chupka et al. 2008). Areas where investments are needed include hardware/infrastructure, load growth/renewable integration, software/cybersecurity, policy and training.

Title XIII of the *Energy Independence and Security Act of 2007 (EISA)* was designed to support the advancement of the nation's electricity system, to maintain a reliable and secure infrastructure that can meet future load growth and achieve the characteristics of a smart grid. Title XIII also identifies grid modernization as a U.S. policy (15 USC 17382). ARRA appropriated $4.5 billion to advance grid modernization through the deployment of thousands of smart grid technologies managed through several smart grid programs and related activities.[1]

This report evaluates progress in meeting the objectives of Title XIII through the measurement of 21 metrics. This report is accompanied by two appendices. Appendix A includes a detailed analysis of each of the 21 metrics chosen to monitor the progress of smart grid deployment. Appendix B presents the results of interviews conducted with 30 electricity service providers (ESPs) serving approximately 26.5 million customers. By comparison, the 2009 and 2010 Smart Grid System Reports (SGSRs) reported the results of interviews conducted with 21 and 24 ESPs, respectively (DOE 2009 and DOE 2012a).

1.1 Scope of a Smart Grid

A smart grid uses digital technology to improve the reliability, security, flexibility, and efficiency of the electric system, from large generation through the delivery systems to electricity consumers and a growing number of distributed generation (DG) and storage resources. The information networks that are transforming our economy in other areas are also being used to support applications for dynamic optimization of electric system operations, maintenance, and planning. Resources and services that had been separately managed are now being integrated and bundled as we address traditional problems in new ways, adapt the system to tackle new challenges, and discover new benefits that have transformational potential.

Areas of the electric system within the scope of a smart grid include the following:

- the delivery infrastructure (e.g., transmission and distribution lines, transformers, switches)
- the end-use systems and related distributed energy resources (e.g., distributed generation or DG, storage, electric vehicles [EVs])
- management of the generation and delivery infrastructure at the various levels of system coordination (e.g., transmission and distribution control centers, regional reliability coordination centers, national emergency response centers)

[1] Under the Smart Grid Investment Grant program, federal investment is to be matched 1:1 (minimum) by private sector investment, bringing the total investment from $3.4 billion to $7.8 billion. There is an additional $45 million in loan guarantees in 2013 provided to rural electric utilities for smart grid technology provided by the U.S. Department of Agriculture.

- the information networks themselves (e.g., remote measurement and control communications networks, inter- and intra-enterprise communications, public Internet)
- the financial environment that fuels investment and motivates decision makers to procure, implement, and maintain all aspects of the system (e.g., stock and bond markets, government incentives, regulated or nonregulated rate-of-return on investment).

Figure 1.1 provides a pictorial view of the many elements of the electricity system touched by smart grid concerns. The 21 metrics evaluated in this report touch every element identified in the figure, from the accommodation of all generation and energy options to the integration of end-user equipment, including EVs, smart appliances, and DG.

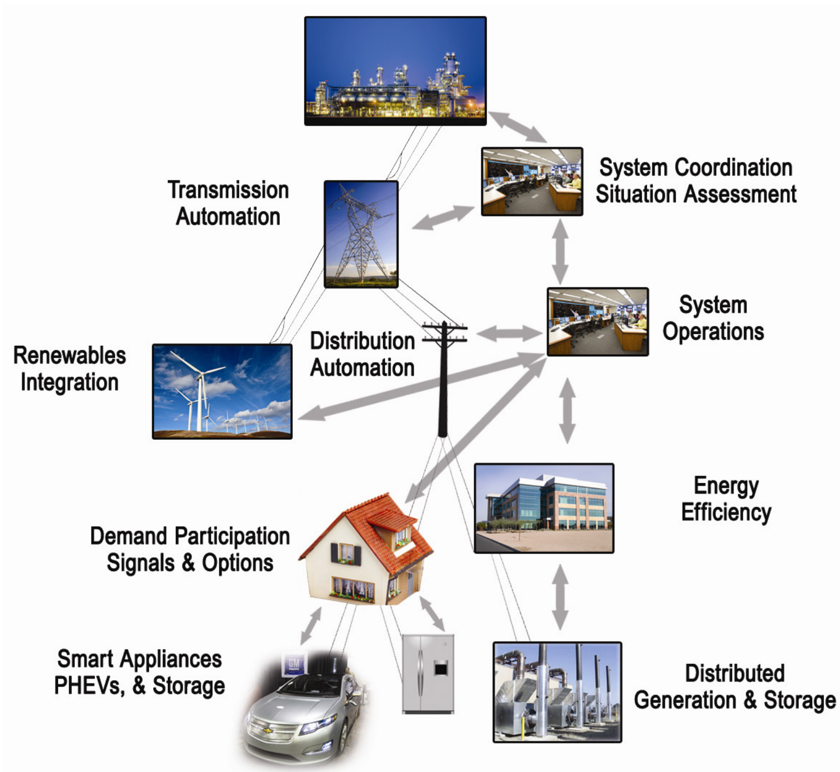

Figure 1.1. Scope of Smart Grid Concerns

1.2 Stakeholder Landscape

Some aspect of the electricity system touches every person in the nation. The smart grid stakeholder landscape is complex, as demonstrated in Figure 1.2. The lines of distinction are not always well defined as corporations and other organizations can take on the characteristics and responsibilities of multiple functions.

The electric system provides reliable, cost-effective service to connected end users who obtain electricity from distribution service providers, energy service retailers, and in some cases, self-generation. Note the arrows connecting these stakeholders and the bottoms up approach to building the landscape from left to right in Figure 1.2. Today, these services are usually handled by the same organization, but that is not always the case. The energy service retailer purchases wholesale electricity and can use aggregated end-use load for use in wholesale generation and demand response contracts. The wholesalers then negotiate generation and demand response as coordinated by wholesale market operators. To see that the delivery of electricity supports these agreements, distribution providers coordinate with transmission providers who operate within the directives of the balancing authorities. The reliability coordinators provide the regional processes and checks and balances to ensure stable, interconnected system operations. This involves coordination with all the bulk electric power stakeholders. The North American Electric Reliability Corporation (NERC) has been given the responsibility by the Federal Energy Regulatory Commission (FERC) to be the national electric reliability organization for coordination of all groups with bulk system reliability responsibility.

All of these organizations are critical to the real time operation of the electric system. They are supported in their operations (see supporting organizations box in Figure 1.2) by companies that provide technology products and services, as well as the legislative and regulatory bodies that initiate and enforce local, regional, and national policies. Advocates for various operational aspects attempt to drive new policies and revisions. Standards organizations convene relevant stakeholders to align communities on technical interfaces and best practices. Lastly, the financial community supports operations and planning with monetary exchange, investment vehicles, and other financial trades. These major stakeholder groups are referenced throughout the report as appropriate to the topic in question.

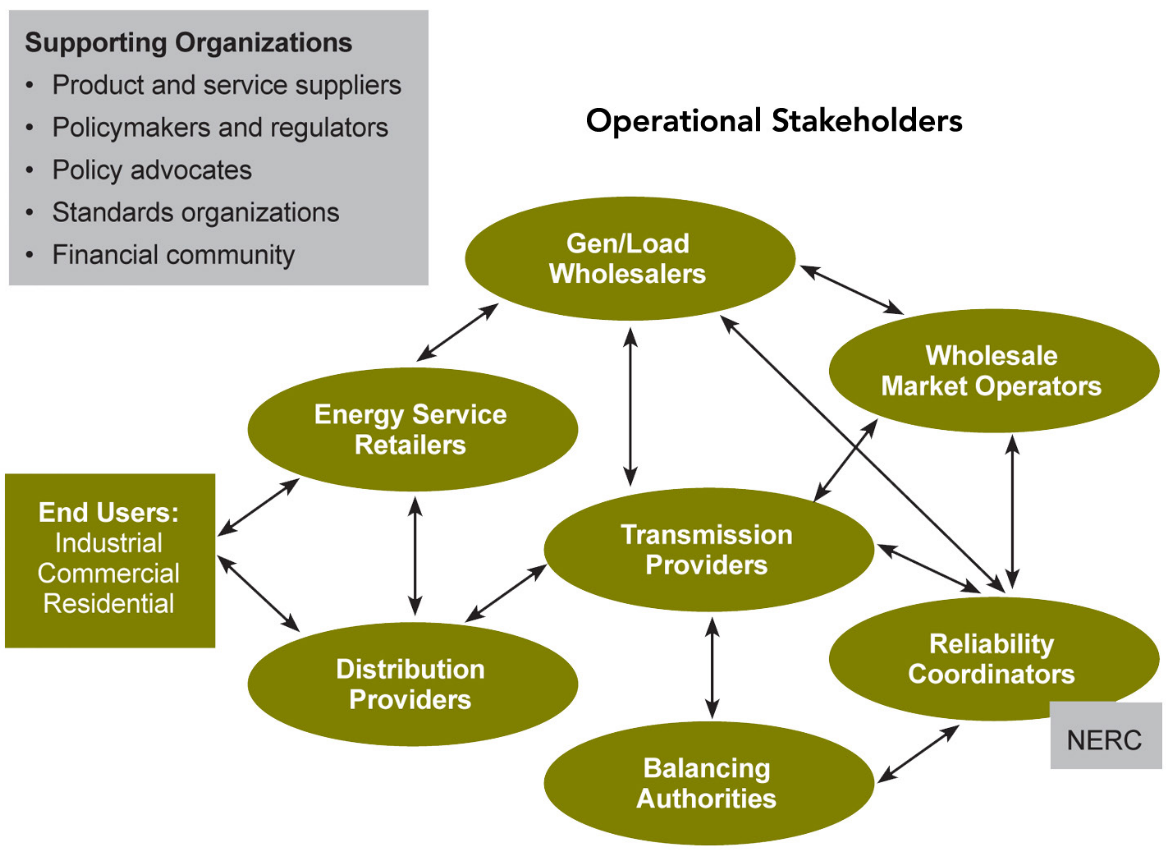

Figure 1.2. Stakeholder Landscape

1.3 Regional Influences

Different areas of the country have distinctions with regard to their generation resources, their economy, climate, topography, environmental concerns, markets and public policy. These distinctions influence the picture for smart grid deployment in each region, provide different incentives, and pose different obstacles for development. The major regions of the country can be divided into the ten NERC reliability regions (see Figure 1.3) (EPA 2008). The U.S. Environmental Protection Agency (EPA) further subdivides these into 26 sub-regions (see EPA map, Figure 1.4), and each of these regions has its distinctive state and local governments. Regional factors are woven into various aspects of the report, including the smart grid deployment metrics, deployment attributes, trends, and obstacles. Discussion will target the states and major NERC reliability regions.

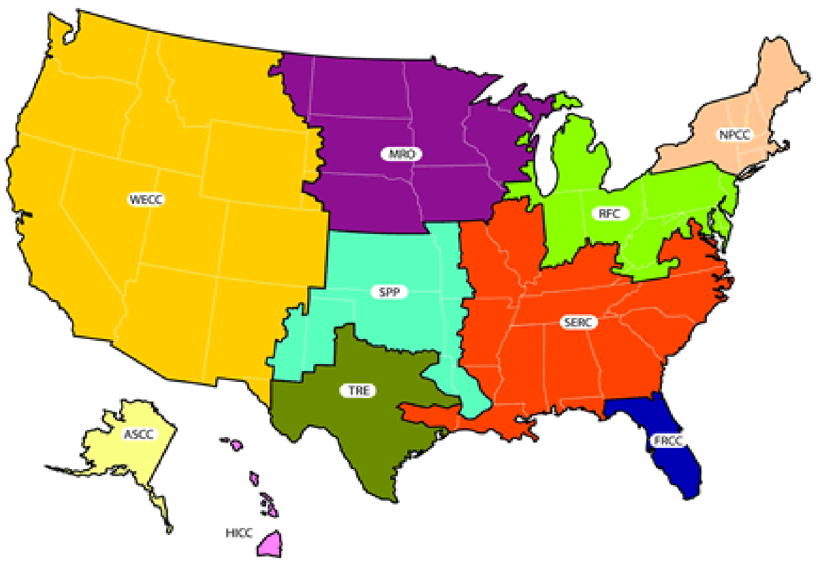

Figure 1.3. NERC Region Representation Map

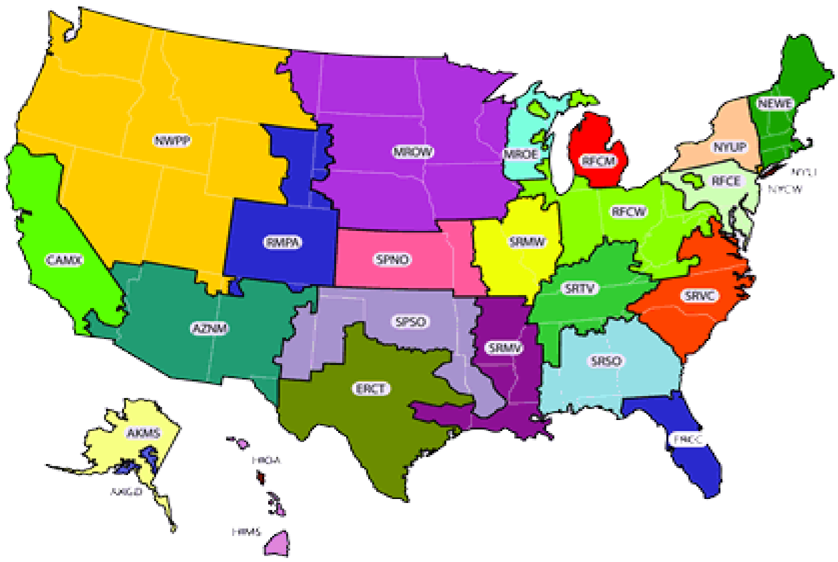

Figure 1.4. EPA eGRID Subregion Representational Map

1.4 About this Document

This report is organized into a main body and two supporting appendices. The main body discusses the metrics chosen to provide insight into the progress of smart grid deployment nationally. The measurements resulting from research into the metrics are used to convey the state of smart grid progress according to six characteristics derived from the National Energy Technology Laboratory (NETL) Modern Grid Initiative's work in this area and discussions at the Department of Energy (DOE) Smart Grid Implementation Workshop. The metric measurements are compared against those presented in the 2009 and 2010 SGSRs. Note that this is not an SGSR but rather a report designed to assess the metrics measured previously in past SGSRs. The main body of this report also summarizes the barriers to smart grid deployment, including technical, business, and financial challenges. Appendix A presents a discussion of each of the metrics chosen to help measure the progress of smart grid deployment. Appendix B summarizes the results of interviews with 30 ESPs chosen to represent a cross section of the nation in terms of size, location, and type of organization (e.g., public or private company, rural electric cooperative).

2.0 Deployment Metrics and Measurements

The scope of smart grid functionality extends throughout the electricity system and its supply chain. The supply chain includes all the entities required to get a product or service from the supplier to the consumer. To measure the status of smart grid deployments, multiple metrics were chosen as indicators of smart grid progress. Although these metrics do not cover all aspects of a smart grid, they were chosen to address a balance of coverage in significant functional areas and to support the communication of its status through a set of smart grid attributes that have been formed through workshop engagements with industry.

2.1 Smart Grid Metrics

On June 19–20, 2008, DOE brought together 140 experts, representing the various smart grid stakeholder groups, at a workshop in Washington, D.C. The objective of the workshop was to identify a set of metrics for measuring progress toward implementation of smart grid technologies, practices, and services. Breakout sessions for the workshop were organized around seven major smart grid characteristics as developed through another set of industry workshops sponsored by the NETL Modern Grid Strategy (Miller 2009). The results of the workshop document more than 50 metrics for measuring smart grid progress (DOE 2008). Having balanced participation across the diverse electricity system stakeholders is important for deriving appropriate metrics and was an important objective for selecting individuals to invite to the workshop.

The workshop described two types of metrics: *build* metrics that describe attributes that are built in support of smart grid capabilities and *value* metrics that describe the value that may be derived from achieving a smart grid. Although build metrics tend to be easily quantifiable, value metrics can be influenced by many developments and therefore generally require more qualifying discussion. Both types are important to describe the status of smart grid implementation.

After reviewing the workshop results, distilling the recorded ideas, and augmenting them with additional insights provided by the research team, DOE defined 20 metrics for the 2009 SGSR. These metrics were slightly modified for the 2010 SGSR.

To solicit stakeholder input regarding ideas for refining the metrics presented in this report, a series of stakeholder webinars was held by the Pacific Northwest National Laboratory (PNNL) from January 17 through January 20, 2012. The webinars were attended by 193 experts representing ESPs, standards organizations, smart grid demonstration projects, distribution service providers, telecommunications companies, products and services suppliers, and policy advocacy groups. The webinars were designed to register feedback regarding metric definition/refinement, data sources/availability, identification of relevant stakeholder groups, and regional influences.

In reviewing the webinar results, the research team identified several relevant messages:

- Most metrics in the 2010 SGSR are well structured and relevant, but some are in need of modification.
- The consumer perspective should be addressed on a broader scale.

- In terms of regulatory recovery, Metric 4 [Policy/Regulatory Recovery Progress] should be modified to focus more on decoupling programs, which are often used to help utilities recover costs where shortfalls in revenue would result from the implementation of energy efficiency programs.
- We should consider a metric tied to reliability improvements resulting from microgrids.
- Several sources could be used to close data gaps present in the SGSRs, including data available through the National Association of Regulatory Utility Commissioners [NARUC), ARRA projects, third-party data vendors, the Energy Information Administration (EIA), smartgrid.gov, the Smart Grid Maturity Model (SGMM), the Database of State Incentives for Renewable Energy (DSIRE), and other research organizations.
- Numerous metrics were identified as relevant but nascent (e.g., non-generating demand response equipment and dynamic line ratings).
- This report should identify, evaluate, and track the use of energy storage devices to provide various services or value streams (e.g., balancing services, arbitrage, load following).
- This report should measure automation at the transmission, sub-transmission, and distribution levels.
- Additional thought should be given to changing Metric 18 [Cybersecurity]. Potential metrics could include the use of applications being purchased for smart grid-related security or expenditures on such applications.
- A small number of metrics suffer from poor definition—e.g., metrics regarding microgrids and regulatory recovery.
- Additional stakeholders were identified.

Based on the input received through the webinars and further assessment made by the research team, the 21 primary metrics used in the 2010 SGSR were employed for this report.

2.2 Assessing the Smart Grid Metrics

Table 2.1 lists the 21 metrics used in this report. The table indicates each metric's status (penetration level/maturity) and trend. The intent is to provide a high-level, simplified perspective of a complicated picture. If it is a build metric, the penetration level is indicated as nascent (very low and just emerging), low, moderate, or high. Because smart grid activity is relatively new, there are no high penetration levels to report on these metrics at the present time. The trend (recent past and near-term projection over the next 4-6 years) for build metrics is indicated as nascent, low, moderate, or high levels. For value metrics, the maturity of the system is indicated as either nascent or mature. The trend for value metrics is indicated as worsening, flat, or improving. An investigation of the measurements for each metric is presented in Appendix A.

In this report, the following changes have been made to the status of metrics reported in Table 2.1 as compared to those reported in the 2010 SGSR:

- Metric 4 – Electricity service providers interviewed for this report indicated that, on average (weighted), they are recovering 59.8 percent of their investment through rate structures, compared to 23.5 percent in the 2010 SGSR, and 8.1 percent estimated for the 2009 SGSR. The respondents further predicted that regulatory recovery rates will expand in the future, ultimately reaching 94.9

percent (see Appendix B). The predicted recovery rates far exceed the 37.3 percent estimated by ESPs in 2010. Thus, the current penetration/maturity level assigned to policy/regulatory progress was changed from low to moderate. The long-term trend was adjusted to high.

- Metric 6 – Microgrids may become more prevalent with the adoption of the Institute of Electrical and Electronics Engineers (IEEE) Standard 1547.4-2011 (IEEE 2011). Microgrids currently provide 575 megawatts (MW) of capacity in the United States and have the potential to reach 1,500 MW by 2017, according to Pike Research (Asmus and Wheelock 2012). Thus, the current penetration/maturity level assigned to this metric was changed from nascent to low, while the long-term trend remained low. A microgrid is defined as a "group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to be operated in both grid-connected or island mode" (Bossart 2012).
- Metric 10 – From 2003 through 2011, transmission and distribution (T&D) reliability, as measured in the IEEE benchmarking studies, was flat in the United States. From 2003 through 2011, there was no change in the Customer Average Interruption Duration Index (CAIDI) and a slight increase in the System Average Interruption Frequency Index (SAIFI) (IEEE 2012). Thus, the trend was changed to flat.
- Metric 20 – Venture capital funding of smart grid startups topped $878 million during the 2010–2011 timeframe (Cleantech Group 2012). The current penetration/maturity level for this metric was changed from nascent to low, while the long-term trend remained high.

Table 2.2 presents the metric findings of the two SGSRs completed to date and for this report. Unless otherwise noted, the information presented in the 2009 and 2010 SGSR columns was obtained from those SGSRs.

Table 2.1. Assessment of Smart Grid Metrics

#	**Metric Title** (*Type: build or value*)	**Penetration/ Maturity**	**Trend**
1	Dynamic Pricing (*build*): fraction of customers and total load served by RTP, CPP, and TOU tariffs*	low	moderate
2	Real-Time System Operations Data Sharing (*build*): total SCADA points shared and fraction of phasor measurement points shared*	moderate	high
3	Distributed-Resource Interconnection Policy (*build*): percentage of electricity service providers with standard distributed-resource interconnection policies and commonality of such policies across electricity service providers	moderate	high
4	Policy/Regulatory Progress (*build*): weighted-average percentage of smart grid investment recovered through rates (respondents' input weighted based on total customer share)	moderate	high
5	Load Participation Based on Grid Conditions (*build*): fraction of load served by interruptible tariffs, direct load control, and consumer load control with incentives	low	low
6	Load Served by Microgrids (*build*): percentage of total summer grid capacity	low	low
7	Grid-Connected Distributed Generation (renewable and non-renewable) and Storage (*build*): percentage of distributed generation and storage	low	high
8	EVs and PHEVs (*build*): percentage shares of on-road light-duty vehicles comprising EVs and PHEVs*	nascent	low
9	Non-Generating Demand Response Equipment (*build*): total load served by smart, grid-responsive equipment	nascent	low
10	T&D System Reliability (*value*): CAIDI, SAIDI, SAIFI, MAIFI*	mature	flat
11	T&D Automation (*build*): percentage of substations having automation	moderate	high
12	Advanced Meters (*build*): percentage of total demand served by AMI customers	low	high
13	Advanced Measurement Systems (*build*): percentage of substations possessing advanced measurement technology	moderate	high
14	Capacity Factors (*value*): yearly average and peak-generation capacity factor	mature	flat
15	Generation and T&D Efficiencies (*value*): percentage of energy consumed to generate electricity that is not lost	mature	improving
16	Dynamic Line Ratings (*build*): percentage of miles of transmission circuits being operated under dynamic line ratings	nascent	low
17	Power Quality (*value*): percentage of customer complaints related to power quality issues, excluding outages	mature	worsening
18	Cybersecurity (*build*): percentage of total generation capacity under companies in compliance with the NERC critical infrastructure protection standards	low	low
19	Open Architecture/Standards (*build*): interoperability maturity level – weighted-average maturity level of interoperability realized between electricity system stakeholders	nascent	low
20	Venture Capital Funding (*build*): total annual venture capital funding of smart grid startups located in the United States,	low	high
21	Grid-Connected Renewable Resources (*build*): percentage of renewable electricity, in terms of both generation and capacity	low	moderate

*AMI = advanced metering infrastructure; RTP = real time pricing; CPP = critical peak pricing; TOU = time-of-use pricing; SCADA = supervisory control and data acquisition; EV = electric vehicle; PHEV = plug-in hybrid electric vehicle; CAIDI = customer average interruption duration index; SAIDI = system average interruption duration index; SAIFI = system average interruption frequency index; MAIFI = momentary average interruption frequency index; NERC = North American Electric Reliability Corporation

Table 2.2. Smart Grid Metrics and Status (2009, 2010, and 2012 SGSRs)

#	**Metric Title** (*Type: build or value*)	**2009 SGSR**	**2010 SGSR**	**2012 Smart Grid Status and Metrics Report**
1	Dynamic Pricing (*build*): fraction of customers and total load served by Real-Time Pricing, Critical-Peak Pricing, and Time-of-Use Pricing Tariffs	Number of entities in 2008 offering, and customers served by, dynamic pricing tariffs: • Real-Time Pricing: 100 ESPs • Critical Peak Pricing: 88 ESPs • Time-of-use Pricing: 315 ESPs and 1.3 million customers (1.1 percent).	Number of entities in 2008 offering, and customers served by, dynamic pricing tariffs: • Real-Time Pricing: 100 ESPs • Critical Peak Pricing: 88 ESPs • Time-of-use Pricing: 315 ESPs and 1.3 million customers (1.1 percent).	Number of entities in 2010 offering, and customers served by, dynamic pricing tariffs: • Real-Time Pricing: 26 ESPs • Critical Peak Pricing: 52 ESPs • Time-of-use Pricing: 169 ESPs and 1.1 million customers (1.1 percent) (FERC 2011).[1]
2	Real-Time System Operations Data Sharing (*build*): total SCADA points shared and fraction of phasor measurement points shared	A survey by Newton-Evans Research Company indicated that 28 percent of responding utilities were sharing SCADA information with ISO/RTOs and 21 percent had linkages with regional control systems. NASPI documented the number of networked phasor measurement units (PMUs) in the United States at 140 in 2009.	A survey by Newton-Evans Research Company (2010) indicated that 5 percent of reporting utilities had invested in distribution management systems (DMS) only, 21 percent in SCADA/DMS combined, 40 percent SCADA only, 31 percent energy management systems (EMS)/SCADA combined, and 11 percent EMS only. NASPI documented the number of networked PMUs in the United States at 166 in 2010.	A survey by Newton-Evans Research Company (2010) indicated that 5 percent of reporting utilities had invested in DMS only, 21 percent in SCADA/DMS combined, 40 percent SCADA only, 31 percent EMS/SCADA combined, and 11 percent EMS only. In March 2012, there were approximately 500 networked PMUs in the United States (EIA 2012a).
3	Distributed-Resource Interconnection Policy (*build*): percentage of electricity service providers with standard distributed-resource interconnection policies and commonality of such policies across ESPs	In 2008, 31 states plus Washington DC had adopted variations of an interconnection policy, representing an estimated 61 percent of all utilities. The favorability of interconnection policies was rated as follows: • Favorable Interconnection Policies: 15 • Neutral: 12 • Unfavorable: 5 • No Policy: 19.	In 2010, 39 states plus Washington DC had adopted variations of an interconnection policy, representing an estimated 84 percent of all utilities. The favorability of state interconnection policies was rated as follows: • Favorable Interconnection Policies: 13 • Neutral: 15 • Unfavorable or no policy: 22 states.	In 2012, 43 states plus Washington DC had adopted variations of an interconnection policy, representing an estimated 87 percent of all utilities (DSIRE 2012a). The favorability of state interconnection policies was rated as follows: • Favorable Interconnection Policies: 23 • Neutral: 7 • Unfavorable or no policy: 20 (NNEC 2011)

[1] The decline in the number of ESPs reporting dynamic pricing tariffs is due in part to a change in FERC's methodology, which was made in order to eliminate double counting of pricing programs and sharpen the classification of pricing and demand response programs.

Table 2.2. (contd)

#	Metric Title (*Type: build or value*)	2009 SGSR	2010 SGSR	2012 Smart Grid Status and Metrics Report
4	Policy/Regulatory Recovery Progress (*build*): weighted-average percentage of smart grid investment recovered through rates (respondents' input weighted based on total customer share)	ESPs surveyed for the SGSR indicated that, on average (weighted), they were recovering 8.1 percent of their smart grid investments through rate structures. The status of alternative rate structures that encourage smart grid deployment at the state level are as follows: • Decoupling not used: 10 states • Decoupling proposed but not adopted: 11 states • Investigating decoupling: 3 states plus Washington D.C. • Decoupling has been approved for at least one utility: 10 states.	ESPs surveyed for the SGSR indicated that, on average (weighted), they were recovering 23.5 percent of their smart grid investments through rate structures. The status of alternative rate structures that encourage smart grid deployment at the state level are as follows: • Electric decoupling mechanisms in place: 13 states • Policies pending: 8 states • Lost Revenue Adjustment Mechanisms: 9 states.	ESPs surveyed for this report indicated that, on average (weighted), they were recovering 59.8 percent of their smart grid investments through rate structures (Appendix B). The status of alternative rate structures that encourage smart grid deployment at the state level are as follows: • Electric decoupling mechanisms in place: 13 states plus Washington DC • Policies pending: 9 states • Lost Revenue Adjustment Mechanisms: 9 states (IEE 2011).
5	Load Participation Based on Grid Conditions (*build*): fraction of load served by interruptible tariffs, direct load control, and consumer load control with incentives	In 2007, 12,545 MW, or 1.2 percent of net summer capacity, of peak load reduction was realized through direct load control and interruptible demand.	In 2008, 12,064 MW, or 1.2 percent of net summer capacity, of peak load reduction was realized through direct load control and interruptible demand.	In 2010, 12,536 MW, or 1.2 percent of net summer capacity, of peak load reduction was realized through direct load control and interruptible demand (EIA 2012b and EIA 2013).
6	Load Served by Microgrids (*build*): percentage of total summer grid capacity	In 2005, 20 microgrids were identified providing 785 MW of capacity.	In 2005, 20 microgrids were identified providing 785 MW of capacity.	In 2012, microgrids were providing 575 MW of capacity in the United States. Microgrids have the potential to reach 1,500 MW by 2017 (Asmus and Wheelock 2012).
7	Grid-Connected Distributed Generation (renewable and non-renewable) and Storage (*build*): percentage of distributed generation and storage	In 2007, distributed generation capacity reached 12,702 MW, or 1.6 percent of summer peak load.	In 2008, distributed generation capacity reached 12,863 MW, or 1.7 percent of summer peak load.	In 2010, the EIA changed its definition of DG. Through 2009, DG values were reported based on the "less than or equal to 10 megavolt-ampere (MVA)" definition; DG capacity reached 14,273 MW in 2009, up 154 percent from 2004. Actively managed DG represents approximately 1.4 percent

Table 2.2. (contd)

#	Metric Title (*Type: build or value*)	2009 SGSR	2010 SGSR	2012 Smart Grid Status and Metrics Report
				of total generating capacity and 89 percent of total DG. After 2009, the 1 MVA definition was used. Under the revised definition, 2,002 MW of DG capacity (0.3 percent of summer peak load) was measured in 2010 (EIA 2011a).
8	EVs and PHEVs (*build*): percentage shares of on-road light-duty vehicles comprising EVs and PHEVs	In 2008, the number of plug-in electric vehicles (PEVs) operating on-road in the United States was 26,823, or .01 percent of the light-duty vehicle fleet.	In 2010, the number of PEVs operating on-road in the United States was 21,601, or .01 percent of the light-duty vehicle fleet.	In 2010, the number of PEVs operating on-road in the United States was 21,601, or .01 percent of the light-duty vehicle fleet (EIA 2012c). In 2012, new PEV sales reached 52,835, or 0.4 percent of the U.S. light-duty vehicle market (Electric Drive Transport Association 2013).
9	Non-Generating Demand Response Equipment (*build*): total load served by smart grid-responsive equipment	Non-generating demand response equipment remains in a nascent commercial stage. According to interviews conducted for the SGSR: • 45.0 percent of responding ESPs had no automated responses for signals sent to major energy-using equipment • 45.0 percent had some automated responses in development, and • 10.0 percent had a small amount (less than 10 percent of all customers) of automated responses in place.	Non-generating demand response equipment remains in a nascent commercial stage. According to interviews conducted for the SGSR: • 62.5 percent of responding ESPs had no automated responses for signals sent to major energy-using equipment • 29.2 percent had some automated responses in development, and • 8.3 percent had a small amount (less than 10 percent of all customers) of automated responses in place.	As of September 30, 2012, 186,687 programmable communicating thermostats and 282,571 direct load control devices had been deployed under the Smart Grid Investment Grant (SGIG) Program and Smart Grid Demonstration Program (SGDP) combined (DOE 2012b). According to interviews conducted for this report: • 43.3 percent of responding ESPs had no automated responses for signals sent to major energy-using equipment • 23.3 percent had some automated responses in development, and • 33.3 percent did not respond to the question

Table 2.2. (contd)

#	**Metric Title** (*Type: build or value*)	**2009 SGSR**	**2010 SGSR**	**2012 Smart Grid Status and Metrics Report**
10	T&D System Reliability (*value*): CAIDI, SAIDI, SAIFI, MAIFI	The IEEE benchmarking study analyzes SAIDI, SAIFI and CAIDI data for companies representing millions of customers in the United States and Canada. For 2008, IEEE reported the following findings: • SAIDI – 142 • SAIFI – 1.25 • CAIDI – 113.	The IEEE benchmarking study analyzes SAIDI, SAIFI and CAIDI data for companies representing millions of customers in the United States and Canada. For 2010, IEEE reported the following findings: • SAIDI – 136 • SAIFI – 1.21 • CAIDI – 112.	The IEEE benchmarking study analyzes SAIDI, SAIFI and CAIDI data for companies representing millions of customers in the United States and Canada. For 2011, IEEE reported the following findings (IEEE 2012): • SAIDI – 143 • SAIFI – 1.29 • CAIDI – 111.
11	T&D Automation (*build*): percentage of substations having automation	The results of the interviews conducted for the 2009 SGSR indicated that of the substations owned by responding ESPs: • 27.9 percent were automated • 46.4 percent had outage detection • 46.2 percent had circuits with outage detection • 81.2 percent of total relays were electromechanical relays • 20.3 percent of total relays were microprocessor relays.	The results of the interviews conducted for the 2010 SGSR indicated that of the substations owned by responding ESPs: • 47.7 percent were automated • 78.2 percent had outage detection • 82.1 percent had circuits with outage detection • 46.4 percent of total relays were electromechanical relays • 13.4 percent of total relays were microprocessor relays.	The results of the interviews conducted for this report indicated that of the substations owned by responding ESPs: • 85.7 percent were automated • 93.0 percent had outage detection • 93.6 percent had circuits with outage detection • 58.4 percent of total relays were electromechanical relays • 41.5 percent of total relays were microprocessor relays.
12	Advanced Meters (*build*): percentage of total demand served by AMI customers	The total number of advanced meters deployed in the United States reached 6.7 million in 2008, or 4.7 percent of all US meters.	The total number of advanced meters deployed in the United States reached 16.0 million in 2010, or 10.0 percent of all US meters.	The number of advanced meters installed in the United States reached 36 million in 2012, or 24.2 percent of all U.S. meters (IEE 2012).
13	Advanced Measurement Systems (*build*): percentage of substations possessing advanced measurement technology	NASPI documented a total of 140 networked PMUs installed in the United States in 2009.	In 2010, the number of installed PMUs had reached 166 in the United States.	In March 2012, the number of networked PMUs had reached approximately 500 in the United States (EIA 2012a). The number of networked PMUs had grown to nearly 1,700 by December 2013 (Silverstein 2013).

Table 2.2. (contd)

#	Metric Title (*Type: build or value*)	2009 SGSR	2010 SGSR	2012 Smart Grid Status and Metrics Report
14	Capacity Factors (*value*): yearly average and peak-generation capacity factor	In 2006, capacity factors in the United States were estimated as follows: • Peak Summer: 82.7 percent • Peak Winter: 65.2 percent.	In 2008, capacity factors in the United States were estimated as follows: • Peak Summer: 75.7 percent • Peak Winter: 66.1 percent.	In 2011, capacity factors in the United States were estimated as follows: • Peak Summer: 72.0 percent • Peak Winter: 62.0 percent (NERC 2011a).
15	Generation and T&D Efficiencies (*value*): percentage of energy consumed to generate electricity that is not lost	In 2007, generation and T&D efficiencies in the United States were estimated at 32.3 percent and 92.9 percent, respectively.	In 2009, generation and T&D efficiencies in the United States were estimated at 34.1 percent and 93.5 percent, respectively.	In 2011 generation efficiencies in the United States were estimated at 37.0 percent (EIA 2011b). In 2010, T&D efficiencies in the U.S. were estimated at 93.7 percent (EIA 2012d)
16	Dynamic Line Ratings (*build*): percentage of miles of transmission circuits being operated under dynamic line ratings	ESPs interviewed for the 2009 SGSR indicated that, on average, 0.3 percent of all conductors were dynamically rated.	ESPs interviewed for the 2010 SGSR indicated that, on average, 0.6 percent of all conductors were dynamically rated.	None of the ESPs interviewed for this study reported lines with dynamic rating (Appendix B).
17	Power Quality (*value*): percentage of customer complaints related to power quality issues, excluding outages	The percentage of all customer complaints related to PQ issues were estimated by the ESPs interviewed for the 2009 SGSR at 3.1 percent.	The percentage of all customer complaints related to PQ issues were estimated by the ESPs interviewed for the 2010 SGSR at 0.6 percent.	The percentage of all customer complaints related to PQ issues were estimated by the ESPs interviewed for this report as follows: • Residential customers: 1.2 percent • Commercial customers: 0.4 percent • Industrial customers: 0.1 percent (Appendix B).
18	Cybersecurity (*build*): percentage of total generation capacity under companies in compliance with the NERC critical infrastructure protection standards	NERC CIP violations were not reported in the 2009 SGSR.	In 2010, there were 1,059 NERC CIP violations (NERC 2010).	In 2012, there were 1,113 NERC CIP violations (NERC 2013).

Table 2.2. (contd)

#	**Metric Title** (*Type: build or value*)	**2009 SGSR**	**2010 SGSR**	**2012 Smart Grid Status and Metrics Report**
19	Open Architecture/Standards (*build*): interoperability maturity level – weighted-average maturity level of interoperability realized between electricity system stakeholders	Interoperability maturity levels were not reported in the 2009 SGSR.	Interoperability maturity levels were not reported in the 2010 SGSR.	ESPs interviewed for this study reported the following levels of interoperability maturity: • Initial (Level 1): 20.0 percent • Managed (Level 2): 16.7 percent • Defined (Level 3): 36.7 percent • Quantitatively management (Level 4): 13.3 percent • Optimizing (Level 5): 0.0 percent • No Response: 13.3 percent (Appendix B).
20	Venture Capital Funding (*build*): total annual venture capital funding of smart grid startups located in the United States	In 2008, venture capital funding of smart grid startups totaled $345 million.	In 2009, venture capital funding of smart grid startups totaled $422 million.	In 2011, venture capital funding of smart grid startups reached $455 million (Cleantech Group 2012).
21	Grid-Connected Renewable Resources (*build*): percentage of renewable electricity, in terms of both generation and capacity	Not included in 2009 SGSR.	Renewable generation was 3.7 percent of total grid-connected electricity generation in 2009. Non-hydro renewable energy capacity as a percentage of total summer peak was 4.8 percent in 2009.	Renewable generation was 4.1 percent of total grid-connected electricity generation in 2010. Non-hydro renewable energy capacity as a percentage of total summer peak was 5.2 percent in 2010 (EIA 2011c).

2.3 Smart Grid Characteristics

The metrics identified in Table 2.1 are used in Section 4 to describe deployment status as organized around six major characteristics of a smart grid, as described in Table 2.3. The characteristics are derived from the seven characteristics in the Modern Grid Strategy work described earlier and augmented slightly in the organization of the metrics workshop. The sixth characteristic in the table is a merger of the workshop characteristics a) Addresses and Responds to System Disturbances in a Self-Healing Manner and b) Operates Resiliently Against Physical and Cyber Attacks and Natural Disasters. The same metrics substantially contribute to both of these concerns.

2.4 Mapping Metrics to Characteristics

Section 4 of this report evaluates the trends associated with smart grid deployment using the six characteristics presented in Table 2.3. A map of how the 21 metrics support the six characteristics is shown in Table 2.4. Notice that nearly every metric contributes to multiple characteristics. To reduce the repetition of statements about the metrics, each metric was assigned a primary characteristic for emphasis. The table indicates the characteristic in which a metric is emphasized as “Emphasis.” The other characteristic cells where a metric plays an important but not primary role are indicated by “Mention.” This should not be interpreted to indicate secondary importance, only that a metric finding is mentioned under the characteristic in order to reduce redundancy of material in explaining the status of smart grid deployment.

Table 2.3. Smart Grid Characteristics

Characteristic	Description
1. Enables Informed Participation by Customers	Consumers are participating in the management of electricity due to the deployment of advanced metering infrastructure (including smart meters) and associated customer-based information and control technologies. These technologies will permit consumers to adjust their use of electricity, especially when deployed in conjunction with time-based rates or other incentives that influence demand.
2. Accommodates All Generation & Storage Options	A smart grid accommodates not only large, centralized power plants, but also the growing array of DER. Intelligent systems are required to effectively handle variable power introduced by renewable generation, as well as the need to rapidly use different power sources to effectively balance changing load and demand patterns. DER integration will increase rapidly all along the value chain, from suppliers to marketers to customers. Those distributed resources will be diverse and widespread, including renewables, DG and energy storage.
3. Enables New Products, Services, & Markets	Markets that are correctly designed and efficiently operated reveal cost-benefit tradeoffs to consumers by creating an opportunity for competing services to bid. A smart grid accounts for all of the fundamental dynamics of the value/cost relationship. Some of the independent grid variables that must be explicitly managed are energy, capacity, location, time, rate of change, and quality. Markets can play a major role in the management of these variables. Regulators, owners/operators, and consumers need the flexibility to modify the rules of business to suit operating and market conditions.
4. Provides Power Quality for the Range of Needs	Not all commercial enterprises, and certainly not all residential customers, need the same quality of power. The cost of premium PQ features can be included in the electricity service contract. Advanced control methods monitor essential components, enabling rapid diagnosis and precise solutions to PQ events, such as those that arise from lightning, switching surges, line faults and harmonic sources. A smart grid also helps buffer the electricity system from irregularities caused by consumer electronic loads.
5. Optimizes Asset Utilization & Operating Efficiency	A smart grid applies the latest technologies to optimize the use of its assets. For example, optimized capacity can be attainable with dynamic ratings, which allow assets to be used at greater loads by continuously sensing and rating their capacities. Maintenance efficiency involves attaining a reliable state of equipment or "optimized condition." This state is attainable with condition-based maintenance, which signals the need for equipment maintenance at precisely the right time. System-control devices can be adjusted to reduce losses and eliminate congestion. Operating efficiency increases when selecting the least-cost energy-delivery system available through these adjustments of system-control devices.
6. Operates Resiliently to Disturbances, Attacks, & Natural Disasters	Resilience refers to the ability of a system to react to events such that problematic elements are isolated while the rest of the system is restored to normal operation. These self-healing actions result in reduced interruption of service to consumers and help service providers better manage the delivery infrastructure. A smart grid using continuous self-assessments detects and takes corrective action to respond to momentary outages. A smart grid responds resiliently to attacks, whether the result of natural disasters or organized by others. These threats include physical attacks and cyber-attacks. A smart grid addresses security from the outset, as a requirement for all the elements, and ensures an integrated and balanced approach across the system.

Table 2.4. Map of Metrics to Smart Grid Characteristics

Metric No.	Metric Name	Enables Informed Participation by Customers	Accom-modates All Generation & Storage Options	Enables New Products, Services, & Markets	Provides Power Quality for the Range of Needs	Optimizes Asset Utilization & Efficient Operation	Operates Resiliently to Disturbances, Attacks, & Natural Disasters
1	Dynamic Pricing	Emphasis	Mention	Mention			Mention
2	Real-Time Data Sharing					Mention	Emphasis
3	DER Interconnection	Mention	Emphasis	Mention		Mention	
4	Regulatory Policy			Emphasis			
5	Load Participation	Emphasis			Mention	Mention	Mention
6	Microgrids		Mention	Mention	Emphasis		Mention
7	DG & Storage	Mention	Emphasis	Mention	Mention	Mention	Mention
8	Electric Vehicles	Mention	Mention	Emphasis			Mention
9	Grid-Responsive Load	Mention	Mention	Mention	Mention		Emphasis
10	T&D Reliability						Emphasis
11	T&D Automation				Mention	Emphasis	Mention
12	Advanced Meters	Emphasis	Mention	Mention			Mention
13	Advanced Sensors						Emphasis
14	Capacity Factors					Emphasis	
15	Generation, T&D Efficiency					Emphasis	
16	Dynamic Line Rating					Emphasis	Mention
17	Power Quality			Mention	Emphasis		
18	Cybersecurity						Emphasis
19	Open Architecture/Stds.			Emphasis			
20	Venture Capital/			Emphasis			
21	Renewable Resources		Emphasis	Mention	Mention	Mention	

3.0 Recent Advancements in the Smart Grid

This report looks across a spectrum of smart grid concerns and uses the 21 metrics presented in Table 2.1 for measuring the status of smart grid deployment and impacts. Across the vast scope of smart grid deployments, many things have been measured and a number of advancements have taken place since the 2010 SGSR was published. This section presents the main findings with respect to recent developments in smart grid deployments.

3.1 ARRA Investments

The EISA authorized programs designed to incentivize electricity company investments in the smart grid. Section 1306, as amended by ARRA, authorized the Secretary of the DOE to establish the SGIG program, which provides matching grants to cover up to 50 percent of an ESPs investment in smart grid technologies. Section 1304 authorized a smart grid regional demonstration initiative. In 2009, ARRA designated $4.5 billion in awards for all programs described under Title IV (123 Stat. 138).

ARRA funded two major technology deployment initiatives: the SGIG and the SGDP. These programs are currently implementing 131 deployment and demonstration projects. As of September 30, 2012, investments made under the SGIG and SGDP include deployment of the following: 12.1 million advanced meters, 569 phasor measurement units, 7,269 automated feeder switches, 10,749 automated capacitors, 15,376 substation monitors, 775 electric vehicle charging stations and 186,687 programmable communicating thermostats (DOE 2012b and Wang 2013). DOE maintains a website (www.smartgrid.gov) to provide information about progress and results from these projects. The website also contains background information, case studies, data on the numbers of installed devices and their costs, and a library with more than 1,400 smart grid documents and reports.

3.1.1 Smart Grid Investment Grant Program

The SGIG program, which received $3.4 billion under ARRA, has authorized 99 projects at a total cost of $8 billion. Figure 4.1 presents the status of SGIG investments made through September 30, 2012 (DOE 2012b). These values represent total costs, which are the sum of the federal investment and cost share of the recipient. The recipient cost share under ARRA must be at least 50 percent of the total overall project cost.

Approximately 56 percent of the total SGIG funding is for deployment of AMI and customer systems. This funding covers investments in smart meters, communications networks, back-office data management systems (e.g., meter data management), in-home displays, programmable communicating thermostats, pricing programs, and web portals. The Edison Foundation recently estimated that approximately 65 million smart meters will be deployed nationwide by 2015, which represents approximately 45 percent of all customers in the country (IEE 2012). ARRA funding will result in approximately 15.5 million new smart meters, or approximately 24 percent of those that will be deployed by 2015 [Metric 12 − Advanced Meters].

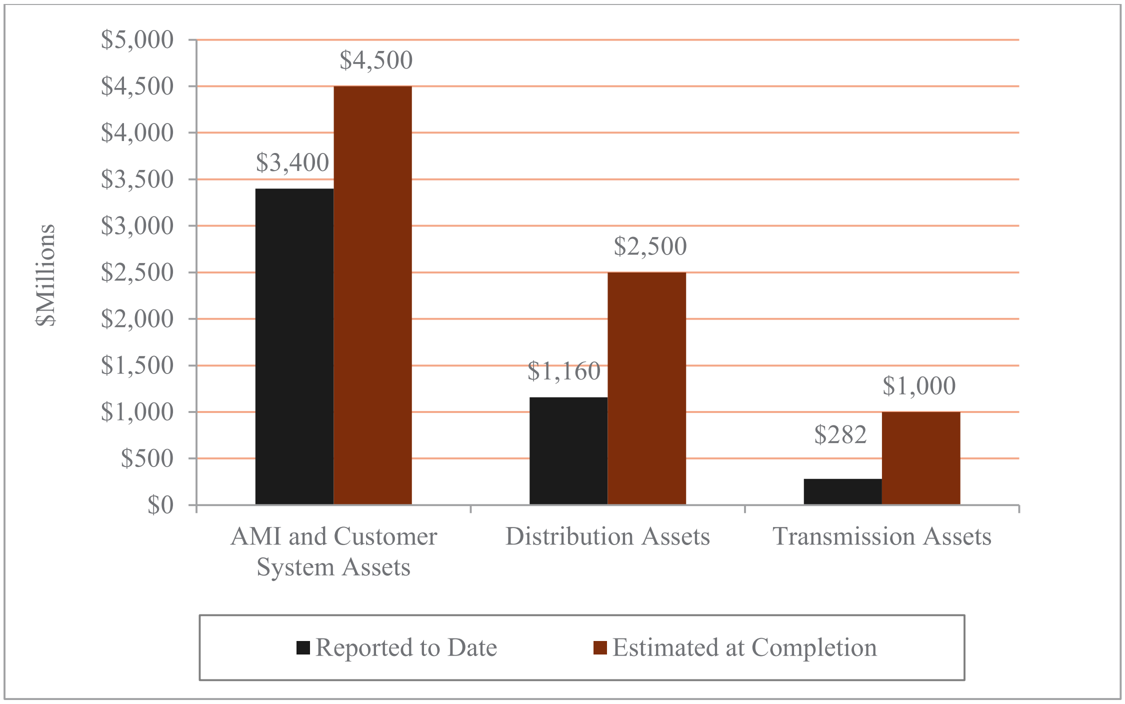

Figure 3.1. SGIG Total Investments Deployed as of September 30, 2012

As of September 30, 2012, nearly 11.9 million advanced meters had been installed through the SGIG program. Total expenditures on all smart meter installations reported by 92 entities (as of September 30, 2012) amount to almost $2.0 billion. Further, the SGIG program has co-funded projects supporting communications networks and hardware that enable two-way communications ($542.9 million); the development of information technology (IT) hardware, systems, and applications ($389.5 million); and other AMI-related systems ($190.6 million) (DOE 2012b). Many of the SGIG AMI projects have not finished integrating the smart meters with billing and other enterprise systems, but 15 projects representing more than 3.5 million smart meters have reported initial results to DOE for an operational period from April 2011 to March 2012. These projects have reported reductions in meter operations cost of between 13 and 77 percent and reductions in vehicle miles driven, fuel consumption, and CO_2 emissions of 12 to 59 percent (DOE 2012c).

ARRA projects are deploying and testing a variety of communications and control schemes, including distributed and centralized control systems with various levels of integration among information management systems (e.g., outage management systems, distribution management systems, AMI, and geographic information systems). Multiple options are available depending upon location-specific conditions and utility objectives.

ARRA also co-funded projects to purchase and install programmable communicating thermostats as well as other demand response equipment, including smart appliances and load controllers for water heaters and air conditioners [Metric 9 – Non-Generating Demand Response Equipment]. As of September 30, 2012, 181,942 programmable communicating thermostats valued at $68.0 million were deployed under the SGIG program, as were 279,427 direct load control devices valued at $105.5 million (DOE 2012b).

Approximately 31 percent of total SGIG funding is for deployment of distribution automation technologies and systems. This funding covers investments in automated switches and capacitors, fault detection equipment, equipment health monitors, voltage management technology, communications networks, and data management systems (e.g., distribution management systems). DOE estimates that there are approximately 160,000 distribution feeder lines nationwide. ARRA funding will affect approximately 4 percent of the nation's feeder lines.

As of September 30, 2012, the SGIG program had co-funded the installation of 6,770 automated feeder switches at a cost of $376.3 million, 10,408 automated capacitors ($94.7 million), 6,905 automated regulators ($27.1 million), 3,913 feeder monitors ($107.1 million), and 15,376 substation monitors ($111.7 million) [Metric 11 – T&D Automation] (DOE 2012b). Automated feeder switches improve reliability (reduced outages), while automated regulators and capacitors with appropriate control technology provide near real time voltage and reactive power management, which improves energy efficiency and system flexibility.

Of the 99 SGIG projects, 48 seek to improve electric distribution reliability. Most of these projects (42 of 48) are implementing automated feeder switching. Most of the distribution reliability projects are in the early stages of implementation and have not finished deploying, testing, and integrating field devices and systems. However, four projects reported initial results to DOE based on operational experiences through March 31, 2012. Initial results from these projects indicate that automated feeder switching reduced the frequency of outages, the number of customers affected by both sustained outages and momentary interruptions, and the total amount of time that customers were without power (as measured by customer minutes interrupted). Reductions in SAIFI have been reported in the 11 to 49 percent range (DOE 2012d).

Approximately 13 percent of total SGIG funding is for deployment of synchrophasors and other transmission technologies and systems. This funding covers investments in PMUs, phasor data concentrators, communications networks for acquiring and processing synchrophasor data, and synchrophasor applications software for managing and analyzing data and producing visualization tools, state estimators, and other decision support systems to support both on- and off-line analysis. Approximately 166 networked PMUs were in place nationwide prior to the passage of ARRA. SGIG and SGDP funding was planned to increase the total to well over 1,000, which would enable grid operators in the three interconnections (Eastern, Western, and Electric Reliability Council of Texas [ERCOT]) to have nearly 100 percent wide-area visibility. PMUs provide real time grid measurements and monitoring of line loading, stability, and available capacity, which in turn allows tighter operating margins, reduces congestion costs, increases electricity transfers, and helps avert cascading outages and blackouts. As of September 2012, the number of SGIG-funded installations of PMUs had reached 546 units [Metric 13 – Advanced Measurement Systems] (DOE 2012b). The total number of networked PMUs in the U.S. had grown to nearly 1,700 by December 2013 (Silverstein 2013).

3.1.2 Smart Grid Demonstration and Other ARRA Programs

The second major technology deployment initiative funded under ARRA, the SGDP, is designed to demonstrate how a suite of existing and emerging smart grid concepts can be innovatively applied and integrated to prove technical, operational, and business-model feasibility. The aim is to demonstrate new and more cost-effective smart grid technologies, tools, techniques, and system configurations that significantly improve on the ones commonly used today.

SGDP projects were selected through a merit-based solicitation process in which the DOE provides financial assistance of up to 50 percent of the project's cost. The program consists of 32 projects in two areas: smart grid regional demonstrations (16 projects) and energy storage demonstrations (16 projects). The total budget for the 32 projects is about $1.6 billion; the federal share is about $620 million. Figure 3.2 presents the status of SGDP investments made through September 30, 2012, on laboratory energy storage demonstrations, grid-connected energy storage, and the regional demonstration projects (Bossart 2013).

ARRA provided significant investment for DG and storage under the SGDP, awarding $185 million in support of 16 energy storage projects valued at $777 million [Metric 7 – Grid Connected Distributed Generation] (DOE 2012b). These energy storage projects are focused on grid-scale applications of energy storage involving a variety of technologies, including advanced batteries, flywheels, and underground compressed air systems.

DOE also awarded $435 million for 16 smart grid regional demonstration projects collectively valued at $874 million. These regional demonstrations are focused on advanced technologies for use in power system sensing, communications, analysis, and power flow controls, and are assessing the integration of advanced technologies with existing power systems including those involving renewable and distributed energy systems and demand response programs.

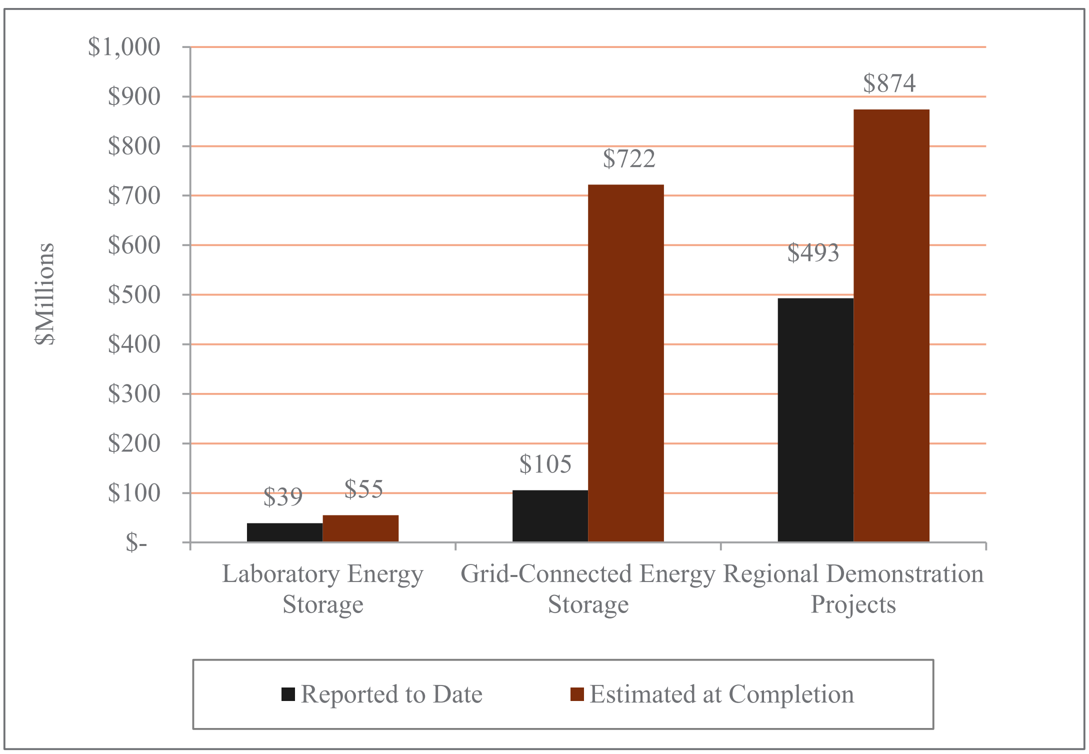

Figure 3.2. SGDP Investments Deployed as of September 30, 2012

As of September 30, 2012, the SGDP program had co-funded the installation of 235,812 advanced meters, 497 automated feeder switches, 341 automated capacitors, 4,745 programmable communicating thermostats, 497 PEV charging stations, 13,021 feeder monitors and 23 PMUs (Wang 2013). Total expenditures on AMI and customer systems had reached $89.3 million under the SGDP through September 30, 2012, while investments in distribution assets totaled $90.1 million. The SGDP also co-funded projects that deployed an additional $34.3 million in distributed energy resources and $7.4 million in transmission assets (Wang 2013).

Investments in microgrid projects made under the SGDP are building on recent investments made under the Renewable and Distributed Systems Integration (RDSI) program. Together, these programs co-funded nine projects valued at over $427 million that either built microgrids or included technologies that would support microgrids. The RDSI projects are nearing completion [Metric 6 – Microgrids] (Bossart 2009 and 2012; DOE 2012b).

Under ARRA, each grant recipient was required to address cybersecurity concerns by creating a project-specific cybersecurity program and implementation plan. Each participant addressed core programmatic elements, including roles and responsibilities, cybersecurity risk management, defensive strategies, security controls, incident response and recovery, development lifecycle, policies and procedures, and training [Metric 18 – Cybersecurity].

The DOE assisted participants with onsite engagements to ensure they had qualified resources fully available to them to address certain questions related to their implementation areas. Facilitated annual cybersecurity workshops also provided a valuable and highly attended collaboration environment where cybersecurity experts and program stakeholders could exchange best practices and lessons learned. Online resources such as www.arrasmartgridcyber.net provide guidance to foster a non-prescriptive and flexible approach for participants to customize their cybersecurity programs commensurate with their specific project characteristics and requirements.

In addition to the technology deployment programs, ARRA funded workforce training and development programs, as well as standards and interoperability activities. One outcome of these investments was the National Institute of Standards and Technology's (NIST) Release 1.0 and Release 2.0 of the *Framework and Roadmap for Smart Grid Interoperability Standards,* which provides a framework and action plan for transforming the nation's electric power system into an interoperable smart grid (NIST 2010a and NIST 2012). NIST also developed *Guidelines for Smart Grid Cyber Security* (NIST 2010b). FERC was required under EISA to provide a rulemaking process to implement the standards identified by NIST. FERC could not find consensus (Troutman Sanders LLP 2011) and in late July 2011, FERC issued a statement declining to adopt the five smart grid interoperability standard families. At the same time, they recommended that the NIST framework for interoperability be the basis for efforts going forward in conjunction with the work of the Smart Grid Interoperability Panel (EL&P 2011).

ARRA funded the EIA to expand data collection for the smart grid. The EIA has undertaken an extensive review process, which will be finalized after a formal comment period. The DOE Office of Electricity Delivery and Energy Reliability has coordinated with the EIA to ensure that the expanded information base assists future SGSRs.

3.2 Other Developments Affecting the Smart Grid

In addition to the advancements made under ARRA, a number of other significant developments affected the deployment trends reported in this report. This section highlights several of the key smart grid-related policy gains, investments, and other advancements unrelated to ARRA made since 2010.

In 2011, the National Science and Technology Council (NSTC) issued *A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future.* This report, which built on the policy direction outlined in the EISA, presented a framework for modernizing the grid, based on principles related to enabling cost-effective smart grid investments, unlocking the potential for innovation in the energy sector, empowering consumers to make informed decisions, and achieving grid security (NSTC 2011). Progress in meeting these policy directions was overviewed in *A Policy Framework for the 21st Century Grid: A Progress Report* (NSTC 2013).

Interconnection policies continue to advance. To date, 43 states plus Washington, D.C. and Puerto Rico have adopted variations of an interconnection policy [Metric 3 – Distributed-Resource Interconnection Policy]. Since the 2010 SGSR was published, distributed-resource interconnection policies have been adopted or expanded in seven states—Alaska, Delaware, Illinois, Montana, New Hampshire, Utah, and West Virginia (DSIRE 2012b). These policies provide a basis for the integration of DERs, including renewable energy resources, into the grid; effective integration of these resources will require the application of intelligent grid technologies -- e.g., advanced sensing and control. When ESPs are assigned to states based on the location of their headquarters, it is estimated that 86.8 percent of utilities currently have a standard resource interconnection policy in place, compared to 83.9 percent in 2010 and 61 percent in 2008. When weighted based on sales in each state, the interconnection rate rises to 87.8 percent. Further, an assessment of interconnection policies carried out by the Network for New Energy Choices (NNEC) graded 23 states' policies as "A" (no barriers, and best practices in place) or "B" (good interconnection standards, but barriers remain for certain customers) in 2011, compared to 20 in 2010, 15 in 2009, and 11 in 2008 (NNEC 2011).

Thirteen states plus Washington, D.C. now have a revenue decoupling mechanism in place; nine states have pending policies; and another nine states have lost revenue adjustment mechanisms (LRAMs) (IEE 2011). The decoupling mechanism allows ESPs to recover the fixed costs, including an approved return on investment (ROI), of certain smart grid investments approved by regulatory commissions. Since the 2010 SGSR was published, decoupling policies have been enacted in Arkansas, Rhode Island, and Montana [Metric 4 – Policy/Regulatory Progress].

Twenty-nine states plus Washington, D.C. and two territories now have renewable portfolio standards (RPSs) [Metric 21 – Grid-Connected Renewable Resources], which include specific percentage goals to lower fossil fuel consumption by incorporating energy efficiency goals and renewable energy generation. An additional eight states plus two territories now have renewable portfolio goals.

Since 2010, numerous steps have been taken to address the risks associated with cybersecurity. Government and industry collaborated to provide an Energy Sector − Cybersecurity Capability Maturity Model (ES-C2M2), which culminated in an effective and consistent method for electric utilities and grid operators to assess their cybersecurity capabilities and prioritize their actions and investments to improve cybersecurity. DOE then participated in a series of onsite asset owner assessments using the ES-C2M2 tool, which reported significant success and support of all participant sites involved. This tool will help measure the progress in implementing strategies outlined in DOE's "Roadmap to Achieve Energy Delivery Systems Cybersecurity" which over the next decade will provide a framework for designing, installing, operating, and maintaining a resilient energy delivery system capable of surviving cybersecurity incidents while maintaining critical functions (DOE 2011a).

The DOE Office of Electricity Delivery and Energy Reliability released guidelines for the electricity subsectors in its cybersecurity risk management process (RMP). This collaborative effort with the NIST, NERC, and a significant number of industry and utility-specific trade groups resulted in the creation of a tailorable RMP that could effectively meet the stringent organizational requirements throughout the electric subsectors' generation, transmission, and distribution environments. It has also been crafted to be extended into the electricity market and supporting organizations such as vendors and suppliers. The RMP aims to reduce the likelihood and impact of a cybersecurity event on operations, assets, and individuals through risk-managed processes. The process is designed to improve cybersecurity resource allocation, operational efficiencies, and the ability to mitigate and rapidly respond to cybersecurity risk. The RMP leverages the larger stakeholder community by facilitating information exchanges between other critical infrastructure and key resource domains, and private, federal, and international entities (Canada and Mexico).

The National Board of Information Security Examiners (NBISE) was formed with a mission to increase the security of information networks, computing systems, and industrial and military technology by improving the potential and performance of the cybersecurity workforce. NBISE leverages the latest advances in assessment and learning science towards the solution of one of the United States' most critical workforce shortages: cybersecurity professionals. Through its Advanced Defender Aptitude and Performance Testing and Simulation program, NBISE coordinates the work of teams of practitioners, researchers, and educators, which develop and validate or enhance existing performance-based learning and assessment vehicles to materially accelerate the acquisition of hands-on skill and tacit knowledge by students and practitioners in collegiate and continuing education programs. NBISE's work and research seeks to develop assessment instruments to reliably predict future performance and aptitude for cybersecurity jobs, allowing for a better understanding of the efficacy of performance-based learning platforms.

Other significant developments reported here include the following:

- In 2010, the Rural Utility Service (RUS) issued $7.1 billion in loans to support efforts to modernize electrical infrastructure supporting rural America (NSTC 2011).
- The Advanced Technology Vehicles Manufacturing (ATVM) Loan Program provided $8.4 billion in loans in support of advanced vehicle technologies and associated components (DOE 2012e). Under the ATVM program, the federal government provided a $5.9 billion loan to the Ford Motor Company to upgrade factories and increase the fuel efficiency of more than a dozen vehicles. Nissan also secured a loan under the ATVM program to retool its Smyrna, Tennessee, facility to build an advanced battery manufacturing plant [Metric 8 – EVs and PHEVs].
- In addition to the well-publicized Nissan LEAF and Chevrolet Volt, 20 PEV models are either currently available or ready for release in 2014, including the Toyota Prius Plug-in Hybrid, Honda Fit EV, and Ford Focus EV [Metric 8 – EVs and PHEVs] (Plugincars.com 2014).

- Non-generation demand response equipment [Metric 9] showed impressive gains for programmable, communication-enabled thermostats; more than 1 million devices now are installed (Neichin et al. 2010).
- The number of installed smart meters [Metric 12 – Advanced Meters] reached 36 million in 2012 (approximately 24.2 percent of all electric customers), up from 7 million meters in 2007 (IEE 2012).
- Non-hydro renewable electricity generation climbed from a little over 2 percent of total grid-connected electricity generation in 2005 to more than 4 percent in 2010 [Metric 21 – Grid-Connected Renewable Resources] (EIA 2011c). Carbon dioxide emission reductions, driven mainly by wind power, reached almost 95 million metric tons in 2010, up from 81 million metric tons in 2009 (EIA 2011d). One of the advantages of the smart grid will be its ability to incorporate renewable energy resources and the resultant reduction in greenhouse gases.

4.0 Deployment Trends and Projections

Deploying the U.S. smart grid is a process that has been under way for some time but will accelerate because of EISA, ARRA, and the recognition of characteristics and benefits collected and emphasized under the term "smart grid." Although there has been much debate over the exact definition, a smart grid comprises a broad range of technology solutions that optimize the energy value chain. Depending on where and how specific participants operate within that chain, they can benefit from deploying certain parts of a smart grid solution set. Based on the identification of deployment metrics, this section of the report presents recent deployment trends. In addition, it reviews plans of the stakeholders relevant to smart grid deployments to provide insight about near-term and future directions.

The status of smart grid deployment expressed in this section is supported by an investigation of 21 metrics obtained through available research, such as advanced metering and T&D substation-automation assessment reports of emerging energy resources, market assessment studies, industry surveys, and studies exploring capabilities enabled by a smart grid. In each section, the emphasis is placed on data and trends registered since the 2010 SGSR was completed. In each subsection that follows, the metrics contributing to explaining the state of the smart grid characteristic are called out so the reader may review more detailed information in Appendix A. The metrics emphasized to explain the status of a characteristic are highlighted with an asterisk (*).

4.1 Enables Informed Participation by Customers

A part of the vision of a smart grid is its ability to enable informed participation by customers, making them an integral part of the electric power system. With bidirectional flows of energy and coordination through communication mechanisms, a smart grid should help balance supply and demand and enhance reliability by modifying the manner in which customers use electricity. These modifications can be the result of consumer choices that motivate shifting patterns of behavior and consumption. These choices involve new technologies, new information, and new pricing and incentive programs.

The primary metrics of progress for this characteristic include dynamic pricing programs [Metric 1], load participation based on grid conditions [Metric 5], and advanced meter deployments [Metric 12]. Other metrics that affect this category include distributed-resource interconnection policy [Metric 3], grid-connected distributed generation [Metric 7], market penetration of EVs and PHEVs [Metric 8], and grid-responsive non-generating demand-side equipment [Metric 9].

Technologies that aid in achieving this characteristic include advanced meters that enable two-way communication and supporting communications networks, hardware, and other AMI-related systems; in-home displays and web portals that respond to time-based rates; communicating thermostats, responsive appliances, responsive space conditioning equipment, in home displays, responsive lighting controls, controllable wall switches and other emerging products that can directly monitor the electric system or receive signals from smart grid technologies.

Related Metrics
1*, 3, 5*, 7, 8, 9, 12*

Over the past 10 years, the costs of interval meters, the communications networks to connect the meters with utilities, and the back-office systems necessary to maintain and support them (i.e., advanced metering infrastructure or AMI) have all dramatically decreased. The implementation of AMI and interval meters by utilities, which allows electricity consumption information to be captured, stored, and reported at 5- to 60-minute intervals in most cases, provides an opportunity for utilities and public policymakers to employ time-based rate programs and more fully engage electricity customers in better managing their own usage.

Utilities can now collect customer electricity usage data at a level that allows them to offer time-based rate programs, which provides customers with opportunities to respond to diurnal and/or seasonal differences in the cost of producing power (i.e., time-of-use pricing) and/or dynamically to deteriorating power system conditions, high wholesale power costs, or both (i.e., critical peak pricing, real-time pricing). Under these new "dynamic pricing" schemes, rates can change hour-to-hour and day-to-day. Customers also have the ability with AMI to better understand their own overall daily and even hourly usage patterns, whereas before only monthly consumption information was available to them in their monthly bills. Other non-utility opportunities for use of this data include virtual energy audits, energy usage monitoring services, or non-utility demand response programs.

The impacts of ARRA on AMI deployment [Metric 12 – Advanced Meters] have been significant. As of September 30, 2012, more than 12.1 million advanced meters have been installed through the SGIG program and SGDP; the ultimate goal is 15.5 million meters (DOE 2012b). The SGIG has co-funded projects supporting communications networks and hardware that enable two-way communications; the development of IT hardware, systems, and applications ($389.5 million); and other AMI-related systems ($190.5 million) (DOE 2012b). Due to ARRA and the significant investments made by ESPs across the nation, the total number of advanced meters deployed in the United States grew from approximately 6.7 million meters in 2007 to 36 million in 2012, or 24.2 percent of all meters in the United States (IEE 2012).

Many of the SGIG AMI projects have not finished integrating the smart meters with billing and other enterprise systems; however, 15 projects representing more than 3.5 million smart meters have reported initial results to DOE for an operational period from April 2011 to March 2012. These projects have reported meter operations cost reductions of between 13 and 77 percent and reductions in vehicle miles driven, fuel consumption and CO_2 emissions of 12 to 59 percent (DOE 2012c).

AMI technologies enable the communication of grid conditions, consumption information, and real time pricing data necessary for implementing dynamic pricing [Metric 1] programs. FERC collects comprehensive data on trends in dynamic pricing programs. The 2010 FERC survey was distributed to 3,454 organizations in all 50 states. In total, 1,755 entities responded to the survey for a total response rate of 52 percent. Of the ESPs responding to the survey, 169 reported offering TOU pricing, down from 241 in 2008. In those participating utilities, approximately 1.1 million electricity consumers were enrolled in TOU programs. In 2010, customers were enrolled in CPP tariffs offered by 52 entities, as compared to 88 in 2009. The number of ESPs offering RTP programs fell from 100 in 2008 to 26 in 2010 (FERC 2011). The decline in the number of ESPs reporting dynamic pricing tariffs is due in part to a change in FERC's methodology, which was made in order to eliminate double counting of pricing programs and sharpen the classification of pricing and demand response programs.

The number of electricity customers enrolled in time-based rate programs could grow due to the impact of ARRA. ARRA investments in AMI have made time-based rate programs available to more than three million customers, expanding the number of enrolled customers by nearly 278,000 (DOE 2012b). These systems, when used in combination, offer significant opportunities for peak demand reductions. The initial results from the SGIG projects using AMI, customer systems, and/or time-based rates to reduce electricity consumption during peak periods suggest that peak reductions from these systems can be as high as 37 percent. A project being implemented by Oklahoma Gas and Electric (OG&E) uses programmable communicating thermostats, in-home displays, and web portals to respond to time-based rates that include combinations of time-of-use, critical peak, and variable peak pricing. Consumers participating in the program reported positive experiences and peak demand reductions of as much as 30 percent (DOE 2012f).

ESPs and customers can use simple measures, such as turning off or adjusting water heaters, dishwashers, or heating and cooling systems, to reduce load and lower costs through the smoothing of peak versus off-peak power consumption. Emerging products also can directly monitor the electric system or receive signals from smart grid technologies. Examples of grid-responsive equipment include communicating thermostats, responsive appliances, responsive space conditioning equipment, in home displays, responsive lighting controls, and controllable wall switches. These evolving technologies can provide dynamic responses either through automated responses or through transfers of information to customers, who in turn might respond to better manage their electricity use. Transactive control is currently being tested in the Pacific Northwest Smart Grid Demonstration Project (Battelle 2013).

Traditionally, load participation has principally taken place through interruptible demand and direct-control load-management programs implemented and controlled by ESPs [Metric 5 – Load Participation]. Demand response participation, however, has not played a strong historic role in energy markets. Figure 4.1 illustrates that load management was 1.21 percent of net summer capacity in 2010, up from a low of 0.96 percent in 2004 but below the 1.6 percent measured in 1999 (EIA 2011e, EIA 2011f). Despite the load management shares presented in Figure 4.1, the Electric Power Research Institute (EPRI) estimates that by 2030, realistically achievable levels of summer peak reductions due to demand response could exceed 7 percent with a maximum achievable potential of 9.1 percent (EPRI 2009). Net summer capacity only includes utility scale generators and does not include a demand response component. As such, the metric provides only an indication of the scale of peak load reduction.

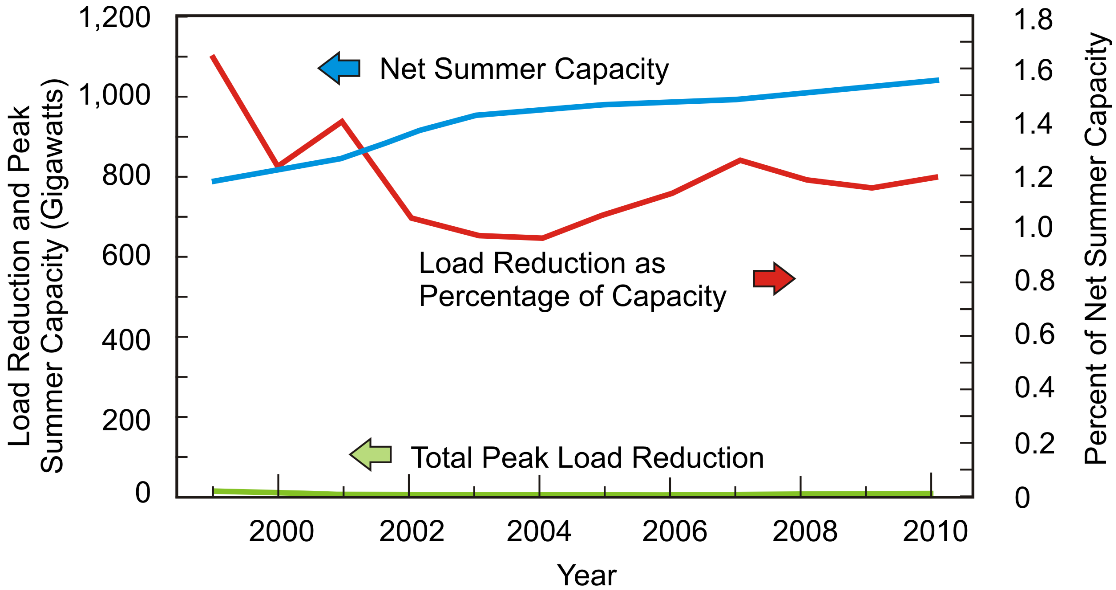

Figure 4.1. Load-Management Peak Reduction as a Percentage of Net Summer Capacity

As emerging products expand consumer participation in electric markets, smart grid elements (e.g., time-based rate structures, smart appliances, demand response programs, AMI) will facilitate bidirectional flows of energy and manage load. In the case of PEVs, for example, vehicle-to-grid software may be necessary to manage charging profiles in order to minimize grid impacts. Further, off-peak charging can be encouraged through time-based rate structures, which are supported using AMI. In the absence of several smart grid elements, the full benefits of PEVs and other emerging products with the potential for fundamentally changing how electricity is managed cannot be realized.

To achieve these gains through enhanced user participation, consumers will need access to energy consumption information. To that end, in January 2011, the Chief Technology Officer and Associate Director for Technology in the White House Office of Science and Technology challenged the nation's utilities to deliver on the vision of a Green Button providing customers access to their energy usage information electronically in a unified or standardized format. The goal was to enable consumers to make more informed decisions about their energy usage. By January 2012, Pacific Gas and Electric and San Diego Gas and Electric in California announced they were delivering Green Button data to approximately 6 million customers. An additional 4 million customers will soon be provided Green Button data by Southern California Edison, and programs are being developed at Texas-based Oncor and Mid-Atlantic utility Pepco (GTM 2012a). Using a standard data format across the electricity industry will encourage the development of applications to use the data.

The Green Button program was enhanced by DOE's Apps for Energy contest. The contest offered $100,000 in prizes for software that helps utility customers make the most of Green Button data. The apps should allow consumers to manage their in-home appliances and equipment (e.g., thermostats, dryers, freezers) in a manner that will enable them to lower electricity consumption while, if they are enrolled in dynamic pricing programs, achieve the lowest desired cost of usage. The competition ended May 15, 2012 and winners were announced May 22, 2012 (Challenge.gov 2012). In addition, the Open Energy Information project provides an open data source for renewable energy and energy efficiency technologies (OpenEnergyInfo 2013).

4.2 Accommodating All Generation and Storage Options

Accommodating a range of diverse generation types, including centralized and distributed generation, as well as diverse storage options is a core principle of the smart grid. A smarter, more flexible, and faster acting grid enables operations that can instantly balance generation and demand, which become highly dynamic with the variability of power output caused by renewable resources (i.e., wind and solar power) and the application of demand response programs (e.g., time-based rates for customers) that vary load. Energy storage devices provide a buffering mechanism to accommodate rapidly changing generation and demand patterns. Distributed energy resources can help reduce peak demand, supply needed system support during emergencies, and reduce the cost of power by reducing the need for higher cost peaking generators.

The primary metrics of progress for this characteristic include the amount of grid-connected DG and storage [Metric 7], progress in connecting diverse generation types, standard distributed-resource connection policies [Metric 3], and grid-connected renewable resources [Metric 21]. Other measures that affect this category include dynamic pricing [Metric 1], microgrids [Metric 6–Load Served by Microgrids], market penetration of EVs and PHEVs [Metric 8], grid-responsive non-generating demand-side equipment [Metric 9], and advanced meters [Metric 12]. They also describe the current ability of a smart grid to accommodate all generation and storage options, and these metrics are also addressed in this section of the report.

Related Metrics
1, 3*, 6, 7*, 8, 9, 12, 21*.

A number of technologies are driving progress toward achieving this characteristic, including small DG systems that enhance reliability, energy storage technologies (e.g., advanced battery systems, flywheels, pumped hydro) that aid in integrating the growing renewable generation capacity, and wind and solar units that reduce carbon emissions and dependence on foreign oil.

In recent years, energy production and generation capacity from DG [Metric 7 – Grid-Connected Distributed Generation] has continued to grow. DG systems are smaller-scale, local power generation (10 MVA or less) that can be connected to primary and/or secondary distribution voltages as compared to the larger, more centralized generation that provides most of the grid's power. DG capacity from actively managed fossil-fired, hydro, and biofuels generators reached 14,273 MW in 2009, up 154 percent from 2004. Actively managed DG represents approximately 1.4 percent of total generating capacity and 89 percent of total DG. The EIA changed its definition of DG in 2010. Through 2009, DG values were reported based on the "less than or equal to 10 MVA" definition. After 2009, the 1 MVA definition is used. Under the revised definition, 2,002 MW of DG capacity (0.3 percent of summer peak load) was measured in 2010 (EIA 2011a).

The growth of energy storage lags DG. ESPs interviewed for this study reported that energy storage capacity (e.g., batteries, flywheels, thermal, pumped hydro) was equal to 1.3 percent of total grid capacity (Appendix B). With the expanded deployment of intermittent renewable generation sources, however, growth in terms of both revenue and installed energy storage capacity is forecast to be strong through 2021 (Dehamna and Bloom 2011). The vast majority of existing storage capacity is in the form of pumped hydro; a total of 39 systems currently operate in the United States with a total potential power output of up to 22 gigawatts (GW) (EIA 2011a). The remaining U.S. energy storage capacity is distributed across many different technologies, including compressed-air energy storage (CAES) (115 MW), flywheels (28 MW), and advanced battery systems (e.g., sodium sulfur, lithium-ion, flow batteries) (EAC 2011).

In addition to DG and energy storage, many renewable resources are tied to the grid but are not necessarily utility-operated and will require additional smart grid applications to incorporate their generation as growth is fueled by improving economics, RPSs, and government subsidies. Renewable energy capacity as a percentage of total summer peak capacity has grown from 2 percent of total grid-connected electricity generation in 2005 to more than 5.2 percent in 2010 (EIA 2011c). The increase in renewables generation resulted primarily from new wind generation. Wind generation increased dramatically since 2004, from approximately 18 terawatt-hours (TWh) in 2005 to almost 95 TWh in 2010 (EIA 2012e). Excluding wind, production by other grid-connected renewable electricity sources remained relatively constant (Figure 4.2).

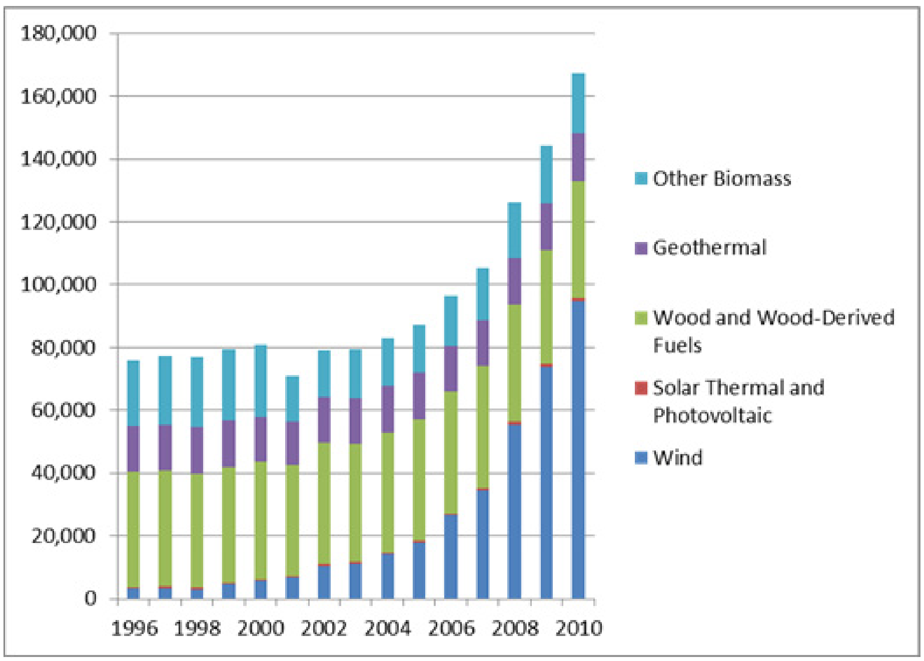

Figure 4.2. Net Generation by Renewable Energy Resource Type (thousand MWh)

Wind and solar summer capacity as a percentage of total electric power sector summer peak capacity is used to indicate the U.S. average market penetration for intermittent renewables. Intermittent renewables are those that do not provide a continuous source of energy to the grid. The capacity forecast for intermittent generators is expected to increase nationwide by 91 percent, reaching 6.8 percent of net summer capacity by 2035. Wind is expected to grow by 71 percent while solar thermal and photovoltaics are forecast to grow by more than 1,000 percent (EIA 2012e). Renewable-resource electricity output is expected to grow significantly between 2010 and 2035, when total renewables generation excluding conventional hydropower is forecast to more than double. Production by renewables is forecast to moderate starting in 2026, with growth slowing to approximately 1 percent per year. The main contributors to overall growth are biomass and wind. Municipal solid waste does not contribute significantly to other renewable-resource electricity generation. In the 2012 EIA Annual Energy Outlook (AEO) Reference Case, renewables account for nearly 39 percent of the increased generation by 2035. The reference case continues to assume that the federal tax credit will remain in effect depending on the renewable type. The outlook also assumes that state and federal policies will require increased renewable energy as a percentage of total production (EIA 2012e).

Interconnection policies are required to encourage the deployment of new energy generation and storage options. To date, 43 states plus Washington, D.C. and Puerto Rico have adopted variations of an interconnection policy (Figure 4.3) [Metric 3 – Distributed-Resource Interconnection Policy]. Since the 2010 SGSR was completed, distributed-resource interconnection policies were adopted or expanded in seven states—Alaska, Delaware, Illinois, Montana, New Hampshire, Utah, and West Virginia (DSIRE 2012a). When ESPs are assigned to states based on the location of their headquarters, it is estimated that roughly 86.8 percent of utilities currently have a standard resource interconnection policy in place, compared to 83.9 percent in 2010 and 61.2 percent in 2008. When weighted based on sales in each state, the interconnection rate rises to 87.8 percent. Further, an assessment of interconnection policies carried out by the NNEC graded 23 states' policies as "A" (no barriers, and best practices in place) or "B" (good interconnection standards, but barriers remain for certain customers) in 2011, compared to 20 in 2010, 15 in 2009, and 11 in 2008 (NNEC 2011).

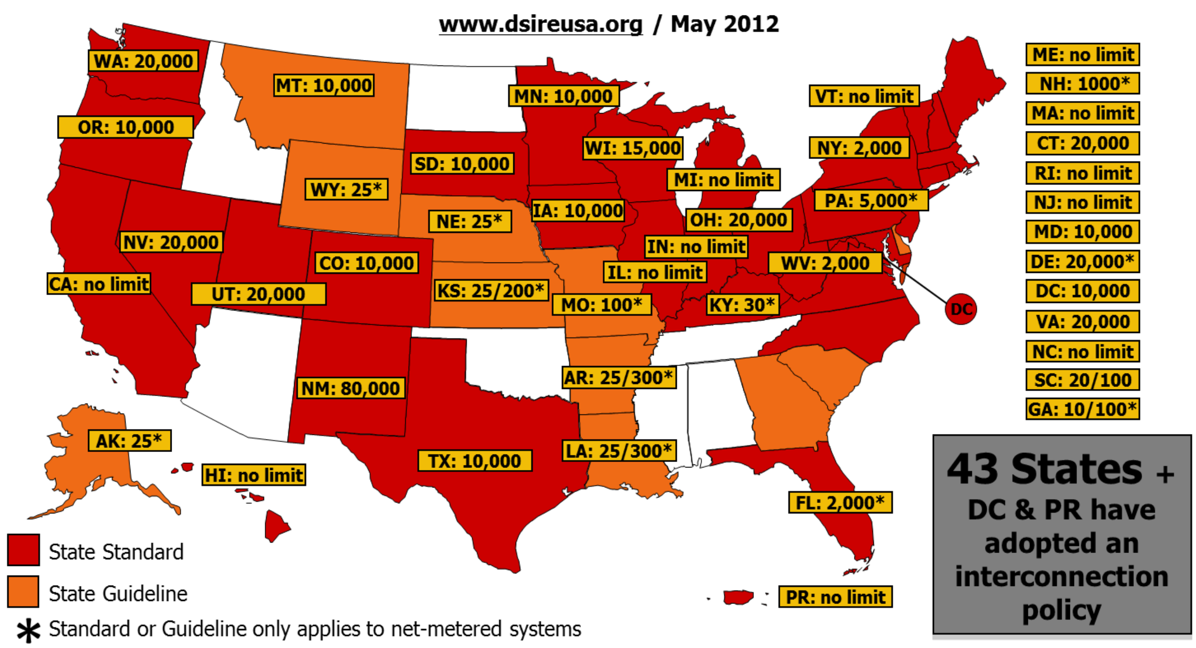

Figure 4.3. State Interconnection Standards[1]

4.3 Enables New Products, Services, and Markets

Energy markets that are well designed and operated can efficiently reveal benefit-cost tradeoffs to consumers by creating an opportunity for competing services to bid. A smart grid enables a more dynamic monitoring of the benefit/cost relationship by acquiring real-time information, conveying information to consumers, and supporting variable pricing policies that promote consumer responses to price signals. Some of the grid variables that must be explicitly managed are energy, capacity, location,

[1] System capacity limits denoted in kW (numbers in blocks). States vary in how they structure their interconnection standards. Some are strict limits by customer type, e.g., residential and non-residential. No limit indicates there is no limit on the capacity size. Typically the state standards only impact investor owned utilities.

time, rate of change, and quality. Markets can play a major role in the management of those variables. Regulators, owner/operators, and consumers need the flexibility to modify the rules of business to suit operating and market conditions.

The primary metrics of progress for this characteristic include policy/regulatory progress towards recovering smart grid investments [Metric 4], market penetration of EVs and PHEVs [Metric 8], open architecture/standards [Metric 19], and venture capital funding of smart grid startups [Metric 20]. Other metrics that affect this category include dynamic pricing programs [Metric 1], distributed-resource interconnection policies [Metric 3], grid-connected distributed generation [Metric 7], grid-responsive non generating demand-side equipment [Metric 9], advanced meters [Metric 12], power quality [Metric 17] and grid-connected renewable resources [Metric 21].

Related Metrics
1, 3, 4*, 7, 8*, 9, 12, 17, 19*, 20*, 21.

A smart grid enables new products and services through automation, communication sharing, facilitating and rewarding shifts in customer behavior in response to changing grid conditions, and its ability to encourage development of new technologies. A number of products have emerged and continue to evolve that either directly monitor the system or receive communicated recommendations from the smart grid. This equipment then provides dynamic responses useful to system needs either through automated responses or through the conveyance of useful information to consumers who then might respond appropriately.

Examples of grid-responsive equipment include communicating thermostats, responsive appliances (e.g., microwave ovens, refrigerators, clothes washers and dryers), responsive space conditioning equipment, consumer energy monitors, responsive lighting controls, and controllable wall switches. This category of equipment also encompasses switches, controllable power outlets and various other controllers that could be used to retrofit or otherwise enable existing equipment to respond to smart grid conditions. For example, a new “smart” refrigerator may be equipped with a device that coordinates with an energy management system to adjust temperature controls, within user-specified limits, based on energy prices.

These new products also include advanced meters, communications gateways (e.g., home management systems, building automation systems, and equipment that generate or store electrical energy, including solar panels and vehicle technologies. Enabling AMI technology itself represents a major driver in smart-grid investment. Total expenditures on all 12.1 million AMI smart meter installations under ARRA (as of September 30, 2012) amount to approximately $2.0 billion (DOE 2012b and Wang 2013).

The smart grid also supports the deployment of new vehicle technologies. Bi-directional metering coupled with real-time monitoring and control of financial transactions would allow customers to purchase energy at off-peak hours and sell unused, stored energy back to the utility during peak periods at higher rates. These two elements could enhance the customer’s return on investment, though the impact on the life of the battery must reach minimal levels to justify the practice. Further, load management technologies could reduce the impact of PEV charging on the grid and enable PEV energy storage capabilities.

After years of technology development and market testing, consumer acceptance of the PEV is finally being put to the test. In 2010, Nissan introduced the LEAF to the U.S. market. In 2011, Chevrolet introduced the Volt, which is a PHEV. In addition to these PEV models, several others have been, or are expected to be, introduced shortly into the U.S. market. Table 4.1 presents a list of existing and upcoming PEV models. The variety of designs, price levels, and battery ranges will provide consumers with more PEV options in the coming years (Plugincars.com 2014). As these options find appeal with consumers, market penetration rates will be expected to grow.

Table 4.1. Existing and Upcoming PEVs

Vehicle Make / Model	Vehicle Type	Availability
BMW i3	EV	Available now
BMW i8	PHEV	Available in 2014
Cadillac ELR	PHEV	Available now
Chevrolet Spark	EV	Available now
Chevy Volt	PHEV	Available now
Fiat 500e	EV	Available now
Ford C-Max Energi	PHEV	Available now
Ford Focus Electric	EV	Available now
Ford Fusion Energi	PHEV	Available now
Honda Accord Plug-in Hybrid	PHEV	Available now
Kia Soul EV	EV	Available in 2014
Mercedes B-Class Electric Drive	EV	Available in 2014
Mitsubishi I-MiEV	EV	Available now
Nissan LEAF	EV	Available now
Porsche Panamera S E-Hybrid	PHEV	Available now
Smart Electric Drive	EV	Available now
Tesla Model S	EV	Available now
Tesla Model X	EV	Available in 2015
Toyota Rav4 EV	EV	Available now
Toyota Prius Plug-in Hybrid	PHEV	Available now
Volkswagen E-Golf	EV	Available in 2014

In the past 5 years, the HEV market has expanded significantly while PEVs have neared market readiness. The PEV market remains in its nascent stage, but as the first wave of PEVs hit the market, sales began to register. In 2011, PEV sales exceeded 2,700 while total HEV sales topped 266,300. In 2012, HEV sales in the United States reached 434,645 while PHEV and EV sales were 38,584 and 14,251, respectively. Total combined HEV and PEV sales reached 487,480 vehicles in 2012 or 3.4 percent of the U.S. light-duty vehicle market (Electric Drive Transport Association 2012). Although the DOE reference-case forecasts contained in the AEO exceeded actual sales for HEVs and PEVs in 2011 (317,800 vs. 286,367), market penetration rates in 2012 (3.4 percent) exceeded DOE forecasts (2.5 percent) (Electric Drive Transport Association 2013; EIA 2012c).

The presence of EV charging stations (Level 2 and Level 3) facilitates the operation of EVs and encourages their adoption. As of November 2012, there were 14,594 public and private EV charging stations located in the U.S. (DOE 2012g). ARRA encouraged EV penetration by co-funding projects that installed 775 electric vehicle charging stations (DOE 2012b).

The new products, services, and markets highlighted in this section depend on regulatory recovery [Metric 4] and the business case for smart grid investments. The smart grid interviews conducted for this study included 30 ESPs comprised of 19 investor owned utilities, 10 municipal utilities, and one state-operated power district. Respondents were asked to estimate the percentage of smart grid investments to date that has been recovered through rate structures and to compare that total against their expectations for future investments in the smart grid. The ESPs interviewed for this study indicated that, on average (weighted by number of customers served by each respondent), they are recovering 59.8 percent of their investment through rate structures, compared to 23.5 percent in the 2010 SGSR and 8.1 percent estimated for the 2009 SGSR. The respondents further predicted regulatory recovery rates will expand in the future, ultimately reaching 94.9 percent (see Appendix B). The predicted recovery rates far exceed the 37.3 percent estimated by ESPs in 2010.

The market established through new energy technologies has gained increasing recognition with private investors as venture capital firms have expanded their investments in smart grid technology providers [Metric 20 – Venture Capital]. Venture capital data for the smart grid market for the 2010–2011 timeframe were obtained from the Cleantech Group, LLC. The Cleantech Group's database includes detailed information at the company level. For each transaction, the transaction amount, company name, and the company's focus are identified; transactions are stratified by year. Based on the data presented in Figure 4.4, venture capital funding secured by smart grid startups was estimated at $422.5 million in 2010 and $455.5 million in 2011 (Cleantech Group 2012).

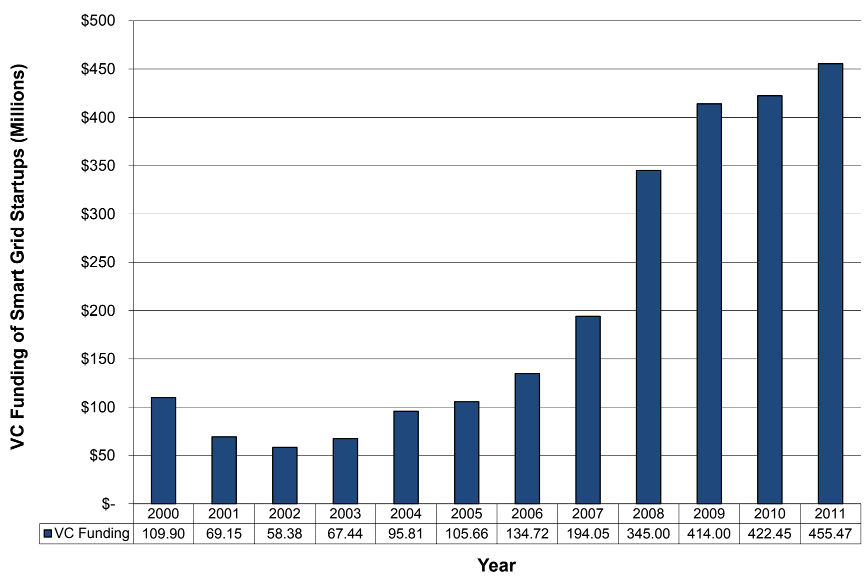

Figure 4.4. Venture Capital Funding of Smart Grid Startups (2000–2011)

The scope of the smart grid includes the T&D areas (such as substation automation), the control centers, and the consumer-side resources. An open architecture that supports the integration of a heterogeneous mix of technologies is desirable for all of these elements. Information exchange may be SCADA information sharing with other applications or between operating organizations. Customer-side equipment such as DG, storage, and end-use resources also exchange information. Efforts have been under way for some time to integrate equipment and systems in substation automation, control centers, and enterprise (software) systems, and within industrial, commercial-building, and residential energy management systems. The level of integration is increasing in each of these areas, as is the amount of integration between them. Many companies have developed software for outage management systems, data management systems, and meter data management systems, which utilities are using to visualize and analyze the data collected. Utility spending on grid analytics reached $700 million in 2012 and is forecast to more than quintuple by 2020 (GTM 2012b).

In 2007, integration was formally made NIST's responsibility [Metric 19 – Open Architecture/Standards]. Under the EISA, NIST has "...primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems." NIST, with $17 million in ARRA funding, published a framework and roadmap for smart grid interoperability in 2010 (NIST 2010a). The NIST document identified 75 standards that can be applied or adapted to smart grid interoperability or cybersecurity needs. It identified priority action plans to address 16 standardization gaps and issues. NIST continues to collaborate with industry to advance interoperability as described in the framework and roadmap efforts. As of June 2013, the current catalog contains 56 standards that have been submitted and approved for inclusion by a super-majority of the Smart Grid Interoperability Panel (SGIP) participating members (NIST 2013). This super-majority represents a substantial stakeholder-wide approval and consensus process. The catalog of standards incorporates standards developed through the SGIP's priority action plans (PAPs). The PAPs represent efforts to address an identified gap where a standard or standard extension is needed. The PAPs also address overlaps where two complimentary standards address some information that is common but different for the same scope of an application. The PAP process enables resolution when an urgent need to address an interoperability concern is raised.

In February 2012, NIST issued Release 2.0 of the *NIST Framework and Roadmap for Smart Grid Interoperability Standards* (NIST 2012). Release 2.0 adds to the 2010 work a further 22 new standards, specifications, and guidelines. The Release 2.0 document provides a framework and action plan for transforming the nation's electric power system into an interoperable smart grid. The NIST smart grid standards process has resulted in improvements to standardization supporting many smart grid technologies, including PMUs, distributed energy resources, and smart meters. The EISA required FERC to provide a rulemaking process to implement the interoperability standards identified by NIST (Troutman Sanders LLP 2011). FERC issued a statement declining to adopt the NIST's five interoperability standard families after they could not find consensus in late July 2011. At the same time, they recommended that the NIST framework for interoperability be the basis for efforts going forward in conjunction with the work of the SGIP (EL&P 2011).

A group cooperating with NIST and the SGIP is the GridWise® Architecture Council (GWAC). The GWAC was formed by DOE in 2004 with the goals of engaging stakeholders and identifying concepts and architectural principles to advance interoperability (GWAC 2012). The GWAC is developing a smart grid interoperability maturity model (SGIMM) for application to smart grid products and projects. The model helps improve the integration of automation devices and systems through the use of a self-evaluation tool. The evaluation results are used to make recommendations for improving interoperability (Widergren et al. 2010).

4.4 Provides Power Quality for the Range of Needs

Customer requirements for power quality (PQ) are not uniform across the residential, commercial, and industrial sectors. PQ issues can include voltage sags, lightning strikes, flicker, and momentary interruptions. Residential customers tend to be affected more by sustained interruptions. Commercial and industrial customers are troubled mostly by voltage sags and momentary interruptions. Commercial and industrial customers include data centers, which currently require on-site uninterruptible power supplies, to industrial plants, which need continuous power requiring dual distribution feeders and backup generation. The increase in power-sensitive and digital loads has forced PQ to be more narrowly defined.

In recent years, PQ has moved from customer-service problem solving to being an integral part of the power-system performance process. The design of PQ devices for monitoring quality has not changed significantly in the past decade; however, the hardware, firmware, and software utilized by these systems have advanced dramatically.

This report and the metric papers presented in Appendix A evaluate several technologies that could greatly increase PQ while reducing costs associated with interruptions and associated productivity losses. For example, T&D automation devices (e.g., automated feeder switches, automated capacitors, automated regulators, feeder monitors, and substation monitors) improve PQ by monitoring real-time grid information and adjusting operations to improve performance. Microgrid technologies also enhance PQ.

Power quality [Metric 17] is integrally tied to microgrids [Metric 6] as they can improve PQ for customers that are more sensitive to power quality issues than the average customer. Demand response [Metric 5] and demand-side non-generating equipment [Metric 9] can improve PQ as load can be reduced to meet changes in peak demand. T&D automation [Metric 11] also advances the incorporation of distributed generation [Metric 7] and renewable energy resources [Metric 21] where intermittency can potentially reduce PQ.

Related Metrics
5, 6*, 7, 9, 11, 17*, 21

Historically, PQ incidents were often rather difficult to observe and diagnose due to their short durations. With the increase in utility data collection and analysis efforts, PQ may become much more quantifiable in the future. ESPs were interviewed to estimate the percentage of customer complaints tied to PQ-related issues (excluding outages). Respondents indicated that PQ-related issues comprised 1.2 percent, 0.4 percent, and 0.1 percent of all customer complaints submitted by residential, commercial, and industrial customers, respectively (see Appendix B). In 2010, the ESPs indicated that 0.6 percent of all customer complaints were related to PQ issues. Weighting the percentages by customer class indicates that PQ issues increased since the survey conducted for the 2010 SGSR. The 2010 SGSR results were not differentiated by customer type.

A loss of power or a fluctuation in power causes commercial and industrial users to lose valuable time and money each year. Cost estimates of power interruptions and outages vary. A 2002 study prepared by Primen concluded that PQ disturbances alone cost the U.S. economy between $15 and $24 billion annually (McNulty and Howe 2002). In 2004, the Lawrence Berkeley National Laboratory (LBNL) estimated the cost at $80 billion per year (Hamachi et al. 2004). A 2009 NETL study suggests that these costs are approximately $100 billion per year, and further projected that the share of load from sensitive electronics (chips and automated manufacturing) will increase by 50 percent in the near future (NETL 2009).

Smart grid technologies can be used to solve many PQ issues. For example, T&D automation [Metric 11] devices serve a variety of functions, including “fault location, fault isolation, feeder reconfiguration, service restoration, remote equipment monitoring, feeder load balancing, volt-VAR controls, remote system measurements, and other options” (Uluski 2007). If operated properly, T&D automation systems can provide more reliable and cost-effective operation through increased responsiveness and system efficiency, which leads to improved PQ.

Microgrids also hold the promise of enhancing PQ and improving efficiency. A microgrid [Metric 6] is “a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode” (DOE 2011b). The findings of a recent Pike Research study indicated that there are more than 439 MW of microgrids located at educational campuses, primarily universities (Asmus and Wheelock 2012). Pike Research estimates that in 2011, there were approximately 575 MW of capacity on microgrids operating in the United States, or about 0.1 percent of net summer capacity, and anticipates that this will increase to 1.5 GW by 2017, or about 0.2 percent of net summer capacity. This growth is expected to occur primarily in the commercial, industrial, and institutional/campus sectors (Asmus and Wheelock 2012).

DOE national laboratories are also cooperating in test-bed applications for the microgrid. LBNL is cooperating in the Consortium for Electric Reliability Technology Solutions (CERTS) microgrid concepts being undertaken at the American Electric Power test bed, the Sacramento Municipal Utility District, Chevron Energy Solutions-Santa Rita Jail, and the U.S. Department of Defense (DOD) projects at Fort Sill and Maxwell Air Force Base. Sandia National Laboratories is working with other national laboratories and the DOD to apply and evaluate the Energy Surety Microgrids™ concept at Joint Base Pearl Harbor Hickam, Hawaii, Camp Smith, Hawaii, and Fort Carson, Colorado. Oak Ridge National Laboratory (ORNL) is developing controllable renewable and non-renewable distributed energy resources (DERs). PNNL is developing GridLAB-D™, a simulation tool for operations at several levels including microgrids (Ton et al. 2011).

4.5 Optimizing Asset Utilization and Operating Efficiency

The smart grid can enable lower operations costs, lower maintenance costs, and greater flexibility of operational control in the power system. These improvements will be driven by advanced sensing, communication, control, and information technologies that facilitate peak load reduction. For example, dynamic pricing programs and active management of peaking generation capacity can reduce the need for new generation plants and transmission lines. Operational efficiencies can be obtained from the smart grid by using sensors to reduce equipment failure rates due to stress, reduce costs of customer meter data collection, allow higher transmission capacities and better target restoration efforts and reduce restoration time.

This section reports on smart grid improvements in asset utilization and operating efficiency primarily through the evaluation of changes in T&D automation [Metric 11], capacity factors [Metric 14], bulk generation and T&D efficiency [Metric 15], and dynamic line ratings [Metric 16]. T&D automation improves asset utilization by automatically detecting issues and recovering before loss occurs. Dynamic line ratings allow greater use of existing transmission lines and improve efficiency on existing capacity. Bulk generation and T&D efficiency along with capacity factors indicate the degree to which automatic sensors and controls have improved the efficiency of generating capacity. Other metrics that affect this category include real-time system operations data sharing [Metric 2], distributed-resource interconnection policies [Metric 3], load participation based on grid conditions [Metric 5], grid-connected distributed generation [Metric 7], and advanced system measurement [Metric 13].

Related Metrics
2, 3, 5, 7, 11*, 13, 14*, 15*, 16*

Electricity generation in the United States has seen relatively steady efficiency rates [Metric 15] for the last 50 years, following rapid growth in the efficiency of coal power in the 1950s. Over the last 10 years, there has been an increase in the efficiency of gas-fueled generation because of the improvement from gas turbines, mostly through greater use of combined-cycle power plants. Figure 4.5 shows the improvement in efficiency over the last decade in terms of a decrease in a parameter called the heat rate (EIA 2012f). Heat rate is the number of British thermal units of heat required to produce a kilowatt-hour of electricity. That is, it represents the amount of input energy per unit of output energy. A decrease in heat rate signifies an increase in efficiency: less fuel is needed to produce a given amount of electricity. As the smart grid reduces the need for peaking plants, the overall generation efficiency could improve. T&D efficiency rates in the United States are high and have held steady in the 93- to 94-percent range for the last two decades. Even so, the energy loss is 260,000 gigawatt hours (GWh) annually, approximately the amount produced by 30 large power stations operating continuously.

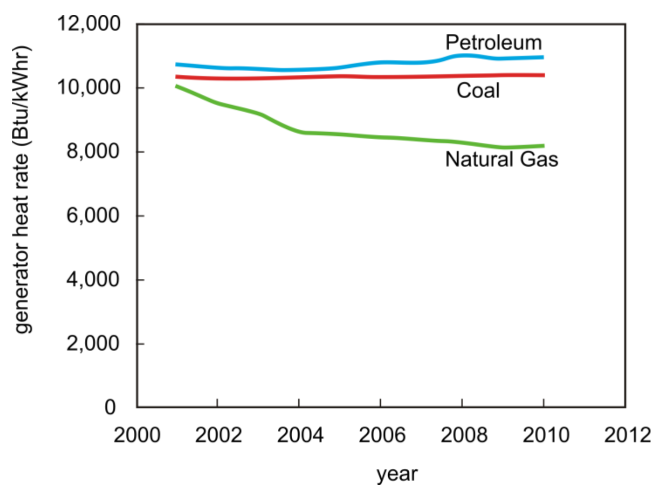

Figure 4.5. Generator Heat Rate for Various Fossil Fuel Sources over Time

It is difficult to discern the effect of the smart grid on generation efficiency. One way to examine generation performance that is smart grid-related is the capacity factor of the generators [Metric 14 – Capacity Factors]. The capacity factor gives the amount of energy produced compared to the amount that would be produced if the generator were working at 100 percent output all the time. A high number means better utilization of capital investment. For a power utility as a whole, the number should never reach 100 percent because a certain amount of generating capacity is required to be held in reserve. Cycling to follow load reduces generation efficiency, so higher efficiencies can be gained by better matching generation to load. Smart grid interaction with the load can lead to a higher capacity factor because peak load can be reduced, and some load can be deferred in this way to fill in the “valleys” in the daily load cycle.

Peak demand reduction can greatly reduce generation capacity requirements. Energy consumption in the United States is approximately 50 percent of capacity, averaged over a year. At the times of summer and winter peak load, however, the load is closer to the generation limits, as shown in Figure 4.6. The details change slowly. For the 10 years before 2000, according to NERC data, the capacity factor increased. Since then it has declined (NERC 2011a) largely due to the economic downturn. Figure 4.6 shows that the capacity factor for the United States has declined for several years but is predicted to remain constant for the next few years and improve toward the end of the decade.

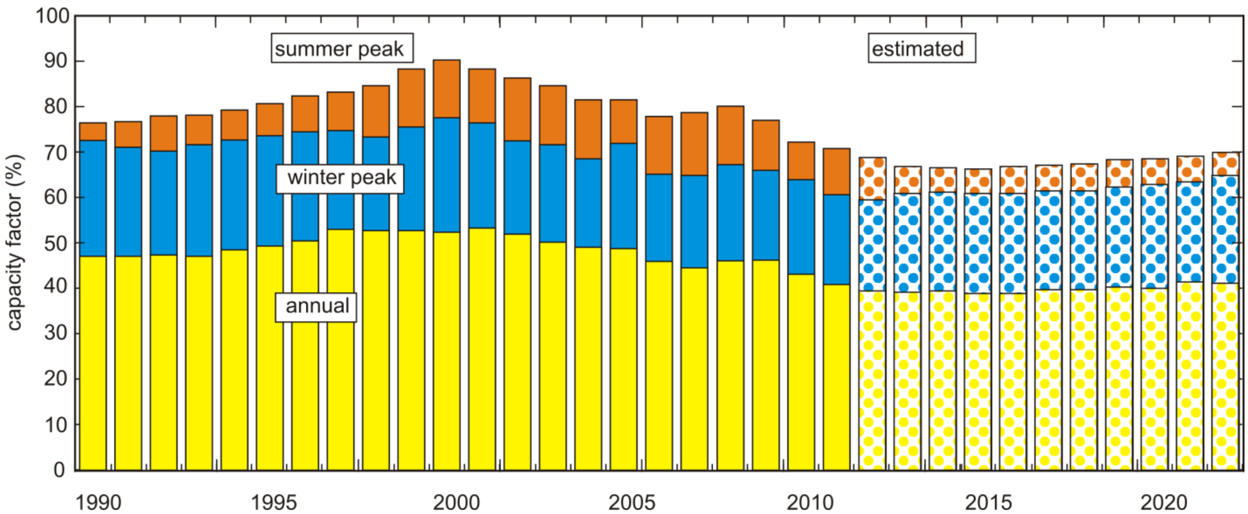

Figure 4.6. Measured and Predicted Peak Summer, Peak Winter, and Yearly Average Generation Capacity Factors

Peak load reduction can be accomplished through demand response activities (e.g., through AMI-enabled dynamic pricing), as well as through techniques used to reduce voltages within distribution circuits. AMI enables the effective application of time-based rate programs that permit utilities to apply electricity rates that more fully reflect the true variability of electricity costs. Response of customers to time-based rates results in peak and overall demand reductions. As a result, these programs help to defer construction of additional power plants and power lines to meet peak demands (measured in kilowatts and megawatts) and reduce overall electricity consumption (measured in kilowatt-hours and megawatt-hours). For example, a time-based rate program (involving a variable rate and a critical peak price component) applied by OG&E resulted in peak demand reductions of 30 percent, which enabled OG&E to defer over 200 MW of peak demand. This is the equivalent of deferring a $200 million investment in a peaking natural gas fired power plant (Global Energy Partners 2012).

T&D automation devices [Metric 11 – T&D Automation] communicate real-time information about the grid and their own operation and then make decisions to bring energy consumption and/or performance in line with their operator's preferences. These smart devices, which exchange information with other substation devices or area control centers, can increase asset utilization and smart grid reliability as well as reduce operating expenses by increasing device and system responsiveness to grid events. T&D automation devices can aid in reducing the differential between average load and peak load.

The SGIG program recognizes the potential of T&D automation. As of September 30, 2012, the SGIG program had co-funded the installation of 6,770 automated feeder switches at a cost of $376.3 million, 10,408 automated capacitors ($94.7 million), 6,905 automated regulators ($27.1 million), 3,913 feeder monitors ($107.1 million) and 15,376 substation monitors ($111.7 million) [Metric 11 – T&D Automation] (DOE 2012b). Automated feeder switches improve reliability (reduced outages) while automated regulators and capacitors with appropriate control technology provide near real time voltage and reactive power management, which improves energy efficiency and system flexibility.

Of the 99 SGIG projects, 48 seek to improve electric distribution reliability. Most of these projects (42 of 48) are implementing automated feeder switching. Most of the distribution reliability projects are in the early stages of implementation and have not finished deploying, testing, and integrating field devices and systems. However, four projects reported initial results to DOE based on operational experiences through March 31, 2012. Initial results from these projects indicate that automated feeder switching reduced the frequency of outages, the number of customers affected by both sustained outages and momentary interruptions, and the total amount of time that customers were without power (as measured by customer minutes interrupted). Reductions in SAIFI have been reported in the 11 to 49 percent range (DOE 2012d).

The results of the interviews undertaken for this report also indicate expanded awareness of the benefits associated with T&D automation. The 30 ESPs interviewed for this study indicated that

- 85.7 percent of the total substations owned by respondents were automated, compared to 47.7 percent in 2010.
- 93.0 percent of the total substations owned by respondents had outage detection, compared to 78.2 percent in 2010.
- 93.6 percent of total customers had circuits with outage detection, compared to 82.1 percent in 2010.
- 58.4 percent of all relays were electromechanical (46.4 percent in 2010), and 41.5 percent were operated by microprocessors (13.4 percent in 2010).

Dynamic line ratings (DLRs) [Metric 16], also referred to as real-time transmission-line ratings, are also a well-proven tool for enhancing the capacity and reliability of our electrical transmission system. One of the primary limiting factors for transmission lines is temperature. When a transmission line's electrical current increases, the conductor heats, the line begins to expand, and the power line sags. The sag may take the line close enough to something (such as a tree) to cause a flashover. In the past, that sequence has sometimes led to what are called cascading blackouts (e.g., the 2003 blackout in the Northeast).

A DLR system can increase line transmission capacity by 10 to 15 percent by informing the operator about the actual conditions in real time. Rather than rely on conservative open-loop ratings, the real time data effectively updates the values used for the normal, emergency, and transient ratings of a line (Seppa 2005). In a particularly interesting twist, transmission of wind energy might become enhanced by DLRs due to the cooling effect of wind (Oreschnick 2007).

The number of locations where DLR equipment is installed appears to be small, monitoring only a fraction of the nation's transmission lines, and restricted largely to demonstration and pilot projects. A smart grid demonstration project is being conducted by the Oncor Electric Delivery Company (Oncor 2011) that uses 45 load-cell tension-monitoring units and eight master locations. Intended to demonstrate that DLRs can relieve congestion and transmission constraints, the study area has encountered little congestion so far. It found that the carrying capacity of the higher-voltage transmission lines was never reached. The limit due to the requirement to have back-up capability for such lines was encountered first. That is, of course, a situation that would not apply in all locations.

The interviews of ESPs conducted for the 2010 SGSR revealed that, on average, only 0.6 percent of respondents' transmission lines were dynamically rated when weighted by the number of customers served by each respondent. None of the ESPs interviewed for this study reported lines with a dynamic rating. At some point in the future, PMUs [Metric 13] may improve electric infrastructure efficiency. Synchrophasor technology enables grid operators to observe voltage and frequency levels across interconnected transmission systems. When synchrophasor data is used to support real-time state estimation, grid operators can then transmit power along lines closer to their dynamic capacity, thereby improving the utilization of transmission assets and reducing congestion.

4.6 Operates Resiliently to Disturbances, Attacks, and Natural Disasters

Resilience refers to the ability of the power system to respond to disturbances in one part of the network in a way that enables the rest of the system to continue operation. The "self-healing" response, due to the actions of what is called the protective relaying system, reduces interruption durations and helps service providers to better control the delivery infrastructure. The relaying system is extraordinarily reliable. It has been designed and evolved over the years to operate as a kind of parallel system to the system that conducts normal operation in the grid. This system is being supplemented by elements of the smart grid.

The primary smart grid metrics that support resilience include real time operations data sharing [Metric 2] and advanced system measurement devices [Metric 13]. Technologies supporting these metrics include EMS, DMS, and PMUs. T&D system reliability [Metric 10] measures changes in electricity interruption frequencies and durations. Cybersecurity [Metric 18] hardens communications to protect grid components from unwanted intrusions that may potentially affect grid operations. Demand side equipment [Metric 9] such as smart appliances, load controllers for water heaters and air conditioners, and programmable communicating thermostats respond to grid conditions, improve economic efficiency, and enhance system resilience.

A number of additional metrics also affect the resilience and reliability of the grid. Dynamic pricing [Metric 1] provides an economic incentive for customers to manage demand. Dynamic pricing programs are enabled by AMI [Metric 12]. Load participation [Metric 5] enables utilities to adjust demand to meet grid conditions. DG and storage [Metric 7] and EVs and PHEVs [Metric 8] can potentially provide support during high demand periods. Islanding of microgrids [Metric 6] also improves the resilience and reliability of the area served by the microgrid. T&D automation [Metric 11] allows automatic responses to grid conditions. Dynamic line ratings [Metric 16] rely on real-time data to continuously update the normal, emergency, and transient ratings of a line, resulting in a less conservative, higher-capacity ratings of the line about 95 to 98 percent of the time while increasing capacity by 10 to 15 percent.

Related Metrics
1, 2*, 5, 6, 7, 8, 9*, 10*, 11, 12, 13*, 16, 18*

Information is being exchanged at both the transmission and the distribution level of the power system [Metric 2 – Real-time System Operations Data Sharing]. A recent survey by Newton-Evans Research Company (2010) indicates there is significant sharing of measurement, analysis, and control data from ESP control systems for T&D SCADA, EMS, and DMS with other grid entities, including regional control centers and other electricity operators. The survey was completed by over 100 utilities in the United States and Canada, representing a total of 66,129,387 end-use customers. Utilities were asked to report the level of EMS/SCADA/DMS in place. Results indicate that 5 percent have invested in DMS only, 21 percent SCADA/DMS combined, 40 percent SCADA only, 31 percent EMS/SCADA combined, and 11 percent EMS only.

In recent years, significant investments have also been made in PMUs [Metric 13 — Advanced System Measurement]. PMUs sample voltages and currents to synchronously provide measurement of the state of the electrical system and PQ in real time. One benefit of this kind of measurement system is that the data can be combined across a large area to give a view of the overall power system operation. This kind of view can help system operators to visualize the power system and react appropriately at times of system disturbances. The lack of this kind of visualization has been identified as a contributing cause of some major blackouts.

Information about the number of PMUs installed in the United States was obtained from the North American Synchrophasor Initiative (NASPI). NASPI is a joint DOE–NERC effort to facilitate and expand the implementation of phasor technology for enhancing power system situational awareness and reliability. Figure 4.7 illustrates the networked and installed PMUs throughout the United States as of March 2012 (EIA 2012a). The map has been updated with information for the ERCOT interconnection from Adams et al. (2012). Most of these PMUs are networked. NASPI documented a total of 140 networked PMUs installed in the United States in 2009. In 2010, the number increased to 166 PMUs. By March 2012, EIA reported 500 networked PMUs (EIA 2012a). The number of networked PMUs had grown to nearly 1,700 by December 2013 (Silverstein 2013).

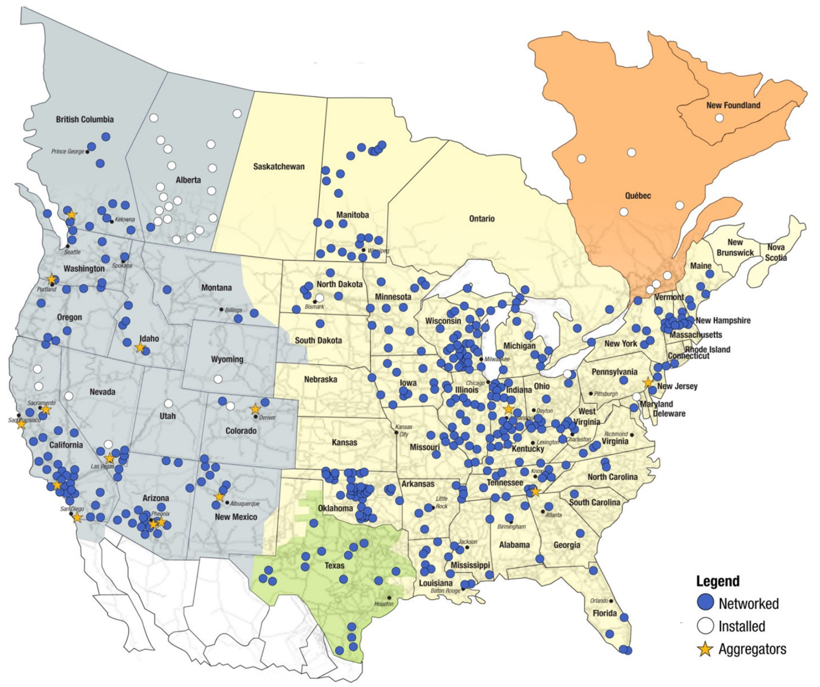

Figure 4.7. Phasor Measurement Units in the North American Power Grid as of March 2012

A transformational aspect of a smart grid is its ability to incorporate DER and demand-side resources into system operations. The ability of these resources to respond to local area, regional, and national conditions contributes to economic efficiency and system resilience. Market-based approaches encourage customers to use these resources to adapt to changing system conditions. The scalability and financial incentives tied to such an approach support adaptation of the system to impending threats, disturbances, and attacks.

Non-generating demand response equipment [Metric 9] such as smart appliances largely remains in its commercialization infancy. However, programmable communicating thermostats are a near-term success in this equipment category. ARRA co-funded 30 projects to purchase and install programmable communicating thermostats as well as other demand response equipment, including smart appliances and load controllers for water heaters and air conditioners. As of September 30, 2012, 186,687 programmable communicating thermostats had been deployed under the SGIG program and SGDP combined (DOE 2012b).

The ability to respond resiliently and adapt to system events is helped by a number of efforts. Automation projects in T&D substations are being undertaken. Efforts are under way to deploy advanced measurement equipment for applications such as wide-area situation awareness and DLRs. The effects should contribute to several statistics collected by the utilities, though multiple changes in the system also affect these metrics. An ongoing benchmarking study by the IEEE collects and examines SAIDI, SAIFI, and CAIDI data. The 2011 survey included data from 90 companies in the United States and Canada, representing 69.8 million customers. Figure 4.8 shows these statistics from 2003 through 2011. The primary axis (on the left) presents the minutes of interruption for SAIDI and CAIDI. The secondary vertical axis (at right) measures the number of interruptions per year for SAIFI. As shown, the trend has been flat over the past 8 years. From 2003 through 2011, there was no change in CAIDI and a slight increase in SAIDI (IEEE 2012).

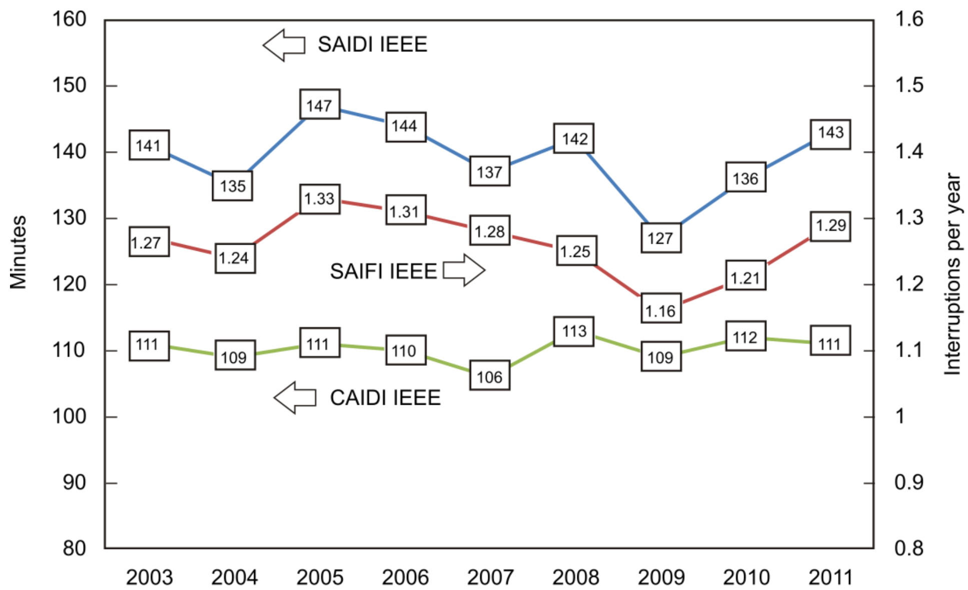

Figure 4.8. 2003–2011 IEEE Benchmarking Reliability Study Findings

The interconnected North American grid has an enviable record of reliability through the application of numerous technological and operational efficiencies and strong regulatory oversight. The grid's complexity and interconnected nature, however, pose unknown risks since under certain circumstances, problems occurring in one area may cascade out of control and affect large geographic regions. The security challenges, including cybersecurity, constitute a challenge to implementing smart grid technologies and must be adequately addressed. Some legacy communications schemes were planned and built during an era of relative trust in network communications. However, now the increased automation and informational intelligence in the field associated with the smart grid create new security challenges since interconnected functional dependencies are more coordinated among systems and devices.

Steady progress has been made on the development of cybersecurity standards and their implementation and enforcement. The NERC critical infrastructure protection (CIP) standards establish minimum requirements for cybersecurity programs protecting electricity control and transmission functions of the bulk electric system. However, it should be noted that these standards do not apply to distribution systems, which typically fall under the purview of the states. In early 2008, FERC directed NERC to tighten the standards even further to provide for external oversight of classification of critical cyber assets and removal of language allowing variable implementation of the standards. Since then, NERC CIP standards have gone through a series of revisions. The most current standard approved by the Board of Trustees is Version 4a (NERC 2012). Versions 3, 4, and 4a are in effect in various regulatory jurisdictions. Version 3 is the most current enforced version in the United States.

Enforcement of the standards has identified a lack of compliance and, therefore, violations. Identified violations are being reported according to the date on which the violation was found to occur. Violations of CIP-002 through CIP-009 have grown as a portion of all new violations. Figure 4.9 illustrates this trend (NERC 2011b). Two observations are worth noting about this graph. First, the ramp-up in accordance with the NERC CIP implementation plans makes more entities subject to the CIP regulations. Second, a preliminary screening process resulted in roughly 200 CIP violations submitted by the Western Electricity Coordinating Council (WECC) in May 2011. As more entities go through their implementation plan and mitigate violations, these numbers should begin to drop. In addition, NIST has published three volumes of cybersecurity guidelines (NIST 2010b).

Of late, CIP Version 5 has been issued by FERC in the form of a notice of proposed rulemaking (NOPR). This latest version, as noted in the NERC petition for rulemaking, will improve the current reliability standards through the adoption of new cybersecurity controls and extended scope of the systems that are currently protected. This progression aims to provide a more performance-based approach addressing the last set of comments issued by FERC. With the current Version 4a in effect, Version 5 will present eight modified standards and two new standards. There remain questions that FERC seeks to have answered during the period of public comment wherein certain "potentially ambiguous" provisions in the new Version 5 standard may raise enforceability questions. Version 5 also enables industry to jump from the industry implemented Version 3 over Version 4. At a minimum, industry's implementation plans will be challenged, as there are vast differences between Version 3 and 5. Version 5 remains focused on systems above the distribution level where state and public utility commissions retain authority.

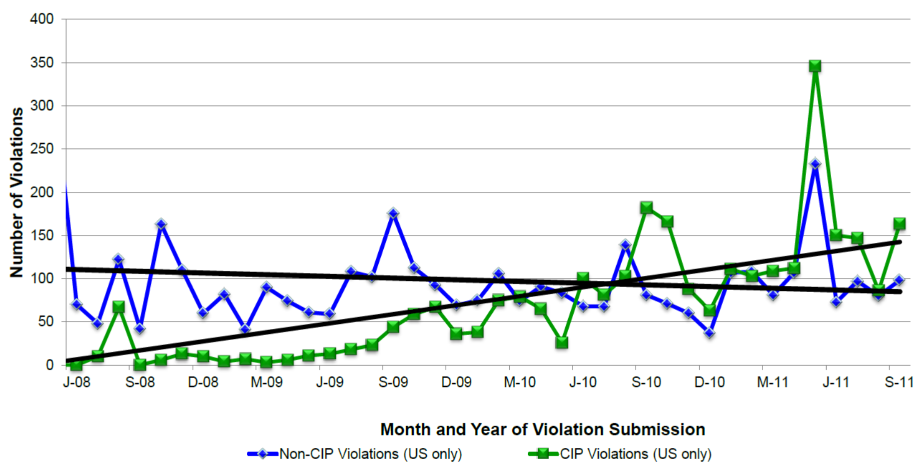

Figure 4.9. Comparison of Violation Trends: Critical Infrastructure Protection Standards vs. Non-Critical Infrastructure Protection Standards

5.0 Challenges to Deployment

Although significant gains have been made toward the development of a smart grid in recent years, challenges persist. Primary among them is the ability to make the business case for smart grid technologies based on cost effectiveness. Without adequate data to estimate the cost-effectiveness case, obtaining the capital required to implement smart grid deployments will be extremely difficult. Cost estimates for modernizing the grid (above and beyond the requirements for growth) reach as high as $880 billion. In turn, the projected modernization could return up to $2.0 trillion in value (EPRI 2011); however, for these benefits to be realized, specific smart grid technologies need to provide measurable value.

Education of smart grid stakeholders may aid in its adoption. A recent survey of industry insiders indicated that the term "smart grid" is undefined, leading to confusion and low customer confidence. In addition, lack of coordination between utilities and regulators has impeded smart grid initiatives, potentially affecting external stakeholders and investment. The greatest impediments to smart grid investments identified by interviewees are presented in Figure 5.1. Included are a lack of customer interest and knowledge, funding insecurities due to stimulus money slowdown, and poor business-case justification (Black & Veatch 2011).

Figure 5.1. Impediments to Smart Grid Investments

5.1 Technical Challenges

There are a number of technical challenges facing the smart grid associated with implementing demand response, monitoring and communicating loads and prices, and developing the standards required to ease the integration of these resources by participants in system operations. Due to the expanding number of automation devices and systems, interoperability and standards development are required for smart grid technology to integrate simply and operate properly. Progress in this area, however, requires general agreement on the points in these systems at which interfaces can be defined and stabilized. Such standards are being composed by a large number of standards organizations with a level of coordination being provided by the NIST-led SGIP. While there has been progress, there are areas still under development.

Interoperability is also closely intertwined with cybersecurity challenges. The electricity system of the future could become much more vulnerable to disruption by skilled electronic intrusion. The interface standards need to address cybersecurity requirements as they are developed and avoid or mitigate retrofitting cybersecurity–related capabilities because they were not always considered at the beginning. Legacy standards have suffered from this problem, but new standards efforts recognize the need to address cybersecurity needs at the start and accommodate revisions as threats and risks change.

Although smart meter deployment has increased dramatically since 2010 partly due to ARRA funding, many regions still lack AMI infrastructure. The challenge is to integrate new smart grid equipment with legacy infrastructure. For example, AMI interoperability challenges will be faced by providers who install smart meters that are not designed to be integrated with other AMI systems or technologies. Hardware and software applications necessary to handle dynamic pricing, allowing consumers and service providers to communicate with each other and respond to dynamic tariffs, are immature.

Similarly, the technical challenges to demand response lie mainly with the timely acquisition, communication, and storage of data. Adoption of common standards, business paradigms, and regulations for the seamless interaction between consumers and ESPs are viewed as important steps toward the widespread adoption of demand response. Considerable communications infrastructure improvements will be required to support the interactions between consumers and service providers. Nationally, at a rate of 400 megabytes per year (using 15-minute intervals), if every electricity customer had an advanced meter, the data needs of the smart grid would be 57.3 petabytes ($57.3 * 10^{15}$) of data storage per year (Miller 2009).

Standardization of the DG system interface with the grid remains a challenge. The system interfaces associated with incorporating DG resources differ widely between technologies, with internal combustion engines, combustion turbines, and small hydropower generation requiring synchronous or induction generators to convert to the electric system while fuel cells, wind turbines, PV and batteries require inverters.

Perhaps the largest technical hurdle for intermittent renewable energy resources to overcome is the impact on grid stability. A Bonneville Power Administration (BPA) study indicated that five classes of technologies are needed to improve integration of intermittent wind production: storage, fuel synthesis, generation, demand response, and operational techniques (BPA/NWPCC 2007). Noted among the approaches as providing flexibility, and in some level of development, were capacitors/ultra capacitors, redox flow batteries, megawatt-size batteries, flywheels, hydrogen storage, fuel cells, call rights on PEVs, and stretching wind prediction time. Most of these technologies/techniques, which are not at the mature stage, were listed as having high capital costs. Power electronics were also indicated as a technology where the movement to advanced high voltage semiconductors could further reduce cost by increasing round-trip efficiency (Johnson et al. 2010).

5.2 Business and Financial Challenges

Important business and financial challenges include obtaining the capital to finance smart grid project deployments, followed by the ability to justify costs, removing customer-perception barriers, improving reliability, and improving PQ. Whether it is AMI, load participation, dynamic line rating equipment, PMUs, time-based pricing, or implementing cybersecurity requirements, investments hinge upon whether investors can recover their costs and/or make a profit.

The long duration for the adoption of smart grid technologies and regulatory barriers present the two largest risks to venture capital investors. Investors are unwilling to wait 10 to 20 years for an ultimate payoff. Furthermore, regulatory obstacles, such as the process to recognize value streams and allow cost recovery, further discourage investment in smart grid technologies. Regulators require justification of electricity rates based on savings to consumers. However, net positive benefits are often difficult to demonstrate.

Another issue relates to cybersecurity threats and vulnerabilities with the potential for electricity disruption and the resulting lost value of production. Although NERC Standards CIP-002 through CIP-009 are an effective start to begin addressing cybersecurity and are achieving increased awareness and action within the ESP industry, there is growing recognition, based on NERC's reporting of noncompliance, that the standards have not yet been uniformly defined in a manner that, if implemented, can provide adequate security against cyber threats to the electric infrastructure. This inconsistency has provided significant concerns based on disparate interpretations of auditing activities resulting in fines that discourage investment in CIP related digital assets that may offer not only greater efficiencies in the electric system, but more tightly controlled cybersecurity protective measures. Subsequent versions extend the scope of systems protected by the CIP Reliability Standards and may exacerbate this issue without consideration of less prescriptive requirements, but rather focusing on more performance-based approaches in cybersecurity (because of the potential significance of audit findings and fines, other cybersecurity efforts could have a secondary focus on compliance vs. security). In addition, NIST has developed three volumes providing guidelines for smart grid cybersecurity (NIST 2010a) but the standards came well after some of the technology was developed and placed in the field.

Making the grid compatible with DG systems, load participation, AMI, and grid automation could be expensive for system operators. To better justify these investments, technology vendors and service providers are recognizing the need for "selling" technology advancement within their own organizations and to regulators. Technology road mapping is becoming a common tool to reach internal and external audiences. Examples of organizations using technology road mapping successfully to organize research and development efforts or implement smart grid strategies include the BPA, Southern California Edison (SCE 2010), and General Electric (Berst 2009).

Another smart grid challenge that faces both utilities and consumers is the protection of consumer energy consumption data while still enabling smart grid innovation. The smart grid provides an opportunity to match generation with demand more efficiently than the grid of the past. The challenge is to protect the consumers need for security and privacy while providing the data required to match energy demand with energy generation (DOE 2010). NIST dedicated an entire volume to privacy issues in their Guidelines for Smart Grid Cyber Security (NIST 2010b).

6.0 Conclusions

This report concludes that near-term progress in smart grid deployments has benefitted from the investments made under ARRA and the policy direction outlined in the EISA. With that noted, significant challenges to realizing smart grid capabilities persist. Foremost among these are the challenges tied to the value proposition, education of smart grid stakeholders, interoperability standards, security risks, and the limited availability of capital required to purchase the new technologies envisioned for communicating information between end-users and ESPs.

This report represents a snapshot on smart grid progress, as measured through 21 metrics. This report highlights transformational smart grid research and development (R&D) technologies that touch every part of the electricity system, from the accommodation of new generation and energy storage options to the integration of end-user equipment, including PEVs, smart appliances, and DG. Because this report and past SGSRs track investments made in smart grid technologies and document the resulting impacts, they inform public policy decisions.

Adoption rates for smart grid technologies will ultimately depend on associated business cases. For certain metrics, such as AMI deployments, the case for total conversion has not been made. Full conversion is, therefore, not desirable for all smart grid technologies. As benefits are clearly defined and realized, adoption rates will expand.

The status report provided for each of the 21 metrics is compared against levels reported in the 2009 and 2010 SGSRs. Each metric paper presented in Appendix A includes recommendations for improving measurement in the future. Thus, the research presented in this study could easily be built upon in the future to meet the changing needs of the research community and industry partners.

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