Smart Grid System Report

U.S. Department of Energy

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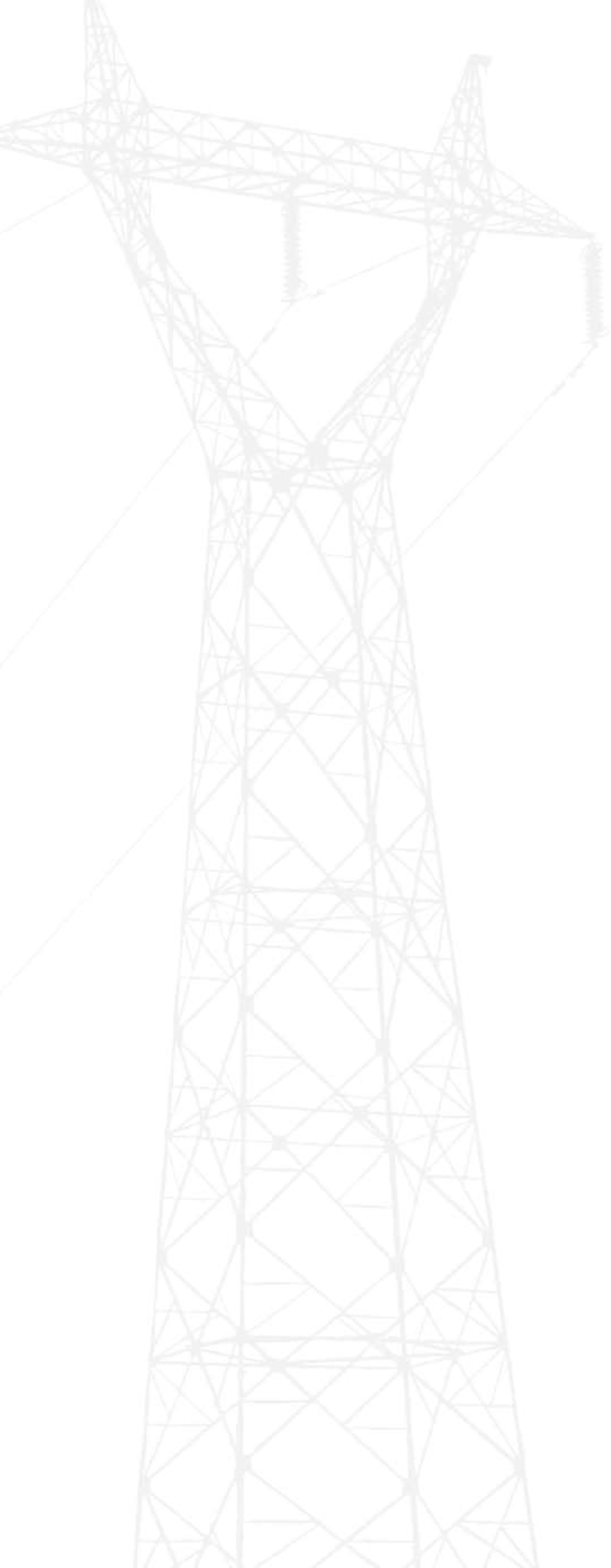
of Energy

July 2009



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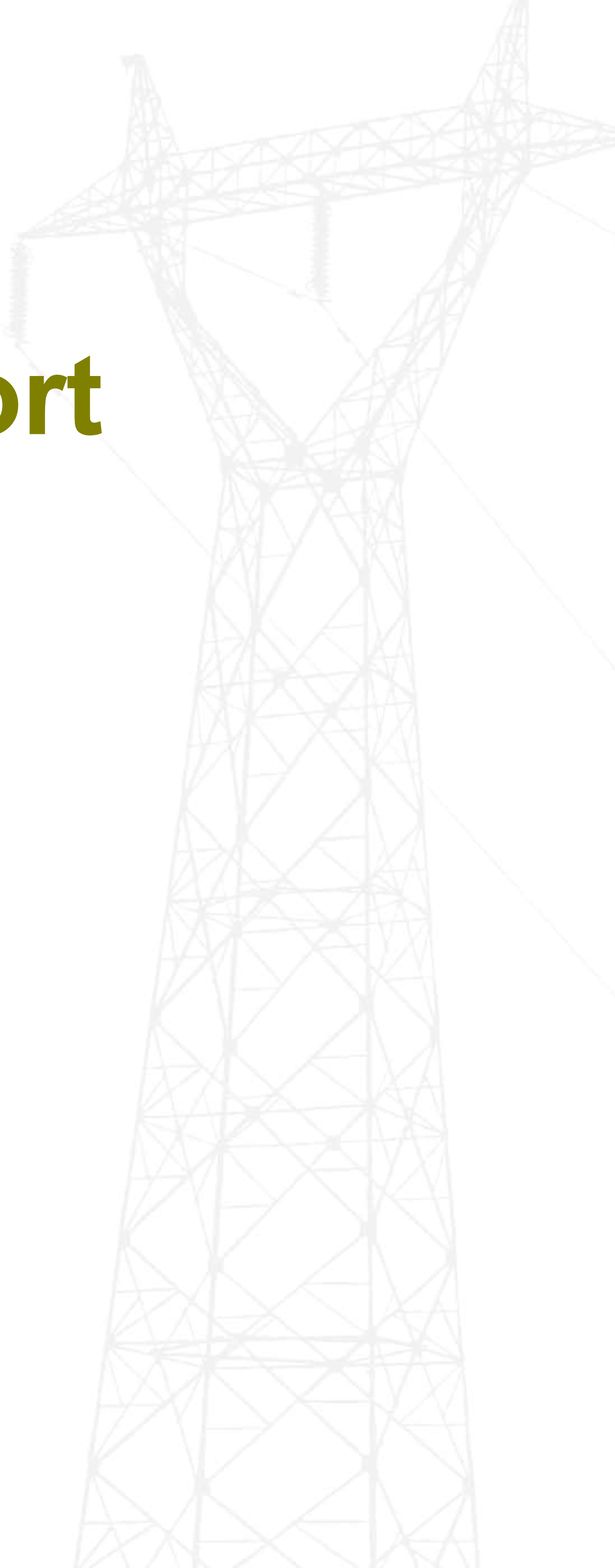
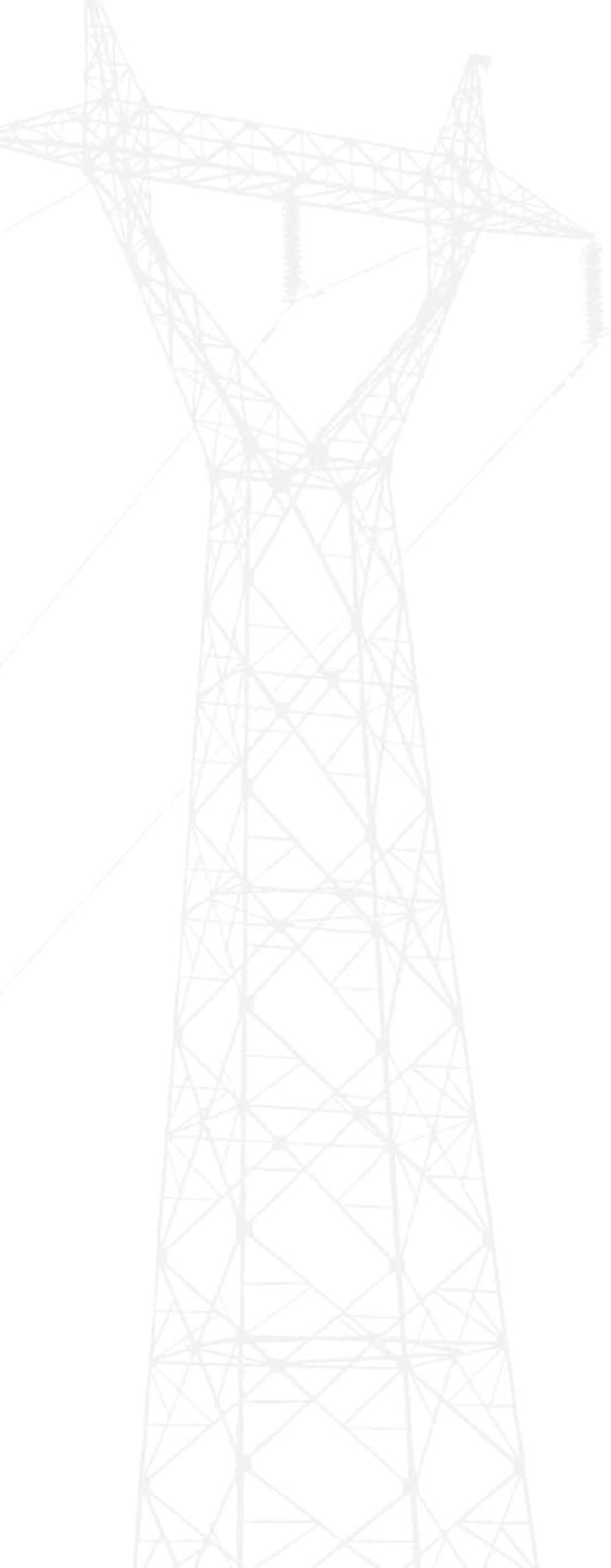
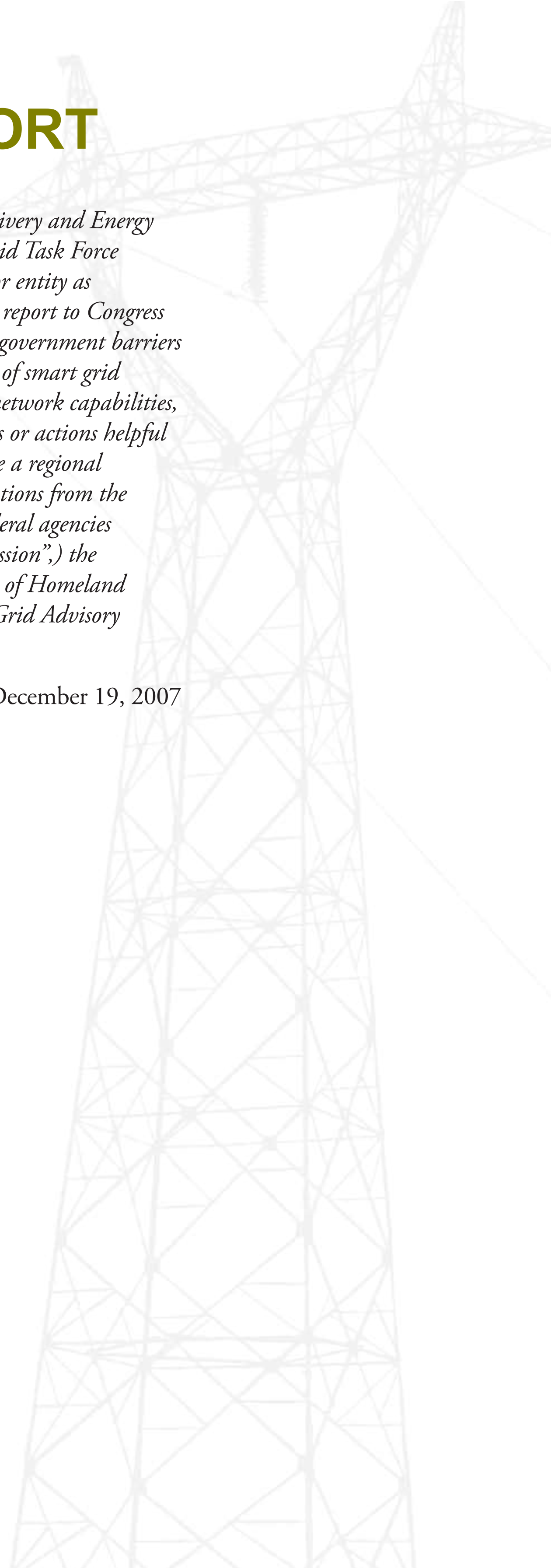


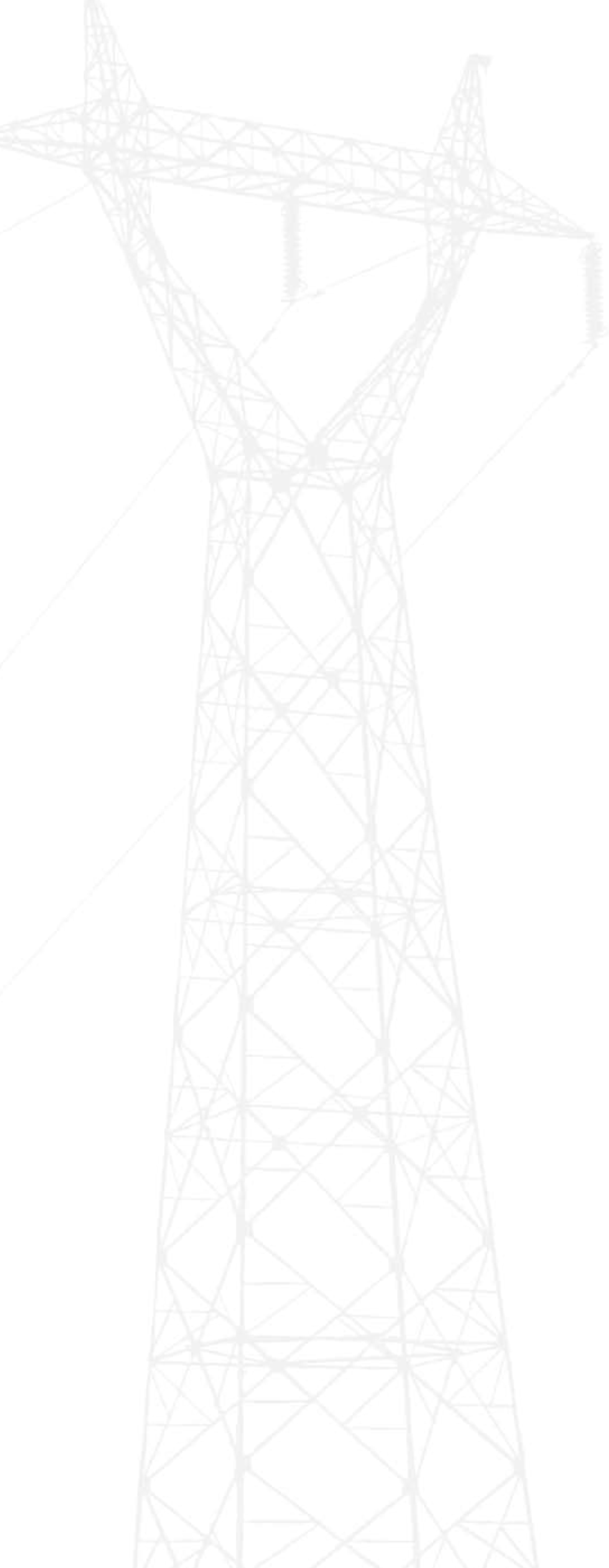


SEC. 1302.
SMART GRID SYSTEM REPORT

The Secretary, acting through the Assistant Secretary of the Office of Electricity Delivery and Energy Reliability (referred to in this section as the "OEDER") and through the Smart Grid Task Force established in section 1303, shall, after consulting with any interested individual or entity as appropriate, no later than one year after enactment and every two years thereafter, report to Congress concerning the status of smart grid deployments nationwide and any regulatory or government barriers to continued deployment. The report shall provide the current status and prospects of smart grid development, including information on technology penetration, communications network capabilities, costs, and obstacles. It may include recommendations for State and Federal policies or actions helpful to facilitate the transition to a smart grid. To the extent appropriate, it should take a regional perspective. In preparing this report, the Secretary shall solicit advice and contributions from the Smart Grid Advisory Committee created in section 1303; from other involved Federal agencies including but not limited to the Federal Energy Regulatory Commission ("Commission",) the National Institute of Standards and Technology ("Institute"), and the Department of Homeland Security; and from other stakeholder groups not already represented on the Smart Grid Advisory Committee.

—Energy Independence and Security Act of 2007, December 19, 2007





Executive Summary

Section 1302 of Title XIII of the Energy Independence and Security Act of 2007 directs the Secretary of Energy to "…report to Congress concerning the status of smart grid deployments nationwide and any regulatory or government barriers to continued deployment." This document satisfies this directive and represents the first installment of this report to Congress, which is to be updated biennially.

The state of smart grid deployment covers a broad array of electric system capabilities and services enabled through pervasive communications and information technology, with the objective to improve reliability, operating efficiency, resiliency to threats, and our impact to the environment. By collecting information from a workshop, interviews, and research of existing smart grid literature and studies, this report attempts to present a balanced view of progress toward a smart grid across many fronts. The Department of Energy sponsored a workshop, "Implementing the Smart Grid," that engaged stakeholders from utilities, reliability coordinators, electricity market operators, end users, suppliers, trade organizations, and state and federal regulators, as well as the National Institute of Standards and Technology and the Federal Energy Regulatory Commission. The workshop's outcomes provide a foundation for the metrics identified in this report. In addition, the Department's Energy Advisory Committee and their Smart Grid Subcommittee were consulted along with the inter-agency Smart Grid Task Force that includes representatives from NIST, FERC, the Department of Homeland Security, and the Environmental Protection Agency among others. While future reports will improve the measurement and perspective of this progress, the investigation done for this first report reveals the following key findings.

Key Findings

- **Distributed energy resources**: The ability to connect distributed generation, storage, and renewable resources is becoming more standardized and cost effective. While the penetration level remains low, the area is experiencing high growth. Several other concepts associated with a smart grid are in a nascent phase of deployment these include the integration of microgrids, electric vehicles, and demand response initiatives, including grid-sensitive appliances.
- **Electricity infrastructure**: Those smart grid areas that fit within the traditional electricity utility business and policy model have a history of automation and advanced communication deployment to build upon. Advanced metering infrastructure is taking automated meter reading approaches to a new level, and is seen as a necessary step to enabling dynamic pricing and consumer participation mechanisms. Though penetration of these systems is still low, the growth and attention by businesses and policymakers is strong. Transmission substation automation remains strong with greater levels of information exchanged with control centers. Cost/benefit thresholds are now encouraging greater levels of automation at the distribution substation level. While reliability indices show some slight degradation, generation and electricity transport efficiencies are improving.
- **Business and policy**: The business cases, financial resources, paths to deployment, and models for enabling governmental policy are only now emerging with experimentation. This is true of the regulated and non-regulated aspects of the electric system. Understanding and articulating the environmental and consumer perspectives also

remains in its infancy, though recent reports and deliberations indicate that significant attention is beginning to be given to these issues.

- **High-tech culture change**: A smart grid is socially transformational. As with the Internet or cell phone communications, our experience with electricity will change dramatically. To successfully integrate high levels of automation requires cultural change. The integration of automation systems within and between the electricity delivery infrastructure, distributed resources, and end-use systems needs to evolve from specialized interfaces to embrace solutions that recognize well-accepted principles, methodology, and tools that are commonly recognized by communications, information technology, and related disciplines that enable interactions within all economic sectors and individual businesses. The solutions to improving physical and cyber security, information privacy, and interoperability (conveniently connect and work within a collaborative system) require disciplines and best practices that are subscribed to by all stakeholders. A cross-disciplinary change that instills greater interaction among all the stakeholders is a necessary characteristic as we advance toward a smart grid. Progress in areas such as cyber security and interoperability is immature and difficult to measure, though improved approaches for future measurements are proposed.

The Scope of a Smart Grid

A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources (DOE/OEDER 2008a(1)). The information networks that are transforming our economy in other areas are also being applied to applications for dynamic optimization of electric system operations, maintenance, and planning. Resources and services that were separately managed are now being integrated and rebundled 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 that cover 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., building and factory loads, distributed generation, storage, electric vehicles),
- 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),
- the information networks themselves (e.g., remote measurement and control communications networks, inter- and intra-enterprise communications, public Internet), and
- the financial and regulatory 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 non-regulated rate-of-return on investment).

Some aspect of the electricity system touches every person in the Nation.

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(1) Items in parentheses such as this indicate source material listed in Section 6.0 References.

Some aspect of the electricity system touches every person in the Nation. The stakeholder landscape for a smart-grid is complex. The lines of distinction are not always crisp, as corporations and other organizations can take on the characteristics and responsibilities of multiple functions. Stakeholders include the following: end users (consumers), electric-service retailers, distribution and transmission service providers, balancing authorities, wholesale-electricity traders/brokers/markets, reliability coordinators, product and service suppliers, energy policymakers, regulators, and advocates, standards organizations, and the financial community.

The State of Smart Grid Deployments

The report looks across a spectrum of smart-grid concerns and identifies 20 metrics for measuring the status of smart-grid deployment and impacts. Across the vast scope of smart-grid deployment, many things can be measured. The approach is to identify key indicators that can provide a sense of smart-grid progress while balancing detail and complexity. The metrics are derived from a Department of Energy-sponsored workshop on "Implementing the Smart Grid" (DOE/OEDER 2008b). At this workshop a cross-section of the stakeholder representation worked to identify over 50 areas for measurement. This list was distilled to remove areas of overlap and metrics that, while appropriate, were deemed too hard to measure. The result is the list shown in Table ES.1, *Summary of Smart Grid Metrics and Status*. The list covers the various areas of concern in a smart grid. Finding accurate measurements is difficult in a few cases, but recommendations for improving the metric or measurement capture are included in the report.

The approach is to identify key indicators that can provide a sense of smart-grid progress while balancing detail and complexity.

Besides describing the 20 metrics, the table summarizes a broad indication of the penetration level (if a build metric) or maturity level (if a value metric), as well as the trending direction. Build metrics describe attributes that are built in support of a smart grid, while value metrics describe the value that may derive from achieving a smart grid. While build metrics tend to be quantifiable, value metrics can be influenced by many developments and therefore generally require more qualifying discussion. The indication levels used in the table for build metrics refer to level of penetration: nascent (very low and just emerging), low, or moderate. Because smart grid activity is relatively new, there are no high penetration levels to report on these metrics. The value metrics indicate whether the present state is nascent or mature. The trend (recent past and near-term projection) is indicated for either type of metric as declining, flat, or growing at nascent, low, moderate, or high, levels.

As smart-grid concerns are future-looking, several of the metrics represent areas where deployment activities are just being explored. Finding baseline status information for these areas is difficult. This is the case with several metrics in the Distributed Resource Technology area and Information Networks. Microgrids, electric or hybrid vehicles, and grid-responsive, non-generating demand-side equipment fall into this category. In the Delivery Infrastructure area, dynamic line limit technology deployment is also emerging; though the concept and pilots have been around for several years, the value proposition keeps it at the nascent level. Cyber security and open architecture/standards metrics are also listed as nascent. Even though attention is being paid to these areas, the application of a disciplined approach to cyber security and interoperability issues is new. A development and operational culture that addresses these concerns needs to mature and better methods are needed to measure progress.

Other smart-grid metrics are in areas that have been receiving attention for several years, and while the technology deployment may be low or moderate, implementation paths have had time to mature. The area of Delivery (T&D) Infrastructure is a good example. Substation automation has a long history of progress in the transmission area and is now beginning to penetrate the distribution system. Advanced metering infrastructure has a low level of penetration today, but the attention given to this area by utilities and regulators has resulted in significant investments with large near-term deployment growth projections. Though not as dramatic, advanced measurement systems, such as synchro-phasor technology deployment, are also growing.

In the Area, Regional, and National Coordination area, the metrics indicate a moderate level of activity, though the penetration level is low and regional progress is diverse. Policy makers are naturally cautious in making dynamic-pricing and rate-recovery decisions as value propositions remain immature, untested, and therefore, risky. Distributed-resource interconnection rules and procedures vary significantly across different service regions. Distributed energy resources, including renewable and non-renewable generation, storage, and grid-responsive load are being integrated, but at low penetration level.

Venture capital funding of startups grew at an average annual rate of 27%

The report monitors the following value metrics that pertain to the Delivery Infrastructure area: reliability, capacity, operating efficiency, and power quality. While operating efficiency has seen some improvement,the trends for the other indices have been flat or deteriorating over recent history. Though these values are difficult to cleanly associate with steps toward a smart grid, we expect improvement of these trends.

To convey the present situation of smart-grid deployment, the report uses a set of six characteristics derived from the seven characteristics of the National Energy Technology Laboratory (NETL) Modern Grid Strategy project and documented in “Characteristics of the Modern Grid” (NETL 2008).(1) The metrics listed in Table ES.1 provide insights into progress toward these characteristics. Nearly all of the metrics contribute information to understanding multiple characteristics. The main findings are summarized below:

- **Enables Informed Participation by Customers**: Supporting the bi-directional flow of information and energy is a foundation for enabling participation by consumer resources. Advanced metering infrastructure (AMI) is receiving the most attention in terms of planning and investment. Currently AMI comprises about 4.7% of all electric meters being used for demand response. Approximately 52 million more meters are projected to be installed by 2012. A large number of the meters installed are not being used for demand response activities [Metric 12]. Pricing signals can provide valuable information for consumers (and the automation systems that reflect their preferences) to decide on how to react to grid conditions. A FERC study found that in 2008 slightly over 1% of all customers received a dynamic pricing tariff [Metric 1], with nearly the entire amount represented by time-of-use tariffs. Lastly, the amount of load participating based on grid conditions is beginning to show a shift from traditional interruptible demand at industrial plants 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 [Metric 5].
- **Accommodates All Generation and Storage Options**: Distributed energy resources and interconnection standards to accommodate generation capacity appear to be moving in positive directions. Accommodating a large number of disparate generation and storage resources requires anticipation of intermittency and unavailability, while balancing costs, reliability, and environmental emissions. Distributed generation (carbon-based and renewable) and storage, although a small fraction (1.6%) of total

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(1) The sixth characteristic is a merger of the Modern Grid Initiative’s characteristics a) Self- Heals and b) Resists Attack. The same metrics substantially contribute to both of these concerns.

summer peak, appear to be increasing rapidly [Metric 7]. In addition, 31 states have interconnection standards in place, with 11 states progressing toward a standard, one state with some elements in place, and only 8 states with none. Unfortunately, only 15 states had interconnection standards that were deemed to be favorable to the integration of these resources [Metric 3].

- **Enables New Products, Services, and Markets**: Companies with new smart-grid concepts are receiving a significant injection of money. Venture-capital funding of startups grew from $58.4 million in 2002 to $194.1 million in 2007, yielding an average annual rate increase of 27% [Metric 20]. Electric utilities are finding some incentives from regulatory rulings that allow them rate recovery for smart-grid investments [Metric 4]. Some of these rulings have allowed AMI deployments to move forward and more information is being obtained to characterize the consumer benefits from the emerging new products and services. Great interest and investment in electric vehicles, including plug-in hybrids, is changing the future complexion of transportation and represents a significant demand for new products and services, including bi-directional information flow as being supported in AMI systems and smart charging systems. Today only 0.02% of light-duty vehicles are grid-connected, but most forecasts estimate ultimate penetration of this market at 8-16%, with some aggressive estimates at 37%, by 2020 [Metric 8]. A smart grid will also include consumer-oriented "smart" equipment, such as thermostats, space heaters, clothes dryers, and water heaters that communicate to enable demand participation. This smart equipment and related demand participation program offerings are just emerging, primarily in pilot programs [Metric 9].
- **Provides the Power Quality for the Range of Needs**: Not all customers have the same power-quality requirements, though traditionally these requirements and the costs to provide them have been shared. While the state of power quality has been difficult to quantify, the number of customer complaints has been rising slightly [Metric 17]. 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 substation automation [Metric 11] (see next bullet). As mentioned earlier, distributed energy resource deployment is trending upward, while microgrid parks are just emerging and are mostly represented in pilot programs.
- **Optimizes Asset Utilization and Operating Efficiently**: Gross annual measures of operating efficiency have been improving slightly as energy lost in generation dropped 0.6 % to 67.7% in 2007 and transmission and distribution losses also improved slightly [Metric 15]. The summer peak capacity factor declined slightly to 80.8% while overall annual average capacity factor is projected to increase slightly to 46.5% [Metric 14]. Contributions to these measures include substation automation deployments. While transmission substations have considerable instrumentation and coordination, the value proposition for distribution-substation automation is now receiving more attention. Presently about 31% of substations have some form of automation, with the number expected to rise to 40% by 2010 [Metric 11]. The deployment of dynamic line rating technology is also expected to increase asset utilization and operating efficiency; however, implementations thus far have had very limited penetration levels [Metric 16].
- **Operates Resiliently to Disturbances, Attacks, and Natural Disasters**: The national averages for reliability indices (outage duration and frequency measures SAIDI, SAIFI, and MAIFI) appear to be trending upward [Metric 10]. Smart-grid directions, such as demand-side resource and distributed-generation participation in system operations

discussed in the first two bullets are expected to more elegantly respond to disturbances and emergencies. Within the delivery-system field operations, substation automation (discussed in the previous bullet) is showing progress [Metric 11]. At the regional system operations level, advanced measurement equipment is being deployed within the delivery infrastructure to support situational awareness and enhance reliability coordination. Deployment numbers for one technology, synchro-phasor measurements, have increased from 100 units in 2006 to roughly 150 in 2008. Lastly, cyber-security challenges are beginning to be addressed with a more disciplined approach. NERC Critical Infrastructure Protection security assessments are more common with about 95% of companies interviewed for this report indicating that they have conducted at least one security assessment of their operations [Metric 18]. This characteristic is a merger of the Modern Grid Initiative's characteristics a) Self-Heals and b) Resists Attack. The same metrics substantially contribute to both of these concerns.

Different areas of the country have distinctions with regard to their generation resources, their business economy, climate, topography, environmental concerns, and public policy. These distinctions influence the picture for smart-grid deployment in each region, provide different incentives, and pose different obstacles for development. Where appropriate, the report discusses progress and issues associated with the state of smart-grid deployment measures on a regional basis.

Challenges to Smart Grid Deployments

Among the significant challenges facing development of a smart grid are the cost of implementing a smart grid, with estimates for just the electric utility advanced metering capability ranging up to $27 billion (Kuhn 2008), and the regulations that allow recovery of such investments. For perspective, the Brattle Group estimates that it may take as much as $1.5 trillion to update the grid by 2030 (Chupka et al. 2008). Ensuring interoperability of smart-grid standards is another hurdle state and federal regulators will need to leap. Major technical barriers include developing economical storage systems; these storage systems can help solve other technical challenges, such as integrating distributed renewable-energy sources with the grid, addressing power-quality problems that would otherwise exacerbate the situation, and enhancing asset utilization. Without a smart grid, high penetrations of variable renewable resources may become more difficult and expensive to manage due to the greater need to coordinate these resources with dispatchable generation and demand.

A smart grid challenge is the uncertainty of the path that its development will take.

Another challenge facing a smart grid is the uncertainty of the path that its development will take over time with changing technology, changing energy mixes, changing energy policy, and developing climate change policy. Trying to legislate or regulate the development of a smart grid or its related technologies can severely diminish the benefits of the virtual, flexible, and transparent energy market it strives to provide. Conversely, with the entire nation's energy grid potentially at risk, some may see the introduction of a smart grid in the United States as too important to allow laissez-faire evolution. Thus, the challenge of development becomes an issue of providing flexible regulation that leverages desired and developing technology through goal-directed and business-case-supported policy that promotes a positive economic outcome.

Policy Questions for Future Reports

Many policy questions continue to be raised surrounding smart-grid systems. Listed below are policy questions to consider related to reporting on smart grid deployments.

- As the first in a series of biennial smart-grid status reports, consideration should be given to the information gathered for this report as a framework and measurement baseline for future reports. The metrics identified are indicators of smart grid deployment progress that facilitate discussion regarding the main characteristics of a smart grid, but they are not comprehensive measures of all smart grid concerns. Because of this, should they be reviewed for continued relevance and appropriate emphasis of major smart grid attributes?
- Should the status of smart grid deployment project as balanced a view as possible across the diverse stakeholder perspectives related to the electric system? Should workshops, interviews, and research into smart grid related literature reflect a complete cross-section of the stakeholders? Should future reports review the stakeholder landscape to ensure coverage of these perspectives?
- Given the time period for developing the report, investigation was restricted to existing literature research and interviews with 21 electricity-service providers, representing a cross section of organizations by type, size, and location. Is further research needed to better gage the metrics and gain insights into deployment directions, as well as engage the other stakeholder groups? Will a more extensive interview process facilitate gathering this information?
- Should coordination with other smart grid information collection activities be supported? Should future reports require the development of assessment models that support those metrics that are difficult to measure, particularly regarding progress on cyber-security and automation system interoperability related to open architecture and standards?
- How comprehensive should a review related to smart grid deployment be? Should the number of metrics proliferate beyond the current number? In deciding if a new metric is merited, should consideration be given to how it fits with the other metrics, if a previous metric can be retired, and the strength of a metric's contribution to explaining the smart grid progress regarding the identified characteristics?

Report Content

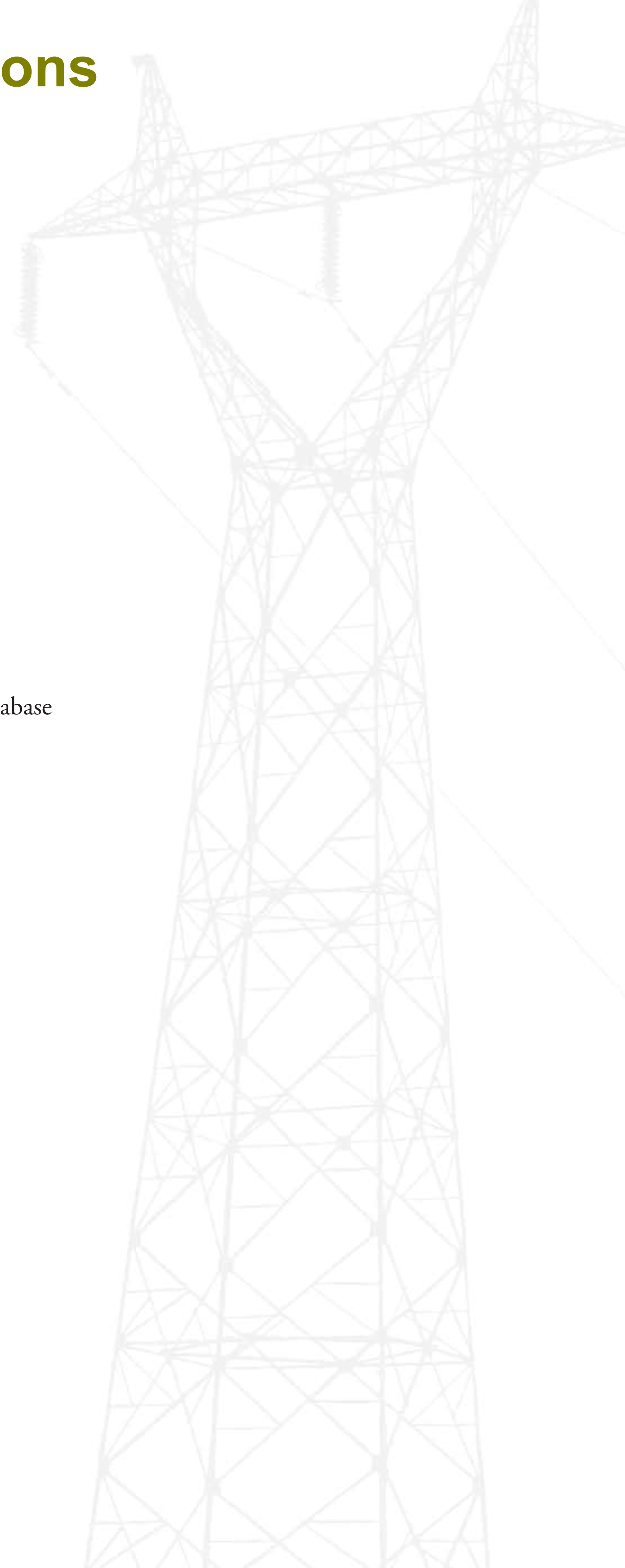
The Smart-Grid System Report is organized into a main body and two supporting annexes. The main body discusses the metrics chosen to provide insight into the progress of smart-grid deployment nationally. The measurements resulting from research into the metrics are used to convey the state of smart-grid progress according to six characteristics derived from the NETL Modern Grid Strategy's work in this area. The main body of the report concludes with a summary of the challenges to smart-grid deployment including technical, business and financial challenges.

The first of two annexes presents a discussion of each of the metrics chosen to help measure the progress of smart-grid deployment. The second summarizes the results of interviews with 21 electricity-service providers 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, etc.). The interview questions were designed to support many of the identified metrics and the results are incorporated into the metric write-ups to support measurement estimates.

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

#	Metric Title	Type	Penetration/ Maturity	Trend
	Area, Regional, and National Coordination Regime			
1	**Dynamic Pricing**: fraction of customers and total load served by RTP, CPP, and TOU tariffs	build	low	moderate
2	**Real-time System Operations Data Sharing**: Total SCADA points shared and fraction of phasor measurement points shared.	build	moderate	moderate
3	**Distributed-Resource Interconnection Policy**: percentage of utilities with standard distributed-resource interconnection policies and commonality of such policies across utilities.	build	moderate	moderate
4	**Policy/Regulatory Progress**: weighted-average percentage of smart grid investment recovered through rates (respondents' input weighted based on total customer share).	build	low	moderate
	Distributed-Energy-Resource Technology			
5	**Load Participation Based on Grid Conditions**: fraction of load served by interruptible tariffs, direct load control, and consumer load control with incentives.	build	low	low
6	**Load Served by Microgrids**: the percentage total grid summer capacity.	build	nascent	low
7	**Grid-Connected Distributed Generation (renewable and non-renewable) and Storage**: percentage of distributed generation and storage.	build	low	high
8	**EVs and PHEVs**: percentage shares of on-road, light-duty vehicles comprising of EVs and PHEVs.	build	nascent	low
9	**Grid-Responsive Non-Generating Demand-Side Equipment**: total load served by smart, grid-responsive equipment.	build	nascent	low
	Delivery (T&D) Infrastructure			
10	**T&D System Reliability**: SAIDI, SAIFI, MAIFI.	value	mature	declining
11	**T&D Automation**: percentage of substations using automation.	build	moderate	high
12	**Advanced Meters**: percentage of total demand served by advanced metered (AMI) customers	build	low	high
13	**Advanced System Measurement**: percentage of substations possessing advanced measurement technology.	build	low	moderate
14	**Capacity Factors**: yearly average and peak-generation capacity factor	value	mature	flat
15	**Generation and T&D Efficiencies**: percentage of energy consumed to generate electricity that is not lost.	value	mature	improving
16	**Dynamic Line Ratings**: percentage miles of transmission circuits being operated under dynamic line ratings.	build	nascent	low
17	**Power Quality**: percentage of customer complaints related to power quality issues, excluding outages.	value	mature	declining
	Information Networks and Finance			
18	**Cyber Security**: percent of total generation capacity under companies in compliance with the NERC Critical Infrastructure Protection standards.	build	nascent	nascent
19	**Open Architecture/Standards**: Interoperability Maturity Level – the weighted average maturity level of interoperability realized among electricity system stakeholders	build	nascent	nascent
20	**Venture Capital**: total annual venture-capital funding of smart-grid startups located in the U.S.	value	nascent	high

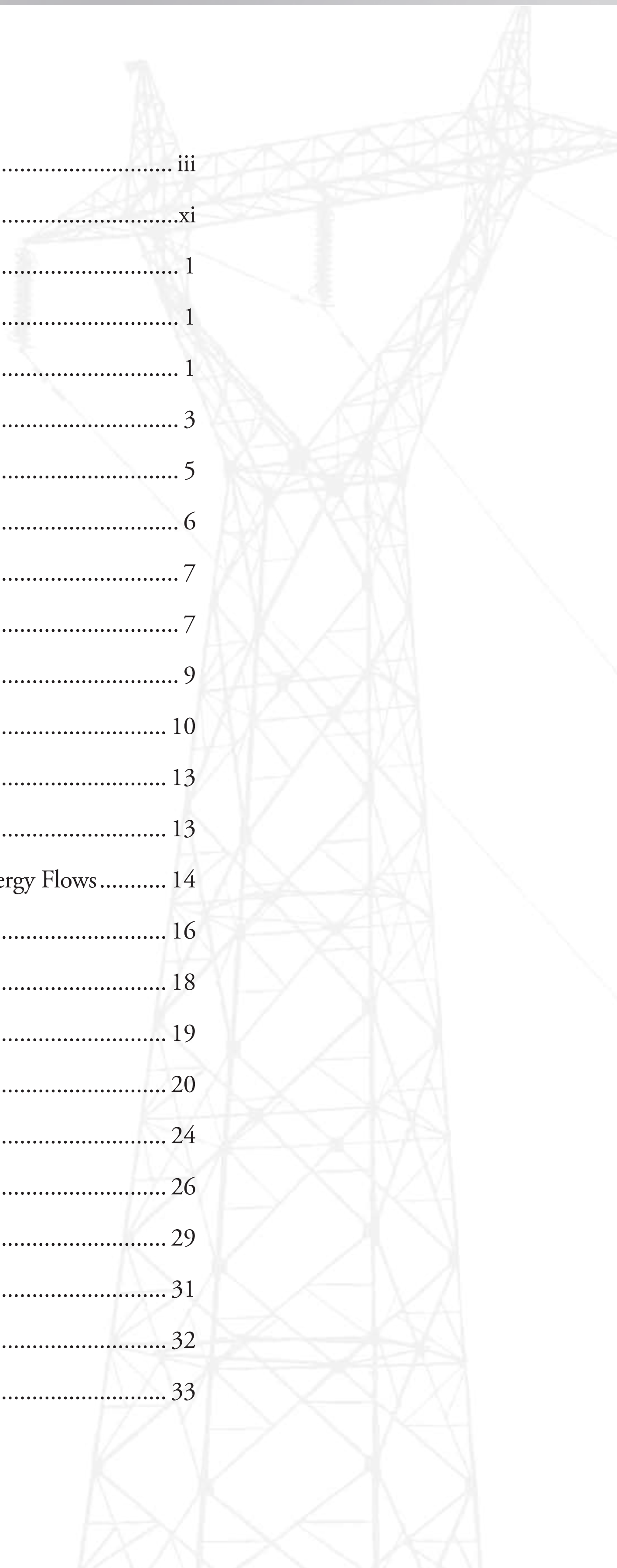
Acronyms and Abbreviations



AMI	advanced metering infrastructure
AMR	automated meter reading
AMS	advanced metering system
CA	Control Area
CAIDI	Customer Average Interruption Duration Index
CBL	customer baseline load
CHP	combined heat and power
CIP	critical infrastructure protection
CPP	critical peak pricing
CPUC	California Public Utilities Commission
DC	District of Columbia
DER	distributed energy resources
DG	distributed generation
DLR	dynamic line ratings
DMS	distribution management systems
DOE	Department of Energy
eGRID	Emissions and Generation Resource Integrated Database
EIA	Energy Information Administration
EIOC	Electricity Infrastructure Operations Center
EMS	energy management systems
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
EV	electric vehicle
FERC	Federal Energy Regulatory Commission
GW	gigawatt, billion watts
GWAC	GridWise® Architecture Council
HAN	home area network
IED	intelligent electronic device
IEEE	Institute of Electrical and Electronic Engineers
IOU	investor-owned utilities
ISO	independent system operator
IT	information technology
KVAR	KilovoltAmpere Reactive
kWh	kilowatt-hours
LBNL	Lawrence Berkeley National Laboratory

MAIFI	Momentary Average Interruption Frequency Index
MDMS	meter data management system
MW	megawatts
MWh	megawatt-hours
NASPI	North American Synchro-Phasor Initiative
NERC	North American Electric Reliability Corporation
NETL	National Energy Technology Laboratory
NIST	National Institute of Standards and Technology
NRDC	National Resources Defense Council
OEM	original equipment manufacturer
OWL	Web Ontology Language
PG&E	Pacific Gas and Electric Company
PHEV	plug-in hybrid electric vehicles
PMU	phasor measurement units
PQ	power quality
PSC	public service commission
PUC	public utility commission
RCC	Reliability Coordination Center
RFC	Reliability First Corporation
RFP	request for proposal
RTO	regional transmission operator
RTP	real-time pricing
SAIDI	system average interruption duration index
SAIFI	system average interruption frequency index
SCADA	supervisory control and data acquisition
SDG&E	San Diego Gas & Electric Company
SERC	Southeastern Electric Reliability Company
SPP	Southwest Power Pool
T&D	transmission and distribution
TCP	Transmission Control Protocol
TOU	time-of-use pricing
TW	terawatt, trillion watts
TWh	terawatt-hours
UML	Unified Modeling Language®
VAR	volt-amps reactive
WAMS	Wide Area Measurement System
WECC	Western Electricity Coordination Council
XML	Extensible Markup Language

Contents



Executive Summary ... iii

Acronyms and Abbreviations ... xi

1.0 Introduction ... 1

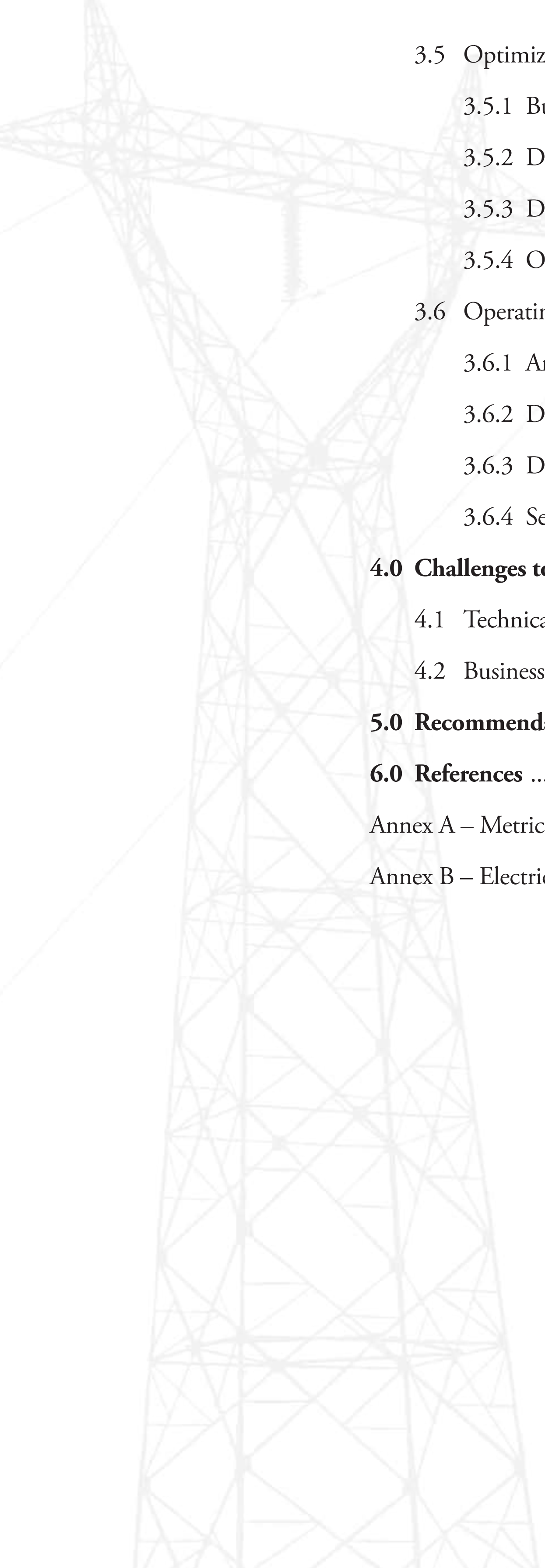
- 1.1 Objectives ... 1
- 1.2 Scope of a Smart Grid ... 1
- 1.3 Stakeholder Landscape ... 3
- 1.4 Regional Influences ... 5
- 1.5 About this Document ... 6

2.0 Deployment Metrics and Measurements ... 7

- 2.1 Smart-Grid Metrics ... 7
- 2.2 Smart-Grid Characteristics ... 9
- 2.3 Mapping Metrics to Characteristics ... 10

3.0 Deployment Trends and Projections ... 13

- 3.1 Enables Informed Participation by Customers ... 13
  - 3.1.1 Grid-Enabled Bi-Directional Communication and Energy Flows ... 14
  - 3.1.2 Managing Supply and Demand ... 16
- 3.2 Accommodating All Generation and Storage Options ... 18
  - 3.2.1 Distributed Generation and Storage ... 19
  - 3.2.2 Standard Distributed-Resource Connection Policy ... 20
- 3.3 Enables New Products, Services, and Markets ... 24
  - 3.3.1 Enabling New Products and Services ... 26
  - 3.3.2 Enabling New Markets ... 29
- 3.4 Provides Power Quality for the Range of Needs ... 31
  - 3.4.1 The Cost of Poor Power Quality ... 32
  - 3.4.2 Smart-Grid Solutions to Power Quality Issues ... 33



3.5 Optimizing Asset Utilization and Operating Efficiency 35
  3.5.1 Bulk Generation 35
  3.5.2 Delivery Infrastructure 37
  3.5.3 Distributed Energy Resources 39
  3.5.4 Overall System Efficiency 40
3.6 Operating Resiliently to Disturbances, Attacks, and Natural Disasters 41
  3.6.1 Area, Regional, National Coordination 42
  3.6.2 DER Response 44
  3.6.3 Delivery Infrastructure 45
  3.6.4 Secure Information Networks 46

4.0 Challenges to Deployment 49
4.1 Technical Challenges 49
4.2 Business and Financial Challenges 51

5.0 Recommendations for Future Reports 53

6.0 References 55

Annex A – Metrics A.1

Annex B – Electricity Service Provider Interviews B.1

Figures

1.1 Scope of Smart-Grid Concerns 2

1.2 Stakeholder Landscape 4

1.3 United States Portions of NERC Region Representation Map 5

1.4 EPA eGRID Subregion Representational Map 6

3.1 Overview of AMI Interface 14

3.2 Demand Response by NERC Region 17

3.3 Yearly Installed DG Capacity by Technology Type 19

3.4 Projected DG Capacity in GW 21

3.5 State Interconnection Standards 22

3.6 Favorability of State Interconnection Standards 22

3.7 Venture-Capital Funding of Smart-Grid Startups 25

3.8 Interoperability Categories 30

3.9 Measured and Predicted Peak Summer, Peak Winter, and Yearly Average Generation Capacity Factors in the U.S. 36

3.10 Generation Efficiency for Various Fossil Fuel Sources over Time 36

3.11 Current/Future Plans for Connecting EMS/SCADA/DMS Systems to Other Data Systems 38

3.12 North American Electric Power T&D Automation Expenditures, ... 39

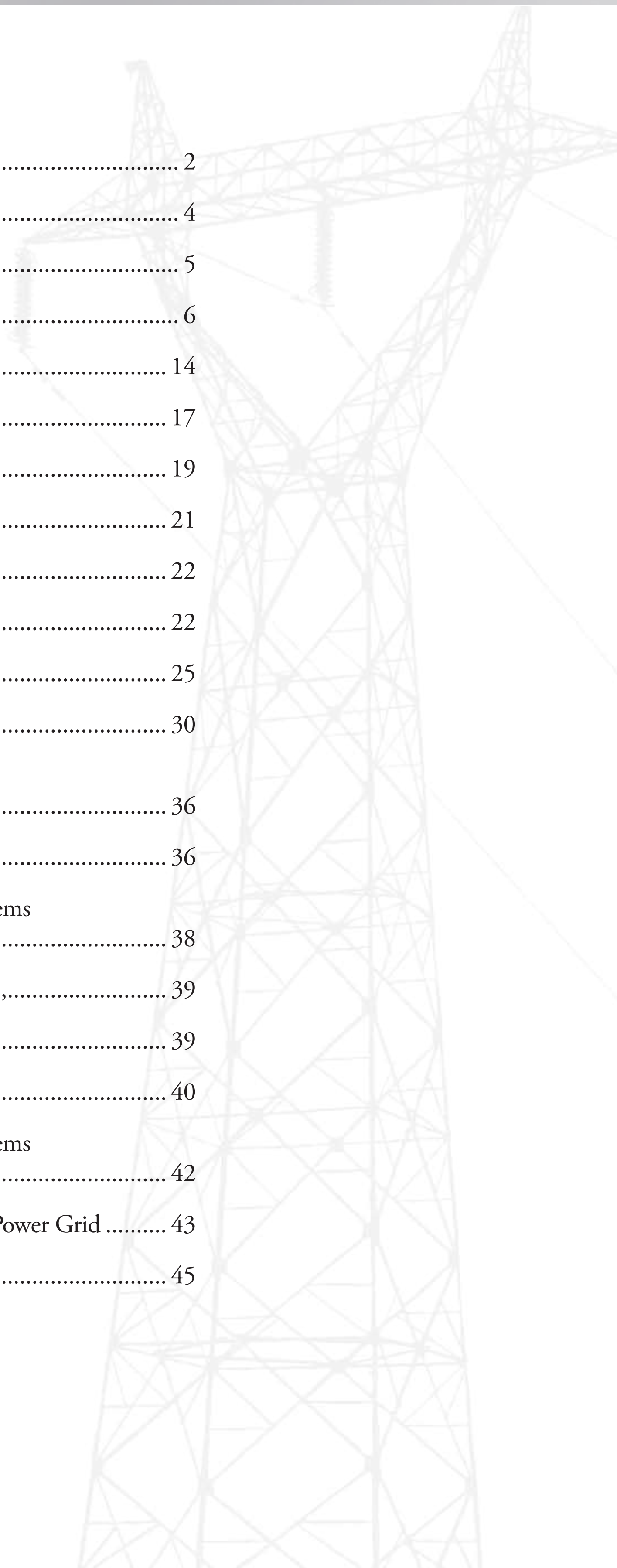
3.13 Winter Peak Demand for the Contiguous U.S. 39

3.14 Electricity Flow Diagram 2007 40

3.15 Current/Future Plans for Connecting EMS/SCADA/DMS Systems to Other Data Systems 42

3.16 Networked Phasor Measurement Units in the North American Power Grid 43

3.17 Trends for 55 Utilities Providing Data Between 2000-2005 45



Tables

2.1 Summary of Smart Grid Metrics and Status 8

2.2 Smart-Grid Characteristics........ 10

2.3 Map of Metrics to Smart-Grid Characteristics........ 11

3.1 Number of Entities Offering and Customers Served by Dynamic Pricing Tariffs 15

3.2 Capacity of Distributed Generators by Technology Type 2004 and 2008........ 20

3.3 EV and PHEV Market Penetration........ 27

3.4 Capacity of Microgrids in 2005 34

3.5 Entities Offering Load-Management and Demand-Response Programs........ 35

3.6 Measured and Projected Peak Demands and Generation Capacities for Recent Years in the U.S., and Calculated Capacity Factors........ 37

3.7 Summary of the NERC Critical Infrastructure Protection Standards........ 47

3.8 Sample Security Question from Service Provider Interviews........ 47

1.0 Introduction

Section 1302 of Title XIII of the Energy Independence and Security Act of 2007 directs the Secretary of Energy to, "…report to Congress concerning the status of smart grid deployments nationwide and any regulatory or government barriers to continued deployment." The first report is to occur no later than one year after enactment. This is the first installment of this report to Congress, which is to be updated biennially. Please note that this report does not include impacts related to the American Recovery and Reinvestment Act of 2009.

1.1 Objectives

The objective of Title XIII is to support the modernization 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. The Smart Grid System Report is to provide the current status of smart-grid development, the prospects for its future, and the obstacles to progress. In addition to providing the state of smart-grid deployments, the legislation includes the following requirements:

1. report the prospects of smart-grid development including costs and obstacles;
2. identify regulatory or government barriers;
3. may provide recommendations for state and federal policies or actions; and
4. take a regional perspective.

In the process of developing this report, the advice of the Electricity Advisory Committee and its Subcommittee on Smart Grid has been solicited, in addition to the advice from the Federal Smart Grid Task Force, an inter-agency group that includes representation from U.S. Department of Energy (DOE), Federal Energy Regulatory Commission (FERC), National Institute for Standards and Technology (NIST), U.S. Department of Homeland Security (DHS), U.S. Environmental Protection Agency (EPA), and other involved federal agencies.

As the first in a series of biennial smart-grid status reports, aspects of this report are expected to form the framework for future reports. However, such future reports will be able to go into greater assessment detail using this framework and measure smart-grid-related progress based on the baseline established in this report.

A smart grid uses digital technology to improve reliability, security, and efficiency of the electric system.

1.2 Scope of a Smart Grid

A smart grid uses digital technology to improve reliability, security, and efficiency of the electric system. Due to the vast number of stakeholders and their various perspectives, there has been debate on a definition of a smart grid that addresses the special emphasis desired by each participant. To define the scope of a smart grid for this report, we reviewed application areas throughout the electric system related to dynamic optimization of system operations, maintenance, and planning. Figure 1.1 provides a pictorial view of the many aspects of the electric system touched by smart grid concerns.

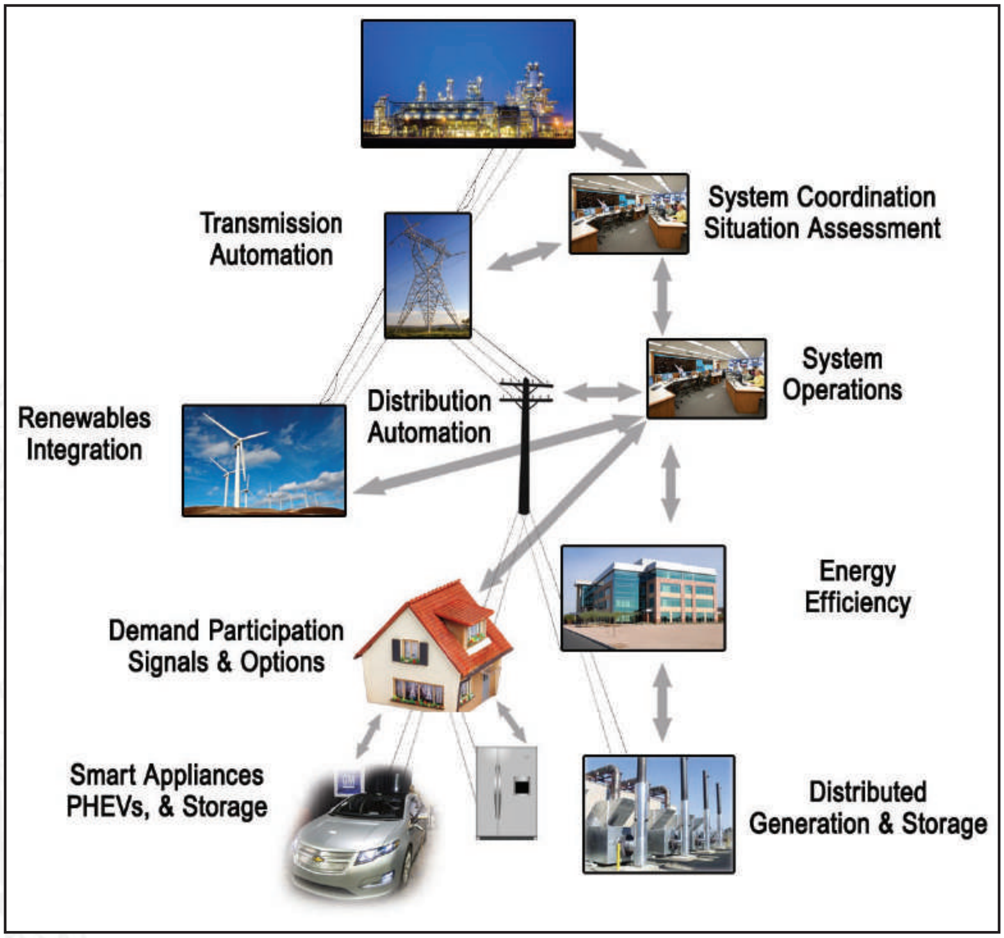


Figure 1.1. Scope of Smart-Grid Concerns

The following areas arguably represent a reasonable partitioning of the electric system that covers the scope of smart grid concerns. To describe the progress being made in moving toward a smart grid, one must also consider the interfaces between elements within each area and the systemic issues that transcend areas. The areas of the electric system that cover the scope of a smart grid include the following:

- **Area, regional and national coordination regimes**: A series of interrelated, hierarchical coordination functions exists for the economic and reliable operation of the electric system. These include balancing areas, independent system operators (ISOs), regional transmission operators (RTOs), electricity market operations, and government emergency-operation centers. Smart-grid elements in this area include collecting measurements from across the system to determine system state and health, and coordinating actions to enhance economic efficiency, reliability, environmental compliance, or response to disturbances.
- **Distributed-energy resource technology**: Arguably, the largest "new frontier" for smart grid advancements, this area includes the integration of distributed-generation, storage, and demand-side resources for participation in electric-system operation. Consumer products such as smart appliances and electric vehicles are expected to

become important components of this area as are renewable-generation components such as those derived from solar and wind sources. Aggregation mechanisms of distributed-energy resources are also considered.

- **Delivery (transmission and distribution [T&D]) infrastructure**: T&D represents the delivery part of the electric system. Smart-grid items at the transmission level include substation automation, dynamic limits, relay coordination, and the associated sensing, communication, and coordinated action. Distribution-level items include distribution automation (such as feeder-load balancing, capacitor switching, and restoration) and advanced metering (such as meter reading, remote-service enabling and disabling, and demand-response gateways).
- **Central generation**: Generation plants already contain sophisticated plant automation systems because the production-cost benefits provide clear signals for investment. While technological progress is related to the smart grid, change is expected to be incremental rather than transformational, and therefore, this area in not emphasized as part of this report.
- **Information networks and finance**: Information technology and pervasive communications are cornerstones of a smart grid. Though the information networks requirements (capabilities and performance) will be different in different areas, their attributes tend to transcend application areas. Examples include interoperability and the ease of integration of automation components as well as cyber-security concerns. Information technology related standards, methodologies, and tools also fall into this area. In addition, the economic and investment environment for procuring smart-grid-related technology is an important part of the discussion concerning implementation progress.

Some aspect of the electricity system touches every person in the Nation.

Section 1301 of the legislation identifies characteristics of a smart grid. The NETL Modern Grid Initiative provides a list of smart-grid attributes in "Characteristics of the Modern Grid" (NETL 2008). These characteristics were used to help organize a Department of Energy-sponsored workshop on "Implementing the Smart Grid" (DOE/OEDER 2008b). The results of that workshop are used to organize the reporting of smart grid progress around six characteristics. The sixth characteristic is a merger of the Modern Grid Initiative's characteristics a) Self- Heals and b) Resists Attack. The same metrics substantially contribute to both of these concerns.

- Enabling Informed Participation by Customers
- Accommodating All Generation and Storage Options
- Enabling New Products, Services, and Markets
- Providing the Power Quality for the Range of Needs
- Optimizing Asset Utilization and Operating Efficiently
- Operating Resiliently: Disturbances, Attacks, and Natural Disasters

1.3 Stakeholder Landscape

Some aspect of the electricity system touches every person in the Nation. The stakeholder landscape for a smart-grid is complex (see Figure 1.2). The lines of distinction are not always

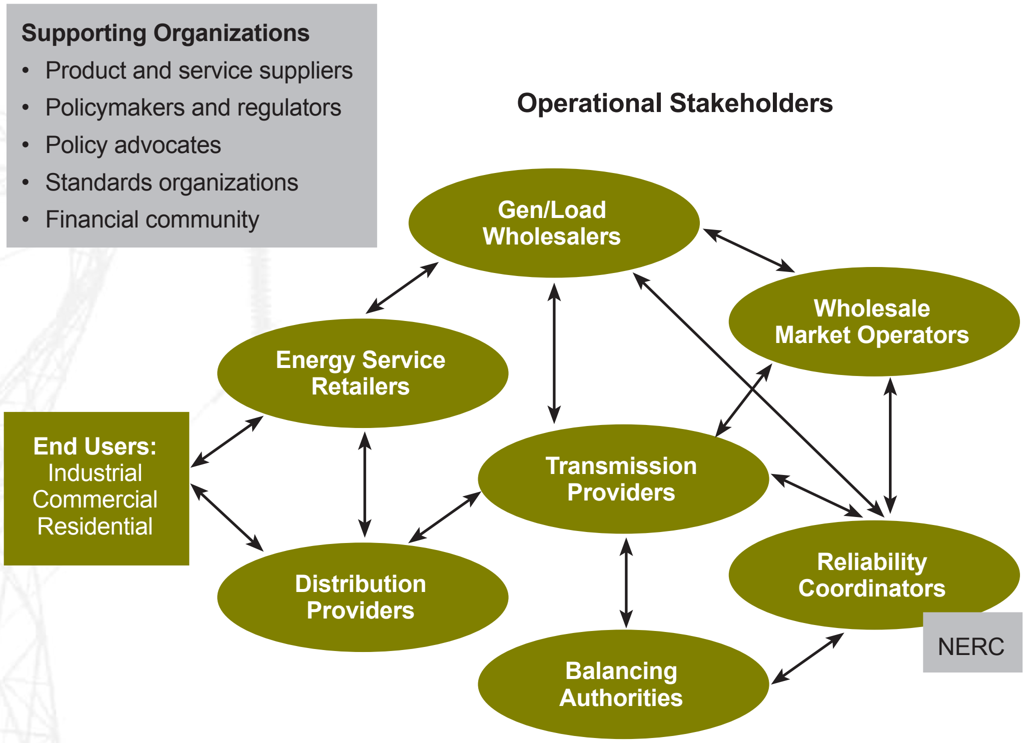


Figure 1.2. Stakeholder Landscape

crisp, as corporations and other organizations can take on the characteristics and responsibilities of multiple functions.

Stakeholders include the following:

- end users (consumers): industrial, commercial, residential
- electric-service retailers: regulated and unregulated electricity and other service providers (including service and resource aggregators)
- distribution-service providers: generally electric distribution utilities (public and private)
- transmission providers: generally electric transmission owners and operators (public and private)
- balancing authorities
- generation and demand wholesale-electricity traders/brokers
- wholesale market operators
- reliability coordinators including North American Electric Reliability Council (NERC)
- products and services suppliers including information technology (IT) and communications
- local, state, and federal energy policymakers (regulators, legislators, executives, and related offices)

- policy advocates (consumer groups, trade organizations, environmental advocates)
- standards organizations
- financial community

The major stakeholder groups are referenced throughout the report as appropriate to the topic in question.

1.4 Regional Influences

Different areas of the country have distinctions with regard to their fuel and generation resources, their business economy, climate, topography, environmental concerns, demography (e.g., rural versus urban), consumer values, and public policy. These distinctions influence the picture for smart-grid deployment in each region and service territory. They provide different incentives and pose different obstacles for development. The result is a transformation toward a smart grid that will vary across the nation. The major regions of the country can be divided into the 10 NERC reliability regions (see Figure 1.3) (EPA 2008a). The EPA further subdivides these into 26 subregions (see EPA map, Figure 1.4), and each of these regions has their 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. The primary regional influences focus on the states and major NERC reliability regions; however, other regional aspects are presented as appropriate.

Figure 1.3. United States Portions of NERC Region Representation Map

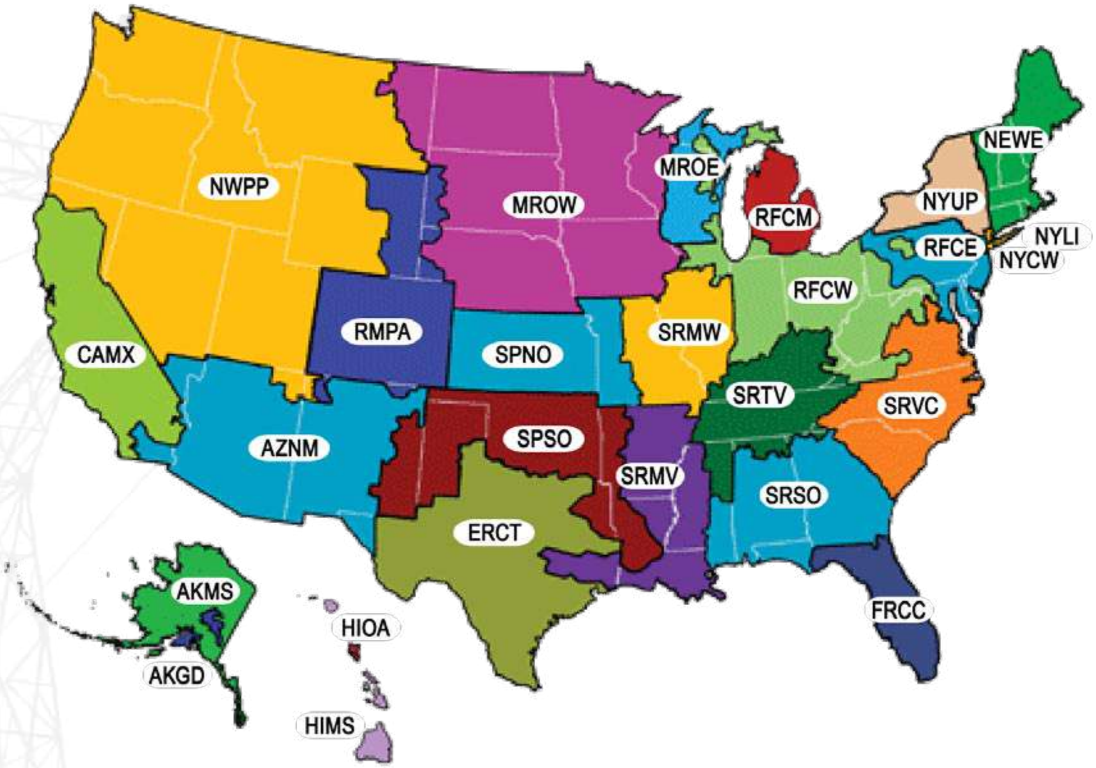


Figure 1.4. EPA eGRID Subregion Representation Map

1.5 About This Document

The Smart-Grid System Report is organized into a main body and two supporting annexes. 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 NETL Modern Grid Strategy's work in this area and discussions at the DOE Smart Grid Implementation Workshop. The main body of the report concludes with a summary of the challenges to smart-grid deployment including technical, business and financial challenges, and implications for state and federal policy.

The main body of the report is supported by two annexes. The first presents a discussion of each of the metrics chosen to help measure the progress of smart-grid deployment. The second summarizes the results of interviews with 21 electricity-service providers 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, etc.). The interview questions were designed to support many of the identified metrics and the results are incorporated into the metric write-ups to support measurement estimates.

Different regions will deploy smart grid capabilities to varying degrees.

As mentioned earlier, throughout this discussion, special concerns of stakeholders and regional influences are described. As this is the first edition of this biennial report to Congress, recommendations for further investigation and improvements for future reports are also provided.

2.0 Deployment Metrics and Measurements

The scope of a smart grid extends across the electricity system and its supply chain. To measure the status of smart-grid deployments, a set of metrics has been chosen as indicators for discussing smart-grid progress. Though these metrics do not comprehensively 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 characteristics that have been formed through workshop engagements with industry.

2.1 Smart-Grid Metrics

On June 19-20, 2008, the U.S. Department of Energy brought together 140 experts, representing the various stakeholder groups associated with a smart grid, 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 (NETL 2008). The results of the workshop document submissions of over 50 metrics for measuring smart-grid progress (DOE/OEDER 2008b). Having balanced participation across the diverse electric system stakeholders is important to deriving appropriate metrics and was an important objective for selecting individuals to invite to the workshop. While most aspects of the stakeholder landscape described in Section 1.3 were well represented, the following groups arguably deserve to have greater representation in the future: end users (industrial, commercial, and residential) and their consumer advocates, environmental groups, as well as the financial community, including venture capitalists.

The workshop described two types of metrics: build metrics that describe attributes that are built in support of a smart grid, and value metrics that describe the value that may derive from achieving a smart grid. While build metrics tend to be quantifiable, value metrics can be influenced by many developments and therefore generally require more qualifying discussion. Build metrics generally lead the value that is eventually provided, while value metrics generally lag in reflecting the contributions that accrue from implementations. A metric's type is specifically identified in the discussion below. Both build and value metrics are important to describe the status of smart grid implementation.

In reviewing the workshop results, one finds several similar metrics identified by different breakout groups; the overlap arises because a metric may be an indicator of progress in more than one characteristic of a smart grid. The list of metrics in Table 2.1 results from a distillation of the recorded ideas into a relatively small number of metrics and augmented to provide a reasonable prospect of measurement or assessment. These 20 metrics are used in this report to describe the state of smart grid deployment. A detailed investigation of the measurements for each metric can be found in Annex A of this report.

Table 2.1. Summary of Smart Grid Metrics and Status

#	Metric Title	Type	Penetration/ Maturity	Trend
	Area, Regional, and National Coordination Regime			
1	**Dynamic Pricing**: fraction of customers and total load served by RTP, CPP, and TOU tariffs	build	low	moderate
2	**Real-time System Operations Data Sharing**: Total SCADA points shared and fraction of phasor measurement points shared.	build	moderate	moderate
3	**Distributed-Resource Interconnection Policy**: percentage of utilities with standard distributed-resource interconnection policies and commonality of such policies across utilities.	build	moderate	moderate
4	**Policy/Regulatory Progress**: weighted-average percentage of smart grid investment recovered through rates (respondents' input weighted based on total customer share).	build	low	moderate
	Distributed-Energy-Resource Technology			
5	**Load Participation Based on Grid Conditions**: fraction of load served by interruptible tariffs, direct load control, and consumer load control with incentives.	build	low	low
6	**Load Served by Microgrids**: the percentage total grid summer capacity.	build	nascent	low
7	**Grid-Connected Distributed Generation (renewable and non-renewable) and Storage**: percentage of distributed generation and storage.	build	low	high
8	**EVs and PHEVs**: percentage shares of on-road, light-duty vehicles comprising of EVs and PHEVs.	build	nascent	low
9	**Grid-Responsive Non-Generating Demand-Side Equipment**: total load served by smart, grid-responsive equipment.	build	nascent	low
	Delivery (T&D) Infrastructure			
10	**T&D System Reliability**: SAIDI, SAIFI, MAIFI.	value	mature	declining
11	**T&D Automation**: percentage of substations using automation.	build	moderate	high
12	**Advanced Meters**: percentage of total demand served by advanced metered (AMI) customers	build	low	high
13	**Advanced System Measurement**: percentage of substations possessing advanced measurement technology.	build	low	moderate
14	**Capacity Factors**: yearly average and peak-generation capacity factor	value	mature	flat
15	**Generation and T&D Efficiencies**: percentage of energy consumed to generate electricity that is not lost.	value	mature	improving
16	**Dynamic Line Ratings**: percentage miles of transmission circuits being operated under dynamic line ratings.	build	nascent	low
17	**Power Quality**: percentage of customer complaints related to power quality issues, excluding outages.	value	mature	declining
	Information Networks and Finance			
18	**Cyber Security**: percent of total generation capacity under companies in compliance with the NERC Critical Infrastructure Protection standards.	build	nascent	nascent
19	**Open Architecture/Standards**: Interoperability Maturity Level – the weighted average maturity level of interoperability realized among electricity system stakeholders	build	nascent	nascent
20	**Venture Capital**: total annual venture-capital funding of smart-grid startups located in the U.S.	value	nascent	high

The table includes two columns to indicate the metric's state (penetration level/maturity) and trend. The intent is to provide a high level, simplified perspective to a complicated picture. If it is a build metric, the penetration level is indicated as nascent (very low and just emerging), low, or moderate. Because smart grid activity is relatively new, there are no high penetration levels to report on these metrics. If it is a value metric, the maturity of the system with respect to this metric is indicated as either nascent or mature. The trend (recent past and near-term projection) is indicated for either type of metric as declining, flat, or growing at nascent, low, moderate, or high, levels.

Other observations about selecting metrics follow:

- Metrics can be combined in various ways to provide potentially interesting insights into smart-grid progress. The same metric is used multiple times in this report to explain progress with respect to smart grid characteristics.
- The selection process strove to identify fundamental metrics that can support more complex combinations.
- Though the list of metrics is flat, headings are used to group metrics into logically-related areas that support balanced coverage of smart-grid concerns.
- For each metric, serious consideration is required regarding how measurements can be obtained. In some situations (particularly with value metrics), qualifying statements tend to dominate how a smart grid may influence the measurement.
- Wherever appropriate, metrics should be expressed on a proportional basis.

Metrics can be combined in various ways to provide potentially interesting insights into smart-grid progress.

2.2 Smart-Grid Characteristics

The metrics identified above are used in Section 3 to describe deployment status as organized around six major characteristics of a smart grid, as described in Table 2.2. These 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.

Table 2.2. Smart-Grid Characteristics

Characteristic		Description
1.	Enables Informed Participation by Customers	Consumers become an integral part of the electric power system. They help balance supply and demand and ensure reliability by modifying the way they use and purchase electricity. These modifications come as a result of consumers having choices that motivate different purchasing patterns and behavior. These choices involve new technologies, new information about their electricity use, and new forms of electricity pricing and incentives.
2.	Accommodates All Generation and Storage Options	A smart grid accommodates not only large, centralized power plants, but also the growing array of distributed energy resources (DER). 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, distributed generation and energy storage.
3.	Enables New Products, Services, and Markets	Correctly-designed and -operated markets efficiently 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 the Power Quality for the Range of Needs	Not all commercial enterprises, and certainly not all residential customers, need the same quality of power. A smart grid supplies varying grades of power and supports variable pricing accordingly. The cost of premium power-quality (PQ) features can be included in the electrical service contract. Advanced control methods monitor essential components, enabling rapid diagnosis and precise solutions to PQ events, such as arise from lightning, switching surges, line faults and harmonic sources. A smart grid also helps buffer the electrical 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	Resiliency 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 responds resiliently to attacks, whether organized by others or the result of natural disasters. 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.

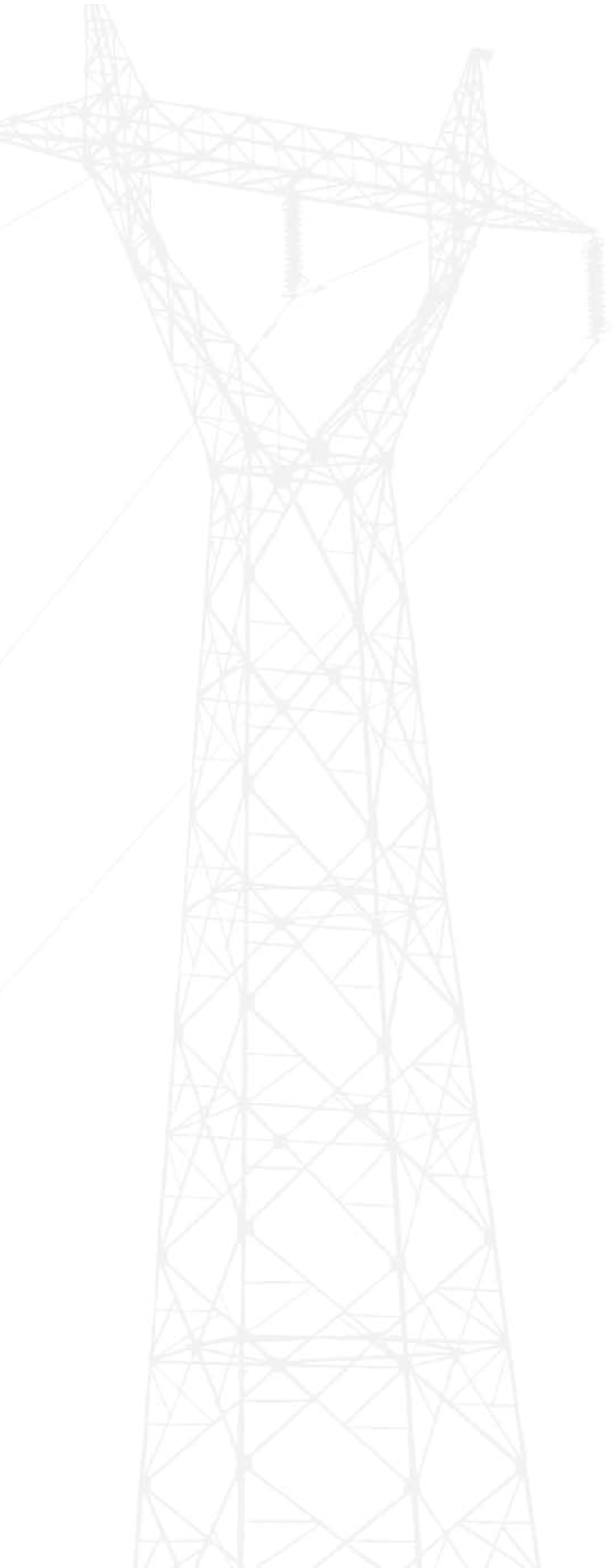
2.3 Mapping Metrics to Characteristics

Section 3 of the report describes the status of smart-grid deployment using the six characteristics discussed above. A map of how the 20 metrics support the 6 characteristics is shown in Table 2.3. 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 where a metric is emphasized as "emphasis." The other characteristic cells where a metric plays an important role are indicated by "mention." This should not be interpreted to be of secondary importance, only that a metric finding is mentioned under that characteristic in order to reduce redundancy of material in explaining the status of smart grid deployment.

The interviews with 21 electric-service providers also provide insight into a measure of the metrics and how they relate to the smart-grid characteristics. The interview questions were designed to gather information related to the metrics of interest. The interview results are presented in Annex B and the information gained from these interviews is woven into the metric write-ups in Annex A as well as the smart-grid status descriptions presented for each characteristic in the next section.

Table 2.3. Map of Metrics to Smart-Grid Characteristics

Metric No.	Metric Name	Enables Informed Participation by Customers	Accommodates 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					Mention	Emphasis
14	Capacity Factors					Emphasis	
15	Generation, T&D Efficiency					Emphasis	
16	Dynamic Line Rating					Emphasis	Mention
17	Power Quality			Mention	Emphasis		
18	Cyber Security						Emphasis
19	Open Architecture/Stds			Emphasis			
20	Venture Capital			Emphasis			



3.0 Deployment Trends and Projections

Deploying a smart grid is a journey that has been underway for some time, but will accelerate because of the Energy Independence and Security Act of 2007, and the recognition of characteristics and benefits collected and emphasized under the term "smart grid." Though 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 (EAC 2008). 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 deployment 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 20 metrics obtained through available research, such as advanced metering and T&D substation-automation assessment reports, penetration rates for energy resources, and capability enabled by a smart grid. An important contribution to that investigation is information collected through interviews of a diverse set of 21 electric service providers. 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 Annex A. The metrics emphasized to explain the status of a characteristic are so highlighted with a asterik (*).

3.1 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 bi-directional 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 and purchase 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 regarding electricity use, and new pricing and incentive programs.

A smart grid adds consumer demand as another manageable resource, joining power generation, grid capacity, and energy storage. From the standpoint of the consumer, energy management in a smart-grid environment involves making economic choices based on the variable cost of electricity, the ability to shift load, and the ability to store or sell energy.

Consumers who are presented with a variety of options when it comes to energy purchases and consumption are enabled to:

- respond to price signals and other economic incentives to make better-informed decisions regarding when to purchase electricity, when to generate energy using distributed generation, and whether to store and re-use it later with distributed storage.
- make informed investment decisions regarding more efficient and smarter appliances, equipment, and control systems.

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

3.1.1 Grid-Enabled Bi-Directional Communication and Energy Flows

A smart grid system relies on the accurate, up to date, and predictable delivery of data between the customer and utility company. A conduit through which this information may be exchanged is advanced metering infrastructure (AMI). AMI, unlike conventional metering systems, relies on fixed, digital network technologies. At the most basic level, AMI serves as a middleman between a consumer's energy consumption and the utility that provides electricity, by reading household energy consumption at some predetermined requested interval (e.g., hourly) and then storing and transmitting the data via a wired or wireless network to the service provider. This basic level supports automated meter reading (AMR). At higher levels, AMI technology can incorporate bi-directional communication, including transmitting real-time price and consumption data between the household and utility, and coordinating with a Home Area Network. Figure 3.1 presents an overview of an AMI interface enabling the bi-directional flow of information [Metric 12].(1) Currently, AMI composes about 4.7%, or 6.7 million, of total U.S. electric meters (FERC 2007). The number of installed meters has been projected to grow by another 52 million by 2012.

When customers are motivated by economic incentives through dynamic pricing structures or other programs, their investments in "smart" devices could facilitate reductions or shifts in energy consumption. "Smart" devices (e.g., communicating thermostats, clothes washers and dryers, microwaves, hot water heaters, refrigerators) use signaling software or firmware to communicate with the grid [Metric 9]. For example, a "smart" water heater could be equipped with a device that coordinates with a facility's energy-management system to adjust temperature controls, within specified limits, based on energy prices.

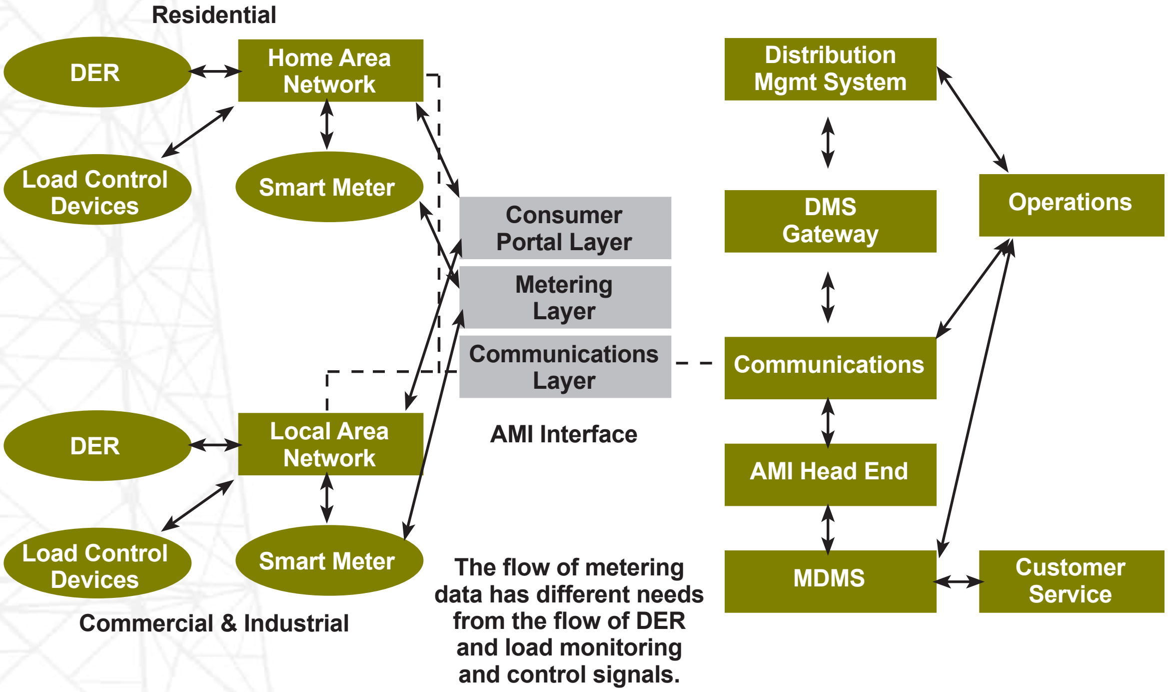


Figure 3.1. Overview of AMI Interface (DOE/OEDER 2008c)

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(1) DMS: Distribution management system. MDMS: Meter data management systems.

One recent experiment that focused on the "smart" device concept in combination with smart-grid technologies and dynamic pricing was conducted in the Olympic Peninsula of Washington State by the U.S. Department of Energy (Hammerstrom 2007). In the experiment, thermostats, washers, dryers, and water heaters were fitted with smart grid-responsive equipment and were programmed to respond to peak loads. The results of the experiment were promising; the smart devices reduced load fluctuations, decreased peak loads, and significantly reduced energy costs.

The technology exists today to implement grid-responsive equipment. Industrial plants and modern, large commercial buildings are generally well-equipped to respond to incentives to change their demand because they have energy management systems. However, in residences and small commercial buildings, there is little supporting installed technology to communicate to the equipment, though products are emerging.

Increasing demand participation in electric system operations centers on incentive offerings.

A primary issue to increasing demand participation in electric system operations centers on incentive offerings. Smart grid related technology, such as advanced meters, has enabled dynamic pricing programs implemented across the U.S. [Metric 1]. Generally, these tariffs take the following forms:

- **Time of use (TOU)**. Under TOU, prices are differentiated based solely on a peak versus off-peak period designation, with prices set higher during peak periods. TOU pricing is not dynamic because it does not vary based on real-time conditions. It is included here though because it is viewed as an intermediate step towards a more dynamic real-time pricing (RTP) tariff.
- **Critical peak pricing (CPP)**. Under a CPP tariff, the higher critical peak price is restricted to a small number of hours (e.g., 100 of 8,760) each year, with the peak price being set at a much higher level relative to normal conditions.
- **Real-time pricing (RTP)**. Under RTP, hourly prices vary based on the day-of (real time) or day-ahead cost of power to the utility.

The Federal Energy Regulatory Commission conducted an extensive survey of demand response and advanced metering initiatives in 2008. The FERC survey was distributed to 3,407 organizations in all 50 states. In total, 100 utilities that responded to the survey reported offering some form of a real time tariff to enrolled customers (Table 3.1), as compared to 60 in 2006 (FERC 2008).

FERC also found through its 2008 survey that 315 utilities nationwide offered TOU rates, compared to 366 in 2006. In those participating utilities, approximately 1.3 million residential electricity consumers were signed up for TOU tariffs, representing approximately 1.1% of all U.S. customers (Table 3.1). In 2008, customers were enrolled in CPP tariffs offered by 88 utilities, as compared to 36 in 2006. No studies were found to estimate the total number of customers served by RTP and CPP tariffs.

Table 3.1. Number of Entities Offering and Customers Served by Dynamic Pricing Tariffs

Method of Pricing	Number of Entities	Customer Served	
		Number	Share of Total
Real Time Pricing	100		
Critical Peak Pricing	88		
Time of Use	315	1,270,000	1.1%

The interviews conducted for this report included 21 companies with an annual peak capacity of 150,000-175,000 megawatts. The respondents were asked two questions relevant to dynamic pricing. The first question asked respondents: Do you have dynamic or supply based price plans?

- Seven companies (35 percent) indicated no dynamic price plans were in place.
- Twelve companies (60 percent) indicated they had TOU plans.
- Three companies (15) percent offered CPP plans.
- Seven companies (35 percent) indicated they had both dynamic price plans and the ability to send price signals to customers.

The respondents were also asked whether their utility had automated response to pricing signals for major energy using devices within the premises. Responses were as follows:

- Nine companies (45 percent) indicated there were none.
- Eight companies (40 percent) indicated that automated price signals for major energy using devices were in the development stage.
- Three companies (15 percent) indicated that a small degree of implementation (10-30 percent of the customer base) had occurred.

Smart grid also facilitates the bi-directional flow of energy, enabling customers to generate or store energy and sell it back to the grid during peak periods when prices are highest to the utility. For example, solar panels installed on rooftops by homeowners can safely generate power at a current cost of $10 to $12 per watt. In the future, as electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) penetrate the U.S. light-duty vehicle market, these alternative-fuel vehicles could also advance load shifting through their energy storage capabilities [Metric 8]. Finally, the more than 12 million backup generators operated in the U.S., representing 200 GW of generating capacity, could also be used to help alleviate peak load, provide needed system support during emergencies, and lower the cost of power provided by the utility [Metric 7] (Gilmore and Lake 2007).

Utilities could realize enormous cost savings over the long term.

Utilities that facilitate the integration of these resources and use them effectively could realize enormous cost savings over the long term. Most projections show increasing deployment of these resources, especially in the commercial sector where power quality and reliability are a serious consideration. Smart grid technologies may be required, along with DG-friendly regulatory structures, in order to integrate DG technologies.

Consumer participation of DG can be facilitated with agreed upon policies for interconnection to the grid. A 2008 EPA study found that only 15 states have "favorable" interconnection standards, with 12 states being "neutral." There are five states classified as having unfavorable policies towards distributed generation [Metric 3] (EPA 2008).

3.1.2 Managing Supply and Demand

Measures, such as turning off or adjusting water heaters, dishwashers, and heating and cooling systems, result in load shifting and reduced costs through the smoothing of peak power consumption throughout the day. With appropriate metering capability in place, dynamic pricing signals received by customers can encourage greater demand response.

Traditionally, demand participation has principally taken place through interruptible demand and direct control load management programs implemented and controlled by electricity suppliers. Nationally, demand-response participation is low. Potential load managed is 1.5% based on 2008 projections. [Metric 5]. Figure 3.2 shows the aggregate demand response by type and region in 2006 and 2007. From this graph one sees the general increase in direct load control, with little or no increase in interruptible demand.

Though dynamic-pricing and demand-response programs have historically been responsible for modest levels of load shifting, current research suggests that there is significant potential for the programs to manage supply and demand in the future. For example, a recent study, sponsored by the Electric Power Research Institute (EPRI) and the Edison Electric Institute (EEI), estimated that 37 percent of the growth in electricity sales (419 TWh) between 2008 and 2030 could be offset through energy-efficiency programs and 52 percent of peak demand growth (164 GW of capacity) could be offset by a combination of energy-efficiency and demand-response programs. More specifically, approximately 2,824 MW of peak demand could be offset by 2010 through price-responsive policies, 13,661 MW of peak demand could be offset through price response by 2020, and 24,869 MW could be offset by 2030. The largest share of the price-response benefits are forecast to take place in the residential sector (10,838 MW or 43.6% of the offset in 2030), with the commercial (8,350 MW or 33.6% of the offset in 2030) and industrial sectors (5,681 MW or 22.8% of the offset) trailing behind (Richmond et al. 2008).

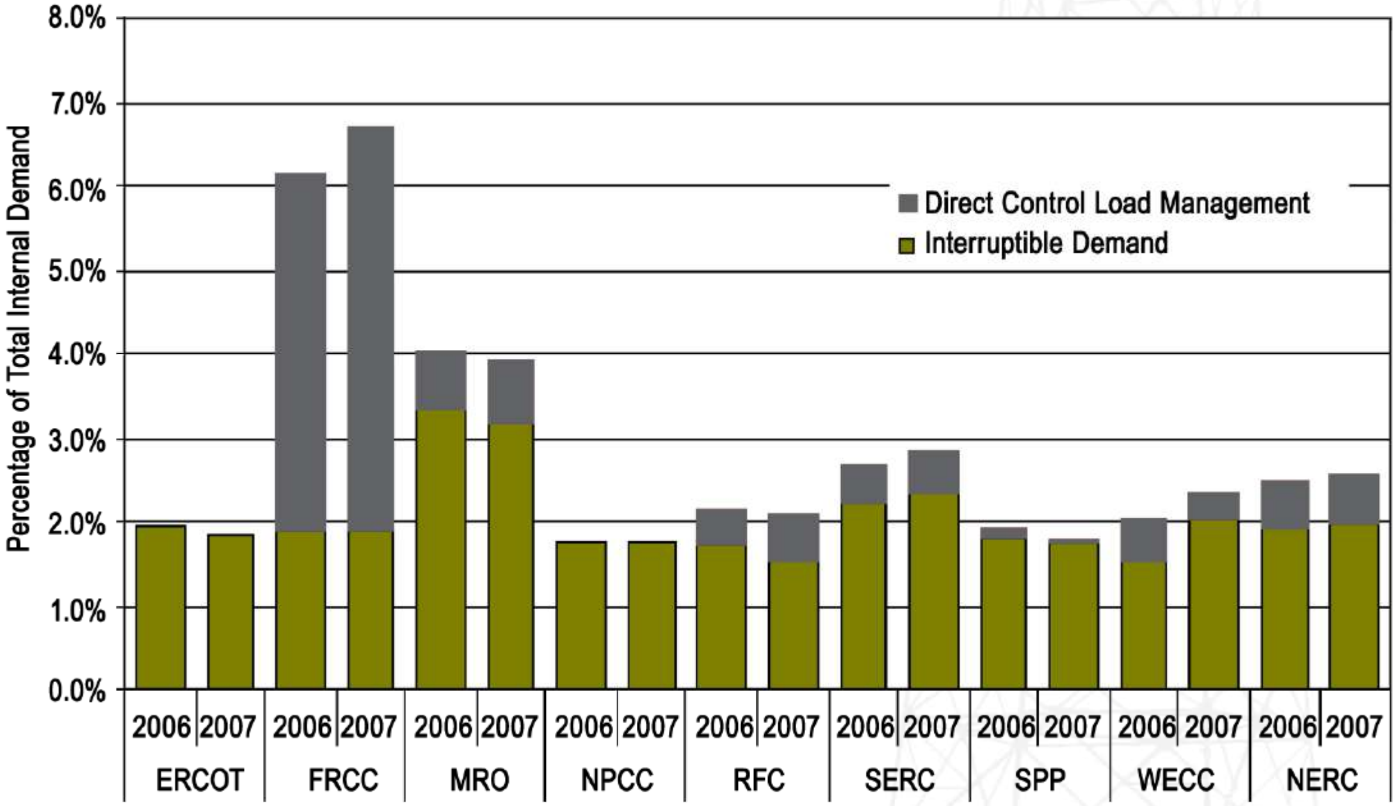


Figure 3.2. Demand Response by NERC Region

3.2 Accommodates All Generation and Storage Options

The ability to accommodate a diverse range of generation types, including centralized and distributed generation as well as diverse storage options, is central to the concept of a smart grid. Through these generation and storage types, a smart grid can better meet consumer load demand, as well as accommodate intermittent renewable-energy technologies. Distributed resources can be used to help alleviate peak load, provide needed system support during emergencies, and lower the cost of power provided by the utility. Accommodating a large number of disparate generation and storage resources requires anticipation of intermittency, unavailability, while balancing costs, reliability, and environmental emissions. Accommodating the diverse nature of these options requires an interconnection process similar to the computer industry's "plug-and-play" environment (DOE/OEDER 2008b).

The primary metrics that measure progress for this characteristic include grid-connected DG and storage, progress in connecting diverse generation types, and a standard distributed-resource-connection policy. There are a number of the other metrics that describe the current ability of a smart grid to accommodate all generation and storage options.

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

Distributed generation and interconnection standards to accommodate generation capacity appear to be moving in positive directions. Distributed-generation (DG) systems are noted for their smaller-scale local power-generation (10 MVA or less) and distribution systems, and generally have low installation and maintenance costs. DG includes power generators such as wind turbines connected at the distribution system level, micro hydro installations, solar panels, diesel, etc. DG also covers energy-storage devices such as batteries and flywheels which could be used to store energy produced or purchased during off-peak hours and then sold or consumed during on-peak hours. Distributed generation, although a small fraction (1%) of total available summer capacity, appears to be increasing rapidly [Metric 7]. In addition, 31 states have interconnection standards in place, with 10 states progressing towards a standard, 1 state with some elements in place, and only 8 states with none. The bad news is that only 15 states had interconnection standards that were deemed to be favorable to distributed generation [Metric 3]. More complete details on the metrics discussed in this section can be found in Annex A.

Another measure that impacts this category is dynamic pricing. In this case, time-of-use pricing seems to be gaining momentum, at 1.1% of customers served, and real-time tariffs appear to be slowing increasing. Real-time tariffs would seem to drive the most efficient use of DG, bringing it on-line when prices are high and using more cost-effective central capacity when loads are more manageable [Metric 1] (FERC 2006). The use of smart meters, a driving force behind being able to evaluate grid load and support pricing conditions, has been increasing significantly, almost tripling between 2006 and 2008 to 19 million meters, although the increase from 2007 to 2008 was slower [Metric 12]. Grid responsive load is just beginning to develop with 10% of utilities indicating limited entry into this field, with 45% saying it is in development and 45% having no plans [Metric 9]. The business case for microgrids needs to be made [Metric 6] before commercial capacity will be developed. Currently, universities and petrochemical facilities comprise most of the capacity in microgrids. However, both grid responsive load and microgrids can play a larger role once dynamic pricing and interconnection standards are universally available.

Microgrids can play a larger role once dynamic pricing and interconnection standards are universally available.

Accommodating distributed resources impacts a wide range of stakeholders, including end-users, service providers, regulators, and third-party developers. The interests of these stakeholders will need to be balanced to ensure appropriate evolution of a smart grid while improving the cost efficiency of grid resources (DOE/OEDER 2008b). For example, end-users who implement grid-connected distributed-generation devices will directly affect utilities and service providers whose revenues may decline. Both end-users and service providers must see recovery of investments in distributed resources, smart meters and other smart-grid accessories that allow the grid resources and entities to communicate and respond to changing grid conditions (DOE 2006). Otherwise, end users and service providers will not invest.

The following sections describe distributed generation and storage and interconnection standards in more detail.

3.2.1 Distributed Generation and Storage

Carnegie Mellon's Electricity Industry Center reports that there are now about 12 million backup generators in the United States, representing 200 GW of generating capacity; backup generation is growing at a rate of 5 GW per year [Metric 7] (Gilmore and Lave 2007). Utilities that facilitate the integration of these resources and use them effectively can realize enormous cost savings over the long term. Of the 200 GW of backup generators, currently grid-connected distributed-generation capacity is a small part of total power generation, with combined total grid-connected distributed-generation capacity ranging from 5,423 MW in 2004 to 12,702 MW in 2007 (DOE/EIA 2009a) (see Figure 3.3 and Table 3.2). Available U.S. generating capacity in 2007 comprised 915,292 MW, while summer peak demand reached 782,227 MW and winter peak demand was 637,905 (DOE/EIA 2009b). Thus, while wind and other grid-connected distributed generation increased 134 percent over three years, it still only represented 1.4 percent of grid capacity, 1.6 percent of summer peak and 2.0 percent of winter peak.

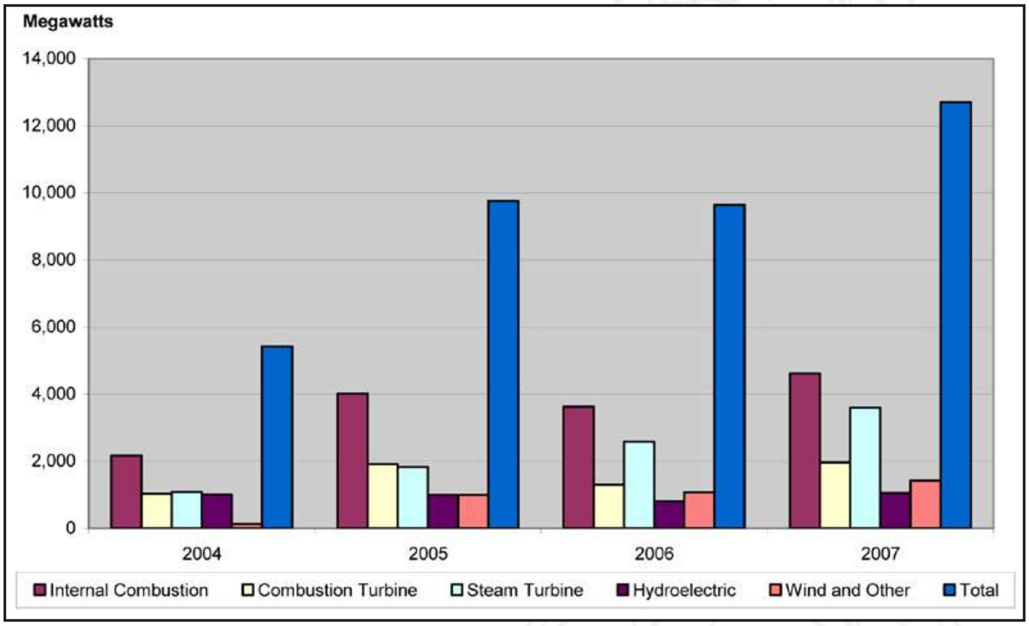


Figure 3.3. Yearly Installed DG Capacity by Technology Type (DOE/EIA 2009b).

Actively-managed fossil-fired, hydrogen, and biofuels distributed generation reached 10,173 MW in 2007, up 112 percent from 2004. This represented approximately 1.1 percent of total generating capacity and 80 percent of total DG. Wind and other renewable-energy sources grew significantly between 2004 and 2007, increasing by 941 percent, yet renewable energy represents only 0.6 percent of total available generating capacity, 0.18 percent of summer peak capacity, and

0.22 percent of winter peak. Intermittent renewable-energy resources such as wind may not be effective countermeasures for peak-demand reduction, although solar has the potential to be more coincident with summer peak-demand periods. Central wind farms are not included in grid-connected wind DG resources; central wind farms are connected at the transmission level rather than at the distribution level.

Table 3.2. Capacity of Distributed Generators by Technology Type 2004 to 2006 (count and MW) (DOE/EIA 2009b)

	Internal Combustion	Combustion Turbine	Steam Turbine	Hydroelectric	Wind and Other	Total	
Period	Capacity	Capacity	Capacity	Capacity	Capacity	Number of	Capacity
2004	2,169	1,028	1,086	1,003	137	5,863	5,423
2005(*)	4,024	1,917	1,831	998	994	17,371	9,766
2006	3,625	1,299	2,580	806	1,078	5,044	9,641
2007	4,614	1,964	3,595	1,053	1,427	7,103	12,702

(*) Distributed generator data in 2005 includes a significant number of generators reported by one respondent that may be for residential applications.

Note: Distributed generators are commercial and industrial generators that are connected to the grid. They may be installed at or near a customer's site, or at other locations. They may be owned by either the customers of the distribution utility or by the utility. Other Technology includes generators for which technology is not specified.

Interviews conducted for this report (see Annex B) indicated the following about grid-connected DG:

- Grid connected DG was reported by only 0.9 percent of the customers of the companies interviewed.
- Three entities indicated they have some customers with storage capacity which comprised about 0.3 percent of their total customer base
- Non-dispatchable renewable generation was reported by only 1.4% of total customers.

Battery storage continues to pose cost-effectiveness problems by requiring a large degree of maintenance and adding significantly to the overall costs of building DG systems, and thus increasing the payback period. PHEVs are unlikely to play a significant role as a storage mode or as a distributed generator in the near term due to cost considerations. Some forecasts indicate that it will be at least 2020 before PHEVs hit the market in significant quantities (DOE/EIA 2008b). Microgrids could eventually provide resource capacity to supplement low-cost centralized facility power. Currently the number of microgrids is very small but is expected to grow to 5.5 gigawatts by 2025 [Metric 6].

Forecasts of utility-owned-and-controlled DG capacity indicate DG will reach 5.1 GW by 2010 (DOE/EIA 2007b) (see Figure 3.4). This forecast accounts for only about one-fifth of total DG based on 2006 data, which indicates the DG had more than 9 GW total. The trend however, is positive and significant.

3.2.2 Standard Distributed-Resource Connection Policy

Federal legislation attempting to deal with this issue emerged in progressively stronger language, culminating in the Energy Policy Act of 2005 (EPACT 2005), which requires all

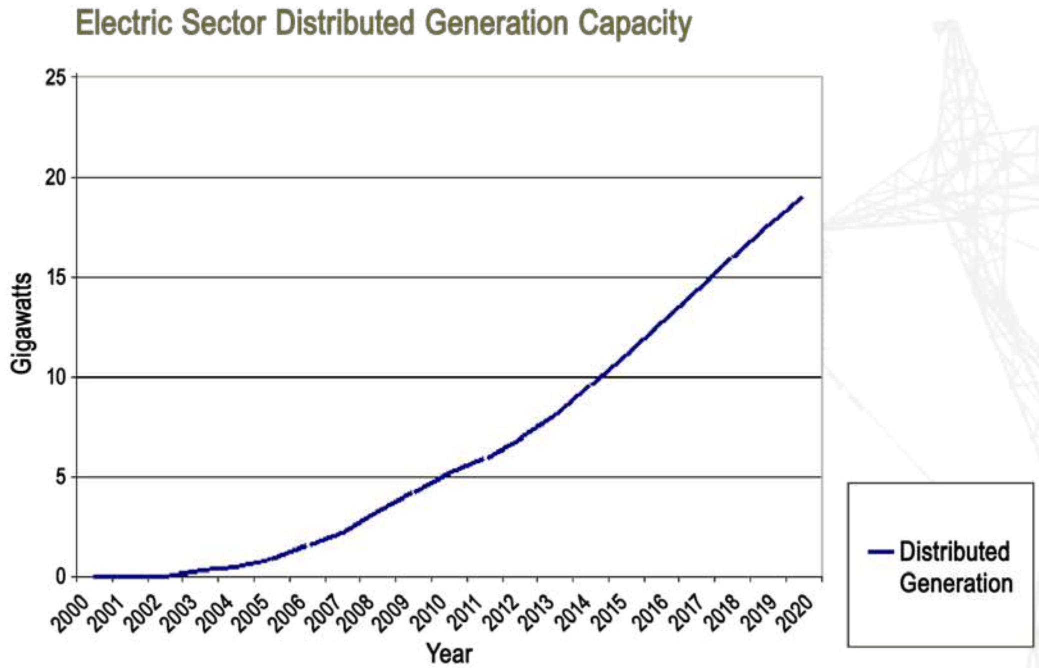


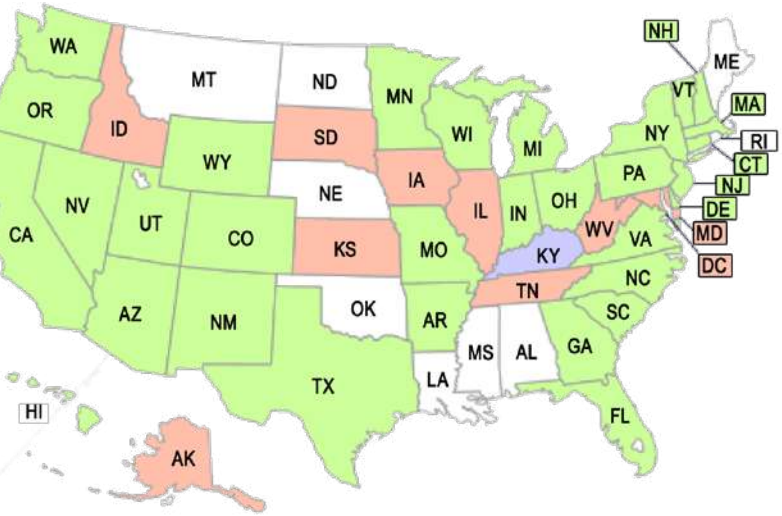
Figure 3.4. Projected DG Capacity in GW (Eynon 2002)

state and non-state utilities to consider adopting interconnection standards based on Standard IEEE 1547. IEEE 1547, which was published in 2003, looks strictly at the technical aspects of distributed generation interconnection, providing a standard that limits the negative impact of these resources on the grid [Metric 3] (Cook and Haynes 2006). In part to address some of the permitting aspects of interconnection, the FERC issued FERC Order 2006, which mandated that all public utilities that own transmission assets provide a standard connection agreement for small generators (under 20 MW) (FERC 2005).

While compliance with the FERC 2006 order is mandatory for public utilities that own transmission assets, other utilities have come under similar legislation at the state level. The progress in developing these laws, however, has been fairly slow. Even states complying with the mandatory FERC order have taken over two years to enact these relatively simple rules. States that have taken aggressive action on distributed generation have tended to do so for other reasons, such as meeting renewable-portfolio standard requirements.

In February 2008, the EPA did a study of the 50 states and the District of Columbia, assessing their standards for interconnection. They found 31 states with standard interconnection rules for distributed resources, and 11 additional states in the process of developing rules (see Figure 3.5). Of these, the EPA found that 55% had standard interconnection forms, 29% had simplified procedures for smaller systems, 35% had a set timeline for application approval, and 45% had larger system-size limits (over 10 kW for residential and over 100 kW for commercial systems) (see Figure 3.6) (EPA 2008b).

By multiplying the percentages above by the number of utilities in each state, it is estimated that roughly 61% of utilities have a standard interconnection policy in place, and that 84% of utilities either have a policy in place or will have one soon based on pending legislation or regulation (DOE/EIA 2002).



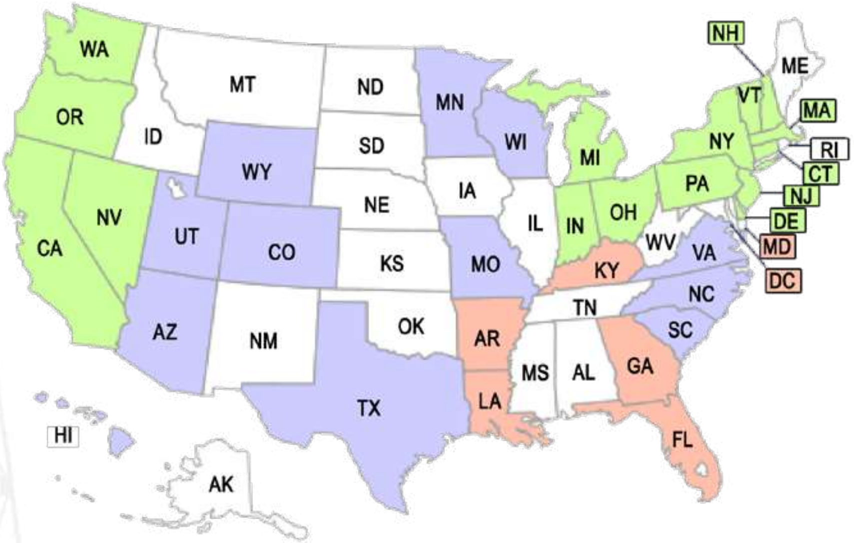
🟩 **Policy in place:**
AR, AZ, CA, CO, CT, DE, FL, GA, HI, IN, MA, MI, MO, MN, NH, NJ, NM, NY, NV, NC, OH, OR, PA, SC, TX, UT, VT, VA, WA, WI, WY

🟥 **Action is pending/possible:**
AK, DC, IA, ID, IL, KS, MD, SD, TN, WV

🟪 **Some elements of policy are in place:**
KY

⬜ **Policy not in place:**
AL, LA, ME, MS, MT, NE, ND, OK, RI

Figure 3.5. State Interconnection Standards (EPA 2008b)



🟩 **Favorable Interconnection Standards:**
CA, CT, DE, IN, MA, MI, NH, NJ, NY, NV, OH, OR, PA, VT, WA

🟥 **Unfavorable Interconnection Standards:**
AR, FL, GA, KY, LA

🟪 **Neutral Interconnection Standards:**
AZ, CO, HI, MN, MO, NC, SC, TX, UT, VA, WI, WY

⬜ **No policy in place:**
AL, AK, DC, ID, IA, IL, KS, ME, MD, MS, MT, NE, NM, ND, OK, RI, SD, TN, WV

Figure 3.6. Favorability of State Interconnection Standards (EPA 2008b)

The EPA's study based its criteria for favorability on whether or not standard forms were in place, time frames for application approval, insurance requirements, distributed resource sizes allowable, and interconnection study fees. With these factors considered, only 15 states were classified as having "favorable" interconnection standards, with 27 states either being "favorable" or "neutral." The fact that there are five states with unfavorable policies towards distributed generation is also cause for concern, although it is worth noting that that these states are all in the southeast region of the United States perhaps indicating a regional issue.

There are currently about 10 states with new DG interconnection standards under consideration (AK, DC, IA, ID, IL, KS, MD, SD, TN, and WV). Most projections show increasing deployment of these resources, especially in the commercial sector where power quality and power reliability are of increasing concern.

Only 15 states were classified as having "favorable" interconnection standards.

States and regions may have different regulations for the quality of the power being sold or the way the power is produced. Some states may value DG capacity differently from others and offer different subsidies and/or taxes based on those values. For example, Oregon state law has specific plant site emissions standards for minor sources emitting pollutants such as NO_x, SO_2, CO, particulate matter (PM), etc. whereas Ohio relies on the Best Available Technology (BAT) standard with specific limitations for PM and SO_2 based on location, generator type, and size (EEA 2004). The following are further examples of different policies for interconnection standards:

- California's progressive distributed-generation interconnection policies place no limits on the size of the resource. This is coupled with strong incentives for renewable sources of energy, such as photovoltaic solar panels, primarily for the purpose of promoting cleaner alternative power sources and reducing transmission congestion. California's policies have had a strong impact along the west coast (Shirley 2007).
- New York, which was one of the first states to adopt a standard interconnection policy in 1999, has continued to provide support for distributed generation. Among the driving forces for this have been power outages and transmission congestion, which continue to plague much of the state.
- The Mid-Atlantic Distributed Resources Initiative (MADRI), representing the utility interests of Delaware, the District of Columbia, Maryland, New Jersey, and Pennsylvania, has been a strong driver of interconnection standards for distributed resources and has proposed a model that has been adopted by many states.
- Many states in the Southeast region have been resistant to implementing favorable standards for interconnection (Figure 3.6). This resistance may be due to regional challenges that must be overcome specifically in those states, which would require special assistance.

The electricity industry's ability to accommodate a diverse range of generation types, including centralized and distributed generation as well as diverse storage options, is an important aspect of realizing a smart grid. The business case for real-time pricing needs to be made to end-users and interconnection standards need to be put in place universally before significant progress can be made to accommodate all generation options. Real-time pricing may be making a resurgence after declining from peaks in the early 1990s. Dynamic pricing and favorable interconnection standards are necessary to encourage more grid-connected distribution. Grid-connected DG provided 9,600 MW of generating capacity in 2006. Intermittent renewable energy resource DG needs more cost-effective storage to reach its maximum potential. Once favorable interconnection standards are completed, DG will have more opportunity to expand. Currently, less than one-third of (only 15) states have standards that are favorable to DG and 27 states have interconnection standards that are neutral to favorable.

3.3 Enables New Products, Services, and Markets

Markets that are correctly designed and operated can efficiently reveal benefit-cost 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 those variables. Regulators, owners/operators, and consumers need the flexibility to modify the rules of business to suit operating and market conditions.

Related Metrics
1, 3, 4*, 6, 7, 8*, 9, 12, 17, 19*, 20*

While the primary objectives for implementing a smart grid may encompass environmental, energy efficiency, and national security goals, the effort falls short if utilities are unable or unwilling to make an effective business case to regulatory agencies. Smart-grid investments are often capital intensive, expensive, and include multiple jurisdictions within a utility's service area. While smart-grid investments can enable numerous new products (e.g., advanced meters, solar panels, electric vehicles, and smart appliances) and operational efficiencies (e.g., reduced meter reading costs, fewer field visits, enhanced billing accuracy, improved cash flow, and enhanced response to outages), such benefits may be difficult to quantify and to build into business cases given the nascent stages in which these technologies often exist, and the lack of industry standards and best practices for integrating smart-grid technologies.

Because a smart grid holds great potential for enabling new products, services, and markets, public and private interests have aligned in support of smart-grid technologies. For example, the Energy Independence and Security Act (EISA) provided incentives for utilities to undertake smart grid investments in Section 1306, which authorizes the Secretary of Energy to establish the Smart Grid Investment Matching Grant Program. This program was designed to provide reimbursement for up to 20 percent of a utility's investment in smart grid technologies. Section 1306 of EISA also defined what constituted a qualified investment and outlined a process for applying for cost reimbursement. Section 1307 of EISA encouraged states to require utilities prior to investing in non-advanced grid technologies to demonstrate consideration for smart grid investments. Section 1307 also encouraged states to consider regulatory requirements that included the reimbursement of book-value costs for any equipment rendered obsolete through smart grid investment [Metric 4].

Public and private interests have aligned in support of smart-grid technologies.

The private sector is also supporting smart grid investment [Metric 20]. This interest is spurred by several investment drivers:

- Significant increases in fossil fuel prices
- Peak demand growing at a time when energy infrastructure is in need of updating and replacement
- New infrastructure costs to meet load of approximately $500B over the next 20 years

- Shrinking capacity margin
- Increasing recognition of clean and efficient technologies.

These drivers suggest that in the future new products, services, and markets will be required to address the growing demand for energy over the long term. As a result, investment in smart-grid technologies has continued to gain traction in recent years. In 2008 alone, numerous significant venture-capital deals were announced:

- Optimal Technologies International, Inc. received $25 million towards the development of software for managing electrical grids.
- SmartSynch, Inc. secured $20 million to develop wirelessly communicating meters.
- Trilliant Incorporated secured $40 million toward the development of intelligent networks powering smart grid related functions.
- Tendril Networks received $12 million to develop smart grid networking products.
- Fat Spaniel Technologies received $18 million toward the development of an energy intelligence platform.
- GridPoint, Inc. received $15 million for their management of distributed storage, renewable generation, and load, bringing the firm's total funding to over $100 million.
- eMeter Corporation secured $12.5 million to support development of advanced metering technologies.

The surge in private-sector interest in smart-grid investment was validated using data from Cleantech Group LLC, which reported venture-capital funding secured by smart-grid startups of $194.1 million in 2007 and $129.3 million during the first two quarters of 2008.(1) In total, the Cleantech Group identified 99 deals during the 2000-2008 timeframe totaling $964.4 million; (the average deal was $9.7 million). Figure 3.7 documents recent trends in venture-capital funding of firms

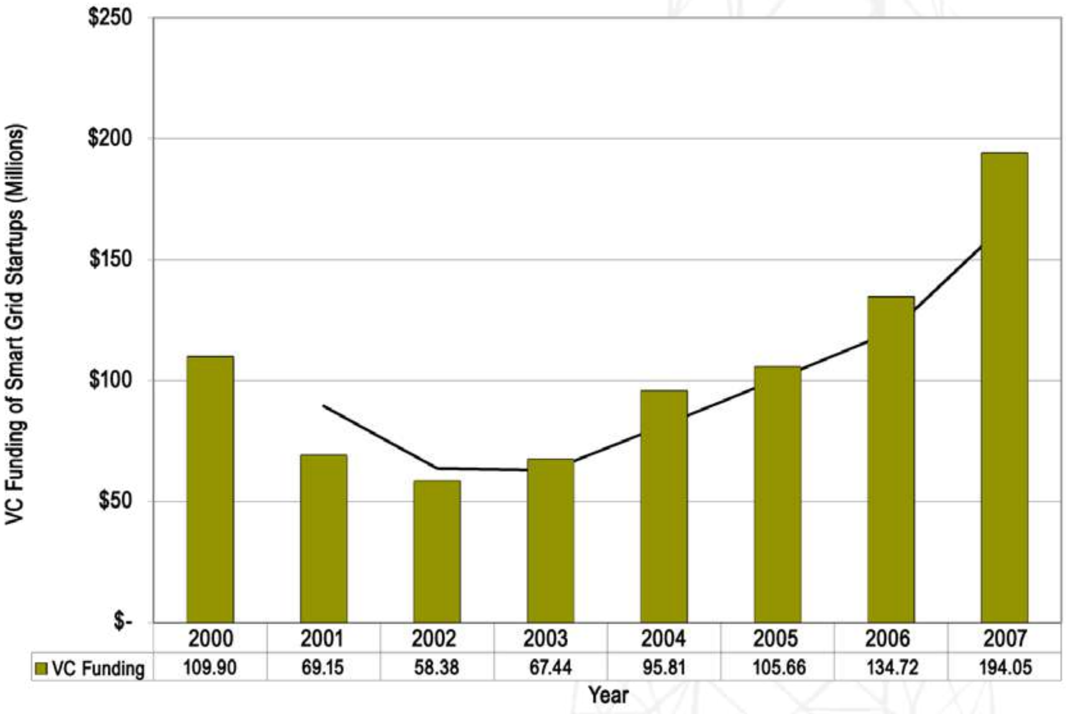


Figure 3.7. Venture-Capital Funding of Smart-Grid Startups (2002-2007)

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(1) per email communication with Brian Fan of the Cleantech Group on September 10, 2008.

developing smart-grid technologies. As shown, venture-capital funding of startups slumped between 2000 and 2002 but has since rebounded, growing from $58.4 million in 2002 to $194.1 million in 2007. Cleantech Group data suggest that 2008 levels could well exceed those of 2007 as venture-capital funding has topped $129 million in the first two quarters of 2008. Between 2002 and 2007, venture-capital funding of smart-grid startups grew at an average annual rate of 27.2 percent.

3.3.1 Enabling New Products and Services

A smart grid enables new products and services through automation, communication sharing, facilitating and rewarding shifts in customer behavior in response to changing grid and market conditions, and encouraging development of new technologies (e.g., AMI, plug-in hybrid electric vehicles). For example, Carnegie Mellon's Electricity Industry Center reports that there are now approximately 12 million backup generators in the United States, representing 200 GW of generating capacity [Metric 7]. This backup generating capacity is growing at a rate of 5 GW per year (Gilmore and Lave 2007). A smart grid, by enabling the bi-directional flow of energy in combination with programs allowing customers to use these backup generating devices to sell energy back to the grid during high-cost peak periods, could enhance the market for these new products and the services they provide.

Approximately 4.7% of all U.S. customers are currently served by AMI.

A smart grid that incorporates real-time pricing structures and bi-directional information flow through metering and information networks is expected to support the introduction of numerous technologies into the system [Metric 20]. Enabling AMI technology itself represents a major driver in smart-grid investment, as evidenced by several large-scale deployment programs:

- The three largest utilities in California are installing millions of smart meters at homes and businesses and charging customers $4.6 billion for the enhanced service.
- Duke Energy is installing 800,000 smart meters.
- Texas utility Oncor is installing smart meters at a cost of $690 million.
- Pacific Gas and Electric is retrofitting 9 million meters with communications electronics to enable TOU pricing.
- The Los Angeles Department of Water and Power has purchased 9,000 smart meters to enable transmission of real-time data through public wireless networks (Wesoff 2008).

Approximately 4.7% of all U.S. customers are currently served by AMI with states in the Mid-Atlantic and Midwest experiencing the highest rates of usage at around 8-11 percent. Pennsylvania has the highest penetration with 23.9 %.

The smart grid also supports the deployment of new vehicle technologies (e.g., EVs and PHEVs) [Metric 8].(1) Real-time pricing enabled through AMI would allow customers to recharge vehicles at reduced cost during off-peak hours. Bi-directional metering would enable 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 feasibly enhance the customer's return on investment (ROI) for EV and PHEV technologies, and accelerate market penetration. Note, technical challenges with regard to battery performance due to charge and discharge cycles need further investigation and remediation.

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(1) The PHEV is a hybrid electric vehicle with batteries that can be recharged when plugged into the electric wall outlet and an internal combustion engine that can be activated when batteries require recharging.

The market penetration of EVs and PHEVs demonstrates the potential application of a new technology enabled by the smart grid. Table 3.3 shows that the number of EVs reached 28,891 in 2006, representing roughly .01 percent of all light-duty vehicles in use. Light-duty vehicles include automobiles, vans, pickups, and sport utility vehicles (SUVs) with a gross vehicle weight rating of 8,500 pounds or less.(1) The U.S. DOE does not estimate current PHEV sales. There are several companies that perform aftermarket conversions (e.g., Amberjac Products, Hybrids-PlusTM, Plug-In Conversions Corp.) but there are no original-equipment manufacturers (OEMs) currently marketing PHEVs. Recent announcements by the automotive industry suggest that PHEVs and EVs will be commercially available in the 2010 to 2012 timeframe. PHEV sales are forecast by DOE to reach 237, 212 (1.4% of light-duty vehicle sales) by 2020 and 443,207 (2.2% of light-duty vehicle sales) by 2030.

Table 3.3. EV and PHEV Market Penetration (DOE/EIA 2009c)

Year	EVs On-Road		PHEVs On-Road		EV Sales		PHEV Sales	
	Total in Use	% of Light-Duty Vehicles	Total in Use		Total Suites	% of Light-Duty Market	Total Sales	% of Light-Duty Vehicles
2006	28,891	0.01%	-	0.00%	173	0.00%	-	0.00%
2010	24,247	0.01%	35,526	0.02%	130	0.00%	35,526	0.26%
2015	17,840	0.01%	442,570	0.18%	149	0.00%	139,164	0.86%
2020	11,453	0.00%	1,322,438	0.51%	153	0.00%	237,212	1.43%
2025	6,787	0.00%	2,701,419	0.98%	165	0.00%	350,386	1.95%
2030	4,351	0.00%	4,282,767	1.44%	184	0.00%	443,207	2.21%

Table 3.3 presents a forecast to 2030 of the number of EVs and PHEVs operating on-road based on the Energy Information Administration's (EIA) Annual Energy Outlook 2009, Early Release. As shown, the number of light-duty EVs in use reached nearly 29,000 in 2006 but is forecast to decline to 4,351 by 2030. The decline in EVs in use does not reflect a trend away from alternative vehicle technologies but rather a transition towards more competition among alternative technologies, some of which have not yet entered the marketplace (e.g., PHEVs). The PHEV share of on-road light-duty vehicles is forecast by U.S. DOE to grow slowly through 2030, reaching 4.3 million (DOE/EIA 2008b).

The U.S. DOE forecast presented in the Annual Energy Outlook is conservative compared to a small number of recent forecasts prepared by industry. While most forecasts estimate ultimate hybrid-electric and EV penetration of the light-duty vehicle market in the 8-16 percent range, (Greene et al. 2004), the EPRI and Natural Resources Defense Council (NRDC) were more aggressive, estimating PHEV market penetration rates ranging between 20% and 80% by 2050 (medium PHEV scenario estimate of 62% in 2050). EPRI and NRDC used a consumer choice model to estimate market penetration rates (EPRI/NRDC 2007).

A report recently prepared for the U.S. DOE presented and examined a series of PHEV market-penetration scenarios given varying sets of assumptions governing PHEV market potential. Based on input received from technical experts and industry representatives contacted for the U.S. DOE report and data obtained through a literature review, annual market-penetration rates for PHEVs were forecast from 2013 through 2045 for three

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(1) The definition of light-duty vehicles includes motorcycles. Although electric motorcycles are commercially available, plug-in hybrid motorcycles are unlikely to be pursued as a product. Therefore, we omitted motorcycles from this analysis.

scenarios. Under the scenario that examines market penetration assuming all the current U.S. DOE goals for PHEV development are achieved (e.g., $4,000 marginal cost of PHEV technology over existing hybrid technology, 40 miles all-electric range, 100 miles-per-gallon equivalent, and that PHEV batteries meet industry standards regarding economic life and safety), PHEV market penetration is forecast to ultimately reach 30 percent of new light-duty vehicle sales, reaching 9.9 percent by 2023 and 27.8 percent by 2035 (Balducci 2008).

The forecasts in Balducci (2008) and EPRI/NRDC (2007) were designed with scenarios based on increasingly aggressive assumptions. These scenarios assume that the PHEV will ultimately become the dominant alternative fuel vehicle. The EPRI/NRDC study was focused on the potential environmental impact of PHEV market penetration. Therefore, aggressive assumptions were required under some of the scenarios to generate a reasonably significant and measurable environmental impact. Neither study presents the scenarios as definitive or assigns probabilities to their outcomes. Rather, the studies are designed to measure the impact, or in the case of Balducci (2008) estimate the penetration rate, given certain sets of assumptions. If the goals outlined in Balducci (2008) are not reached, market penetration rates would certainly be lower than estimated. DOE estimates are generated by the National Energy Modeling System (NEMS), which does not use aggressive assumptions to determine the market potential of PHEVs. Instead, the light-duty alternative fuel vehicle market is forecast by NEMS to be dominated by diesel, flex fuel, and hybrid electric vehicles, not PHEVs.

New products and services depend on regulatory recovery for smart grid investments.

A smart grid will also enable consumer-oriented "smart" equipment, including communicating thermostats, microwaves, space heaters, refrigerators, clothes washers and dryers, and water heaters [Metric 9]. This equipment will be fitted with signaling software, or more specifically firmware, which enables the device to communicate with other components of a smart grid. These technologies will allow the customer and/or the utility or other authorized third parties to dynamically control the device's energy consumption based on energy prices and grid conditions.

In addition to specific appliances, this category of equipment encompasses other devices including meters, switches, 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" water heater may be equipped with a device that coordinates with the facility's energy management system to adjust temperature controls within user-specified limits based on energy prices. These technologies are under development but not yet commercially available on a widespread basis.

There are a number of other technologies that are currently commercially available that take advantage of smart grid features. For example, solar panels can be easily installed on rooftops by homeowners and safely generate power for years. Solar power can generate power at a cost of $10 to $12 per watt [Metric 7c] (Solar Guide 2008). These costs could be much lower in the future.

The new products and services highlighted in this section depend on regulatory recovery for smart grid investments. Historically, utilities have been rewarded for investment in capital projects and energy throughput. That is, expanded peak demand has driven the need for additional capital projects, which increase the rate base. As energy sales grow, revenues increase. Both factors run counter to encouraging smart grid investments. Thus, regulatory frameworks can discourage energy efficiency, demand reduction, demand response, distributed generation, and asset optimization (Anders 2007).

Electricity service providers participating in interviews conducted for this report indicated that, on average, they are recovering 8.1 percent of their investment through rate structures but predict that regulatory recovery rates will expand significantly in the coming years, ultimately reaching 90 percent. In addition, there are opportunities for expanded smart grid investment when sales are decoupled from revenues. When states decouple sales from revenues, a significant disincentive for utility investment in energy efficiency measures, including those that may be enabled by smart grid, is removed. In addition, consumer concerns that efficiency measures should reduce electric bills also needs to be addressed. This may be done in part by energy efficiency programs.(1) There are currently 10 states with energy efficiency programs where decoupling is not used, 11 states with energy efficiency programs where decoupling was proposed but not adopted, three states plus the District of Columbia with energy efficiency programs where decoupling is being investigated, nine states with energy efficiency programs where decoupling has been approved for at least one utility, and one state with no energy efficiency program where at least one utility has been approved for decoupling [Metric 4].

3.3.2 Enabling New Markets

A smart grid enables a more efficient allocation of resources through the use of information systems enabling communication between the grid and "smart" appliances, distributed generation units, and other consumer-oriented devices. Further, a smart grid rewards customers who engage in load-shifting behavior through the use of advanced meters, communication of real-time prices, and other incentive structures. In doing so, a smart grid establishes markets to manage these resources and reduce costs to consumers and utilities.

Advanced metering technology is a key facilitator of new markets through its ability to record energy usage at finer time intervals [Metric 12]. Bi-directional communication with the meters and with customers enables an exchange of information to support transactions with customers who can alter their consumption and may even generate excess energy to sell energy back to the grid. Smart-grid technology increases the accuracy of pricing policies, demand forecasts, and responses to grid disturbances and outages. The exchange of real-time prices and market data allows utility customers unprecedented access to information that, when acted upon, may impact energy costs and promote electric system savings. As noted previously, AMI penetration has reached 4.7 percent of total electric meters. In some areas (e.g., Midwestern states) AMI penetration rates have reached 8-11 percent. Pennsylvania has the highest penetration with 23.9 % (FERC 2008).

A smart grid, with "smart" meters, appliances, and real-time information exchange between customers and service providers uses dynamic pricing programs to encourage energy efficiency and load shifting. The most prevalent pricing strategies include time of use (prices are differentiated based solely on a peak versus off-peak period designation), critical peak price (higher critical peak price is restricted to a small number of hours each year), and real time pricing (hourly prices vary based on the day-of (real-time) or day ahead cost of power to the utility [Metric 1]. These pricing strategies incentivize investment in a broad spectrum of energy efficiency programs and equipment by offering customers the opportunity to shift load and reduce marginal energy cost.

A smart grid establishes markets to manage resources and reduce costs to consumers and utilities.

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(1) A policy and program framework to encourage greater end-use energy efficiency can be found in (EPA 2008c).

Demand-response equipment also enables the design and function of new markets. Demand response attempts to capture why consumers want electric power, when they want it, and how much they are willing to pay for this consumption. Demand response is typically viewed from a system operations point of view as a form of additional capacity and is discussed in terms of MW. Thus, a 2008 FERC survey estimated that the potential reduction due to such demand-response programs is approximately 41,000 MW per year, an increase of 9 percent and 5.8 percent of U.S. peak demands (FERC 2008).

Microgrids also represent a new smart grid-enabled market area [Metric 6]. A microgrid is a distribution system with distributed energy sources, storage devices and controllable loads, which may generally operate connected to the main power grid but is capable of operating as an island. From the grid's perspective, the primary advantage of a microgrid is that it can operate as a single collective load within the power system. Customers benefit from the quality of power produced and the enhanced reliability over relying solely on the grid for power. In the U.S. Department of Energy's vision of the electric power infrastructure (Grid 2030), microgrids are one of the three technical cornerstones. Microgrids are envisioned as local power networks that use distributed energy resources and manage local energy supply and demand. In 2006, less than 0.1% of the nation's generation capacity was met by microgrids, indicating that this is a nascent aspect of smart grid deployment.

The ability to better manage where power is going, how it is being used, and when it is being used also enables markets for premium power [Metric 17]. That is, managing load served by service type, such as firm service or interruptible service and their corresponding tariffs will enable utility and government agencies to differentiate between consumer types, enable demand curve estimation, and identify energy consumption schedules.

The cost of connecting and configuring smart devices and systems into the electric grid remains an obstacle to the high volume penetration levels anticipated. For automation components to connect and work, alignment is needed in communications networks, information understanding, business processing, and business and regulatory policy (see Figure 3.8). This alignment results in interoperability and it is aided by integration methods, tools, as well as adherence to standards and agreements that cover all these aspects [Metric 19]. Given the fast pace of change in technology, the evolving and competitive approaches to conducting business, and the local, state, and federal aspects of policymaking, interoperability cannot rest on a fixed set of standards, but requires a flexible framework, much like contract law. Progress is being made at technical levels with

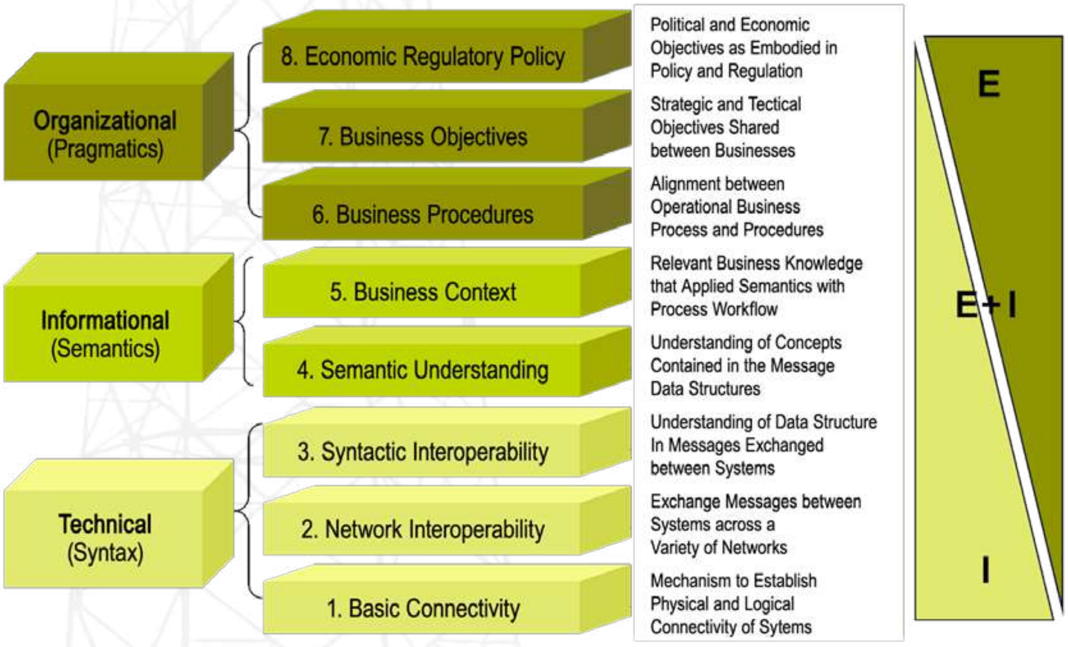


Figure 3.8. Interoperability Categories (GridWise 2008)

openly available communications architectures and standards, while work is just beginning to understand the information and business processes involved in application areas such as demand response.

Determining a quantifiable measurement of progress to improving interoperability for a smart grid is difficult; however, significant progress has been made in educating stakeholders on the nature of the issues and their importance. In the Energy Independence and Security Act of 2007, NIST was given the directive to develop an interoperability framework of protocols and standards to support a smart grid. Stakeholders are assembling to contribute and align their ideas for such a framework. As interoperability improvement is akin to software quality improvement, a more quantifiable measurement based upon a Capability Maturity Model (SEI 2008) is proposed for future reports. With such a model, assessments can be made by interviewing a representative sample of smart grid projects.

3.4 Provides Power Quality for the Range of Needs

Not all commercial enterprises, and certainly not all residential customers, need the same quality of power. Examples of power quality (PQ) issues include voltage sag, flicker, and momentary interrupts. Some customers have critical computer systems and complex processes that require high PQ, while others, such as most residential customers would not appreciate paying for better PQ. A smart grid supplies varying grades of power and supports variable pricing accordingly. The cost of premium PQ features can be included in the electrical service contract. Advanced control methods monitor essential components; enabling rapid diagnosis and precise solutions to PQ events, such as arise from lightning, switching surges, line faults and harmonic sources. A smart grid also helps buffer the electrical system from irregularities caused by consumer electronic loads.

When consumers consider PQ, they are typically concerned with the ability of the electrical grid to provide a continuous flow of energy with a quality to power all their electrical requirements. Not all customers, however, have the same energy needs. Residential customers tend to be affected more by sustained interruptions while commercial and industrial customers are troubled most by sags and momentary interruptions. With greater flexibility to locally target power quality resources, the ability to offer several pricing levels for varying grades of power can be considered. For those customers who are deemed power sensitive, the extra cost of premium power would be a worthwhile investment when compared with the lost revenue due to a loss of power.

A smart grid enables enhanced PQ through a number of specific technologies and approaches, including:

- PQ meters
- System-wide PQ monitoring
- Smart appliances
- Premium-power programs
- Demand-response programs
- Storage devices (e.g., batteries, flywheels, superconducting magnetic energy storage)

Not all customers need the same quality of power.

- Power electronic devices with the capacity to correct waveform deformities
- Monitoring systems used to identify system health and correct impending failures
- New distributed-generation devices with the ability to provide premium power to sensitive loads (NETL 2007)
- Active control of voltage regulators, capacitor banks, and inverter-based distributed generation and storage to manage voltage and VARs
- Remote fault isolation
- Dynamic feeder reconfiguration
- Microgrids
- Distribution state estimation

Together, these technologies and other elements of a smart grid could offer tremendous benefits to energy consumers through cost avoidance and associated productivity gains. While PQ is generally viewed in terms of both disruptions and disturbances, this section focuses entirely on PQ issues relating to power disturbances. See Section 3.6 for a discussion of power disruptions.

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

3.4.1 The Cost of Poor Power Quality

Power quality incidents in the past were often rather difficult to observe and diagnose due to their short interruption periods. The increase in power-sensitive and digital loads has forced us to more narrowly define PQ. For example, ten years ago a voltage sag might be classified as a drop by 40% or more for 60 cycles, but now it may be a drop by 15% for five cycles (Kueck et al. 2004).

There have been several PQ studies completed in the U.S. over the past 30 years [Metric 17]. The two most widely cited studies were the 1969-1972 Allen-Segall (IBM) study and the 1977-1979 Goldstein-Speranza (AT&T study). A third more recent and considerably larger study was conducted by the National Power Laboratory (NPL) in the earlier 1990's. The consistent conclusion among all three aforementioned PQ studies was that disturbances are a practical reality, and there is a need for different grades of power to protect sensitive loads (Dorr 1991).

Comparing the studies and assessing trends, however, is more difficult, as each study uses different definitions, parameters, and instrumentation. NPL filtered data to compare it with that of IBM and then the AT&T surveys in their PQ paper to examine trends in disturbances and outages. When the data examined by NPL were compared to both the IBM and AT&T studies, the NPL research team found a decrease in total disturbances per month but an increase in outages and sag disturbances. Thus, the data suggest the electrical grid has improved in terms of its ability to provide clean power free of disturbances but has become less capable over time to meet the growing demand placed on it and provide an uninterrupted power supply to electricity consumers.

Loss and fluctuations in power cause users to lose valuable time and money each year.

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 power quality disturbances alone cost the US economy between $15-$24 billion annually (McNulty and Howe 2002). In 2001 EPRI estimated power interruption and power quality cost at $119 billion a year (EPRI 2001), and a more recent 2004 study from Lawrence Berkeley National Laboratory (LBNL) estimated the cost at $80 billion a year (Hamachi LaCommare and Eto 2004).

3.4.2 Smart-Grid Solutions to Power Quality Issues

Interviews were conducted for this report with 21 companies meeting an annual peak demand of 150,000-175,000 megawatts and 0.8-1.2 billion megawatt hours of generation served. The companies were asked to estimate the percentage of customer complaints related to PQ issues (excluding outages). The utilities indicted that 3.1 percent of all customer complaints were related to PQ issues.

A smart grid can address PQ issues at various stages in the electricity delivery system. For example, smart-grid technologies address transmission congestion issues through demand response and controllable load. Smart-grid-enabled distributed controls and diagnostic tools within the transmission and distribution system help dynamically balance electricity supply and demand, thereby helping the system to respond to imbalances and limiting their propagation when they occur [Metric 11]. This reduces the occurrence of outages and power disturbances attributed to grid overload.

Smart-grid-enabled distributed controls and diagnostic tools help the system dynamically respond to power imbalances.

There are a number of technologies that serve to automate the transmission and distribution system and are enabled by a smart grid, including: Supervisory Control and Data Acquisition (SCADA) technologies, remote sensors and monitors, switches and controllers with embedded intelligence, and digital relays [Metric 11]. Nationwide data has shown that transmission automation has penetrated the market, while distribution automation is primarily led by substation automation, with feeder automation still lagging. Recent research shows that while 84% of utilities had substation automation and integration plans underway in 2005 and about 70% had deployed SCADA systems to substations, the penetration of feeder automation is still limited to approximately 20% (ELP 2008; McDonnell 2008).

Microgrids are also serving to enhance PQ at specific sites [Metric 6]. Technologic, regulatory, economic, and environmental incentives are changing the landscape of electricity production and transmission in the United States. Distributed production using smaller generating systems, such as small-scale combined heat and power (CHP), small-scale renewable energy sources (RES) and other DERs can have energy efficiency, and therefore, environmental advantages over large, central generation. The growing availability of new technologies in the areas of power electronics, control, and communications supports efforts in this area. These new technologies enable small power generators, typically located at user sites where the energy (both electric and thermal) they generate is used, to provide sources of reliable, quality power, which can be organized and operated as microgrids.

A microgrid is defined as a distribution system with distributed energy sources, storage devices, and controllable loads, that may generally operate connected to the main power grid but is capable of operating as an island. Currently, approximately 20 microgrids can be found at universities, petrochemical facilities and U.S. defense facilities. According to RDC (2005), the microgrids provided 785 MW of capacity in 2005. They noted additional microgrids that were in planning at the time as well as demonstration microgrids. RDC also noted that by examining the Energy Information Administration's database they could determine approximately 375 potential sites for microgrids if they weren't already microgrids. Outside of the petrochemical microgrids, there are no commercial microgrids in the United States

(PSPN 2008). Given EIA's net summer capacity of 906,155 MW and assuming no devolution of microgrid capacity from 2005, the percentage of capacity met by microgrids is about 0.09% in 2006.

Table 3.4. Capacity of Microgrids in 2005 (MW) (RDC 2005)

	University	Petrochemical	DoD
Capacity (MW)	322	455	8

Navigant Consulting, in their base case scenario, projected 550 microgrids installed and producing approximately 5.5 GW by 2020 (Navigant 2005) or about 0.5% of projected capacity (DOE/EIA 2009a). Navigant (2005) predicts a range of 1 13 GW depending on assumptions about pushes for more central power, requirements and demand for reliability from customers and whether there is a environmental requirement for carbon management.

Grid-connected distributed generation (DG) and storage technologies can enhance PQ due to their smaller scale, localized support for power generation and distribution systems, and potential ability to respond to power disruptions and disturbances (e.g., islanded operation). These technologies include power generators, such as wind turbines connected at the distribution system level, micro hydro installations, solar panels, and gas microturbines. These distributed generators produce power for onsite or adjacent consumption and could sell surplus power back into the grid under an established fee-in tariff. These technologies also include energy storage devices such as batteries and flywheels, which could be used to store energy produced or purchased during off-peak hours and then sold or consumed on-peak. While these technologies have considerable potential for enhancing PQ, distributed generation capacity is currently a small part of total power generation, with combined total distributed generation capacity reaching 12,702 megawatts in 2007 [Metric 7] (DOE/EIA 2007).

The ability to track where power is going, what is being done with it, and when it is being used is paramount to addressing PQ issues. Further, the tracking of load served by service type, such as firm service or interruptible service, and their corresponding tariffs (fixed or marginal-cost based) will enable utility and government agencies to discriminate between consumer types, enable demand-curve estimation, and identify energy-consumption schedules.

According to estimates published in the 2008 Annual Energy Outlook, residential and commercial energy sales are expected to outpace industrial energy sales (DOE/EIA 2008a). With both residential and commercial energy demands approaching approximately double their 1995 values by 2030, the ability to disaggregate and track not only who is consuming the most energy, but how it is being consumed, will become an increasingly more valuable asset of a smart grid as utility and government agencies strive to further increase energy efficiencies, manage ever-increasing loads, and provide high PQ.

Load management involves demand-response equipment that can respond to load conditions [Metric 5]. There are a number of organizations (e.g., Electric Reliability Council of Texas, Public Utility Commission of Texas) that act to balance and curtail loads to avoid and manage power disruptions and disturbances. Nationally, however, demand response is low. Table 3.5 shows the number of entities with demand response programs.

Table 3.5. Entities Offering Load-Management and Demand-Response Programs (FERC 2008)

Type of Program	Number of Entities
Direct Load Control	209
Interruptible/Curtailable	248
Emergency Demand Response Program	136
Capacity Market Program	81
Demand Bidding/Buyback	57
Ancillary Services	80

Grid-responsive demand-side equipment includes “smart” appliances (e.g., communicating thermostats, microwaves, space heaters, hot water heaters, refrigerators) and other devices, including switches, power-outlets, and various other controllers that could be used to retrofit or otherwise enable existing equipment to respond to smart grid conditions. This type of equipment enhances power quality by enabling customers, utilities, and/or third parties to dynamically control energy consumption based on energy prices and grid conditions. A recent smart grid experiment conducted by the U.S. Department of Energy, which tested thermostats, washers and dryers, and water heaters fitted with “smart” grid-responsive equipment, found these “smart” devices reduced load fluctuations, decreased peak loads, and significantly reduced energy costs. However, only approximately 8% of U.S. energy customers have any form of time-based or incentive-based price structure that would enable customers to reap the benefits associated with load shifting behavior [Metric 9] (FERC 2008). Only 5 percent were reported as having a time-based rate in the 2006 FERC Survey (FERC 2006a).

3.5 Optimizes Asset Utilization and Operating Efficiency

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

One of the key features of a smart grid is its lower costs of operations, maintenance, and expansion compared with those of traditional forms of operation. A smart grid is able to optimize operating efficiency and utilization of assets by employing advanced information and communication technologies; this allows better monitoring of equipment maintenance, minimizes operation costs, and “replaces iron with bits” (DOE/OEDER 2008b) by reducing the need for increased generation and infrastructure through demand-response measures and other technologies.

This section looks at asset utilization and operating efficiency of the bulk generation, transmission and distribution delivery infrastructure, and the distributed energy resources in the electric system. It concludes with an overall view of system efficiency.

3.5.1 Bulk Generation

The United States crept closer to its generation capacity limits for at least the ten years preceding 1998-2000, according to NERC, but reversed that trend during the next 5 years and returned to more conservative capacity factors [Metric 14]. Figure 3.9 shows measured and predicted winter and summer peak generation capacity factors from 1999 and projected

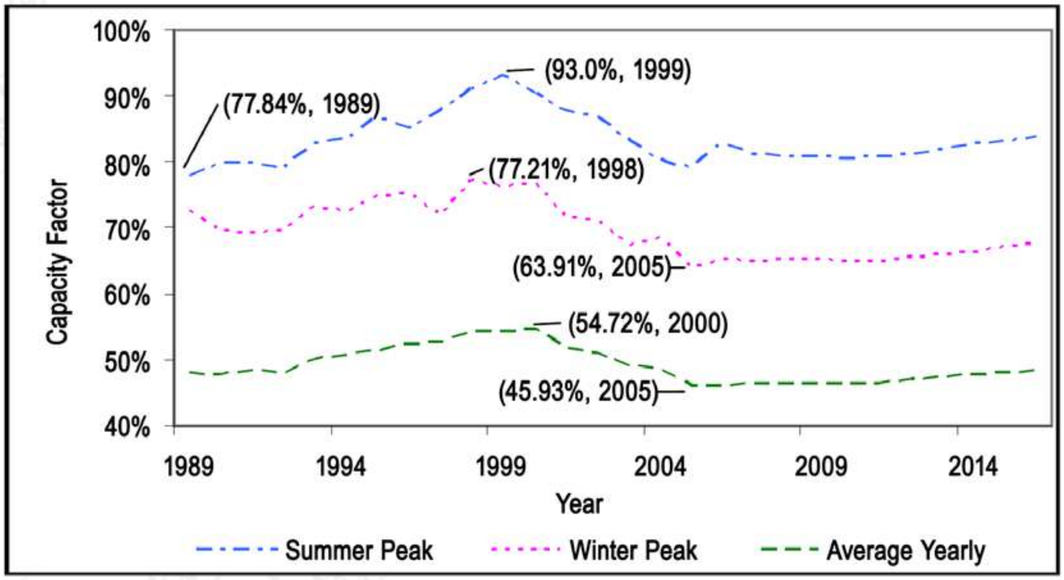


Figure 3.9. Measured and Predicted Peak Summer, Peak Winter, and Yearly Average Generation Capacity Factors in the U.S. (NERC 2008)

to 2014. It indicates that, after a recent decline, the generation capacity factors are predicted to increase slightly in the next 8 years. The large differential between available capacities and average capacity is built to accommodate a few hours of peak demand during winter and summer regionally.

For bulk generation, efficiencies for coal, petroleum, and gas remain almost constant for the last 20 years; there is no new breakthrough in sight (see Figure 3.10). The combination of coal, petroleum, and natural gas makes up about 80% of the nation's electric power-generation base [Metric 15].

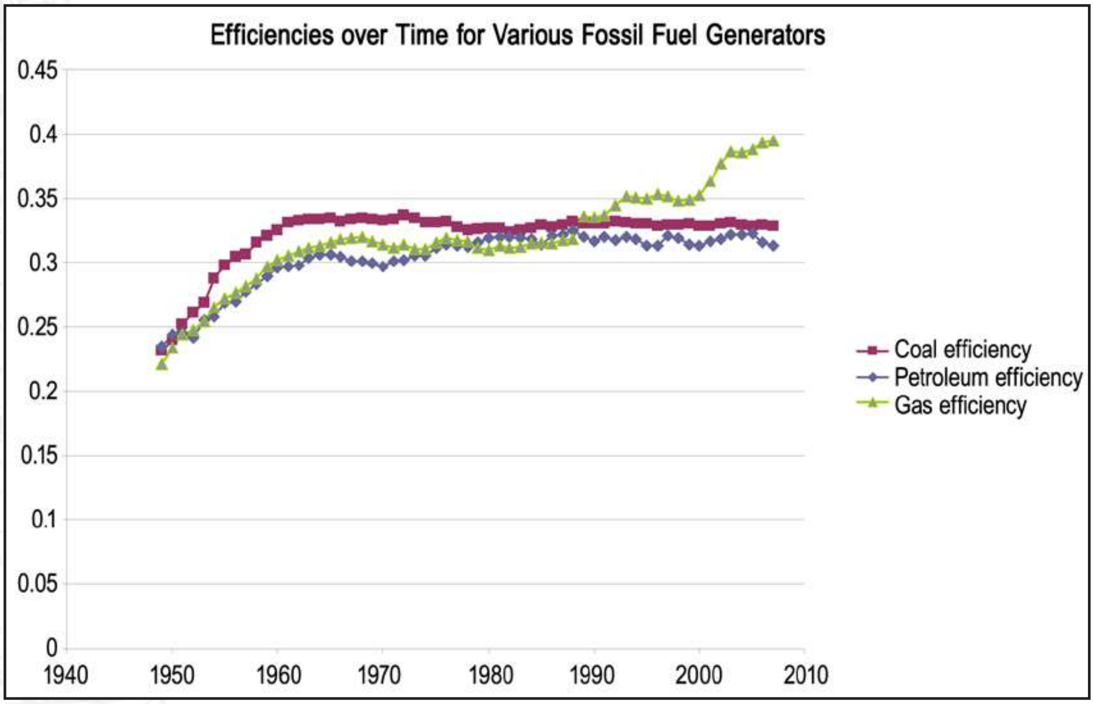


Figure 3.10. Generation Efficiency for Various Fossil Fuel Sources over Time (DOE/EIA 2007a)

Table 3.6 shows the 2006 and projected 2008 peak demand and generation capacities. The grid currently runs with a generation capacity factor of about 46%.

Table 3.6. Measured and Projected Peak Demands and Generation Capacities for Recent Years in the U.S., and Calculated Capacity Factors (NERC 2008)

Measurement	2006 Measured	2008 Projected
Summer peak demand (MW)	789,475	801,209
Summer generation capacity (MW)	954,697	991,402
Capacity factor, peak summer (%)	82.69	80.82
Winter peak demand (MW)	640,981	663,105
Winter generation capacity (MW)	983,371	1,018,124
Capacity factor, peak winter (%)	65.18	65.13
Yearly energy consumed by load (GWhr)	3,911,914	4,089,327
Capacity factor, average (%)(1)	46.08	46.46
(1) The average of the NERC (2006) summer and winter capacities was used for this calculation.		

3.5.2 Delivery Infrastructure

T&D automation devices 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. Recent research found that about 60% of the control centers in North America have linkages with other utilities [Metric 2] (Newton-Evans 2008).

Data from utilities across the nation show a clear trend of increasing T&D automation and increasing investment in these systems. Key drivers for the increase in investment include operational efficiency and reliability improvements to drive cost down and overall reliability up. The lower cost of automation with respect to T&D equipment (transformers, conductors, etc.) is also making the value proposition easier to justify. With higher levels of automation in all aspects of the T&D operation, operational changes can be introduced to operate the system closer to capacity and stability constraints [Metric 11].

Results of interviews undertaken for this report (see Annex B) indicate that:

- 28% of the total substations owned were automated
- 46% of the total substations owned had outage detection
- 46% of total customers had circuits with outage detection
- 81% of total relays were electromechanical relays
- 20% of total relays were microprocessor relays (presumed rounding error)

Other nationwide data has shown that transmission automation has already penetrated the market highly, while distribution automation is primarily led by substation automation, with feeder equipment automation still lagging. Recent research shows that while 84% of utilities had substation automation and integration plans underway in 2005, and about 70% of utilities had deployed SCADA systems to substations, the penetration of feeder automation is still limited to about 20% (ELP 2008; McDonnell 2008). Because feeder automation lags other automation efforts so significantly, this should be an area addressed directly in future work.

A significant component of the measurement, analysis, and control of the T&D infrastructure relates to control centers at the transmission and distribution levels of the system (SCADA, energy management systems – EMS, and distribution management systems - DMS). According to a recent survey by Newton-Evans Research, almost all utilities with over 25,000 customers have SCADA/EMS systems in place, while only about 17% of utilities have DMS systems (Newton-Evans 2008). One smart grid trend is to integrate other functions with these centers. For example, about 30% of the SCADA/EMS systems are linked to Distribution Automation/DMS. Figure 3.11 shows the projected integration of EMS/SCADA/DMS systems to a variety of other data systems.

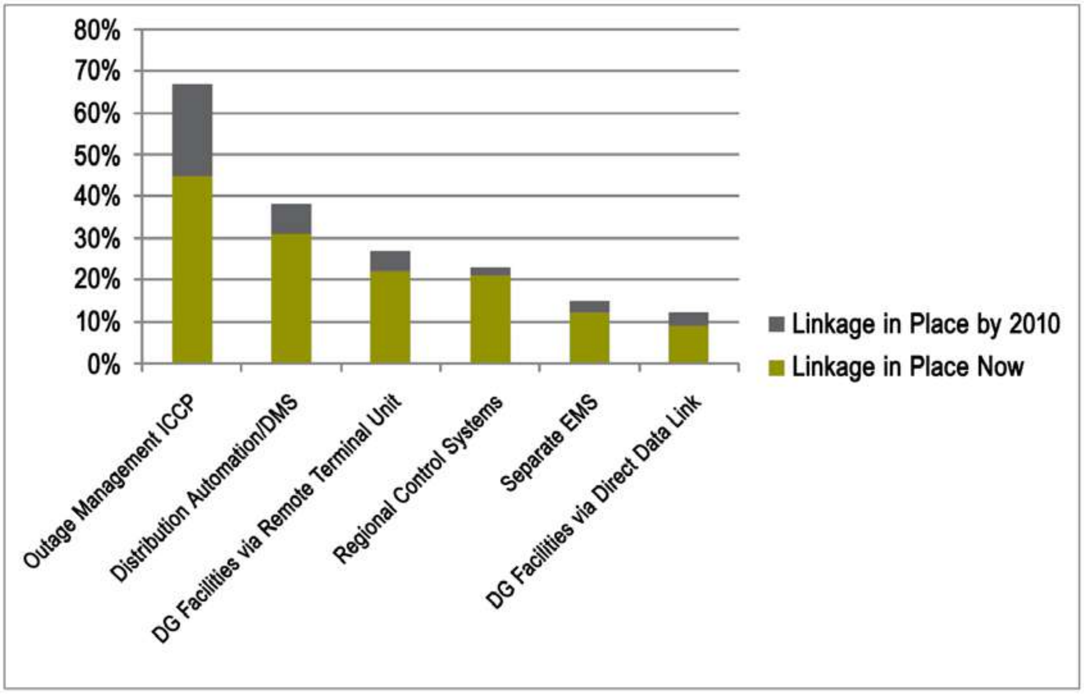
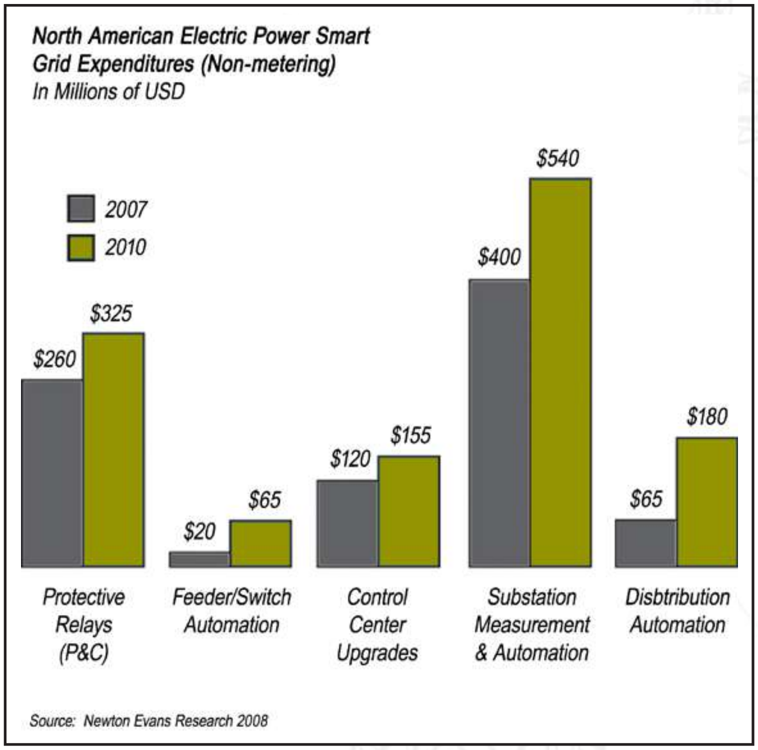


Figure 3.11. Current/Future Plans for Connecting EMS/SCADA/DMS Systems to Other Data Systems (Newton-Evans 2008)

The investment in T&D automation can be estimated either from total industrial output of specific automation products to US markets or from the receiving demand side (utility company) as purchases. Market statistics for T&D investment already exist and could be readily utilized. Newton-Evans Research provides market-volume estimates on automation products aggregated to categories such as shown in Figure 3.12. The figure shows that significant increases in T&D automation are expected between 2007 and 2010. For example, spending on distribution automation is expected to almost triple by 2010 to nearly $180 million. Protective relays are expected to increase 25% to $235 million, feed-switch investment by 225% to $65 million, control-center upgrades by 29% to $155 million; and substation investment by 35% to $540 million (Newton-Evans 2008).

Data sharing from the field and between control centers and reliability coordination centers improves the true operational view of the system. Without an accurate view, operating procedures are developed with engineering buffers that allow for inaccuracy or unpredictable situations. The level of situation awareness is also being raised by advanced measurements, such as synchro-phasors, that are beginning to be shared across large regions of the country. The North American Synchro-Phasor Initiative (NASPI) reports that in 2008, 175 phasor measurement units are operating in North America [Metrics 2, 13]. In addition, control centers have more data to gather from the field with the growth in T&D automation. This further reduces the number of system disruptions, the downtime from a disruption, and the total impact of such an occurrence [Metric 11]. Distribution automation investment is expected to triple to almost $180 million in 2010, while transmission automation investment is expected to increase by 35% to $540 million.

Dynamic line ratings [Metric 16] can also help increase grid utilization by allowing the delivery infrastructure to operate closer to its true limits. Concern rises as long-term growth of transmission capacity is dramatically short of keeping up with growth of peak demand. Forecasts predict there will be a less than 1% increase in total miles of transmission cables and GW-miles between 2002 and 2012 (Hirst 2004). Dynamic line ratings have the potential to provide an additional 10-15% transmission capacity 95% of the time and fully 20-25% more transmission capacity 85% of the time (Seppa 1997). Currently, only a small fraction of the nation's transmission lines are monitored to support dynamic line ratings. The interviews of electricity service providers conducted as part of this report (see Annex B) reveal that, on average, only 0.5% of respondents' transmission lines were dynamically rated, and that number dropped to 0.3% when weighted by the number of customers served by each respondent.



Source: Newton Evans Research 2008

Figure 3.12. North American Electric Power T&D Automation Expenditures (in Millions of USD) (Newton-Evans 2008; Ockwell 2008)

3.5.3 Distributed Energy Resources

Smart grid applications, such as demand response [Metric 5] and grid-connected distributed generation (DG) [Metric 7], should also improve grid operating efficiency by controlling load and adding localized resources when required. In order for this to occur, favorable DG interconnection standards are needed [Metric 3]. Currently the amount of load-managed distributed generation has been declining since 1995 and is currently just above 1% of net summer capacity. Grid-connected DG, on the other hand, increased 134% between 2004 and 2007. This still represents only 1.6% of summer peak capacity. Once favorable interconnection standards are approved by all states, the amount of DG should become a more significant portion of grid capacity. Currently only 15 states have favorable standards although significantly more have interconnection standards.

At present about 10 states are considering new DER interconnection standards, and it is estimated that 85% of utilities will have a policy in place in the near future [Metric 3]. Only 15 states have what are considered favorable interconnection standards (EPA 2008b).

The demand for smart technologies will only increase as grid demand increases. In fact, current trends suggest a significant increase in load in the

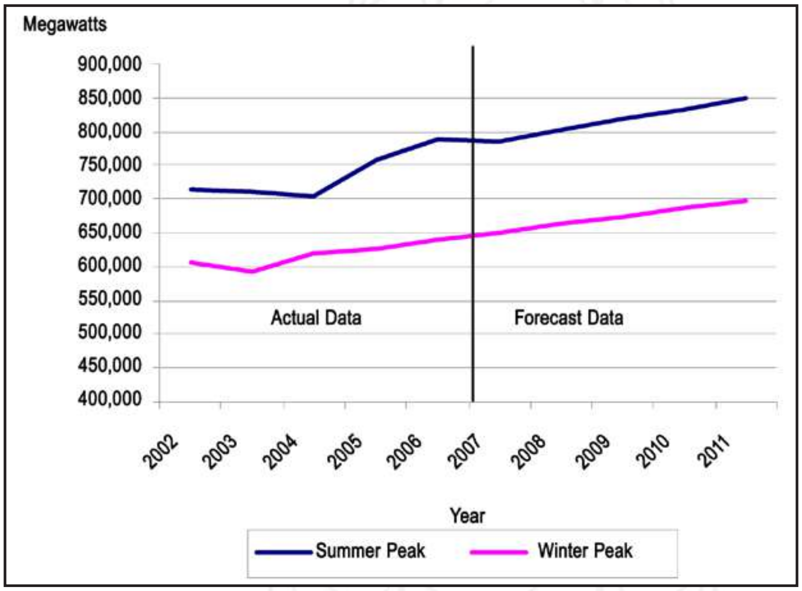


Figure 3.13. Peak Demand for the Contiguous U.S. (DOE/EIA 2007c)

near future. For example as shown in Figure 3.13, the Energy Information Administration predicts that the winter peak demand for energy will increase to almost 700,000 megawatts by 2011 (DOE/EIA 2007c).

3.5.4 Overall System Efficiency

Currently, gross annual measures of grid operating efficiency have been steady or improving slightly as the amount of energy lost in generation dropped 0.6 percentage points to 67.7% in 2007 and transmission and distribution losses improved very slightly by 0.05 percentage points to 9.44% of net generation [Metric 15]. Presently, load is growing at almost double the rate of growth in transmission capacity; however, most regions have very limited plans to expand generation and transmission facilities. Using traditional planning and operations practices, the current delivery infrastructure is not capable of bringing renewable-energy generation online at a capacity that is consistent with the amount of construction.

Figure 3.14 shows overall grid operating efficiency. In this figure T&D losses are shown to be approximately 1.34 quadrillion BTU. Compared with net generation of electricity at 14.19 quadrillion BTU, T&D losses are about 9.4 %. This is a very slight improvement over 2004.

DG represents one of the most promising technologies in this regard [Metric 7]. The Electric Power Research Institute, for example, forecasts that 25% of new electric power generation by the year 2010 will be distributed generation (Dugan et al. 2001). Currently only 1.2 percent of net summer capacity is met by grid-connected DG.

With these considerations in mind, the benefits of a smart grid become clear; advanced sensors and control technologies will enable more efficient management and delivery of existing capacity, and will provide a strong framework for infrastructure support and the

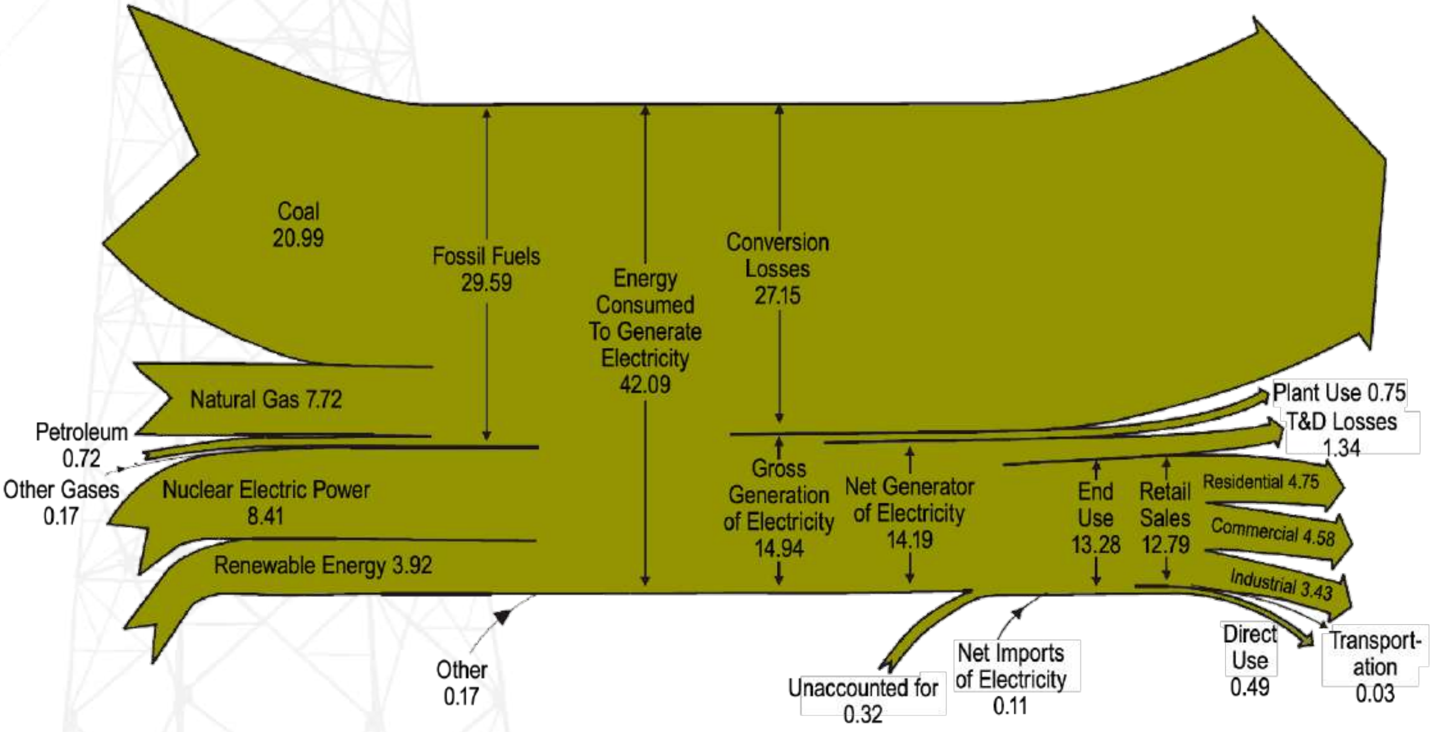


Figure 3.14. Electricity Flow Diagram 2007 (Quadrillion Btu) (DOE/EIA 2007a)

development of additional, distributed generators. This will be especially true in the case of renewable energy sources such as solar, wind, and small hydro generation, as current regional initiatives support the focus and development of these technologies.

3.6 Operates Resiliently to Disturbances, Attacks, and Natural Disasters

"Resiliency" refers to the ability of a system to react to events such that problematic consequences are isolated with minimal impact to the remaining system, and the overall system is restored to normal operation as soon as practical. These self-healing actions result in reduced interruption of service to consumers and help service providers more effectively manage the delivery infrastructure. Resiliency includes protection against all hazards, whether accidental or malicious, and needs to span natural disasters, deliberate attack, equipment failures, and human error. A smart grid inherently addresses security from the outset as a requirement for all the elements, and ensures an integrated and balanced approach across the system.

Resiliency is embedded in operational culture: policy, procedures, and vigilance.

From the point of view of the Nation's national security, this characteristic is arguably the most important. Resiliency in the face of adverse conditions or aggression, particularly high-consequence events, underlies all aspects of a smart grid and cuts across the other characteristics. Resiliency is embedded in operational culture: policy, procedures, and vigilance. It is embodied through effective risk management, with thorough understanding and management of threats, vulnerabilities, and consequences.

Given the great numbers of automation components interacting with a smart grid, an important operational paradigm going forward is distributed decision making. That is, equipment and smart-grid subsystems need to share actionable information so that local decision making not only serves local self-interest, but collaboratively supports the overall health of the system. As individual components of the system fail, including processing and communications components, the remaining connected components have the ability to adapt and reconfigure themselves to best achieve their objectives much like a society of devices. Though hierarchical command-and-control approaches will continue to occupy important roles in system design, distributed decision-making approaches are becoming more prevalent.

The strength of our electricity system does not lie in its ability to optimally reach a predefined mission or objective, but in the fact that its business and infrastructure components can adapt and evolve to meet the changing needs of an unpredictable future. As in nature, disturbances may impact portions of the ecosystem to varying degrees, and in the case of natural disasters, render regions incapacitated; however, the remainder of the system reacts to contain the damage, and amass a reconstruction effort once the event has past.

Operational resiliency has three basic descriptive properties (Caralli et al. 2006):

1. ability to change (adapt, expand, conform, contort) when a force is enacted,
2. ability to perform adequately or minimally while the force is in effect,
3. ability to return to a predefined, expected normal state whenever the force relents or is rendered ineffective.

Related Metrics

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

A majority of the metrics identified for measuring smart-grid advancement contribute in some way to resiliency.

3.6.1 Area, Regional, National Coordination

At the transmission-system level, area control centers and regional reliability coordination centers have been exchanging system status information for many years. These systems are continually being upgraded to share more information including SCADA data, state-estimation results, and market data. The communication links between these systems now cover the country with increasing exchange of information between electric utility companies. There is also an increased level of data exchange between transmission and distribution levels within the system.

According to a recent survey by Newton-Evans Research (Newton-Evans 2008), one smart grid trend is to share this information between other reliability and control centers. For example, the research found that about 60% of the control centers in North America have linkages with other utilities. Figure 3.15 shows the projected integration of EMS/SCADA systems to a variety of other area and regional control systems as well as operations planning and DMS [Metric 2].

An interview of electricity service providers conducted for this report finds that 40% of the companies interviewed have new information flowing across functions and systems due to recent project implementations.

A transformational aspect of a smart grid is its ability to incorporate distributed energy resources, particularly demand-side resources, into system operations. The ability to send area, regional, and national signals to these resources, which enables distributed decision making, supports adaptation of these resources to impending threats, disturbances, and

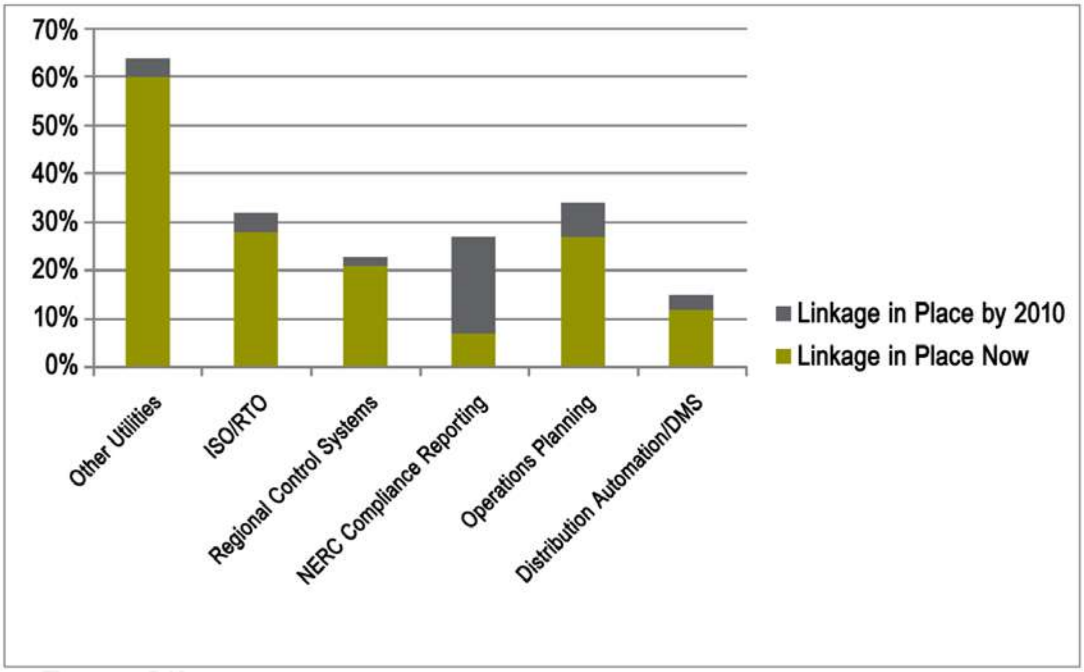


Figure 3.15. Current/Future Plans for Connecting EMS/SCADA/DMS Systems to Other Data Systems (Newton-Evans 2008)

attacks. In particular, critical-peak and real-time pricing programs provide a mechanism for system operators and reliability coordinators to access these resources to enhance operational resiliency. In a 2006 survey, FERC found that approximately 1.1% of the total customer base was served by time-of-use price offerings [Metric 1], nearly all of which were residential customers.

Finally, situational awareness of grid behavior is being transformed by wide-area-measurement networks. Initiatives in the western interconnection have been underway for many years and have contributed to reviews of major outages and questioned system dynamics models for planning and operations. Only recently have time-synchronized, high quality measurements (from phasor measurement units – PMUs) worked their way into operating rooms of reliability coordinators and balancing authorities [Metric 13]. The North American Synchro-Phasor Initiative (NASPI), led by NERC and supported by DOE, is advancing the coordination of the deployment of PMUs and the networking of their measurements for wide-area situation awareness and other applications. Currently there are approximately 165 PMUs installed. In the eastern interconnection, there are 104 PMUs with 89 networked and 61 PMUs in the western interconnection (Dagle 2008). One trade source indicates there were 150 PMUs installed in early 2008 within the eastern and western interconnections (Galvan et al. 2008) up from the 100 PMUs indicated in 2006 (DOE 2006a).

Figure 3.16 shows, as of 2007, the existing and planned PMU deployment locations in North America. There are many PMUs installed that are not networked across organizations not shown on the map, with many more projected in the future.

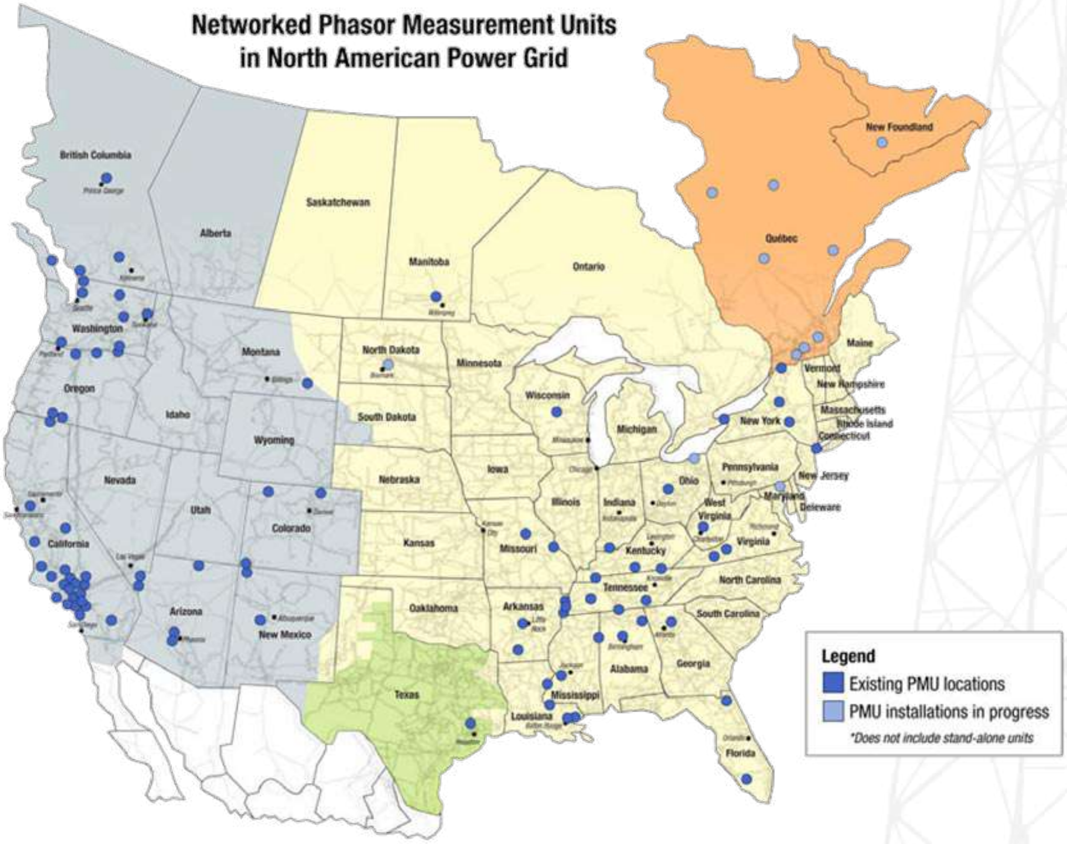


Figure 3.16. Networked Phasor Measurement Units in the North American Power Grid (PNNL/EIOC 2008)

3.6.2 DER Response

A smart grid provides the flexibility to adapt to a changing mix of demand-side resources, including changeable load, dispatchable distributed generation and storage, as well as variable-output local generation such as wind and solar. In the event of a disturbance, attack, or natural disaster, these resources can help alleviate constraints or support electrically energized islands that can mitigate the impact to events, and improve response times for post-disturbance reconstruction.

According to a 2008 FERC Survey (FERC 2008), only about 8% of customers have time-based rates or are involved in some form of incentive-based program [Metric 5]. Similarly, the number of entities offering such programs is low, with direct load control (DLC) and interruptible/curtailable tariffs listed as the most common incentive-based demand response programs. It also indicates increases in direct controlled-load management in nearly every region of the country. Interruptible loads, primarily industrial loads, are more mixed with several regions indicating decreases.

Grid-connected distributed generation and storage increased from 5,423 MW in 2004 to 12,702 MW in 2007 (DOE/EIA 2007d) [Metric 7]. While grid-connected distributed generation increased 134 percent over two years, it still only represented 1.4 percent of grid capacity, 1.6 percent of summer peak and 2.0 percent of winter capacity. Growth projections indicate a doubling of distributed generation capacity in five years (Eynon 2002).

Only about 8% of customers are involved in some form of incentive-based program.

Other distributed energy resources are just now emerging on the scene. These include microgrids [Metric 6] that are designed to operate in islanded and grid-connected modes, distributed storage, electric vehicles [Metric 8], and grid-responsive appliances in homes and other facilities [Metric 9]. The ability of a microgrid to run autonomously as an island (off of the main grid) provides these communities with greater reliability to withstand disturbances that may affect the greater electric system, while still being able to use grid resources should internal equipment fail or need maintenance. Today the amount of these resources is extremely small. While they will be good indicators for smart-grid progress, they are expected to have little impact on overall operational resiliency in the near future.

Grid-responsive equipment [Metric 9] has the potential to significantly enhance the resiliency of the overall system. Communicating thermostats, responsive appliances, responsive space conditioning equipment, etc. can quickly respond to frequency deviations or voltage changes. This can enhance the system reserve capacity that provides the necessary margin to respond to contingencies, and it can do it by measuring local system conditions or responding to communicated information. Currently there is significant interest in this field. Businesses such as LG Electronics and Westinghouse are designing and producing more “web-enabled” household appliances. Research and development in these fields will poise producers to easily transition into “smart” devices. However, incorporating electronics into increasing numbers of appliances, as well as developing and maintaining software for these appliances, will require a new look at the products’ life-cycle costs. Manufacturers and grid entities have not yet settled on standards that would give manufacturers the confidence necessary to fully integrate and launch grid-responsive equipment.

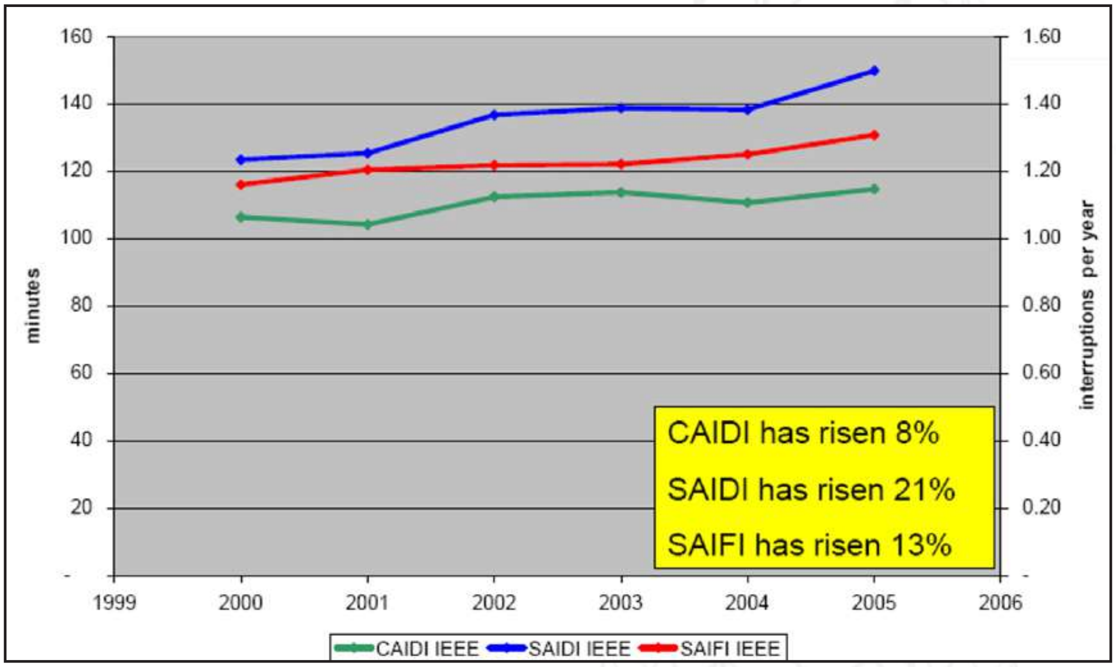
3.6.3 Delivery Infrastructure

For many years, electric-service providers have realized the benefits of adding sensing, intelligence, and communications to equipment in the transmission and distribution infrastructure. Smart-grid initiatives are encouraging faster deployment of this capability with ever-greater functionality. Transmission and distribution substation automation projects and efforts to deploy advanced measurement equipment for applications such as wide-area situational awareness and dynamic line ratings, are helping to improve the ability to respond resiliently and adapt to system events.

Smart-grid-enabled distributed controls and diagnostic tools within the delivery system will help dynamically balance electricity supply and demand, thereby helping the system respond to imbalances and limiting their propagation when they occur. This could reduce the occurrence of outages and power disturbances attributed to grid overload as well as reduce planned rolling brownouts. These technologies could also quickly diagnose outages due to physical damage of the transmission and distribution facilities and direct crews to repair them quickly (Baer et al. 2004).

The national averages for outage disruptions (SAIDI, SAIFI, and MAIFI) [Metric 10] were estimated in a 2004 LBNL study at 106 minutes, 1.2 interruptions per year, and 4.3 minutes respectively. Recent trends in the reliability indicators SAIDI, SAIFI, and CAIDI are shown in Figure 3.17. An IEEE 2005 benchmarking study analyzed data from 55 companies between 2000 and 2005. Results showed an eight percent increase in CAIDI, a 21% increase in SAIDI and a 13% increase in SAIFI.

The relatively worsening trend in these indices suggests that a lack of investment in the delivery infrastructure is having an impact. The North American Electric Reliability Council's 2007 Long Term Reliability Assessment (NERC 2006) predicts capacity margins declining in the coming years, suggesting that the reliability indices can be expected to continue to increase given current operating practices. While it is difficult to attribute the ability of smart grid implementation to slow any degradation or enhance the increase in reliability, smart grid related resources in terms of substation automation equipment, sensing and management should play a significant role.



CAIDI has risen 8%

SAIDI has risen 21%

SAIFI has risen 13%

Figure 3.17. Trends for 55 Utilities Providing Data Between 2000-2005 (IEEE 2006)

Data from utilities across the nation show a clear trend of increasing T&D automation and increasing investment in these systems [Metric 11]. Increases in investment in T&D automation systems should lead to greater operational resiliency in the delivery infrastructure. Recent research shows that while 84% of utilities had substation automation and integration plans underway in 2005, and about 70% of utilities had deployed SCADA systems to substations, the penetration of automation at the distribution-feeder level is still limited to about 20% (ELP 2008; McDonnell 2008). This suggests a large area for growth in smart-grid deployment.

Another important trend within the electricity-delivery infrastructure is the rollout of advanced meters [Metric 12]. The capabilities of these systems promise to dramatically increase the accuracy of data to pricing policies, demand forecasts, and consumer applications, as well as increase the ability of the grid to respond to emergency occurrences such as blackouts and brownouts. Because AMI can play an enabling role in load participation in system operations it can have a significant influence on operational resiliency. Currently, AMI composes about 4.7% of total U.S. electric meters (FERC 2006a). Activity in the use of advanced metering has been increasing rapidly, growing nearly 700% from 2006 to 2008. While it is difficult to assess precisely which functions these AMI deployments support, the penetration rates indicate that this enabling technology is being positioned to support greater participation by distributed energy resources to the benefit of operational resiliency.

An increase in the penetration of dynamic line ratings and the associated measurement equipment will also contribute to understanding the status of the deployment of a smart grid [Metric 16]. The capacity of transmission equipment is not static, but can change significantly according to several variables, most notably conductor sag caused by thermal properties. Sensors for measuring the impact on sag are appearing more frequently, particularly in pilot programs for critical corridors. Though the number of miles of transmission with dynamic ratings is anticipated to increase, it is so small now as to be negligible on an interconnection basis.

3.6.4 Secure Information Networks

Economic forces and technology development are making the power system more dependent on information systems and external communications networks. The interconnected nature of the communications systems that support regional and interregional grid control, and the need to continue supporting older legacy systems in parallel with newer generations of control systems, further compound these security challenges. Additionally, with the advent of inexpensive microcontrollers and smart-grid implementation, there is a growing trend for increased intelligence and capabilities in field equipment installed in substations, within the distribution network, and even at the customer's premises. This increased control capability, while vastly increasing the flexibility and functionality to achieve better economies, also introduces cyber-vulnerabilities that have not previously existed and presents a significantly larger number of targets.

A vigilant security culture needs to permeate the stakeholder base to continually assess evolving cyber threats, risks, and response.

An understanding of component and associated system vulnerabilities will be necessary to quantify cyber-security issues inherent in smart grid deployments, particularly when these systems can be used to control or influence the behavior of the system. Assessments will be needed, both in controlled laboratory and test-bed environments, and in actual deployed field conditions, to explore and understand the implications of various cyber-attack scenarios, the resilience of existing security measures, and the robustness of proposed countermeasures.

Vendor and operator adoption of these countermeasures will be critical in broadly influencing the installed base of future deployments. The asset owners remain responsible for their legacy systems as smart grid technologies are deployed. A security culture that is vigilant to continually assess evolving threats and risks, then balance those with countermeasures needs to permeate the stakeholder base.

The interviews with service providers in Annex B of this report offer a sampling of data with regard to industry compliance with NERC cyber-security standards, including percentage of utilities that have conducted assessments at various frequencies for NERC Critical Infrastructure Protection (CIP) Standards 002 through 009 (see Table 3.7). The interviews indicate 5% of the utility respondents have never conducted an assessment. It's not clear whether this is because these utilities are not large enough to have an impact on the bulk electric power system or because they are still in the process of phasing in their compliance. As the timeline for mandatory compliance of all entities associated with the bulk electric system becomes fully implemented, and NERC establishes procedures for more formally tracking compliance with these standards, it will become increasingly easier to gather data for this metric and assess it for trends.

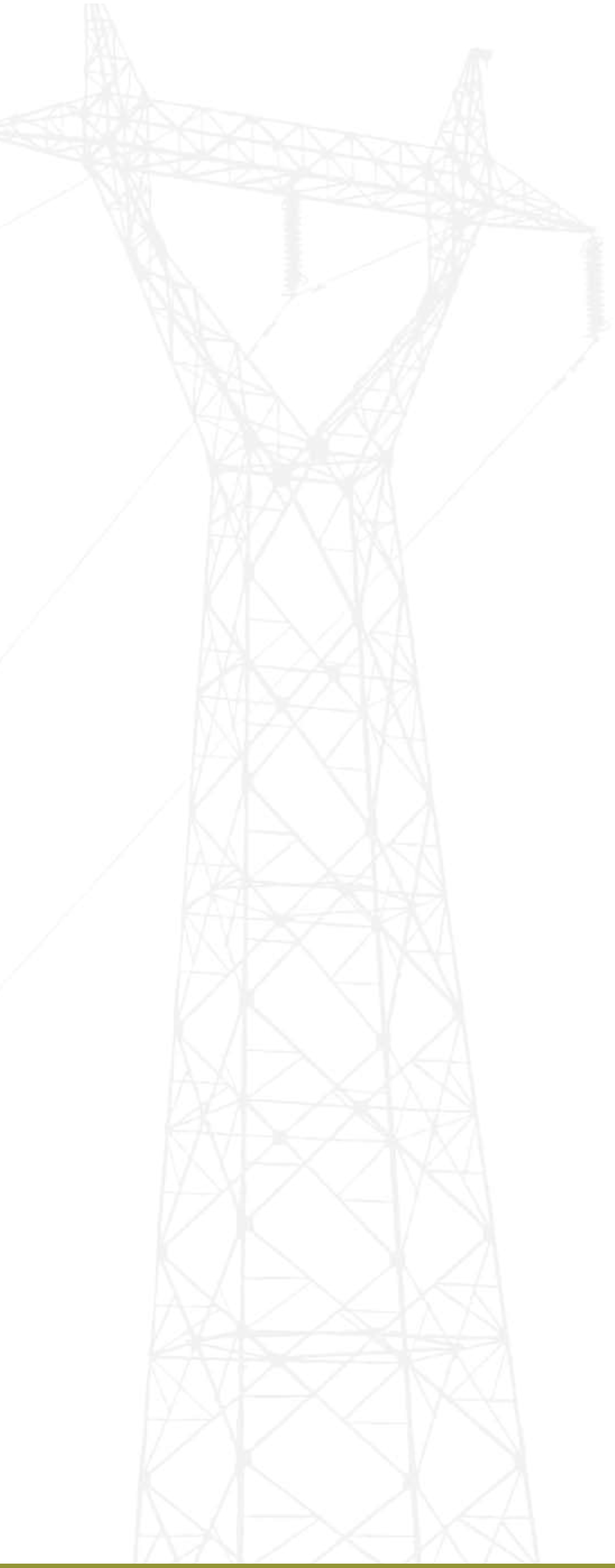
Table 3.7. Summary of the NERC Critical Infrastructure Protection Standards

NERC Standard	Subject Area
CIP-001-1	Sabotage Reporting
CIP-002-1	Critical Cyber Asset Identification
CIP-003-1	Security Management Controls
CIP-004-1	Personnel & Training
CIP-005-1	Electronic Security Perimeter(s)
CIP-006-1	Physical Security of Critical Cyber Assets
CIP-007-1	Systems Security Management
CIP-008-1	Incident Reporting and Response Planning
CIP-009-1	Recovery Plans for Critical Cyber Assets

Additionally, the interviews of 21 electricity service providers (Annex B) included a question about specific security measures that utilities are implementing. The sample results are shown in Table 3.8. While this information can be valuable for trending as a preliminary view, the interview questions need to be focused to better reveal the security culture instituted as more smart-grid capabilities are integrated by system operators, customers, and oversight organizations.

Table 3.8. Sample Security Question from Service Provider Interviews

Have you deployed the following security features? *(Select all that apply)*	Affirmative Responses
a. Intrusion detection	65.0%
b. Key management systems	50.0%
c. Encrypted communications	70.0%
d. Firewalls	95.0%
e. Others (Please describe)	30.0%



4.0 Challenges to Deployment

Among the significant challenges facing development of a smart grid are the cost of implementing a smart grid, with estimates for just the electric utility advanced metering capability ranging up to $27 billion, and the regulations that allow recovery of such investments. For perspective, the Brattle Group estimates that it may take as much as $1.5 trillion to update the grid by 2030 (Chupka et al. 2008). Ensuring interoperability of smart-grid standards is another hurdle state and federal regulators will need to overcome. Major technical barriers include developing economical storage systems; these storage systems can help solve other technical challenges, such as integrating distributed renewable-energy sources with the grid, addressing power-quality problems that would otherwise exacerbate the situation, and enhancing asset utilization. Without a smart grid, high penetrations of variable renewable resources (e.g., wind or solar) may become increasingly difficult and expensive to manage over time as they penetrate to high levels due to the greater need to coordinate these resources with dispatchable generation (e.g., natural gas combined cycle) and demand.

There are a variety of technical challenges facing a smart grid.

Another challenge facing a smart grid is the uncertainty of the path that its development will take over time with changing technology, changing energy mixes, and changing energy policy. Trying to legislate or regulate the development of a smart grid or its related technologies can severely diminish the benefits of the virtual, flexible, and transparent energy market it strives to provide. Conversely, with the entire nation's energy grid potentially at risk, some may see the introduction of a smart grid in the United States as too important to allow laissez-faire evolution. Thus, the challenge of development becomes an issue of providing flexible regulation that leverages desired and developing technology through goal-directed and business-case-supported policy that promotes a positive economic outcome. These and other challenges are discussed in the following sections.

4.1 Technical Challenges

There are a variety of technical challenges facing a smart grid, some of the greatest being developing, implementing, and deploying the array of different technologies required to enable both sides of the meter to communicate in a cost-effective way. One of the most important developments facing a smart grid is AMI technology. These devices help coordinate consumer equipment, as well as receive market signals and adjust household consumption based on a combination of this data and consumer preferences. However, alternatives to such AMI systems do exist. For example, market information such as prices and grid conditions can be decoupled from communication of energy consumption. Thus, the meter can be separate while pricing signals and the like can be transmitted via other public communication mechanisms such as phone, internet, cable, and wireless radio. A decoupled situation can make sense for commercial buildings and industrial uses where energy savings can be significant, while a more traditional bundled AMI package may be more desirable for residential consumers due to its "all-in-one" and "plug-and-play" aspects. Implementing price- and consumption-bundled AMI technology has been estimated to cost as much as $27 billion (Kuhn 2008) and will require very aggressive deployment to meet desired market penetration levels in the near future. Failure to successfully deploy technology that captures bi-directional power flow rather than net consumed energy, as well as dynamic pricing support, such as AMI technology or others, will keep the two sides of the market from properly communicating, and a smart grid will not function as desired regardless of other successful technical deployments, such as distributed generation, demand-response measures, or automated distribution schemes. Without real-time demand-response signals being promptly communicated and quickly addressed by consumers, the power system will not be flexible enough to provide the market transparency or the price signals required for a functioning energy market (FERC 2006a). Further, AMI billing techniques and the machines themselves may require regional customization reducing potential economies of scale in production and deployment. Regional customization may be required because of differences in consumer preferences, aggressiveness of service providers, state and local regulations, and the speed with which smart grid structures and technology change over time. Not all regions are likely to respond identically and may have different needs.

Another significant technical consideration is the impact of high levels of new technology penetration on existing grid infrastructure. Implementing new improvements into the grid, including smart-grid technologies, is pivotal to increasing efficient operations, as the operating efficiency gains from familiar technologies have begun to plateau (DOE/EIA 2007a). In addition, a NERC survey recently ranked the number one challenge to grid reliability as "aging infrastructure and limited new construction." How this aging infrastructure will function when combined with new "smart" technology remains to be seen, particularly with regard to solar, wind, and other forms of distributed generation (NERC 2007). Adding large amounts of variable and distributed generation, for example, requires a fundamental reworking of how the delivery system is managed, power quality is monitored, faults are detected, and maintenance is handled (Pai 2002). This problem is compounded when PHEVs and EVs are considered, potentially making each vehicle its own DG resource and requiring supporting infrastructure to draw, generate, and price power transactions.

However, these technologies themselves face several technical challenges. Cost-effective battery technology continues to be a challenge for PHEVs and EVs and local wind and solar resources. Issues such as discharge, battery life, size and weight are all serious considerations. Additionally, incorporating battery power storage into current automobile frames will require manufacturing adjustments; including systems to monitor the status of the battery (including battery charge and temperature) as well as structural design changes to accommodate the battery itself.

There may be smaller sub-markets that would be better served if differentiated power quality standards existed.

A smart grid is needed at the distribution level to manage voltage levels, reactive power, potential reverse power flows, and power conditioning, all critical to running grid-connected DG systems, particularly with high penetrations of solar and wind power and PHEVs. Advanced voltage regulation, fault-detection, and system-protection practices need to be rethought as an increasing number of DG resources become available. This may require new equipment to identify and isolate DG resources in the event of a fault occurrence (Driesen and Belmans 2006). Another consideration for power-generation systems, distributed or otherwise, is power quality. Customers and the utilities that serve them lack standards for classifying varying qualities of power. Because customers have different power quality requirements (e.g., willingness to accept outages of varying durations, and load sensitivity to power harmonics) and with the increasing availability of DG resources to produce power locally, there may be smaller sub-markets for power that would be better served if such differentiated power standards existed.

Designing and retrofitting household appliances, such as washers, dryers, and water heaters with technology to communicate and respond to market signals and user preferences via home automation technology will be a significant challenge. Substantial investment will be required to implement user-friendly communication equipment which ensures that data storage and transmissions are tamper proof, reliable, and do not corrupt or break down over the lifetime of an appliance. Devices that communicate wirelessly with their facility energy-management systems must broadcast powerful-enough signals, or other technical barriers to effective communication must be resolved. For example, a washer/dryer located in a house's basement attempting to communicate with an energy-management system on the far side of the building will require a stronger signal than a closer device on the ground floor. Therefore communication equipment may need a flexible and dynamic range of broadcast strengths.

Finally, aggregating and sharing system data involves its own concerns; for example, providing infrastructure to communicate wide-area measurement data across the grid requires agreement by the stakeholders on the information network architecture, the supported functions, data exchange interface definitions, and legal conditions for granting use of the data.

Utilities and regulators may need to look at full system life cycle costs and benefits in order to fully justify investments.

4.2 Business and Financial Challenges

The business case for a smart grid needs to be firmly established for deployment decisions to progress. In many situations, individual applications may not be cost effective in isolation, but where common hardware and information network infrastructure can be leveraged to accomplish a number of objectives, the value proposition can become compelling. The business challenge is to prove that out with field deployments. Smart grid investments often require large upfront costs relative to their benefits. However, future benefits may come at small incremental costs. Utilities and regulators may need to look at full system life cycle costs and benefits in order to fully justify added investments. Some of the benefits may come in the form of societal benefits which will need to be clearly understood and evaluated. Payback periods may be longer than stakeholders would like. The service providers, regulators, and ultimately ratepayers are going to have to believe it before such substantial investments are made.

Since the technology and value propositions are emerging, utility companies may be reluctant to expend the significant amount of capital required to move toward a smart grid, especially because expected cost-recovery timelines are only theoretical and have no precedent. Currently, regulated utilities and their flat-rate customers have no risk or reward signal. Regulation makes it difficult for them to raise rates and recover costs, and makes them reluctant to change. Moreover, transmission-planning difficulties may or may not offset revenue losses incurred from reduced transmission; with uncertainty about market penetration of DG these effects can be difficult to model. Without effective cost recovery mechanisms in place, increased market penetration of DG will translate into lost demand for utilities. The uncertainty about market penetration is increased when utilities start to consider the time and cost of training a new smart-grid-skilled labor force (NERC 2007). Thus, utilities seeking to balance costs and operating efficiency will seek to increase asset utilization through the implementation of demand response measures and AMI technology, as opposed to expensive infrastructure upgrades. Further, as more and more devices become "web enabled" and move toward becoming fully "smart" devices, the inclusion of electronics in these devices, as well as the development and maintenance of this hardware and its respective software, will require manufacturers to reevaluate these devices' life-cycle costs. A smart grid will require service providers to operate in new ways and be willing to take reasonable risks for reasonable rewards. Regulators will need to design rules such that customers who do not change are not worse off, but that businesses can pursue advantageous arrangements between participating suppliers and consumers.

Aside from making a strong analytical business case with existing distribution models, the first few successful deployments of these new "smart" technologies will be pivotal to ensuring deep market penetration. Not all of these technologies are necessarily complementary. For example, when metering residential customers, drive-by and walk-by meters (AMR) are considered a competing technology and currently are out-shipping AMI products. Other than the more-convenient data gathering over traditional meters, AMR meters offer very few to none of the benefits and functions necessary to enable residential customers to meaningfully participate in a smart grid. However, implementing smart-grid technologies is daunting; the cost to implement AMI technology alone has been forecast between $19 and $27 billion (Kuhn 2008). Customers desire good value for the investments reflected in their power bills and they may want more options to manage their energy usage and bills, especially during a rate increase.

Data from wide-area measurement systems could have eliminated the $4.5 billion in losses as a result of the 2003 blackout of the northeastern U.S. and Canada.

While utilities must be able to recover their investment costs, the potential savings from some of these technologies is considerable. For example, use of data from wide-area measurement systems (WAMS), including synchro-phasor measurements, could have mitigated or even avoided the estimated $4.5 billion in losses suffered by over 50 million people in the 2003 blackout of the northeastern U.S. and Canada (DOE 2004). To fully realize these benefits, high levels of market penetration must be encouraged; to accomplish this, new technologies will need simple, streamlined user interfaces, "plug-and-play" setups, and cost models that accurately forecast a reasonable payback period for newly developed and installed technologies for both utility companies and consumers, followed by reports on actual and successful deployments. Prior to successful deployments, important questions remain, including identifying winners and losers with bulk system reliability, evaluating those losses and gains, and how reasonable investments are recouped.

As consumer participation increases, a higher level of distributed-generation resources are expected to become available (Eynon 2002). The costs of making these DG resources dispatchable are estimated to be high and vary significantly between utilities. Storing energy generated by DG resources will continue to be a problem until a cost-effective, low-maintenance solution is introduced. Trends suggest this might be done with highly efficient batteries or by pre-heating and cooling buildings. Until then however, viable payback strategies, such as storing generated power during off-peak hours and selling it back into the grid during high-price on-peak hours, will not be feasible. The lack of cost-effective, low-maintenance batteries is a particular hindrance for renewable energies such as solar and wind generation, because their generation varies over time and may not match demand patterns.

Lastly, consumer concerns about hybrid electric vehicles including price, insufficient power, and dependability will need to be addressed by PHEV and EV manufacturers. The cost to convert a hybrid vehicle to a PHEV is currently considered prohibitive; it can vary between six and eight thousand dollars and consumers may consider the payback period too long. Because of these concerns, PHEVs will be unlikely to penetrate all markets, leaving heavy-duty and long-range vehicles, such as semi-trucks, and high-performance vehicles such as sports cars requiring contemporary infrastructure, such as gas stations, while PHEVs and EVs require new supporting infrastructure, such as charge stations. Economies of scale for these services may or may not exist.

5.0 Recommendations for Future Reports

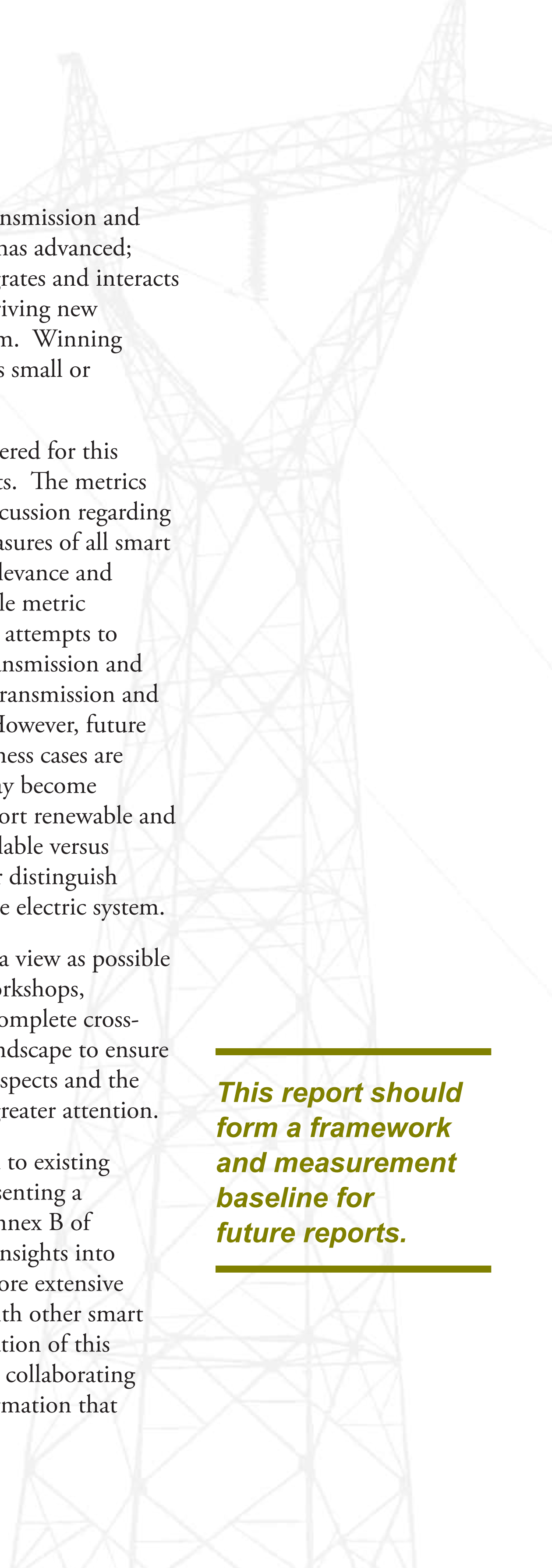
The transition toward a smart grid has made advances within the electric transmission and distribution infrastructure as information technology and communications has advanced; however, recent visions of an electric system that not only services, but integrates and interacts with its use, generation, and storage in factories, businesses, and homes is driving new business and policy models and the technology deployments to support them. Winning directions are only emerging making calibration of potentially useful metrics small or otherwise difficult to measure.

As the first in a series of biennial smart-grid status reports, information gathered for this report should form a framework and measurement baseline for future reports. The metrics identified are indicators of smart grid deployment progress that facilitate discussion regarding the main characteristics of a smart grid, but they are not comprehensive measures of all smart grid concerns. Because of this, they deserve to be reviewed for continued relevance and appropriate emphasis of major smart grid attributes. For example, a desirable metric considered for reporting in this report is smart grid cost savings. The report attempts to address cost savings through capacity factors [Metric 14] and generation, transmission and distribution efficiencies [Metric 15], subject to non-deteriorating trends in transmission and distribution system reliability [Metric 10] and power quality [Metric 17]. However, future reports should consider improvements to this approach. As smart grid business cases are developed and gain acceptance, a new cost savings or value added metric may become apparent. Also, this report describes the flexibility of the smart grid to support renewable and non-renewable generation sources [Metric 7] while emphasizing the controllable versus variable aspects of distributed generation. Future reports may wish to better distinguish progress on renewable generation as well as the environmental impacts of the electric system.

In addition, the status of smart grid deployment should project as balanced a view as possible across the diverse stakeholder perspectives related to the electric system. Workshops, interviews, and research into smart grid related literature needs to reflect a complete cross-section of the stakeholders. Future reports should review the stakeholder landscape to ensure coverage of these perspectives. In particular, the smart grid environmental aspects and the electricity consumer perspectives are important areas that arguably deserve greater attention.

This report should form a framework and measurement baseline for future reports.

Given the time period for developing the report, investigation was restricted to existing literature research and interviews with 21 electricity-service providers, representing a cross-section of organizations by type, size, and location (see Table B.1 in Annex B of this report). Further research is needed to better gage the metrics and gain insights into deployment directions, as well as engage the other stakeholder groups. A more extensive interview process can facilitate gathering this information. Coordination with other smart grid information collection activities whose products can be used in the creation of this report should also be supported. For example, the Department of Energy is collaborating with other organizations to create a clearinghouse of smart grid related information that should be useful for this report.



In addition, future reports require the development of assessment models that support those metrics that are difficult to measure, particularly regarding progress on cyber-security and automation-system interoperability related to open architecture and standards. Other models and tools to measure smart grid progress may also be useful.

Besides reviewing the progress of measurements to the metrics identified in this report, future reports should consider addressing the following potential improvements:

- Track significant smart grid demonstration and deployment projects.
- Review progress toward resolving smart grid challenges, identify new challenges, and describe places where opportunities to advance smart grid concepts are taking place.
- Track the evolvement of legislative and regulatory decisions and structures to describe how government agencies are embracing smart grid objectives and are working on paths that enable and support smart grid advancement.
- The sixth characteristic in the table is a merger of the Smart Grid Implementation 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. Though this report found that the same metrics substantially contribute to both of these concerns, future reports may find it advantageous to keep these characteristics separate.
- Support a glossary of terms related to smart grid deployment status.

Further recommendations specific to each metric can be found in Annex A, which presents the detailed results of investigation into the metrics. The end of each metric description includes a subsection on metric recommendations. Future reports should include a review of these recommendations in addition to those summarized above.

A final consideration for future reports on the status of smart grid deployments is perhaps more of a warning; attempts to be comprehensive about all things related to a smart grid can overwhelm the investigation effort and threaten to create so much material that the report compromises its ability to convey the major aspects of smart grid progress. Care should be taken to avoid the tendency to proliferate the number of metrics. In deciding if a new metric is merited, consideration should be given to how it fits with the other metrics, if a previous metric can be retired, and the strength of a metric's contribution to explaining the smart grid progress regarding the identified characteristics.

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