Overview of the Smart Grid—Policies, Initiatives, and Needs

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Executive Summary

This research paper is a technical overview of Smart Grid technologies and how these technologies are being implemented around the country and in New England to improve the efficiency of the power grid. It presents a range of views about Smart Grid; describes the mix of technologies Smart Grid comprises; and summarizes various federal, state, and other programs aimed at bringing these technologies into more widespread use.

The *Energy Independence and Security Act of 2007* (EISA) directs federal and state agencies to implement programs that advance the implementation of the "Smart Grid." EISA describes the "Smart Grid" as follows:

> *a modernization of the Nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth*

A fundamental assertion of the EISA Smart Grid is that the existing transmission and distribution (T&D) infrastructure is capable of delivering greater efficiencies, and simply adding more generators and transmission lines is not the sole answer to America's energy needs going forward, as indicated by the National Electrical Manufacturers Association (NEMA) and the Congressional Research Service (CRS):[1]

> *The goal is to use advanced, information-based technologies to increase power grid efficiency, reliability, and flexibility, and reduce the rate at which additional electric utility infrastructure needs to be built.*

The Smart Grid message in EISA is clear—make the existing grid infrastructure as efficient as possible through the use of intelligent, automated supply-side and demand-side devices and legislate business practices that provide incentives for the efficient production, transport, and consumption of electricity across the entire electricity supply chain.

In theory, the expanded deployment of intelligent load and supply devices that can sense and respond (S&R) to various signals (e.g. pricing, grid voltage stability, frequency, etc.) and communicate bidirectionally with utilities and system operators will enable the existing grid infrastructure to deliver greater efficiencies without compromising reliability. Demand-side devices, such as intelligent thermostats, will automatically reduce consumption during high-price periods, while supply-side devices, such as plug-in hybrid electric vehicles (PHEVs) that store energy and communicate directly with the grid, will automatically provide energy during peak periods. A communication framework will ensure that system operators have visibility of and control over the capacity and capabilities of Smart Grid devices to ensure system security and reliability.

An evolutionary process will be required to achieve EISA's Smart Grid vision and real-time distributed control of the electricity grid. Traditional generating, transmission, and demand-response facilities, which are essential for meeting today's reliability requirements and electricity demand, will serve as the starting point and cornerstone for the Smart Grid. It is anticipated that these facilities will

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[1] (1) NEMA, *Standardizing the Classification of Intelligence Levels and Performance of Electricity Supply Chains* (Rosslyn, VA: December 2007). (2) Congressional Research Service, *Smart Grid Provisions in H.R. 6, 110th Congress* (Washington, DC: December 20, 2007). (NEMA-2 and CRS-1)

evolve into a Smart Grid through the addition of intelligent functions that will improve their overall efficiency.

The Smart Grid evolution already is well underway in New England, as demonstrated through several state initiatives and projects within ISO New England. For example, the Remote Intelligent Gateway (RIG) communications equipment is being replaced with standards-based equipment, Eastern Interconnect phasor measurement equipment is being installed, demand-response resources (DRR) are being used to provide ancillary services and capacity, and the Alternative Technology Regulation Pilot Program and the advanced grid simulator are being implemented.

The National Institute of Standards and Technology (NIST) has been directed to lead the development of interoperability standards and protocols that are the "critical-path-enabling" technologies required to achieve the EISA Smart Grid vision. The NIST "Interoperability Framework" will describe the standards and protocols needed by "smart devices" to enable the S&R and communication capabilities required for the automated real-time control of electricity supply and demand. The NIST 2008 work plan calls for the establishment of technical domain expert groups that will be responsible for identifying interoperability issues and leading the development of standards that may become recommendations for adoption by the Federal Energy Regulatory Commission (FERC).

The EISA law contains billions of dollars in financial incentives through 2012 that are available to parties that invest in Smart-Grid-related research, development, and implementation. This has attracted interest from the investment community, the National Electrical Manufacturers Association, and others in the utility industry.[2] Some states, such as Massachusetts and California, are working on legislation to advance the implementation of the Smart Grid.[3]

The challenges facing Smart Grid implementation are daunting, however. The lack of standards and uncertainty over business practices (e.g., cost allocation between transmission and distribution) are just a few of the current issues.[4] The shift from a centrally controlled grid, with relatively large, predictable resources, into a more distributed system that would rely on a greater number of smaller, variable-output resources—that in some cases would have the capability to automatically increase or decrease energy based on real-time information—will add significant complexity to the operation of the bulk power system.[5] New, sophisticated optimization algorithms and control systems that co-optimize existing supply- and demand-side technologies with variable-output renewable resources and automated Smart Grid sense-and-respond devices will be needed. The volume of data is expected to increase exponentially within the Smart Grid, which will require solutions that are more sophisticated than those presently in use. System and capacity planning processes will need to be enhanced significantly, and system operators and planners will require extensive training in new "Smart-Grid-aware" tools and techniques.

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[2] (1) Nick Hodge, "Smart Grid," *Wealth Daily* (June 11, 2008). (2) Eric Hsieh, "Grid Modernization and the 2007 EISA," NEMA presentation (Rosslyn, VA: NEMA, March 10, 2008). (3) Xcel Energy, "Xcel Energy begins work on SmartGridCity in Boulder," (Minneapolis: May 15, 2008); http://www.xcelenergy.com/Company/Newsroom/News%20Releases/Pages/Xcel_Energy_begins_work_on_SmartGridCity_in_Boulder.aspx (accessed November 3, 2008). (Hodge-1, Hsieh-1, and Xcel-2)

[3] (1) Commonwealth of Massachusetts, *Chapter 169 of the Acts of 2008: An Act Relative to Green Communities* (Boston: July 2008). (2) California Public Utility Commission, *Defining the Pathway to the California Smart Grid of 2020* (San Francisco: August 5, 2008). (Mass-1 and CPUC-1)

[4] CRS-1

[5] Variable-output resources include intermittent wind energy, electric energy storage devices, flywheels, and solar resources.

Smart Grid Overview

Over the past few years, the electric power industry, state and federal regulators, government agencies, and academics have been grappling with how to best update the aging electric power infrastructure. The general consensus is that the updated grid not only must secure the future reliability of the power system in light of the ever increasing demand for electricity, but it also must operate with greater efficiency overall. Many viewpoints on how to implement such a strategy, technologically and economically, have been voiced, addressing such topics as what technologies are needed, how these technologies can and should be developed, what standards and protocols are needed as a foundation for this development, what implementation timeframe is most achievable, and how costs should be allocated. These collective discussions and subsequent regulations about the sweeping modernization of the electric power grid have coined this new upgraded and efficient grid the "Smart Grid."

According to the National Electrical Manufacturers Association (NEMA), the primary goal of upgrading today's transmission grid into a Smart Grid is to maximize and manage the power transfer capacity of the grid.[6] This viewpoint seems widespread and clear—squeeze more efficiency out of the existing grid infrastructure through the use of intelligent, automated supply and demand devices and legislate business practices that provide incentives to efficiently produce, transport, and consume electricity across the entire electricity supply chain.

On December 19, 2007, the U.S. *Energy Independence and Security Act of 2007* (EISA) was signed into law.[7] Title XIII of EISA is dedicated to the Smart Grid, which, according to EISA, is a modernization of the country's electric power transmission and distribution (T&D) system aimed at maintaining a reliable and secure electricity infrastructure that can meet the increasing demand for electricity. A fundamental assertion of EISA is that the existing T&D infrastructure is capable of delivering greater efficiencies, and simply adding more generators and transmission lines is not the sole answer to America's energy needs going forward:[8]

> *The goal is to use advanced, information-based technologies to increase power grid efficiency, reliability, and flexibility and reduce the rate at which additional electric utility infrastructure needs to be built.*

The law describes policies, timelines, and specific implementation milestones, and sets out a number of objectives, as follows, which together characterize the Smart Grid that the nation is to achieve:

- Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric power grid
- Dynamic optimization of grid operations and resources, with full cybersecurity

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[6] NEMA-2

[7] United States Congress (H.R. 6, 110th), *Energy Independence and Security Act of 2007* (GovTrack.us database of federal legislation: December 19, 2007); http://www.govtrack.us/congress/bill.xpd?bill=h110-6 (accessed Dec 2, 2008). (U.S. Congress-1)

[8] NEMA-2; CRS-1

- Deployment and integration of distributed resources and distributed generation (DG), including renewable resources[9]
- Development and incorporation of demand response (DR), demand-side resources, and energy-efficiency resources[10]
- Deployment of ‘‘smart’’ technologies (i.e., real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communicating about grid operations and status, and facilitating distribution automation
- Integration of ‘‘smart’’ appliances and consumer devices (e.g., a home air conditioner that is able to be shut off remotely to reduce the demand for electric energy, such as during periods of peak demand)
- Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs), and thermal-storage air conditioning[11]
- Provision to consumers of timely information and control options (i.e., for making decisions about equipment use based on electricity prices)
- Development of standards for communication and interoperability of smart appliances and equipment connected to the electricity grid, including the infrastructure serving the grid
- Identification and lowering of unreasonable or unnecessary barriers hampering the adoption of Smart Grid technologies, practices, and services

In December 2008, DOE’s Electricy Advisory Committee (EAC) issued a draft report that summarized the current status of the Smart Grid and provided a set of seven recommendations to facilitate Smart Grid implementations.[12]

The U.S. Department of Energy (DOE) held a workshop in June 2008 that brought together over 140 representatives from government agencies and the electric power industry to discuss EISA’s

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[9] Distributed generation resources are “behind-the-meter” generators, such as combined heat and power (CHP) systems, wind turbines, and photovoltaic generators that generate electricity on site. Most CHP resources generate electricity from a depletable resource, such as oil or gas, and thus are different from renewable resources (e.g., wind, solar power, or sustainable biomass) that continually are regenerated. The benefit of CHP, however, is that it uses fuel more efficiently because, in addition to generating electricity, it makes use of thermal energy that other types of thermal power plants often waste.

[10] In general, *demand-side resources* are measures that reduce consumer demand for electricity from the bulk power system, such as using energy-efficient appliances and lighting, advanced cooling and heating technologies, electronic devices to cycle air conditioners on and off, and equipment to shift load to off-peak hours of demand. They also include using DG. *Demand response* occurs in wholesale electricity markets when market participants reduce their consumption of electric energy from the network in exchange for compensation based on wholesale market prices.

[11] DOE defines PHEVs as hybrid vehicles that can be driven in electric-only or hybrid modes and be recharged from a standard electric outlet (see below). Thermal storage air conditioning transfers heat generated by an engine (such as in a vehicle) though a coolant loop to precool air that will be used for air conditioning (Delphi Corporation, Troy Michigan; http://delphi.com/news/featureStories/fs_2008_10_10_001/; accessed December 10, 2008).

[12] DOE, *Draft Report on Smart Grid*, Appendix B (Washington, DC: DOE, Office of Electricity, December 2008); http://www.oe.energy.gov/DocumentsandMedia/FINAL__Smart_Grid_12-9-08.pdf (accessed December 18, 2008). (DOE-3)

implications and how to meet its objectives. This workshop produced broad industry consensus on the following Smart Grid characteristics:[13]

- Enables active participation by consumers
- Accommodates all generation and storage options
- Enables new products, services, and markets
- Provides power quality for the range of needs in a digital economy
- Optimizes asset utilization and operating efficiency
- Anticipates and responds to system disturbances in a self-correcting manner
- Operates resiliently against physical and cyber attack and natural disasters

In addition, workshop participants concluded that consistent educational materials and programs are urgently needed to educate regulators and legislative bodies about EISA and its implications.

The implementation and operation of the Smart Grid will affect every type of organization across the electricity supply chain, from regulators to consumers. The Smart Grid portion of EISA provides the strategic direction to address the challenges of an aging grid infrastructure in the face of increasing electricity demand and the added constraints imposed by a number of factors. These factors include the diminishing availability (and rising costs) of fossil fuels, climate change, and other environmental factors (i.e., the need for power plants to comply with air emission regulations and for the states to meet their standards for providing electricity using renewable sources of fuel and comply with the Regional Greenhouse Gas Initiative [RGGI]).[14]

Xcel Energy offers a particularly optimistic definition of Smart Grid:[15]

> *While details vary greatly, the general definition of a smart grid is an intelligent, auto-balancing, self-monitoring power grid that accepts any source of fuel (coal, sun, wind) and transforms it into a consumer's end use (heat, light, warm water) with minimal human intervention. It is a system that will allow society to optimize the use of renewable energy sources and minimize our collective environmental footprint. It is a grid that has the ability to sense when a part of its system is overloaded and reroute power to reduce that overload and prevent a potential outage situation; a grid that enables real-time communication between the consumer and utility allowing us to optimize a consumer's energy usage based on environmental and/or price preferences.*

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[13] U.S. DOE, *Metrics for Measuring Progress toward Implementation of the Smart Grid* (Washington, DC: July 31, 2008). (DOE-7)

[14] ISO New England, *2008 Regional System Plan* (RSP08), Chapter 8 (Holyoke MA: October 16, 2008); http://www.iso-ne.com/trans/rsp/2008/rsp08_final_101608_public_version.pdf. (ISO-NE-2)

[15] Xcel Energy, *A Smart Grid White Paper* (Minneapolis: February 2008). (Xcel-1)

Smart Grid Implementation—Challenges, Issues, and Initiatives

Multiple challenges and issues surround the implementation of the Smart Grid as defined by EISA.[16] Some of the more significant issues are as follows:

- The Federal Energy Regulatory Commission (FERC) and the states cannot agree on how to allocate costs for Smart Grid investments across transmission (federally-regulated) and distribution (state-regulated) systems.
- The lack of consistent standards and protocols for Smart Grid technologies limits grid interoperability (i.e., the sense and respond [S&R] communication capabilities that are required for the automated real-time control of electricity supply and demand).
- The lack of coordination among Smart Grid forums (e.g., GridWise™, Modern Grid, Intelligrid, etc.; see below) has produced different descriptions of the Smart Grid.[17]

FERC and the National Science Foundation (NSF) have identified three primary courses of action needed to support the implementation of a Smart Grid:[18]

- Create new standards, protocols, and optimization methods that efficiently utilize supply resources (i.e., conventional generation, renewable resources, and storage systems) and load-reducing demand resources to maximize reliability and minimize costs in real time and defer capital investments in infrastructure.
- Use government incentives to drive the development and deployment of new Smart-Grid-enabled generation, storage, T&D, and load-response technologies that implement the new standards, protocols, and optimization methods.
- Make the entire transmission and distribution system more efficient, reliable, and resilient by employing intelligent S&R capabilities to dynamically predict, avoid, and overcome problems in real time.

Federal, State, and Industry Initiatives

Efforts are underway to address EISA's Smart Grid issues and move forward on implementation. For example, a Smart Grid Collaborative sponsored by FERC and the National Association of Regulatory Utility Commissions (NARUC) is providing the forum for state and federal regulators to discuss issues and make recommendations for state and federal policies to support the Smart Grid.[19] In

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[16] CRS-1 and DOE-2

[17] (1) GWAC, *GridWise Architecture Council* (Richland, Washington: Pacific Northwest National Laboratory, 2008); http://www.gridwiseac.org/ (accessed October 31, 2008). (2) DOE, The Modern Grid Initiative (Pittsburg: DOE, Office of Electricity Delivery and Energy Reliability, National Energy Technology Laboratory, January 2007); http://www.netl.doe.gov/moderngrid/docs/ModernGridInitiative_Final_v2_0.pdf (accessed November 3, 2008). (3) EPRI, Intelligrid (Palo Alto, CA; 2008); http://intelligrid.epri.com/ (accessed November 3, 2008). (GWAC-1, DOE-8, and EPRI-3)

[18] (1) Jon Wellinghoff, *Efficient Energy Services: Road to the Smart Electric Grid* (Washington, DC: FERC, February 5, 2008). (2) National Science Foundation, *Bridges to the Future: A Vision for Infrastructure in the 21st Century* (Washington, DC: April 10, 2008). (Wellinghoff-2 and NSF-1)

[19] Eric Lightner, "Evolution and Progress of Smart Grid Development at the Department of Energy," presentation at FERC-NARUC Smart Grid Collaborative Workshop (Washington, DC: DOE, July 23, 2008). (Lightner-1)

August 2008, the California Public Utilities Commission (CPUC) held a workshop in preparation of a Smart Grid rulemaking and forthcoming request for proposal (RFP) to assist California in identifying its Smart Grid for 2020 and how to implement it.[20]

Another project is the Electric Power Research Institute (EPRI)'s IntelliGrid initiative, which has developed a utility-centric, technical project framework and engaged in pilot implementations.[21] The Modern Grid Initiative is a DOE-funded effort to enable and accelerate grid modernization, including providing analytic support to DOE-supported demonstration programs.[22] The GridWise™Alliance is a coalition of utilities, technology vendors, and others.[23] Although each of these groups has been conducting research and development toward the same goal (a Smart Grid), their messages can appear to be in conflict or disconnected. Figure 1 depicts some of the numerous groups involved in Smart Grid initiatives. Table 1 summarizes these programs and their project scopes.

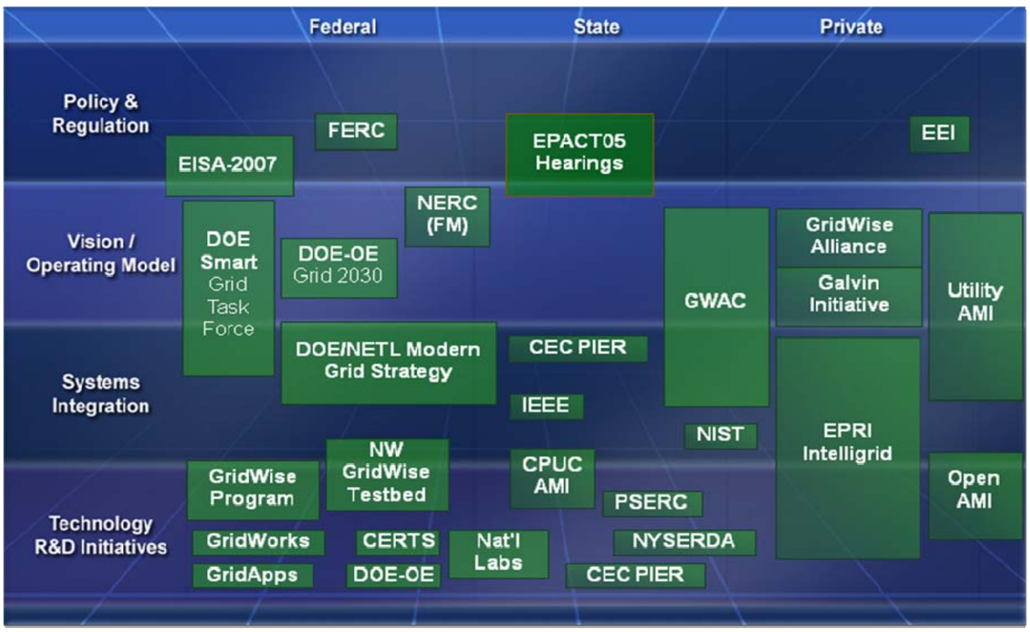

Figure 1: Selected federal, state, and private Smart Grid initiatives.
Source: E. Lightner, 2008 (Lightner-1)

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[20] California Public Utility Commission, *Defining the Pathway to the California Smart Grid of 2020* (San Francisco: August 5, 2008). (CPUC-1)

[21] ERPI-3

[22] DOE-8

[23] The Gridwise™ Alliance (Washington, DC: Gridwise Alliance Inc., 2008); http://www.gridwise.org/ (accessed December 2, 2008). (GWA-1)

Table 1
Selected Participation by Federal, State, and Private Organizations in Smart Grid

Program	Description	Program Scope			
		Policy & Regulation	Vision/ Operating Model	Systems Integration	Technology R&D Initiatives
FERC	Issued several orders, one Notice of Proposed Rulemaking (NOPR), and regulations that aim to advance the use of demand-response programs and provide guidance on implementing demand-response capabilities. FERC also has identified needed actions to support the implementation of the Smart Grid and cosponsored a Smart Grid Collaborative workshop. It also is in the position to recommend the adoption of Smart Grid standards and address how to allocate costs for Smart Grid investments.	X			
EISA 2007	(See above.)	X	X		
DOE Electricity Advisory Committee (EAC)	Provides advice to the Assistant Secretary for Electricity Delivery and Energy Reliability for implementing the *Energy Policy Act of 2005* and EISA and modernizing the Nation's electricity delivery infrastructure. The topics the EAC has addressed in 2008 include electricity supply adequacy, Smart Grid, and energy storage technologies.	X			
DOE Smart Grid Task Force	Established under Title XIII of the Energy Independence and Security Act of 2007 to coordinate Smart Grid activities across the Federal government.		X	X	
GridWise™	Funded by the DOE Office of Electricity Delivery and Energy Reliability, Distribution Area Program, this organization includes the GridWise™Alliance and the GridWise™ Architecture Council (see below),		X	X	X
GridWorks	A program activity in DOE's Office of Electricity Delivery and Energy Reliability (OE) to improve the reliability of the electric power system through the modernization of key grid components, such as cables and conductors, substations and protective systems, and power electronics.				X
Advanced Grid Applications Consortium (GridApps™)	Formed by Concurrent Technologies Corporation in 2005 and sponsored by DOE, GridApps applies best utility technologies and practices to modernize electric transmission and distribution operations.				X

Program	Description	Program Scope			
DOE Office of Electricity Delivery and Energy Reliability (Grid 2030)	Developed during a 2003 meeting sponsored by the DOE Office of Electric Transmission and Distribution, the vision of a group of senior executives representing the electric utility industry, equipment manufacturers, information technology providers, federal and state government agencies, interest groups, universities, and national laboratories of an electric power system that connects everyone to abundant, affordable, clean, efficient, and reliable electric power anytime, anywhere and provides the best and most secure electric services available in the world. This office has an R&D Energy Storage Program.		X		X
DOE/NETL Modern Grid Strategy (MGS)	Seeks to accelerate the modernization of the nation's electricity grid by fostering the development of a common, national vision among grid stakeholders. MGS is also working toward developing a framework that enables utilities, vendors, consumers, researchers, and other stakeholders to form partnerships and overcome barriers. MGS supports demonstrations of key technologies that can serve as the foundation for an integrated, modern power grid.			X	
National Institute of Standards and Technology (NIST)	The (EISA) law assigned NIST the primary responsibility for coordinating the development of a framework to achieve interoperability of Smart Grid devices and systems that includes protocols and model standards for information management.			X	X
Northwest GridWise™ Testbed	A collaborative effort by DOE and several companies to facilitate field demonstrations of Smart Grid technologies being developed by PNNL.				X
Consortium for Electric Reliability Technology Solutions (CERTS)	Created in 1999 and funded by DOE and the California Energy Commission, CERTS researches, develops, and disseminates new methods, tools, and technologies to protect and enhance the reliability of the U.S. electric power system and the functioning of a competitive electricity market.				X
Nat'l Labs	DOE laboratories, such as the Pacific Northwest National Laboratory and the NETL, sponsor programs to improve the planning, operation, and reliability of the electric power system and conduct R&D on Smart Grid technologies, measurement, monitoring, and control.				X
NERC Reliability Functional Model (FM)	Defines the set of functions that must be performed to ensure the reliability of the bulk electric system based on NERC standards. The model also explains the relationship between and among the entities responsible for performing the tasks within each function and provides the foundation and framework upon which NERC develops and maintains its reliability standards.		X		

Program	Description	Program Scope			
California Energy Commission Public Interest Energy Research (CEC PIER) Program	An annual awards program for conducting promising public interest energy research by partnering with research, development, and deployment (RD&D} organizations, including individuals, businesses, utilities, and public or private research institutions.			X	X
Institute of Electrical and Electronic Engineers (IEEE)	The IEEE assists in coordinating information exchange among all the groups working on Smart Grid projects and is developing standards to address interconnection, operations, control, and monitoring capabilities for implementing DG.			X	
California Public Utilities Commission (CPUC) advanced metering infrastructure (AMI)	CPUC sponsored a Smart Grid workshop and will issue an RFP to assist California in identifying and implementing its Smart Grid.			X	X
Power Systems Engineering Research Center (PSERC)	Established in 1994, this association of universities works with the electric power industry to find innovative solutions to the challenges facing the industry and to educate the next generation of power engineers.				X
New York State Energy Research and Development Authority (NYSERDA)	Conducting R&D on advanced technologies that will improve the efficiency and delivery of power for electric customers in New York State. One pilot project is researching upgrades to substations and associated distribution circuits for performing as "intelligent" networks with advanced sensors, field devices, on-line decision-making software and improved communications.				X
Edison Electric Institute (EEI)	Sponsor Smart Grid forums; publish articles,	X			
GridWise™ Architecture Council (GWAC)	An association of experts who seek to articulate guiding principles, or architecture, of a highly intelligent and interactive electric power system and help to identify areas for standardization that allow significant levels of interoperation between system components (see below).		X	X	
NIST projects	Under the direction of NIST, technical domain expert groups are identifying interoperability issues and leading the development of standards and protocols. Numerous organizations across the supply chain are working collaboratively under NIST's direction to formulate the "interoperability framework" (see below).			X	

Program	Description	Program Scope			
GridWise™ Alliance	A consortium of public and private stakeholders with a shared vision of an electric power system that integrates the infrastructure, processes, devices, information and market structure for generating, distributing, and consuming electricity more efficiently and cost effectively to achieve a more resilient, secure, and reliable energy system.		X		
Galvin Electricity Initiative	Founded in 2005 by the former CEO and son of the founder of Motorola, this program applies the concepts of total quality management to the electric power industry, with the goal of developing one or more configurations of a "perfect" power delivery system to meet the needs of the rapidly evolving digital economy and society.		X		
EPRI Intelligrid Consortium	Founded by EPRI in 2001, IntelliGrid seeks to create a new electric power delivery infrastructure that integrates advances in communications, computing, and electronics to meet the energy needs of the future. Its mission is to enable the development, integration, and application of technologies to facilitate the transformation of the electric infrastructure to cost effectively provide secure, high-quality, reliable electricity products and services.			X	X
EPRI Energy Storage and DG Options for Grid Support and Reliability (Project 94.002)	Conducts objective technology assessments, lab tests, field demonstrations, and case studies on electric energy storage (EES) and delivers critical information to utilities to enable them to apply and leverage distributed generation and EES assets. The program also seeks to assist in implementing photovoltaic energy systems and renewable fueled systems.			X	X
Utility AMI	A forum to define serviceability, security, and interoperability guidelines for AMI and demand-responsive infrastructure (DRI) from a utility and energy service provider perspective.		X	X	
Open AMI Task Force	Funded by EPRI to enhance functionality, reduce costs, and foster rapid market adoption of advanced metering and demand-response solutions through the development of an open-standards-based reference design and data model.			X	X

Sources: DOE-4, DOE-5, DOE-8, EEI-1, EnerNex-1, EPRI-3, Lightner-1, NERC-1, NYSERDA-1, and OSGUG-1.

The Gridwise® Interoperability Framework

Over the past few years, several research and development groups have been working on various aspects of an "intelligent" electricity grid. For example, the Gridwise® Architecture Council, formed by DOE, has developed common principles for an "interoperability framework" or "architecture." This framework spans the entire electricity supply chain and provides a logical organization of the standards needed to ensure interoperability between components operating on the Smart Grid.[24] The framework also provides a structure to identify areas of concern and their interdependencies that would need to be addressed.[25] This framework and the numerous groups working on Smart-Grid-related projects would advance EISA's Smart Grid vision and contribute to the widespread implementation of Smart Grid.

Figure 2 depicts the "layers" of an interoperability framework identified by GWAC along with issues that cut across the layers. The organizational, informational, and technical layers, which address such issues as policymaking, understanding semantics, and connectivity, serve to organize the many needed actions to attain interoperability. The cross-cutting issues, such as security, system preservation, and reliability, typically are relevant to more than one layer of the framework and also must be addressed and agreed upon. Figure 3 depicts the important role that an all-encompassing, common interoperability framework provides to enable the complex interactions that would take place among system operators, transmission and distribution companies, market participants, and other electricity stakeholders.

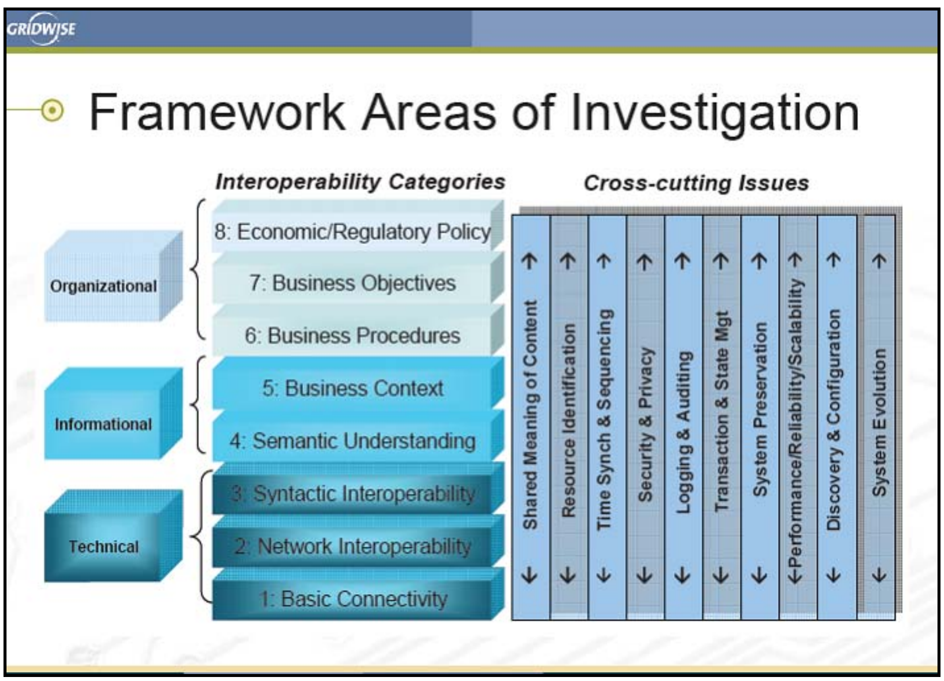

Figure 2: Smart Grid interoperability framework and cross-cutting issues.
Source: The Gridwise™ Architecture Council, 2008 (GWAC-1)

[24] GridWise Architecture Council (Richland, WA: 2008); http://www.gridwiseac.org/ (accessed November 3, 2008). (GWAC-1)

[25] GWAC, *Gridwise® Interoperability Context-Setting Framework*. (Richland, WA: March 2008); http://www.gridwiseac.org/pdfs/interopframework_v1_1.pdf (accessed November 25, 2008). (GWAC-2)

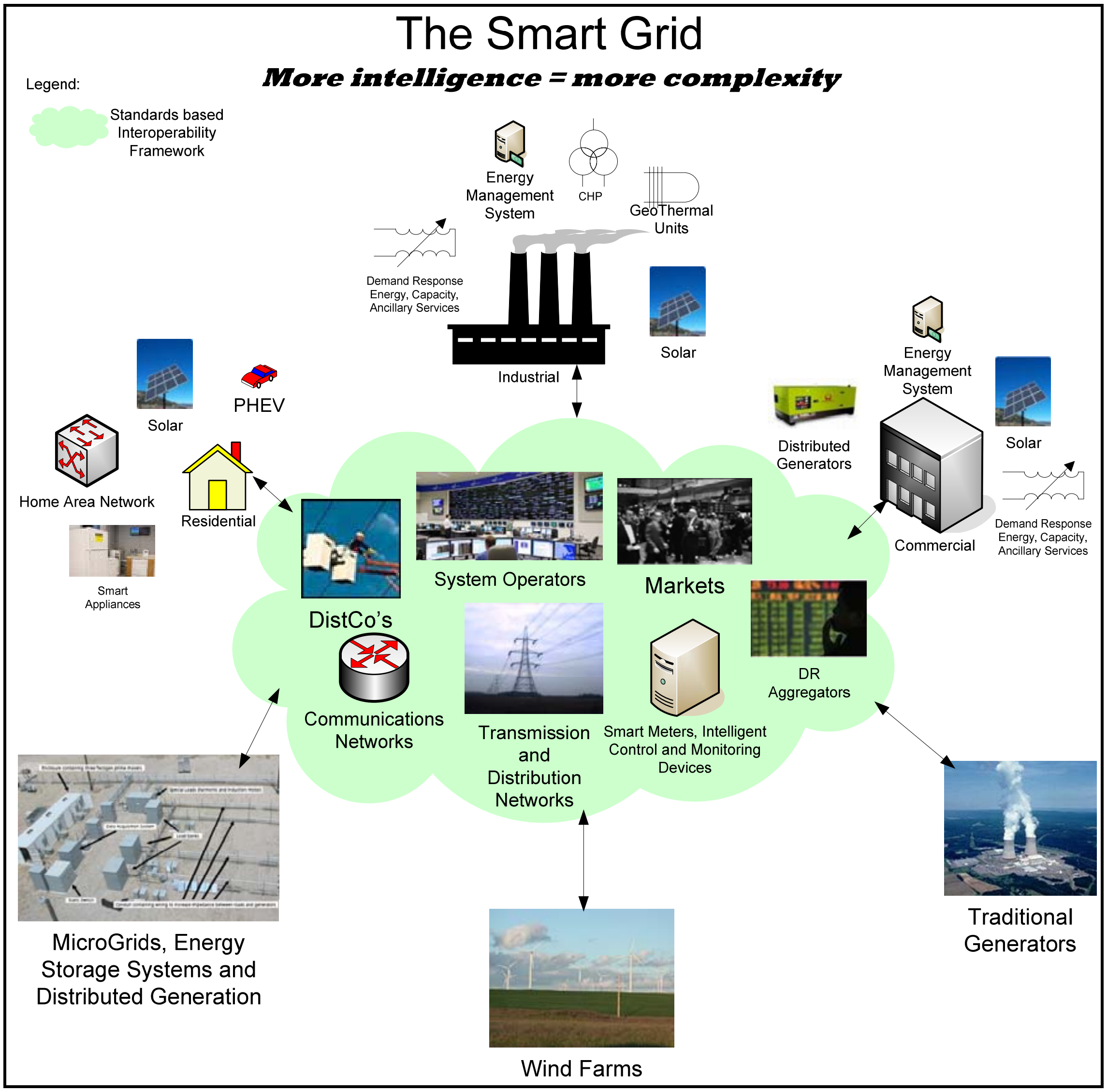

Figure 3: Important role of a standard interoperability framework in the Smart Grid.

Smart Grid Standards and Protocols

One federal government effort to lay the foundation for an interoperability framework is the EISA law charter for NIST to coordinate the development of standards and protocols for Smart Grid "critical-path-enabling" technologies.[26] The standards and protocols for these "smart devices" will enable the development of the S&R and other communication capabilities that are essential for the automated real-time control of electricity supply and demand and the success of the Smart Grid.

[26] National Institute of Standards and Technology, *NIST EISA Smart Grid Coordination Plan* (Gaithersburg, MD: June 2, 2008). (NIST-1)

NIST Domain Expert Groups

The NIST 2008 work plan calls for establishing technical domain expert working groups (DEWGs) that will be responsible for identifying interoperability issues and leading the technical direction and development of standards to ensure interoperability. The DEWGs also are addressing areas that lack standards or require additional standards development, including the following:[27]

- Building-to-grid (B2G) standards
- Industrial-to-grid (I2G) standards
- Home-to-grid (H2G) standards
- Transmission and distribution standards
- Domain interfaces
- Cross-cutting issues

One notable exception from this list is a domain expert group for plug-in hybrid electric vehicles equipped with vehicle-to-grid (V2G) capabilities (see below). This relatively new and promising technology is an area of intense interest within the research and development community and among policymakers, including those at FERC.[28]

Standards Landscape Map

NIST is planning to work with GWAC, domain experts, and others to develop a "Standards Landscape Map" to identify areas where standards already exist to enhance system interoperability and where new or upgraded standards are needed. Table 2 lists several existing technical standards that are expected to provide the foundation for some of these developments.

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[27] NIST-1

[28] (1) Jon Wellinghoff, "Efficient Energy Services Road to the Smart Electric Grid," FERC presentation (Washington, DC: February 5, 2008); http://www.ferc.gov/eventcalendar/Files/20080206075346-Smart-Grid.pdf (accessed November 25, 2008). (2) Jon Wellinghoff and Willet Kempton, *DOE PHEV R&D Plan* (External Draft) (FERC and the University of Delaware: March 2007); http://www.ferc.gov/about/com-mem/wellinghoff/3-30-07-wellinghoff.pdf (accessed November 25, 2008). (Wellinghoff-1 and Wellinghoff-2)

Table 2
Existing Technical Standards for Smart Grid Applications[a]

Standard[b]	Description	Application
IEC 61970[c]	Common information model	Data exchange
IEC 61850	Communication networks and systems in substations	Grid management
IEC 61968	System interfaces for distribution management	Network management
ANSI C12[c]	Revenue quality metering standards	AMI
Open AMI	Group of standards for advanced metering infrastructure and home-area networks	AMI
IEEE 1547[c]	Monitoring and control of distributed resources interconnected with electric power systems	Demand response Distributed generation/ storage
ASHRAE[c] BACnet	Data communication protocol for building automation and control networks	Demand response Energy efficiency DSM

(a) Sources: Lightner-1 and DOE-3

(b) May or may not represent "official" standards produced by a recognized standards body.

(c) *IEC stand*s for International Electrotechnical Commission. ANSI stands for the American National Standards Institute. ASHRAE stands for the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Numerous organizations across the supply chain are now working collaboratively under NIST's direction to identify and develop the Smart Grid standards and protocols needed within the interoperability framework. The recently formed Intelligent Grid Coordinating Committee (IGCC) of the IEEE is acting as a clearinghouse for information and will assist in coordinating information exchange among all the groups working on Smart Grid projects.[29]

EISA Smart Grid Timeline, Target Dates, and Project Status

Although a large gap exists between the commercial availability of Smart Grid technologies and the standards needed to implement the EISA Smart Grid, several areas of opportunity exist today to begin the implementation of Smart Grid initiatives. Table 3 lists a timeline for Smart Grid initiatives, deadlines contained in EISA, and the status of each initiative.

[29] Erich Gunther, "Smart Grid Development, Interoperability and Coordination," presentation at the *IEEE 2008 Transmission and Distribution* show (Chicago: IEEE, April 23, 2008). (Gunther-2)

Table 3
EISA Smart Grid Initiatives and Deadlines

Initiative	Target Date	Status
NIST begins to develop an interoperability framework that includes protocols and model standards for information management to achieve interoperability of Smart Grid devices and systems.	February 2008	Success
DOE establishes the Smart Grid Advisory Committee and Smart Grid Task Force.	March 2008	Success
Smart Grid Task Force reports to Congress on the status of Smart Grid deployments nationwide and regulatory or government barriers to continued deployment.	December 2008	Completed January 2009
NIST publishes progress report on recommended or consensus standards and protocols in the interoperability framework.	December 2008	Pending
DOE publishes procedures for reimbursement of qualifying Smart Grid investments.	December 2008	Pending
DOE studies and reports on the effect of private distribution wire laws on the development of combined heat and power (CHP) facilities.	December 2008	Pending
DOE reports to Congress identifying existing and potential impacts of the deployment of Smart Grid systems on improving the security of the nation's electricity infrastructure and operating capability.	June 2009	Pending
DOE develops advanced R&D of power grid digital information technology.	None	Unknown
DOE establishes a regional Smart Grid demonstration initiative that specifically focuses on demonstrating advanced technologies for use in power grid sensing, communications, analysis, and power-flow control.	None	Unknown

Smart Grid Projects in New England

Table 4 lists a sampling of the Smart Grid initiatives indentified within the New England states.

Table 4
Smart Grid Initiatives in New England

Description	Reference
The Massachusetts *2008 Act Relative to Green Communities*, signed into law in July 2008 ,contains mandates for utilities to file plans for Smart Grid pilot projects by April 1, 2009.	July 2, 2008 http://www.mass.gov/legis/laws/seslaw08/sl080169.htm
Rhode Island Senate Bill S 2851 contains an amendment to implement "smart meters" and to demonstrate Smart Grid implementations.	http://www.rilin.state.ri.us/BillText08/SenateText08/S2851Aaa.pdf
NSTAR's Marshfield, Massachusetts, Energy Challenge is a three-pronged approach of promoting energy efficiency, advanced demand-response thermostats, and solar power.	March 30, 2008 http://www.boston.com/news/local/articles/2008/03/30/marshfield_to_be_test_site_for_new_energy_saving_plan/
Southern New Hampshire University is testing a real-time controller for PHEVs that can respond to price signals from the five-minute electricity grid spot market. The vehicles will make money selling power into the grid during high-load conditions by responding to five-minute spot market price signals, for example, $0.25/kilowatt-hour (kWh).	May 9, 2008 http://www.nhbr.com/apps/pbcs.dll/article?AID=/20080509/INDUSTRY17/437649673/-1/Industry17
Connecticut Governor Jodi Rell asked the chairman of the Department of Public Utility Control (DPUC) to work closely with utilities and automakers to prepare for the arrival of electric vehicles into the market.	July 29, 2008 http://www.govtech.com/gt/381806
Central Vermont Public Service CVPS Smart Power is a collaborative program between CVPS and the Vermont Department of Public Service (DPS).	August 1, 2008 http://www.cvps.com/AboutUs/news/viewStory.aspx?story_id=190
Connecticut announces the Solar Lease program to help low- and moderate-income residents acquire photovoltaic solar power systems.	August 20, 2008 http://www.sustainablebusiness.com/index.cfm/go/news.display/id/16603
Connecticut Light and Power currently is engaged in an advanced metering infrastructure project.	http://www.amra-intl.org/symposium/2007Papers/Papers/4EScott.pdf

Current Smart Grid Projects at ISO New England

Several Smart Grid initiatives may have an impact on ISO New England and market participant activities, such as control room operations, planning, and settlements. The NIST initiative to develop an interoperability framework could likely have the greatest impact given that FERC could recommend the adoption of the standards identified in the framework, as indicated within the NIST Smart Grid Work Plan for 2008.[30] This could require the ISO to upgrade its market rules to account for the use of various types of Smart Grid equipment, incorporate the effects of Smart Grid into the electricity use forecasts, and update the co-optimization algorithms needed for the real-time operation of the system.

[30] NIST-1

The ISO is implementing several Smart Grid projects in line with EISA's vision. One initiative that already is being implemented in New England is demand response. The North American Energy Standards Board (NAESB) is developing demand-response standards, and FERC and the North American Electric Reliability Corporation (NERC) have issued regulations that provide guidance to implement DR capabilities. An ISO New England pilot program on using demand-response resources (DRR) for ancillary services (e.g., reserves) is just beginning, and the region's ongoing demand-response programs continue to deliver results. In addition, the ISO's Forward Capacity Auction (FCA) for 2010 produced approximately 1,100 new "negawatts" of capacity obligations from demand resources (representing almost two-thirds of the new capacity that will come online in 2010).[31] Table 5 lists the ISO's current demand-response programs, as well as other types of Smart Grid projects. While some of the demand-response programs are well underway, some of the R&D projects will take time to mature. (See below for more information about the development of demand-response resources and technologies.)

Table 5
ISO New England Smart Grid Projects

Project	Description
Integration of demand resources within ISO/Regional Transmission Organization (ISO/RTO) operations	A project to develop real-time dispatch and telemetering capabilities for demand-response resources with capacity obligations for 2010 obtained via the Forward Capacity Market. See http://www.iso-ne.com/committees/comm_wkgrps/othr/dritwg/mtrls/index.html.
Demand-Response Reserves Pilot Program—Phase II	Thirty-Minute Real-Time Demand-Response Program to provide load-reduction capability of less than 5 megawatts (MW). See http://www.iso-ne.com/genrtion_resrcs/dr/sp_proj/pilot/index.html.
Demand-response programs	Consists of reliability programs where customers respond to system reliability conditions, as determined by the ISO New England control room, and price programs where customers respond to wholesale spot prices, as determined by the market. See http://www.iso-ne.com/genrtion_resrcs/dr/index.html.
RIG replacement project	A project to replace the proprietary Qualitrol Remote Intelligent Gateway (RIG) master communications equipment located at ISO New England with equipment that supports interfacing with industry-standard equipment for substation automation. See http://www.iso-ne.com/genrtion_resrcs/nwgen_inter/elec_disp/a10_iso_ presentation_02_12_08.ppt.
Alternative Technology Regulation (ATR) Pilot Program	An 18-month program in response to FERC Order 890 that will test the impact of nongenerating technologies on the Regulation Market and allow owners of ATR resources to evaluate the technical and economic suitability of their technologies as possible regulation-service sources. The ATR Pilot Program is limited to 13 MW of participation, and no single entity will be allowed to provide more than 5 MW of regulation service. Eligible nongenerating resources include flywheel technology, battery technology, and certain demand-response resources. Resources must be commercially on line by November 1, 2009. See http://www.iso-ne.com/support/faq/atr/index.html.

[31] RSP08, Section 5.1.3 (ISO-NE-2)

Project	Description
North America Synchrophasor Initiative (NASPI)	A program sponsored by DOE's PNNL to improve the planning, operation, and reliability of the electric power system through wide-area measurement, monitoring, and control. The mission of the group is to create a robust, widely available, and secure synchronized data measurement infrastructure for the interconnected North American electric power system with associated analysis and monitoring tools. Under NAPSI, over 40 synchronized phasor-measurement units (PMU) have been dispersed across the eastern United States. A super-phasor data concentrator (super PDC) collects real-time phasor data at the Tennessee Valley Authority, which makes tools available to view and analyze the information. ISO New England has installed two PMUs and is planning to install more as part of this project. Control room operators will be able to view the accurate phasor information, which will assist in understanding system dynamics in real time. The phasor data also will be integrated with the state estimator (SE) to improve the performance of the SE.
Situational awareness (SA)/visualization	The ISO's implementation of advanced alarm management and wide-area power system visualization, for example, and new technologies, such as PMUs, interactive 3D, and Google Earth, to help operators better assess and visualize system operation states. System operators' situational awareness and monitoring capability is important to the reliability and security of power systems. Many advanced technologies in SA and visualization exist, although they have not been used in the power industry.
Real-time stability analysis and control	A planned automated day-ahead and real-time (voltage and transient) stability assessment to improve the accuracy of stability analysis and control options available to operators when instability conditions occur. Currently, the stability limits used in daily operations are based on off-line studies, which are conservative and have numerous uncertainties.
System black start and restoration automation	A planned on-line decision-support tool to help operators restore the system in real time. System restoration primarily is based on off-line planning and manual work by system operators. An actual blackout may have different characteristics from the off-line studied system.
Advanced Grid Simulator project	A project to create a simulator based on the current dispatcher simulator, which will simulate the operational characteristics of the grid of the future. It is envisioned that this tool will be built using a 2020 calendar year network model of the New England grid and will analyze the operational impacts of various alternative resources and Smart Grid technologies tied to the grid. This tool also could be used to conduct economic analysis at a higher level of detail than what was done in the ISO's *2007 Scenario Analysis*.[32]

The ISO also is conducting a number of other activities related to Smart Grid research, education, standards development, and planning, as shown in Table 6. These activities aim to enhance the ISO's understanding about Smart Grid technologies; educate market participants, regulators, legislators, and others in New England and across the industry about Smart Grid; develop standards; and implement Smart Grid technologies.

[32] ISO New England, *New England Electricity Scenario Analysis*: (Holyoke, MA: August 2, 2007); http://www.iso-ne.com/committees/comm_wkgrps/othr/sas/mtrls/elec_report/index.html. (ISO-NE-4)

Table 6
ISO New England Activities Supporting Smart Grid Research, Education, Standards Development, and Implementation

Activity Type	Description
Research	• Monitor DOE, FERC, and NIST activities pertaining to the Smart Grid • Monitor Smart-Grid-related activities of standards-making bodies, specifically IEEE, IEC, NERC, and NAESB • Monitor trade journals and industry Web sites for important developments pertaining to Smart Grid • Participate in industry consortia and workshops (e.g., Gridwise Constitutional Convention, Modern Grid Initiative) • Share information with other ISOs and RTOs
Education	• Deliver two presentations at the Electric Utility Consultants, Inc. (EUCI) Smart Grid conference in Phoenix, September 2009 • Make presentation to the Massachusetts Department of Public Utilities (DPU) in support of the *Green Communities Act* • Provide information to interested parties on request • Also made keynote presentation at Grid-Interop 2008 conference in Atlanta • Distribute this research paper
Standards development	• Develop measurement and verification standards for demand response within NAESB • Participate in NIST Smart Grid domain expert working group activities • Lead the development of enterprise architecture standards within the ISO/RTO Council.[a] Development of these standards has been transitioned to CIGRE (International Council on Large Electric Systems)
Planning	• Conduct wind integration studies within New England

(a) The ISO/RTO Council (IRC) is an association of the nine functioning North American ISOs and RTOs. IRC members collaborate to develop effective processes, tools, and standard methods for improving competitive electricity markets across North America.

Development of Smart Grid Technologies

Although technological innovation already is changing the nature of the grid, the end-state Smart Grid (as envisioned by EISA) is still largely an abstract concept of what could exist. To come to fruition, many of the ideas contained in the EISA Smart Grid vision require extensive research and development, some of the standards and technologies needed to implement the Smart Grid have yet to be designed, and some of the existing technologies necessary to create the Smart Grid are not yet commercially available. The need to accomplish EISA's Smart Grid objectives, along with the billions of dollars in financial incentives contained in EISA, has generated significant interest from academia, equipment manufacturers, software vendors, venture capitalists, energy companies, and other energy industry stakeholders and government entities to develop and implement Smart Grid capabilities and technologies.[33] This will result in needed investment in R&D, standards development, and manufacturing. As new technologies become available and fully deployed, supply side and demand side, they will improve the efficiency that can be extracted from the power grid.

[33] Hodge-1; NEMA-1; Xcel-2

To develop the Smart Grid, system designers and operators, equipment manufactures, and others also must take into consideration the expectation by electricity consumers that the Smart Grid must provide the same, or perhaps a higher, level of reliability compared with today's grid. Thus, investment in the core foundational infrastructure of the existing transmission system and generation and demand resources that are "keeping the lights on today" will continue to be necessary to preserve the integrity of the bulk power system into the foreseeable future.

DOE Technology Roadmap

In 2004, DOE published a "technology roadmap" for developing Smart Grid technologies, as shown in Table 7. This "map" appears to be consistent with advances observed to date and Smart Grid activities currently underway.[34]

Table 7
U.S. DOE "Technology Roadmap"
for Developing and Implementing "Critical" Smart Grid Technologies[(a)]

	Phase 1 Present to 2010	Phase 2 2010 to 2020	Phase 2020 to 2030
Technology Type	**Design and Testing**	**Technology Development and Market Acceptance**	**Manufacturing and Scale-Up**
Advanced conductors	• Develop tools to make better use of widely used existing assets. • Field test composites. • Accelerate materials RD&D.	• Prove lower-cost underground techniques. • Field test and demonstrate advanced conductors demonstrated • Continue materials RD&D.	• Conduct local, regional, and North American deployment.
High-temperature superconductors	• Develop and make available first commercial, first-generation high-temperature superconducting (HTS) cables at transmission voltages. • Accelerate deployment of first-generation HTS power applications (transformers and synchronous condensers). • Scale up manufacturing process of low-cost, second-generation HTS wire. • First demonstrate transmission cable using second-generation HTS wire.	• Commercially deploy first-generation HTS transmission cables, including regional power hubs. • Demonstrate second-generation HTS transformers and fault-current limiters. • Discover and develop next-generation HTS wire. • Expand international applications.	• Conduct national deployment of Interconnection of regional HTS hubs.
Electric storage	• Field test advanced storage devices. • Accelerate storage RD&D.	• Expand demonstrations and deployment. • Expand international applications. • Continue storage RD&D.	• Conduct local, regional, and North American deployment.
Distributed intelligence and smart controls	• Make progress on protocols and standards. • Field test prototypes. • Accelerate RD&D.	• Approve national and international standards. • Expand demonstrations and deployment. • Continue RD&D.	• Conduct local, regional, and North American deployment.
Power electronics	• Deploy advanced devices. • Accelerate RD&D.	• Expand demonstrations and deployment. • Continue RD&D.	• Conduct local, regional, and North American deployment.

(a) DOE, 2004 (DOE-10)

[34] DOE, *National Electric Delivery Technologies Roadmap* (Washington, DC: 2004). (DOE-10)

As shown in Figure 4, the technologies required for a Smart Grid implementation cut across all areas of the electricity supply chain and have varying levels of intelligence. Some devices are "smarter" than others, which has prompted NEMA to propose a classification scale with six intelligence levels: level 0 devices, which have no intelligence (e.g. a wire or cable) to level 5 devices, which are capable of inter-control-area coordination).[35] NEMA asserts that this scale will allow regulators to measure the degree of adoption of Smart Grid technologies within a control area or region and provide a yardstick for industrywide benchmarking of Smart Grid capabilities.

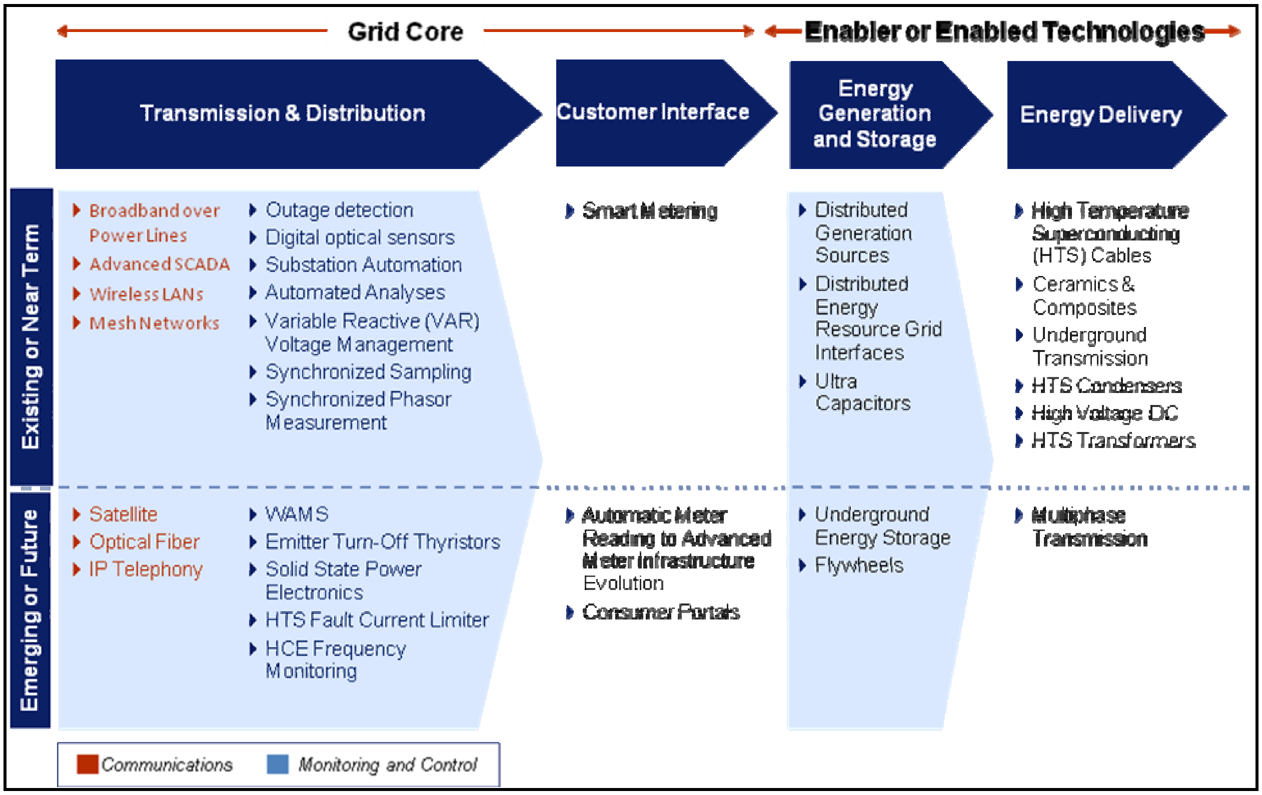

Figure 4: Existing and emerging Smart Grid communications and monitoring and control technologies in the electricity supply chain.

Note: SCADA refers to supervisory control and data acquisition. LANs refers to local-area networks. IP refers to Internet protocol. WAMS refers to wide-area monitoring systems. HCE refers to high current effect.

Source: EEI, 2007 (EEI-2)

Supply-Side Technologies

Smart Grid generation technologies address governor response; regulation; real-time energy balancing; reserve augmentation; intra-day production shifting; and diurnal, weekly, and seasonal leveling.[36] Other supply-side Smart Grid technologies under development include various types of distributed generation," microgrids," and electric energy storage.

[35]NEMA, *Standardizing the Classification of Intelligence Levels and Performance of Electricity Supply Chains* (Rosslyn. VA: December 2007). (NEMA-2)

[36] DOE-3, Table 2-3.

Distributed Generation

A 2009 research project conducted by EPRI provides specific solutions, information, and guidelines for using DG and electricity storage systems for grid asset management.[37] The goal of this project is to provide key information to enable utilities to apply, deploy, and leverage DG and EES systems for managing grid assets and supporting system reliability by 2010 in a Smart Grid configuration.

High-efficiency and renewable distributed generation includes the deployment of high-efficiency and renewable generation sources at residential, commercial, and industrial facilities.[38] These technologies include such commercially available technologies as photovoltaics, microturbines, reciprocating engines, and combustion turbines. Future technologies will include advanced low-cost solid-state photovoltaics, fuel cells, and vehicle-based electricity storage (see below). DG technologies offer significant benefits for addressing locational energy needs, but significant challenges and issues must be overcome before widespread deployment will be practical.

One of the primary technical obstacles for the implementation of DG is the lack of official standards and, hence, the lack of standard products. The IEEE is working on developing a set of standards to address interconnection, operations, control, and monitoring capabilities that are needed for widespread DG implementation to occur (see Table 5).[39] The IEEE 1547.3 standard, which was completed in December 2007, provides a foundation for monitoring and control. Other critical-path standards are in draft form and address islanded operation, requirements for interconnecting dispatchable electric power sources with a capacity of more than 10 megavolt-amperes (MVA) to a bulk power transmission grid, and guidelines for distribution-level subnetworks (standards 1547.4, 1547.5 and 1547.6, respectively).

Other difficult challenges exist specific to different types of distributed generators, for example wind farms, which frequently require expensive capital investments in transmission lines to connect the typically remote location of the farms to the grid and load centers.[40] Fossil-fuel-based DG resources frequently are required to meet federal or state air quality emission standards, which can be cost prohibitive and may prevent their operation when they are most needed.[41] For example, in the summer months during peak periods, when DG resources are most beneficial and energy prices are high, some fossil-fuel-based DG resources may be prohibited from running because of poor air quality and high smog conditions that typically accompany hot humid weather.

Microgrids

A *microgrid* is an aggregate of small loads and distributed energy resources (DERs) (i.e., distributed generation), which operate as a single system that provides both power and heat.[42] A microgrid's

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[37] EPRI, *2009 Research Portfolio: Energy Storage and Distributed Generation Options for Grid Support and Reliability* (Project 94.002) (Palo Alto, CA: 2008). (EPRI-1)

[38] Science Applications International Corporation (SAIC), *San Diego Smart Grid Study Final Report* (San Diego: October 2006). (SAIC-1)

[39] Wayne Shirley, "IEEE 1547-1: The DG Interconnection Standard," presentation at a Utah Public Service Commission workshop (December 4, 2007). (Shirley-1)

[40] DOE, *20% Wind Energy by 2030 Increasing Wind Energy's Contribution to U.S. Electricity Supply* (Washington, DC: DOE, May 2008). (DOE-1)

[41] Joel Bluestein, et al., *The Impact of Air Quality Regulations on Distributed Generation* (Golden, CO: DOE National Renewable Energy Laboratory, April 10, 2002). (Bluestein-1)

[42] SAIC-1

distributed energy resources contain power electronics and can include high-frequency AC (microturbines) and DC systems (e.g., solar, fuel cells).

DERs in a microgrid must operate as a single aggregated system that can present itself to the bulk power system as one "control area" that meets the local needs for reliability and security. The integrated DERs must be able to provide sufficient and continuous energy to a significant portion of the demand internal to the microgrid, and they must possess independent controls that can island and reconnect with the electric power grid with minimal service disruption.[43] This type of configuration provides flexibility in configuring and operating the power delivery system and the ability to optimize a large network of load, the local DERs, and the broader power system.

Microgrids can serve load from small individual facilities through entire substations. Microgrid ownership also can vary and can range from end-use customers to landlords, municipal utilities, and investor-owned utilities.

Microgrid Benefits

DOE research on whether viable business cases for microgrids could exist, assuming the technical and regulatory barriers were removed, found that microgrids potentially could provide six complementary values, as follows:

- **Reduced cost**—reducing the cost of electric energy and managing price volatility
- **Reliability**—improving customer and system reliability
- **Security**—increasing the power delivery system's resiliency and security by promoting the dispersal of power resources
- **Green power**—helping to manage the variable nature of renewables and promoting the deployment and integration of energy-efficient and environmentally friendly technologies
- **Power system**—assisting in optimizing the power delivery system, including the provision of services
- **Service differentiation**—providing different levels and quality of service to customer segments at different price points

Because microgrids potentially could deliver many different types of values under various market conditions and scenarios, the market size and public benefits of microgrids also could vary significantly. DOE estimates that microgrids could be applied to support between 1 gigawatt (GW) and 13 GW of connected load by 2020.[44] For microgrids to capture this market, however, they must be able to deliver electric energy at favorable costs. A microgrid's market opportunity primarily is driven by how much it can reduce the price of electric energy and how it manages energy volatility. These factors are driven by a microgrid's *spark* spread (i.e., the difference between the wholesale price of electricity and the cost of the fuel used to generate it) and the generation-specific cost to produce the electric energy (e.g., by fuel cells, solar, wind).[45]

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[43] Poonum Agrawal, et al., "How 'Microgrids' are Poised to Alter the Power Delivery Landscape," *Utility Automation and Engineering T&D* (Penwell Publishing Corp.; 2006). (Agrawal-1)

[44] Agrawal-1

[45] ISO New England, *2007 Annual Markets Report* (AMR07), p. 170 (Holyoke, MA: June 6, 2008); http://www.iso-ne.com/markets/mkt_anlys_rpts/annl_mkt_rpts/2007/amr07_final_20080606.pdf. (ISO-NE-1)

DOE estimates that the “reduced-cost” value proposition for microgrids could generate 45 to 80% of the market for microgrids, the largest portion. The potential “reliability” and “green power” values are likely to generate the next largest markets, each accounting for up to 25% of the total market. According to DOE, the benefits from microgrids could total almost $1 billion/year by 2020, the largest benefits are estimated to be from reducing the level of emissions, which could save $550 million/year by 2020; DOE estimates that microgrids would lead to an annual reduction of 17.4 million tons of CO_2, 108,000 tons of SO_X, and 18,000 tons of NO_X.

Microgrid Requirements

For the benefits cited to be realized, microgrids must meet certain technical functional requirements (i.e., for performance, design, quality, protection, monitoring and control, operations, flexibility, and infrastructure). The greatest challenges are associated with protection, monitoring, and control. Microgrids most likely will need three levels of control: internal, external, and individual asset. Microgrids will need to be controlled via a central controller (as opposed to relying on local generation control) to accommodate a wide range of load and generation output scenarios and power flow constraints created by line constraints and generation availability. Sophisticated algorithms also will need to be developed. For external control, a microgrid must integrate with the utility’s or ISO’s communications infrastructure. To maintain voltage and frequency, individual generators in the microgrid must be able to respond rapidly to changes in load. Microgrid fault-current interruption is particularly challenging because microgrids must be able to coordinate protection devices in both stand-alone and grid-parallel modes. This issue will be exacerbated further as more inverter-based generation penetrates microgrids.

DOE estimates that another requirement for microgrids is the ability to autosynchronize with the grid. This is a complex problem for microgrids that contain numerous generators that all must be in phase for successful synchronization. Microgrid research on power quality management is ongoing, especially for operating in an islanded mode from the grid.[46]

Electric Energy Storage Technologies

Electric energy storage is increasingly being recognized as a key element in improving grid reliability and stability in the Smart Grid.[47] Advances in battery technology and large-scale storage systems and the introduction of electrochemical “super capacitors” and high-capacity flywheels into the grid will enable electricity storage benefits across the power system. DOE’s *Market Analysis of Emerging Electric Energy Storage Systems* contains a comprehensive table of advantages and disadvantages of various EES technologies along with an economic analysis of EES technologies in the PJM Interconnection (PJM) and New York ISO (NYISO) territories.[48]

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[46] Thomas Degner, et al., *Distributed Generation with High Penetration of Renewable Energy Sources Final Report* (Kassel, Germany: ISET, 2006). (Degner-1)

[47] DOE, *Transforming Electricity Delivery: Strategic Plan 2007* (Washington, DC: DOE, Office of Electricity Delivery and Energy Reliability, Research and Development Division, September 2007). (DOE-13)

[48] Rahul Walawalkar and Jay Apt, *Market Analysis of Emerging Electric Energy Storage Systems*, Appendix 1-A, “Summary of EES Technologies” (DOE/NETL-2008/1330) (Washington, DC: July 31, 2008). (Walawalkar-1). PJM Interconnection is the RTO for all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and the District of Columbia.

Compressed Air Energy Storage

Compressed air energy storage (CAES) actually is a hybrid storage and power production system.[49] The system stores compressed air that is fed into a natural-gas-fired combustion turbine, which allows the turbine to operate at high efficiency. At present, the only existing CAES systems are combined with large central-station power plants. However, the technology potentially could be applied as distributed energy by using a small air compression station with a gas cylinder that feeds a single combustion turbine or a modified microturbine.

Flywheels

Conventional and superconducting flywheels are electromechanical devices that couple a motor generator with a rotating mass to store energy for short durations.[50] Conventional flywheels are "charged" and "discharged" via an integral motor/generator. Flywheel design involves creating a flywheel out of a lightweight, yet strong composite fiber. This wheel is then levitated on conventional magnetic or superconducting bearings and spun at speeds exceeding 100,000 rpm. Magnets are imbedded within the flywheel structure that allows the flywheel to act as a rotor of a three-phase brushless DC motor/generator.

Other Types of Electric Energy Storage

EPRI's electric energy storage program considers distributed generation and electricity storage systems to be key assets in enhancing the value of a "clean" Smart Grid, helping utilities reduce greenhouse gas emissions and creating value to utility business operations while improving relationships between the utilities and end-use customers.[51] The program conducts objective technology assessments, lab tests, field demonstrations, and case studies and delivers critical information to utilities to enable them to apply and leverage distributed generation and EES assets. The program's research portfolio includes low-emission fossil-fuel DG, such as engines, microturbines, small gas turbines; Stirling engines and fuel cells; all types of electric energy storage technologies, such as sodium-sulfur (NaS), lithium-ion (Li-ion), and zinc-bromine (ZnBr) systems; and large compressed electric energy storage systems. The program also seeks to implement a goal for photovoltaic energy systems and renewable fueled systems to provide value to business operations while supporting regulatory strategies to meet the states' Renewable Portfolio Standards (RPSs).[52]

Vehicle-to-Grid Technology

DOE describes plug-in hybrid electric vehicles as hybrid vehicles that can be driven in electric-only or hybrid modes and be recharged from a standard electric outlet.[53] PHEVs equipped with vehicle-to-grid technology add to a system's total capacity. These vehicles can store electric energy and supply it for ancillary services (e.g., regulation services and spinning reserves).[54] For example, V2G could

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[49] DOE, *Case Studies: Energy Storage Technologies* (Washington, DC: DOE, Electricity Delivery and Energy Reliability, Distributed Energy Program, 2006); http://www.eere.energy.gov/de/cs_energy_storage.html (accessed November 3, 2008) (DOE-2)

[50] DOE-2

[51] EPRI-1

[52] RSP08, Section 8. (ISO-NE-2)

[53] DOE, *Plug-In Hybrid Electric Vehicle R&D Plan* (Washington, DC: DOE, Energy Efficiency and Renewable Energy, June 2007). (DOE-11)

[54] *Regulation service* is contracted capacity on an hourly basis that typically is dispatched at intervals between four seconds and one minute to correct area control errors (ACE). *Spinning reserves are* on-line capacity electrically synchronized to the system that can provide power to the grid instantaneously in response to signals from grid operators and be at full capacity

provide distribution system support when parked V2G cars are concentrated along overloaded elements in the distribution system, and they have the potential to either supplement or replace spinning reserves. As demand fluctuates, V2G cars also can provide up and down regulation service, and they can do so at a much faster ramp rate than existing generation.

A 2006 DOE meeting on PHEV, attended by representatives of the automotive and electric utility industries, government, national laboratories, and academia, resulted in substantial agreement among participants about PHEVs.[55] The more positive conclusions of the workshop were that the electric power grid is not a limiting factor (in the foreseeable future) and the potential benefits of PHEVs warrant support for the critical technologies. However, workshop participants also concluded that the main challenges for developing and implementing PHEVs are to reduce costs and increase energy and battery life span while meeting safety standards and customer expectations.

DOE concluded that the commercialization by 2016 of cost-competitive batteries that perform adequately and have an adequate life span is highly uncertain and that lithium-ion batteries need further improvements before a large penetration of PHEVs and EVs can take place.[56] PHEV concept cars and hybrid conversions can increase the electric range up to about 25 miles, but they add $15,000 to $30,000 to current hybrid vehicle prices, which are only marginally cost competitive today. Additionally, acceptable battery life with the demanding (deep discharge) duty cycle of PHEVs has not been demonstrated, which increases the risk of substantial replacement costs. A pilot program was conducted in 2007 to 2008 in the PJM/Mid-Atlantic region to test V2G for electric energy storage and frequency regulation.[57] The pilot produced encouraging results but also highlighted the limitations of existing battery technology.

Demand-Side Technologies

Traditional demand-side programs, such as energy efficiency, demand response, and demand-side management, and their associated technologies are an important part of the EISA Smart Grid vision. These programs have made significant progress in recent years and are gathering support from government regulators, government laboratories, and the energy industry as a means to produce electricity more efficiently. In 2007, FERC issued two orders (Orders 890 and 693) and one Notice of Proposed Rulemaking (NOPR) (RM07-19) that contain specific provisions for grid and market operators to advance the use of DR programs for reliability and economic purposes and place greater

within 10 minutes. (1) Mid-Atlantic Grid Interactive Cars (MAGIC) Consortium, "What is V2G;" http://www.magicconsortium.org/research_partners.html (accessed November 3, 2008). (2) Willett Kempton, et al., *A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System* (Delaware Green Energy Fund, Delaware Economic Development Office, Google.org, and Pepco Holdings, Inc., August 2008). (MAGIC-1 and Kempton-1)

[55] DOE-11

[56] (1) DOE-11. (2) James Francfort, "Battery Technology for PHEVs," DOE Vehicle Technologies Program, presentation at *Power Up 2008 Summit,* Wenatchee, Washington (Idaho National Laboratory, May 2008). (Francfort-1)

[57] Kempton-1

emphasis on the use of demand-side resources for ancillary services.[58] Refer to Table 5 for information on the ISO's demand-response initiatives in New England.

Energy Efficiency

Energy-efficiency measures have the advantage of permanently reducing demand on the grid, thereby capturing energy savings and, over time, reducing the need for incremental infrastructure and eliminating the incremental environmental impacts associated with that demand. Advances in solid-state electronics have led to the development of very efficient light-emitting diode (LED) technology that has demonstrated 35% reductions in energy consumption, compared with traditional lighting technology, without compromising total illumination quality.[59]

Demand-Response Resources

According to the Electric Reliability Council of Texas (ERCOT), properly configured demand-response resources serve extremely well as first and fast responders during system emergencies.[60] Several pilot projects and a significant body of research work provide additional support, which indicates that demand-response resources provide adequate, and sometimes superior, solutions for ancillary services (e.g. fast ramp time, pin-point location). However, high penetration levels of demand response also create some operational complexities (see below). The ISO/RTO Council (IRC) and the NAESB are working on establishing best practices and methods for incorporating DR across the system life cycle (i.e., planning, forecasting, operations, maintenance, billing, and settlement).[61]

Ample empirical evidence shows that demand-response programs can significantly reduce peak pricing and have other desirable economic impacts (e.g., mitigation of market power).[62] However, many economic DR programs are voluntary, and therefore the resources enrolled in these programs cannot be relied on to respond when needed. Average response rates from pilot and actual DR program resources range from 13 to 40% of total DR capacity.[63] This uncertainty makes it difficult to determine the value of a DRR as a capacity resource, especially during peak periods when it is needed most. Compounding this challenge is the lack of best practices and standards to accurately estimate customer base load, which is used to measure performance and determine payments to DRRs.

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[58] (1) FERC, *Preventing Undue Discrimination and Preference in Transmission Service, Final Rule*, 18 CFR Parts 35 and 37, Order No. 890 (Docket Nos. RM05-17-000 and RM05-25-000) (Washington, DC: FERC, February 16, 2007); http://www.ferc.gov/whats-new/comm-meet/2007/021507/E-1.pdf (accessed December 3, 2008). More information on Attachment K of the OATT is available online at http://www.iso-ne.com/regulatory/tariff/sect_2/oatt/index.html. (2) FERC, *Mandatory Reliability Standards for the Bulk Power System*, Final Rule, 18 CFR Part 40, Order No. 693 (Docket No. RM06-16-000) (Washington, DC: FERC, March 16, 2007). (3) FERC, *Wholesale Competition in Regions with Organized Electric Markets*, 122 FERC ¶ 61,167, NOPR (Docket Nos. RM07-19-000 and AD07-7-000) (Washington, DC: FERC, February 22, 2008); http://www.ferc.gov/whats-new/comm-meet/2007/062107/e-3.pdf (accessed December 3, 2008). (FERC-3, FERC-2, and FERC-4)

[59] Pacific Gas and Electric Company, *Demonstration Assessment of Light Emitting Diode (LED) Street Lighting, Host Site: City of Oakland, California* (Application Assessment Report #0726) (Oakland, CA: November 2008). (PG&E-1)

[60] NERC, *Demand-Side Management Influence on Reliability* (Princeton, NJ: NERC, Demand-Side Management Task Force of the Resource Issues Subcommittee, November 2007). (NERC-2)

[61] ISO/RTO Council, *Harnessing the Power of Demand, How ISOs and RTOs Are Integrating Demand Response into Wholesale Electricity Markets* (October 16, 2007). (IRC-1)

[62] FERC, *2007 Assessment of Demand Response and Advanced Metering* (Washington, DC: September 2007). (FERC-1); IRC-1

[63] Ahmad Faruqui, et al., *The Power of Five Percent* (Cambridge, MA: The Brattle Group, May 2007). (Faruqui-1)

One of the most frequently cited benefits of DR stems from the deferral of capital investments for generation and transmission facilities. However, environmental tradeoffs may result. For example, DR that is based on a customer's switching from grid-supplied electricity to local distributed generation that either is inefficient or has significant emissions may increase air pollution under certain conditions.

The infrastructure requirements for DR programs can be significant. An ISO/RTO cannot implement a broad DR program without the ongoing support of government regulators, market participants, and electricity consumers. Ubiquitous communication networks and advanced metering and other intelligent devices are needed to implement real-time DR programs. Technical standards and model business practices for DR metering, measurement, verification, and command control are critical success factors, which are absent in today's DR product offerings, although the NAESB recently has begun to address some, but not all, of these voids. System operators would greatly benefit from standards and technologies that provide real-time insight into actual system load (current consumption) that DR would be able to curtail at any given moment, provided the DR resources reliably respond to their dispatch signals.

Advanced Metering Infrastructure

EPRI refers to advanced metering infrastructure as follows:[64]

> *the full measurement and collection system that includes meters* ("smart meters") *at the customer site; communication networks between the customer and a service provider, such as an electric, gas, or water utility; and data reception and management systems that make the information available to the service provider.*

Smart meters can measure and record usage data in time registers and provide quality information to electricity customers, utilities, and other parties on hourly usage and usage during shorter intervals (e.g., minutes). This can facilitate participation in demand-response programs, including price-based programs, and provide support for time-of-use rates.[65] Systems with AMI also can support additional features and functionality associated with system operation and customer service (e.g., outage management, connection and disconnection, etc.).[66] The key components of an AMI are shown in Figure 5.

[64] EPRI, *Advanced Metering Infrastructure* (Palo Alto, CA: February 2007). (EPRI-2)

[65] The ISO's AMR07, Section 8.1.2, contains information on price-based programs.

[66] Aeris Communications, *Advanced Metering Infrastructure* (San Jose, CA: 2008). (Aeris-1)

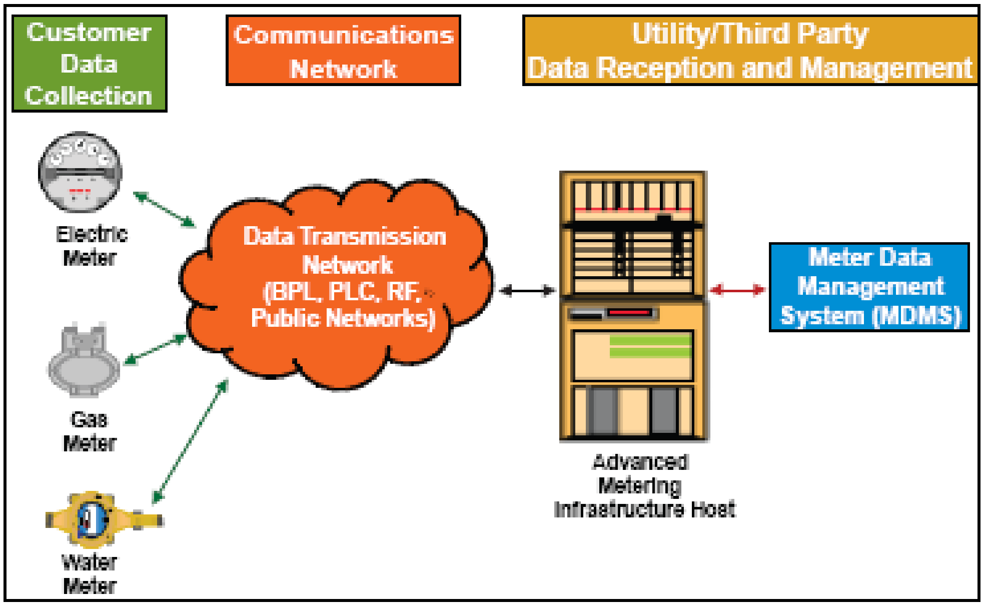

Figure 5: Building blocks for advanced metering interfaces.

Source: FERC, 2007 (FERC-1)

It is important for regulators, policymakers, utilities, and ISO/RTO organizations to realize that achieving the Smart Grid will be an evolutionary process. Investments made in today's advanced metering initiatives are important first steps on the path to the Smart Grid, and many of the capabilities envisioned for the Smart Grid will not be possible without an advanced metering infrastructure. Figure 6 shows the relationship between AMI and the Smart Grid.

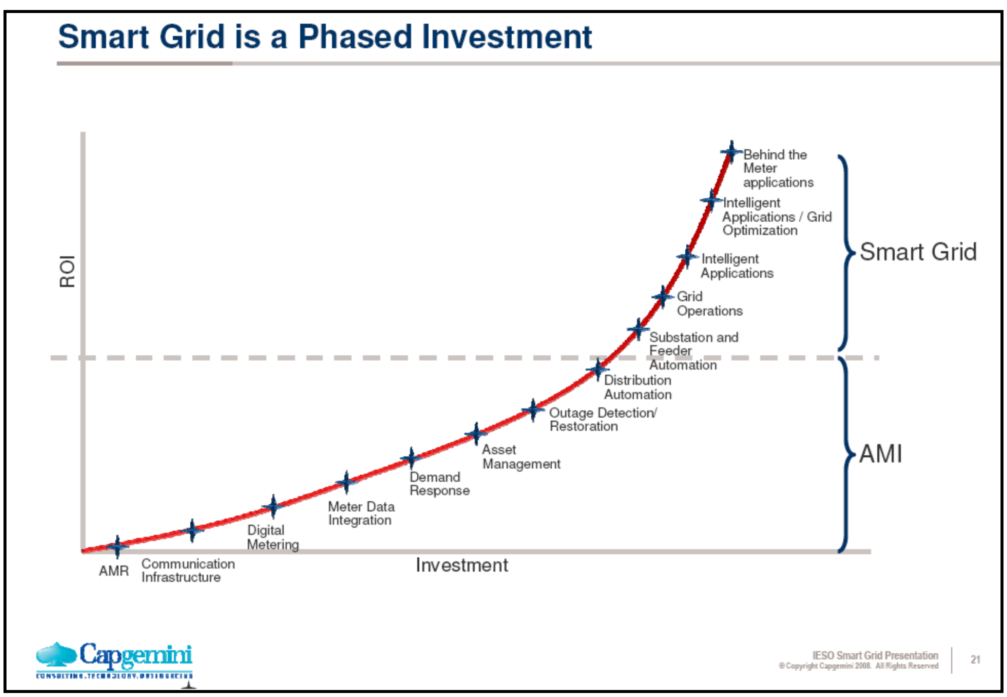

Figure 6: The phased return on investments from advanced metering infrastructure to Smart Grid.

Source: Independent Electricity System Operator (IESO), 2008

Home-Area Networks

A home-area network (HAN) connects a home's smart devices, such as smart thermostats, energy management systems, load-control switches, in-home displays, smart appliances, and even PHEVs, and the congruous operation of these devices to efficiently manage and monitor the home's electricity supply and demand. The HAN home-energy "ecosystems" empower individual consumers by providing information for making decisions about their electricity use.[67] HANs work in close association with smart meters, which represent the demarcation point between utility and homeowner control. Utility control stops at the meter (outside the home), and homeowner control begins inside the home with a HAN, which the consumer owns. A HAN has secure two-way communication with the meter and supports the following types of communications:

- public price signaling
- consumer-specific signaling
- control signaling
- distributed generation
- submetering

Figure 7 depicts a mature HAN implementation. This HAN space is significantly fragmented and has up to 45 different identified protocols, including those for a smart thermostat control, remote appliance control, and a dashboard display showing electricity use.[68]

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[67] Erich Gunther, *The Home Area Network and Electric Service Provider Applications; The UtilityAMI 2008 Home Area Network Systems Requirements Specification*—(UtilityAMI 2008 HAN SRS). (UCA® International Users Group, UtilityAMI Working Group, and Open HAN Task Force, 2008); http://www3.dps.state.ny.us/PSCWeb/PIOWeb.nsf/a89c0117705349e7852573e0007a0a57/437dc4650447e96285257428006dc568/$FILE/OpenHAN-Spec-Overview.pdf (accessed December 1, 2008). (Gunther-3)

[68] Erich Gunther, "Field and Device Technologies: Consumer Portals, Home Area Networks and Connected Devices," *Forum Proceedings Grid Interop 2007*, Albuquerque, NM, November 7–9, 2007 (Richland, WA: Gridwise Architecture Council, December 2007). (Gunther-1)

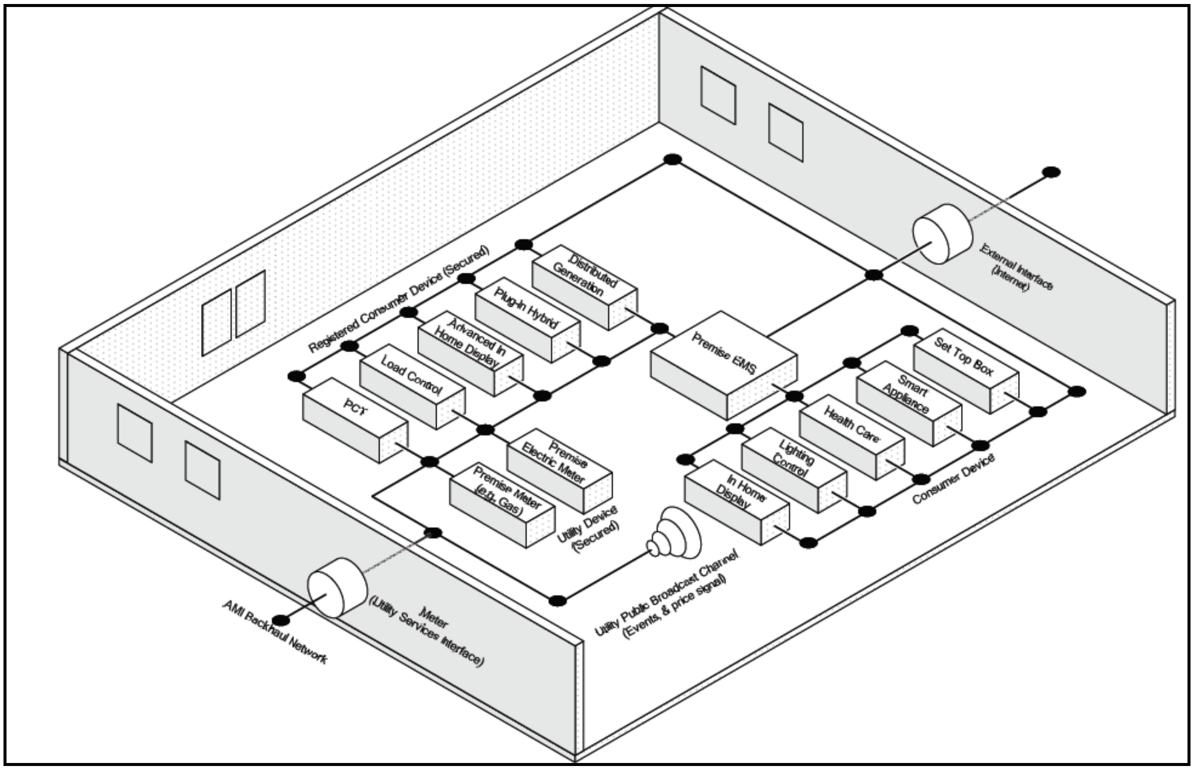

Figure 7: Diagram of a mature HAN implementation.

Smart Appliances

Smart appliances are beginning to emerge from field trials with impressive results.[69] From 2006 to 2007, the Pacific Northwest National Laboratory conducted a field trial on the Olympic Peninsula in Washington State where 50 hot water heaters and 150 clothes dryers were equipped with “grid-friendly appliance” (GFA) controllers. The GFA controller was configured to monitor voltage and shed load whenever an underfrequency event (below 59.95 hz) occurred. The graph in Figure 8 depicts the result of one such event. It appears that devices equipped with GFA capabilities may be able to operate both autonomously and as part of a HAN. Consensus about standards for smart-appliance interfaces apparently is lacking, however.[70]

[69] Don Hammerstron, et al., *Part II: Grid Friendly™ Appliance Project* of the Pacific Northwest GridWise™ Testbed Demonstration Projects (PNNL-17079) (Richland, WA: DOE, PNNL, Gridwise, October 2007). (Hammerstron-1)

[70] Conrad Eustus, et al., *Appliance Interface for Grid Responses*, Grid Interop 2007 (December 2007). (Eustus-1)

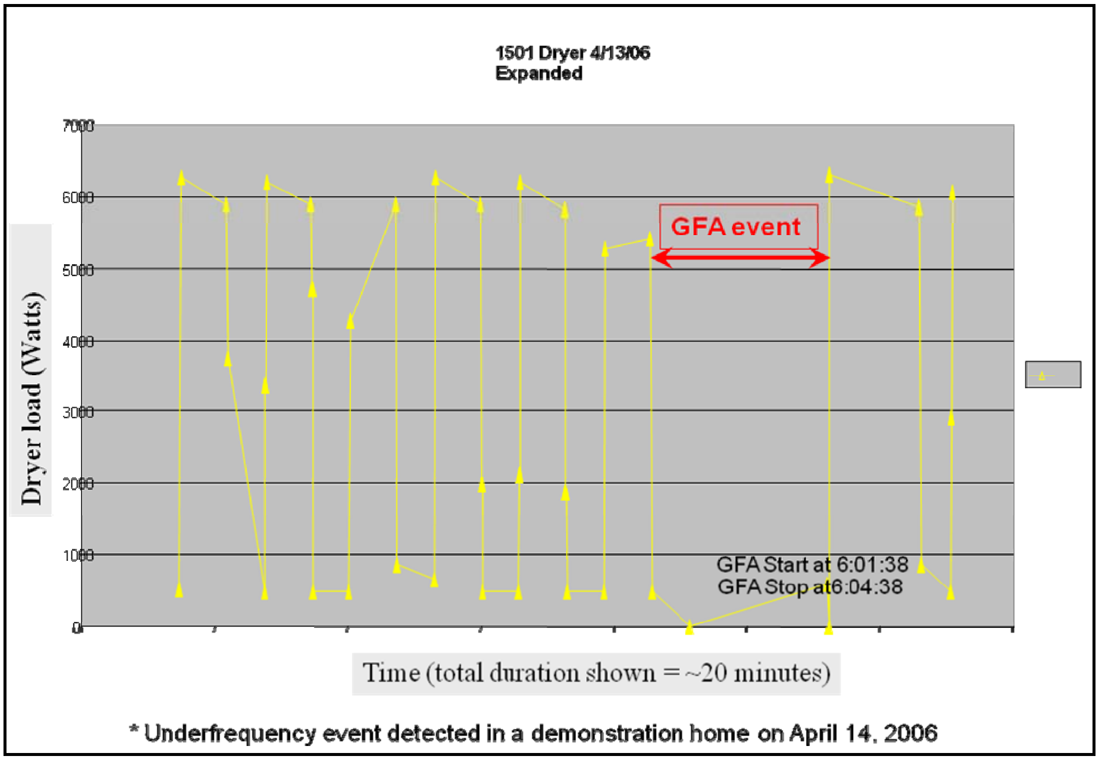

Figure 8: GFA voltage-frequency event.

Building Automation and Control Network

The ASHRAE/ANSI standards for building automation and control networks, referred to as BACnet, are designed to support common building control and energy management applications, including trending, scheduling, alarm and event processing, and command prioritization.[71] BACnet defines a standard "data communication protocol" and object model to facilitate energy management control operations within a building. A certification and testing laboratory must conduct interoperability tests to verify product claims for BACnet compliance and issue BACnet testing laboratory certification for products that prove compliance.

While a core group of dedicated professionals have actively supported BACnet since 1987, and ASHRAE/ANSI approved it as a standard in 1995, the International Organization for Standardization (ISO) recognized BACnet as an official set of standards more recently in 2003.[72] Several companies that are familiar names within the energy industry (e.g., ABB and Siemens, etc.) have since developed BACnet-certified products, such as HVAC and lighting controls, fire detection and alarm, security, smart elevators, and other building equipment controllers. NIST has provided insight into the potential for BACnet-based energy management systems to interface with a utility as part of a demand-response program and the regulatory, business, and technical framework that must be in

[71] Jim Butler, "Achieving Interoperability using BACnet," *Forum Proceedings Grid Interop 2007*, Albuquerque, NM, November 7–9, 2007 (Richland, WA: Gridwise Architecture Council, December 2007). (Butler-1)

[72] ANSI/ASHRAE. Standard 135-2004. *BACnet®—A Data Communication Protocol for Building Automation and Control Networks* (Altanta, GA: ASHRAE, 2008). (ANSI-1)

place to facilitate this.[73] For example, regulatory, commercial, and utility stakeholders must understand each others' interests and requirements associated with communicating about real-time and day-ahead electric energy prices, confidentiality and security, and technological capabilities for the response to price-peak events to succeed.

Transmission and Distribution Technologies

Many types of Smart Grid technologies can be applied to improve the efficiency of conducting and monitoring transmission and distribution activities and to enhance these operations in other ways. Improving the quality of the data that grid operators receive and how they receive these data and modernizing ways to control T&D operations are several examples of T&D Smart Grid applications.

Wide-Area Monitoring Systems

The Pacific Northwest National Laboratory is conducting research that will help grid operators understand the status of grid stability in real time, which will provide the opportunity for the operators to improve a situation before consequences are realized.[74] In collaboration with the University of Wyoming, Montana Tech, the University of Montana, Bonneville Power Administration, and Electric Power Group, PNNL is developing mathematical algorithms to detect the stability of the grid at any moment in time. These algorithms use synchrophasor data that are instantaneously acquired from across the western grid. Current research is moving forward on developing tools that will be able to quickly provide grid operators with corrective actions should an instability exist.

Interest in the potential for phasor measurement units to more precisely estimate the state of the system also is growing. An EPRI research project investigated approaches to using both PMU and traditional SCADA measurement to create a hybrid-state estimator that could provide system operators with more accurate results and improved visibility of the system state.[75] The research found that the most important reason for adding PMUs to a system is not to achieve observability but to increase measurement redundancy and to improve state-estimation accuracy. The report introduces a new method that determines the optimal placement of PMUs on a grid, which converts existing critical measurements and data sets into redundant ones and allows for the identification of flawed data.

ABB conducted a WAMS pilot project that found that a wide-area monitoring system can help to significantly improve the use of the grid during periods of peak transmission demand while detecting critical factors influencing network stability.[76] Oak Ridge National Laboratory (ORNL) recently announced the availability of VERDE (Visualizing Energy Resources Dynamically on Earth), a software program that combines the display capabilities of Google Earth with analysis and modeling components developed by ORNL's Computational Sciences and Engineering Division. According to

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[73] David Holmberg, *Utility Communications with BACnet Commercial Building for Price Peak Response* (Gaithersburg, MD: NIST, Building and Fire Research Laboratory, 2007); http://www.gridwiseac.org/pdfs/interop_papers_0407/briefingkeynote_closing/holmberg_bacnet.pdf (accessed December 1, 2008). (Holmberg-1)

[74] DOE, *Grid Stability Initiative* (Richland, WA: DOE, PNNL, Electricity Infrastructure Operations Center, 2008). (DOE-6)

[75] EPRI, *Program on Technology Innovation: Next Generation State Estimation* (Palo Alto, CA: EPRI, December 19, 2007). (EPRI-4)

[76] J. Bertsch, et al., "Experiences with and Perspectives of the System for Wide Area Monitoring of Power Systems," ref. #103,CIGRE/IEEE-PES International Symposium on Quality and Security of Electric Power Delivery Systems (Montreal: October 7–10, 2003). (Bertsch-1)

the ORNL, the wider-area view provided by VERDE enhances situational awareness and accelerates the recovery from power outages.[77] Another WAMS project is the Eastern Interconnection Phasor Project (EIPP), which aims to provide grid operators with greater visibility of and more accurate and detailed information about system operating conditions. ISO New England is an active participant in this project.

Transmission and Distribution Control

The DOE Electricity Advisory Committee summarized the benefits of T&D Smart Grid technologies.[78] These applications address the following:

- Transmission capacity factors for renewables
- Transmission congestion relief
- Relaxation of transmission reliability limits
- Transmission capital deferral
- Substation peak load and backup
- Voltage support
- Reliability enhancement

The benefits include capturing renewable production and delivering it when transmission capacity is available, relieving congestion, deferring transformer upgrades attributable to peak load growth, and providing down-circuit supply while outages are being restored.

Another possible way to improve the overburdened transmission system is to apply high-voltage direct-current (HVDC) and "flexible alternating-current transmission system" (FACTS) technology.[79] HVDC may be used when asynchronous systems are interconnected, power is transmitted over long distances, or the control of real power is needed.[80] FACTS is a combination of solid-state switches and computerized automation that enable nearly instantaneous customized control of power flows—far faster than traditional electromechanical switches. The devices can be used to accomplish a number of tasks:

- Precisely move power along transmission lines
- Provide dynamic voltage support
- Increase transfer limits
- Help stabilize the transmission system after a disturbance

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[77] Oak Ridge National Laboratory, *VERDE Fact Sheet* (Visualizing Energy Resources Dynamically on Earth) (Oak Ridge, TN: DOE, ORNL, August 2008); http://www.smartgridnews.com/pdf/VERDEFactSheet.pdf (accessed November 4, 2008). (ORNL-1)

[78] DOE-3, Table 2-4.

[79] Roger Anderson, et al., *Smart Electric Grid of the Future: A National "Distributed Store-Gen" Test Bed,* Smart Grid White Paper (New York City: Columbia University, n.d.); http://www.ldeo.columbia.edu/res/pi/4d4/testbeds/Smart-Grid-White-Paper.pdf (accessed November 4, 2008). (Anderson-1)

[80] Mike Henderson, et al., "Planning HVDC and FACTS in New England," (Draft Paper) Presentation to be made at the IEEE Power Engineering Society 2009 Power Systems Conference & Exposition, scheduled to take place March 16, 2009, in Seattle. (Henderson-1)

- Relieve or even eliminate congestion
- Tie grids together
- Integrate distributed generation resources into the grid
- Combat the phenomenon of loop flow

HVDC and FACTS applications have the potential to provide a much-needed boost to the transmission system and some other technical advantages, especially when dynamic voltage support is needed. However, a thorough economic evaluation of the costs and system performance of proposed FACTS applications compared with alternative plans is required within the framework of the wholesale markets and transmission tariff. Studies that project the prices of electric energy, capacity, and ancillary services, as well as the potential effects on loop flow, are important considerations.[81]

Because of the growing complexity of the needed controls for operating T&D systems, particularly when systems are faced with the large, diverse range of devices operating at the demand side of the network, centralized control systems are facing significant challenges associated with reliability and scalability.[82] Given these limitations, the research community is moving toward a decentralized approach for controlling electricity networks. Such techniques often employ agent-based technology (smart devices that manage particular network components). A Strategic Power Infrastructure Defense (SPID) System employs multiple cooperating agents and provides the various components that may be equipped with intelligent-agent technology, as shown in Figure 9. SPID systems are designed with self-correcting strategies and adaptive reconfiguration schemes to accomplish the following tasks:[83]

- Achieve autonomous, adaptive, and preventive remedial control actions
- Provide adaptive, intelligent protection
- Minimize the impact of power system vulnerability

[81] Michael Henderson and Donald Ramey, "Planning Issues for FACTS," presentation at the IEEE Power Engineering Society General Meeting, (Tampa: IEEE, June 2007). (Henderson-2)

[82] Glenn Platt, "The Decentralised Control of Electricity Networks—Intelligent and Self-Healing Systems," *Forum Proceedings Grid Interop 2007*, Albuquerque, NM, November 7–9, 2007 (Richland, WA: Gridwise Architecture Council, December 2007). (Platt-1)

[83] Chen-Ching Liu, *Security of Supply Issues: Technical and Economic Aspects,* presentation at the Westbury Hotel, Dublin, July 29, 2004 (Seattle, WA: University of Washington, Advanced Power Technologies Center, 2004); http://ee.ucd.ie/erc//securitywestbury.pdf and http://ee.ucd.ie/erc//ccliuppt.pdf (accessed December 2, 2008). (Liu-1)

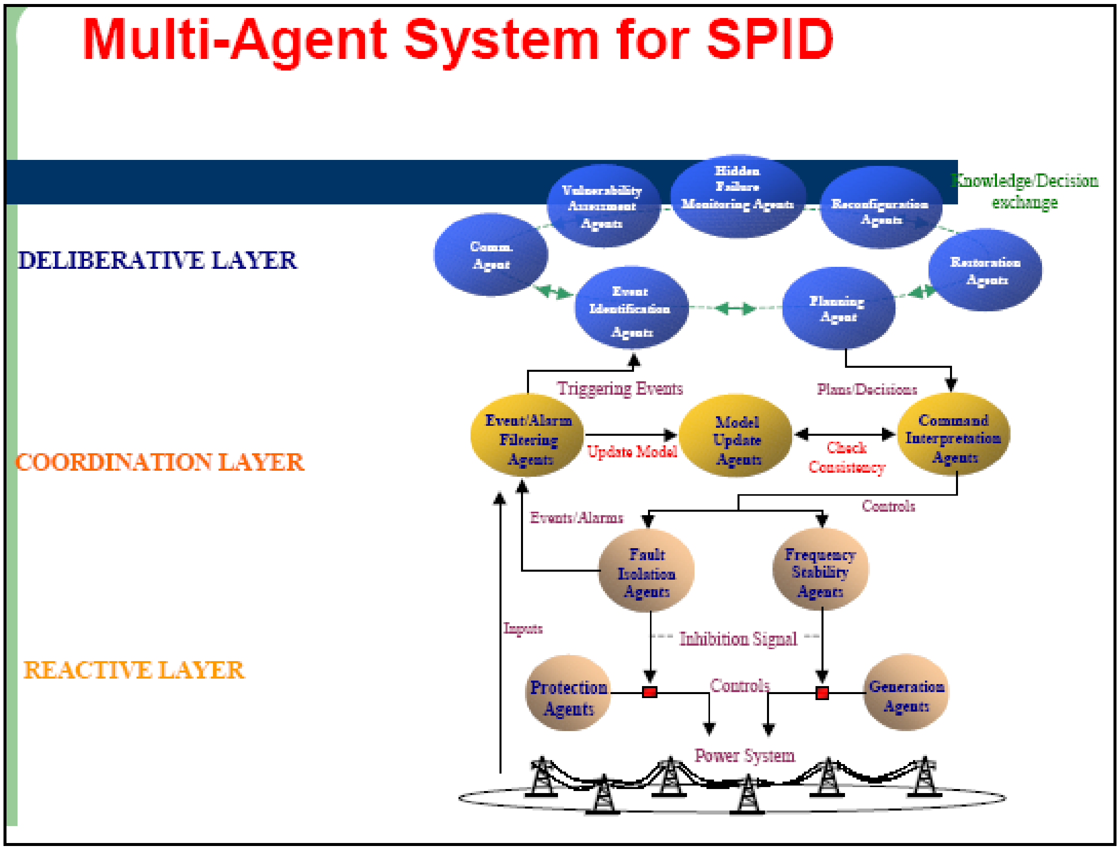

Figure 9: Multi-agent strategic power infrastructure defense.

Source: Chen-Ching Liu, 2004 (Liu-1)

Southern California Edison (SCE) is considering another agent-based decentralized control approach.[84] SCE is designing a decentralized control algorithm in concert with its "Circuit of the Future" program, which aims to use intelligent agents to control voltages and perform restoration within a distribution circuit.

Smart Grid Market Aspects

Information is sparse on the real market impacts of the Smart Grid. The available literature provides information on some pilot studies and speculation about some possible impacts, both positive and negative. New paradigms for utility cost recovery, the way clean power is bought and sold, and the market potential for electricity storage all are being explored.

One market aspect of the Smart Grid is the buying and selling of cleaner power options offered on the market using smart devices equipped with two-way communications and "market-aware software."[85] These devices will be capable of responding to pricing signals as well as emergency situations (e.g., underfrequency conditions).[86] IBM researcher, Ron Ambrosio, stated that "*Your thermostat and your*

[84] Paul Hines, et al., "Integrated Agent-Based, Real-time Control Systems for Transmission and Distribution Networks," *Forum Proceedings Grid Interop 2007*, Albuquerque, NM, November 7–9, 2007 (Richland, WA: Gridwise Architecture Council, December 2007). (Hines-1)

[85] Patrick Mazza, *Powering Up the Smart Grid* (Olympia, WA: Climate Solutions, July 2005) (Mazza-1).

[86] Hammerstron-1

water heater are day-trading [electricity] *for you*" when describing the capabilities of Smart Grid appliances that were used in the PNNL Olympic Peninsula trial.[87] Estimates from this study indicate that as a result of smart appliances reducing peak loads by 15% per year, $70 billion in capital expenditures could be deferred over a 20-year period. One big hurdle to achieve this deferral is that, in most states, utilities still are granted rates of return that depend mainly on the power plants and equipment they own and operate instead of how much energy they save.

Xcel Energy cites that while smart metering, energy storage, conservation, and energy efficiency are key components of a Smart Grid, they potentially can degrade the utility shareholders' regulated return and lead to uncompensated demand response.[88] Regulators will need to partner with load-supplying entities in establishing different pricing regimes that will provide incentives for utilities to earn revenue using means that are not linked to selling greater amounts of electricity. One of the objectives of Xcel Energy's Smart Grid City project is to work with regulators to identify policy changes that will reward utilities and customers for the conservation of electricity.

DOE conducted a significant study in 2008 that examined the market potential for two emerging electric energy storage technologies: sodium sulfur (NaS) batteries for energy arbitrage and flywheel EES systems for regulation services.[89] The study used data from the NYISO and PJM territories from 2001 to 2007 (2001 to 2007 data for NYISO and 2005 to 2007 data for PJM). Using Monte Carlo simulation to study the effect of capital costs, round-trip efficiency, and location on the distribution of net present value (NPV) for each energy storage system, the study found that a NaS battery has over a 98% probability of having a negative NPV in both the NYISO and PJM areas for the base case scenario. However, flywheel systems showed a 100% probability of having a positive NPV in both areas.

This analysis also showed that although current policies in NYISO and PJM allow emerging EES technologies to participate in electric energy markets for capturing energy arbitrage opportunities, changes in some of the ancillary service-related policies also would reduce financial and regulatory uncertainty for EES. Additionally, while the primary barriers to EES penetration in both PJM and NYISO are economic, the study showed that changing each respective ISO's current market rules and reliability criteria could permit EES to participate in these ISOs' synchronous spinning reserve markets, which would reduce the current uncertainty in regulation market rules. The report concluded that the case for EES to participate in regulation markets could be enhanced further if the opportunity costs paid to traditional generators were captured as part of the regulation market clearing price (RMCP) in PJM. PJM is considering changes to the RMCP payment that may include electric energy storage.

A proof-of-concept project conducted by the University of Delaware and PJM involved the use of a single PHEV for regulation and spinning reserve ancillary services.[90] A PHEV is ideally suited to provide both regulation up and regulation down capacity, albeit in very small amounts (relative to a

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[87] (1) Steve Lohr, "Digital Tools Help Users Save Energy, Study Finds*," New York Times*, January 10, 2008. (Lohr-1) (2) Hammerstron-1

[88] Xcel Energy, *A Smart Grid White Paper* (Minneapolis: February 2008). (Xcel-1)

[89] Rahul Walawalkar and Jay Apt, *Market Analysis of Emerging Electric Energy Storage Systems*, Appendix 1-A, "Summary of EES Technologies" (DOE/NETL-2008/1330) (Washington, DC: July 31, 2008). (Walawalkar-1)

[90] Willett Kempton, et al., *A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System,* (Delaware Green Energy Fund, Delaware Economic Development Office, Google.org, and Pepco Holdings, Inc., August 2008). (Kempton-1)

traditional generating unit providing the same). The PHEV used in the project was limited by its maximum power exchange capability (10 to 12 kW) and total power storage of 35 kWh. Theoretically, a PHEV could earn capacity revenues from regulation and spinning reserve services for 21.5 hours each day. However, its ability to actually supply and consume energy is severely constrained. Several times throughout the test, the vehicle tested was unable to respond to up or down regulation signals due to battery limitations, which resulted in a failure-to-follow condition. The report contains a recommendation that ISO/RTOs consider implementing a separate "regulation signal for storage resources" to accommodate such limitations.

Power System Planning

The New England region faces many planning challenges that include the need to successfully integrate resources that provide fuel diversity, a significant penetration of renewable resources, and the increase in the amounts of demand resources. While the application of Smart Grid technologies provides many opportunities for meeting system needs, it also poses many technical and process issues that must be resolved. In addition, for Smart Grid technologies to be successfully applied to New England's transmission and distribution systems, the technologies must be observable, controllable, and reliable.[91]

New England has a successful history in applying Smart Grid technologies to the transmission system. FACTS, HVDC equipment, and other technologies have been integrated with the transmission system to provide network control, voltage support, and power transfers over long distances. Additional FACTS and HVDC applications most likely will be required to integrate renewable resources, especially those that are remote from load centers.[92] Planners will need to remain mindful of control system interactions and operating procedures to successfully integrate these technologies and ensure the reliable operation of the system.

The application of Smart Grid technologies to the distribution system can facilitate the integration of variable-output resources, such as wind. These technologies also can provide automatic generation control and increased operating reserves, and they can delay the need for transmission improvements. However, these applications raise many issues, including the need to accomplish the following tasks:

- Accurately project Smart Grid applications and characteristics and coordinate the projections with the load forecast
- Monitor performance and account for customer fatigue, maintenance requirements, and changes in the economic incentives for Smart Grid applications
- Properly model real and reactive load characteristics in power flow and stability studies and fully account for protection systems, such as underfrequency and undervoltage trip points
- Ensure that control system actions of Smart Grid are fully coordinated to ensure reliable performance of the transmission system overall
- Determine desired characteristics of smart appliances
- Apply an open architecture to accommodate evolving technologies and system needs

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[91] RSP08 (ISO-NE-2)

[92] Don Ramey and Michael Henderson, *A Special Publication for System Planners (IEEE WG15.05.13), Transmission System Application Planning Requirements for FACTS Controllers* (New York: IEEE, January 2007). (Ramey-1)

- Standardize communications and synchronize data to achieve a secure and reliable network operation overall
- Indicate the desired system characteristics and locations of Smart Grid applications
- Monitor the system for the unwanted development of Smart Grid applications (e.g., poor locations, too many or two few applications, inadequate or undesired performance characteristics) and make appropriate adjustments to system operations
- Develop wholesale market rules that account for the operation of Smart Grid technologies, including load reductions (achieved by generation) and the provision of ancillary services

Conclusions

In the long run, the EISA Smart Grid initiative will have a significant impact on ISO New England and its market participants. The implementation of the Smart Grid will likely require ongoing changes to the market rules and will significantly increase operational complexity. Because Smart Grid devices are capable of making intelligent decisions about energy consumption and supply, the ISO's ability to co-optimize these smart devices with existing grid infrastructure will require more sophisticated tools than those in use today. Accompanying the implementation of the Smart Grid could be the exponential growth in the number of assets under ISO control, especially if and when PHEV and distributed generation technology reach critical mass. Smart Grid applications also are expected to significantly increase the volume of data that will need to be gathered and analyzed, which will require more sophisticated solutions than those presently in use. New software programs and algorithms will be needed for energy balancing and control functions. Operators will require a new breed of visualization tools to aid situational awareness and improve decision making and response time. System planners will need "Smart-Grid-aware" tools that extract efficiencies from existing infrastructure when new "smart devices" are used.

Relatively few formal standards and business practices exist at present upon which to build Smart Grid tools and capabilities. The DOE's Electricity Advisory Committee and Smart Grid Task Force are working diligently to provide a strategy and direction for Smart-Grid-related developments. NIST has recently begun an initiative to develop Smart Grid standards and business practices. Expert domain groups are being established to develop standards for building-to-grid, industrial-to-grid, home-to-grid, and transmission and distribution functions.

The success of the EISA Smart Grid depends on several critical characteristics and a collaborative effort across the electricity supply chain. These characteristics include the following:

- A ubiquitous, reliable, and secure communications infrastructure
- A Smart Grid interoperability framework, which contains communication and control protocols that operate across the entire electricity supply chain (i.e., generators, transmission operators, distribution companies, consumers, marketers, regulators)
- Long-term investment and implementation commitments across the entire supply chain
- Ubiquitous and timely deployment of Smart-Grid-enabled infrastructure
- A methodical and practical transition and implementation plan
- Practical regulations that satisfy the needs of stakeholders across the entire electricity supply chain

Significant research and development efforts also are needed to create the technical and business practice standards that will facilitate a successful Smart Grid as envisioned in the Energy Independence and Security Act of 2007. Presently, the most urgent needs are for educational programs, knowledge sharing, and close coordination among the parties that are helping to create Smart Grid policies, regulations, standards, and project plans.

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