Smart Grid

Quick Facts

- The smart grid refers to the application of digital technology to the electric power sector to improve reliability, reduce cost, increase efficiency, and enable new components and applications.
- Compared to the existing electrical grid, the smart grid promises improvements in reliability, power quality, efficiency, information flow, and improved support for renewable and other technologies.
- Smart grid technologies, including communication networks, advanced sensors, and monitoring devices, form the foundation of new ways for utilities to generate and deliver power and for consumers to understand and control their electricity consumption.
- Some of the largest utilities in the country, including Florida Power and Light, Xcel Energy, Pacific Gas and Electric, and American Electric Power, have undertaken initiatives to deploy smart grid technologies.
- Smart grid technologies could contribute to greenhouse gas emission reductions by increasing efficiency and conservation, facilitating renewable energy integration, and enabling plug-in electric vehicles.

Background

The Smart Grid and Its Potential Benefits

The smart grid is a concept referring to the application of digital technology to the electric power sector. It is not one specific technology. Rather, the smart grid consists of a suite of technologies expected to improve the performance, reliability, and controllability of the electrical grid. Many of these technologies have been employed in other sectors of the economy, such as the telecommunications and manufacturing sectors.

Smart grid technologies offer several potential economic and environmental benefits:

- Improved reliability
- Higher asset utilization
- Better integration of plug-in electric vehicles (PEVs)[1] and renewable energy
- Reduced operating costs for utilities
- Reduced expenditures on electricity by households and businesses
- Increased efficiency and conservation
- Support for new components and applications
- Lower greenhouse gas (GHG) and other emissions

Digital technologies have been integral to the modernization of many sectors of the economy and have resulted in efficiency gains, new opportunities, and greater productivity. The electric power sector, however, has lagged behind. Many utilities still use the same designs as they did when most of the grid was built in the 1960s and 1970s.

Issues with the Existing Grid

The U.S. electrical grid is an enormous and extremely complex system consisting of centralized power plants, transmission lines, and distribution networks.[2] It is capable of carrying over 850 gigawatts (GW) of power and continuously balancing supply with fluctuating demand. It does so with remarkable reliability, providing 99.97 percent uptime (when the grid is operational), or about 160 minutes of downtime a year.[3,4]

However, the traditional electric power grid was designed neither with the latest technology nor with the goal of supporting a high-tech economy and enabling low-carbon technologies, energy efficiency, and conservation. Some of the grid issues described below are addressed by smart grid technologies but do not relate directly to GHG emission reductions.

- **Power outages and power quality disruptions cost more than $150 billion annually.**[5,6]

  The power still goes out for customers at an average of 2.5 hours per year, which leads to sizeable economic losses. Power quality disruptions for ordinary consumers may be no more than lights flickering or dimming, but for high-tech manufacturing and critical infrastructure that rely on high quality power (such as communications networks and pipelines), these events can disrupt operations and collectively can cost millions.[7]

- **The grid is inefficient at managing peak load.**

  Peak load is the short period when electricity demand is at its highest within a day, season, or year. Electricity demand is cyclical and variable, and the cost of meeting that demand varies, but because utilities have limited tools for managing demand, supply must be adjusted continuously to track demand. In addition, the power grid must constantly maintain a buffer of excess supply, which is primarily fossil fuel based, resulting in lower efficiency, higher emissions, and higher costs.

- **The grid does not support robust information flow.**

  For example, utilities often do not find out about blackouts until consumers call to notify them. Moreover, consumers have very little knowledge about how their electricity is priced or how much energy they are using at any given time. This limits the incentives for efficiency, conservation, and demand response.

- **Very high levels of renewable energy pose challenges for the grid.**[8,9]

  The electricity generation from certain important renewable technologies fluctuates based on the availability of variable resources (e.g., the wind and sunlight). The ability of the existing grid to support high levels of variable renewable generation is uncertain.[10] Efforts are currently underway to better understand the impact of high levels of renewable energy in the electricity grid, and will become more important as renewable energy increases. For instance, California aims to incorporate

33 percent renewable energy by 2020.[11]

The grid has limited support for distributed generation.

Because the grid was designed for a one-way power flow from centralized power stations to end users, it has to be upgraded to allow a two-way power flow that supports small distributed generators. Adding variable generators such as rooftop solar or micro wind (small wind turbines able to be mounted on a residential rooftop) makes managing distributed generation even more difficult for the existing grid.

The grid would be strained by high PEV deployments.

A significant deployment of PEVs over the next few decades would represent a major strain on the electric power system. Due to the nature of the charging cycles of PEVs, it will be both expensive and technically difficult to manage the fleet's demands through the existing grid.

Description

Characteristics of smart grid technologies enable many functions beyond what the existing grid does. A smart grid:

- **Gives the utility actionable information**[12]

  Instead of estimating network activity or having to send out physical readers to many locations, utilities receive a constant flow of information about their network, their customers, and their options for managing their operations.

- **Gives the consumer actionable information**[13]

  Customers can be provided with information about their electricity usage patterns and costs. They can use this information to reduce their energy costs and their environmental impact.

- **Automates and decentralizes decisions**[14]

  Instead of forcing centralized system operators and planners to make decisions, a smart grid automates easy decisions[15] and empowers consumers to take informed actions.

- **Supports and enhances new technologies**[16]

  A smart grid provides support for new applications and components, such as smart appliances, PEVs, distributed generation, and renewable energy by allowing for better management of their interaction with the grid.

Key Technologies

The technologies that comprise a smart grid address the existing grid's shortcomings by providing actionable intelligence and enhanced management capabilities that can improve operational efficiency and performance. These technologies are available now, and some of the largest utilities in the country, including Xcel Energy[17], Pacific Gas and Electric (PG&E)[18], and American Electric Power (AEP)[19], have begun large-scale deployment of these technologies to their customers.[20]

According to the Smart Grid Information Clearinghouse (SGIC) the smart grid consists of five key technology areas[21]:

- **Integrated Communications**

  High-speed, standardized, two-way communication allows for real-time information flows and decision-making among all grid components. Several existing technologies, including wide-area wireless internet and cellular networks, could provide the communications infrastructure needed.

- **Sensing and Measurement**

  Sensing and measurement allow utilities and consumers to understand and react to the state of the electrical grid in real-time. For example, households could monitor their energy demand and the current price of electricity through smart meters, which communicate with home networks that link smart appliances and display devices.

- **Advanced Components**

  Advanced components such as GPS systems, current-limiting conductors, advanced energy storage, and power electronics will improve generation, transmission, and distribution capacity and operational intelligence for utilities.

- **Advanced Control Methods**

  As more information is available to grid controllers and faster response times are required, the task of managing an electrical grid is becoming more complex. Advanced control systems find and process important information quickly, streamlining operations and providing clarity to human operators.

- **Improved Interfaces and Decision Support**

  New tools, such as software to visualize networks at any scale (from an individual neighborhood to the entire national grid), provide system operators with greater situational awareness and diagnostics and allow planners, operators, and policymakers to make informed decisions.

Key Applications

The smart grid technologies that form the foundation of a new grid enable new smart grid applications, including:

- **Automatic Meter Reading / Advanced Metering Infrastructure (AMR / AMI)**[22,23]

  AMR allows utilities to read electricity, water, and gas meters electronically; as opposed to sending a meter-reader to each house every month. AMI goes the next step, adding 2-way communications that allow the utility to act on information coming back from meters, adjusting prices and responding to outages or power quality events in real-time.

- **Real-Time Pricing (RTP)**[24]

  RTP charges electricity prices dynamically to reflect the realities of the electricity market. Successful

RTP depends on a price-elastic demand for electricity, allowing markets to determine prices quickly and keeping prices in a reasonable range for consumers. A smart grid lets consumers prioritize and monitor their electricity use, resulting in cost savings and a more economically efficient electricity market.

- Demand Response (DR)[25,26]

  DR allows utilities to reduce demand during periods of peak load and thus avoid dispatching high-cost generating units which are often among the least efficient and dirtiest. DR can distinguish between valuable and low-priority electricity uses – for example, dimming lights and adjusting air conditioners without disrupting vital services.

- Smart Charging / Vehicle-to-Grid (V2G)[27]

  PEVs will greatly increase the load on the grid. A single PEV can draw more power than a typical household. Smart Charging devices allow PEVs to communicate with the utility, timing the charging to coincide with low prices, low grid impact, and potentially low emissions periods (e.g., when renewable energy sources are available). V2G takes this concept one step further by allowing PEVs to feed their power back into the grid to help stabilize voltage and frequency, reducing the need for spinning reserves and regulation services and thus avoiding emissions from electricity generating units that would otherwise need to provide these services.[28]

- Distribution Automation[29]

  Distribution automation allows distribution systems to reconfigure themselves when a fault occurs, restricting the problem to a smaller area.[30] This reduces the amount of time that backup generators (usually diesel-based) operate and cuts total outage time.

- Distributed Generation Integration[31]

  By providing greater fault tolerance and islanding detection, a smart grid allows for safer and more reliable connections of distributed generation units such as rooftop solar installations, small natural gas turbines used for heat and electricity in commercial buildings, and building integrated wind systems.[32]

Environmental Benefits/Emissions Reduction Potential[33]

Smart grid technologies reduce GHG emissions in a number of ways. This Climate Techbook entry focuses on three:

- Increasing efficiency and conservation
- Enabling renewable energy integration
- Enabling PEV integration

The Electric Power Research Institute (EPRI) calculates that a national smart grid could reduce annual GHG emissions by 60-211 million metric tons of carbon dioxide equivalent (MMT CO_2e) compared to “business-as-usual” by 2030, an amount equal to 2.7-9.6 percent of GHG emissions from electricity generation in

2009.[34,35]

- **Increasing Efficiency and Conservation**

  More than half of this potential reduction in GHG emissions would be achieved through energy efficiency and conservation measures enabled by the smart grid, such as:

  - Reducing transmission losses through better management of distribution systems.[36]
  - By having a better understanding of equipment conditions through real-time equipment monitoring, utilities can keep vital components operating at high efficiency.
  - Managing peak-load through demand response instead of spinning reserves.
  - Increasing transparency in electricity prices, helping customers understand the true cost of electricity. The simple act of giving consumers continuous direct feedback on electricity use could reduce annual CO_2 emissions by 31-114 MMT CO_2e/year in 2030 as consumers adjust their usage in response to pricing and consumption information.[37]

- **Enabling Renewable Energy Integration**

  EPRI estimated that the increased renewable generation enabled by a smart grid could reduce GHG emissions by 19-37 MMT CO_2e /year in 2030.[38] There are two separate components to better renewable integration:

  Support for distributed generation

  - Control technologies enable safer and more reliable integration of distributed renewable generation (e.g., rooftop solar)
  - More accurate accounting for distributed generation with advanced meters makes net metering more attractive

  Network-wide resilience to variable renewable supply

  - Demand response resources buffer variability in supply[39]
  - PEV integration offers distributed energy storage and ancillary services
  - Better pricing mechanisms and demand side management can reduce transmission congestion, allowing more utility-scale renewable projects to connect to the grid

- **Enabling Plug-in Electric Vehicles**

  A large source of GHG emissions in the United States is the auto fleet. PEVs can have lower emissions than traditional automobiles with gasoline internal combustion engines. EPRI estimated that the incremental adoption of plug-in hybrid electric vehicles (PHEVs) enabled by a smart grid could result in GHG emission reductions of 10-60 MMT CO_2e/year by 2030.[40] A smart grid is needed to integrate PHEVs, and PEVs more generally, without putting intense strain on grid resources.

  Smart Charging

  With real-time pricing and system-wide price signals, PEV charging can be done primarily during off-peak periods, avoiding reliance on costlier and often more polluting "peaker" plants.

Vehicle-to-Grid (V2G)

PEVs can be used to provide regulation services for the grid instead of relying on fossil fuel generation such as diesel or natural gas generators.

Cost

The business case for a smart grid can be separated into costs and benefits for three major stakeholders: utilities, consumers, and society. Unlike some technologies whose primary benefit is direct avoidance of GHG emissions, the smart grid provides a wide array of benefits beyond helping combat climate change, and also indirectly reduces GHG emissions to a large degree by enabling other low-carbon technologies. Moreover, the benefit-cost rationale for smart grid investments is not dominated by GHG emission reductions.

- Utilities

Smart grid projects represent large capital expenditures for utilities. For example, an AMI deployment is estimated to have a cost about $70 to $140/meter for residential users and $7 to $15/meter installation cost.[41] As metering components and communications systems become more standardized costs may come down. EPRI estimates that a national smart grid could cost $338 to $476 billion over 20 years, but resulting in $1,294 to $2,028 billion in benefits over the same period.[42] As of May 2011, California's Pacific Gas and Electric (PG&E) company installed 7.9 million meters at a cost of $2.095 billion.[43] PG&E reports that it has already accumulated $111.3 million in benefits since the start of the transition to smart meters that began in 2007.[44]

- Consumers

Consumers undoubtedly bear much of the cost of smart grid projects through rate increases. At the same time, consumers who are active in managing their electricity consumption will benefit in the long-run from decreased peak electricity consumption and a lower total cost of energy. A Department of Energy (DOE) smart grid demonstration project in Olympic Peninsula, Washington found that consumers save 10 percent on their utility bills.[45] Consumers also stand to benefit from improved power quality and fewer outages. For example, estimated incremental monthly costs for consumers of providing advanced meters for every household and business vary from $9 to $12 per residential and $60 to $84 per commercial customer,[46] but consumers can benefit from monthly rate savings from greater control over electricity usage. A benefit to utilities can in turn benefit consumers through rate reductions or reduced rate increases.[47]

- Society

Society stands to benefit from the environmental benefits, increase in reliability, and other benefits of a smart grid. For example, EPRI estimates that $102 to $390 billion benefits to the environment in terms of lower carbon dioxide emissions from greater electricity system efficiency, and $281 to $444 billion in benefits to society from improved grid reliability.[48]

Current Status

According to National Energy Technology Laboratory (NETL), most of the needed smart grid technologies are commercially available now or are actively being developed.[49] This availability of technology is reflected by the hundreds of AMI projects currently underway across the country.[50] At least 10 different coalitions exist to promote smart grid technologies, conduct R&D, and organize standards and interoperability.[51] The market penetration for advanced meters has also increased, jumping from 1 percent of households and businesses in 2005 to 8.7 percent in 2009.[52] Certain states, such as Arizona, Oregon and Idaho, have reached about 25 percent smart meter penetration.[53] Examples of recent projects include:

- Southern California Edison, through its SmartConnect program, is planning to install advanced meters for all its household and small business customers (approximately 5.3 million meters) by 2012 and initiate dynamic pricing and demand reduction practices; the efforts are expected to avoid as much as 1 GW of capacity additions and to lower electricity bills for consumers[54], while reducing GHGs per year by 365,000 metric tons.[55] As of July 2011, it has installed more than 2.7 million smart meters.[56]
- Florida Power and Light has partnered with General Electric (GE), Cisco Systems, and Silver Spring Networks in a $200 million overhaul of 1 million homes and businesses with open-standards, internet-based smart grid system. The system is expected to save customers 10-20 percent on their power bills, with half the cost of the smart grid investments paid by the utility and half by the American Recovery and Reinvestment Act of 2009 (ARRA).[57,58]
- PG&E has installed more than 7.9 million meters and reported $111.3 million in benefits since the first smart meter became active in 2007.[59]

Obstacles to Further Development or Deployment

Several obstacles prevent the implementation of a nationwide smart grid:

- Upfront Consumer Expenses

In the responses of 200 utility managers to a 2009 survey, 42 percent cited "upfront consumer expenses" as a major obstacle to the smart grid.[60] These concerns were confirmed by consumer responses in which 95 percent of respondents indicated they are interested in receiving detailed information on their energy use; however, only 1 in 5 were willing to pay an upfront fee to receive that information.[61] Regulatory approval for rate increases needed to pay for smart grid investments is always difficult, and the receptiveness of regulators varies from state to state.

- Lack of Standardization

30 percent of utility managers cited "lack of technology standards" as a major obstacle to smart grid deployment.[62] Uncertainty about interoperability and technology standards present the greatest risk to utilities, who do not want to purchase components that will not work with new innovations down the road.[63]

- **Regulatory Barriers**

Many of the obstacles to a smart grid are regulatory issues. Electric power is traditionally the regulatory domain of states. The patchwork of regulatory structures and jurisdictions is only loosely coordinated, and final authority on many decisions can be unclear, as projects are subject to multiple levels of review. Local (municipal, county), state-level, and federal jurisdictions overlap, and conflicting decisions can result in regulatory lead times of several years. Some regulatory decisions can also be challenged in court, resulting in more potential delays at each level. This series of delays adds significantly to the cost and regulatory risk of pursuing a smart grid project.

- **Lack of Widespread Understanding**

Because smart grid is still a new concept and the technologies that enable it are rapidly evolving, there is misunderstanding amongst consumers, regulators, policymakers, and businesses about what its costs and benefits are. Stakeholders that are generally aligned may reach different conclusions based on a different understanding of the smart grid. As an example of the mistrust of new smart meter technologies, some customers have complained about rate increases after receiving a smart meter, which resulted in a lawsuit against California's PG&E.[64] The suit has damaged consumer confidence with new technology and prompted California's PG&E to slow smart meter deployment.[65] Ultimately, the suit was dismissed based on California Public Utilities Commission's findings that the smart meters are accurate and functioning properly.[66]

Policy Options to Help Promote a Smart Grid

- **Develop National Standards**

The 2007 Energy Security Act tasked the National Institute of Standards and Technology (NIST) with developing nationwide standards for smart grid technology in consultation with industry groups, such as the GridWise Alliance, and other standards bodies, such as the Institute of Electrical and Electronics Engineers (IEEE). Because technology risk from changing standards represents the largest risk to utilities, developing and institutionalizing national standards that are available to all players will greatly accelerate development. Standards would cover such technical areas as communication among smart grid devices and security.

- **Provide Federal Funding for Smart Grid**

The Energy Independence and Security Act of 2007 (EISA) and the economic stimulus bills of 2008 and 2009 all authorized federal funding for smart grid projects and R&D.[67] The American Recovery and Reinvestment Act of 2009 (ARRA) directs $4.5 billion to modernize the electrical grid.[68] Over 150 smart grid projects[69] have been funded through ARRA as of July 2011. The projects include replacing traditional meters with smart meters, adding monitoring and controlling software to existing electric power infrastructure to enable smart grid features and to conduct consumer behavior surveys to see how consumers react to time-based electricity pricing.[70] In addition, the federal government could provide a direct incentive to utilities in the form of tax credits to accelerate smart grid deployment.

- **Require Greater Reliability**

The current grid is 99.97 percent reliable on average, however this varies amongst utilities.[71] Increasing the requirement for grid reliability or establishing performance-based rates that would allow utilities to charge a higher rate for better reliability, would incentivize utilities to invest in new technologies.[72]

- **Develop the National Communications Infrastructure**

Many utilities engaged in smart grid projects find that they are spending significant portions of their project costs on communications and IT infrastructure rather than physical smart grid components. Creating a nationwide broadband infrastructure and allowing the smart grid to leverage it could have benefits for both the communications and electric power sectors.

- **Provide for Utility Cost Recovery**

Because states bear the primary responsibility for approving smart grid projects and cost recovery for utilities, there is significant disparity in smart grid deployment levels among states. Coupling federal incentives for smart grid with prudent cost recovery at the state level can help to accelerate deployment.

- **Increase Consumer Awareness**

Greater educational efforts could be made to inform consumers about smart grid and the environmental impacts of energy use.

Business Environmental Leadership Council (BELC) Company Activities

- ABB
- Alstom
- American Electric Power
- Boeing
- Dow Chemicals
- DTE Energy
- Duke Energy
- Entergy
- Exelon
- GE
- GM
- HP

- IBM
- Intel
- Johnson Controls
- Lockheed Martin
- NRG Energy
- PG&E
- PNM Resources
- Whirlpool

Related Pew Center Resources

Climate Change 101: Technology, 2011

The U.S. Electric Power Sector and Climate Change Mitigation, 2005

Wind and Solar Electricity: Challenges and Opportunities, 2009

Further Reading / Additional Resources

SMART 2020: Enabling the Low Carbon Economy in the Information Age, The Climate Group, Prepared for the Global eSustainability Initiative (GeSI), 2008

Edison Foundation , *Transforming America's Power Industry: Investment Challenge 2010-2030*, 2008

Electric Power Research Institute (EPRI), *The Green Grid: Energy Savings and Carbon Emissions Reduction Enabled by a Smart Grid*, 2008

U.S. Energy Information Administration (EIA), *Energy in Brief: What Is the Electric Power Grid, and What Are Some Challenges It Faces?*

EPRI, Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid, 2011

The Electricity Advisory Committee, *Smart Grid: Enabler of the New Energy Economy*, 2008

Federal Smart Grid Task Force

IEEE, Smart Grid Technology Portal

National Energy Technology Lab (NETL), "The NETL Smart Grid Implementation Strategy"

SmartGridNews.com

Smart Grid Information Clearinghouse

Smartgrid.gov

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[1] PEVs include plug-in hybrid electric vehicles and battery-electric vehicles.

[2] For a useful overview of the electricity grid, see the U.S. Energy Information Administration (EIA), *Energy in Brief: What Is the Electric Power Grid, and What Are Some Challenges It Faces?*

[3] Jon Wellinghoff, Prepared Testimony of Jon Wellinghoff, Commissioner Federal Energy Regulatory Commission, 2007.

[4] The Smart Grid - An Introduction (U.S. Department of Energy).

[5] Ibid.

[6] U.S. Department of Energy Electricity Advisory Committee. "Smart Grid: Enabler of the New Energy Economy" December 2008.

[7] Power quality is defined as the provision of power with specified voltage and frequency characteristics to the customer. Small imbalances in the sub-minute time frame between electric power supply and demand, and the physical properties of electric power generators, electricity-consuming devices, and the transmission grid itself lead to small deviations (1 to 5 percent) between the expected and actual voltage and frequency of power delivered, which can cause highly sensitive equipment such as computers to fail. When electric power supply and demand are in balance, these deviations in voltage and frequency are eliminated.

[8] Tuophy, A. "Integrating Wind Generation in the Bulk Electricity System". EPRI. 2011.

[9] Smith, C., Demeo E., Smith, S. "Integrating Wind Generation Into Utility Systems" North American Wind Power. September 2006.

[10] Kintner-Meyer, M. et. al. "Energy Storage for Variable Renewable Energy Resource Integration – A Regional Assessment for the Northwest Power Pool (NWPP)" Pacific Northwest National Laboratory. 2010.

[11] California Governor Issues Executive Order Increasing State RPS. Pew Center on Climate Change. September 2009.

[12] Smart Grid Information Clearinghouse. "Learn More About Smart Grid". Accessed August 5, 2011.

[13] U.S. Department of Energy National Energy Technology Laboratory. "Smart Grid Principal Characteristics: Enables Active Participation by Consumers". September 2009.

[14] U.S. Department of Energy National Energy Technology Laboratory. "A Systems View of the Modern Grid – Appendix A1: Self-Heals v2.0" 2007.

[15] Software that monitors the smart grid could automatically sense power fluctuation that could interrupt service and make adjustments without operator intervention. See Smart Grid Information Clearinghouse: distributed intelligent control systems.

[16] U.S. Department of Energy National Energy Technology Laboratory. "Smart Grid Principal Characteristics: Enables New Products, Services, and Markets" February 4, 2010.

[17] "SmartGridCity." Xcelenergy.com. Accessed August 11, 2011.

[18] "SmartMeter™ – See your power." Pge.com. Accessed August 11, 2011.

[19] "AEP Texas – Smart Meters." Aeptexas.com. Access August 11, 2011.

[20] "Smart Power Grids - Talking about a Revolution," IEEE, 2009.

[21] Enabling Technologies. Smart Grid Information Clearninghouse. Accessed July 26, 2011.

[22] Electric Power Research Institute. "Advanced Metering Infrastructure (AMI) Factsheet" February 2007.

[23] Department of Energy National Energy Technology Laboratory. "Advanced Metering Infrastructure: Powering our 21st-Century Economy." February 2008.

[24] ComEd. "The ComEd Residential Real-Time Pricing Program: Guide to Real-Time Pricing." 2010.

[25] National DR Directory. "Demand Response Overview." Accessed August 5, 2011.

[26] Federal Energy Regulatory Commission. "Assessment of Demand Response & Advanced Metering." February 2011.

[27] University of Delaware. "The Grid-Integrated Vehicle with Vehicle to Grid Technology." Accessed August 5, 2011.

[28] Spinning reserve is an ancillary service in the electricity market defined as the ability of (usually a generator) to remain on and ready to start generating given notice over a short period of time (15 minutes to an hour). Regulation refers to an ancillary service (usually provided by electricity generators) to maintain power quality by ramping generation up and down to follow unpredicted minute-by-minute fluctuations in electricity demand.

[29] Smart Grid Information Clearinghouse. "Distribution Automation." Accessed August 5, 2011.

[30] Distribution automation is the use of intelligence to create automated operational decisions in electric power distribution infrastructure for the purpose of maintaining or restoring power.

[31] Reitenbach, G. "The Smart Grid and Distributed Generation: Better Together." POWER. April 1, 2011. Accessed August 5, 2011.

[32] Fault tolerance allows distributed generation to "ride through" fault events on the distribution system that would otherwise force it to disconnect and stop producing power. This allows the distributed generation to be connected for a larger amount of time and provide a better return on investment for the investor. Islanding detection refers to the ability of utilities to detect unintentional islanding (or parallel operation) of distributed generation systems, which can result in poor power quality, be harmful to equipment and dangerous for electricians. Island operation occurs if one or more distributed generators continue to energize a part of the grid after the connection to the rest of the system has been lost, this can be dangerous to utility workers, the generation equipment itself, and other equipment connected to the grid.

[33] U.S. Department of Energy National Energy Technology Laboratory. "Environmental Impacts of Smart Grid." January 10, 2011.

[34] The Green Grid - Energy Savings and Carbon Emissions Reduction Enabled by a Smart Grid, Technical Update (Electric Power Research Institute (EPRI), June 2008), 1016905.

[35] Environmental Protection Agency, 2011, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009*. Table 2-13.

[36] Greater information availability about distribution systems will allow utilities to make better decisions about maintenance and operations. The information allows utilities to make informed decisions about field equipment.

[37] The Green Grid, EPRI 2008.

[38] The Green Grid, EPRI 2008.

[39] Wind and solar power are both variable electricity generation technologies insofar as they only generation power when the wind is blowing or the sun is shining, respectively.

[40] The Green Grid, EPRI 2008.

[41] Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid. EPRI. March 29, 2011. 1022519.

[42] Ibid

[43] SmartMeter™ Steering Committee Update. Pacific Gas and Electric Company. May 2011. Accessed July 26,2011.

[44] Ibid.

[45] Gridwise.org. *A Smart Grid: Cost Reduction*. 2011. Accessed August 10, 2011.

[46] EPRI 2011.

[47] Ibid.

[48] Ibid.

[49] Compendium of Modern Grid Technologies, NETL Modern Grid Strategy, July 2009.

[50] Smart Grid Projects. Smart Grid Information Clearinghouse. Accessed July 2011.

[51] Profiling and Mapping Intelligent Grid R&D, EPRI, 2008.

[52] Assessment of Demand Response & Advanced Metering. Federal Energy Regulatory Commission. February 2011.

[53] FERC 2011.

[54] Amy Abel, “Smart Grid Provisions in H.R. 6, 110th Congress”, Congressional Research Service, Dec 2007

[55] Edison SmartConnect™: Benefits to You. Southern California Edison. Accessed July 22, 2011.

[56] Edison SmartConnect™: About Edison SmartConnect™. Southern California Edison. Accessed July 28, 2011.

[57] “Get Smart: GE, FPL Announce ‘Biggest’ Smart Grid Deal in Miami.” WSJ Blogs. Keith Johnson. April 2009.

[58] Open standards, as opposed to proprietary standards, allow any firm to develop devices or applications that interface with a system rather than limiting a system, such as the smart grid or a component thereof, to devices and applications from a single or limited set of firms. Open standards are thought by many to be more conducive to innovation and flexibility.

[59] SmartMeter™ Steering Committee Update. PG&E 2011.

[60] Turning Information Into Power, Survey (Oracle, March 2009).

[61] Oracle 2009.

[62] Oracle 2009.

[63] Barriers to Achieving the Modern Grid, NETL Modern Grid Initiative, June 2007.

[64] See Flores v. Pacific Gas and Electric. Kern County Superior Court of California, case number S-1500-CV-268647.

[65] PG&E Sued Over Smart Meters, Slows Down Bakersfield Deployment. Greentech Grid. November 11, 2009. Accessed July 28, 2011.

[66] SmartMeter™ Updates: Lawsuit Dismissed; Final CCST Report Issued. PG&E Currents. April 18, 2011. Accessed July 28, 2011.

[67] The stimulus bills are the Economic Stimulus Act of 2008 and the American Recovery and Reinvestment Act of 2009.

[68] Overview. Smartgrid.gov. Accessed on July 25, 2011.

[69] DOE Recovery Act Awardees – July 22, 2011. Accessed July 29, 2011.

[70] Smart Grid Investment Grant (SGIG) Program Asset Investment. U.S. Department of Energy. June 10, 2011. Accessed July 28, 2011.

[71] In addition to raising the reliability standard from 99.97 percent, the minimum outage duration counted against reliability could be lowered. Currently, reliability standards ignore outages of less than 5 minutes.

[72] Policy Framework for a Consumer-Driven Electric Power System. Perfecting Power. Galvin Electricity Initiative. January 2010.