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U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY DELIVERY & ENERGY RELIABILITY

Smart Grid Investment Grant Program Final Report

EXECUTIVE SUMMARY

December 2016

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View the complete Final Report at:

https://energy.gov/sites/prod/files/2017/01/f34/Final%20SGIG%20Report%20-%202016-12-20_clean.pdf.

EXECUTIVE SUMMARY

In 2009, the U.S. Department of Energy (DOE) launched the Smart Grid Investment Grant (SGIG) program, funded by $3.4 billion invested through the American Recovery and Reinvestment Act of 2009 (ARRA) to modernize the nation's electricity system. Projects began in 2010, and the program was completed in 2015.

While the SGIG program has published an extensive series of technical reports throughout the program on SmartGrid.gov, this final report summarizes the major SGIG achievements, key project results, and lessons learned across the smart grid landscape, which included:

- Synchrophasor technologies on electric transmission systems.
- Distribution automation (DA) technologies and systems, including advanced sensors and self-healing controls.
- Advanced metering infrastructure (AMI), including smart meters and two-way communications networks.
- Customer systems, including in-home displays (IHD), programmable communicating thermostats (PCT), and direct load control devices (DLC) that enable utilities to offer time-based rates and incentives.

The SGIG program stimulated near-term economic growth, created jobs, and enhanced the reliability and resilience of the nation's electric grid through the deployment of smart grid technologies, tools, and practices. To catalyze continued investment in grid modernization, the SGIG program analyzed the impact, costs, and benefits of smart grid technologies and shared the data to help reduce the financial and technical risks for follow-on smart grid efforts.

SGIG projects were competitively selected and required a minimum 50 percent cost share, attracting an additional $4.5 billion in private, local investment during an economic downturn—bringing the total SGIG investment to $7.9 billion. Because of this public-private partnership, many utilities accelerated their grid modernization plans by as many as 10 years, or were able to broaden the scope of planned projects to benefit more customers.

SGIG projects helped to rapidly mature the smart grid vendor marketplace. By 2012, SGIG had created 12,000 direct jobs in the smart grid ecosystem of manufacturers, IT, and technical service providers, and created another 35,000 full-time equivalent positions throughout vendor supply chains.[1] As the program was expressly designed to help utilities tackle the learning curve of new technologies and functions, the projects demonstrated smart grid technology benefits and cost savings that were expected but not yet proven—and documented results and lessons learned to educate industry peers.[2]

The U.S. electricity system reached key grid modernization targets up to four years faster than expected during SGIG. By 2012, U.S. utilities had already surpassed the program's 2015 target for nationwide smart meter deployments; by 2015, nearly half of U.S. customers had smart meters—almost 65 million—a milestone that would not have been met until 2019 based on pre-ARRA utility plans and proposals.[3]

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[1] U.S. Department of Energy, Economic Impact of Recovery Act Investments in the Smart Grid (April 2013).
[2] SmartGrid.gov serves as a library of SGIG project information and smart grid technology results, benefits, and lessons learned.
[3] The Edison Foundation Institute for Electric Efficiency, *Utility-Scale Smart Meter Deployments, Plans & Proposals* (September 2009).

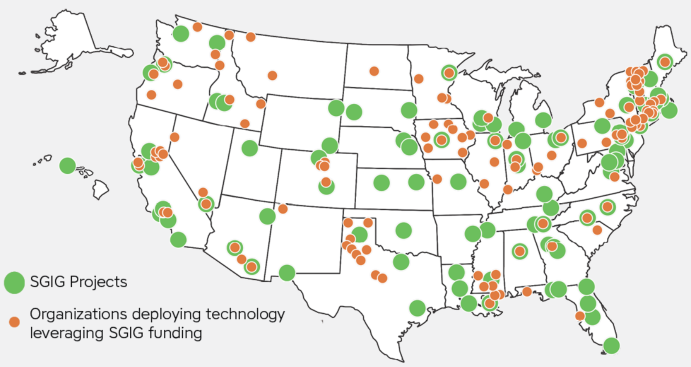
SMART GRID INVESTMENT GRANT (SGIG) PROGRAM OVERVIEW

SGIG PROGRAMS AND FUNDING

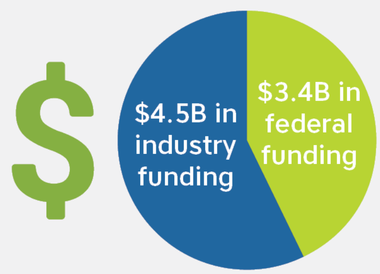
99 competitively selected projects

228 participating utilities and organizations

6 years (2010-2015)

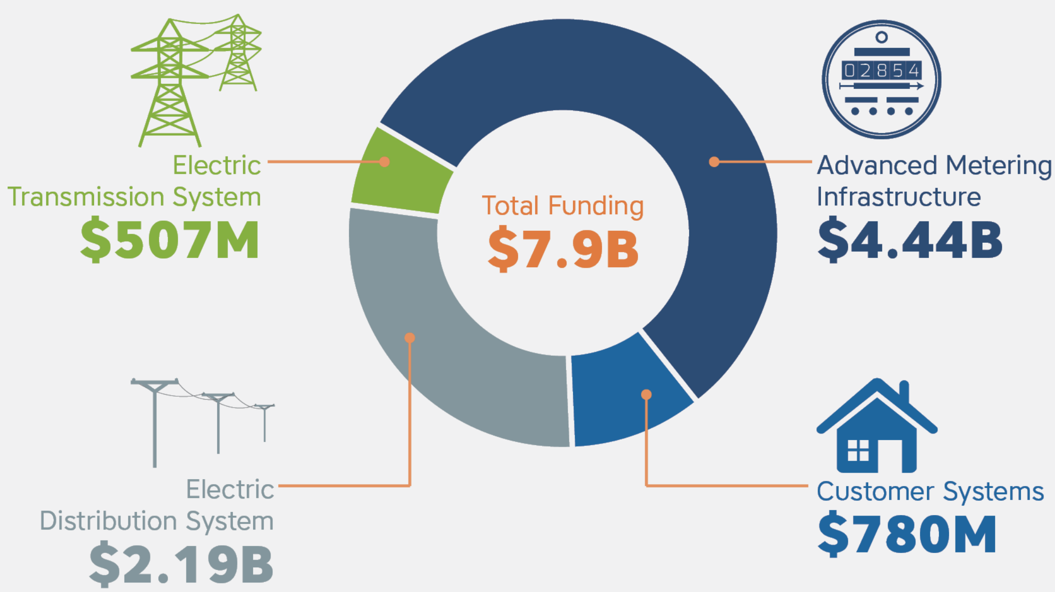


$7.9B public/private investment



ARRA funding was matched or exceeded dollar for dollar by recipients.

SGIG PROJECT TECHNOLOGY AREAS



SGIG TECHNOLOGY DEPLOYMENTS

ELECTRIC TRANSMISSION SYSTEM

1,380 networked synchrophasors contributed to a more than **10** fold increase in North American synchrophasors from 2007 to 2015.

CUSTOMER SYSTEMS

Nearly **700,000** customer devices

ELECTRIC DISTRIBUTION SYSTEM

82,000 intelligent, automated devices

ADVANCED METERING INFRASTRUCTURE

16M SGIG smart meters about **33%** of the **49M** total smart meters installed in the U.S. from 2010 – 2014

DEMONSTRATED SMART GRID TECHNOLOGY BENEFITS

- Increased wide-area visibility and faster situational awareness in the transmission system to prevent local disturbances from cascading into major regional blackouts.
- Fewer and shorter outages that result in less inconvenience and lower outage costs for customers.
- Improved grid resilience to extreme weather events by automatically limiting the extent of major outages and improving operator ability to diagnose and repair damaged equipment.
- Faster and more accurate outage location identification for improved repair crew dispatching and service restoration, reducing operating costs, truck rolls, and environmental emissions.
- More effective equipment monitoring and preventative maintenance that reduce operating costs and the likelihood of equipment failures, make more efficient use of capital assets, and resulting in fewer outages.
- Lower peak demand and higher power factors for improved asset utilization and deferral of capital investments in capacity additions.
- Reduced costs for metering and billing from fewer truck rolls, labor savings, more accurate and timely bills, and fewer customer disputes.
- Improved customer control to manage electricity consumption, costs, and bills from new customer tools (e.g., web portals and PCTs) and programs (e.g., time-based rates, incentives, and DLC) for shifting demand from peak to off-peak periods.

SGIG was the largest program of a broader $4.5 billion ARRA-funded grid modernization effort managed by the DOE Office of Electricity Delivery and Energy Reliability (OE).[4] This portfolio included the Smart Grid Demonstration Program, the Smart Grid Workforce Training Program, projects for regional electric transmission planning and renewable and distributed energy integration, and development of smart grid cybersecurity and interoperability standards in collaboration with the National Institute of Standards and Technology.

Major Findings and Key Results

The SGIG program helped jumpstart grid modernization by proving that an array of smart grid technologies, tools, and techniques can work effectively in utility applications and improve grid planning and operations in a variety of ways. The data collected from the projects provided evidence of grid improvements and financial benefits at different scales and utility environments.

For many participating utilities, SGIG provided an opportunity to gain confidence and experience while resolving both expected and unforeseen issues. Several utilities used SGIG funding to test the integration of new technologies and systems on a small scale, while others used the opportunity for large-scale or system-wide deployments—creating variation in costs and impacts. Many of the projects implemented some but not all of the smart grid capabilities that new devices made available, with the plan to activate more functions over time, depending on results.

DOE published technology results and lessons learned on SmartGrid.gov throughout the program to reduce investment uncertainty for utilities, regulators, and other key decision-makers.[5] Because many of the technologies and systems were new to most of the utilities, evaluating results was often a challenge, particularly when establishing baselines and estimating before-and-after grid impacts. Unprecedented volumes of data challenged utilities to develop new methods, models, and more advanced data analytics. Nevertheless, information developed under SGIG provided quantitative evidence, insights, and lessons learned for guiding future investments in grid modernization, as highlighted in the major findings below.

Synchrophasor deployments improve transmission system visibility and help grid operators prevent large-scale outages.[6]

The SGIG program deployed more than 1,300 phasor measurement units (PMUs) to enhance visibility by measuring and delivering data 100 times faster than conventional technologies, permitting grid operators to identify and correct for system instabilities, such as frequency and voltage oscillations, and operate transmission lines at higher capacity levels. The SGIG projects marked the first time that many transmission owners and operators installed modern, production-grade PMUs on an operational scale—transitioning synchrophasor technology from a research and off-line analysis tool to one that actively enhances real-time operations.

> Synchrophasors also proved valuable in detecting and diagnosing transmission and generation issues before they become threats to the power system. The American Transmission Company **identified and replaced a potentially failing transformer, avoiding an extended transmission substation outage**. The New York Independent System Operator (NYISO) **detected a malfunctioning automatic voltage regulator controller** in one generating station and a failed power system stabilizer in another.

[4] DOE OE, "ARRA Grid Modernization Investment Highlights," fact sheet (October 2015).
[5] See Appendix A. SGIG Project Information, Case Studies, and Key Reports for a detailed list of publications.
[6] DOE OE, *Advancement of Synchrophasor Technology in Projects Funded by the ARRA* (March 2016).

Before SGIG, there were fewer than 200 PMUs in the U.S. transmission system, used primarily for research. By 2015, there were more than 1,700 networked synchrophasors, providing visibility across nearly 100 percent of the U.S. transmission system at varying degrees of resolution. Grid operators across the country are beginning to use this synchrophasor data to enhance situational awareness and wide-area monitoring, improve state estimator models for better understanding of real-time grid conditions, improve dynamic planning models for better understanding of how power systems respond to grid disturbances, and provide more thorough and accurate forensic analysis of disturbances and outages.

In 2008, 14 transmission lines taken out of service by Hurricane Gustav formed an electrical island. Entergy's **synchrophasors enabled operators to detect the island and then diagnose and mitigate instabilities within that island, preventing a blackout of New Orleans and Baton Rouge.** This was a motivator for Entergy to triple its number of PMUs to 49 and expand its synchrophasor system capabilities under its SGIG project.

DA and AMI improve reliability with fewer and shorter outages, faster service restoration, and customer savings.[7]

DA technologies provided advanced capabilities for operators to detect, locate, and diagnose faults. In particular, fault location, isolation, and service restoration (FLISR) technologies can automate power restoration in seconds by automatically isolating faults and switching some customers to adjacent feeders. FLISR can reduce the number of affected customers and customer minutes of interruption by half during a feeder outage. For customers, DA operations during major storms saved one utility's customers on a 14-feeder segment $1.2 million in one year. Fully automated switching and validation typically resulted in greater reliability improvements than operator-initiated remote switching with manual validation.

FLISR and smart meters at the Electric Power Board of Chattanooga, TN helped operators **restore system-wide power about 17 hours earlier than without DA** after a July 2012 derecho. After another storm in February 2014, EPB was able to restore power **36 hours faster and reduce affected customers from 70,000 down to 33,000.**

Precise fault location enabled operators to dispatch repair crews accurately and notify customers of outage status, which reduced outage length and repair costs, reduced the burden on customers to report outages, and increased customer satisfaction. As a result, SGIG projects were able to:

- Remotely pinpoint the location and extent of outages, better direct resources, and equip repair crews with precise, real-time information—**often shaving hours or days off restoration time following major storms**. By integrating DA with AMI, utilities reduced outage duration, limited customer inconvenience, and reduced labor hours and truck rolls for outage diagnosis and restoration.
- Isolate disruptions and restore downstream customers within seconds by automating distribution tasks such as fault detection and feeder switching. For *each* outage event, **utilities reduced the number of affected customers by as much as 55 percent and reduced the total customer minutes of interruption by up to 53 percent** using "self-healing" FLISR capabilities.
- In 2013, 3 utilities reported **System Average Interruption Frequency Index (SAIFI) improvements of 17–58 percent** from pre-deployment baselines.

[7] DOE OE, *Distribution Automation: Final Report from the SGIG Program* (September 2016).

Utilities facing regular, severe weather events and storm-induced outages often have greater incentives for using AMI for outage management than those that do not.[8] AMI data integration with other information and management systems, including geographic information systems, enabled utilities to create detailed outage maps, and in some cases posted these maps on utility websites to keep the public informed on service restoration progress.

Automated controls for voltage and reactive power management improve efficiency and power factors and reduce energy consumption and costs.[9]

Automated voltage regulation and power factor correction enabled SGIG utilities to reduce peak demand, use assets more efficiently, defer capital investments, and improve power quality for customers. Several utilities used conservation voltage reduction (CVR) techniques to reduce feeder voltage levels, improve the efficiency of distribution systems, and reduce energy consumption, especially during peak demand periods.

Automated power factor correction provided new capabilities for managing reactive power flows and boosting power quality. Several utilities improved power factors to near unity through integrated volt/VAR controls, and one utility reduced reactive power requirements by about 10 to 13 percent over one year.

Several utilities found **CVR to produce energy savings of 2-4 percent** on affected feeders—a change that when applied system-wide could save hundreds of thousands of dollars in yearly energy costs and reduce power plant emissions.

Voltage monitoring provides another promising benefit stream to include in business case analysis of AMI investments. Utilities can use AMI voltage monitoring capabilities to enhance the effectiveness of automated controls for voltage and reactive power management, particularly for CVR programs.

Con Edison used its voltage control and reactive power management technologies to **increase its 4kV unit substation capability by 2.8 percent, resulting in a net savings of $15.7 million.**

Equipment health sensors prevent equipment failures, reduce outages, and lower O&M costs.[10]

Installing sensors on key components (e.g., power lines and transformer banks) to measure equipment health parameters provides real-time alerts for abnormal equipment conditions and data for new analysis tools for utility engineers to improve preventative maintenance and equipment repairs and replacement. These technologies and systems also equip grid operators with new capabilities to better dispatch repair crews based on diagnostics data.

Florida Power and Light **prevented an outage for 15,000 customers** and avoided $1 million in restoration costs by identifying and repairing a transformer before it failed.

[8] DOE OE, *Advanced Metering Infrastructure and Customer Systems: Final Report from the SGIG Program* (September 2016).
[9] DOE OE, *Distribution Automation: Final Report from the SGIG Program* (September 2016).
[10] Ibid.

Operational efficiencies from AMI and DA deliver cost savings and improve customer service and satisfaction.[11]

CenterPoint Energy reported total **AMI cost savings of more than $61 million from 2012-2014.** Tamper detection functions alone prevented revenue losses exceeding $450,000 in 2012 and $130,000 in 2014.

AMI and DA projects together reduced an estimated 17,510 metric tons of CO_2-equivalent emissions by eliminating nearly 14 million truck rolls and 71.8 million vehicle-miles[12] that were previously required to read meters, detect outages and confirm restoration, manually detect faults, inspect equipment health, and conduct manual feeder switching. Nine SGIG utilities together avoided $6.2 million in distribution operations costs over a one-year period[13] and eight utilities avoided $1.46 million in switching costs over three years.[14] AMI operations from 19 projects also cumulatively saved $316 million in O&M costs over a three-year period—an average of $16.6 million per project reporting.[15]

- Large-scale deployments and utilities with low customer densities or geographically dispersed territories had the greatest savings potential. Utilities with AMI are now able to fulfill remote service connection and disconnection orders in hours instead of days.
- Many utilities improved billing accuracy, reduced customer complaints, and used AMI data to resolve billing disputes faster. AMI enabled some utilities to proactively identify and notify customers of unusual usage patterns in advance of bills.
- Pre-pay billing plans helped customers to better manage energy consumption and costs. Several utilities improved revenue collection and cost recovery by implementing pre-pay billing programs. AMI capabilities for tamper and theft detection also enhanced revenue collection and cost recovery.

AMI and customer systems improve time-based rate, incentive, and DLC programs that reduce peak demand, power consumption, and bills for many participating customers.[16]

Oklahoma Gas & Electric reported **average annual electricity savings of $191.78 for participating residential customers** and $570.02 for commercial customers.

More than 417,000 customers participated in one or more time-based rate or incentive programs under SGIG, including critical peak pricing (CPP), variable peak pricing (VPP), time-of-use (TOU) pricing, and critical peak rebates (CPR). In particular, a subset of 10 utilities participated in the Consumer Behavior Studies (CBS)[17], which evaluated different recruitment strategies, rate structures, and customer systems for customer acceptance, retention, and response.

- CBS utilities implemented programs in which customers reduced their peak demand by up to 23.5 percent.
- Several utilities found that PCT automation enabled greater peak demand reductions than manual responses.

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[11] Ibid; DOE OE, *Advanced Metering Infrastructure and Customer Systems: Final Report from the SGIG Program* (September 2016).

[12] DA operations avoided 197,000 truck rolls (reported by 16 projects) and 3.4 million vehicle-miles (reported by 18 projects) from 2011 to 2015. AMI operations avoided 13,785,708 truck rolls (reported by 42 projects) and 68,374,295 vehicle-miles (reported by 39 projects) from summer 2011 to winter 2014.

[13] Distribution operations cost savings data reported by 9 DA utilities from April 2013 to September 2014.

[14] Switching cost savings data reported by 8 DA utilities from April 2011 to March 2014.

[15] DOE OE, *Advanced Metering Infrastructure and Customer Systems: Final Report from the SGIG Program* (September 2016).

[16] DOE OE, *Customer Acceptance, Retention, and Response to Time-Based Rates from the Consumer Behavior Studies* (September 2016); DOE OE, *Advanced Metering Infrastructure and Customer Systems: Final Report from the SGIG Program* (September 2016).

[17] DOE OE, *Customer Acceptance, Retention, and Response to Time-Based Rates from the Consumer Behavior Studies* (September 2016).

- IHDs had minimal impact on demand reductions, and in many cases, participating customers declined to use them or used them for a short period of time.

DA and AMI improve integration of distributed energy resources (DER) for grid planning and operations.[18]

Burbank Water and Power in California used DER management systems to control ice storage systems **that made ice overnight to power daytime air conditioning loads**, which reduced the buildings' cooling requirements by about 5%.

Grid integration of DERs requires advanced tools to monitor and dispatch DERs, and to address new power flow and control issues, such as low-voltage ride through, harmonic injection, voltage fluctuations, and reactive power management. Some SGIG utilities evaluated distributed energy resource management systems and integrated automated dispatch systems on small DER installments. A small number also tested two types of DERs: thermal energy storage for commercial and government buildings, and charging stations for electric vehicles. These projects gained valuable insight into future grid impacts of DER technologies and load patterns.

SGIG cybersecurity policies improve utility business and technology protection practices to address emerging threats.

As top priority for every aspect of the program from its inception, cybersecurity under SGIG accelerated progress toward a more secure grid not only for participants but for the entire electric power industry. Smart digital devices added new IP-based access points to the grid, making customer privacy and cybersecurity paramount to smart grid success. All SGIG recipients were required to implement comprehensive cybersecurity plans and build cybersecurity into their policies, technologies, and business practices. SGIG expert cyber teams augmented these measures with over 300 onsite reviews to monitor project progress, including cybersecurity implementation. Two cybersecurity information exchange meetings held in 2011 and in 2012 promoted peer-to-peer sharing of best practices and lessons learned among SGIG projects.[19] Through this intensive effort, many SGIG utilities—particularly smaller ones—enhanced cybersecurity practices across their entire system and continue to use the SGIG cybersecurity plan as a model.

Lessons and Conclusions

The SGIG projects showed that further deployment of smart grid technologies, tools, and techniques can achieve favorable grid impacts and benefits for customers and utilities. Achieving these impacts and benefits involved changes in communications systems, workforce training, and business practices, especially for systems integration and cybersecurity.

Comprehensive planning for communications systems enables multiple and improved smart grid functions. Greater communications network capabilities are the backbone of grid modernization. Several SGIG utilities adopted long-term, comprehensive smart grid strategies that included building communications networks with large capacities to handle future smart grid applications, and with high bandwidth to accommodate additional services beyond electricity metering—such as gas and water metering and internet services. Network upgrades included many types of systems based on local conditions and needs including RF-based local mesh networks, high-bandwidth fiber optic cables, powerline carrier systems, and one-off microwave repeater solutions. With such systems in place, utilities can

[18] DOE OE, *Distribution Automation: Final Report from the SGIG Program* (September 2016).
[19] DOE OE, "2012 DOE Smart Grid Cybersecurity Information Exchange," workshop report (June 2013).

deploy smart grid devices faster and at full scale, and unlock additional capabilities from their investments in smart devices.

Effective systems integration is paramount for successful smart grid operations. Multiple information management and control systems all need access to a wide variety of new data streams to effectively accomplish smart grid functions. SGIG utilities installed new management information systems for meter data, distribution operations, outages, customer information, and enterprise service buses to promote interfacing between these systems. Systems integration proved to be one of the most significant challenges for many SGIG utilities, particularly for those deploying smart grid for the first time. Integration often required developing customized software for data processing, error checking, and coding.

Smarter grids require workforce training and new business practices, particularly for cybersecurity. Many of the SGIG projects made organizational changes in metering, customer service, marketing, and distribution operations, particularly in areas that require enhanced levels of integration of both new information systems and job functions. In many instances, these changes involved workforce training programs to develop new skillsets in areas such as database management, information systems, data analytics, and cybersecurity. Cybersecurity was a cornerstone of the SGIG program from its onset and required utility staff to develop and implement new cybersecurity policies, plans, and practices throughout the lifecycle of each project. This includes new levels of oversight and awareness for cybersecurity by utility managers and increased levels of time and resources devoted to it.

Future Directions and Next Steps

The majority of SGIG utilities are building on project results and planning for more technology deployments, offering successful pilot programs to more customers, and improving the integration of smart grid technologies, tools, and techniques within their electricity delivery systems. Several opportunities and challenges are guiding future grid modernization investments:

- **Many utilities have untapped opportunities to maximize the capabilities of new smart grid technologies**. For example, many utilities installed smart meters but have not yet used the embedded capabilities to monitor customer voltage levels, or have combined voltage monitoring with automated controls for voltage and reactive power management. Planned follow-on activities include expanding deployments to larger portions of service territories, expanding communications networks, and integrating various information management systems to realize untapped automation capabilities.

- **Vast amounts of new data require development of new data exchange and management capabilities, including new models and analysis tools to unlock the full value of smart grid technologies.** Smart meters, PMUs, and other devices provide timely and granular data at large volumes that require investments in high-bandwidth communications networks and advanced data analytics to better automate controls and inform operator decisions. These advanced capabilities are necessary to integrate large amounts of distributed and renewable generation, reduce susceptibility of the system to destabilizing events, and bring together utility functions for generation, transmission, distribution, and demand-side programs.

- **Cybersecurity systems, processes, and personnel continue to be a critical component of utility operations**. Smart grid technologies provide many benefits but also open up opportunities for adversaries to attack critical infrastructure. Generation and utility operators need to continue efforts to identify and deploy protections against ever-evolving cybersecurity threats.

- **The electric power industry is exploring new business models and planning requirements to address grid modernization and integration of distributed energy resources.** Increases in DER adoption requires new approaches to resource planning, economic and environmental regulations, and market development to sustain reliability and boost resilience while involving consumers and third-parties in electricity management and generation to a much greater extent than before. Policy makers, regulators, consumer advocates, utilities, and other service providers need to continue working closely to ensure grid capabilities keep pace with changing requirements for DER integration, reliability, and security.

In addressing these and other technology, policy, and market challenges, DOE continues to be an important contributor to grid modernization through research, development, demonstration, analysis, and technology transfer activities. **SGIG showed what can be achieved in grid modernization through public-private partnerships involving DOE and the electric power industry.** New technologies are driving changes on multiple fronts and the need continues for strong national efforts to modernize the grid.

Following SGIG, grid modernization remains important national priority for DOE programs. For example, DOE recently launched a **new Grid Modernization Initiative (GMI) and released a Grid Modernization Multi-Year Program Plan (MYPP)** of proposed activities for achieving a more modern, secure, sustainable, and reliable grid. DOE plans to work toward these goals through a comprehensive set of programs and activities. The Grid Modernization Lab Consortium, a multi-year collaboration among 14 national laboratories and regional networks, is assisting DOE in developing and implementing the activities in the MYPP.[20]

[20] DOE, *Grid Modernization Multi-Year Program Plan* (November 2015).