LBNL- XXXX

A Review of the American Recovery and Reinvestment Act Smart Grid Projects and Their Implications for China

Xu Liu, Chris Marnay, Wei Feng, Nan Zhou, and Nihan Karali

Energy Analysis and Environmental Impacts Division

Lawrence Berkeley National Laboratory

China Energy Group

January 2017

This work was suported by the Energy Foundation China under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

Disclaimer

Acknowledgements

The work described in this study was funded by Energy Foundation China under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

Table of Contents

List of Tables

List of Figures

Executive Summary

The Chinese government has paid growing attention to renewable energy development and has set ambitious goals for carbon dioxide (CO_2) emissions reduction and energy savings. Smart grid (SG) technologies have been regarded as emerging ways to integrate renewable energy and to help achieve these climate and energy goals.

This report first reviews completed SG demonstrations under the U.S. American Recovery and Reinvestment Act (ARRA); especially two key programs: the SG Investment Grant (SGIG) and the SG Demonstration Project (SGDP). Under the SGIG, the larger of the two programs, over $3.4 billion was used to help industry deploy existing advanced SG technologies and tools to improve grid performance and reduce costs. Including industry investment, a total of $8 billion was spent on 99 cost-shared projects, which involved more than 200 participating electric utilities and other organizations. These projects aimed to modernize the electric grid, strengthen cyber security, improve interoperability, and collect comprehensive data on SG operations and benefits.

The second largest program was the SGDP. Under it, the U.S. Department of Energy (U.S. DOE) invested over $600 million, along with $900 million industry cost share, in 16 Regional SG Demonstration projects and 16 Energy Storage Demonstration projects. The SGDP demonstrated new and more cost-effective SG technologies, tools, techniques, and system configurations and evaluated performance for future applications.

The report provides three cases studies with a renewable component and demand response features that have demonstrated successful business models. The first case is Southern California Edison's (SCE) Irvine SG Demonstration project, which was a comprehensive demonstration with eight sub-projects. This case study provides an overview of how a large demonstration project, with about $80 million involved, was implemented under the ARRA, and also provides the results of SCE's cost-benefit analysis on this project. The second case study is an SGDP demonstration that focused on energy storage with Duke Energy at the Notrees wind farm. This case demonstrates a business model of using energy storage to provide ancillary services. The last case study is an SGIG project conducted by Sacramento Municipal Utility District (SMUD) that tests demand response consumer behavior. This SMUD project demonstrates how advanced metering infrastructure (AMI) could be utilized with various pricing options to reduce peak load.

This report summarizes successful aspects of ARRA SG demonstrations, including strong legislative and financial support from the federal government. ARRA's primary intention was to stimulate the economy, to motivate matching

funders to boost federal expenditures into lar ger amounts of investment, to demonstrate or install SG technologies, to develop a diversified electricity market that allows monetary benefits to be realized through implementing SG technologies, and to ensure scientific reporting and information sharing.

This report proposes policy recommendations for SG development in China, including a clear definition of SG; strong regulatory and financial support of SG from the government; a gradually matured electricity market where the electricity price reflects the true costs of fuels, generation, transmission, and distribution; a stringent reporting mechanism; and a standardized framework and methods for cost-benefit analysis of the demonstration projects.

1.Introduction

1.1 Smart Grid Definitions

While *smart grid* (SG) is a relatively new term, which was developed by the European Technology Platform for Smart Grids and formed during the International Conference on Integration of Renewable and Distributed Energy Resources in Brussels in 2004, most of the technologies it involves had been proposed or under development for some time (Smartgrids 2016). The SG usage emerged in response to increasingly apparent severe modern challenges facing the power grid, including: the urgent drive to decarbonization and its implied high renewables penetration, security threats, constraints on infrastructure expansion, increasing loads from transportation electrification, high demands for power quality, and others (U.S. DOE 2008).

In the United States, Title XIII of the Energy and Security Act of 2007 (EISA-2007) states that the following features together characterize an SG:

(1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.
(2) Dynamic optimization of grid operations and resources, with full cyber-security.
(3) Deployment and integration of distributed resources and generation, including renewable resources.
(4) Development and incorporation of demand response, demand side resources, and energy-efficiency resources.
(5) Deployment of “smart” technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.
(6) Integration of “smart” appliances and consumer devices.
(7) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning.
(8) Provision to consumers of timely information and control options.
(9) Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.
(10) Identification and lowering of unreasonable or unnecessary barriers to adoption of SG technologies, practices, and services.

Based on this EISA-2007 definition, the Federal Energy Regulatory Commission (FERC) and the U.S. Department of Energy (U.S. DOE) have further defined the term, *smart grid.* FERC is the U.S. federal agency that regulates interstate transmission of natural gas, oil, and electricity (FERC 2016). In FERC’s 2008 report, *Assessment of Demand Response and Advanced Metering, smart grid* is defined to “include a variety of operational and energy measures—including smart meters, smart appliances, renewable energy resources, and energy efficiency resources” (FERC 2008).

The U.S. DOE is a Cabinet-level department of the U.S. government assigned to “ensure America’s energy future, scientific and technological leadership, nuclear security and to resolve the environmental legacy of the cold war” (U.S. DOE 2016a). On its website, the U.S. DOE defines *smart grid* as “a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation” and states that *smart grid* means “‘computerizing’ the electric utility grid” and “includes adding two-way digital communication technology to devices associated with the grid” (U.S. DOE 2016b).

In China, the national government has also provided definitions of *smart grid* in some policy documents. For example, China’s National Development and Reform Commission, in its guidance on promoting SG development, states that the *smart grid* is a new electricity generation system that integrates new energy, new materials, new equipment and advanced sensor, information, control and storage technologies, which is information rich, automated and interactive, and can better achieve safe, reliable, economical and highly efficient grid operation (NDRC 2015). The Ministry of Science and Technology (MOST) in its Special Planning for the Twelfth Five-Year Plan (2011–2015) on SG Major Science and Industrialization Projects asserts that SG covers generation, transmission, transformation, distribution, use, and dispatch of electricity which comprehensively uses advanced information and materials technologies to achieve large-scale clean energy connection to the grid and utilization, to improve energy efficiency and ensure safe, reliable, and good quality electricity supply (MOST 2012).

Third-party organizations in the electricity sector and researchers also have their definition of *smart grid.* For example, the China Electricity Council (CEC) defined *smart grid* as a modernized grid that highly integrates advanced technologies for advanced sensing and measurement, communication, information flow, and control (CEC 2011). Yu et al. (2012) stated that “SGs in China are an integration of renewable energy, new materials, advanced equipment, information, control and energy storage technologies, which can realize digital management, intelligent decision making and interactive transactions of electricity generation, transmission, deployment, usage and storage.”

Definitions of *smart grid* from the United States, China, and other jurisdictions typically have three key elements: (1) improved operation of the legacy centralized power supply system, e.g., synchrophasor systems; (2) improved grid-customer interaction, e.g., smart meters and real-time pricing; and (3) local control dispersed around the system, e.g., microgrids and related technologies. While the United States has clearly defined and started to promote SG in national law over about the last decade, China has only more recently brought up the concept in some policies.

1.2 Renewable Energy in the Smart Grid

The SG addresses a key electricity system challenge—integrating renewable energy—by using advanced technology to accommodate the renewable variability and utilizing distributed sources such as combined heat and power (CHP) and rooftop photovoltaics (PV). Further, SG is usually considered to be a way to integrate storage and demand response; in fact, all dispersed assets. The focus on renewable variability naturally leads to two key SG features. First, inclusion of storage assets—primarily batteries, but also heat or other storage mediums—to store unpredictable energy output to loads. Second, by dealing with supply fluctuations locally, the main grid is buffered from their effects. It should be noted that the variability of loads increases in small-scale power systems, so to the extent microgrids are involved, management of variability becomes more critical.

With the urgent need to reduce carbon and air pollutant emissions, large-scale generation of wind and solar is under rapid installation and operation; however, the integration and optimal usage of wind and solar electricity needs storage, responsive demand, automation, resource forecasting, and other supporting technologies. In addition, with the growth of distributed generation, more and more electricity consumers have become suppliers to complement large-scale generation. The flexibility and reliability of the grid is hence required to accommodate these renewable sources.

Integrating renewable energy using SG technologies needs to not only address technical challenges but also ensure economic feasibility. Research, development, and deployment, and stimulation of subsequent investment in advanced SG technologies, needs government regulation and policies that encourage various stakeholders (including private and public utilities, generation companies, technology companies and research organizations) to work together and explore appropriate business models for expanded application of SG technologies.

Smart grid technologies associated with renewable energy include (Kempener et al. 2013):

- Advanced metering infrastructure (AMI)
- Advanced electricity pricing
- Demand response
- Automation
- Renewable resource forecasting

- Smart inverters
- Distributed storage
- Microgrids and virtual power plants
- Bulk power technologies

1.3 Renewable Energy and SG in the China Context

China has goals to reduce carbon and air pollutant emissions, as well as fossil fuels as a share of its energy consumption, in both its domestic policies and international commitments. In its Twelfth Five-Year Plan (FYP), China set the 2015 goals of reaching an 11.4 percent non-fossil share of primary energy consumption, while reducing carbon dioxide (CO_2) emissions per unit of gross domestic product (GDP) by 17 percent, reducing sulfur dioxide (SO_2) emissions by 8 percent, and reducing nitrogen oxides (NOx) by 10 percent (China Gov. 2011). By the end of 2015, the non-fossil share had reached 12 percent, CO_2 emissions per unit of GDP were reduced by 20 percent, and SO_2 and NOx were reduced by 18 percent and 18.6 percent, respectively. In the Thirteenth FYP, China set 2020 goals of a 15 percent non-fossil share, CO_2 intensity of GDP reduction of 18 percent, and both NOx and SO_2 by 15 percent (China Gov. 2016).

China submitted its intended nationally determined contribution for reducing greenhouse gases on June 30, 2015. It stated that it intends to achieve peak CO_2 emissions around 2030 and make its best efforts to peak early, to lower GDP CO_2 intensity by 60 percent to 65 percent below the 2005 level, and to increase its non-fossil share to around 20 percent (UNFCCC 2015).

China's renewable energy and SG goals were connected to each other. This report focuses on SG development, with special consideration to integrating and adopting renewable, distributed generation, and energy storage technologies.

1.4 Current Policies and Status of SG Deployment in China

To achieve their combined goals of CO_2 and air pollutant emissions reduction and increased non-fossil share, China has established many policies to accelerate the deployment of renewable energy. In 2009, an amendment to China's Renewable Energy Law added an article to urge utility companies to develop and apply smart-grid and energy storage technologies to improve grid operation and management, and to facilitate the integration of renewable energy (Brown and Zhou 2013; NPC 2009). China's Twelfth Five-Year (2011–2015) Plan identified SG as one of the key areas for new energy industry development, and it is seen as an effective approach to achieve China's major energy and carbon targets (Xinhua Net 2011; China Gov. 2011; Brown and Zhou 2013).

The Thirteenth FYP identifies eight key energy projects, including a high-efficiency smart electricity system; renewable energy, which includes distributed wind and solar; and key energy technology and equipment, which includes accelerating the development and application of SG technology (Xinhua Net 2016). The SG is also identified as one of the nine key projects for science and technology innovation 2030 (Xinhua Net 2016). In the *Guidance on Energy Work in 2016* released by the National Energy Administration (NEA), SG development is also a key work area. The guidance asks to study and establish an SG technology roadmap, development mode, and achievement pathway that is suitable to China's situation. It also calls for microgrid, energy storage, and flexible high-voltage direct current (HVDC) projects. In addition, the guidance asks to explore a new business model for SG operation and allows the integration of distributed energy and electric vehicles (NEA 2016). The Energy Plan for the Thirteenth FYP identified distributed wind and solar as priorities for development.

Key objectives for SG development in China include: (1) long-distance transmission capability, (2) high renewable penetration, (3) higher distributed energy adoption (including renewables), (4) flexible control for transmission and distribution, and (5) diversification of demand usage to satisfy the diverse load demand (NDRC 2015). This wide array of initiatives for low-carbon growth and clean energy development in place will potentially change patterns of renewable energy and SG development dramatically over the next decade. However, even though the government has set relevant policies to nurture an environment for SG development, there are few specific policies or specific subsidies or funding for the development and application of SG technologies.

Under current policies, China has experienced rapid growth in overall power generating capacity and large-scale clean energy generation, and has started some demonstrations of small-scale renewables, energy storage, and microgrids (Yuan et al. 2014). By the end of 2015, overall power generating capacity reached 1,525 gigawatts (GW), an increase of 10.6 percent compared to 2014. Wind installed capacity reached 131 GW, an increase of 35.4 percent compared to 2014. Solar installed capacity more than doubled in 2015, reaching 43 GW. Power generation from wind and solar accounted for 3.9 percent of total power generation in 2015, compared to 3.2 percent in 2014 (CEC 2016). Distributed solar installed capacity increased from 4.67 GW in 2014 to 6.06 GW in 2015 (CNREC 2016). For electrochemical energy storage, there were 118 projects by 2015, with total installed capacity of 105.5 GW, representing 11 percent of global energy storage projects. The main technologies in use are lithium-ion (two-thirds of China's total installed capacity) and lead-acid and flow batteries (CNREC 2016). Nonetheless, progress on distributed generation, microgrids, and intelligent demand management is slow and limited.

At present in China, SG development is focusing more on transmission than distribution (Hashmi et al. 2011). Great progress has been made in SG transmission development, such as the HVDC transmission and flexible AC transmission systems (FACTS), in terms of both technology and application (Yuan et al. 2014; Rackliffe 2014). Shanghai commissioned the first flexible HVDC transmission project in Asia in July 2011. By 2012, a variety of FACTS devices had been successfully used in practical projects, including static volt ampere reactive compensator (SVC), fixed series compensation (FSC), thyristor-controlled series compensation (TCSC), controlled shunt reactor (CSR), and static synchronous compensator (STATCOM) devices (Yuan et al. 2014). However, issues remain for the coordination of planning and development between power grids and renewable energy, which impede the development of renewable energy in China (Yuan et al. 2014). China has also deployed some comprehensive SG demonstration projects such as the Sino-Singapore Eco-City SG Demonstration Project and the Shanghai Expo Demonstration Project.

1.5 Current Collaboration on SG between the United States and China

Smart grid has been recognized at the intergovernment level as a particularly promising area for U.S.-China cooperation and was identified as one of the five initiatives under the U.S.-China Climate Change Working Group (U.S. DOS 2013). Then in 2016, SGs, combined with Power Consumption, Demand, and Competition, jointly formed the Electric Power Systems Initiative (U.S. DOS 2016). Both the United States and China have notable SG technology to offer, and many of the problems, such as renewables integration, are common to both countries.

Clearly, widespread recognition now permeates the highest government levels that microgrids can help China meet these various energy and emissions goals cost-effectively, while continuing to supply the high-quality energy essential for its growing end-use demand.

The U.S. ARRA smart grid program has invested over $4 billion of federal funds to deploy the smart grid. From 2010 to 2013, the electricity industry has spent a total of $18 billion for SG deployment in the United States, nearly half of which (about $8 billion) came from ARRA investment. From 2010 to 2012, most investment was for AMI, while investment in AMI dropped significantly in 2013. Spending for distribution system SG technology has gradually increased from $1 billion in 2010 to $1.2 billion in 2013, and that was expected to grow continuously in the future (U.S. DOE 2014a).

Learning from the U.S. experience on addressing microgrid and renewables issues is a valuable service for Chinese policy makers. As economic development in China is slowing, a financial stimulus similar to that of the U.S. ARRA can potentially incentivize research, development and demonstration of SG technologies. This report reviews and analyzes ARRA SG projects, and provides summaries of particularly interesting ones with notable results. Focus is on the effects of new technology for renewables deployment and the 32 SGDPs. Demonstrations and technologies that have strong relevance to SG development in China will be analyzed. These are the most innovative projects, but if any of the SGIG projects seem of interest, they too will be included. This report also examines ARRA business models for SG projects and provides a few insights and recommendations on how to leverage public and private capital to support the development of SG, given China's specific situation.

2. The American Recovery and Reinvestment Act

2.1 Pre-ARRA U.S. Situation

The 109th U.S. Congress passed the Energy Policy Act of 2005 (EPACT-2005), which provided tax incentives and subsidies for renewable energy integration and energy-efficiency technologies (Simões et al. 2012). EPACT-2005 promoted smart meter development by requiring electric utilities to "make available upon request net metering and time-based (smart) metering service" (Brown and Zhou 2013; U.S. Congress 2005).

The 110th U.S. Congress passed the EISA-2007 (U.S. Congress 2007), which explicitly characterized the SG and formalized the national SG Initiative in Title XIII (Simões et al. 2012). EISA-2007 is the key legislation intended to modernize the U.S. electricity transmission and distribution system. It directs the U.S. DOE to establish an SG Task Force to "insure awareness, coordination and integration of the diverse activities of the Office and elsewhere in the Federal government related to smart-grid technologies and practices." It attempts to "implement a program that includes: (1) developing advanced techniques for measuring peak load reductions and energy-efficiency savings from smart metering, demand response, distributed generation, and electricity storage systems;
(2) investigating means for demand response, distributed generation, and storage to provide ancillary services; and (3) conducting research to advance the use of wide-area measurement and control networks, including data mining, visualization, advanced computing, and secure and dependable communications in a highly-distributed environment." It asks for establishment of an SG regional demonstration initiative and projects in different regions, and it asks "the National Institute of Standards and Technology [to take] primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of SG devices and systems." It also asks for "establish[ment of] a SG Investment Matching Grant Program to provide reimbursement of 20% of qualifying SG investments" (Congress 2007).

2.2. The ARRA Legislation

2.2.1 Introduction to ARRA

On February 17, 2009, President Obama signed the ARRA into law. The ARRA was an unprecedented action to stimulate the economy, which invested about $800 billion of government investment and tax incentives (Chodorow-Reich et al.

2012). The total for clean energy was $90 billion, of which $10 billion was for grid modernization and SG development, including sophisticated meters, high-tech electricity distribution and transmission grid censors, and energy storage. Initial federal investment through the ARRA was $4.5 billion, which was matched by SG award recipients through cost share of $5.6 billion, delivering a total investment of nearly $10 billion (U.S. DOE 2015). The U.S. DOE Office of Electricity Delivery and Energy Reliability (OE) was responsible for managing numerous five-year projects.

This investment in SG technologies and training aimed to help improve the efficiency and reliability of the electrical system. It was expected to provide fact-based information from real projects on all aspects of SG applications—transmission, distribution, metering, and customer systems—plus their impacts and a cost-benefits analysis. The purpose of the investment was to help public and private decision makers identify the most cost-effective SG technologies, tools, and techniques. Through the investment in demonstration and training, operators could acquire better information and control over the flow of electricity, larger-scale renewable energy sources could be integrated onto the grid, consumers could reduce their energy use and save money, and workers could be trained to deploy and utilize these new technologies (U.S. DOE 2012).

The total $4.5 billion investment from the federal government was allocated into eight major programs: SGIG; SGDP; the Workforce Development Program; Interconnection Transmission Planning; State Assistance for Recovery Act Related Electricity Policies; Enhancing State Energy Assurance; Enhancing Local Government Energy Assurance; and Interoperability Standards and Frameworks (Table 1).

Under the largest program, SGIG, more than $3.4 billion was used to help industry deploy existing advanced SG technologies and tools to improve grid performance and reduce costs. Including industry investment, a total of $8 billion was spent on 99 cost-shared projects, which involved more than 200 participating electric utilities and other organizations. These projects aimed to modernize the electric grid, strengthen cyber security, improve interoperability, and collect comprehensive data on SG operations and benefits.

The second-largest program was the SGDP. Under the SGDP, U.S. DOE invested more than $600 million, along with $900 million industry cost share, in 16 Regional SG Demonstrations and 16 Energy Storage Demonstration projects under SGDP. The SGDP demonstrated new and more cost-effective SG technologies, tools, techniques, and system configurations, and evaluated performance for future applications.

The ARRA also provided funding for: (1) SG workforce development programs that develop and implement training programs to prepare next-generation workers in the utility and electrical manufacturing industries; (2) projects that strengthened the capabilities for long-term analysis and planning in the three interconnections serving the lower 48 states; (3) assisting states to hire new staff and retrain existing employees to ensure they have the capacity to quickly and effectively review proposed electricity projects; and (4) developing or expanding energy assurance plans in the 47 states, Washington D.C., and 43 cities to improve electricity reliability and energy security.

Table 1. Allocation of Government Funding for SG Programs under the ARRA

Programs	Total Obligations (million $)	Number of Award Recipients
SGIG	3,483	99
SGDP	685	32
Workforce Development Program	100	52
Interconnection Transmission Planning	80	6
State Assistance for Recovery Act Related Electricity Policies	49	49
Enhancing State Energy Assurance	43.5	50
Enhancing Local Government Energy Assurance	8	43
Interoperability Standards and Frameworks	12	1
Program Direction*	28	

*Program Direction supports the administration and management of OE's recovery funds.

2.2.2 Selection Process for SGIG and SGDP

To access ARRA funding, projects were selected and awarded through a competitive merit-based solicitation.[1] U.S. DOE released a Funding Opportunity Announcement (FOA) for SGIG (U.S. DOE 2009a) and SGDP (U.S. DOE 2009b). The U.S. DOE performed an initial review before a comprehensive merit review to determine if the applicant was eligible and met all mandatory requirements and funding objectives. Then U.S. DOE performed a technical merit review to evaluate applications against the FOA's intended purpose (U.S. DOE 2009a).

---

[1] This report focuses on SGIG and SGDP.

The U.S. DOE established the criteria and weighting system shown in Table 2 for SGIG and SGDP merit review.

Table 2. SGIG and SGDP Merit Review

SGIG Merit Review		SGDP Merit Review	
Criteria	Weight	Criteria	Weight
Technical Approach for Enabling SG Functions	40%	Project Approach	35%
Plan for Project Task, Schedule, Management, Qualifications, and Risks	25%	Significance and Impact	25%
Technical Approach for Addressing Interoperability and Cyber Security	20%	Cyber Security and Interoperability	20%
Plan for Data Collection and Analysis of Project Costs and Benefits	25%	Project Team	20%

Based on the merit review recommendation, the selection official would also consider program policy factors identified in the FOA and the amount of funds available to determine selected applicants. Each project recipient needed to share costs with U.S. DOE, which provided financial assistance of up to 50 percent of the overall project cost. SGIG projects were grant agreements, while the SGDP projects were cooperative agreements.[2] Applicants for selected projects needed to file Metrics and Benefits Reporting Plans, which had

---

[2] Both grants and cooperative agreements are legal instruments “reflecting a relationship between the Federal Government and a State or local government or other recipient” when “the principal purpose of the relationship is the transfer of money, property, services, or anything of value to the State or local government or other recipient to accomplish a public purpose of support or stimulation authorized by Federal statute, rather than acquisition, by purchase, lease, or barter, of property or services for the direct benefit or use of the Federal Government. However, “substantial involvement is anticipated between the executive agency, acting for the Federal Government, and the State or local government or other recipient during performance of the contemplated activity” for cooperative agreements, while no such involvement is anticipated for grant agreements (Grants.Gov 2016).

formatted outlines.[3] Selected projects decided what they wanted to demonstrate, subject to approval and selection.

Ultimate goals for SGIG and SGDP were different. SGIG aimed to enable SG functions on the electric system as soon as possible, while SGDP aimed to demonstrate new and more cost-effective SG technologies, tools, techniques, and system configurations that would significantly improve upon the ones that are either in common practice today or are likely to be proposed in the SGIG program. Furthermore, SGDP projects should serve as models for other entities to readily adapt and replicate across the country (U.S. DOE 2009a).

The U.S. DOE did not provide the full amount of funds obligated to the projects at one time but provided funding by budget period, contingent upon the submission and approval of the recipient's continuation application.[4]

2.2.3 Smart Grid Investment Grant

The SGIG program aimed to promote investments in manufacturing, purchasing, and installation of ready-to-use SG devices and related technologies, tools, and techniques to increase flexibility, functionality, interoperability, cyber security, situational awareness, and operational efficiency of the electric transmission and distribution systems (U.S. DOE 2009a).

The SGIG projects covered electric transmission and distribution technologies, customer systems, equipment manufacturing, AMI, and integrated systems. Entities eligible to apply were electric utilities, load-serving entities, appliance and equipment manufacturers, and IT vendors. National Laboratories and Federally Funded Research and Development Centers were not eligible. Each project was expected to get awards ranging from $100,000 to $20,000,000 for phasor measurement unit (PMU) projects and $500,000 to $200,000,000 for others.

The 99 SGIG projects with a total budget of about $8 billion, including a federal share of about $3.4 billion, were awarded in the following categories: customer systems (5 projects), advanced metering infrastructure (30 projects), electric distribution systems (13 projects), electric transmission systems (10 projects), and equipment manufacturing (2 projects). Some projects involved equipment and/or software applications that covered two or more topic areas, such as AMI and electric distribution systems, customer systems and AMI, or electric transmission systems and electric distribution systems. U.S. DOE categorized

---

[3] Smart Grid Demonstration Program (SGDP) and Renewable and Distributed Systems Integration (RDSI) Program Outline for Metrics and Benefits Reporting Plans https://www.smartgrid.gov/files/outline_for_sgdp_regional_demo_metrics_and_benefits_reporting_plans.pdf

[4] FedConnect. Opportunity: Recovery Act - Smart Grid Investment Grant Program https://www.fedconnect.net/FedConnect/?doc=DE-FOA-0000058&agency=DOE

these projects as integrated or cross cutting (39 projects). Appendix A summarizes all 99 SGIG projects and their demonstrated technologies.

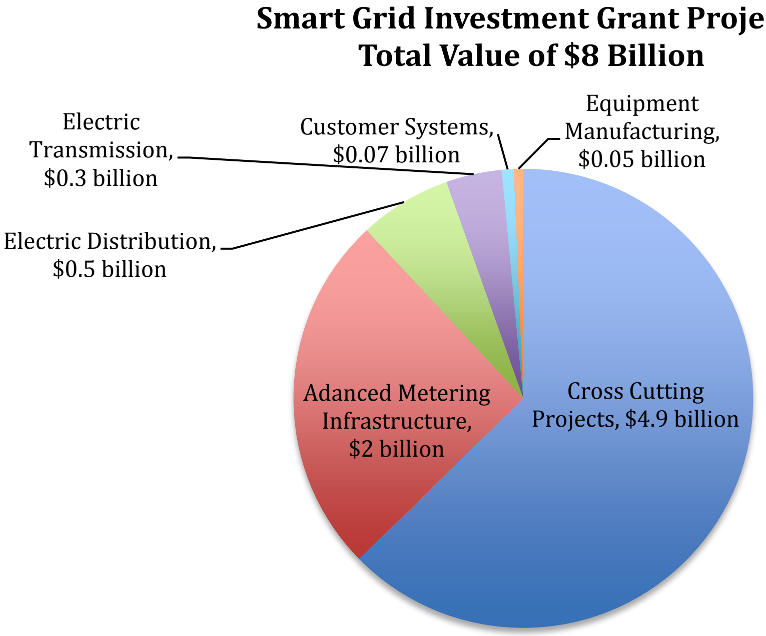


Figure 1. SGIG Projects

2.2.4. Smart Grid Demonstration Program

The SGDP Program aimed to demonstrate a suite of existing, emerging, and more cost-effective SG technologies, tools, techniques, and system configurations to be innovatively applied and integrated to prove technical, operational, and business-model feasibility (U.S. DOE 2009a).

The SGDP demonstrated a series of advanced SG technologies, including automated metering, distribution automation, volt / volt ampere reactive (VAR) control, intelligent universal transformers, integration of electric vehicles, direct load control, in-home displays, time-differentiated rate designs, and distributed generation.

Projects covered electric transmission, distribution, and customer-side projects at a scale that can be replicated across the country. All types of organizations—including state and local agencies, universities, electric utilities, equipment manufacturers, and project developers—could apply, while other federal agencies, and certain non-profits that engaged in lobbying activities after December 31, 1995, were not eligible.

The U.S. DOE signed cooperative agreements with for-profit and non-profit entities to allocate the funding. The terms and conditions on the award included a specific schedule the recipient was to adhere to for the duration of the project for cost-share contributions (U.S. DOE 2013).

Two types of SG projects were selected for the SGDP. One type included regional SG demonstrations to verify SG viability, quantify SG costs and benefits, and validate new SG business models at scales that can be readily replicated across the country. The second type included energy storage technologies such as batteries, flywheels, and compressed air energy storage systems for load shifting, ramping control, frequency regulation services, distributed applications, and the grid integration of renewable resources such as wind and solar power.

The program consisted of 32 projects in the two areas: SG Regional Demonstrations (16 projects) and Energy Storage Demonstrations (16 projects). The total budget for all projects was about $1.6 billion; the federal share was about $600 million (Figure 2). Each project had an average four-year length. The federal share was usually $20–$89 million for large projects (12 projects) and $720,000–$20 million for smaller ones (20 projects). Recipients of the federal funding included investor-owned utilities (IOU), technology and manufacturing companies, municipal utilities, non-profit organizations, and electric cooperatives (Figure 3) (Bossart 2014).

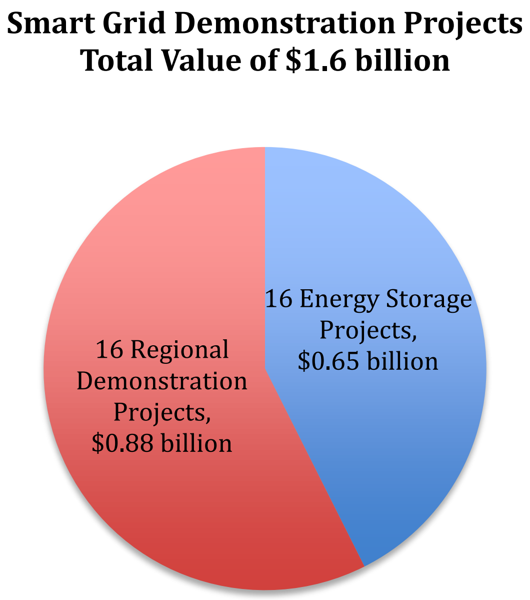


Figure 2. Total Budget for SG Demonstration Projects

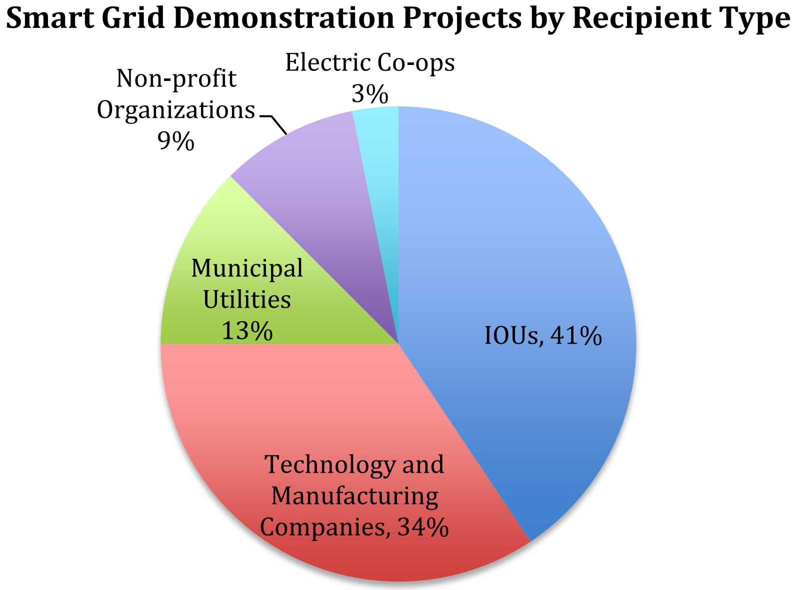


Figure 3. SGDP by Recipient Type

Table 3 summarizes the 16 SGDP regional demonstrations and the main technologies demonstrated. Table 4 summarizes the 16 SGDP Energy Storage Demonstration projects and the main technologies demonstrated.

Table 3. Summary of SGDP Projects: Regional Demonstrations

	Project	Project Type*	ARRA Award Amount ($)	Total Project Value ($)
1	Battelle Memorial Institute (Pacific Northwest Division SG Demonstration Project)	AMI, CS, DER, DS	88,821,251	177,642,503
2	AEP Ohio (gridSMART^{SM} Demonstration Project)	AMI, CS, DER, DS, P	75,161,246	148,821,823
3	Los Angeles Department of Water and Power (SG Regional Demonstration)	AMI, CS, DER, DS, P	60,280,000	120,560,000
4	Consolidated Edison Company of New York, Inc. (Secure Interoperable Open SG Demonstration Project)	CS, DER, DS, TS	45,388,291	92,388,217
5	Southern California Edison Company (Irvine SG Demonstration)	AMI, CS, DER, DS, P,TS	39,621,208	79,242,416
6	National Rural Electric Cooperative Association (Enhanced Demand and Distribution Management Regional Demonstration)	AMI, CS, DER, DS, P	33,932,146	67,864,292
7	Kansas City Power and Light (Green Impact Zone SmartGrid Demonstration)	AMI, CS, DER, DS, P	23,940,112	49,830,280
8	CCET (Technology Solutions for Wind Integration)	CS, DER, DS, P, TS	13,516,546	27,075,457

Table 3. (continued)

	Project	Project Type*	ARRA Award Amount ($)	Total Project Value ($)
9	Long Island Power Authority (Long Island Smart Energy Corridor)	AMI, CS, DER, DS, P, TS	12,496,047	25,293,801
10	Pecan Street Project Inc (Energy Internet Demonstration)	AMI, CS, DER, P	10,403,570	24,657,078
11	Waukesha Electric Systems Inc (Fault Current Limiting Superconducting Transformer)	TR	10,239,411	20,478,822
12	The Boeing Company (Boeing SG Solution)	TS	8,561,396	17,172,844
13	NSTAR Electric and Gas Corporation (Urban Grid Monitoring and Renewables Integration)	AMI, DER, DS, TS	5,267,592	10,591,934
14	Oncor Electric Delivery Company (Dynamic Line Rating)	TS, DS	3,471,681	7,136,552
15	NSTAR Electric and Gas Corporation (Automated Meter Reading-Based Dynamic Pricing)	AMI, CS, P	2,362,000	4,877,989
16	New York Power Authority (Evaluation of Instrumentation and Dynamic Thermal Ratings for Overhead Lines)	TS, DS	720,000	1,440,000

*AMI: advanced metering infrastructure, CS: customer systems (i.e., in-home displays, direct load control devices, smart appliances, etc.), DER: distributed energy resource, DS: distribution systems, P: dynamic pricing, TS: transmission system, TR: transformer

Table 4. Summary of SGDP Projects: Energy Storage Demonstrations

	Project	Project Type*	ARRA Award Amount ($)	Total Project Value ($)
1	Pacific Gas and Electric Company (Advanced Underground Compressed Air Energy Storage)	ES	25,000,000	355,938,300
2	Beacon Power (20 MW Flywheel Frequency Regulation Plant)	DER, ES	24,063,978	52,415,000
3	Southern California Edison Company (Tehachapi Wind Energy Storage Project)	ES	24,978,264	49,956,528
4	Primus Power Corporation (Wind Firming EnergyFarm)	ES	14,000,000	46,700,000
5	Duke Energy Business Services (Notrees Wind Storage Demonstration Project)	DER, ES	21,806,226	43,612,464
6	SustainX Inc. (Isothermal Compressed Air Energy Storage)	DER, ES	5,396,023	13,046,588
7	Premium Power (Distributed Energy Storage System)	DER, ES, P	6,062,552	12,514,660
8	Seeo Inc (Solid State Batteries for Grid-Scale Energy Storage)	ES	6,196,060	12,392,122
9	Detroit Edison (Advanced Implementation of Energy Storage Technologies)	DER, ES	4,995,271	10,877,258
10	Aquion Energy (Sodium-Ion Battery for Grid-level Applications)	ES	5,179,000	10,359,827

Table 4. (continued)

	Project	Project Type*	ARRA Award Amount ($)	Total Project Value ($)
11	Ktech Corp (Flow Battery Solution for SG Renewable Energy Applications)	ES	4,764,284	9,528,568
12	City of Painesville, Ohio (Vanadium Redox Battery Demonstration Program)	DER, ES	4,243,570	9,462,623
13	Amber Kinetics, Inc. (Flywheel Energy Storage Demonstration)	ES	3,694,660	7,457,591
14	Public Service Company of New Mexico (PV Plus Battery for Simultaneous Voltage Smoothing and Peak Shifting)	DER, ES, DS	2,305,931	6,113,433
15	East Penn Manufacturing Co. (Grid-Scale Energy Storage Demonstration Using UltraBattery Technology)	DER, ES	2,543,523	5,087,269
16	New York State Electric and Gas (Advanced Compressed Air Energy Storage)	ES	1,394,453	2,942,265

*DER: distributed energy resource, ES: energy storage, P: dynamic pricing

SG Regional Demonstrations

The SG Regional Demonstration projects were comprehensive demonstration projects that focused on integrating advanced SG technologies with existing power systems, including those involving renewable and distributed energy systems and demand response programs. Key demonstrated technologies included power system sensing, communications, analysis, and power flow controls. These demonstration projects assessed the technical and economic performance of these technologies for applications such as microgrids, automated distribution systems, AMI, and plug-in electric vehicles.

Energy Storage Demonstrations

Energy Storage Demonstration projects focused on grid-scale applications of energy storage at a variety of size ranges and system configurations. Demonstrated technologies included advanced batteries, flywheels, and underground compressed air systems. These projects evaluated the technical and economic performance of these technologies and their impacts on the electric transmission and distribution grid under different applications, including load shifting, ramping control, frequency regulation services, voltage smoothing, distributed energy, and the grid integration of renewable resources such as wind and solar power.

2.2.5 Performance Metrics and Evaluation for SGIG and SGDP

Performance evaluation and feedback are crucial in facilitating experiences and lessons sharing and linking many implementation activities, which help stakeholders continuously improve their performance, avoid pitfalls, and learn from the best practices of others to more effectively, efficiently, and safely achieve their SG vision (Goellner et al. 2011). To the extent possible, impacts, costs, and benefits of projects in both programs were assessed in a consistent and comparable manner (U.S. DOE 2009a).

SGIG and SGDP recipients were required to submit interim and final performance reports to U.S. DOE. These reports include the following information (SmartGrid.Gov 2016):

- An overview of the project, including a list of objectives, system designs, schedules and milestones, and interactions with project stakeholders.
- Descriptions of the technologies and systems used in the projects.
- Descriptions of the methodologies and algorithms for estimating the physical and financial performance of the systems, their grid impacts, and the value of the benefits.
- Summaries of the results of the performance of the systems and technologies derived from lab tests, field tests, or grid-connected applications.
- Summaries of the results of the analysis of grid impacts and estimation of benefits.
- Summary of the major finding and conclusions, including lessons learned and best practices.

- Summary of future plans and next steps with respect to additional testing, demonstration, or deployment.

The SGIG and SGDP projects aimed to provide data and establish proven experience that showed the demonstrated technologies have value. To achieve this goal, U.S. DOE collaborated with the Electric Power Research Institute (EPRI) to communicate valuable information and insights from these projects to the public. The U.S. DOE and EPRI provided performance data across a wide variety of SG devices and systems, promoted comparability and transferability of results, and provided technical assistance for projects, including methodologies and a computational tool, to conduct cost-benefits analyses (Roark 2011; SmartGrid.Gov 2016).

The SGIG and SGDP project recipients were required to report performance data, and those data are available online at SmartGrid.gov. The information reported includes the quantity of technologies applied or installed (such as AMI, distributed energy resources, and customer systems) and their associated costs.

The U.S. DOE and EPRI published a report, *Methodological Approach for Estimating the Benefits and Costs of SG Demonstration Projects,* which provided a standard framework for estimating benefits and costs, including definitions, concepts, and data sources. The U.S. DOE developed a Smart Grid Computational Tool (SGCT), which was built on methods developed by EPRI and the U.S. DOE, to assist in cost and benefit analyses of the smart grid investments made in the ARRA projects. The U.S. DOE and EPRI also published a report, *Guidebook for Cost/Benefit Analysis of Smart Grid Demonstration Projects,* which provided step-by-step instruction for practical application of the methodology, guidance and templates for documenting the project in detail, and an approach to perform a cost-benefit analysis (Roark 2011; Smartgrid Gov. 2016).

The framework of the cost-benefits analysis and SGCT is to: (1) describe SG assets as a list of technologies, devices, and systems; (2) define SG functions that describe the system’s intended functions, such as real-time load management or volt/VAR control; (3) estimate physical impacts of the demonstrated technologies that compare project performance to the baseline case; and (4) determine the monetary benefits of the physical impacts that estimate the economic viability of the demonstrated applications (Roark 2011; Smartgrid Gov. 2016; EPRI 2010). One function might have multiple benefits; therefore, all should be summed up to estimate the project’s total monetized value (EPRI 2010).

Besides the EPRI/DOE method, which is embedded in the SGCT, there are several other approaches for cost-benefit analysis on smart grid projects. For example, the SG-Multi-Criteria Analysis method, which has been used in China, includes both qualitative and quantitative indicators and employs a combined Analytic Hierarchy Process and fuzzy evaluation method over four dimensions: practicality, technological, economic, and social. It was applied to analyze the Tianjin eco-city project in China. An example of a method developed for one specific project is the Navy Yard Benefit Assessment method, based on computing a set of project benefits and costs for a given operational scenario compared to a baseline in four cost-benefit analysis categories (CBACs): (1) financial / economic, (2) operational reliability and efficiency, (3) environmental, and (4) innovation and economic growth (CCWG 2016).

Information about the projects is publicly available. Two main websites record the information: SmartGrid.Gov and the SG Information Clearinghouse (sgiclearinghouse.org) (Roark 2011). The SG Information Clearinghouse (U.S. DOE 2016d) serves as a central repository for SG project information, applications, requirements, performance, costs and benefits, and standards implementation. It includes all the ARRA SG projects.

Information sharing of SGIG and SGDP has promoted collaboration. Information shared includes basic project characteristics, progress reports, metrics and benefits reports, case study presentations, briefings and articles, best practices and lessons learned, consumer behavior reports, technology performance reports, and more (Paladino 2014). Channels for information sharing, such as conferences and webinars, have also been established.

The ARRA SG investments, $9.5 billion ($8 billion for SGIG and $1.6 billion for SGDP), were the largest-ever one-time investment in upgrading the U.S. electric infrastructure. Jointly coming from U.S. DOE and the electricity industry, these investments helped utilities acquire and deploy more than 15 million smart meters, 20,000 substation monitors, 1,000 new synchrophasors, and 492 electric vehicle-charging stations. The ARRA SG programs will also have impacts on the future operations of the electric power industry because they helped utilities take the first steps, mitigate some of the risk of being first, and facilitate information sharing among utilities (U.S. DOE 2014b).

3. ARRA Case Studies

This section presents three case studies with different focus areas, to show the different features of SGDP and SGIG projects. The first case study is a comprehensive SGDP that included eight sub-projects. This case study provides an overview of how a comprehensive demonstration project with about $80 million was implemented under ARRA and also provides the results of the project's cost-benefit analysis. The second case study is an SGDP focusing on energy storage with Duke Energy at the Notrees wind farm. That case demonstrated a business model of using energy storage to provide ancillary services. The last case study is an SGIG project that tested demand response consumer behaviors that were enabled by AMI. This case study describes how an SGIG project contributed to in-depth research on pricing policies that support government policy making.

3.1. Comprehensive SGDP: SCE’s Irvine SG Demonstration (ISGD)

3.1.1. Project Overview

Southern California Edison (SCE) is one of the nation’s largest electric utilities, delivering power to 15 million people in Southern California (excluding the City of Los Angeles and some other cities with municipal systems). It received an SGDP award with a total budget of $79 million, including a federal share of $39.6 million.

SCE operated the ISGD project primarily in the California’s City of Irvine, in Orange County. Many of the project components were located on or near the University of California, Irvine (UCI) campus, which is 60 kilometers southeast of the Los Angeles airport (LAX). Key project participants included UCI, General Electric Energy (the ENERGY STAR appliance provider), SunPower Corporation (the PV panel provider), LG Chem (the provider of the Residential Energy Storage Unit with Smart Inverter), Space-Time Insight, and EPRI (Figure 4).

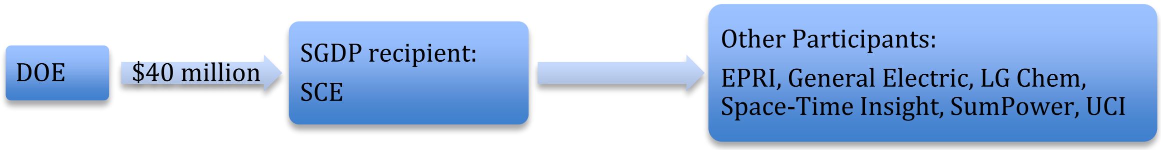


Figure 4. Participants in SCE’s ISGD Project

The primary objective of the ISGD project (Figure 5) was to verify and evaluate the ability of SG technologies to operate effectively and securely when deployed in an integrated framework (Irwin and Yinger 2015). The ISGD was a comprehensive demonstration that spanned the electricity delivery system and extended into customer homes. The ISGD’s evaluation approach included four distinct types of testing: simulations, laboratory tests, commissioning tests, and field experiments. The project used simulations and laboratory testing to validate a technology’s performance capabilities prior to field installation. The purpose of the field experiments was to evaluate the physical impacts of the various technologies on the electric grid and to quantify the associated benefits for different types of stakeholders.

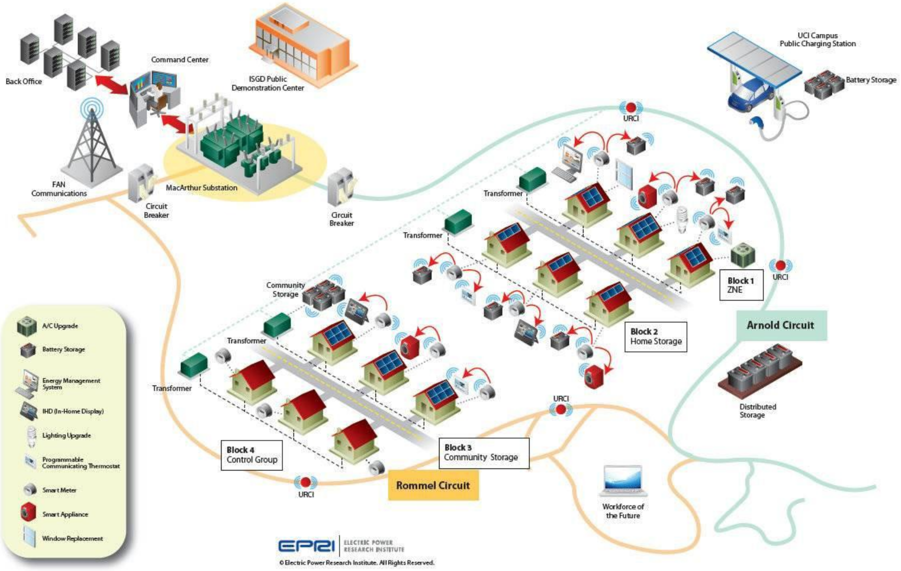


Figure 5. ISGD project

The project included four domains. Each domain included one or more sub-projects with distinct objectives, technical approaches, and research plans. There were eight sub-projects within these four domains:

- Smart Energy Customer Solutions (Sub-projects 1 and 2)
  Sub-project 1: Zero Net Energy Homes
  Sub-project 2: Solar Car Shade
- Next-Generation Distribution System (Sub-projects 3, 4, 5, and 6)
  Sub-project 3: Distribution Circuit Constraint Management Using Energy Storage
  Sub-project 4: Distribution Volt/VAR Control
  Sub-project 5: Self-healing Distribution Circuits
  Sub-project 6: Deep Grid Situational Awareness
- Interoperability and Cybersecurity (Sub-project 7 only)
- Workforce of the Future (Sub-project 8 only)

In this report, sub-projects 1 and 2 were covered because they have renewable energy aspects.

In Sub-project 1, the ISGD evaluated a variety of integrated demand side management (IDSM) technologies designed to help empower customers to make informed decisions about how and when they consume (or produce) energy, including energy efficiency measures, demand response capabilities, PV, and storage. Such technologies have the potential to better enable customers to manage their energy costs, while also improving grid reliability and stability (Irwin and Yinger 2015).

The project extended into a residential neighborhood on the UCI campus used for faculty housing. The ISGD equipped three blocks of homes with an assortment of advanced energy technologies, including energy efficiency upgrades, energy storage, rooftop PV panels, thermostats and smart appliances capable of demand response, and in-home displays.[5]

The project used one block of homes to evaluate strategies and technologies for achieving zero net energy (ZNE) or near-ZNE. Energy efficiency upgrades were only included in this block of homes. A building achieves ZNE when it produces at least as much (usually renewable) on-site energy as it consumes over a given period, including both natural gas and electricity, typically on an annual basis. The concept of ZNE buildings was widespread and has been incorporated into California's next Title 24 building code, effective in 2017 (CEC-CPUC 2015). From this point of view, the objectives of this sub-project were to evaluate the impact of advanced demand side measures to better understand their impacts on the electric grid, as well as their contributions toward enabling homes to achieve ZNE.

The three levels of home retrofits and details were as follows:

1. ZNE block (9 homes)
    a) Demand response devices
    b) Energy efficiency upgrades
    c) Residential energy storage units (4 kilowatts (kW)/10 kilowatt-hours (kWh)
    d) Solar PV arrays (~3.9 kW)
2. Residential Energy Storage Unit (RESU) block (6 homes)
    a) Demand response devices
    b) Residential energy storage units (4 kW/10 kWh)
    c) Solar PV arrays (3.2–3.6 kW)
3. Community Energy Storage (CES) block (7 homes)
    a) Demand response devices
    b) Community energy storage unit (25 kW/50 kWh)
    c) Solar PV arrays (3.2–3.6 kW)

The solar car shade sub-project (Sub-project 2) demonstrated a plug-in electric vehicle (PEV) charging system, which was expected to minimize net energy consumption from the grid resulting from PEV charging, aiming at minimizing the impact of PEV charging on the grid during peak hours. This sub-project mainly utilized three technologies: distributed PV, a battery energy storage system (BESS), and electric vehicle supply equipment (EVSE) for smart charging.

---

[5] Additionally, there is a fourth block of homes, which was used to provide baseline data in B-C analysis, although in this work a time series comparison was used.

The solar car shade sub-project installed a 48 kW solar PV array and 20 parking spaces with EVSE (each EVSE has a maximum rating of 6.6 kW) in a parking garage on the UCI campus. This sub-project also installed a stationary BESS with 100 kW of power output and 100 kW of energy storage to allow PEV charging during peak hours and cloudy days and to allow it to be charged from solar PV and off-peak grid energy.

The project team conducted field experiments to evaluate the performance and impact of the technologies demonstrated, such as the behavior of the BESS and the impact of PEV on the grid.

SCE only submitted cost-benefit analyses of three sub-projects: 1, 3, and 4. Lawrence Berkeley National Laboratory conducted the cost-benefit analyses for these three sub-projects using the U.S. DOE/EPRI method and the SGCT. The cost-benefit analyses found Sub-project 4—distributed volt and VAR control—a big success, with a benefit-cost ratio of 12.9. Distribution volt/VAR control (DVVC) optimizes the customer voltage profiles in pursuit of conservation voltage reduction. The DVVC technology significantly improves capability and can also provide VAR support to the transmission system, i.e., control high voltages to maximize capacity. Field experiments showed an average 2.6 percent energy savings, making this demonstration a major success. SCE intends to gradually roll out the technology systemwide, although it may not be applicable to all distribution networks, depending on pre-existing equipment.

Sub-project 3—a distribution-level battery energy storage system (DBESS)—demonstrated good performance as well, with a benefit-cost ratio of 2.5. The DBESS, which has a rating of 2 megawatts (MW) of real power and 500 kWh of energy storage, could help prevent a distribution circuit load from exceeding a set limit, to mitigate overheating of the substation getaway and reduce peak load on the circuit.

Sub-project 1—zero net energy homes—was not economically attractive at the current project performance and expenditures. The cost of this sub-project needs to be about 91 percent lower to achieve breakeven. However, the project did help reduce the total electricity bill by 68 percent, and 95 megawatt-hours (MWh) out of 138 MWh total electricity consumption was met by PV generation. These effects resulted in a large reduction of coincident peak load, from 17 kW in the baseline period to 3.7 kW during the test period. However, electricity requirements grew by 3.4 MWh. The substitution of heat pump heating in the ZNE block homes, along with behavioral changes, tend to increase electricity consumption, while PV and other measures reduce it (SCE 2014).

The description above summarizes the procedure and key stakeholders of an SGDP, including receiving and matching federal funding, conducting the demonstration project, performing a cost-benefit analysis of the demonstration, and reporting the results to the U.S. DOE. A comprehensive demonstration project could have several different sub-projects, and each project could focus on a specific smart grid technology. Cost-benefit analyses for the sub-projects inform interested parties about the economics and applicability of the demonstrated technologies.

3.2. Energy Storage: Duke Energy's Notrees Wind Storage Demonstration

Duke Energy Business Services was the recipient of an SGDP award. The U.S. DOE awarded half of the total $44 million budget through a cooperative agreement with EPRI as a sub-recipient. Duke Energy and EPRI worked together to select Xtreme Power as the BESS provider.

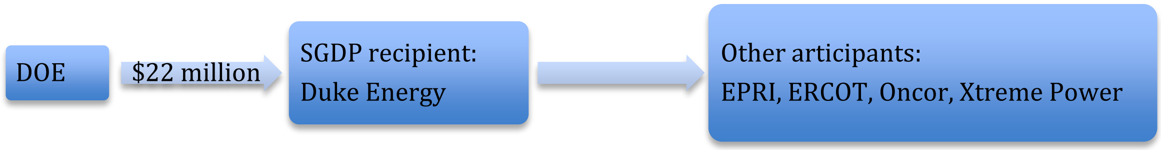


Figure 6. Participants in Duke Energy's Notrees Project

Duke Energy Business Services operates the Notrees Wind Storage Demonstration Project within its 152.6 MW wind farm in Ector and Winker counties of west Texas. Duke Energy Renewables is the owner and operator of the wind farm, and they provided operational expertise during project design, installation, commissioning, and operation. Other project participants included EPRI, which supported Duke Energy by developing metrics, reporting work plans, conducting the benefits analysis, documenting activities, and preparing reports; Xtreme Power (acquired by Younicos AG in 2014) which was the BESS vendor; Oncor, which provided transmission services; and the Electric Reliability Council of Texas (ERCOT), which verified that the energy storage operated within the market protocols for its Fast-Responding Regulation Service (FRRS) pilot project. Duke Energy coordinated its efforts with ERCOT to support data collection and analysis related to generation resources and costs, and worked with ERCOT to develop best practices for system-benefit reporting and potential support from stakeholders.

The project's primary objective was to analyze and discern how, when integrated with wind power, energy storage can compensate for the inherent intermittency of this renewable power generation resource. Specific objectives include the following:

1. Store energy during non-peak generation periods and reissue the power to meet demand.
2. Quantify the value of wind storage.
3. Demonstrate the reliability and dispatchability of wind storage.

4. Use the storage system for balancing.
5. Determine if energy storage solutions are commercially viable to support wind generation.

The project completed site preparation in October 2011. Installation of an advanced BESS with a capacity of 36 MW/24 MWh to optimally dispatch energy production from the wind farm started in February 2012, and commercial operation was completed by February 2013. The project then started to test the FRRS pilot program, which provided frequency regulation services to ERCOT and conducted monitoring and analysis during February 2013 and February 2014. The BESS continued to demonstrate the reliability and dispatchability of stored wind energy by monitoring and analyzing the regulation services it provided from February 2014 to February 2015. Total investment was more than $43 million in allowable costs from 2011 through 2014.

The project committed to providing 32 MW of FRRS-Up capacity and 30 MW of FRRS-Down capacity.[6] The BESS remained operationally profitable through the 24-month study period with net revenues of $2.8 million, demonstrating the potential to cover Duke Energy's $21.8 million cost share within 20 years of operation, assuming a 3 percent interest rate. For a first-of-a-kind system of this scale, it is good financial performance in the utility industry. For the year, the main revenue stream was from FRRS (both for Reg-Up and Reg-down separately). Awards were collected for each hour the BESS participated in FRRS, while the main costs were generation and congestion (Duke Energy 2015).

This demonstration project supported the business cases of applying energy storage in arbitrage of peak to on-peak energy and earning revenues from providing ancillary services for grid development (Duke Energy 2015).

3.3. Demand Response Consumer Behavior: SMUD's SmartSacramento

The U.S. DOE awarded the Sacramento Municipal Utility District (SMUD) $127 million toward its SmartSacramento® project. It was an effective and strategic partnership between SMUD; California State University, Sacramento; the State of California's Department of General Services; the County of Sacramento; the Los Rios Community College District; and the Elk Grove and Sacramento City Unified School Districts. Together with its partners, SMUD implemented an AMI demonstration that serves as a model for California and the rest of the United States.

This project's main objective was to test the impacts of dynamic pricing and its enabling SG technology on peak load shaving, energy conservation, and customer satisfaction, using rigorous experimental research methods. The AMI

---

[6] Please see Appendix B for definitions of FRRS, FRRS-UP and FRRS-DOWN.

solution was implemented for all residential and commercial customers, enabling the introduction of new energy efficiency, demand response, and pricing programs, and providing tools for SMUD and its customers to reduce their environmental footprint. In addition, the advanced technologies are expected to reduce operational costs. This project established a foundation on which future SG functionality will be built.

Project expenditures equaled approximately $9.9 million. The project reduced operating and maintenance costs, as the AMI system helped SMUD significantly reduce the need for manual meter operations, mainly through automated meter reading and automated service switching. SMUD's AMI system avoided $32 million in meter operation costs for SMUD from project initiation through March 31, 2014.

The project also improved distribution system reliability. SMUD deployed automated sectionalizing and restoration (ASR) equipment on 171 distribution circuits, which allowed automatic responses to power disruptions (Parks 2014). The ASR system has helped SMUD reduce both the number of customers affected by outages and the duration of outages. SMUD estimates that if the ASR system had been implemented in 2007–2012, it would have reduced the impact of outage events by 37 percent in terms of customer-minutes interrupted (a measure of the total number of customers and the minutes they were without power), based on the historical reliability performance of SMUD's distribution grid and the observed performance of the ASR system.

SMUD implemented the first year of the Smart Pricing Options (SPO) pilot in June 2012 and the second year of the pilot in June 2013. With the SGIG funding, SMUD conducted a consumer behavior study (CBS) and a dynamic pricing trial. SMUD provided a report examining the implementation, operations, and load impacts of the SPO pilot after the completion of the second year.

There were a total of seven treatment groups in this project; four groups receiving their pricing plan offer as an opt-in opportunity and three treatment groups receiving their pricing plan offer on a default basis. All customers could leave the pricing plan at any point with minimal effort. All customers under the default pricing plan receive the offer of a free In-Home Display (IHD). For the three default pricing plan treatment groups, three rate structures were included in the plan: critical peak pricing (CPP), time of use (TOU) and a combination TOU-CPP. For the four opt-in groups, two had CPP plans and the other two had TOU plans, where one of the CPP plans offered free IHDs and the other CPP plan did not. Similarly, for the two TOU opt-in groups, one plan offered free IHDs and the other plan did not (Jimenez et al. 2013). In summary, the seven treatment groups were: Opt-in TOU (no IHD offer), Opt-in TOU (with IHD offer), Opt-in CPP (no

IHD offer), Opt-in CPP (with IHD offer), Opt-out/Default TOU (with IHD offer), Opt-out/Default CPP (with IHD offer), Opt-out/Default TOU-CPP (with IHD offer).

The SPO Pilot's TOU pricing plans reduced peak significantly for both opt-in and default participants. Peak load reductions were higher when pricing plans were coupled with IHDs (Jimenez et al. 2013). There was a much higher acceptance rate for the default population than the opt-in population, so aggregate load impacts were much larger for default enrollment (Benjamin et al. 2014). The California Public Utilities Commission (CPUC) heavily cited the results of SMUD's study in their order to make California's IOUs move to default TOU in 2019 (Benjamin et al. 2014).

This SGIG project has provided useful information in TOU, CPP, and customer behaviors for in-depth analysis of pricing policies for residential consumers. Using the customer-level interval meter and demographic data reported by SMUD, comprehensive studies have been performed to analyze customer acceptance, retention, and load response to time-based rates that were enabled by AMI and control/information technology (Cappers et al. 2016a; Cappers et al. 2016b).

4. Conclusions and Policy Proposals

4.1. ARRA Successful Factors

Strong Legislation and Financial Support

The ARRA SG program provides a model of an effective government program to foster public-private investment in grid infrastructure, and the results are widely perceived as beneficial, although very uneven as one might expect from field demonstrations of new technology. Nonetheless, it is important to note that economic and political circumstances in early 2009 were unusual. Preexisting legislation provided a basis for the program by defining SG and setting up a structure for its deployment. The U.S. economy was in poor shape, and the newly elected President Obama and his party were in a strong position to pass a fiscal stimulus. In other words, these were far from routine policy making times. A program of this ambition and scope would be improbable in normal times. This was perhaps a case that supports the adage that challenges are also opportunities and Winston Churchill's famous advice, "Never let a good crisis go to waste."

Motivated Matching Funders

The primary recipients of ARRA funding were utilities and technology companies, which were motivated and eager to invest and participate in the program. Energy utility companies do not face direct competition; indeed the regulatory compact fundamentally trades monopoly franchise for price regulation. This creates two relevant effects.

First, lack of direct threat diminishes the pressure to innovate, which is a common criticism of natural monopoly regulation. A silver lining from an economic stimulus perspective is that an available technology backlog is likely to accumulate. In other words, utilities typically have many technologies close to deployment that have not made it into the field simply because there is no competitor threatening to do it first.

Second, because it is well understood that utilities lack direct competitive pressure, incentive regulation is often in place to reward socially beneficial improvement. Even without apparent direct obligations, utilities are often keenly focused on improving grid reliability, increasing renewable penetration, lowering administrative costs, and making other improvements. A government program together with a subsidy can effectively spur action in this environment. The motives of technology companies are more transparent. They are eager to develop their products and through sponsored demonstrations hope to figure out the potential and applicability of their technologies in the market, and hopefully generate some good publicity in the process. Smart grid is a particularly fertile area in this regard, with a broad array of big engineering players, new entrants, crossover companies, and others eying opportunities. However, in China, developing this kind of public-private partnerships with diverse partners, as was achieved with ARRA, would be a new model for deploying large demonstration projects.

Electricity Market Diversity

The U.S. electricity supply system has a hybrid structure. That is, there are many different types of entities involved, among them, traditional vertically integrated companies, disaggregated open markets, and local cooperatives. There is probably no other country with such a diverse mix of players. While this creates many problems, it definitely stimulates creativity. Proposals responding to any U.S. DOE funding opportunity announcement can come from organizations with quite different perspectives operating in quite different commercial environments. This naturally leads to innovative proposals coming from unexpected quarters. The SMUD project covered herein as a case study is one of many innovative activities by that municipal utility that is outside of most California regulation. By partnering with some other agencies, obtaining some state funds, and finding ARRA match, this quite small utility with only about 625,000 customers managed to execute over $300 million of ARRA smart grid projects. As was mentioned in the description above, some of SMUD’s work has been quite influential.

Scientific Reporting and Information Sharing

The U.S. ARRA SG program strongly requires information sharing and reporting. All awarded projects were asked to provide interim and final technical reports and also performance data based on performance metrics developed by the U.S. DOE, which also established the SmartGrid.Gov website collecting ARRA SG project materials which are all available to the public. As a result, ARRA SG projects provide a large amount of data and technical information to both the government and the utility to help them better apply the SG technologies.

All the SGDP projects conducted a cost-benefit analysis following the methodology and guidance provided by the U.S. DOE and EPRI. A cost-benefit analysis can maximize learning from SG projects by advancing understanding of where, how, and why the SG technologies perform as they do and by promoting transferability of results. By providing and applying the scientific method of formulating, testing, and modifying hypotheses through experimentation, observation, and measurement, the U.S. DOE ensures the credibility of the methodologies and results (Roark 2011; SmartGrid.Gov 2016).

4.2. Policy Proposals for China

An overview of China's smart-grid related policies during the Twelfth and Thirteenth FYPs showed that the government has paid growing attention to SG development and electricity sector reform. There are policies to encourage the development of microgrid and distributed energy; however, unlike the U.S., there are no specific policies in China that provide real financial assistance for SG development. In addition, in China's amended Renewable Energy Law, wording encourages SG development, but no clear definition of SG and no specific areas or technologies of SG were specified. Without strong legislative support and financial incentives, it is difficult to systematically demonstrate and develop SG technologies. If China wants to develop an SG program similar to the ARRA, they must consider a few other key factors besides a strong support from legislation and finance from the government.

To encourage the deployment of smart grid technologies, two factors are necessary: the technologies must be technically and economically feasible, and there must be an economic and regulatory environment that allows companies to obtain benefits from applying those technologies. China is undergoing comprehensive power sector reform, including pilots in the areas of (1) liberalizing retail electricity markets to allow retail competition and retailers without generation to sell power to end users, (2) establishing direct power purchases for large customers to directly negotiate with independent producers, and (3) standardizing transmission and distribution tariffs. However, at present, there is no mature electricity market where the electricity price reflects the true costs of fuels, generation, transmission, and distribution. In addition, there is no mechanism for utilizing demand response resources and other assets enabled by AMI. Although many buildings and facilities have smart meters installed, they are mostly used for data collection, while the transmitting complex price signals to customers has not been utilized.

China would also need to design a stringent reporting mechanism to ensure that progress of demonstration projects is being monitored and managed. A standardized framework and methods for cost-benefit analysis of the demonstration projects is also important, together with supplementary policies to guarantee that the cost-benefits analysis is properly conducted and evaluation results are made widely available.

References

Benjamin, R., M. Kito, R. Mutialu, G. Petlin, P. Phillips, and J. Rahman. 2014. *Staff Proposal for Residential Rate Reform in Compliance with R.12-06-013 and Assembly Bill 327.* California Public Utilities Commission, Energy Division, May 9, 2014.

Brown, M., and S. Zhou. 2013. "Smart-grid Policies: An International Review." *Wiley Interdisciplinary Reviews: Energy and Environment* 2(2): 121–139.

Bossart, S. 2014. Government & Military SGs & Microgrids Symposium-Topical Report on U.S. DOE SG ARRA Microgrid Projects. April 9, 2014. Arlington, VA.

Cappers, P., A. Spurlock, A. Todd, and L. Jin. 2016a. *Experiences of Vulnerable Residential Customer Subpopulations with Critical Peak Pricing.* Lawrence Berkeley National Laboratory. LBNL-1006294.

Cappers, P., A. Spurlock, and A. Todd. 2016b. *Time-of-Use as a Default Rate for Residential Customers: Issues and Insights.* Lawrence Berkeley National Laboratory. LBNL-1005704.

CEC (Chinese Electricity Council). 2011. Promoting SG. January 2011. http://www.cec.org.cn/zhuanti/2011nianzhuantihuigu/dianlixingyeshierwuguihua/jiakuaituijinjianqiangzhinengdianwangjianshe/2011-01-18/38644.html

CEC (Chinese Electricity Council). 2016. Power Sector Statistics in 2015.

California Energy and Public Utilities Commissions (CEC-CPUC), 2015. CA Energy Efficiency Strategic Plan: New Residential Zero Net Energy Action Plan 2015-2020. http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/eesp/res_zne_action+plan.htm

CCWG (U.S.-China Climate Change Working Group). Benefits Analysis of Smart Grid Projects. White Paper. https://china.lbl.gov/sites/all/files/ccwg_benefits_wp_v28-0_20161027_v3-0.pdf

China Government. 2016. The 13th Five-Year Plan for National Economic and Social Development of the People's Republic of China. March 17, 2016. http://www.gov.cn/xinwen/2016-03/17/content_5054992.htm

China Government. 2011. The 12th Five-Year Plan for National Economic and Social Development of the People’s Republic of China. March 16, 2011. http://www.gov.cn/2011lh/content_1825838_2.htm

Chodorow-Reich, G., L. Feiveson, Z. Liscow, and W. G. Woolston. 2012. “Does state fiscal relief during recessions increase employment? Evidence from the American Recovery and Reinvestment Act.” *American Economic Journal: Economic Policy* 118–145.

CNREC (China National Renewable Energy Center). 2016. *China Renewable Energy Industry Development Report 2016.* China Economic Publishing House: Beijing. 2016.

Duke Energy. 2015. *Technology Performance Report: Duke Energy Notrees Wind Storage Demonstration Project 2015 Final Report.* November 2015. https://www.smartgrid.gov/files/OE0000195_Duke_FinalRep_2015.pdf

Electric Power Research Institute (EPRI). 2010. *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects*.

FERC. 2008. Assessment of Demand Response and Advanced Metering. December 2008.

FERC. 2016. About FERC. http://www.ferc.gov/about/about.asp.

Goellner, J., M. Prica, J. Miller, S. Pullins, J. Westerman, T. Grabowski, B. Renz, S. Knudsen, and C. Wyatt. 2011. *Sharing SG Experiences through Performance Feedback.* National Energy Technology Laboratory. March 31, 2011. https://www.smartgrid.gov/files/Sharing_Smart_Grid_Experiences_through_Performance_Feed_Back_201112.pdf

Grants.Gov. 2016. Federal Grant and Cooperative Agreement Act (1977). http://www.grants.gov/web/grants/learn-grants/grant-policies/federal-grant-cooperative-agreement-act-1977.html

Hashmi, M., S. Hänninen, and K. Mäki. 2011. Survey of SG Concepts, Architectures, and Technological Demonstrations Worldwide. IEEE PES Conference on Innovative SG Technologies (ISGT Latin America), 2011, 1–7.

Irwin, M., Yinger, R., 2015. Technology performance report 2: Irvine smart grid demonstration, a regional smart grid demonstration project. DE-OE0000199, Southern California Edison. https://www.smartgrid.gov/document/technology_performance_report_2_irvine_smart_grid_demonstration_regional_smart_grid

Jimenez, L., J. Potter, and S. George. 2013. SmartPricing Options Interim Evaluation - An interim evaluation of the pilot design, implementation, and evaluation of the Sacramento Municipal Utility District's Consumer Behavior Study. October 23, 2013. Prepared for U.S. DOE Lawrence Berkeley National Laboratory. https://www.smartgrid.gov/files/MASTER_SMUD_CBS_Interim_Evaluation_Final_SUBMITTED_TO_TAG_20131023.pdf

Kempener, R., P. Komor, and A. Hoke. 2013. SGs and Renewables. November 2013. IRENA. http://www.irena.org/documentdownloads/publications/smart_grids.pdf

Ministry of Science and Technology of the People's Republic of China (MOST). 2012. Special Planning of 12th Five-Year Plan (2011–2015) on SG Major Science and Industrialization Projects. http://www.most.gov.cn/tztg/201205/t20120504_94114.htm.

NEA (National Energy Administration). 2016. Guidance on Energy Work in 2016 (in Chinese). March 2016. http://zfxxgk.nea.gov.cn/auto82/201604/t20160401_2219.htm

National Development and Reform Commission (NDRC). 2015. Guidance on promoting SG development. July, 2015. http://www.sdpc.gov.cn/gzdt/201507/t20150706_736625.html/

National People's Congress (NPC). 2009. China's Renewable Energy Law. September, 2009. http://www.npc.gov.cn/huiyi/lfzt/kzsnyf/2009-08/23/content_1514455.htm

Paladino, J. 2014. Progress and Results from ARRA SG Programs. September 24, 2014. https://www.smartgrid.gov/files/EAC-Sept-24-2014.pdf

Parks, J. 2014. Sacramento Municipal Utility District: SmartSacramento® Project Fact Sheet. https://www.smartgrid.gov/files/SMUD-Project-Description_final.pdf

Rackliffe, G. 2014. Smart Transmission Technologies. http://www.abb-conversations.com/2014/04/smart-transmission-technologies/

Roark, J. 2011. U.S. Government Support for SG presentation.

Simões, M., R. Roche, E. Kyriakides, S. Suryanarayanan, B. Blunier, K. McBee, P. Nguyen, P. Ribeiro, and A. Miraoui. 2012. "A comparison of SG technologies and progresses in Europe and the U.S." IEEE Transactions on Industry Applications, 48(4): 1154–1162.

Smartgrids. 2016. Smart Grids European Technology Platform. http://www.smartgrids.eu/Background

SmartGrid.Gov. 2016. Analytical Approach. https://www.smartgrid.gov/recovery_act/analytical_approach/index.html

Southern California Edison (SCE). 2014. Final Technical Report, Irvine Smart Grid Demonstration, a Regional Smart Grid Demonstration Project.

The National People's Congress Standing Committee (NPC). 2009. Renewable Energy Law of the People's Republic of China (Amended). December. http://www.npc.gov.cn/huiyi/cwh/1112/2009-12/26/content_1533216.htm

UNFCCC (United Nations Framework Convention on Climate Change). 2015. China Submits its Climate Action Plan Ahead of 2015 Paris. 30, June. http://newsroom.unfccc.int/unfccc-newsroom/china-submits-its-climate-action-plan-ahead-of-2015-paris-agreement/

U.S. Congress. 2007. Energy Independence and Security Act of 2007. https://www.congress.gov/bill/110th-congress/house-bill/6/text

U.S. Congress. 2005. H.R.6 - Energy Policy Act of 2005, 109th Congress (2005–2006).https://www.congress.gov/bill/109th-congress/house-bill/6

U.S. DOE. 2008. The Smart Grid: An Introduction. November 2008.

U.S. DOE. 2009a. Funding Opportunity Announcement SG Investment Grants. DR-FOA-0000058. June 25, 2009. http://energy.gov/sites/prod/files/edg/recovery/documents/DE-FOA-0000058.pdf

U.S. DOE. 2009b. SG Demonstration Funding Opportunity Announcement. DE-FOA-0000036. Frequently Asked Questions. June 26, 2009. http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/SGDP_0036_FOA_FAQs_62609.pdf

U.S. DOE. 2012. Successes of the Recovery Act. http://energy.gov/sites/prod/files/RecoveryActSuccess_Jan2012final.pdf

U.S. DOE. 2013. *Audit Report: The Department of Energy's $700 million Smart Grid Demonstration Program Funded through the American Recovery and Reinvestment Act of 2009.* http://energy.gov/sites/prod/files/OAS-RA-13-08.pdf

U.S. DOE. 2014a. The American Recovery and Reinvestment Act SG Highlights-Jumpstarting a Modern Grid. October 2014.

U.S. DOE. 2014b. *Municipal Utilities' Investment in SG Technologies Improves Services and Lowers Costs.* https://www.smartgrid.gov/files/B4-revised-10-03-2014-100614.pdf

U.S. DOE. 2015. A Glimpse of the Future Grid through Recovery Act Funding http://www.energy.gov/sites/prod/files/2015/10/f27/OE%20ARRA%20Grid%20Modernization%20Highlights%20october2015.pdf

U.S. DOE. 2016a. About Us. http://www.energy.gov/about-us

U.S. DOE. 2016b. Smart Grid. http://energy.gov/oe/services/technology-development/smart-grid

U.S. DOE. 2016c. Recovery Act. http://energy.gov/oe/information-center/recovery-act

U.S. DOE. 2016d. Smart Grid Information. https://energy.gov/gc/services/smartgrid-information

U.S. DOS (Department of State). 2013. Fact Sheet: U.S.-China Climate Change Working Group. July 10, 2013. http://www.state.gov/r/pa/prs/ps/2013/07/211768.htm

U.S. DOS. 2016. Report of the U.S.-China Climate Change Working Group to the 8th Round of the Strategic and Economic Dialogue. June 9, 2016. http://www.state.gov/e/oes/rls/rpts/258282.htm

Xinhua Net, 2011. The 12th Five-Year Plan for China's National Economic and Social Development. March, 2011. http://news.xinhuanet.com/politics/2011-03/16/c_121193916.htm

Xinhua Net, 2016. The 13th Five-Year Plan for China's National Economic and Social Development. March, 2016. http://news.xinhuanet.com/politics/2016lh/2016-03/17/c_1118366322.htm

Yu, Y., J. Yang, and B. Chen. 2012. The SGs in China—A review. *Energies* 5(5) (2012): 1321–1338.

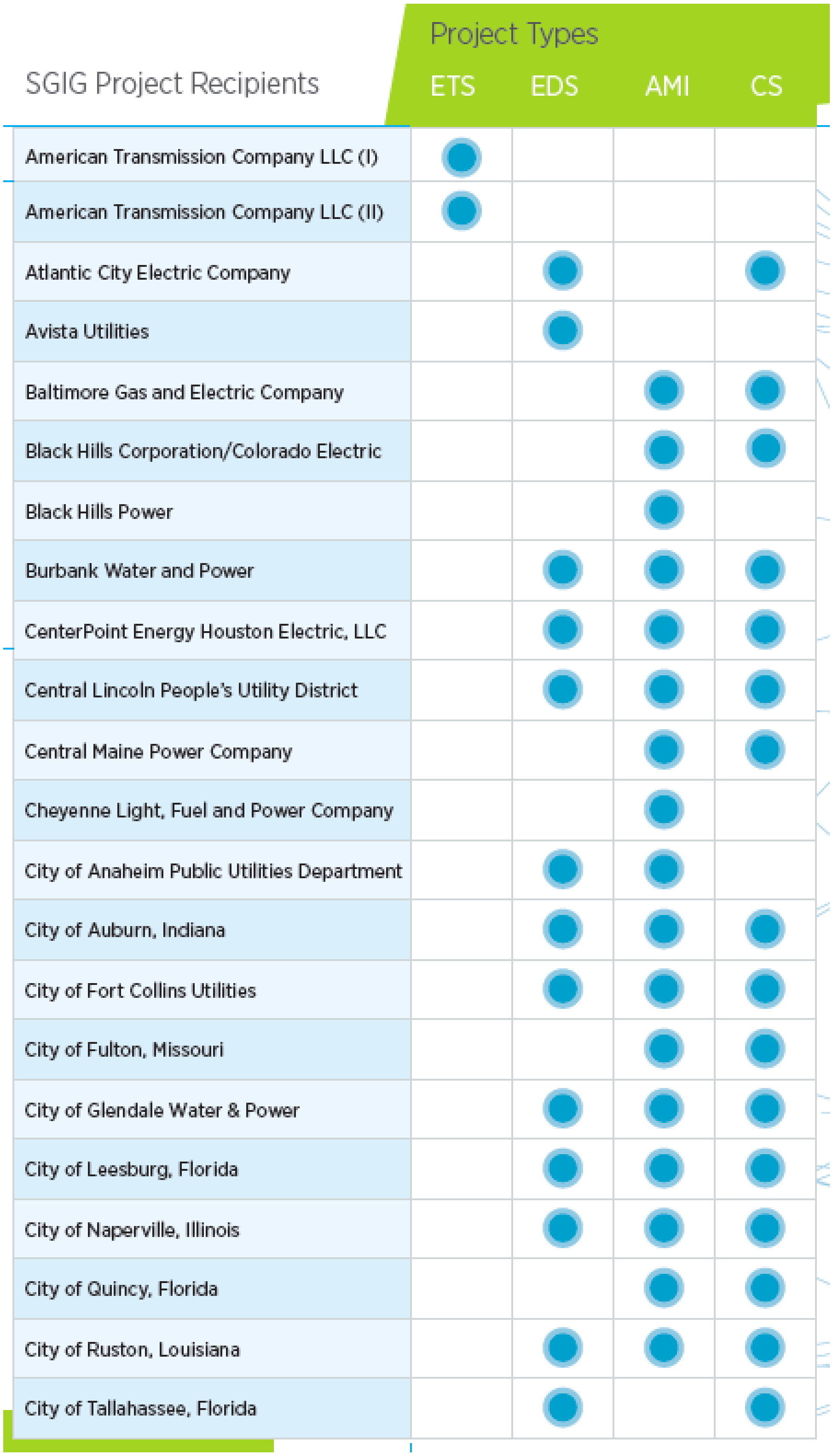
Yuan, J., J. Shen, L. Pan, C. Zhao, and J. Kang. 2014. "Smart Grids in China." *Renewable and Sustainable Energy Reviews* 37 (2014): 896–906.

Acronyms and Abbreviations

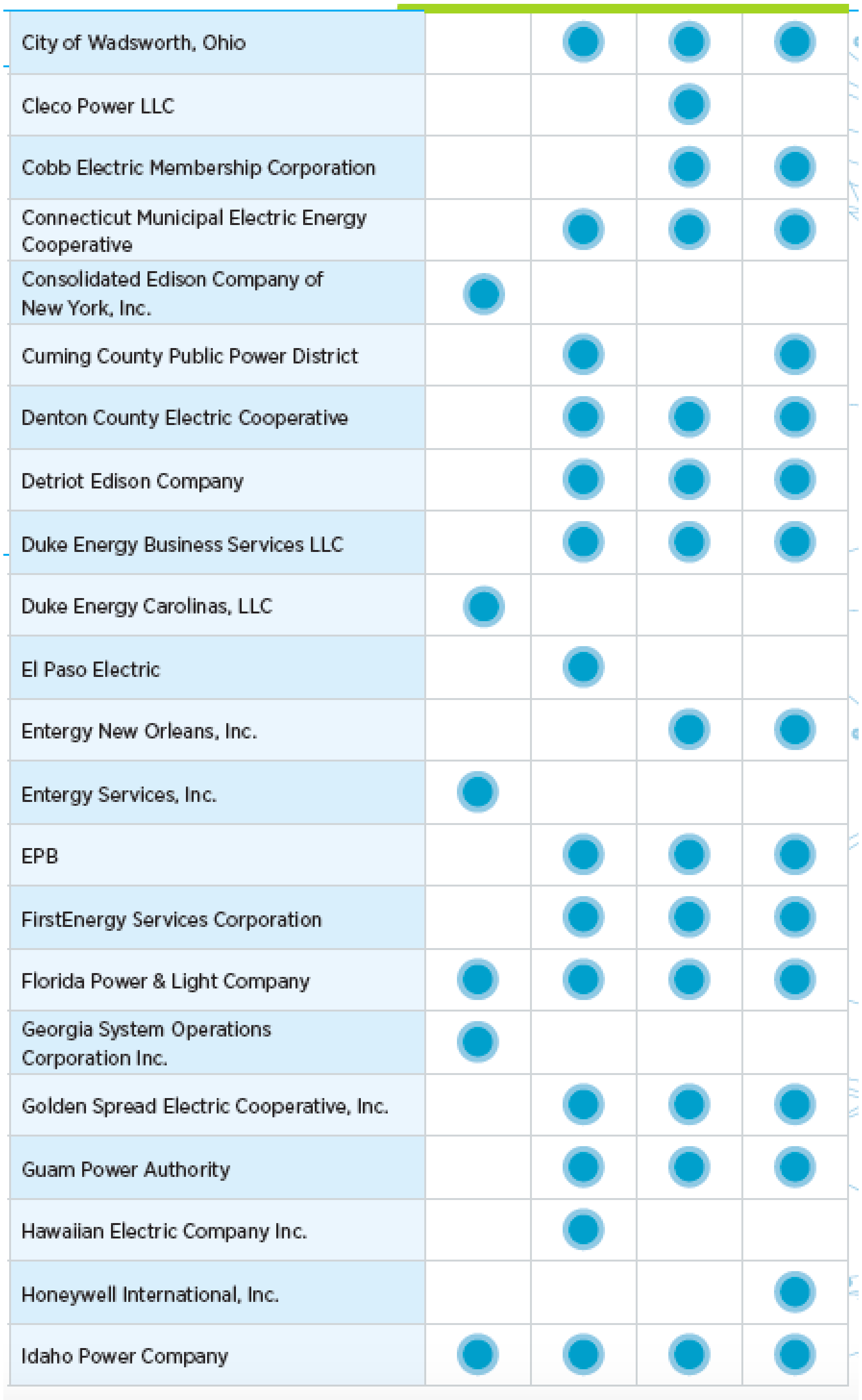
ARRA	American Recovery and Reinvestment Act of 2009
AMI	advanced metering infrastructure
ASR	automated sectionalizing and restoration
BESS	battery energy storage system
CBS	consumer behavior study
CEC	China Electricity Council
CES	community energy storage
CO_2	carbon dioxide
CPP	critical peak pricing
TOU-CPP	time of use plus critical peak pricing combination
CPUC	California Public Utilities Commission
CS	customer systems
CSR	controlled shunt reactor
DER	distributed energy resource
DOE	U.S. Department of Energy
DVVC	distribution Volt/VAR control
EISA-2007	Energy Independence and Security Act of 2007
EPACT-2005	Energy Policy Act of 2005
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ES	energy storage
EVSE	electric vehicle supply equipment (charging stations)
FACTS	flexible AC Transmission Systems
FERC	Federal Energy Regulatory Commission
FOA	funding opportunity announcement
FRRS	fast-responding regulation service
FSC	fixed series compensation
HVDC	high-voltage direct current
IDSM	integrated demand side management
IHD	in-home display
IOU	investor-owned utilities
ISGD	Irvine Smart Grid Demonstration
ISO	independent system operator
LAX	Los Angeles airport
MOST	Ministry of Science and Technology
NEA	National Energy Administration
NDRC	National Development Reform Commission
OE	DOE Office of Electricity Delivery and Energy Reliability
DP	dynamic pricing
PEV	plug-in electric vehicles
PMU	phasor measurement units
PV	photovoltaic
RESU	residential energy storage unit

SG	smart grid
SGCT	Smart Grid Computational Tool
SGDP	ARRA Smart Grid Demonstration Program
SGIG	ARRA Smart Grid Investment Grant
SMUD	Sacramento Municipal Utility District
SOS	standard offer service
SPO	smart pricing options
STATCOM	static synchronous compensator
SVC	static VAR compensator
TCSC	thyristor-controlled series compensation
TOU	time of use
TS	transmission system
UCI	University of California, Irvine
U.S.	United States
VAR	volt ampere reactive
ZNE	zero net energy

Appendix A. SGIG Project Types



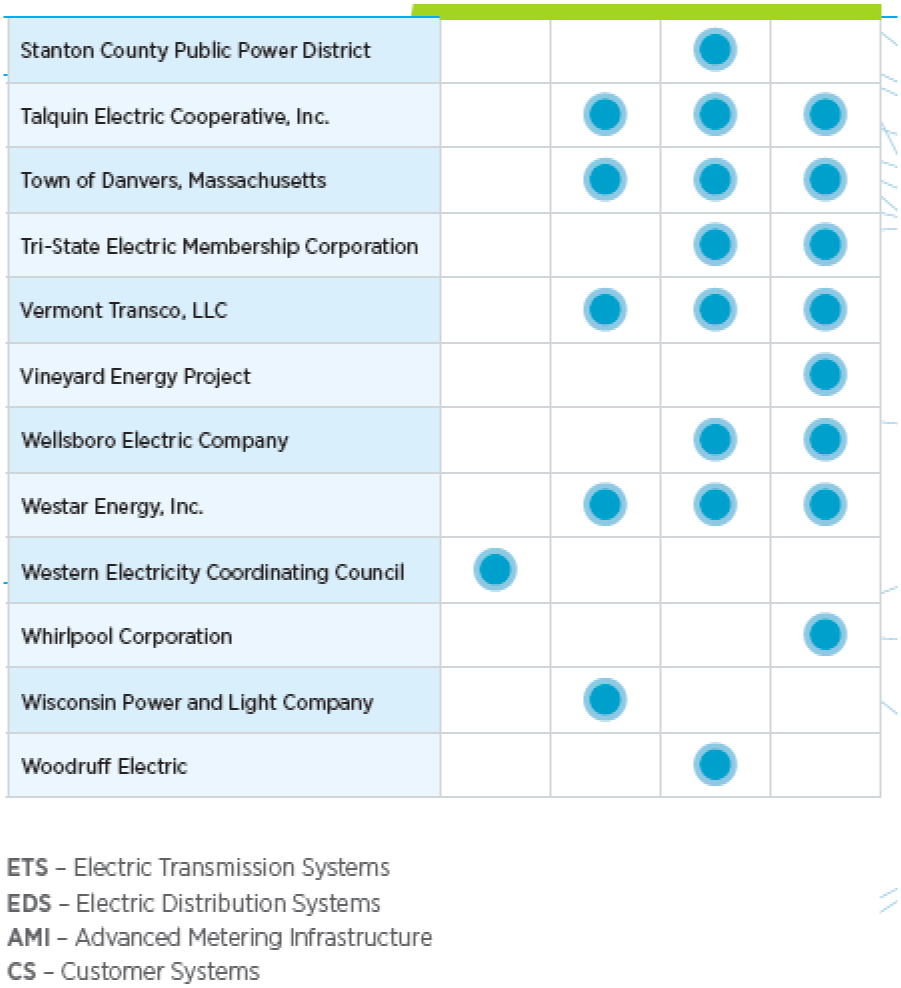
SGIG Project Recipients	Project Types ETS	EDS	AMI	CS
American Transmission Company LLC (I)	●			
American Transmission Company LLC (II)	●			
Atlantic City Electric Company		●		●
Avista Utilities		●		
Baltimore Gas and Electric Company			●	●
Black Hills Corporation/Colorado Electric			●	●
Black Hills Power			●	
Burbank Water and Power		●	●	●
CenterPoint Energy Houston Electric, LLC		●	●	●
Central Lincoln People's Utility District		●	●	●
Central Maine Power Company			●	●
Cheyenne Light, Fuel and Power Company			●	
City of Anaheim Public Utilities Department		●	●	
City of Auburn, Indiana		●	●	●
City of Fort Collins Utilities		●	●	●
City of Fulton, Missouri			●	●
City of Glendale Water & Power		●	●	●
City of Leesburg, Florida		●	●	●
City of Naperville, Illinois		●	●	●
City of Quincy, Florida			●	●
City of Ruston, Louisiana		●	●	●
City of Tallahassee, Florida		●		●



City of Wadsworth, Ohio		●	●	●
Cleco Power LLC			●	
Cobb Electric Membership Corporation			●	●
Connecticut Municipal Electric Energy Cooperative		●	●	●
Consolidated Edison Company of New York, Inc.	●			
Cuming County Public Power District		●		●
Denton County Electric Cooperative		●	●	●
Detriot Edison Company		●	●	●
Duke Energy Business Services LLC		●	●	●
Duke Energy Carolinas, LLC	●			
El Paso Electric		●		
Entergy New Orleans, Inc.			●	●
Entergy Services, Inc.	●			
EPB		●	●	●
FirstEnergy Services Corporation		●	●	●
Florida Power & Light Company	●	●	●	●
Georgia System Operations Corporation Inc.	●			
Golden Spread Electric Cooperative, Inc.		●	●	●
Guam Power Authority		●	●	●
Hawaiian Electric Company Inc.		●		
Honeywell International, Inc.				●
Idaho Power Company	●	●	●	●

Indianapolis Power and Light Company		●	●	●
Iowa Association of Municipal Utilities			●	●
ISO New England, Inc.	●			
JEA			●	●
Knoxville Utilities Board		●	●	●
Lafayette Consolidated Government	●	●	●	●
Lakeland Electric			●	●
M2M Communications				●
Madison Gas and Electric Company		●	●	
Marblehead Municipal Light Department			●	●
Memphis Light, Gas and Water Division		●		
Midwest Energy	●			
Midwest Independent Transmission System Operator	●			
Minnesota Power		●	●	●
Modesto Irrigation District		●	●	●
Municpal Electric Authority of Georgia	●	●		
Navajo Tribal Utility Authority			●	
New Hampshire Electric Cooperative			●	●
New York Independent System Operator, Inc.	●			
Northern Virginia Electric Cooperative		●		
NSTAR Electric Company		●		

NV Energy			●	●
Oklahoma Gas and Electric Company		●	●	●
Pacific Northwest Generating Cooperative			●	●
PECO Energy Company		●	●	●
PJM Interconnection, LLC	●			
Potomac Electric Power Company (DC)		●	●	●
Potomac Electric Power Company (MD)		●	●	●
Powder River Energy Corporation		●		
PPL Electric Utilities		●		
Progress Energy Service Company	●	●	●	●
Qualcomm Atheros, Inc.				●
Rappahannock Electric Cooperative		●	●	●
Reliant Energy Retail Services, LLC				●
Sacramento Municipal Utility District		●	●	●
Salt River Project			●	●
San Diego Gas & Electric Company	●	●		
Sioux Valley Energy			●	●
Snohomish County PUD		●		
South Kentucky Rural Electric Cooperative Corp.			●	●
South Mississippi Electric Power Association		●	●	●
Southern Company Services, Inc.	●	●		
Southwest Transmission Cooperative, Inc.	●	●	●	●



Stanton County Public Power District			●	
Talquin Electric Cooperative, Inc.		●	●	●
Town of Danvers, Massachusetts		●	●	●
Tri-State Electric Membership Corporation			●	●
Vermont Transco, LLC		●	●	●
Vineyard Energy Project				●
Wellsboro Electric Company			●	●
Westar Energy, Inc.		●	●	●
Western Electricity Coordinating Council	●			
Whirlpool Corporation				●
Wisconsin Power and Light Company		●		
Woodruff Electric			●	

ETS – Electric Transmission Systems
EDS – Electric Distribution Systems
AMI – Advanced Metering Infrastructure
CS – Customer Systems

Customer Systems projects primarily involve adding SG functions to equipment and/or software applications including “smart” appliances and equipment, home area networks, building or facility energy management systems, distributed energy systems, demand response and load control equipment, energy storage devices, plug-in electric vehicles, and microgrids.

AMI is a system of smart meters, two-way communications networks, and data management systems implemented to enable metering and other information exchange between utilities and their customers. In addition, a subset of SGIG projects are conducting statistically rigorous studies of consumer behavior and demand response. These projects include applications of AMI, time-based rate programs, and enabling technologies such as Web portals, in-home displays, and programmable communicating thermostats. They also include the use of randomized and controlled experimental designs with treatment and control groups. This effort presents an opportunity to advance the electric power industry’s understanding of consumer behavior through highly rigorous statistical methods.

Electric Distribution Systems projects add SG functions to local electric distribution systems in retail electricity markets. Projects primarily involve adding SG functions to devices, equipment, and/or software applications including substations, transformer banks, feeder lines, pole-top transformers, and customer interconnection and communications systems. Projects in this area involve distribution automation systems; supervisory control and data acquisition (SCADA) systems; distribution monitoring, control, and optimization systems; load control systems for lowering peak demand; and electric distribution applications of distributed generation and energy storage equipment.

Electric Transmission Systems projects are aimed at adding SG functions to the electric transmission systems in bulk power markets that typically involve power delivery over long distances including multi-state regions. Projects primarily involve adding SG functions to devices, equipment, and/or software applications such as phasor measurement units, phasor data concentrators, and visualization tools that use phasor or other data; other types of remote sensing, monitoring, data acquisition and retrieval equipment; planning and control room applications; advanced communications and interconnection systems; and retrofit of electric transmission systems with SG functions and capabilities.

Equipment Manufacturing projects produce or purchase SG systems, equipment, devices, software, or communications and control systems for modifying existing electric system equipment; building, office, commercial, or industrial equipment; consumer products and appliances; or distributed generation, demand response, or energy storage devices to enable SG functions.

Appendix B Definitions of Regulating Reserve Service and Fast Responding Regulation Service

Regulating Reserve Service: An Ancillary Service that consists of either Regulation Down Service (Reg-Down) or Regulation Up Service (Reg-Up).

Fast Responding Regulation Service (FRRS)

A subset of Regulation Service that consists of either Fast Responding Regulation Down Service (FRRS-Down) or Fast Responding Regulation Up Service (FRRS-Up). Except where otherwise specified, all requirements that apply to Regulation Service also apply to FRRS.

Regulation Down Service (Reg-Down)

An Ancillary Service that provides capacity that can start responding to signals from ERCOT within five seconds . Such capacity is the amount available below any Base Point but above the LSL of a Generation Resource and may be called on to change output as necessary throughout the range of capacity available to maintain proper system frequency. A Load Resource providing Reg-Down must be able to increase and decrease Load as deployed within its Ancillary Service Schedule for Reg-Down below the Load Resource's MPC limit.

Fast Responding Regulation Down Service (FRRS-Down)

A subset of Reg-Down in which the participating Resource provides Reg-Down capacity to ERCOT within 1 second of either its receipt of an ERCOT Dispatch Instruction or its detection of a trigger frequency independent of an ERCOT Dispatch Instruction. Except where otherwise specified, all requirements that apply to Reg-Down also apply to FRRS-Down.

Regulation Up Service (Reg-Up)

An Ancillary Service that provides capacity that can start responding to signals from ERCOT within five seconds . Such capacity is the amount available above any Base Point but below the HSL of a Generation Resource and may be called on to change output as necessary throughout the range of capacity available to maintain proper system frequency. A Load Resource providing Reg-Up must be able to increase and decrease Load as deployed within its Ancillary Service Schedule for Reg-Up above the Load Resource's LPC limit.

Fast Responding Regulation Up Service (FRRS-Up)

A subset of Reg-Up in which the participating Resource provides Reg-Up capacity to ERCOT within 1 second of either its receipt of an ERCOT Dispatch Instruction or its detection of a trigger frequency independent of an ERCOT Dispatch Instruction. Except where otherwise specified, all requirements that apply to Reg-Up also apply to FRRS-Up.

Reference: ERCOT. 2014. Definition of Regulating Reserve Service.