Grid Impacts, Benefits, and Lessons Learned

Key Documents from DOE's Recovery Act Smart Grid Investment Grant and Demonstrations Programs

This document provides a list of key reports and case studies, and will be updated periodically as new materials are published and posted on SMARTGRID.GOV

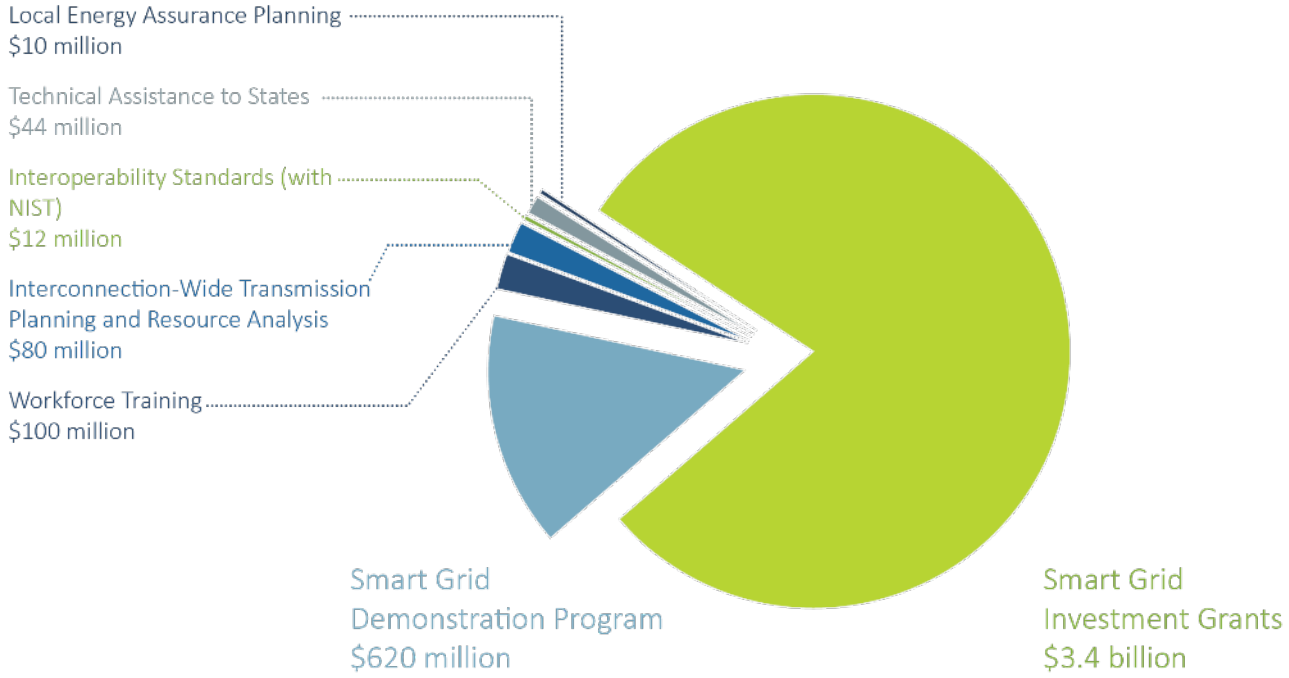
Document Contents

Smart Grid Investment Grant Program (SGIG)	**SGIG Program-Level Documents**
	SGIG Reports on Technology Applications and Results These documents cover the following areas: 1. Advanced metering infrastructure for peak and overall energy reduction through customer based technologies and to improve the operational efficiencies of utilities 2. Distribution automation technologies to improve reliability through the use of fault location, isolation and service restoration technology—such as automated feeder switches—and improve energy efficiency through the use of volt/VAR optimization techniques, including conservation voltage reduction 3. Synchrophasor and other technologies in transmission systems to improve reliability and efficiency (via improved operations and asset utilization)
	Reports on Consumer Behavior Studies (CBS) DOE-developed and recipient-developed reports on time-based rate and pricing pilots
Smart Grid Demonstration Program (SGDP)	**Regional Demonstration Projects**
	Energy Storage Demonstration Projects
Case Studies	**Project-Specific Documents from SGIG and SGDP Projects**

Recovery Act Smart Grid Overview

In 2009, the U.S. Department of Energy (DOE) Office of Electricity Delivery and Energy Reliability (OE) received $4.5 billion in funds to support grid modernization activities under the American Recovery and Reinvestment Act (ARRA, or Recovery Act). The Recovery Act was an economic stimulus package enacted by the 111th United States Congress in February 2009 and signed into law on February 17, 2009, by President Barack Obama.

Much of the funding was applied to activities articulated within Title XIII of the Energy Infrastructure and Security Act of 2007, which states grid modernization policies leading to a smarter grid. OE apportioned the funding among several programs:



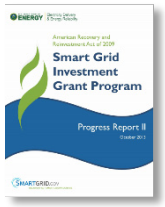
Although these programs are managed by various offices within OE, the Advanced Grid Initiatives (AGI) Office is largely responsible for managing the Smart Grid Investment Grant Program (SGIG) and the Smart Grid Demonstration Program (SGDP), and for reporting information on progress, grid impacts, benefits, and lessons-learned. (DOE's National Energy Technology Laboratory is responsible for implementing the SGDP under AGI management.) Information on the project activities associated with these programs is conveyed through conferences, reports, case studies, and other documents produced by Recovery Act funding recipients and by DOE (including supporting contractors and national laboratories).

Much of this information is housed in a central repository located on SMARTGRID.GOV

Smart Grid Investment Grant Program

The Smart Grid Investment Grant (SGIG) program is authorized by the EISA, Section 1306, as amended by the Recovery Act. The purpose of the grant program is to accelerate the modernization of the nation's electric transmission and distribution systems and promote investments in smart grid technologies, tools, and techniques that increase flexibility, functionality, interoperability, cybersecurity, situational awareness, and operational efficiency. The SGIG projects were selected through a merit-based, competitive solicitation by which successful projects were eligible to receive federal financial assistance for up to 50% of eligible costs. There are 99 SGIG projects with a total budget of about $8 billion; the federal share is about $3.4 billion. Project descriptions of these 5-year projects can be found on **SmartGrid.gov**, in addition to the following documents (where links are provided).

SGIG Program-Level Documents



Smart Grid Investment Grant Progress Report 2013

Economic Impact of Recovery Act Investments in Smart Grid

SGIG Final Report

Forthcoming – July 2015

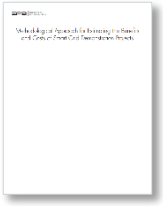
DOE Smart Grid Computational Tool Users Guide 2.0

Smart Grid Computational Tool

OMB Metrics Report

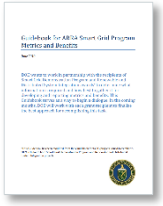
Forthcoming – May 2015

Analysis Guidance Documents



Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects

EPRI 1020342, January 2010



Guidebook for ARRA Smart Grid Program Metrics and Benefits

June 2010

Guidebook for Cost/Benefit Analysis of Smart Grid Demonstration Projects, Revision 1

EPRI 1025734, November 2012

SGIG Reports on Technology Applications and Results

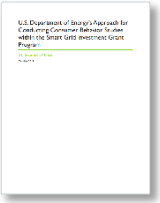
Technology-specific reports using results from SGIG projects have been published in the following topics areas:

- **AMI Demand Management** – Consumer-Based Demand Management Programs enabled by Advanced Metering Infrastructure (AMI)
- **AMI Operations** – AMI Applied to Operations
- **Distribution Automation** – Reliability Enhancements Achieved via Distribution Automation Technologies
- **Volt/VAR** – Improved Voltage and VAR Management
- **Transmission** – Transmission System Technology Advancements
- **Integration** – Integration of Renewable and Distributed Energy Resources

SGIG Reports on Technology Applications and Results	Date	AMI Demand Management	AMI Operations	Distribution Automation	Volt/VAR	Transmission	Integration
Published Documents							
Demand Reductions from the Application of Advanced Metering Infrastructure, Pricing Programs, and Customer-Based Systems - Initial Results	Dec 2012	●					
Operations and Maintenance Savings from Advanced Metering Infrastructure - Initial Results	Dec 2012		●				
Reliability Improvements from the Application of Distribution Automation Technologies - Initial Results	Dec 2012			●			
Application of Automated Controls for Voltage and Reactive Power Management - Initial Results	Dec 2012				●		
Synchrophasor Technologies and their Deployment in the Recovery Act Smart Grid Programs	Aug 2013					●	
Model Validation Using Synchrophasor - NASPI Technical Workshop	Oct 2013					●	
PMU Data Flows in North America	Mar 2014					●	
Phasor Tools Visualization – NASPI Technical Workshop	Jun 2014					●	
Synchrophasor Technology and Renewables Integration - NASPI Technical Workshop	Jun 2014					●	

SGIG Reports on Technology Applications and Results	Date	AMI Demand Management	AMI Operations	Distribution Automation	Volt/VAR	Transmission	Integration
Use of IEC 61850-90-5 to Transmit Synchrophasor Information According to IEEE 73.118: NASPI Tutorial (October 16, 2012 – August 2014 Update)	Aug 2014					●	
Customer Participation in the Smart Grid – Lessons Learned	Sep 2014	●					
Municipal Utilities' Investment In Smart grid Technologies Improves Services and Lowers Costs	Oct 2014	●	●	●			●
Factors Affecting PMU Installation Costs	Oct 2014					●	
Smart Grid Investments Improve Grid Reliability, Resilience, and Storm Response	Nov 2014			●			
Evaluating Electric Vehicle Charging Impacts and Customer Charging Behaviors - Experiences from Six Smart Grid Investment Grant Projects	Dec 2014						●
Fault Location, Isolation, and Service Restoration Technologies Reduce outage Impact and Duration	Dec 2014			●			
Forthcoming Documents							
Advanced Metering Infrastructure and Customer Systems	Feb 2015	●					
Distribution Automation	Apr 2015			●	●		
Final Report on Synchrophasor Deployment	Jun 2015					●	
Operations and Maintenance Benefits of Smart Grid	Jun 2015		●	●			
Smart Grid Software Systems	Jul 2015			●	●		
Smart Grid Technology Investment Analysis	Aug 2015	●	●	●	●		

Reports on Consumer Behavior Studies (CBS)



U.S. Department of Energy's Approach for Conducting Consumer Behavior Studies within the Smart Grid Investment Grant Program

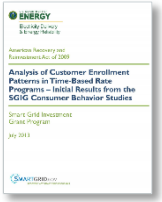
October 2011

Smart Grid Investment Grant Consumer Behavior Study Analysis: Summary of Utility Studies

June 2013

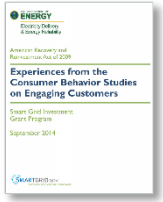
Quantifying the Impacts of Time-based Rates, Enabling Technology, and Other Treatments in Consumer Behavior Studies: Protocols and Guidelines

July 2013



Analysis of Customer Enrollment Patterns in Time-Based Rate Programs - Initial Results from the SGIG Consumer Behavior

July 2013



Experiences from the Consumer Behavior Studies on Engaging Customers

September 2014

Interim CBS Program Impact Report

Forthcoming – March 2015

Inter-Temporal Load Impacts

Forthcoming – June 2015

Evidence of Default Bias

Forthcoming – December 2015

Impacts on Vulnerable Populations

Forthcoming – December 2015

Experimental Design as the "Gold Standard"

Forthcoming – February 2016

Final CBS Program Impact Report

Forthcoming – December 2015

Guidance Documents

See the **Consumer Behavior Section** on SMARTGRID.GOV for the complete set of ten Consumer Behavior Guidance Documents.

CBS Utility Evaluation Reports

Participating Utilities	Evaluation Reports	
	Interim	Final
Central Vermont Public Service to "Green Mountain Power" – eEnergy Vermont	**Nov 2013**	Dec 2014
Detroit Edison – SmartCurrents Home Project	**Jan 2014**	**Sept 2014**
First Energy – Smart Grid Modernization Initiative	**May 2013**	Sep 2014
Lakeland Electric – Smart Metering Infrastructure Initiative	Dec 2014	Mar 2015
Marblehead Municipal Light Department – Residential Dynamic Pricing Pilot Project	**May 2012**	**Jun 2013**
Minnesota Power – AMI Behavioral Research	**Mar 2014**	Dec 2014
NV Energy – Nevada Dynamic Pricing Trial of the Advanced Services Delivery Project	Mar 2015	Dec 2015
Oklahoma Gas and Electric – Smart Study TOGETHER	**Mar 2011**	**Aug 2012**
Sacramento Municipal Utility District – SmartSacramento Project	**Oct 2013**	**Sep 2014**
Vermont Transco, LLC – eEnergy Vermont	**Oct 2013**	Dec 2014

Smart Grid Demonstration Program

The Smart Grid Demonstration Program (SGDP) is authorized by EISA, Section 1304, as amended by the Recovery Act, to demonstrate how a suite of existing and emerging smart grid concepts can be innovatively applied and integrated to prove technical, operational, and business-model feasibility. The aim is to demonstrate new and more cost-effective smart grid technologies, tools, techniques, and system configurations that significantly improve on the ones commonly used today. SGDP projects were selected through a merit-based solicitation in which provides financial assistance of up to 50% of the project's cost. Note that SGDP projects are cooperative agreements, whereas the Smart Grid Investment Grant projects are grants.

Two types of smart grid projects were selected for the SGDP. One includes regional smart grid demonstrations to verify smart grid viability, quantify smart grid costs and benefits, and validate new smart grid business models at scales to promote replication. The second includes 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 consists of 32 projects in the two areas: Smart Grid Regional Demonstrations (16 projects) and Energy Storage Demonstrations (16 projects). The total budget for the 32 projects is about $1.6 billion; the federal share is about $600 million.

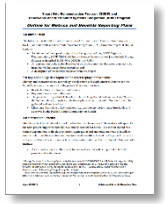
The recipients of SGDP awards are required to submit interim and final Technology Performance Reports (TPRs) to DOE. Each TPR contains the following information:

- 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 project, including the sizes, types, and configurations of the storage module, power conversion devices, and balance of plant equipment.
- Descriptions of the methodologies and algorithms for estimating the physical and financial performance of the energy storage 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.

Regional Demonstration Projects

Smart Grid Regional Demonstration projects involve assessments of the integration of advanced technologies with existing power systems including those involving renewable and distributed energy systems and demand response programs. The technical and economic performance of these technologies are being evaluated for applications such as microgrids, automated distribution systems, advanced metering infrastructure, time-based rate programs, and plug-in electric vehicles.

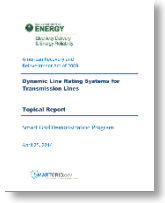
The recipients of SGDP awards for regional demonstrations are required, in most cases, to submit interim and final Technology Performance Reports according to the following guidance:



Outline for SGDP Regional Demo Metrics and Benefits Reporting Plans

May 2010

Program-Level SGDP Reports – Regional Demonstration



Dynamic Line Rating Systems for Transmission Lines

April 2014

Conservation Voltage Reduction

Forthcoming – January 2015

Transactive Energy Communications Systems

Forthcoming – January 2015

Distributed Energy Resources Integration

Forthcoming – March 2015

Microgrids

Forthcoming – April 2015

SGDP Interim Report

Forthcoming – May 2015 (many SGDP projects continue after this date)

NRECA Topical and Case-Based Technology Performance Reports

AMI-Based Load Research - KIUC Demonstration	May 2014
Building Consumer Acceptance to Maximize the Value of Grid Modernization	May 2014
Communications: The Smart Grid's Enabling Technology	May 2014
Conservation Impact of Prepaid Metering Motivation and Incentives for Pre-Pay Systems	May 2014
Costs and Benefits of Conservation Voltage Reduction: CVR Warrants Careful Examination	May 2014
Costs and Benefits of Smart Feeder Switching: Quantifying the Operating Value of SFS	May 2014
Delaware County Electric Cooperative: DR Capability and Predictability	May 2014
Demand Response: Testing the Theoretical Basis for DR	May 2014
Energy Storage-The Benefits of "Behind-the-Meter" Storage Adding Value with Ancillary Services	May 2014
Multi-Tenant Meter Data Management: A Systems Approach to Hierarchical Value	May 2014
Washington-St. Tammany Case Study Stress-Testing Designs Before Deployment	May 2014

Technology Performance Reports for Regional Demonstration Projects

Project Lead	Regional Demonstration Project Title	Technology Performance Reports	
		Interim	Final
AEP Ohio	gridSmart Demonstration Project	**Mar 2013** (outline only)	**Jun 2014**
Battelle Memorial Institute	Pacific Northwest Smart Grid Demonstration Project	Nov 2013 (unpublished)	Dec 2015
Boeing Co	Demonstrating a Cyber Secure, Scalable, Interoperable, and Cost-Effective Smart Selection for Optimizing Regional Transmission System Operation	**Dec 2012** **Oct2013** **Nov 2014**	Mar 2015
Center for Commercialization of Electric Technologies	Technology Solutions for Wind Integration in ERCOT	**Sep 2013**	Apr 2015
Consolidated Edison Company of NY	Secure Interoperable Open Smart Grid Demonstration	**Jul 2012**	Dec 2014
Kansas City Power & Light Co	KCP&L Green Impact Zone Smart Grid Demonstration	**Mar 2013** **Dec 2013**	May 2015
Long Island Power Authority	Long Island Smart Energy Corridor	**Jun 2013** **Jul 2014**	May 2015
LA Department of Water & Power	LA Department of Water & Power Smart Grid Regional Demonstration Project	Dec 2014 Dec 2015	Sep 2016
National Rural Electric Cooperative Association	NRECA Smart Grid Demonstration Project	**Apr 2013** **Nov 2013**	**Sep 2012**

Project Lead	Regional Demonstration Project Title	Technology Performance Reports	
		Interim	Final
NSTAR Electric & Gas Corporation	NSTAR Automated Meter Reading-Based Dynamic Pricing	**Mar 2013**	Aug 2014
NSTAR Electric & Gas Corporation	NSTAR Urban Grid Monitoring and Renewables Integration	Nov 2014 Feb 2015	Mar 2016
Oncor Electric Delivery Co	Dynamic Line Rating Project	**Dec 2011**	**Aug 2013**
Pecan Street Project	The Pecan Street Project Energy Internet Demonstration	**Jul 2014**	May 2015
Power Authority of the State of New York	Evaluation of Instrumentation and Dynamic Thermal Ratings for Overhead Lines	**Aug 2011**	**Oct 2013**
Southern California Edison	Irvine Smart Grid Demonstration	Jun 2014	Dec 2015
Waukesha Electric Systems	Fault Current Limiting Superconducting Transformer	N/A	Dec 2016

Energy Storage Demonstration Projects

Energy Storage Demonstration projects involve a variety of technologies including advanced batteries, flywheels, and underground compressed air systems. These projects are demonstrating a variety of size ranges and system configurations and their impacts on the grid. Technical and economic performance is being evaluated for a variety of 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.

The recipients of SGDP awards for energy storage projects are required to submit interim and final Technology Performance Reports according to the following guidance:

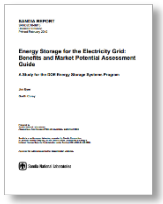
Outline for SGDP Energy Storage Metrics and Benefits Reporting Plans

August 2010

Program-Level SGDP Reports – Energy Storage

DOE Energy Storage Computational Tool User Guide 1.2

Energy Storage Computational Tool



Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide, Sandia Report (SAND2010-0815)

February 2010

Technology Performance Reports for Energy Storage Projects

Project Lead	Energy Storage Project Title	Technology Performance Reports	
		Interim	Final
Amber Kinetics	Demonstration of a Flywheel System for Low Cost, Bulk Energy Storage	**Apr 2012**	Dec 2014
Aquion Energy	Demonstration of Sodium-ion Battery for Grid-level Applications	N/A	**Aug 2012**

Project Lead	Energy Storage Project Title	Technology Performance Reports	
		Interim	Final
Beacon Power	Beacon Power 20MW Flywheel Frequency Regulation Plant	Feb 2015	Feb 2016
City of Painesville	Painesville Municipal Power Vanadium Redox Battery Demonstration Program	Apr 2015	Oct 2015
Detroit Edison Company	Detroit Edison's Advanced Implementation of A123s Community Energy Storage Systems for Grid Support	Nov 2014	Jan 2016
Duke Energy Business Services	Notrees Wind Storage	Nov 2014	Sept 2015
East Penn Manufacturing	Grid-Scale Energy Storage Demonstration for Ancillary Services Using the UltraBattery Technology	**Jan 2014**	May 2015
Ktech Inc.	Flow Battery Solution for Smart Grid Renewable Energy Applications	N/A	Feb 2015
New York State Electric & Gas Corporation	Advanced CAES Demonstration 150 MW Plant Using an Existing Salt Cavern	N/A	**Sep 2012**
Pacific Gas & Electric	Advanced Underground CAES Demonstration Project Using a Saline Porous Rock Formation as the Storage Reservoir	Annually starting Mar 2015	Mar 2023
Premium Power	Distributed Energy Storage System Demonstration	Feb 2017	April 2018
Primus Power Corporation	Wind Firming Energy Farm	Apr 2015	Aug 2016
Public Service Company of New Mexico	PV Plus Battery for Simultaneous Voltage Smoothing and Peak Shifting	**Sep 2012**	**May 2014**
Seeo Inc.	Solid State Batteries for Grid-Scale Energy Storage	N/A	Oct 2014
Southern California Edison	Tehachapi Wind Energy Storage Project	Dec 2014 Dec 2015	Aug 2016
SustainX Inc.	Demonstration of Isothermal Compressed Air Energy Storage to Support Renewable Energy Production	**Jul 2014**	Mar 2015

Case Studies

Project-specific case studies, using results from both SGIG and SGDP projects, have been published in the following topics areas:

- **AMI Demand Management** – Consumer-Based Demand Management Programs enabled by Advanced Metering Infrastructure (AMI)
- **AMI Operations** - AMI Applied to Operations
- **Distribution Automation** – Reliability Enhancements Achieved via Distribution Automation Technologies
- **Volt/VAR** – Improved Voltage and VAR Management
- **Transmission** – Transmission System Technology Advancements
- **Integration** – Integration of Renewable and Distributed Energy Resources
- **Cyber Security** – Cyber Security, System Integration, and Communications Technology
- **Equipment Monitoring**
- **Workforce Development**

Case Studies	Date	AMI Demand Management	AMI Operations	Distribution Automation	Volt/VAR	Transmission	Integration	Cyber Security	Equipment Monitoring	Workforce Development
Published Documents										
A Smart Grid Strategy for Assuring Reliability of the Western Grid	Jun-11					●				
Reducing Peak Demand to Defer Power Plant Construction in Oklahoma	Jun-11	●								
National Rural Electric Cooperative Association - Helping America's Electric Cooperatives Build a Smarter Grid to Streamline Operations and Improve Service	Jun-11							●		
A Smarter Electric Circuit: Electric Power Board of Chattanooga Makes the Switch	Jun-11			●						
Bright Lights, Big City: A Smarter Grid in New York	Jun-11			●	●				●	
Smart Meter Investments Support Rural Economy in Arkansas	Aug-11	●	●							
Synchrophasor Technologies for a Better Grid	Aug-11	●	●			●				

Case Studies	Date	AMI Demand Management	AMI Operations	Distribution Automation	Volt/VAR	Transmission	Integration	Cyber Security	Equipment Monitoring	Workforce Development
Smarter Meters Help Customers Budget Electric Service Costs	Oct-11									
At the Forefront of the Smart Grid: Empowering Consumers in Naperville, Illinois	Oct-11	●		●			●			
Workforce Training Case Study	Oct-11									●
Agricultural Demand Response Program in California Helps Farmers Reduce Peak Electricity Usage, Operate More Efficiently Year-Round	Dec-11	●								
Vermont Pursues a Statewide Smart Grid Strategy	Dec-11	●		●						●
Building a Smarter Distribution System in Pennsylvania	Jan-12			●	●			●		●
A "Model-Centric" Approach to Smarter Electric Distribution Systems	Jan-12			●				●		
Pacific Northwest - Battelle Smart Grid Demonstration Project 2012 Annual Report	Jan-12	●					●	●		
Glendale, California Municipal Invests in Smart Grid to Enhance Customer Services and Improve Operational Efficiencies	Mar-12	●		●			●	●		●
CenterPoint Energy's Smart Grid Solutions Improve Operating Efficiency and Customer Participation	Mar-12	●	●	●						
Transforming Electricity Delivery in Florida	Apr-12		●		●			●		
Critical Peak Pricing Lowers Peak Demands and Electric Bills in South Dakota and Minnesota	Jun-12	●								
Smart Grid Solutions Strengthen Electric Reliability and Customer Services in Florida	Jul-12	●		●	●			●	●	

Case Studies	Date	AMI Demand Management	AMI Operations	Distribution Automation	Volt/VAR	Transmission	Integration	Cyber Security	Equipment Monitoring	Workforce Development
Demand Response Defers Investment in New Power Plants in Oklahoma	Apr-13	●								
Smart Meter Investments Yield Positive Results in Maine	Feb-14	●	●	●	●			●		
Smart Meter Investments Benefit Rural Customers in Three Southern States	Mar-14	●	●					●		
Oncor's Pioneering Transmission Dynamic Line Rating Demonstration Lays Foundation for Follow-On Deployments	May-14					●				
Control Center and Data Management Improvements Modernize Bulk Power Operations in Georgia	Aug-14					●				
Using Smart Grid Technologies to Modernize Distribution Infrastructure in New York	Aug-14			●					●	
Integrated Smart Grid Provides Wide Range of Benefits in Ohio and the Carolinas	Sep-14		●	●						
Automated Demand Response Benefits California Utilities and Commercial/Industrial Customers	Sep-14	●								
New Forecasting Tools Enhance Wind Energy Integration in Idaho and Oregon	Sep-14					●	●			
Forthcoming Documents										
Improving Demand Response for Increasing Load	Oct-14	●		●			●			
Data Shed Light on Energy Use	Oct-14	●								
Energy Storage System Firms a Renewable Resource	Oct-14						●			
Smart Grid Technologies Cut Emissions and Costs in Ohio	Oct-14	●	●	●	●					

Case Studies	Date	AMI Demand Management	AMI Operations	Distribution Automation	Volt/VAR	Transmission	Integration	Cyber Security	Equipment Monitoring	Workforce Development
Massachusetts Pricing Pilot Yields Insights	Nov-14	●								
Optimizing the Smart Grid for Rural Electric Cooperatives								●		
Improving Security in the Growing Smart Energy Corridor	Nov-14		●					●		
East Penn Develops Long Lasting Battery Using UltraBattery Technology	Dec-14						●			
Battelle Extends Energy Markets to Distributed Generation in the Pacific Northwest	Feb-15	●	●				●	●		
Duke Energy Harnesses Large Scale Wind with Energy Storage	Feb-15						●			
CCET Integrates Texas Wind Using Synchrophasors	Feb-15					●	●			
Hazle Spindle Uses Flywheels for Grid Frequency Regulation	Feb-15						●			
Smart Grid Green Impacts in Kansas City	Feb-15	●	●	●						