U.S. DEPARTMENT OF ENERGY

Grid Modernization Multi-Year Program Plan

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Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

AC	alternating current
AGMR	Advanced Grid Modeling Research
AMI	advanced metering infrastructure
ANL	Argonne National Laboratory
AOP	annual operating plan
ARPA-E	Advanced Research Projects Agency-Energy
ARRA	American Recovery and Reinvestment Act
ASCR	Advanced Scientific Computing Research
BMS	building management system
BNL	Brookhaven National Laboratory
BTO	Building Technologies Office
C2M2	Cybersecurity Capability Maturity Model
CEDS	Cybersecurity for Energy Delivery Systems
CERTS	Consortium for Electric Reliability Technology Solutions
CHP	combined heat and power
COS	cost-of-service
CRADA	cooperative research and development agreement
CRISP	Cybersecurity Risk Information Sharing Program
CURENT	Center for Ultra-Wide-Area Resilient Electric Energy Transmission Networks
DC	direct current
DER	distributed energy resource
DMS	distribution management system
DOE	U.S. Department of Energy
DR	demand response
DSM	demand side management
EAC	Electricity Advisory Committee
EE	energy efficiency
EERE	Office of Energy Efficiency and Renewable Energy
EERS	Energy Efficiency Resource Standard
EIPC	Eastern Interconnection Planning Collaborative

EISPC	Eastern Interconnection States' Planning Council
EM&V	evaluation, measurement and verification
EMP	electromagnetic pulse
EMS	energy management system
EPRI	Electric Power Research Institute
EPSA	Office of Energy Policy and Systems Analysis
ERCOT	Electric Reliability Council of Texas
ESIF	Energy Systems Integration Facility
ESPC	Energy Savings Performance Contracts
EV	electric vehicle
FACA	Federal Advisory Committee Act
FACTS	flexible AC transmission system
FCTO	Fuel Cells Technology Office
FE	Office of Fossil Energy
FERC	Federal Energy Regulatory Commission
FLISR	fault location, isolation and service restoration
FOA	funding opportunity announcement
GENI	Green Electricity Network Integration Program
GMD	geomagnetic disturbance
GMI	Grid Modernization Initiative
GMLC	Grid Modernization Laboratory Consortium
GMLC-TN	Grid Modernization Laboratory Consortium – Testing Network
GPS	global positioning system
GPU	graphical processing unit
HIL	hardware-in-the-loop
HPC	high-performance computing
HVAC	heating, ventilation, and air conditioning
HVDC	high-voltage direct current
IE	Office of Indian Energy Policy and Programs
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory
IOU	investor-owned utilities

IRP	integrated resource plan
ISER	Infrastructure Security and Energy Restoration Program
ISO	independent system operator
IT	information technology
kVA	kilovolt-ampere
kVAR	kilovolt-ampere reactive
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
LED	light emitting diode
LPT	large power transformer
MMS	market management system
M&V	measurement and verification
MYPP	multi-year program plan
NASPI	North American Synchrophasor Initiative
NED	National Electricity Delivery Program
NE	Office of Nuclear Energy
NEMA	National Electrical Manufacturers Association
NERC	North American Electric Reliability Corporation
NETL	National Energy Technology Laboratory
NGO	non-governmental organization
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
OE	Office of Electricity Delivery and Energy Reliability
O&M	operations and maintenance
ORNL	Oak Ridge National Laboratory
OT	operational technology
PE	power electronics
PMU	phasor measurement unit
PNNL	Pacific Northwest National Laboratory

PUC	public utility commission
PV	photovoltaics
QER	Quadrennial Energy Review
QTR	Quadrennial Technology Review
RD&D	research, development, and demonstration
R&D	research and development
RFI	request for information
RGP	Regional Grid Partnerships
RMP	risk management plan
ROI	return on investment
RP&RO	regional planning and reliability organization
RPS	renewable portfolio standard
RTO	regional transmission organization
SC	Office of Science
SCADA	supervisory control and data acquisition
SDO	standards development organization
SETO	Solar Energy Technologies Office
SGIG	Smart Grid Investment Grant Program
SLAC	Stanford Linear Accelerator Center National Laboratory
SNL	Sandia National Laboratories
SRNL	Savannah River National Laboratory
SVC	static volt ampere reactive compensator
T&D	transmission and distribution
TA	technical assistance
TRRI	Transmission Reliability Research Investment
VAR	volt ampere reactive
VTO	Vehicle Technologies Office
WECC	Western Electricity Coordinating Council
WIEB	Western Interstate Energy Board
WWPTO	Wind and Water Power Technologies Office

Executive Summary

Our extensive, reliable power grid has fueled the nation's growth since the early 1900s. Access to electricity is such a fundamental enabler for the economy that the National Academy of Engineering named "electrification" the greatest engineering achievement of the 20th century. However, the grid we have today does not have the attributes necessary to meet the demands of the 21st century and beyond.

The traditional grid architecture is based on large-scale generation remotely located from consumers, hierarchical control structures with minimal feedback, limited energy storage, and passive loads. A modern grid must have:

- greater **resilience** to hazards of all type;
- improved **reliability** for everyday operations;
- enhanced **security** from an increasing and evolving number of threats;
- additional **affordability** to maintain our economic prosperity;
- superior **flexibility** to respond to the variability and uncertainty of conditions at one or more timescales, including a range of energy futures; and
- increased **sustainability** through additional clean energy and energy-efficient resources.

Five key trends are driving this transformation that challenges the capacity of the grid to provide us with the services we need, but also provides us with the opportunity to transform our grid into a platform for greater prosperity, growth, and innovation.

- Changing mix of types and characteristics of electric generation (in particular, distributed and clean energy)
- Growing demands for a more resilient and reliable grid (especially due to weather impacts and cyber and physical attacks)
- Growing supply- and demand-side opportunities for customers to participate in electricity markets
- Emergence of interconnected electricity information and control systems
- Aging electricity infrastructure.

"THE UNITED STATES' ENERGY SYSTEM IS GOING THROUGH DRAMATIC CHANGES. THIS PLACES A HIGH PREMIUM ON INVESTING WISELY IN THE ENERGY INFRASTRUCTURE WE NEED TO MOVE ENERGY SUPPLIES TO ENERGY CONSUMERS."

Dr. Ernest Moniz, Secretary of Energy

The current business-as-usual trajectory for the electricity industry will not result in a timely transition to a modernized grid. Innovation in the electric power sector is inhibited by regulatory, market, and business model uncertainties. Moreover, large investments initiated today may not fully come on line for ten years or more, and may remain with us for decades afterwards. Our nation finds itself at the point to make investment decisions that will create the modern grid of the future. The Federal Government recognizes this is a public good issue, and is in a unique position working with states, industry, and other stakeholders to accelerate efforts through research, development, and demonstration (RD&D), analysis, and outreach and convening initiatives.

Through its Grid Modernization Initiative (GMI) and this Grid Modernization Multi-Year Program Plan (MYPP), the U.S. Department of Energy (DOE) will coordinate a portfolio of activities to help set the nation on a cost-effective path to an resilient, secure, sustainable, and reliable grid that is flexible enough to provide an array of emerging services while remaining affordable to consumers. The scope of the GMI focuses on the development of new architectural concepts, tools, and technologies that measure, analyze, predict, protect, and control the grid of the future, and on enabling the institutional conditions that allow for more rapid development and widespread adoption of these tools and technologies. DOE will help frame new architecture elements, develop new planning and operations tools platforms, provide metrics and analytics, and enhance state and industry capabilities in designing the physical and regulatory models for successfully grid modernization. DOE will be supported by the National Laboratories under the Grid Modernization Lab Consortium (GMLC): a multi-year collaboration among 14 DOE National Laboratories and regional networks that will help develop and implement the MYPP.

This MYPP defines a vision for the modern grid and identifies key challenges and opportunities. The direction and priorities outlined in this MYPP draw upon DOE's ongoing work on the Quadrennial Energy Review (QER) and the Quadrennial Technology Review (QTR), as well as DOE program activities and numerous private sector inputs over the past years. It describes the RD&D activities DOE will focus on over the next five years, including opportunities for public-private partnerships.

This plan also lays the foundation for coordination across DOE, linking key programs within the Office of Science (SC), Office of Electricity Delivery and Energy Reliability (OE), Office of Energy Efficiency and Renewable Energy (EERE), Office of Fossil Energy (FE), Office of Nuclear Energy (NE), Advanced Research Projects Agency - Energy (ARPA-E), Office of Energy Policy and Systems Analysis (EPSA), and others. We recognize, however, that this intra-DOE coordination and collaboration is only the prelude to broader collaborative efforts that are needed with and among other federal agencies, regulators, legislators, utilities, vendors, consumer groups, and others.

Vision, Outcomes, and Activities

The vision of the Grid Modernization Initiative is:

The future grid will solve the challenges of seamlessly integrating conventional and renewable sources, storage, and central and distributed generation. It will provide a critical platform for U.S. prosperity, competitiveness, and innovation in a global clean energy economy. It will deliver ***resilient, reliable, flexible, secure, sustainable,*** *and* ***affordable*** *electricity to consumers where they want it, when they want it, how they want it.*

The Initiative will reach this vision by investing in RD&D efforts in individual technical areas and by looking at three types of integrated regional demonstrations.

Six Technical Areas

At the core of GMI are six specific technical areas that can be categorized by three thrusts:

- ***Technology*** *(i.e., hardware)*: Develop and demonstrate technologies for better measurement (e.g., sensors), integration (e.g., inverters), management and control of grid operations (e.g., transformers)
- ***Modeling and Analysis*** *(i.e., software)*: Develop and disseminate new and improved models for analysis, management and optimization of grid performance (e.g., solar and wind prediction)
- ***Institutional and Business:*** Develop the analytical methodologies and frameworks for improving business models that can deliver to consumers the value and benefits of grid modernization.

The six technical areas—equally important and in no particular order below—follow. Together they represent the key developments needed to advance the nation to a modernized grid.

1. Devices and Integrated Systems Testing

New distributed devices and systems will help deliver the flexibility required by the future grid for managing variable generation, engaging consumer, and enhancing reliability and resiliency while keeping electricity affordable.

This technical area develops devices and integrated systems, coordinates integration standards and test procedures, and evaluates the grid characteristics of both individual devices and integrated systems to provide grid-friendly energy services. For example, the DOE-funded collaboration between the National Institute of Standards and Technology (NIST) and electric industry stakeholders in developing smart grid interoperability standards, begun in 2009, has laid the technical foundation for more effective grid investments today.

Specific activities that will be included are:

- Develop advanced storage systems, power electronics, and other grid devices;
- Develop precise models of emerging components and controllers;
- Develop standards and test procedures;
- Build capabilities and conduct device testing and validation; and
- Conduct multi-scale systems integration and testing.

2. Sensing and Measurements

Measuring and monitoring vital parameters throughout the electric power network is necessary to assess the health of the grid in real time, predict its behavior, and respond to events effectively. Lack of visibility and accurate device- or facility-level information makes it difficult to operate the electricity system efficiently and has contributed to large-scale power disruptions and outages. Additionally, next- generation sensors will allow energy management systems to integrate buildings, electric vehicles, and distributed systems.

This technical area focuses on tools and strategies to determine the type, number, and placement of sensors to improve system visibility from individual devices to feeders, distribution systems, and regional transmission networks. This effort includes advanced methods to determine system states not directly accessible by measurement, and estimation methods for broad grid visibility. Finally, it develops frameworks to integrate sensors into grid systems to better determine and forecast solar irradiance and wind generation, integrate and estimate all generation and load uses behind the meter, and monitor and predict interfacing infrastructures such as electrified transportation.

Specific activities that will be included are:

- Develop a roadmap for achieving full electric system observability;
- Improve sensing for devices, buildings, and end-users;
- Enhance sensing for distribution system;
- Enhance sensing for the transmission system;
- Develop data analytic and visualization techniques; and
- Demonstrate unified grid-communications network.

3. System Operations, Power Flow, and Control

The existing grid control systems were developed over several decades using a set of 20th century design characteristics: centralized dispatchable generation connected to transmission, relatively slow system dynamics that permitted manual control, no significant grid energy storage, passive loads, one-way flow of real power at the distribution level, operation for reliability, and generation-following load for balancing. Several of these design parameters have become outmoded by new technologies, changing economics, and shifting customer expectations.

This technical area focuses on new control technologies to support new generation, load, and storage technologies. This effort develops power flow controllers that will permit fine adjustment and multi-directional power flow as well as flow control devices that can optimize transmission flows. It will also develop a consensus grid architecture with industry to frame the requirements for future control paradigms and devices and improved analytics and computation for grid operations and control.

Specific activities that will be included are:

- Develop grid architecture and control theory;
- Develop coordinated system controls;
- Improve analytics and computation for grid operations and control; and
- Develop enhanced power flow control device hardware.

4. Design and Planning Tools

Sound long-term planning and design yields smart capital investment. Electric power grid modeling and simulation applications are fundamental to the successful design, planning, and secure operation of power systems with billions of dollars in capital investments and operations costs. However, existing planning and modeling tools have not kept pace with the complex technology, policy, economics, and outcomes demanded for the electric grid.

This technical area develops the next generation of modeling and simulation tools needed for power system planning. These new tools will handle emerging needs driven by changing technologies and operational capabilities, larger and more complex models, more challenging forecasting, and new types and sources of data that reflect future integration of T&D and communications.

Specific activities that will be included are:

- Scale tools for comprehensive economic assessment;
- Develop and adapt tools for improving reliance and reliability; and
- Build computation technologies and high performance computing capabilities to speed up analyses.

5. Security and Resilience

There are ever increasing natural and man-made threats to the electric grid, including high-impact and low-frequency events, severe storms, fuel delivery failures, and more frequent physical and cyber threats. This technical area aims to meet physical and cybersecurity challenges, analyze asset criticality, assess ways to minimize risk, address supply chain risks (specifically for transformers), and provide situational awareness and incident support during energy-related emergencies. New York State's leadership in Superstorm *Sandy* rebuilding and resilience efforts shows that grid modernization is pivotal for protecting citizens and the economy against natural and human attack.

Specific activities that will be included are:

- Improve ability to identify threats and hazards;
- Increase ability to protect against threats and hazards;
- Increase ability to detect potential threats and hazards;
- Improve ability to respond to incidents; and
- Improve recovery capacity time.

6. Institutional Support

Technical assistance to key decision-makers is important so that they can address the high-priority grid modernization challenges and needs identified by electric power industry stakeholders. It gives particular emphasis to working with state policymakers and regional planning organizations, with support for both analysis of issues and creation of information for stakeholders. Analytic, non-prescriptive workshops and facilitator-led dialogues among stakeholders can build agreement around the value of transforming the grid and the best ways to do that using technology, regulatory, and market tools that meets the unique needs of every region. DOE has already built strong relationships with many institutional leaders through two decades of investments in collaborative work on envisioning the future grid, developing regulatory and planning initiatives, coordinating national action plans for energy efficiency and demand response, and extensive efforts to create regional collaboration for region-wide resource modeling and planning.

In addition to technical assistance, this technical area will develop new analytic frameworks for key grid modernization issues. First, this effort will advance a framework for grid modernization metrics with analytic tools and data sets. It will integrate current metrics and data efforts scattered across grid stakeholders (NERC, state regulators, etc.), and will develop new metrics for emerging grid attributes related to resilience, new energy services, and emerging control and market constructs. Second, this area will define a framework for valuation of distributed energy resources in collaboration with grid stakeholders for advancing new rate structures and utility business models that support grid modernization goals.

Specific activities that will be included are:

- Provide technical assistance to states and tribal governments;
- Support regional planning and reliability organizations;
- Develop methods and resources for assessing emerging technologies, valuation, new markets; and
- Conduct research in future electric utility regulations.

Integrated Regional Demonstrations

The core technologies, tools, and analyses that will be developed in the six technical areas will feed into Integrated Regional Demonstrations designed to accelerate research outputs to widespread deployment. Three specific concepts are envisioned for the first round of demonstration projects:

- **Transmission and distribution system operating reliably on a lean reserve margin:** full visibility of the power system from real-time sensor networks enabling new approaches to system design, control, operations, protection and optimization. An integrated effort to demonstrate the delivery of reliable and affordable grid services with a substantially reduced amount of system reserve capacity.

- **Resilient distribution feeders with high percentages of low-carbon distributed energy resources:** advances in real-time system monitoring, for high penetration of clean, distributed generation, and the proliferation of smart consumer end-use devices. New approaches for distributed control, engagement with bulk system reliability management, and coordination across local intelligent assets, including multiple microgrids, over a range of feeder innovations that meet changing consumer expectations and traditional demand for reliability, resilience, and affordability.
- **Advanced modern grid planning and analytics platform:** a platform that couples high-performance transmission, distribution, and communications, adds the capacity to reflect uncertainty, and substantially increases the speed and productivity of tools to enable stakeholders to achieve timely evaluation of future grid alternatives. This platform will be integrated with vendor products and leveraged into on-going technical assistance with states and regions to substantially improve planning and regulatory assessments of the modern grid.

These regional demonstration projects will build on the past successes of the Smart Grid Investment Grant (SGIG) Program and the Smart Grid Demonstration Program (SGDP), which focused primarily on deploying existing smart grid technologies, tools, and techniques to improve grid performance today, and evaluating emerging technologies for future applications. The Integrated Regional Demonstrations will further advance grid modernization by coupling multiple hardware, software, and institutional solutions into integrated and modernized grids at a scale and a pace necessary to meet national goals. This work will ensure that efforts and capital used to advance the grid are focused on the attributes important to society and that our evolving grid will meet all the demands of the 21st century, realizing the vision of the future electric grid.

1.0 Introduction and Overview

This Multi-Year Program Plan (MYPP) describes an initiative led by DOE and supported by the National Laboratories under the Grid Modernization Lab Consortium (GMLC) structure to enhance grid modernization.[1] It addresses a suite of highly coordinated and integrated RD&D programs and analytical efforts focused on developing new architectural concepts, tools, and technologies that measure, analyze, predict, protect, and control the grid of the future, and on enabling the institutional conditions that allow for more rapid development and widespread adoption of these tools and technologies. The Plan also provides the reasoning why DOE is undertaking the Initiative now, what outcomes it is targeting, and by when, and what activities will be undertaken in six technical areas over the next five years and beyond.

The Plan builds on past work and accomplishments by DOE and others, and it complements, integrates, and supports various activities underway and planned by several DOE Offices and Programs as well as the private sector. The information in this MYPP also builds on concepts and recommendations in ***DOE's Quadrennial Energy Review and Quadrennial Technology Review.***[2]

1.1 National Need for Grid Modernization—Challenges and Opportunities

Our extensive, reliable power grid has fueled the nation's growth and has long been a model for other countries. The National Academy of Engineering named "electrification" the greatest engineering achievement of the 20th century. The structure of the 20th century grid, however, cannot meet all the demands of the 21st century. The traditional architecture was based on large-scale generation remotely located from consumers, hierarchical control structures with minimal feedback, limited energy storage, and passive loads. A modern grid must be more flexible, robust, and agile. It must have the ability to dynamically optimize grid operations and resources, rapidly detect and mitigate disturbances, engage millions if not billions more intelligent devices, integrate diverse generation sources (on both the supply and demand sides), integrate demand response and energy-efficiency resources, enable consumers to manage their electricity use and participate in markets, and provide strong protection against physical and cyber risks.[3]

"IN ORDER TO MANAGE AMERICA'S ENERGY CONSUMPTION MORE EFFICIENTLY AND COST-EFFECTIVELY, RECOVER FROM DISRUPTIONS MORE QUICKLY AND REMAIN GLOBALLY COMPETITIVE, WE MUST MODERNIZE OUR NATION'S ELECTRIC GRID."

Patricia Hoffman, Assistant Secretary for Electricity Delivery and Energy Reliability

Five key trends are driving this transformation that challenges the capacity of the grid to provide us with the services we need, but also provides us with the opportunity to transform our grid into a platform for greater prosperity, growth, and innovation.

- Changing mix of types and characteristics of electric generation (in particular, distributed and clean energy)
- Growing demands for a more resilient and reliable grid (especially due to weather impacts and cyber- and physical-attacks)
- Growing supply- and demand-side opportunities for customers to participate in electricity markets
- Emergence of interconnected electricity information and control systems
- Aging electricity infrastructure.

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[1] See Appendix A for full GMLC Charter.

[2] See http://energy.gov/epsa/downloads/quadrennial-energy-review-full-report and http://energy.gov/quadrennial-technology-review-2015

[3] U.S. Department of Energy, *Quadrennial Technology Review, Chapter 3: Enabling Modernization of the Electric Power System*, http://energy.gov/qtr, September 2015.

The nation's electric generation mix is changing and moving toward the President's goal of reaching 80 percent of the nation's electricity from clean energy resources by 2035.[4] Shifts in fuel prices have helped cause coal's share of total U.S. power generation fuel mix to decrease from 52 percent in 2000 to 39 percent in 2013[5]. Over this same time, natural gas powered generation grew from 16 percent in 2000 to 27 percent, and renewables increased from 9 percent in 2000 to 13 percent (see Figure 1). Furthermore, in 2000, the total U.S. non-hydro renewable generation peak capacity was 16,500 MW, or 1.9 percent of the country's total (see Figure 2). By 2013, this had grown to 93,000 MW, or 8 percent of the total.[6] In some markets the penetration of renewable power is much higher (e.g., solar photovoltaics (PV) provides annually, on average, 64 percent of annual peak load on the island of Kauai, Hawaii).[7] While the grid can easily accommodate new baseload energy sources, the variable characteristics of most renewable and many distributed sources introduces new challenges to utilities and regulators who must continuously balance demand with reliability and affordability. Even more challenging, some variable sources, like wind, tend to be concentrated in specific locations, while others, such as rooftop-mounted PV, are widely distributed.

	Coal	Petroleum Liquids	Petroleum Coke	Natural Gas	Other Gases	Nuclear	Renewables	Other	Total Generation (GWh)
2000	51.6%	2.7%	0.2%	15.8%	0.4%	19.8%	9.4%	0.1%	3,807,955
2001	50.8%	3.1%	0.3%	17.1%	0.2%	20.5%	7.7%	0.3%	3,745,745
2002	50.0%	2.0%	0.4%	17.9%	0.3%	20.2%	8.9%	0.3%	3,867,498
2003	50.7%	2.6%	0.4%	16.7%	0.4%	19.6%	9.1%	0.4%	3,892,115
2004	49.7%	2.5%	0.5%	17.8%	0.4%	19.8%	8.8%	0.4%	3,979,023
2005	49.5%	2.5%	0.6%	18.7%	0.3%	19.2%	8.8%	0.3%	4,062,458
2006	48.9%	1.1%	0.5%	20.1%	0.3%	19.3%	9.5%	0.3%	4,071,962
2007	48.4%	1.2%	0.4%	21.5%	0.3%	19.4%	8.5%	0.3%	4,164,748
2008	48.1%	0.8%	0.3%	21.4%	0.3%	19.5%	9.3%	0.3%	4,127,019
2009	44.4%	0.7%	0.3%	23.3%	0.3%	20.2%	10.6%	0.3%	3,956,990
2010	44.7%	0.6%	0.3%	23.9%	0.3%	19.5%	10.4%	0.3%	4,133,854
2011	42.2%	0.4%	0.3%	24.7%	0.3%	19.2%	12.6%	0.3%	4,112,181
2012	37.3%	0.3%	0.2%	30.3%	0.3%	18.9%	12.4%	0.3%	4,067,551
2013	38.9%	0.3%	0.3%	27.3%	0.3%	19.4%	13.1%	0.3%	4,074,457

FIGURE 1. U.S. ELECTRICITY GENERATION BY SOURCE[8]

[4] The White House, Office of the Press Secretary, *Remarks by the President in State of Union Address*, https://www.whitehouse.gov/the-press-office/2011/01/25/remarks-president-state-union-address, January 25, 2011.

[5] U.S. Energy Information Administration, *Electric Power Annual*, 2012.

[6] U.S. Department of Energy, *2013 Renewable Energy Data Book*, December, 2014.

[7] Presentation from Michael Champley, Public Utility Commissioner from HI, Workshop on September 30, 2014.

[8] U.S. Department of Energy, *2013 Renewable Energy Data Book,* December, 2014.

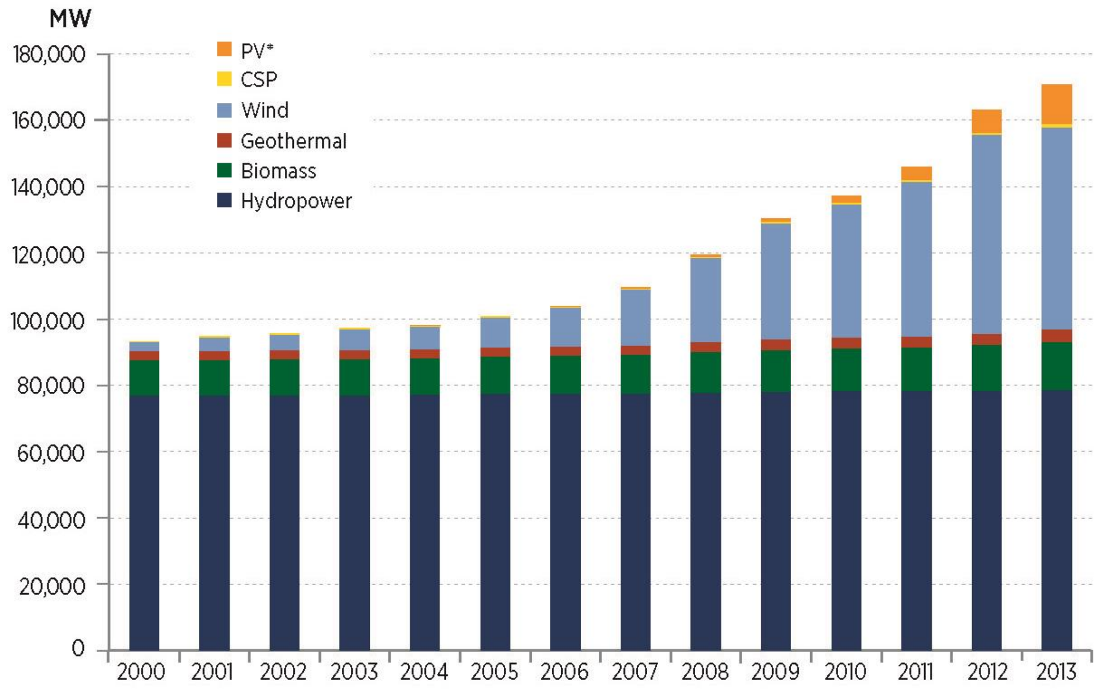

FIGURE 2. U.S. RENEWABLE ELECTRICITY NAMEPLATE CAPACITY BY SOURCE[9]

A more robust and resilient electricity delivery is needed. From Hurricane *Katrina* to Superstorm *Sandy*, the economic and human losses from the destruction of electric grids have become more visible in recent years. When storm devastation covers highly populated or large areas, billions of dollars are lost and millions of people are affected. Severe storms are not the only threat: vulnerabilities to cyber-attacks have emerged as an important potential harm. The U.S. Department of Homeland Security has evidence that cyber-attacks on key infrastructure—and on the electric grid—are increasing both in frequency and sophistication. In fiscal year 2012, some 198 cyber incidents were reported across all critical infrastructure sectors. Forty-one percent of these incidents involved the energy sector, particularly the electric power sector.[10]

Changes in demand-side capabilities are also affecting electricity delivery. Growing installations of rooftop PV and more energy efficient and grid-responsive appliances, buildings and industrial equipment, reduce the amount of peak power capacity needed. In addition, consumers are increasingly becoming “prosumers,” both users and producers of electricity. For example, there are now more than 600,000 homes and businesses with on-site solar PV. In 2014, PV installations reached 6,200 MW, up 30 percent over 2013 and more than 12 times the amount installed five years earlier,[11] and the number of controllable devices in the system is rising sharply, causing problems with current control paradigms.

The emergence of interconnected electricity information and control systems provide both challenges related to cybersecurity threats, and opportunities for real-time control, information and data exchange to optimize system reliability, asset utilization, and security. The information technology (IT) and communications overlay of our electric grid is changing all aspects of grid planning and operations, including new requirements for interoperability, cybersecurity, and the management of massive quantities of data from new meters and sensors.

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[9] U.S. Department of Energy, *2013 Renewable Energy Data Book,* December, 2014.

[10] Bipartisan Policy Center, *Cybersecurity and the North American Electric Grid: New Policy Approaches to Address an Evolving Threat*, February, 2014.

[11] GTM Research and Solar Energy Industries Association, *U.S. Solar Market Insight Report: 2014 Year in Review*, 2015.

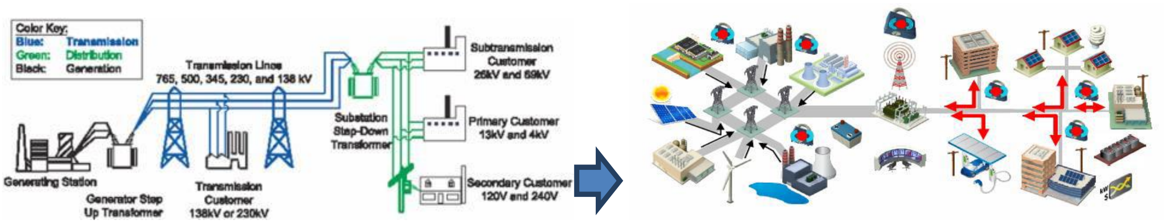
The electric grid was designed to deliver electricity one-way, from centralized power plants to customers, with high reliability at a moderate cost. As aging infrastructure is replaced, and smart meters and other digital communication and control devices proliferate, operators will require advanced control systems and distribution management systems that can securely manage new digital technology and utilize the new data to inform system operations. Furthermore, 70% of large power transformers and transmission lines are 25 years or older, and 60 percent of circuit breakers are 30 years or older.[12] A catastrophic failure of a transmission asset threatens system reliability, and changing system dynamics may increase the likelihood that this can happen. As assets are replaced, there is an opportunity to install next-generation, higher-performance components.

A modernized grid is essential for the prosperity, competitiveness, and innovation of the U.S. economy that increasingly relies on high quality power, and the grid's transformation to lower carbon power and more efficiency will be a critical part of enabling a global clean energy economy. It must deliver reliable, affordable, and clean electricity to consumers where they want it, when they want it, and how they want it, while maintaining flexibility for change and providing a platform for innovation. Additionally, a modernized grid must integrate customers and their end-use decisions into grid operations, rather than assuming that "the grid" represents only supply-side actors and decision-makers.

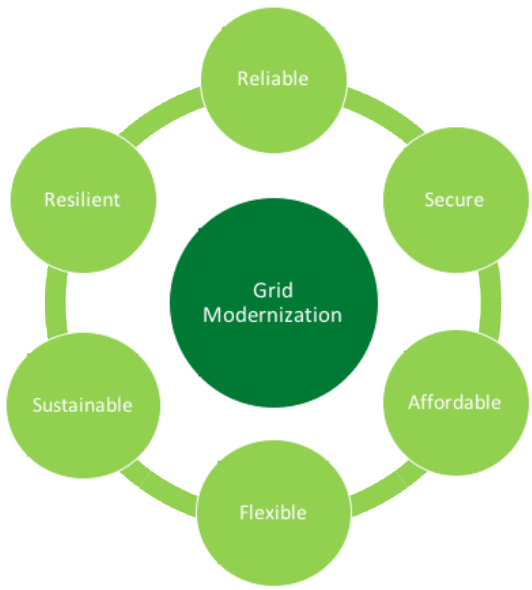
[12] Global Environment Fund and Center for Smart Energy, *The Emerging Smart Grid: Investment and Entrepreneurial Potential in the Electric Power Grid of the Future*, http://assets.fiercemarkets.net/public/smartgridnews/sgnr_2007_0801.pdf, October 2005.

What is a Modernized Grid?

Transitioning to a modernized grid is a process, not an end-point. It is a transformation from a monolithic grid to one that is modular and agile: from centralized generation characterized by decisions driven by affordability and reliability, to one of both centralized and distributed generation and intelligent load control characterized by decisions driven by cost and environmental sustainability, contained events, personalized energy options, and security from all threats.



As well as stimulating innovation, the future modernized grid will therefore balance six attributes. These attributes compete with one another for resource dollars, but with careful design they can be positively reinforcing. Policymakers, regulators, grid planners, and operators must constantly seek to maintain balance among the attributes.



- **Resilient** - Quick recovery from any situation or power outage
- **Reliable** - Improves power quality and fewer power outages
- **Secure** - Increases protection to our critical infrastructure
- **Affordable** - Maintains reasonable costs to consumers.
- **Flexible** - Responds to the variability and uncertainty of conditions at one or more timescales, including a range of energy futures
- **Sustainable** - Facilitates broader deployment of clean generation and efficient end use technologies

1.2 Justification for a National-Scale Grid Modernization Initiative Today

Actions are already underway to modernize the grid but investments at a much larger scale will be needed. For example, investor-owned electric utilities (IOUs) and stand-alone transmission companies invested a record $38 billion in transmission and distribution infrastructure in 2013.[13] The Brattle Group, in a report for the Edison Electric Institute, estimated that the electric utility industry will need to spend about $1.5 to $2 trillion from 2010 to 2030 just to maintain the reliability of electric service.[14] This does not include the additional billions that customers may spend on end-use equipment and generation and automation behind the meter.

The current business-as-usual trajectory for the electricity industry will not result in a timely transition to a modernized grid. We are already 15 years into the new century and large investments decided on today may not fully come on line for ten years or more, remaining with us for decades afterwards.

Innovation in the electric power sector is inhibited by an unclear investment environment, due to regulatory, market, and business model uncertainties. A few trends confirm the magnitude, complexity, and urgency of the enormous task before the nation to modernize the U.S. grid.

- There are a small number of innovators, and many find it difficult to invest at a sufficient scale. A benchmarking study by the Bonneville Power Administration showed the electric utility industry invests just 0.1 percent of its net sales in R&D.[15] This is in part due to a business model that focuses on limiting short- and medium-term cost growth and the lack of appetite for innovation investments in a rate-payer-oriented market relying heavily on large up-front capital investments.
- Investment is hampered by low returns on invested capital. Returns for utilities have fallen about 1.3 percent from 2006 to 2013 due to flattening demand and decreased load factors.[16]
- Several states, such as California, Hawaii, and New York, have embarked on comprehensive (and different) approaches to changing the entire electricity market ecosystem and its interrelationships.[17]
- Traditional regulation of distribution networks can prevent the deployment of innovative technologies and business models such as smart grid solutions and demand-side management. [18]
- Oversight of grid operations rests on a variety of regulators that have authorities from small local areas to entire regions of the country. The physical infrastructure of the grid—including generating stations, power lines, substations, buildings and devices—also includes a variety of ownership and management models. The result is that no one organization is charged with fully managing the grid.
- Decentralized generation raises questions about the traditional economic model for transmission and distribution (T&D) businesses. As customers substitute locally generated electrons for those from centralized power plants, load served by traditional generation falls and grid operators are forced to raise prices on the remaining units to recover their fixed costs. Rising T&D charges create a greater incentive for local generation, creating a downward spiral.[19]

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[13] Edison Electric Institute (EEI). *EEI Annual Property & Plant Capital Investment Survey,* 2014.

[14] The Edison Foundation, *Transforming America's Power Industry: The Investment Challenge 2010-2030*, 2008.

[15] National Science Foundation, *Business Research and Development and Innovation: 2011*, Detailed Statistical Tables, NSF 15-307, December 30, 2014

[16] World Economic Forum, *The Future of Electricity: Attracting investment to build tomorrow's electricity sector*, January 2015.

[17] New York Public Service Commission, *REV: Reforming the Energy Vision*; California Public Utilities Commission, *Distribution Resources Plan* and other overlapping activities; and Hawaii State Energy Office, *Energy Policy Directives.*

[18] World Economic Forum, *The Future of Electricity: Attracting investment to build tomorrow's electricity sector*, January 2015.

[19] World Economic Forum, *The Future of Electricity: Attracting investment to build tomorrow's electricity sector*, January 2015.

- Multiple industry organizations are engaged, but are often focused on issues of concern to their particular segment of the industry making it challenging to agree on common goals.

The development of new technologies and investments in new infrastructure to modernize the electric power grid is largely a private-sector responsibility. Utilities, power providers, consumers, and technology developers make investment decisions in complex and changing regulatory and market conditions. This may cause decision makers to seek locally optimized solutions based on regulatory and economic constraints. Through collaborative RD&D, analysis, outreach, and convening initiatives, DOE can help to catalyze, accelerate, and facilitate the adoption of advanced technologies, tools, and techniques that will benefit the overall system.

1.3 DOE's Role in Grid Modernization

DOE is able to assess regional and national grid modernization efforts, technology and market developments, and institutional barriers affecting generation, transmission, distribution, and end-use technologies. DOE is also the most qualified to conduct foundational work to identify gaps in fundamental knowledge and technology. Finally, DOE is able to convene stakeholders to develop consensus roadmaps, deliver new platforms of tools and analytics to catalyze innovation in industry, and accelerate adoption of new technologies, In summary, DOE's technical expertise, past accomplishments (see box *Building on the Foundations of DOE's Prior Investments and Successes* below*)*, and current activities provide the basis for new grid leadership. Through a coordinated Grid Modernization Initiative, DOE leadership will provide:

- ***Catalyze Private-Sector Innovation***— DOE and its National Laboratories can use their RD&D expertise in collaboration with other key stakeholders to help establish *the technological foundation* for grid modernization. Federal RD&D across National Laboratories, universities, and industry can complement the RD&D being currently carried out by power generation and delivery entities and their vendors. Federally sponsored R&D can (i) de-risk technologies that could provide significant value to the nation; (ii) reduce the cost of such technologies; and (iii) promote innovation and encourage broader investment. With knowledge and tools ranging from technology development to computational expertise to field experience, DOE is well suited to lead and facilitate partnerships among states, regions, tribes, research institutes, non-profits, and private industry. This kind of collaboration is especially important for small municipal and cooperative utilities that have limited resources to conduct R&D.
- ***Regional Breadth***—America's regions vary significantly in their readiness for grid transformation, energy resources, access to transmission, vulnerability to natural disasters, and a wide array of other factors. DOE, in partnership with the National Laboratories, and states can combine knowledge of new technology capabilities, analytical tool-sets, and understanding of unique regional issues to deliver collaborative partnerships and initiatives that are tailored to regional needs yet able to deliver national benefits.
- ***Convening Power***[20]—DOE can listen, synthesize, and help communicate, without being prescriptive. Using its convening power as an honest-broker, DOE can help identify and replicate best practices and avoid duplication or unproductive technology pathways. DOE's leadership can help other stakeholders recognize and respond to the urgency of the need for investment. DOE's assembling efforts were successful in the ARRA funded interconnection wide planning efforts, significantly supporting states and the private sector in interconnection wide planning scenarios.[21] DOE can bring together the multiple actors and influencers to find common visions and identify activities that benefit all parties.

[20] As used in this document, convening power is not a legal authority but a commonly accepted institutional role.

[21] U.S. Department of Energy: http://energy.gov/oe/services/electricity-policy-coordination-and-implementation/transmission-planning/recovery-act

With the relatively small federal investment envisioned in the Grid Modernization Initiative, DOE can help make the trillions of dollars in expected private investments more effective by spurring technology innovation, sharing best practices across the sector, and fostering a common vision among diverse stakeholders. This will lead to a grid that will support our 21st century economy and expectations.

Building on the Foundations of DOE's Prior Investments and Successes

This MYPP builds off of many years of DOE work in grid-related R&D, institutional support and technical assistance, and modeling and analysis, including billions of dollars of direct funding and many more times in cost-shared funds. Below are a few of the more notable DOE accomplishments in this space.

Smart Grid work under ARRA (OE)

Under the Recovery Act smart grid programs administered by DOE, and working closely with utilities, RTOs/ISOs, and vendors, more than 800 networked phasor measurement units were deployed providing near-nationwide coverage of the bulk transmission system. On the distribution system, more than 7,500 automated feeder switches and 18,500 automated capacitor banks were deployed, providing self-healing capabilities and voltage and reactive power management. For customers, more than 15 million smart meters and 240,000 programmable communicating thermostats were deployed enabling millions of consumers to better manage their consumption and costs. As a result of these and other investments, the number of customer interruptions decreased by 37-55% and customer minutes of interruption declined by about 50%. Application of conservation voltage reduction technologies and strategies have yielded customer energy and peak demand reductions of 2-3%. The smart meters have allowed utilities to operate more efficiently (e.g., fewer vehicle trips for service connections and disconnections) and faster service restoration for customers (*Smart Grid Investment Grant Program: Progress Report II*, October 2013).

Synchrophasors (OE)

DOE has been investing in the development of synchrophasor technology for over a decade. Within a few years, this technology will revolutionize grid planning and real-time operation by collecting data on grid conditions that is 100 times faster than current SCADA measurements. This time-synchronized data can be used to detect and diagnose grid conditions at the transmission and distribution levels, and to design and trigger automated grid controls. Working closely with utilities and RTOs/ISOs, more than 800 phasor measurement units were deployed under the Recovery Act smart grid projects overseen by DOE for a nationwide total of more than 1,700 as of 2014. Software applications using synchrophasor data are maturing rapidly thanks to the ARRA grants and subsequent DOE R&D investments. These include wide-area visualization, oscillation detection, voltage stability monitoring, diagnosis of equipment mis-operations, model validation, post-event forensic analysis, and operator training.

Grid-Scale Energy Storage (OE)

Advances to the electric grid must enhance the robustness and resilience of the electricity delivery system. Energy storage does this by improving the operating capabilities of the grid, enhancing reliability, and deferring or reducing infrastructure investments. Storage is also valuable for emergency preparedness, providing backup power as well as grid stabilization services. DOE's Energy Storage Program performs R&D on a wide variety of storage technologies, conducts analytical studies on the technical and economic performance of storage technologies, and collaborates with industry and states to test storage installations. DOE funded 16 Recovery Act storage demonstration projects with industry testing storage applications from renewables integration to frequency regulation. Federal funding of $185M for these projects attracted a cost-share of $585M.

Grid Integration of Solar Power (EERE)

EERE's SunShot Initiative supports the development of innovative, cost-effective solutions that allow increasing amounts of solar energy to integrate seamlessly with the national power grid while mitigating associated risks and reducing system costs. Such solutions will protect system reliability and encourage the widespread deployment of solar technologies such as photovoltaics and concentrating solar power. SunShot's grid modernization focused systems integration work focuses on RD&D to reduce the cost of power electronics and develop technologies and strategies that enable high penetrations of solar electricity on the national power grid. On September 1, 2011, DOE announced $25.9 million to fund eight solar projects that are targeting ways to develop power electronics and build smarter, more interactive systems and components so that solar energy can be integrated into the electric power distribution and transmission grid at higher levels. Part of the SunShot Systems Integration efforts, the Solar Energy Grid Integration Systems - Advanced Concepts (SEGIS-AC) projects will help advance a smart grid that will handle two-way flows of power and communication, in contrast to the one-way power flow and limited communication that exists today.

Grid Integration of Wind and Water Power (EERE)

The Wind and Water Power Technologies Office supports the development, deployment, and commercialization of wind and water power technologies as well as R&D efforts that improve technology performance, lower costs, and—ultimately— deploy technologies that efficiently capture the abundant wind and water energy resources in the United States. From 2006 to 2014, WWPTO announced awards to industry totaling more than $25 million for 41 projects focused on integration, transmission, and resource assessment, and characterization. These projects include monitoring and controls; modeling, simulation, and analysis; transmission planning, integration, and interconnection studies; and resource assessment and characterization. Projects in these topic areas help the industry understand how they can reliably integrate large quantities of wind energy into system operations, and develop capabilities that enable these new wind installations to actively improve the power quality of the electric grid.

1.4 Partnerships for Implementation

DOE will partner with key stakeholders in the electric power sector. Regular reviews will occur between experts leading technical areas and industry to seek input and knowledge for the most promising grid modernization research pathways. DOE and the National Labs will issue Funding Opportunity Announcements (FOA's), Cooperative Research and Development Agreements (CRADA's), and other competitive research funding opportunities in tandem with lab operated projects. Centralized information exchange will facilitate best practices and reduce duplication or unproductive technology pathways. DOE will provide additional focus on translating advances in underlying grid technologies into meaningful knowledge and tools for states, regions, tribes, and the regulatory communities. Finally, DOE will rely on stakeholders to participate in the execution of multi-scale demonstrations, at a regional level, to prove concepts of the modernized grid.

Grid Modernization Roles and Responsibilities within the Department of Energy

DOE proposes to achieve grid modernization through a multi-year collaborative initiative involving public and private sector energy stakeholders including the National Laboratories, utilities, regulators, equipment manufacturers, vendors, developers, universities, associations, and others. This will be led by three DOE offices:

- Office of Electricity Delivery and Energy Reliability (OE) – enables the grid to use all available energy sources to serve all loads while meeting climate, security, reliability, resiliency, safety, and affordability objectives, and provides overall management of DOE's Grid Modernization efforts;
- Office of Energy Efficiency and Renewable Energy (EERE) –develops energy efficiency, renewable power, and sustainable transportation technologies and enables them to be successfully integrated into the grid in a safe, reliable, and cost-effective manner; and
- Energy Policy and Systems Analysis (EPSA) – provides leadership in rigorous analysis, robust stakeholder engagement, and recommendations for policy options that support the public interest in efficient markets, clean reliable energy, and modernization of the nation's energy systems.

Coordination will also occur across other DOE offices, linking key programs within the Office of Science (SC), Office of Fossil Energy (FE), Office of Nuclear Energy (NE), and Advanced Research Projects Agency - Energy (ARPA-E). In addition, the National Laboratories, with their direct connection to basic science, strategic insight into the nature of this challenge, and credibility with regulators, industry, and other stakeholder groups, will be an integral part of DOE's grid modernization activities. The Grid Modernization Laboratory Consortium (GMLC) was established as a strategic partnership between DOE headquarters and the National Laboratories to bring together leading experts and resources to collaborate on the goal of modernizing the nation's grid. The benefits of the GMLC include more efficient use of resources and reduced duplication of efforts; shared networks improving learning and preservation of knowledge; enhanced Lab coordination and collaboration across traditional programmatic "silos"; and regional perspective and relationships with local stakeholders and industry. (See Appendix A for the charter of the GMLC.)

Partnerships with other Federal Agencies and States

DOE will work with other federal, regional, and state agencies that have critical and evolving roles in grid modernization. Key federal agency partners include the Department of Defense (as a large purchaser and user of clean energy), the Power Marketing Administrations (who manage large hydropower resources and operate major transmission systems), the Departments of Interior and Agriculture (for siting on federal lands), the National Institute of Standards and Technology (with a crucial role regarding interoperability standards), and the Department of Homeland Security (with a key role in establishing national security policies affecting the energy sector).

DOE will also seek partnerships with those who regulate of the grid. Wholesale electricity markets and reliability of the bulk power system, both interstate in nature, are regulated by the Federal Energy Regulatory Commission (FERC) and the North American Electric Reliability Corporation (NERC) respectively. State Public Utility Commissions (PUCs) regulate investor-owned utilities that serve retail customers and determine the allowed rate of return for utility investment. Consumer- or publicly owned utilities (e.g., rural co-ops, public utility districts, and municipal utilities) also serve retail customers, and are overseen by elected boards, commissions, and even city councils. State legislatures, governors, and energy offices set policy; consumer advocates often enter into PUC dockets; and state agencies have specific roles such as siting of transmission, environmental compliance, and monitoring energy consumption.

Partnerships with Industry and Groups

DOE will also partner with other major groups of key electric grid stakeholders:

> "CUSTOMER DEMANDS AND PUBLIC POLICY REQUIREMENTS ARE DRIVING THE NEED FOR A MODERN GRID THAT WILL SUPPORT NEW WAYS IN WHICH ELECTRIC ENERGY WILL BE GENERATED, DELIVERED, AND USED."
>
> *Minnesota PUC, Building a Minnesota Conversation on Grid Modernization*

- **Utility companies.** IOUs, utility co-operatives (co-ops), power marketers, municipal utilities, and their trade associations (e.g. APPA, NRECA, EEI) span the nation. Some are regulated and some public power companies are self-regulated. Their role is to produce or acquire electricity and distribute that electricity to consumers.
- **Independent power producers.** Developers who bid into markets to supply generation, both long-term and daily electricity markets.
- **Transmission organizations (RTO, ISO) and reliability organizations.** Organizations that carry out system planning, grid operations, and regional reliability activities.
- **Technology developers and vendors.** Companies with products that sell into the electricity system, ranging from transformers to software control systems.
- **Environmental community.** Advocates, including NGOs, for cleaner energy sources and minimal impacts from new generation, transmission, distribution, and end use.
- **Consumer and technology advocacy groups.** Advocates for major consumers of electricity, individual power generation technology, and electrical system devices.
- **Research community and standards organizations.** This community is vast and makes a vital intellectual contribution to grid modernization in all areas. It includes the Electric Power Research Institute, research divisions of utility trade associations, universities, standards bodies, and others. Many companies have their own private research groups, ranging from small businesses to international corporations like General Electric or Siemens. Universities, either individually or groups of universities (such as those under the Consortium for Electric Reliability Technology Solutions (CERTS) and Power Systems Engineering Research Center (PSERC)), are also key players in grid modernization RD&D.

1.5 DOE's Grid Modernization Initiative

The Grid Modernization Initiative will leverage DOE's federal role to help accelerate the development, demonstration, and adoption of the foundational analyses, technologies, and planning and operations platforms for the grid of the future. DOE's role, a leadership role that includes RD&D efforts, honest-broker analysis, software development, and institutional activities (e.g., technical assistance), will help to enable, de-risk, and demonstrate the value of new grid modernization technologies and applications. Regulators and policymakers will then be able to decide whether to create incentives, policies, and approaches that will enable the appropriate large-scale industry investment needed to achieve a modernized U.S. grid and the national outcomes envisioned by this initiative.

This initiative will provide measurable advancements in the six attributes necessary for the modernized grid: resilient, reliable, secure, affordable, flexible, and sustainable. Each of the R&D efforts, as well as integrated regional demonstrations, will be designed to provide measurable progress in one or more attribute.

Taken as a whole, DOE expects this initiative to enable industry action that delivers (i) a 10 percent reduction in the economic costs of power outages, (ii) a 33 percent decrease in cost of reserve margins, while maintaining reliability, and (iii) a 50 percent decrease in the net integration costs of distributed energy resources; all by 2025. If achieved, these three outcomes would yield more than $7 billion in annual economic benefit to the nation.[22]

Supporting the realization of the GMI vision and goals of a future electric grid are six specific technical areas that are the core of DOE's Grid Modernization Initiative. The six technical areas can be categorized into three thrusts:

- ***Technology*** *(i.e., hardware)*: Develop and demonstrate technologies for better measurement (e.g., sensors), integration (e.g., inverters), management and control of grid operations (e.g., transformers)
- ***Modeling and Analysis*** *(i.e., software)*: Develop and disseminate new and improved models for analysis, management and optimization of grid performance (e.g., solar and wind prediction)
- ***Institutional and Business:*** Develop the analytical methodologies and frameworks for improving business models that can deliver to consumers the value and benefits of grid modernization.

The six technical areas—equally important and in no particular order below—are:

1. **Devices and Integrated Systems Testing –** Develop devices and integrated systems, coordinate integration standards and test procedures, and evaluate the grid characteristics of both individual devices and integrated systems to provide grid-friendly energy services at a variety of scales.
2. **Sensing and Measurements –** Develop tools and strategies to determine the type, number, and placement of sensors on distribution grids to provide operators the visibility for specific utilities and feeders. This will include advanced methods to determine system states not directly accessible by measurement and estimation methods for broad grid visibility. Develop frameworks to integrate sensors into grid systems for solar irradiance, forecasting, and market data, and data from interfacing infrastructures such as electrified transportation.
3. **System Operations, Power Flow, and Control –** Develop future grid architectures to inform development of new operations and control concepts, and improved analytics and computation for grid operations and control. Develop power flow controllers that will permit fine adjustment of power flow and multi-directional flow as well as flow control devices that can optimize transmission flows.
4. **Design and Planning Tools –** Develop the next generation of tools focused on three areas: economic assessment tools required for policy analysis, expansion planning, and day-ahead planning; reliability and resilience tools for design and engineering energy delivery in a resilient and secure manner; and computational technologies and infrastructure required to produce detailed and accurate answers and vastly extend the computational power available for analysis.
5. **Security and Resilience –** Improve the resilience of the electric sector by developing physical and cybersecurity solutions; analyze criticality and assess impacts to minimize risk; provide solutions for supply chain risks (specifically for transformers); and provide situational awareness/incident support during energy-related emergencies.
6. **Institutional Support –** Inform and support high priority grid modernization challenges and needs identified by electric power industry stakeholders, with particular emphasis on state policymakers and regional planning organizations. Support an over-arching stream of grid-related institutional analysis, workshops, and dialogues to

[22] See Appendix B for specific estimates.

highlight challenges and explore options for transforming the grid, focusing on key policy questions related to new technologies, regulatory practices, and market designs.

This MYPP Advances the Recommendations in DOE's QER

In addition to building on past and current work by DOE, this MYPP builds on concepts in DOE's Quadrennial Energy Review (QER). The QER recommendations are:

Recommendations in Brief
Provide grid modernization research and development, analysis, and institutional support. The Department of Energy (DOE) should continue to pursue a multi-year, collaborative, and cost-shared research and development, analysis, and technical assistance program for technology innovation that supports grid operations, security, and management, as well as for analyses, workshops, and dialogues to highlight key opportunities and challenges for new technology to transform the grid. ***The President's Fiscal Year 2016 Budget requests $356 million for DOE's Grid Modernization Initiative***.
Establish a framework and strategy for storage and grid flexibility. DOE should conduct regional and state analyses of storage deployment to produce a common framework for the evaluation of benefits of storage and grid flexibility, and a strategy for enabling grid flexibility and storage that can be understood and implemented by a wide range of stakeholders.
Conduct a national review of transmission plans and assess barriers to their implementation. DOE should carry out a detailed and comprehensive national review of transmission plans, including assessments on the types of transmission projects proposed and implemented, current and future costs, consideration of interregional coordination, and other factors. A critical part of this review should be to assess incentives and impediments to the development of new transmission.
Provide state financial assistance to promote and integrate transmission, storage, and distribution infrastructure investment plans for electricity reliability, affordability, efficiency, lower carbon generation, and environmental protection. In making awards under this program, DOE should require cooperation within the planning process of energy offices, public utility commissions, and environmental regulators within each state; with their counterparts in other states; and with infrastructure owners and operators and other entities responsible for maintaining the reliability of the bulk power system.
Coordinate goals across jurisdictions. DOE should play a convening role to bring together public utility commissioners, legislators, and other stakeholders at the federal, state, and tribal levels to explore approaches to integrate markets, while respecting jurisdictional lines, but allowing for the coordination of goals across those lines.
Value new services and technologies. DOE should play a role in developing frameworks to value grid services and approaches to incorporate value into grid operations and planning. It should convene stakeholders to define the characteristics of a reliable, affordable, and environmentally sustainable electricity system and create approaches for developing pricing mechanisms for those characteristics. The goal should be to develop frameworks that could be used by the Federal Energy Regulatory Commission, state public utility commissions in ratemaking proceedings, Regional Transmission Organizations in their market rule development, or utilities in the operation and planning of their systems.
Improve grid communication through standards and interoperability. In conjunction with the National Institute of Standards and Technology and other federal agencies, DOE should work with industry, the Institute of Electrical and Electronics Engineers, state officials, and other interested parties to identify additional efforts the Federal Government can take to better promote open standards that enhance connectivity and interoperability on the electric grid.
Establish uniform methods for monitoring and verifying energy efficiency. Through its Uniform Methods Project, DOE should accelerate the development of uniform methods for measuring energy savings and promote widespread adoption of these methods in public and private efficiency programs.

This MYPP Integrates with Opportunities Identified in DOE's QTR

This MYPP also builds on concepts and recommendations in DOE's 2015 Quadrennial Technology Review (QTR). The QTR examines the status of the science and technology that are the foundation of our energy system, together with the research, development, and demonstration opportunities to advance them. It focuses primarily on technologies with commercialization potential in the midterm and beyond. Additionally, it provides data and analysis on RD&D pathways to assist decision makers as they set priorities.

Areas of RD&D Needs for Grid Modernization

- **Grid Design and Interoperability**
- **Control Systems for Transmission and Distribution**
- **Transmission and Distribution Components**
- **Physical and Cyber Security**
- **Distributed Energy Resources**
- **Electrical Energy Storage**
- **Planning Tools**

1.6 What Follows in this Multi-Year Program Plan

Chapters 2.0 through 7.0 detail the activities that will be undertaken in the DOE Grid Modernization Initiative's six technical areas: **Devices and Integrated Systems Testing; Sensing and Measurements; System Operations, Power Flow, and Control; Design and Planning Tools; Security and Resilience; and Institutional Support**. Each chapter describes the technical area's core activities, targeted technical achievements by 2020, and the specific tasks that will be performed to accomplish those targeted technical achievements Each chapter also provides descriptions of the timing of each task, how the activities in the technical area interact with and support other technical areas, how they support the proposed integrated regional demonstrations, and how the activities described coordinate with and build on the achievements of ongoing DOE programmatic activities.

Chapter 8.0 describes the integrated regional demonstrations envisioned to be accomplished by the end of this plan. These demonstrations, to be undertaken in 2017 to 2025, will demonstrate synergies among the six technical areas and validate the expected value of new technologies and applications.

Chapter 9.0 describes how this grid modernization effort will be managed as a portfolio, how activities will be coordinated with partners and other stakeholders, and how peer reviews will be used for key input. This chapter will also discuss plans for technology transfer.

2.0 Devices and Integrated System Testing

The electrical grid is fundamentally comprised of *devices*[23] physically connected together and linked by control systems and markets, which form *integrated systems*.[24] These systems provide specific functions that, in aggregate, enable the overall electrical power system to operate effectively as a whole. Collectively, these systems seek to precisely match supply with demand, maintain power reliability and quality delivered to customers, and protect both public safety and device integrity. New, and often distributed, devices and systems on both sides of the electric meter represent new resources that will need to provide future grid with the flexibility required for managing variable generation while enhancing reliability and resiliency, and keeping electricity affordable. These devices must have proven performance as controllable assets when integrated into new and existing systems. To provide the necessary value proposition for such devices, their increased control and communication capabilities must be used to provide a broad range of value-added services and transactions for their owners with the grid and with other parties.

"EFFORTS TO MODERNIZE THE GRID OPEN UP NEW APPROACHES TO DEMAND RESOURCES (INCLUDING ENERGY EFFICIENCY, DEMAND RESPONSE, AND DISTRIBUTED GENERATION) AND FOR COORDINATING PLANNING, OPERATIONS, AND PRICING BETWEEN THE WHOLESALE AND RETAIL SECTORS."

ISO-New England, 2015 Regional Electricity Outlook

The *Devices and Integrated Systems Testing* technical area addresses several key challenges to transforming the electric grid to help reach the Grid Modernization Initiative's targeted National Outcomes. The challenges are:

- Development of cost-effective storage technologies, power electronics and other controllable devices capable of delivering and supporting the wide range of grid applications. Devices must be capable of communicating, coordinating, and transacting with the electrical grid to provide a wide range of grid services[25] that benefit both the device owner and the grid. New functionality is needed from devices to provide grid services and better integrate these devices with overall electrical grid operations.
- Standards that provide requirements for functionality, interoperability, and interconnection to the grid can streamline integration and testing procedures are needed to verify that new devices and integrated systems are able to provide a range of grid services.
- Validation of both individual devices and integrated systems at a variety of scales (from local to regional grids) is needed to demonstrate proper operation.

[23] Devices include individual energy generation, storage, delivery, and consumption technologies that connect to the electric grid including: photovoltaics, concentrating solar power, wind power, electric vehicles, electricity and thermal storage, capacitors, flywheels, building loads, appliances, heating, ventilation, and cooling systems, lighting, fuel cells, electrolyzers, combined heat and power, high efficiency small-scale engines, microturbines, wires, cables, switches, transformers, etc. Sensors are part of the Sensing and Measurement technical area. Power flow controllers are part of the System Operations, Power Flow, and Control technical area.

[24] Examples of integrated systems include: building and industrial facility loads and management systems that respond to the grid; aggregations of buildings into facilities and campuses that respond to grid signals; fleets of electric vehicles, end-use loads, batteries; PV systems, inverters and other distributed generators responding autonomously or in response to active communications; microgrids operating in islanded mode and connected mode; short-circuit protection and voltage management schemes that can support two-way distribution power flows; distribution voltage management schemes that accommodate high penetrations of PV solar and other distributed energy resources; autonomous fault location, isolation, sectionalization, and restoration systems for distribution reliability and resilience; and bulk variable generation connected to transmission systems.

[25] The term "*grid services*" is intended to cover a wide range of energy relevant services. This can include energy production, available capacity, consumption, and storage as well as ancillary services (e.g. primary, secondary, and tertiary reserves and regulation, better inertial response, grid stabilization functions like oscillation damping etc.) needed to maintain normal grid operations.

To address these challenges in a consistent manner, the Grid Modernization Laboratory Consortium – Testing Network (GMLC-TN) will be formed to address some of these challenges and to coordinate testing activities across entities working in the grid area. This federated capability will provide test facility integration and optimization, testing frameworks and component model libraries managed and operated by all the National Laboratories, and select universities and industry groups with unique capabilities. It will act as a coordination entity across all the GMLC MYPP technical areas. GMLC-TN will establish open and accessible capabilities to support devices and systems testing and validation, engage key stakeholders to develop a framework for integration and optimal testing facility utilization for interoperability and interconnection testing on both sides of the meter. It will also support other technical areas including Sensing and Measurements and System Operations in testing integrated systems.

Table 1 gives a high-level description of the four activities and corresponding technical achievements that are targeted to be completed by 2020, assuming adequate funding levels. More specific technical targets are given in subsequent sections. The **Devices and Integrated Systems Testing** technical area will develop devices and integrated systems that interoperate with each other and with grid sensors (developed in **Sensing and Measurements**) and control systems (developed in **System Operations, Control, and Power Flow**) and interconnect to maintain stable grid operations while providing valuable grid and local energy services.

TABLE 1. ACTIVITIES AND TECHNICAL ACHIEVEMENTS FOR DEVICES AND INTEGRATED SYSTEM TESTING

Activity	Technical Achievements by 2020
1. Develop Advanced Storage Systems, Power Electronics and other Grid Devices	• Develop power electronics-based converters for renewable, distributed energy and energy storage systems that can provide grid services, self-optimize around the market and energy environment and meet specific DOE applications' targets[26]. • Decrease the system costs of deployed grid-scale, energy storage system to under $300/kWh by establishing grid-scale storage systems' metrics for safety, reliability and performance, and through new energy storage technologies development. • Enable buildings, large building loads (e.g. HVAC systems, refrigerator systems) and EV charging systems to: 1) diagnose if they are functioning properly, 2) forecast their energy needs over the next day or several days, 3) characterize their available flexibility, and 4) have embedded control and decision-making tools to provide capacity, energy and ancillary services to the electrical grid and other valuable services to system owners. • Develop innovative grid infrastructure technologies that improve electrical grid efficiency and reliability by 10 percent.
2. Develop Standards and Test Procedures	• Updated standards and test procedures that characterize the ability of devices (50% of building loads and all new generation and storage) to provide a full range of grid services and accelerate the uptake of these devices in the market. Codes and standards are also necessary to ensure deployed technologies are safe and effective. • Development of standards and test procedures for microgrids, storage and other systems that reduce customer outages by 10%.
3. Build Capabilities and Conduct Device Testing and Validation	• The Grid Modernization Laboratory Consortium – Testing Network (GMLC-TN) provides test facility integration and optimization, testing frameworks and component model libraries managed and operated by National Laboratories, universities and industry groups. • Development of methods to couple hardware-in-the-loop (HIL) devices with advanced simulations including high performance computers (HPC) systems for evaluating systems at a variety of scales • Characterization of a wide variety of technologies to validate individual devices can provide a full range of grid services using a variety of techniques including HIL.

[26] For specific goals around power electronics, see DOE Office reference documents located in footnotes of Section 2.1.

Activity	Technical Achievements by 2020
4. Conduct Multi-scale Systems Integration and Testing	• Validated multi-scale systems that enable integration of 100% renewable energy at the local level and 35% at the bulk system while reducing reserve margins and interconnection costs. • Validated transactive control constructs that coordinate distributed generation, storage, and controllable loads to reduce reserve margins by 33%. • Validated 10% outage reductions by using advanced distribution system configurations (including microgrids) and fault location, isolation and service restoration (FLISR) systems. • Field demonstrations of energy storage providing multiple grid services cost effectively.

The activities in **Devices and Integrated System Testing** will deliver Technical Achievements for each Activity area (see Table 1 above) as well as support the three "Integrated Regional Demonstrations" outlined in Chapter 8.0. The device development in energy storage and power electronics will deliver enhanced device performance in cost, controllability, and digital functionality that support new grid operations and controls requirements. These achievements will directly support the "Lean Reserve Margin Grid Bulk Power Systems" and the "Clean Distribution Systems" demonstrations through providing new devices that enable new grid services for more precise operation. The standards and test procedure development activities support these two DOE Integrated Regional Demonstrations as well by establishing common testing and interoperability approaches for these complex system demonstrations. The device characterization libraries and multi-scale testing results will support the establishment of the "Advanced Modern Grid Planning & Analytics Platform" regional demonstration by providing common reference libraries and test data that will inform planning and regulatory analysis efforts by stakeholders. Descriptions of each activity area follow.

2.1 Activity 1: Develop Advanced Power Electronics, Energy Storage Systems, Controllable Loads, and Other Grid Devices

Historically, the grid has been comprised of networks of devices, such as generators, wires, cables, transformers, switches, relays, fuses, breakers, re-closers, voltage regulators, capacitors, meters, and sensors. New and improved devices such as energy storage, distributed generation, grid responsive buildings, electric vehicles, fuel cells, and renewable energy technologies are expected to play increasingly critical roles in the future electrical grid. This activity seeks to increase electrical grid flexibility[27], reliability, resiliency and asset utilization by making step changes in the performance of grid-connected devices and technologies. Work will focus on adding grid service functionality to existing devices, development of new technologies, and development of new materials and other core areas of innovation for devices to increase their functionality while decreasing their cost. Standards to determine performance are developed in Activity 2. Validation of the ability of the devices to provide grid services is performed in Activities 3 and 4.

- **Power Electronics (PE)** – Power electronics are increasingly used in a wide variety of converters that interface new energy devices with the electrical grid. From large-scale applications that connect to the transmission grid elements (e.g. HVDC converters) to power electronics based converters used in various generation and storage applications (wind turbines, PV systems, battery systems, electric vehicles, and fuel cells), these devices have unique characteristics that need to be taken into account when connecting to power systems. More specifically, there is a need to develop power electronic based converters and control algorithms for renewable, distributed

[27] Flexibility is the ability of an electrical grid to accommodate technologies with new characteristics and respond as needed. This could include the ability to accommodate high levels of short-term fluctuations due to changes in renewables output, responsive loads, and new loads such as electric vehicles, etc., and also unanticipated long-term variations in the mix of loads and generation.

energy systems, and energy storage that can provide grid services and self-optimize around the market and energy environment. Improvements in wide bandgap semiconductors such as those employing SiC and GaN materials, capacitor, magnetic, and/or energy storage materials are also needed to enable revolutionary device advancements[28] in these devices. Since Nobel laurite Prof. Nakamura revolutionized the LED industry with his development of GaN based diodes in the 90's, there has been a desire to adapt this and other wide bandgap materials to power electronics due to the high operating temperatures and larger bandgap. However, the lack of suitable substrate materials, the high level of intrinsic defects, and the difficulty in developing p-type materials have prevented the widespread production of these devices. Work is currently being done in several DOE Offices including Solar Energy[29,30], Wind Energy[31], Fuel Cell Technologies[32], Vehicle Technologies[33], and Advanced Manufacturing (within EERE) and grid-scale Energy Storage[34] (within OE) that are developing new power electronics technologies to interface with the grid.

Task 2.1.1: Develop and demonstrate new materials that enable increased switching frequencies and power densities of power electronics based devices by a factor of 2-4. [FY16-20]

Task 2.1.2: Develop power electronics-based converters for renewable, distributed energy and energy storage that can provide grid services, self-optimize around the market and energy environment, and meet specific DOE applications' targets. [FY16-20]

- **Energy Storage Systems** – Energy storage devices provide a unique capability to the operations of the electrical grid. They can already perform a variety of grid services, but cost, industrial acceptance, safety, and equitable regulatory treatment remains a limiting factor to widespread use. New developments in novel redox flow battery technology such as: next generation aqueous electrolytes (aqueous soluble organics, hybrid flow, low cost transition metal systems); metal-organic electrolytes, non-aqueous electrolytes, novel membranes, and systems development can lead to improved performance and cost reductions. Further advances in sodium based batteries, modified lithium-systems, and multivalent redox couples are needed to bring these promising technologies to a higher readiness level. Material improvements in flywheel technology can improve the efficiency and lower the cost of next generation flywheel storage systems. Extensive testing of storage technologies in controlled lab environments and field demonstrations are required to validate the safety, reliability, and performance under real world applications. Databases for dissemination of information from energy storage demonstrations and current codes and standards are needed to help speed the adoption of energy storage. Regional demonstrations and value analysis of large-scale storage systems, evaluations of storage in microgrid applications, and demonstrating re-use of automotive batteries for grid applications will

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[28] Power Electronics Research and Development Plan, April, 2011: http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/OE_Power_Electronics_Program_Plan_April_2011.pdf

[29] US Department of Energy, DOE SunShot Vision Study: http://energy.gov/eere/sunshot/sunshot-vision-study

[30] US Department of Energy, DOE Solar FOA: SUNSHOT NATIONAL LABORATORY MULTI-YEAR PARTNERSHIP (SUNLAMP) https://eere-exchange.energy.gov/#FoaId54a44ce1-eaa5-4f50-9c19-54702253559b

[31] US Department of Energy, DOE Wind Vision Study: http://energy.gov/eere/wind/wind-vision

[32] US Department of Energy, DOE Fuel Cell Technologies Office MYPP: http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

[33] US Department of Energy, DOE EV EVERYWHERE GRAND CHALLENGE ROAD TO SUCCESS Report: http://energy.gov/eere/vehicles/downloads/ev-everywhere-grand-challenge-road-success

[34] US Department of Energy, DOE Grid Energy Storage Report: http://energy.gov/oe/downloads/grid-energy-storage-december-2013

foster utility and regulatory acceptance of the technology. Work is currently being conducted by the DOE Energy Storage[35], Solar Energy[36] and Vehicle Technologies[37] programs to advance these technologies.

Task 2.1.3: Decrease the system cost of deployed grid-scale energy storage to under $300/kWh by FY20 by establishing metrics for safety, reliability, and performance storage systems and through new energy storage technologies. Demonstrate deployment and usage models that provide a return on investment (ROI) of under three years. [FY16-FY20]

- **Controlling Building, Electric Vehicle and Other End-Use Technologies** – Buildings, electric vehicles, and other end-use technologies can also provide grid services by regulating how they use energy. The DOE Building Technologies Program is examining the technical opportunities for building assets to seamlessly integrate and transact with grid operations.[38,39,40,41,42] The DOE Vehicle Technologies Program is examining how electric vehicles can provide a range of grid services.[43] The Fuel Cell Technologies Program is examining the use of electrolyzers can be used as controllable loads.

Task 2.1.4: Enable buildings, large building loads (e.g. HVAC systems, refrigerator systems) and EV charging systems to: 1) diagnose if they are functioning properly, 2) forecast their energy needs over the next day or several days, 3) characterize their available flexibility, and 4) have embedded control and decision-making tools to provide capacity, energy and ancillary services to the electrical grid and other valuable services to system owners. [FY16-20]

- **Grid Infrastructure** – According to a recent report by ABB, Inc., and hosted by NEMA, the U.S. transmission and distribution system loses between 6 percent and 8 percent of all power generated due to inefficiency, which equates to approximately $19.5 billion dollar loss to U.S. industry.[44] Improvements to grid infrastructure technologies (advanced switches, wires, cables, transformers, etc.) can help the overall operations of the electrical grid in terms of both efficiency and reliability.

Task 2.1.5: Develop innovative grid infrastructure technologies that improve electrical grid efficiency and reliability by 10 percent [FY17-20]

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35 US Department of Energy, DOE Grid Energy Storage Report: http://energy.gov/oe/downloads/grid-energy-storage-december-2013

36 US Department of Energy, DOE Solar FOA: SUSTAINABLE AND HOLISTIC INTEGRATION OF ENERGY STORAGE AND SOLAR PV (SHINES) https://eere-exchange.energy.gov/#FoaId266730f7-8882-43a5-aa86-dd215373ea22

37 US Department of Energy, DOE EV EVERYWHERE GRAND CHALLENGE ROAD TO SUCCESS Report: http://energy.gov/eere/vehicles/downloads/ev-everywhere-grand-challenge-road-success

38 US Department of Energy, Office of Energy Efficiency and Renewable Energy. 2014. *Buildings-to-Grid Technical Opportunities: Vision and Introduction*. Available at http://energy.gov/eere/buildings/downloads/buildings-grid-technical-opportunities-introduction-and-vision

39 Pratt, RG, S Somasundaram, B Akyol et al. 2014. *Transaction-Based Building Controls Framework, Volume 1: Reference Guide*. Pacific Northwest National Laboratory, Richland WA. Available at: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23302.pdf

40 NOT PUBLISHED YET. US Department of Energy, Offices of Energy Efficiency and Renewable Energy and Energy Policy and Systems Analysis. 2015. *The National Opportunity for Interoperability and its Benefits for a Reliable, Robust, and Future Grid Realized Through Buildings*.

41 U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. 2015. *A Framework for Characterizing Connected Buildings Equipment.* Forthcoming in the Federal Register at http://www.regulations.gov/#!docketDetail;D=EERE-2014-BT-NOA-0016

42 NOT PUBLISHED YET Muehleisen, R, T Levin et al. *Financial Transaction Module for the Building Transactional Network: A Scoping Study.* Argonne National Laboratory, Chicago, IL.

43 Multi-Lab EV Smart Grid Integration Requirements Study: Providing Guidance on Technology Development and Demonstration, http://www.nrel.gov/docs/fy15osti/63963.pdf

44 ABB, Inc., Energy Efficiency in the Power Grid, https://www.nema.org/Products/Documents/TDEnergyEff.pdf, 2007.

2.2 Activity 2: Develop Standards and Test Procedures

Standards, evaluation metrics, methodologies, and other criteria for testing the grid interaction characteristics of devices and integrated systems are essential to ensure their optimal and safe integration into a modern grid. As new devices and systems continue to be integrated into the grid at multiple scales from both sides of the utility meter, these criteria will form the basis for a collective understanding and evaluation of performance expectations. This activity works with standards development organizations (SDOs) to accelerate the development and validation of standards and test procedures for operational characterization of devices, including their grid interconnection, interoperability, performance, and safety. SDOs typically use a consensus-based process to develop these kinds of procedures. National Laboratories can provide an independent party to develop and assess the procedures prior to publication and use with certification agencies. Currently, new market entrants are introducing new systems and devices under new, innovative business models; this results in a need to accelerate updates to existing interconnection and interoperability standards, and to develop new standards that define grid services and provide standardized performance metrics for both devices and integrated systems.

- **Interconnection Standards and Testing Procedures** – Interconnection standards define technical requirements for connecting and operating devices with the electrical grid without impacting reliability or stability. In the modernized grid, a new range of devices will interconnect with the electrical grid at higher penetrations than before, including renewable energy systems, distributed energy resources (DER), and energy storage that have the capability to provide power to the grid.

  Task 2.2.1: Update consensus interconnection standards for both distribution and bulk systems that provide system stability at high penetrations (i.e. voltage and frequency ride through, local voltage regulation). [FY16-17]

  Task 2.2.2: Facilitate establishment of risk evaluation protocols, safety standards, and performance testing methodologies for energy storage [FY16-19]

  Task 2.2.3: Update testing procedures for interconnection standards. [FY17-18]

- **Interoperability Standards and Testing Procedures** – Interoperability standards define technical requirements for defining the capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information securely and effectively.

  Task 2.2.4: Consolidate consensus interoperability standards for the building, distribution, and bulk power systems. [FY16-17]

  Task 2.2.5: Develop testing procedures for interoperability standards. [FY17-19]

- **Grid Services Standards and Testing Procedures** – There are a variety of grid services that can be provided to and from the grid for improved operation and market performance. In addition to energy, there are a variety of ancillary services such as frequency regulation and determination of reserves needed for proper grid operation. Grid services differ from interconnection requirements because of the linkage to economic markets that may be available to provide various services. This task area will also include requirements for devices to send/receive signals from system operators and markets and interact with other devices within the energy system. There are also a variety of mechanisms for providing the signals for grid services including transactive control constructs.[45]

[45] Transactive energy is defined by the DOE GridWise Architecture Council as "A set of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter." http://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf

Task 2.2.6: Develop a standard set of definitions for the full range of grid and ancillary services. [FY16]

Task 2.2.7: Develop requirements for testing transactive-enabled grid devices. [FY16]

Task 2.2.8: Develop a technology neutral consensus-based standard for providing grid services. This includes defining the requirements for transactive control constructs. [FY17-FY18]

Task 2.2.9: Develop testing procedures for evaluating the ability of devices to provide grid services. [FY17-19]

Task 2.2.10: Establish and test methodologies for enabling optimal dispatch of energy storage to serve multiple grid services [FY16-19]

- **Improved Standards and Testing Procedures for Emerging Technologies to Improve Customer Reliability** – There are several ways to reduce customer outage including the use of microgrids, energy storage, and systems that help with fault location, isolation, and service restoration (FLISR). There is a need for improved standards to define technical requirements for these systems.

Task 2.2.11: Update microgrid design and operational standards. [FY16-17]

Task 2.2.12: Develop microgrid-testing procedures. [FY17-18]

Task 2.2.13: Demonstrate enhanced customer reliability through use of energy storage in conjunction with coordinated grid and customer dispatch. Establish and validate reliability of energy storage systems. [FY16-20]

Task 2.2.14: Develop standards and testing procedures for FLISR systems. [FY17-19]

2.3 Activity 3: Build Capabilities and Perform Testing and Validation of Devices

This activity is focused on the application of test procedures developed in Activity 2, *through science-based experimentation and testing in both the laboratory and the field,* to evaluate and validate individual device performance, safety, and reliability with respect to requirement specifications and standards. Enabling a reduction in the net integration costs of distributed energy resources, the cost of reserve margins while maintaining reliability, and the economic costs of power outages will require technology solutions such as responsive loads, energy storage, and advanced control technologies. However, these technologies must conform to requirements of both the existing and future electric grid to be successfully deployed across a wide area over multiple time scales and, more importantly, by multiple entities. The focus for this activity includes developing a comprehensive device and system level testing infrastructure and conducting standards-based testing to evaluate devices' ability to provide a range of grid services. The use of advanced techniques to integrate device hardware, software, and simulations through power system hardware-in-the-loop (HIL) is also developed and tested in this activity. Device testing and validation will be used to: (1) ensure that devices meet the operational needs of a future electrical grid to maintain its key functional requirements while maintaining a high level of safety and reliability, (2) support interoperability of new and emergent devices and systems. Testing and validation is an ongoing and evolving process that is expected to continue throughout the lifetime of a modernized grid.

- **Grid Modernization Laboratory Consortium - Testing Network (GMLC-TN)** – The GMLC-TN will provide a federated laboratory testing capability for resource integration and optimization and testing framework development that will be managed and operated by the entire National Laboratory system, and select universities and industry groups. The GMLC-TN will establish open and accessible capabilities to support testing and validation of devices and systems and engage key stakeholders to develop a framework for test facilities' integration and optimal utilization for interoperability and interconnection testing on both sides of the meter.

Task 2.3.1: Develop a framework document with an index of available National Lab, university, and industry resources. [FY16-17]

Task 2.3.2: Analyze framework document to determine key gaps between existing and eventual desired testing capabilities and provide recommendations to DOE leadership. [FY16-17]

Task 2.3.3: Enhance and expand GMLC-TN as necessary to achieve desired testing capabilities. [FY18-20]

- **Device Modeling and Simulation Library** – As part of GMLC-TN, an open, validated and accessible model library will be developed based on device characterization. The device library will be developed to encompass generation, transmission, distribution, energy storage and loads, and extended to interoperable models from device to system level testing (including HIL). The model library shall consist of open, composable and interoperable modules that implement steady state and dynamic models of real-world grid devices, using the data from device characterization, in the aforementioned device classes. Public and private parties may make use of the model library for understanding system-level impacts of novel devices.

Task 2.3.4: Develop a unified model description for devices that can provide grid services. [FY16]

Task 2.3.5: Develop an open and accessible model library and populate library based on testing results. [FY17]

Task 2.3.6: Develop models for generation, transmission, distribution, storage, and loads and populate library based on testing results. [FY17-FY20]

Task 2.3.7: Develop an open and accessible simulation framework with composable [46]and interoperable models. [FY19]

- **Transactive [47]Device Testing** – This sub-activity focuses on developing a framework for testing and validation of transactive devices. Currently concepts for transactive or responsive loads, generation sources, and storage devices are being developed and devices tested. The next step is to test the devices in the context of a holistic grid responsive control framework. Validation of the transactive devices' performance will be in system-level context.

Task 2.3.8: Develop testing and validation infrastructure for transactive-enabled grid devices that can reliably respond to grid needs without the need for backup generation. [FY16]

Task 2.3.9: Validate and apply test procedures to transactive devices. [FY17-19]

- **Multi-Scale, Multi-Technology Testing** – While previous tasks consider the testing of devices in isolation, this alone is not sufficient for understanding the behavior of devices in an integrated systems context. Standards-based test harnesses that accurately represent multi-scale and multi-technology energy devices along with strategies for trustworthy device testing and validation across multiple-scales is needed to fully enable grid modernization. This sub-activity will develop a framework to perform multi-scale, multi-technology testing to understand the effects of novel grid devices in the context of systems of systems. Validation of existing and

[46] Composable models are those that have the ability to be combined in various ways to satisfy specific user requirements. http://en.wikipedia.org/wiki/Composability

[47] Transactive devices are those that support transactive energy services.

novel grid devices that provide grid services in a system-level context will also be performed. The testing and validation will utilize GMLC-TN, composable model library, and grid standards.

Task 2.3.10: Develop device interface specifications and framework that support communication and control of local output, in pursuit of coordinating device- and system-level testing in conjunction with Activity 2. [FY16]

Task 2.3.11: Validate testing procedures for interconnection, interoperability, and grid services in conjunction with Activity 2 and 4. [FY16-17]

Task 2.3.12: Update testing procedures using feedback from testing framework requirements. [FY18-20]

- **Hardware-in-the-Loop (HIL) Testing** – Integrated simulation frameworks, libraries, and methodologies for coupling multiple HIL tests and integration of HIL with larger-scale simulations on high performance computers (HPC) to capture system impacts from a smaller set of HIL simulations are needed. Currently, there are no standard methods and common use libraries to couple HILs tests across testers and with HPC systems. Research includes development of new methods and modeling capabilities to develop tool integration methods, guidelines, and standards across the industry to couple dynamic HIL simulations including power/controller/communications hardware-in-the-loop. This activity will coordinate closely with the **Design and Planning Tools** technical area.

Task 2.3.13: Develop standard methods and prototypes to federate multiple HIL simulations located at different geographic sites over a high-speed network. [FY16-FY17]

Task 2.3.14: Integrate multiple HIL simulations with large-scale grid simulation on HPC systems. [FY18-FY19]

Task 2.3.15: Demonstrate 10 milliseconds scale HIL-to-HIL and HIL-to-HPC simulation. [FY20]

2.4 Activity 4: Conduct Multi-Scale Systems Integration and Testing

This activity seeks to ensure that integrated systems (devices, sensors, communications, and control systems brought together) are capable of effectively connecting, communicating and operating in a coordinated fashion that maintains the desired grid results from each of the key stakeholders' perspectives across a range of physical scales (buildings, campus, micrograds, distribution, and transmission). Multi-scale systems integration and testing occurs both in controlled laboratory settings as well as in field demonstration locations. The use of advanced techniques to integrate integrated system hardware, software and simulations through power is also developed and tested in this activity. This activity provides clarity to research efforts and the various stakeholder groups so they can effectively address the technology gaps that exist, and adopt new innovations as they become available. This activity will test integrated systems that benefit from the advancements that are developed in the **Sensing and Measurement** and **System Operations, Control, and Power Flow** technical areas.

- **Develop Use Cases** – For integrated systems, standard test cases and scenarios are required to enable systematic evaluation of improvements to system performance. These are analogous to IEEE test cases for power flow solvers, for example, or ancillary services or other functions, as might be embodied in use cases. An example of a use case would be a high reliable distribution feeder with high levels of customer-sited photovoltaics. This example use case would demonstrate a reduced integration cost of DER of 50 percent over current practice while reducing outages. This activity will validate use cases for a range of scalable and integrated systems that enable reductions in reserve margins, reduce renewables integration cost, reduce outages, and demonstrate value propositions.

Task 2.4.1: Establish a standardized baseline set of use cases for a range of scalable and integrated systems. Identify innovative technologies and confirm testing framework validity across all scales. [FY16]

Task 2.4.2: Develop Integrated Systems Testbeds within the GLMC-TN. Based on standardized baseline use cases, confirm the ability to evaluate integrated systems at a variety of scales. Identify any missing integrated system testing capabilities. [FY16]

Task 2.4.3: Establish a defined technology taxonomy[48] associated with multi-scale systems to provide clarity to research, key stakeholders, and direct R&D activities to effectively address existing technology gaps related to validating integrated energy systems' operation. [FY16-18]

Task 2.4.4: Develop needed integrated systems testing capabilities identified in Task 2.4.2. [FY17-18]

- **Renewable Integration** – Validating integrated systems solutions that reduce the cost of interconnecting renewables and reducing reserve margins to enable integration of 100 percent renewable energy[49] at the distribution circuit level and 35 percent at the bulk system level[50]. This will be done through testbeds and HIL approaches that connect to large-scale modeling effort (See **Design and Planning Tools** Technical area).

Task 2.4.5: Implement testing and provide feedback to Grid Modernization Initiative activities to improve device development (Activity 1) and testing procedures (Activity 2) on goal of reducing the cost of integrating renewables. [FY17-20]

Task 2.4.6: Validate testing procedures for future technology applications within pre-defined framework for optimized electric grid integration and grid services. Provide feedback to Grid Modernization Initiative to improve testing procedures (Activity 2). [FY17-19]

- **Reduce Reserve Margins** – Reduce reserve margins by coordinate distributed generation, storage and controllable loads, and flexible central station renewables.

Task 2.4.7: Develop and perform transactive control construct testing to facilitate distributed generation, storage, and controllable loads at representative levels to demonstrate full deployment capability at several scales. Provide feedback to Initiative activities to improve device development (Activity 1) to address overall goal of reducing reserve margins. [FY17-18]

Task 2.4.8: Develop and perform testing on advanced techniques such as active power control[51] from wind and solar plants to demonstrate ability to reduce reserve margins at full deployment and at several scales. Provide feedback to improve device development (Activity 1). [FY17-18]

*Task 2.4.*9: Validate testing procedures for future technology applications within a pre-defined framework for optimized electric grid integration and grid services. Provide feedback to Initiative activities to improve testing procedures (Activity 2). [FY17-18]

- **Reduces Outages** – Reducing customer outages is an important aspect of grid reliability. There are several new technology developments at the distribution level that can be used to improve customer reliability such as

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[48] Technology taxonomy is a discrete mapping of how the pertinent devices, systems (and their constituent components) and other technology elements interrelate to identify dependencies and potential technology gaps.

[49] US Department of Energy, DOE Solar FOA: SUNSHOT NATIONAL LABORATORY MULTI-YEAR PARTNERSHIP (SUNLAMP) https://eere-exchange.energy.gov/#FoaId54a44ce1-eaa5-4f50-9c19-54702253559b

[50] 35% at the bulk-system level is based on the DOE SunShot Vision Study and DOE Wind Vision Report. By 2030, Solar goal is 14% and Wind Goal is 20% of annual energy.

[51] NREL, Active Power Controls for Wind Power: Bridging the Gaps, http://www.nrel.gov/docs/fy14osti/60574.pdf

advanced microgrids that have the ability to disconnect and provide local power when grid disturbances occur as well ask new fault location and restoration methods.

Task 2.4.10: Evaluate current microgrids'[52] ability to reduce customer outages and integrate clean energy resources with and without energy storage. Provide feedback to Initiative activities to improve device development (Activity 1) and testing procedures (Activity 2). [FY16-17]

Task 2.4.11: Test next-generation microgrids and validate they are capable of providing improved, reliable local electricity service (10 percent reduction in customer outages), while allowing significant levels of variable generation and coordinating with grid operations. [FY18-20]

Task 2.4.12: Evaluate current generation of fault location, isolation, and service restoration (FLISR) systems' ability to reduce customer outages. Provide feedback to Initiative activities to improve device development (Activity 1) and testing procedures (Activity 2). [FY16-17]

Task 2.4.13: Evaluate next-generation FLISR and validate they are capable of reducing customer outages by 10 percent. [FY18-FY20]

- **Energy Storage Field Demonstration** – Energy storage has the potential provide a myriad of functions for the modern electric grid, but it requires further field demonstration in order to establish integrated control and dispatch for a wide array of use cases, to establish a knowledge base around grid utilization of storage, to enable adaptation of grid design tools, and validate the tools that are developed.

Task 2.4.14: Facilitate the establishment of field demonstrations of a suite of grid energy storage technologies being applied to multiple use cases. [FY16-19]

Task 2.4.15: Collaboratively monitor the application of grid energy storage for multiple use cases both for functionality and performance, but also for reliability and economic optimization under regional pricing considerations. [FY16-20]

Task 2.4.16: Develop optimization and control algorithms for energy storage operation that maximize the grid benefit, especially for the case of providing multiple simultaneous grid services. Utilize the field demonstration projects to illustrate the improvement in performance with these algorithms. [FY16-20]

2.5 Links to Other Grid Modernization Technical Areas

Efforts in developing advanced grid devices, developing testing and interoperability standards, and conducting integrated systems integration tests depend on tight-coordination amongst all of the GMLC technical teams.

- Device development efforts in energy storage, distribution system inverters and controls, etc., depend upon the **System Operations, Power Flow, and Control** team for insights on emerging requirements in grid architecture and control paradigms to understand new system-level interdependencies that need to be considered in standards and testing. The development of high-resolution models for these new devices provides an important input to the **Design and Planning Tools** team modeling suites to improve the accurate simulation of emerging systems. Finally, interactions with the **Security and Resilience** team are essential to ensure that cyber and recovery issues are built into the controls and communications design of the new device systems.

[52] US Department of Energy, The Advanced Microgrid: Integration and Interoperability, http://energy.gov/oe/downloads/advanced-microgrid-integration-and-interoperability-march-2014

- Testing and interoperability standards development depend upon **System Operations, Power Flow, and Control** and the **Sensing and Measurements** teams to understand new operational paradigms and information dependencies to ensure that new standards fully represent all future operational needs. These standards also inform the **Institutional Analysis** efforts in defining new metrics and analytic approaches that inform regulatory efforts to incorporate new paradigms into future grid planning, operation, and business models. Finally, the **Security and Resilience** team must engage with validation approaches for ensuring security within evolving testing and interoperability standards.
- The Grid Modernization Laboratory Consortium - Testing Network (GMLC-TN) is expected to coordinate closely with the proposed Federated Data Sharing Network, an important component of the **Sensing and Measurements** team activities. It is expected that there will be many shared elements between both activities. The synergistic effect of these two activities will provide a robust mechanism for testing large-scale grid measurements, data analytics and communications under a variety of conditions.

2.6 Links to Existing DOE Portfolio

The proposed work in Devices and Integrated System Testing builds upon the existing activities of the various Program offices within DOE, in the following manner:

- Ongoing coordinated work in the EERE and OE Offices exists in the *Develop Advanced Power Electronic Interfaces, Energy Storage Systems, Controllable Loads and Other Grid Devices* sub-activity areas. Most of this work is broadly focused on device R&D for cost reductions, improved safety and performance and increased reliability improvements, but there are specific targeted R&D programs on advanced power electronic interfaces for photovoltaic systems, wind turbines, electric vehicles and chargers, fuel cell technologies, and energy storage systems. There is also work on developing responsive building, electric vehicles, and other end-use technologies. New activities in the GMI MYPP will focus on ensuring a common vision of grid service functionality across areas at DOE.
- Existing EERE and OE work in the *Develop Standards and Test Procedures* sub-activity area focuses on developing or updating device and system functional, interconnection and interoperability, and safety standards. We will accelerate the completion of these standards and testing procedures as well as focus on the development of standard and testing procedures for transactive controls, microgrids, storage reliability and other integrated systems.
- Ongoing efforts in the *Build Capabilities and Perform Testing and Validation of Devices* sub-activity area focus on evaluating individual technologies supported by EERE and OE offices. We will build on these activities by developing a multi-site, coordinated testing capability and using the testing results to develop device model libraries. This will help the industry by providing a single resource for information on testing capabilities and information on how to model devices for advanced functionality.
- Current activities in *Conduct Multi-scale Systems Integration and Testing* include projects supported by the EERE Solar Energy Technologies Program and Wind and Water Power Program to understand the impacts of high-penetration of solar and wind on distribution and transmission systems. It also supports efforts under the OE Smart Grid R&D and Energy Storage areas to monitor field-testing and demonstration projects conducted by utilities and other stakeholders.

Table 2 contains specific details on the existing funding streams supporting **Devices and Integrated Systems** projects conducted at the DOE National Laboratories in the current baseline year of FY15. The Briefing Papers contained in Appendix C specifically map our proposed future work in this technical area to the goals and objectives of the individual participating DOE Programs.

TABLE 2. EXISTING NATIONAL LABORATORY DEVICES AND INTEGRATED SYSTEM TESTING PROJECTS

Activity	Existing Major DOE Funded GMLC Projects in FY15
Device Development *16 Projects*	• OE – Energy Storage Battery Development • OE – Energy Storage Power Electronics • EERE – VTO Power Electronics • EERE – Solar Power Electronics • EERE - Manufacturing Innovation Institute on Power Electronics
Standards and Test Procedure Development *17 Projects*	• EERE – VTO Interoperability Standards • EERE – SETO Interconnection Standards • OE – Smartgrid Interoperability/Interconnection Standards • OE – Smartgrid Microgrid Standards • OE – Energy Storage Energy Storage Performance, Reliability, Safety
Device Testing and Validation *32 Projects*	• OE – Energy Storage (e.g. SNL Energy Storage Test Pad and Analysis Laboratory) • EERE – VTO • EERE – BTO • EERE – Solar • EERE – Wind
Conduct Multi-Scale System Integration and Testing *23 Projects*	• EERE – FCTO • OE – Smart Grid • OE – Energy Storage • EERE – Solar • EERE – VTO
Total: 88 Projects	

2.0 Devices and Integrated System Testing

<table>
<tr><th>Activity</th><th>FY16</th><th>FY17</th><th>FY18</th><th>FY19</th><th>FY20</th><th>Technical Achievement</th></tr>
<tr><td rowspan="5">Develop Advanced Power Electronic Interfaces, Energy Storage Systems, Controllable Loads and Other Grid Devices</td><td colspan="5">2.1.1: Develop and demonstrate new materials that enable increased switching frequencies and power densities of power electronics based devices by a factor of 2-4.</td><td rowspan="5">Improve power electronics-based converters for renewable, distributed energy and energy storage systems; decrease system costs of grid-scale, energy storage systems; develop enhanced controllable building and load technologies; and develop innovative grid infrastructure technologies</td></tr>
<tr><td colspan="5">2.1.2: Develop power electronics-based converters for renewable, distributed energy and energy storage that can provide grid services, self-optimize around the market and energy environment, and meet specific DOE applications' targets.</td></tr>
<tr><td colspan="5">2.1.3: Decrease the system cost of deployed grid-scale energy storage to under $300/kWh by FY20 by establishing metrics for safety, reliability, and performance storage systems and through new energy storage technologies. Demonstrate deployment and usage models that provide an ROI of under three years.</td></tr>
<tr><td colspan="5">2.1.4: Enable buildings, large building loads and EV charging systems to: 1) diagnose functions, 2) forecast their energy needs (days), 3) characterize flexibility, and 4) have embedded control and decision-making tools to provide capacity, energy and ancillary services to the electrical grid and other valuable services to system owners.</td></tr>
<tr><td></td><td colspan="4">2.1.5: Develop innovative grid infrastructure technologies that improve electrical grid efficiency and reliability by 10 percent.</td></tr>
<tr><td rowspan="12">Develop Standards and Test Procedures</td><td colspan="2">2.2.1: Update consensus interconnection standards for both distribution and bulk systems that provide system stability at high penetrations.</td><td></td><td></td><td></td><td rowspan="12">Updated standards and test procedures that characterize the ability of devices (50% of building loads and all new generation and storage) to provide a full range of grid services

Development of standards and test procedures for microgrids and other systems that reduce customer outages by 10%</td></tr>
<tr><td colspan="4">2.2.2: Facilitate establishment of risk evaluation protocols, safety standards, and performance testing methodologies for energy storage.</td><td></td></tr>
<tr><td></td><td colspan="2">2.2.3 Update testing procedures for interconnection standards</td><td></td><td></td></tr>
<tr><td colspan="2">2.2.4: Consolidate consensus interoperability standards for the building, distribution, and bulk power systems.</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="3">2.2.5: Develop testing procedures for interoperability standards</td><td></td></tr>
<tr><td>2.2.6: Develop a standard set of definitions for the full range of grid and ancillary services.</td><td colspan="2">2.2.8 Develop a technology neutral consensus-based standard for providing grid services. This includes defining the requirements for transactive control constructs.</td><td></td><td></td></tr>
<tr><td>2.2.7: Develop requirements for testing transactive-enabled grid devices.</td><td colspan="3">2.2.9: Develop testing procedures for evaluating the ability of devices to provide grid services.</td><td></td></tr>
<tr><td colspan="4">2.2.10: Establish and test methodologies for enabling optimal dispatch of energy storage to serve multiple grid services.</td><td></td></tr>
<tr><td colspan="2">2.2.11:Update microgrid design and operational standards.</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2">2.2.12:Develop microgrid-testing procedures.</td><td></td><td></td></tr>
<tr><td colspan="5">2.2.13: Demonstrate enhanced customer reliability through use of energy storage in conjunction with coordinated grid and customer dispatch. Establish and validate reliability of energy storage systems.</td></tr>
<tr><td></td><td colspan="2">2.2.14:Develop standards and testing procedures for FLISR systems.</td><td></td><td></td></tr>
</table>

2.0 Devices and Integrated System Testing

Activity	FY16	FY17	FY18	FY19	FY20	Technical Achievement
Build Capabilities and Perform Testing and Validation of Devices	2.3.1Develop a framework document with an index of available National Lab, university, and industry resources.					GMLC-TN provides test facility integration and optimization, testing frameworks, and component model libraries managed and operated by national laboratories, universities, and industry groups
	2.3.2: Analyze framework document to determine key gaps between existing and eventual desired testing capabilities and provide recommendations to DOE leadership.		2.3.3: Enhance and expand GMLC-TN as necessary to achieve desired testing capabilities.			
	2.3.4: Develop a unified model description for devices that can provide grid services.	2.3.5: Develop an open and accessible model library and populate library based on testing results.				Characterization of a wide variety of technologies to validate individual devices can provide a full range of grid services
	2.3.8: Develop testing and validation infrastructure for transactive-enabled grid devices that can reliably respond to grid needs without the need for backup generation.	2.3.6: Develop models for generation, transmission, distribution, storage, and loads and populate library based on testing results.				
		2.3.9: Validate and apply test procedures to transactive devices.		2.3.7: Develop an open and accessible simulation framework with composable and interoperable models.		
	2.3.10: Develop device interface specifications and framework that support communication and control of local output, in pursuit of coordinating device- and system-level testing in conjunction with Activity 2.		2.3.12: Update testing procedures using feedback from testing framework requirements.			
			2.3.14: Integrate multiple HIL simulations with large-scale grid simulation on HPC systems.			
					2.3.15: Demonstrate 10 milliseconds scale HIL-to-HIL and HIL-to-HPC simulation	
	2.3.11: Validate testing procedures for interconnection, interoperability, and grid services in conjunction with Activity 2 and 4.					
	2.3.13: Develop standard methods and prototypes to federate multiple HIL simulations located at different geographic sites over a high-speed network.					
Conduct Multi-Scale Systems Integration and Testing	2.4.1 Establish a standardized baseline set of use cases for a range of scalable and integrated systems. Identify innovative technologies and confirm testing framework validity across all scales.	2.4.4: Develop needed integrated systems testing capabilities identified in Task 2.4.2.				Multi-scale systems that enable integration of 100% renewable energy at the local level and 35% at the bulk system while reducing reserve margins and interconnection costs
		2.4.5: Implement testing and provide feedback to Grid Modernization Initiative activities to improve device development (Activity 1) and testing procedures (Activity 2) on goal of reducing the cost of integrating renewables.				
		2.4.6: Validate testing procedures for future technology applications within pre-defined framework for optimized electric grid integration and grid services. Provide feedback to Grid Modernization Initiative to improve testing procedures (Activity 2).				
	2.4.2 Develop Integrated Systems Testbeds within the GLMC-TN. Based on standardized baseline use cases, confirm the ability to evaluate integrated systems at a variety of scales. Identify any missing integrated system testing capabilities.	2.4.7: Develop and perform transactive control construct testing to facilitate distributed generation, storage, and controllable loads at representative levels to demonstrate full deployment capability at several scales. Provide feedback to initiative activities to improve device development (Activity 1) to address overall goal of reducing reserve margins.				Transactive control constructs that coordinate distributed generation, storage and controllable loads to reduce reserve margins by 33%
	2.4.3: Establish a defined technology taxonomy associated with multi-scale systems to provide clarity to research, key stakeholders, and direct R&D activities to effectively address existing technology gaps related to validating integrated energy systems' operation.					10% outage reductions by using advanced microgrids system configurations and FLISR
		2.4.8: Develop and perform testing on advanced techniques such as active power control from wind and solar plants to demonstrate ability to reduce reserve margins at full deployment and at several scales. Provide feedback to improve device development (Activity 1).				

2.0 Devices and Integrated System Testing

Activity	FY16	FY17	FY18	FY19	FY20	Technical Achievement
Conduct Multi-Scale Systems Integration and Testing		2.4.9: Validate testing procedures for future technology applications within a pre-defined framework for optimized electric grid integration and grid services. Provide feedback to Initiative activities to improve testing procedures (Activity 2).				
	2.4.10: Evaluate current microgrids' ability to reduce customer outages and integrate clean energy resources with and without energy storage. Provide feedback to Initiative activities to improve device development (Activity 1) and testing procedures (Activity 2).					
			2.4.11: Test next-generation microgrids and validate they are capable of providing improved, reliable local electricity service (10 percent reduction in customer outages), while allowing significant levels of variable generation and coordinating with grid operations.			
	2.4.12: Evaluate current generation of fault location, isolation, and service restoration (FLISR) systems' ability to reduce customer outages. Provide feedback to Initiative activities to improve device development (Activity 1) and testing procedures (Activity 2).					
			2.4.13: Evaluate next-generation FLISR and validate they are capable of reducing customer outages by 10 percent.			
	2.4.14: Facilitate the establishment of field demonstrations of a suite of grid energy storage technologies being applied to multiple use cases.					
	2.4.15: Collaboratively monitor the application of grid energy storage for multiple use cases both for functionality and performance, but also for reliability and economic optimization under regional pricing considerations.					
	2.4.16: Develop optimization and control algorithms for energy storage operation that maximize the grid benefit, especially for the case of providing multiple simultaneous grid services. Utilize the field demonstration projects to illustrate the improvement in performance with these algorithms.					

3.0 Sensing and Measurements

To assess the grid's health in real time, predict behavior and potential disruptions, and quickly respond to events, it is necessary to understand vital parameters throughout the electric infrastructure from generation through the end-user. The future grid is expected to have more distributed systems with building owners playing a more active role in their energy consumption. Without accurate information, it is difficult to operate the system efficiently, and this problem has contributed to large-scale power disruptions and outages in the past. Although more observation points have been deployed with recent investments (e.g. smart meters, PMUs), very little visibility is currently available at and below the distribution level, thereby limiting the integration of distributed systems and utilization of loads to their full potential. Improved visibility across multiple spatial scales (from generation to the end-user load) and at multiple time scales (from microseconds to hours and days) is needed to support advances in system operation and control.[53][54]

"DRAMATIC CHANGES ARE OCCURRING IN OUR NATION'S ENERGY MIX, MANY OF WHICH DEMAND A MORE TECHNOLOGICALLY ADVANCED ELECTRIC GRID."

Dr. Michael Knotek, Deputy Under Secretary for Science and Energy

In order to develop visibility across the electric grid several key challenges need to be addressed:

- *Cost of sensor implementation*: according to a Smart Grid Investment Grant (SGIG) report, the average overall cost per phasor measurement unit or PMU (procurement, installation, and commissioning) ranged from $40,000 to $180,000[55]. For industrial applications, the average cost of a sensor is $1,800.[56] These costs are, in part, dependent on the parameter being measured along with complexity of installation.[57] Surveys with industry leaders reveal that cost is a major impediment. "Especially for the nuclear power sector - the cost of sensors/ instruments (be they wired or wireless) available from the MACs (major automation companies) is simply too high to justify the number of devices needed for the optimization software to make a substantive difference in the plant/facility operation and financial bottom line".[58]
- *Accuracy of measurement devices through disturbances*: sensors must minimize uncertainty, especially in transient conditions, to provide accurate measurements and reliably perform key functions.
- *Communication and data framework*: the ability to transfer data with appropriate bandwidth, latency, network loading, and packet loss characteristics that meets functional requirements in a secure manner is essential. Data storage must match application requirements, such that appropriate data levels are realized in both centralized and distributed modes of analytic and control operation.
- *Ability to turn data into action*: data management tools and visualization techniques are needed to derive actionable information from large volumes of data and the information must be connected to decision and control processes. Speed, latency, accuracy, and security will likely create challenges for utilities to manage the projected data deluge. Data quality and integrity must be assured throughout the entire processing chain. Tools must have the ability to work when data is lost or delayed and discern between a disturbance and bad data.

[53] Future of Electric Grid Report; https://mitei.mit.edu/system/files/Electric_Grid_Full_Report.pdf

[54] EPRI Concept Paper, The Integrated Grid, Realizing the Full Value of Central and Distributed Energy Resources.

[55] Synchrophasor Technologies & their Deployment in the Recovery Act Smart Grid Programs, August 2013; https://www.smartgrid.gov/sites/default/files/doc/files/Synchrophasor%20Report%2008%2009%202013%20DOE%20(2)%20version_0.pdf

[56] "Agile Prognostics and Diagnostics for Power Transmission Reliability and Asset Management" White paper, Peter Fuhr, Alex Melin

[57] D. Lineweber , S. McNulty, "Cost of Power Disturbances to Industrial & Digital Economy Companies," *EPRI Report: 3002000476, CEIDS,* 2001.

[58] "Agile Prognostics and Diagnostics for Power Transmission Reliability and Asset Management" White paper, Peter Fuhr, Alex Melin

A modern grid can leverage the DOE Grid Modernization Initiative's *Sensing and Measurements* activities to improve situational awareness and support a more efficient, reliable, and resilient system – starting with the buildings' owners and throughout the entire electric delivery system. Multi-purpose sensors that can effectively perform multiple functions may help drive down costs. Next-generation sensors will provide data for control and optimization of buildings, electric vehicles, and distributed energy resources integration. Leveraging these technologies will create new opportunities when they are combined with communications that tie together regional as well as local grid architectures.

Five key technical activities in this area and their respective outputs are shown in Table 3.

TABLE 3. ACTIVITIES AND TECHNICAL ACHIEVEMENTS FOR SENSING AND MEASUREMENTS

Activity	Technical Achievements by 2020
1. Improve Sensing for Buildings & End-Users	• Development of low cost sensors (under $10 or two year payback per sensor) for enhanced control of smart building loads and distributed energy resources to be "grid friendly" in provision of ancillary services such as regulation and spinning reserve while helping consumers understand benefits of energy options.
2. Enhance Sensing for Distribution System	• Development of low cost, multi-purpose sensors (under $100 per sensor or two year payback) and ability to effectively deploy these technologies to operate in normal and off-normal operations. • Development of "visibility strategy" using visualization techniques and tools to define sensor type, number, location, and data management. Optimize sensor allocation for a given feeder.
3. Enhance Sensing for the Transmission System	• Development of advanced synchrophasor technology that is reliable during transient events as well as steady state measurement and can be upgraded remotely if sensor function needs to be modified. • Development of low cost, multi-purpose sensors for electric grid components to monitor real-time health status, stress accumulation leading to component Loss of Life, and real time loading that takes local environmental conditions into account.
4. Develop Data Analytic and Visualization Techniques	• Real-time data management for the ultra-high velocities and volumes of grid data from T&D systems and the ability to identify and compensate for inaccuracies and errors. • Establish the appropriate visibility of generation, loads, and system parameters across the electric infrastructure through the development of visualization techniques and software tools incorporating measures for secure access and privacy/confidentially. • Development of measurement and modeling techniques for estimating and forecasting renewable generation both for centralized and distributed generation for optimizing buildings, transmission, storage, and distribution systems.
5. Demonstrate comprehensive converged grid-communications networks	• Secure, scalable communication framework with network management tools that addresses grid needs ranging from wide area low latency closed loop protection and control to more localized fast distribution level measurement and control, and secure integration with internet-connected Distributed Energy Resources (up to and including microgrids and buildings) and social networks that can impact critical infrastructure operations.

Activity	Technical Achievements by 2020
6. Regional & Cross-cut Initiatives	• Provide real-time information of solar and wind generation and building loads at high spatial and temporal resolution. • Provide forecasts from minutes to days ahead of solar and wind generation and loads. • Incorporate environmental sensors that identify and predict weather-related effects (e.g., ice buildup on power lines, thermal imbalance, and increased stresses from high velocity winds), thereby mitigating impacts on the infrastructure or preventing widespread disturbances.

The activities in Sensing and Measurements technical area will deliver Technical Achievements for each Activity area (see Table 3 above) as well as support the three "Integrated Regional Demonstrations" outlined in Chapter 8.0. Sensor developments for end-users, distribution systems and the bulk transmission system will deliver low cost devices that are robust across normal and off-normal conditions. These advanced devices will be vital in supporting "Lean Reserve Margin Grid Bulk Power Systems" as well as "Clean Distribution Systems" regional demonstrations as these will demonstrate leverage of full system observability for improved grid operations. The data analytics and enhanced communications activities are fundamental in linking sensors and control elements to operational tools, control systems, and human operators, stakeholders, and others to achieve improved and secure energy operations. In addition, the sensor performance specifications and related interoperability standards for secure communications and data exchange will be important contributions to the Advanced Modern Grid Planning & Analytics Platform regional demonstration. Descriptions of each activity area follow.

3.1 Activity 1: Improve Sensing for Buildings and End-Users

Although buildings represent more than 70 percent of U.S. electricity use, the consumer-utility relationship has largely been "one-way", with buildings being primarily passive energy consumers. As consumers' interest in managing their energy usage through such means as efficiency, and energy generation increases, building owners are re-evaluating their relationships to their utilities. Furthermore, technological advances in network communications and human interfaces through computers and mobile data devices have and will continue to create opportunities for buildings to become active contributors to grid management while providing new benefits to the occupants they serve. Such interaction will enable two-way transactions with the grid, commonly called a "transactive energy" relationship.[59] This paradigm will require novel technological applications to enable transfer of information enabling buildings to communicate with grid control systems for the purpose of offering services of value to grid operations and possibly other parties while continuing to serve occupants and securing sensitive information.

[59] Kris Subbarao et al, "Transactive Control and Coordination of Distributed Assets for Ancillary Services" September 2013.

To realize the 2020 Technical Achievement targets the following efforts will be undertaken:

- **Sensor development** – This activity will leverage ongoing commercial developments[60,61,62,63,64] innovate where necessary, and demonstrate sensors with cost, size, and power requirement profiles suited for buildings applications, electric vehicles, distributed energy resources and other end-uses. Current designs do not meet these requirements, prohibiting widespread adoption. Sensor areas of interest include energy efficiency measurements, real and reactive power, voltage, current, frequency, air/water pressure and flows, occupancy sensing, environmental sensing (temperature, humidity, ambient lighting), and asset health (operating temperature, power consumption, vibration, other asset parameters). Sensors should be low cost, have small form factor and consume very little power, preferably with no external power source required, using energy harvesting. The sensors should be easily installed and very reliable.

  Task 3.1.1: Develop advanced, multi-purpose, low cost sensors (less than $10 per sensor or two-year payback; including installation costs) to monitor parameters that enable building owners and end-users to more effectively assess the state of their energy assets. [FY16-18]

- **Communications with sensors** – This activity will incorporate low-cost, open, advanced communications (both wired and wireless) into advanced sensors and prove that advances seen for consumers can apply across and benefit all buildings. New communication standards and technology will likely be industry driven, but the deployability of the technology for applications in buildings can be accelerated with federal involvement. There is considerable activity in the area of interference-robust wireless sensors and sensor networks in the academic, public and private sectors. Correlation-based spectrum sensing relying on inexpensive, easy to deploy, wireless sensors will utilize cognitive radio-based sensors incorporating shared spectrum technologies to minimize the "spectrum crunch" associated with devices that will be deployed. This could include new and novel fabrication methods to integrate communication capabilities. For individual sensors, future requirements could include each sensor having a unique IP address, configurable, upgradable, and ability to host intelligence in the form of interface and firmware. Price points must be very low relative to current technologies to increase the use throughout the building infrastructure.

  Task 3.1.2: Develop new methods for secure, interference-robust shared spectrum wireless communications technologies to accelerate the incorporation of low-cost, wireless communications with advanced sensors. Bring coherence to the multitude of communications technologies and standards currently being used and/or suggested for next generation devices and systems applicable to grid applications. [FY16-19]

- **Advanced building energy management and control systems** – Future energy management systems should enable self-awareness of building status, incorporate multiple sensor inputs and enhance building capability to participate in demand response and provide ancillary services. Current systems lack awareness of the available

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[60] IBM Case Study: Smart Ehningen: IBM uses state-of-the-art technology to reduce operating costs of the building by more than 35 percent

[61] http://www01.ibm.com/common/ssi/cgibin/ssialias?subtype=AB&infotype=PM&appname=SWGE_LO_LO_DEEN&htmlfid=LOC14346DEEN&attachment=LOC14346DEEN.PDF#loaded

[62] Advanced Sensors and Controls for Building Applications: Market Assessment and Potential R&D Pathways, M.R. Brambley P. Haves, S.C. McDonald P. Torcellini , April 2005

[63] Navigant Report: Advanced Sensors for Smart Buildings: Advanced Occupancy Sensors, Advanced CO2 Sensors, Advanced Thermostats, and Advanced Photosensors: Global Market Analysis and Forecasts, 2013

[64] Siemens website: http://www.buildingtechnologies.siemens.com/bt/global/en/buildingautomation-hvac/gamma-building-control/gamma-instabus-knx/pages/physical_sensors_electrical_installation.aspx

slack to either decrease or increase load for different response latencies and response service length intervals. This feature is critical for widespread building to grid integration.

Task 3.1.3: Develop an open architecture for Building Energy Management Systems that is scalable for any size building. [FY16-18]

3.2 Activity 2: Enhance Sensing for Distribution System

Sensing and measurement on distribution systems covers all aspects of determining the distribution grid status. This includes power state, device state, asset health and utilization, environmental conditions, and meta-data, especially including the electrical connectivity of the distribution grid from substations to edge devices and systems. Sensed variables include typical power system electric parameters, non-electrical parameters (such as device temperature), asset health, and meteorological conditions.[65,66,67,68,69,70]

To realize the 2020 Technical Achievements targets the following efforts will be undertaken:

- **Distribution Visibility** – Substantially improve the situational awareness on distribution systems that may have significant penetration of DER, may operate in flexible modes that use power electronics for flow control in multiple variable topologies, and may use storage, advanced controls, and responsive loads. This will require a new framework for an extended distribution grid state (this includes not just power state but also asset operating state and health, thermal conditions and circuit topology), new tools for developing visibility strategies and sensor network designs, and new low-cost, high-performance sensors for power state, power quality, and asset status.

  Task 3.2.1: Develop, validate and document a new extended grid state framework that encompasses power state, asset operational state, thermal states, etc. [FY16]

  Task 3.2.2: Develop a validated visibility strategy and sensor allocation software tool for distribution networks incorporating the extended grid state framework taking into account sensing capabilities of new and existing devices, including advanced meter infrastructure. [FY16]

- **Grid Connectivity Framework** – A critical need exists to continually rediscover grid connectivity in order to provide missing or incomplete information that limits or inhibits many advanced distribution automation schemes. Inaccuracy in understanding real time grid topology occurs due to constant changes on both short and long time scales. Technology for sensing circuit connectivity all the way to the edge devices will alleviate this problem and enable a wide variety of advanced distribution automation and outage management solutions that will improve reliability and resilience.

  Task 3.2.3: Demonstrate technology for continuous, real-time rediscovery of distribution electrical connectivity/topology. [FY17-FY19]

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[65] "Sensor and Sensor Network Applications in the Smart Grid", W. Kao, *Sensors Con2012*, Santa Clara, CA, March 2012.

[66] "Sensing and Control Challenges for Smart Grids", H. Slootweg, Next Generation Infrastructures Europe, ICNSC, 2012.

[67] Duke Distributed Intelligence Platform: http://www.dukeenergy.com/pdfs/DEDistributedIntelligencePlatformVol01.pdf

[68] On-Ramp Wireless project: http://www.electricenergyonline.com/show_article.php?mag=85&article=709

[69] ABB project: http://www.ieee-pes.org/presentations/gm2014/PESGM2014P-002513.pdf; http://www.osti.gov/scitech/servlets/purl/1132766

[70] The NETL compendium of smart grid technologies is available at http://www.netl.doe.gov/moderngrid/referenceshelf/whitepapers/Compendium_of_Technologies_APPROVED_2009_08_18.pdf

- **New Sensing Capabilities** – New low-cost sensor devices capable of measuring temperature, chemistry, pressure, and relevant environmental parameters while operating under standard utility conditions and at potentially at high voltages and currents are needed for improved monitoring of next-generation grid components. New electrical measurement sensors are needed that can operate at frequencies in the Megahertz range (much higher than typical power line sensors can measure) to monitor the emerging use of power electronics for flow control and for device, subsystem, and building interfaces.

  Task 3.2.4: Develop and demonstrate new, low-cost sensors for distribution-level electrical state and asset condition monitoring for new assets such as storage and power electronics based devices including parameters such as temperature, chemistry, and pressure, as well as very high frequency power quality effects. [FY16-20].

  Task 3.2.5: Demonstrate low-cost synchronized three-phase, unbalanced voltage and current sensors capable of measuring instantaneous frequency and rate of change of frequency. These technologies must be able to measure distribution power state (grid voltages, real and reactive power flow and phase angles), component impedances, and asset loadings with support for distributed/embedded analytics processing. [FY17-FY20]

3.3 Activity 3: Enhance Sensing for the Transmission System

The bulk transmission system is the backbone of the electric grid and historically the economies of scale enabled by large-scale generation have provided low-cost, reliable electricity. However, the rapidly changing generation mix, from renewable energy along with the recent boom in shale gas production, is altering the operation and performance of the grid. As distributed generation sources become increasingly widespread, along with the evolution of responsive loads, the bifurcation between transmission and distribution systems is becoming less clear. Successful implementation of next generation electric power infrastructure technology will hinge on two key aspects: (1) detailed system-wide monitoring of the electric grid and external effects, including weather events for predictive failure analysis, and (2) localized assets such as DER that use the failure analysis to mitigate the effects on consumers and utilities. Sensors do not currently exist at price points that would allow an acceptable return on investment for stakeholders. As new measurement tools are developed, entire life cycle costs must be considered including installation, maintenance, connectivity, etc.[71,72]

To realize the 2020 Technical Achievements targets the following efforts will be undertaken:

- **Situational Awareness Tools** – Through public-private partnerships, DOE and leading industry stakeholders have invested significantly in synchrophasor technologies. These sensors enable better indication of grid health than existing systems and can help maintain reliability by providing data to take corrective actions. However, to realize the full potential of PMUs several advancements must be realized including further cost reductions, optimization of sensor placement and data management, data quality, and increased accuracy under transients or fault conditions. Measuring instantaneous frequency and instantaneous rate of change of frequency are important during transient conditions and poorly done in PMUs now. Present synchrophasor processing methods usually operate on averaged sets of data and inherently assume that frequency is constant throughout the sampling estimation time window, which is usually not accurate for measuring transients. The definition of instantaneous frequency and instantaneous rate of change of frequency that is suitable for power systems

[71] "EPRI White Paper Sensor Technologies for a Smart Transmission System; December 2009

[72] Fischer Block: http://fischerblock.com/sensor.html

should be defined clearly for measuring transients. Additional methods that don't rely on block processing window are needed and must be qualified in terms of accuracy, noise tolerance, etc. comply with IEEE PMU Standard and have a good noise tolerance performance. They should also be able to operate at output rates much faster than the typical 30 to 60 Hz per second in use now and they must still be synchronizable across the grid.

Task 3.3.1: Develop advanced synchrophasors that are reliable during transient events as well as steady state measurement at a sufficiently low-cost (under $100 per sensor or two-year payback) to enable widespread adoption. Next generation synchrophasors need to provide accurate measurements during transients. [FY16-20]

Task 3.3.2: Examine sensor placement strategies as well as measurement accuracy requirements for appropriate applications. Current standards pay too much attention on out-of-band rejection performance, resulting in large measurement latency, thus, limiting real-time control application. [FY16]

- **Asset Monitoring Tools** – Utility companies are faced with aging equipment and tight O&M budgets. A new generation of low-cost sensors can help diagnose equipment health for life cycle optimization, utilization optimization (maintenance), and prevention of catastrophic failures. Although significant research has focused on monitoring generation components, the deployment of renewables and access to natural gas has significantly changed grid operations and thus requiring additional monitoring of the grid components. Some systems running in baseload conditions are now operating in load-following mode, putting greater stresses on these plants. Additionally, as new classes of components and devices emerge onto the scene, such as energy storage and low-cost power flow control technologies, monitoring tools for these systems remain to be developed.

Task 3.3.3: Develop novel inexpensive sensors for component health monitoring and low-cost grid state monitors. This will include sensing and measurement of advanced components such as energy storage devices and power electronics. As advanced manufacturing techniques and diagnostic and prognostic tools are developed, an integrated sensor with multi-parameter sensing, onboard diagnostic, and prognostic as well as built-in communication elements will become possible. [FY16-18]

Task 3.3.4: Develop diagnostic and prognostic algorithms based on computationally efficient methods that interface with and use a suite of sensors. These diagnostic and prognostic techniques will focus on two main power interruption phenomena: localized equipment degradation and failure detection and anticipatory extreme environmental event response. [FY16-19]

Task 3.3.5: Demonstrate key sensor technologies for components at the bulk transmission level and integrate with advancements in the prognostics and diagnostics algorithms. [FY19-20]

3.4 Activity 4: Develop Data Analytics and Visualization Techniques

Through the deployment of new technologies across the transmission, distribution, and end-use system, utilities and even consumers can have access to an extraordinary amount of data. Data is being collected from a variety of sources, including meters, outage management systems, SCADA, weather, distributed energy resources, and PMUs. The diversity of data types and time "stamps" of these data sets are important to many users of the data and the potential outcomes and findings derived from the data. Additionally, many utilities are tapping into other datasets, including smart meters, call centers, social media, billing systems, and mobile apps to support grid planning and operations. Future data sets may include imagery and videos. Data volume from these and additional datasets is expected to grow exponentially in the next few years especially with the introduction of streaming synchronized measurement at the distribution grid level. The key will be to identify and measure the most important parameters and then collect the right amount of data to achieve the desired end-state. In essence the overall objective is the ability to turn data into actionable intelligence.

To realize the 2020 Technical Achievements targeted, the following efforts will be undertaken:

- **Distributed Analytics** –Develop methods for performing analytics on data in motion, including streaming data, with distributed intelligence embedded in the grid, as opposed to being only available in the form of a centralized data and control center. By processing data streams in a distributed fashion, data results and control actions can be calculated and implemented close to the source to enable control related to very low latency problems, while results and data can be passed upstream for other uses at different latency levels. An example of a low latency local problem is reactive power management while long latency system level problem could be day-ahead unit commitment and scheduling of generation and demand response.

  Task 3.4.1: Develop real-time streaming analytics and machine learning paradigms for grid visibility, control, resilience, and security. This includes methods for distributed implementation, using computational resources deployed in the grid outside of the data or operations center (substation and beyond). [FY16-FY19]

  Task 3.4.2: Create a tool to manage distributed analytics using advanced virtualization methods and open distributed application platforms. This includes fault, configuration, accounting, performance, security (FCAPS) functions as are common in network management systems, but for analytics elements. This tool manages the placement, performance monitoring, fault management, and other aspects of operating a distributed analytics set. [FY16-FY19]

- **Tool Development from Data Analytics** – Develop a suite of visualization and software tools that use data from sensor networks for monitoring grid health, anticipating and identifying problems as early as possible, and developing strategies for mitigating future events through machine learning.

  Task 3.4.3: Develop and demonstrate a tool for acquiring heterogeneous sensor data and populating an extended grid state that is informed by continual rediscovery of grid topology. [FY16-FY17]

  Task 3.4.4: Develop data analysis tools that move from today's quasi-static tools used to monitor the grid toward tools that can analyze and predict dynamic behavior. Using high speed PMU data and advanced software tools, awareness of dynamic behavior can become part of a utility operator's toolkit to increase system performance and reliability by having more complete and detailed information about the current grid state and how it is evolving in time. Many types of events are only now visible due to PMUs. [FY16-FY19]

3.5 Activity 5: Demonstrate Unified Grid-Communications Network

Advances in the electric grid, such as wide-area situational awareness and real-time control, will depend on a secure and reliable communication infrastructure. The evolution of grid communications systems will increasingly link data and information throughout the entire electric delivery system, from generator all the way through the delivery system to the end user, with the greatest increase in network connectivity linking distribution with the end-users. Understanding future functional requirements and data needs (volume, velocity, variety, uncertainty, and visibility) will be important in establishing a secure, robust communication infrastructure. In addition, there are a variety of architectural issues for grid data management based on concepts like latency hierarchy, data lifespan, data store typology, and processing classes that provide insight into grid data management with implications for networking.[73]

Interoperability among communications devices through standardized protocols and standards will be imperative as this transformation of the grid occurs. A 2012 review of wireless communications used in the electric utilities revealed a vast array of technologies in service. These communications technologies are supporting a wide range of applications including substation backhaul networks, localized sensors and systems, monitoring, and control of equipment. In addition, there are various "new" (pre)standards (e.g., 802.11ah) and disparate communications for smart grid initiatives and the Internet of Things. Government leadership, in the form of technical guidance, has been requested from industry members to provide an unbiased appraisal of the implications that such rapidly changing technologies have on their existing and future-planned activities

There will be several interconnected networks serving a variety of purposes, as noted above. The overall structure of the grid will continue to require multiple tiers of utility networking. These different tiers will have distinct requirements (e.g., latency needs from a few milliseconds to a day or longer), topologies (e.g., multi-ring, mesh, dual hub and spoke, point to point), owners (e.g., ratepayers, utilities, grid operators), and performance characteristics that have not historically been used for multi-tier sensing and control applications for the electric grid.

These communication systems will support reliable automated operation of the grid to improve reliability and safety in the face of high renewable penetration, and cybersecurity threats. Research is needed to link communications models to grid tools, validation of these models using field data, and widespread adoption of these improved tools along with ensuring a communication infrastructure capable of managing the anticipated explosion of data traffic for sensors (e.g., PMUs) and automated actuation points.

To realize the 2020 Technical Achievement targets, the following efforts will be undertaken:

Task 3.5.1: Incorporate communications models into grid simulation and management tools so that researchers and operators can understand and optimize systems in realistic situations. [FY16-FY17]

Task 3.5.2: Develop methods to manage the heterogeneity of the network and manage abstraction and aggregation across network tiers, segments, and varied quality of service needs. [FY17]

Task 3.5.3: Develop a framework for testing performer's devices in a realistic, reconfigurable "utility-equivalent" environment. A Virtualized Utility Communications-Networking Laboratory integrated with a physical system can allow public, private sector, and academic researchers remote and in-person access to a robust and realistic demonstration test bed. [FY16-17].

Task 3.5.4: Improve dynamic management of data flows (e.g., software defined networking) for low latency protection and control systems so that they can provide closed-loop control and enable a highly interactive grid management framework. This could include development of a shared spectrum environment to address the "spectrum crunch" by providing a realistic environment for commercial entities (vendors and utilities) to test new and innovative spectrum sharing techniques and devices. [FY18-FY19]

[73] Jeffrey Taft and Paul De Martini, "Utility Data Management and Intelligence A Strategic Framework for Capturing Value from Data," May 2012, available online.

Task 3.5.5: Develop and demonstrate a unified grid and network management framework and demonstration network utilizing state-of-the-art networking technology to enable stakeholders to observe feasibility and value with appropriate investment. [FY19-20]

3.6 Activity 6: Regional & Crosscut Initiatives

- **Federated Data Sharing Network** – The DOE national laboratory complex consists of a wide assortment of facilities varying significantly in size, footprint, and geographic location. Leveraging these facilities is an opportunity to pool existing and future data from grid infrastructure, weather, electrical demand, and grid conditions. A shared inventory and catalog of existing data and infrastructure can significantly reduce acquisition costs and time for the required sample data. Many aspects of the research proposed in this document require data for analysis, development, and testing, particularly the data analytics and visualization efforts, but all aspects of grid sensing and measurement and other task areas could benefit from shared data. If operated in coordination with the Grid Modernization Laboratory Consortium - Testing Network discussed in section 2.3, the data sharing network would allow the operational infrastructure of the DOE laboratory complex to act as an additional test bed for sensors and measurements. Most national laboratories maintain a monitoring infrastructure, but an integrated data set is not currently being effectively shared across the DOE laboratory complex. This data could include the following:
    1. Weather (irradiance, temperature, wind speed, humidity),
    2. Grid voltage and frequency at a main substation (e.g., PMU data)
    3. Demand on selected feeders (especially feeders general supplying commercial/residential loads)
    4. Output of wind, PV, or other distributed generation resources
    5. Metadata related to all the items above (e.g., GPS coordinates, type of sensor, size/rating of facilities, etc.)

  Once in place, a data-sharing and visualization network across the National Laboratories would also facilitate scaling data and communications to test systems for meeting the expected increase in data volume and bandwidth in a non-operational context. A federated data sharing network would allow novel sensor technologies and techniques to be tested and experimented side-by-side with existing sensors. It would also facilitate testing of various demand response scenarios and building energy management systems.

  Task 3.6.1: Create inventory of existing sensors and datasets available across the DOE labs; create inter-laboratory data sharing agreement and preliminary work in setting up data sharing system architecture. [FY16]

  Task 3.6.2: Generate models of all DOE facilities with sensor data collection. Identify sensor gaps and candidate target infrastructure for additional sensing to enable increased visibility. [FY17]

  Task 3.6.3: Demonstrate cross-lab sensor network and place new sensors to augment the existing fleet of sensors and increase the amount of measured data. [FY18-FY19]

  Task 3.6.4: Scale up network and tie in virtual simulations and systems to enable testing and demonstration at large scale of analytics and communications, under a variety of scenarios. [FY18-FY20]

- **Environmental Sensing & Forecasting** – For the electric grid to effectively operate under high renewables scenarios it is important to have accurate information about generation and load at various temporal and spatial scales. This is dependent on the ability to sense and forecast the environment and integrate that information into any decision support system that may be deployed. A comprehensive system will be able to:

(a) Provide real-time information of solar and wind generation and building loads at high spatial and temporal resolution.

(b) Provide forecasts from minutes to days ahead of solar and wind generation and loads.

(c) Incorporate environmental sensors that identify and predict weather-related effects (e.g., ice buildup on power lines, thermal imbalance, and increased stresses from high velocity winds), thereby mitigating impacts on the infrastructure or preventing widespread disturbances.

Real-time and forecasted data from environmental sensing and modeling are essential for building operations, as inputs to energy management systems enabling self-awareness of building status, enhancing the capability to participate in demand response, providing ancillary services from distributed resources, managing energy storage operations and optimizing dispatch[74]. Additionally, sensing and forecasts enable utilities to improve system operations and improve load and generation balancing without resorting to excess reserve margin, enabling power producers to effectively bid into the market and maximize profits from their generation.

There are various technologies that have the ability to sense and forecast the environment and most have been developed to serve the needs of weather and climate communities. Generally accurate sensing of both solar and wind is expensive (e.g. solar measurement costs include $2,000 for sensor logger and communications with an added annual cost of $1,000 for calibration) and requires some innovative solutions including improving and using satellite technologies. Forecasting for renewables requires improvement in model physics and data-assimilation in areas that are not the focus of weather forecasting for life and property.

To realize the 2020 Technical Achievement targets the following efforts will be undertaken:

Environmental Sensing – It is important to develop new low-cost systems and adapt current systems to measure, solar radiation, wind profiles of speed and direction, ambient lighting, temperature, humidity and precipitation at appropriate spatial and temporal resolutions. These fundamental parameters are essential for functioning of a modern grid as they form critical inputs to for various aspects of grid management and operations as mentioned above. These parameters also serve as inputs to wind and solar forecasts.

Task 3.6.5: Analyze the economic and reliability benefits of measurements and models. Identify existing infrastructure and gaps. Identify challenges to deployment, data collection, analysis and integration of existing and future ground and satellite-based measurements. [FY16]

Task 3.6.6: Demonstrate prototypical environmental measurement systems at test sites. Integrate information at test sites into building operations and grid integration studies. Develop measurement visualization, data assimilation and incorporation into existing system operations, including methods for uncertainty quantification. [FY17-FY18]

Task 3.6.7: Investigate and improve environmental measurement demonstrations and develop an operational plan for additional deployments. Deploy systems in priority regions where high-penetration of renewable generation is taking place. [FY18-FY20]

[74] Joint Technical Summit on Reliability Impacts of Extreme Weather and Climate Change," *EPRI,* 2008.

Environmental Forecasting – improving accuracy of forecasts at various temporal and spatial scales is important for the future electricity system. Advancement in current technologies as well as new technologies are needed to cover all scales as various levels of maturity exists within those technologies. Innovative technologies using high-quality measurements from various sources including satellites and ground-based instrumentation should be developed to provide short-term forecasts for building energy management and grid operations. Forecasts beyond a few hours must be improved and will require significant effort focused on data assimilation and improvements in model physics. These models will also be operated in configurations that specifically serve the needs of the grid.

Task 3.6.8: Analyze the economic and reliability benefits of improved forecasting. Develop a renewable energy forecast for specific test sites for use in grid management using existing technologies. [FY16]

Task 3.6.9: Improve and optimize current forecasting methods at test sites and incorporate into existing system operations with a focus on probabilistic forecasts. Integrate the forecasts for grid integration studies to improve demand response, ancillary services from distributed resources, energy storage operations, dispatch, reserve margin requirements and unit commitment. [FY17-FY18]

Task 3.6.10: Develop a national baseline operational solar and wind forecast for use in building management and vehicle operations as by utilities, system operators, and forecast providers. This effort will be in collaboration with multiple agencies including NSF and NOAA. [FY18-FY20]

3.7 Links to Other Grid Modernization Technical Areas

Efforts in framing approaches to deliver full system transparency through advanced sensing, measurement, and communications have significant connections across the GMLC technical teams.

- Development of low cost transmission and distribution system sensors that are accurate across most off-normal system events will depend upon new architecture and control concepts (**System Operations, Power Flow, and Control**) and will inform the **Devices and Integration Systems Testing** team regarding testing standards for future grid control systems as well as interoperability requirements for monitoring systems and grid load devices. Development of low cost building sensors will inform the **Design and Planning Tools** and **Institutional Support** teams regarding costs and performance opportunities for designing and evaluating new ancillary grid services as well as market structures for rates and ancillary services markets.
- Development of next generation communications constructs requires an understanding of likely new demands on communications driven by new architecture and control concepts from the **System Operations, Power Flow, and Control** group. These communications specifications must be informed by cyber and disaster recover needs from the **Security and Resilience** team. Finally, the **Institutional Support** team efforts in examining future market and regulatory options that engage broad consumer engagement with grid services will dictate communications requirements of the modernized grid as well.
- New approaches for situational awareness visualization and data analytics must integrate seamlessly with the emerging EMS/DMS/BMS operator tool frameworks developed by the **System Operations, Power Flow, and Control** group. They must also be informed by requirements for security issues and needs of future emergency response needs as developed by the **Security and Resilience** technical team.

3.8 Links to Existing DOE Portfolio

The proposed work in Sensing and Measurements builds upon the existing activities of the various Program offices within DOE, in the following manner:

- Existing *Buildings/Customer Sensors and Communications* work in the EERE Vehicles and Buildings technology offices focuses primarily on the development of advanced sensors for vehicles and buildings, as well as the design of networks and platforms to facilitate transactive control of end-use devices. We will build on this foundation by expanding the number and capability of sensors and by creating an open architecture for building and connected vehicle energy management that is scalable and extensible to all building types and other end-uses.
- Projects in *Distribution System Visibility* supported by the OE Clean Energy Transmission and Reliability and Smart Grid R&D programs are investigating the possibility and value of developing phasor measurement technologies for the distribution system. We will build on these activities by expanding the range of measurements provided by new grid sensors, creating new models for the grid capable of assimilating sensor data, and employing a strategy to ensure full sensing of the emerging grid.
- Ongoing *Transmission Sensors and Asset Monitoring* efforts supported by the OE Clean Energy Transmission and Reliability program maintain the NASPI sensor network for the transmission system and promote next-generation transmission sensor development. Work supported by the DOE Office of Fossil Energy is aimed at developing sensors for harsh environments. We will build on these activities by expanding sensor development activities beyond the grid itself into key transmission assets (generators, transformers, etc.) and by incorporating sensor data into diagnostic and prognostic techniques for key grid asset monitoring and management.
- Current activities in *Data Analytics and Visualization* include projects supported by the EERE Solar Energy Technology Office to look at visualization of impacts from high-penetration of solar PV on distribution systems and work funded by the OE Transmission Reliability program to support advanced applications of data analytics for reliability needs and the use of loads as a resource. We will build upon this work, along with the recent DOE forecasting efforts in SETO and WWPTO, with new projects to employ real-time data analytics and machine learning for dynamic grid health monitoring, improve the characterization and forecasting of renewable generation and distributed loads, and use our own National Laboratory facilities as testbeds for data analytics and visualization of emerging energy systems.

Table 4 contains specific details on the existing funding streams supporting FY15 Sensing and Measurement projects conducted at the DOE National Laboratories. The Briefing Papers contained in Appendix C specifically map our proposed future work in this technical area to the goals and objectives of the individual participating DOE Programs.

TABLE 4. EXISTING NATIONAL LABORATORY SENSING AND MEASUREMENTS PROJECTS

Activity	Existing Major DOE Funded GMLC Projects in FY15
Buildings/Customer Sensors & Communications ***9 Projects***	• EERE – Buildings Technology Office • EERE – Vehicle Technology Office
Tools to Provide Visibility on the Distribution System ***5 Projects***	• OE – Transmission Reliability, Smart Grid • ARPA-e – Green Electricity Network Integration (GENI)

Activity	Existing Major DOE Funded GMLC Projects in FY15
Transmission Sensors & Asset Monitoring ***8 Projects***	• OE – Transmission Reliability • FE – Clean Coal & Carbon Capture
Data Analytics & Visualization ***5 Projects***	• EERE – Solar Energy Technologies Office • OE – Transmission Reliability
Total: 27 Projects	

3.0 Sensing and Measurements

Activity	FY16	FY17	FY18	FY19	FY20	Technical Achievement
Improve Sensing for Buildings & End-Users	3.1.1: Develop advanced, multi-purpose, low cost to monitor parameters that enable building owners and end-users to more effectively assess the state of their energy assets.					Low-cost sensors for enhanced controls
	3.1.2:Develop new methods for secure, interference-robust shared spectrum wireless communications technologies to accelerate the incorporation of low-cost, wireless communications with advanced sensors. Bring coherence to the multitude of communications technologies and standards currently being used and/or suggested for next generation devices and systems applicable to grid applications.					
	3.1.3: Develop an open architecture for Building Energy Management Systems that is scalable for any size building.					
Enhance Sensing for Distribution System	3.2.1: Develop, validate and document a new extended grid state framework that encompasses power state, asset operational state, thermal states, etc.	3.2.3:Demonstrate technology for continuous, real-time rediscovery of distribution electrical connectivity/topology.				Low-cost sensors operable during off-normal operations and advanced visualization techniques and tools
	3.2.2:Develop a validated visibility strategy and sensor allocation software tool for distribution networks incorporating the extended grid state framework taking into account sensing capabilities of new and existing devices, including advanced meter infrastructure.	3.2.5: Demonstrate low-cost synchronized three-phase, unbalanced voltage and current sensors capable of measuring instantaneous frequency and rate of change of frequency. These technologies must be able to measure distribution power state (grid voltages, real and reactive power flow and phase angles), component impedances, and asset loadings with support for distributed/embedded analytics processing.				
	3.2.4: Develop and demonstrate new, low-cost sensors for distribution-level electrical state and asset condition monitoring for new assets such as storage and power electronics based devices including parameters such as temperature, chemistry, and pressure, as well as very high frequency power quality effects.					
Enhance Sensing for the Transmission Systems	3.3.1: Develop advanced synchrophasors that are reliable during transient events as well as steady state measurement at a sufficiently low-cost to enable widespread adoption. Next generation synchrophasors need to provide accurate measurements during transients.					Sensors reliable during transient events and able to monitor real-time conditions

3.0 Sensing and Measurements

Activity	FY16	FY17	FY18	FY19	FY20	Technical Achievement
Enhance Sensing for the Transmission Systems	3.3.2: Examine sensor placement strategies as well as measurement accuracy requirements for appropriate applications. Current standards pay too much attention on out-of-band rejection performance, resulting in large measurement latency, thus, limiting real-time control application.					
	3.3.3: Develop novel inexpensive sensors for component health monitoring and low-cost grid state monitors. This will include sensing and measurement of advanced components such as energy storage devices and power electronics. As advanced manufacturing techniques and diagnostic and prognostic tools are developed, an integrated sensor with multi-parameter sensing, onboard diagnostic, and prognostic as well as built-in communication elements will become possible.					
	3.3.4: Develop diagnostic and prognostic algorithms based on computationally efficient methods that interface with and use a suite of sensors. These diagnostic and prognostic techniques will focus on two main power interruption phenomena: localized equipment degradation and failure detection and anticipatory extreme environmental event response.					
				3.3.5: Demonstrate key sensor technologies for components at the bulk transmission level and integrate with advancements in the prognostics and diagnostics algorithms.		
Develop Data Analytic and Visualization Techniques	3.4.1: Develop real-time streaming analytics and machine learning paradigms for grid visibility, control, resilience, and security. This includes methods for distributed implementation, using computational resources deployed in the grid outside of the data or operations center.					Real-time data management for the ultra-high velocities and volumes of grid data; 100% visibility across electric system; and enhancement of of measurement and modeling techniques for estimating and forecasting renewable generation
	3.4.2: Create a tool to manage distributed analytics using advanced virtualization methods and open distributed application platforms. This includes fault, configuration, accounting, performance, security (FCAPS) functions as are common in network management systems, but for analytics elements. This tool manages the placement, performance monitoring, fault management, and other aspects of operating a distributed analytics set.					
	3.4.3: Develop and demonstrate a tool for acquiring heterogeneous sensor data and populating an extended grid state that is informed by continual rediscovery of grid topology.					
	3.4.4: Develop data analysis tools that move from today's quasi-static tools used to monitor the grid toward tools that can analyze and predict dynamic behavior. Using high speed PMU data and advanced software tools, awareness of dynamic behavior can become part of a utility operator's toolkit to increase system performance and reliability by having more complete and detailed information about the current grid state and how it is evolving in time. Many types of events are only now visible due to PMUs.					

3.0 Sensing and Measurements

Activity	FY16	FY17	FY18	FY19	FY20	Technical Achievement
Demonstrate a Unified Grid Communication Network	3.5.1: Incorporate communications models into grid simulation and management tools so that researchers and operators can understand and optimize systems in realistic situations.		3.5.2: Develop methods to manage the heterogeneity of the network and manage abstraction and aggregation across network tiers, segments, and varied quality of service needs.			Communication framework that serves as a backbone for information and data exchange between stakeholders and decision makers
	3.5.3: Develop a framework for testing performer's devices in a realistic, reconfigurable "utility-equivalent" environment. A Virtualized Utility Communications-Networking Laboratory integrated with a physical system can allow public, private sector, and academic researchers remote and in-person access to a robust and realistic demonstration test bed.					
			3.5.4: Improve dynamic management of data flows (e.g., software defined networking) for low latency protection and control systems so that they can provide closed-loop control and enable a highly interactive grid management framework. This could include development of a shared spectrum environment to address the "spectrum crunch" by providing a realistic environment for commercial entities (vendors and utilities) to test new and innovative spectrum sharing techniques and devices.			
				3.5.5: Develop and demonstrate a unified grid and network management framework and demonstration network utilizing state-of-the-art networking technology to enable stakeholders to observe feasibility and value with appropriate investment.		
Regional & Crosscut Initiatives	3.6.1: Create inventory of existing sensors and datasets available across the DOE labs; create inter-laboratory data sharing agreement and preliminary work in setting up data sharing system architecture.	3.6.2: Generate models of all DOE facilities with sensor data collection. Identify sensor gaps and candidate target infrastructure for additional sensing to enable increased visibility.	3.6.3: Demonstrate cross-lab sensor network and place new sensors to augment the existing fleet of sensors and increase the amount of measured data.			Improved Environmental Sensing and Forecasting
			3.6.4: Scale up network and tie in virtual simulations and systems to enable testing and demonstration at large scale of analytics and communications, under a variety of scenarios.			
	3.6.5: Analyze the economic and reliability benefits of measurements and models. Identify existing infrastructure and gaps. Identify challenges to deployment, data collection, analysis and integration of existing and future ground and satellite-based measurements.	3.6.6: Demonstrate prototypical environmental measurement systems at test sites. Integrate information at test sites into building operations and grid integration studies. Develop measurement visualization, data assimilation and incorporation into existing system operations, including methods for uncertainty quantification.				
			3.6.7: Investigate and improve environmental measurement demonstrations and develop an operational plan for additional deployments. Deploy systems in priority regions where high-penetration of renewable generation is taking place.			
	3.6.8: Analyze the economic and reliability benefits of improved forecasting. Develop a renewable energy forecast for specific test sites for use in grid management using existing technologies.	3.6.9: Improve and optimize current forecasting methods at test sites and incorporate into existing system operations with a focus on probabilistic forecasts. Integrate the forecasts for grid integration studies to improve demand response, ancillary services from distributed resources, energy storage operations, dispatch, reserve margin requirements and unit commitment.				
			3.6.10: Develop a national baseline operational solar and wind forecast for use in building management and vehicle operations as by utilities, system operators, and forecast providers. This effort will be in collaboration with multiple agencies including NSF and NOAA.			

4.0 System Operations, Power Flow, and Control

The Nation's electric grid is experiencing unprecedented changes in the way it is operated. Traditionally, power systems have been operated as a one-way delivery system where electricity is generated at large power plants, transported to load centers via a transmission network, and delivered to customers through distribution systems. This made grid control and communications relatively simple: power plants were controlled to follow the load with grid frequency – and to some extent energy interchange – as the only feedback signal flowing from end-users to grid operators. Today, with the implementation of new smart grid technologies, continued technological advances, and the development of new business models, fundamental transformations in grid control are required. The system is becoming more complex with the integration of a range of new end uses, such as intelligent buildings, electric vehicles, renewable hydrogen stations, and small-scale distributed generation systems (such as combined heat and power, PV, and fuel cell systems). Under this new paradigm, end-users will interface with many more controllable elements connected through interoperable systems with real-time communications to system operators. New approaches for enhancing reliability and efficiency will be employed. The distribution system will support bi-directional flows and become a more integral participant in real-time operations via pooling customer resources in order to seek access to different value streams.[75]The interstate transmission grid will continue to be called upon to move bulk electricity reliably, but because transmission expansion will be slow, it must do so within tighter constraints (i.e., operate with smaller margins). Research and development to improve system operations, power flow, and control is needed to enable these changes.

"THE MODERN GRID NEEDS ENHANCED OBSERVABILITY, CONTROLLABILITY, AND INTEROPERABILITY TO ADAPT TO INCREASING COMPLEXITIES OF GENERATION AND END USE."

Dr. Lynn Orr, Under Secretary for Science and Energy

The system today faces many persistent and new challenges: more generation that is not controlled or dispatched by the system operator (i.e., DERs), difficulties siting and constructing new transmission assets, aging infrastructure, evolving workforce, financial constraints, changing regulatory policies, and increased customer expectations. Historically, reliability has been achieved through redundancy and reserve margins. The opportunity exists to harvest advanced technologies to optimize the operation of the system and react to off-normal conditions in a manner that preserves system reliability and improves its resilience. These include the use of flexible energy storage systems, ubiquitous low-cost communications and distributed computing capabilities, and new business models such as interoperable frameworks enabling new ecosystems of collaborative suppliers and consumers.

Today's grid control and optimization systems rely mostly on a hierarchical architecture and are primarily deterministic, with examples including system protection, automatic controls, and slower manually-initiated dispatch procedures. Achieving the Grid Modernization Initiative goals of increased reliability, reduced margins, and improved integration, will require increased use of distributed and wide-area control, incorporation of uncertainty,[76,77] and the development and leveraging of new storage and power electronics devices. These improvements will rely on advances in fundamental control theory, mathematical solvers, data analytics, and power flow control devices. Implementation of these advances requires harmonization of grid architectures and

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[75] *The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources, EPRI report 3002002733, February 2014. http://tdworld.com/site-files/tdworld.com/files/uploads/2014/02/integratedgridepri.pdf*

[76] D. Kirschen, Y. Dvorkin, H. Pandzic, Y. Wang, and T. Qiu, "A Comparison of Unit Commitment Techniques Dealing with Uncertainty," FERC Technical Conference On Increasing Real-Time And Day-Ahead Market Efficiency Through Improved Software 2014.

[77] Daniel Bienstock, Michael Chertkov and Sean Harnett, Chance Constrained Optimal Power Flow: Risk-Aware Network Control Under Uncertainty. SIAM Rev. 2014, 56(3), 461–495.

integration across various control system platforms. Existing concepts such as global coordination to optimize the grid, while relying on local control for high-speed response to system changes, can be expanded based on the availability of the new approaches described above. Some specific approaches that may contribute to the proposed solutions include: transactive control facilitating distributed control, microgrids providing greater reliability and resiliency, probabilistic/stochastic methods to perform a more rigorous and explicit management of uncertainties to achieve lower cost than through current deterministic approaches, and advanced wide-area controls to dynamically and generally reduce current conservatively estimated reserve margins.

The four activities and respective technical achievements to accomplish these outputs for this technical area are shown in Table 5.

TABLE 5. ACTIVITIES AND TECHNICAL ACHIEVEMENTS FOR SYSTEM OPERATIONS, POWER FLOW, AND CONTROL

Activity	Technical Achievements by 2020
1. Develop Architecture and Control Theory	• Comprehensive consensus reference architectural model encompassing all major structures of the grid with multiple views suitable for various industry segments and geographic regions • Advanced control theory and algorithms to support a variety of applications to improve grid flexibility for clean generation and emerging distribution regulatory models, future adaptability and resilience to increasing weather and human threats while not compromising operational reliability or security. • Wide-area control strategies to improve reliability, resilience, and asset utilization.
2. Develop Coordinated System Controls	• New control grid operating system designs reflecting emerging system control methodologies. • Framework(s) for integrating the next generation energy management system (EMS), distribution management system (DMS), and building management system (BMS) platforms.
3. Improve Analytics and Computation for Grid Operations and Control	• Future and real-time operating conditions with short decision time frames and a high degree of uncertainty in system inputs can be evaluated. • Automation of protection and control with predictive capabilities, advanced computational solvers, and parallel computing. This includes non-linear optimization of highly stochastic processes. • Decision support to operators in control rooms through pinpoint system situational awareness visualization and operator decision support technologies.
4. Develop Enhanced Power Flow Control Device Hardware	• Low-cost, efficient and reliable power flow control devices that enable improved controllability and flexibility of the grid.

The activities in the Systems Operations, Power Flow, and Control technical area will deliver Technical Achievements for each Activity area (see Table 5 above) as well as support the three "Integrated Regional Demonstrations" outlined in Chapter 8.0. Achievements in future grid architecture and control theory are fundamental to designing the "Lean Reserve Margin Grid Bulk Power Systems" and "Clean Distribution Systems" regional demonstrations. They define new grid elements, control requirements and integrated software tools fundamental to both. The activity to develop advanced analytics and computational tools will link the full system observability with high performance computing approaches to deliver predictive tools that deliver improved operations in these demonstrations. The final activity of advanced power flow control devices will improve controllability and flexibility for both demonstrations, further improving grid performance. These new architectures, control concepts and real-time tools will be reflected in design tools and performance data that support the third Integrated Regional Demonstration of “Advanced Modern Grid Planning & Analytics Platform” platform to help industry and regulators better select grid modernization pathways. Descriptions of each activity area follow.

4.1 Activity 1: Develop Architecture and Control Theory

Grid control encompasses a dozen classes of control functions: generator unit commitment, scheduling and dispatch, power balance, primary generator control, load sharing, power flow control, Volt/VAR regulation, system frequency regulation, stabilization, synchronization, secondary load control and coordination of DER. In addition there are special case functions for device and system integrity protection, as well as management of contingencies such as loss of a generator or tripping of a transmission line. These actions cover a wide time spectrum, resulting in a continuum of control actions from the very fast controls in the protection system to the slower controls of system dispatch.[78] The architecture of the entire grid influences the design of the control systems and so while grid architecture encompasses much more than control systems, control structure is closely related to overall grid architecture.

- **Architecture** – A system architecture is the conceptual model that defines the structure, behavior, and essential limits of a system. An architectural description is a representation of a system whose purpose is to help think about the overall shape of the system, its attributes, and how the parts interact. It is comprised of abstract components, structures, and externally visible properties of these elements. Grid Architecture is the application of system architecture, network theory, and control theory to the electric power grid. A grid architecture is the highest level description of the complete grid, and is a key tool to help understand and define the many complex interactions that exist in present and future grids. Improved grid architecture will reduce impediments to improving grid flexibility and resilience without compromising reliability and security. Existing grid architecture has developed organically over decades and has grown so complex that it is impossible to make any significant change with full understanding of all the consequences across electric infrastructure, industry structure including markets, regulatory structure, information and communication structure, control and coordination structure, and relationships to convergent networks such as fuel, transportation, and social networks. Consequently, the industry has realized that there is a need to develop a new complete architectural model comprised of multiple architectural views appropriate for various industry segments methods that have been demonstrated to DOE via initial work on a limited scope in FY14.[79]

    Task 4.1.1: Develop a modern grid system architecture with internal and external stakeholder input to be used as the shared vision of future grid structure and to provide a unifying framework for the Grid Modernization Initiative activities. This effort will also seek adoption by more than 10 key industry players including utilities, vendors, and regulators as a start toward widespread industry acceptance. [FY16-18]

[78] “EMS for the 21st Century, System Requirements,” CIGRÉ – International Council on Large Electric Systems, Working Group D2.24, February 2011, ISBN 978-2-85873-141-1

[79] J. Taft and A. Becker-Dippmann, Grid Architecture, PNNL 24044, prepared for the US Department of Energy, January 2015.

- **Control Theory** – Existing control theory is inadequate to accommodate large numbers of distributed and semi-autonomous systems interconnected through a system that is closely coupled electrically, but loosely coupled in the context of communications and direct control.

  Task 4.1.2: Develop control theory that accommodates distributed architecture that is highly scalable and flexible, able to accommodate a diverse range of devices, and capable of coordinating two orders of magnitude more device and subsystem controls than is possible presently.[80,81] [FY16-18]

  Task 4.1.3: Validate that control theory achieves defined control performance objectives through testing in a realistic demonstration environment. [FY18-20]

4.2 Activity 2: Develop Coordinated System Controls

This activity will create a next generation grid operating system operated under a new system control paradigm that is akin to having an autopilot system for its interconnected components – from the central to distributed energy resources at both bulk power system and distribution system, to local energy networks control system including building management system, to consumers including their electric vehicles, thermostats, appliances. Within this activity, RD&D will be performed to develop and demonstrate advanced grid control technologies that will allow the system to be operated with less reserve margin, dramatically enhancing the energy and economic efficiency of the overall system. To enable this vision, it will be necessary to achieve greater end-to-end integration across all levels of the supply and delivery infrastructure. This technical area activity will accomplish greater integration between grid-level Energy Management Systems (EMS), Distribution Management Systems (DMS), and Building Management Systems (BMS).[82] Linking these systems will enable seamless optimization and control across the entire power system. Open standards and middleware software approaches will be critical to the success of this objective.

- **Prototype New Control Systems** –The continued integration of intermittent resources, such as photovoltaic and wind generation, requires advancements beyond the current deterministic approaches for controlling and optimizing the grid. Probabilistic methods and algorithms are needed that naturally incorporate the effects of stochastic fluctuations. These models must also integrate new technologies, such as storage, which can act as both load and generation. With a move to probabilistic models, decisions regarding risk levels become an explicit decision rather than an implicit assumption[8]; develop risk metrics that estimate the probabilities of violations of system security; optimize costs; minimize the risk of system security violations.

  Task 4.2.1: Develop a prototype next generation grid-level EMS that has the fast and automated control mechanisms and allows the grid to be operated reliably without the N-1 criterion with large-scale system use cases (15,000 buses); and develop DMS and BMS that operate interactively for use cases involving high penetration of DER or microgrids (more than 50 percent). [FY16-18]

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[80] C. Zhao, U. Topcu and S. H. Low. Optimal load control via frequency measurement and neighborhood area communication, IEEE Trans. on Power Systems, 28(4):3576–3587, November 2013. http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6516093

[81] Callaway, D.S.; Hiskens, I.A., "Achieving Controllability of Electric Loads," Proceedings of the IEEE, vol.99, no.1, pp.184-199, Jan. 2011. doi: 10.1109/JPROC.2010.2081652

[82] Needed: A Grid Operating System to Facilitate Grid Transformation, EPRI white paper, July 2011. Available on line: https://www.smartgrid.gov/sites/default/files/doc/files/Needed_Grid_Operating_System_to_Facilitate_Grid_Transformati_201108.pdf

[8] Milligan, M, Donohoo, P., O'Malley, M., "Stochastic Methods for Planning and Operating Power System with large Amounts of Wind and Solar Power", 11th Annual International Workshop on Large-Scale Integration of Wind Power, Lisbon, Portugal, November 2012

Task 4.2.2: Investigate and incorporate probabilistic risk-based approaches into the next generation EMS/DMS/BMS that shifts from a traditional contingency analysis model to a stochastic model. The risk-based control system will be demonstrated with the ability reduce the mitigation costs and minimize security violation risk compared to deterministic approaches in large-scale use cases. [FY17-19]

- **Integration of Control System Platforms** – Utilizing open standards and middleware software approaches to enable integration of EMS, DMS, and BMS.

Task 4.2.3: Develop open framework approaches for coordinating and integrating EMS, DMS, and BMS among themselves and with other local energy network controllers, such as microgrid controllers, etc. The integrated platform will be demonstrated on a large-scale use case with more than 15,000 transmission substations and involving high penetration of DER or microgrids (more than 50 percent). This will require extensive external stakeholder engagement. [FY16-20]

4.3 Activity 3: Improve Analytics and Computation for Grid Operations and Control

Analytical advancements have enabled grid operators to rely less on experience and intuition and more on computational tools incorporated into EMS, DMS, and market management systems (MMS) to guide critical operational and control decisions. Yet, power systems are operated today using the same conservative approaches that they have been for decades. Operators always take side of caution, mainly because they have very few tools to reliably evaluate future and real-time operating conditions, especially to maintain critical generation-demand balance during stressed conditions and under short required decision time frames.[83] Financial penalties for not meeting prescribed (and sometimes arbitrary) deterministic reliability criteria aggravate this situation. This current grid operational paradigm results in an underutilized electric grid infrastructure, higher energy costs to consumers, and expensive or difficult deployment of new grid technologies.

To address these current weaknesses and enable more efficient grid control and operation, the Grid Modernization Initiative will develop a new suite power grid analytics capabilities along three frontiers areas:

- **Control Applications** – Power grid operation and control applications need to (1) consider the changing nature of the grid to effectively address stochastic and dynamic behavior, (2) efficiently incorporate measurements from ubiquitous sensors[84], and (3) make use of advanced visualization tools that facilitate enable efficient decision-making.

Task 4.3.1: Develop applications that incorporate uncertainty and integrate with sensor data to provide decision support for control room automation applications. Examples include making better operational decisions with real-time information (such as dynamic line ratings or real-time assessment of stability limits) and more precisely managing risk associated with potential future conditions (such as probabilistic forecasting and contingency analysis which provide confidence information). [FY16-18]

[83] M. Milligan, P. Donohoo, M. O'Malley, "Stochastic Methods for Planning and Operating Power Systems with Large Amounts of Wind and Solar Power," 11th International Workshop on Large-Scale Integration of Wind Power as well as on Transmission Networks for Offshore Wind Power Plants Conference, Nov. 13-15, 2012.

[84] "Smart Grid System Report", U.S. Department of Energy, Report to Congress, August 2014. Available online at: https://www.smartgrid.gov/sites/default/files/doc/files/2014-Smart-Grid-System-Report.pdf

- **System Modeling and Numerical Methods** – To meet the diverse requirements of next-generation power grid applications, advancements need to be made in developing and incorporating higher fidelity models and improving their core mathematical engines to be more accurate, robust, and fast.

  Task 4.3.2: Develop new stable, efficient, and accurate numerical methods for stochastic systems to push the state-of-the-art from a deterministic analysis to a stochastic one. Demonstrate the applicability of these algorithms on medium and large-scale use cases. These demonstrations will need to establish the value of stochastic methods and how they augment and enhance decision support tools based on traditional methods. [FY16-18]

  Task 4.3.3: Develop efficient linear, mixed-integer, and nonlinear mixed-integer optimization solution techniques customized for stochastic power system models, novel bounding schemes to use in branch and bound, and structure exploiting algorithms. Demonstrate the cost-benefit achieved by these techniques relative to existing ones. [FY18-20]

- **Leveraging Computational Advancements** – The computer industry has seen an evolution in the last decade from single-processor machines to multiple-processors and now to multi-processor machines with multiple cores. In addition, several applications from other domains have reported significant speed-ups by using graphical processing units (GPUs). Yet, most power system applications today are run on single processors and thus do not leverage the potential of these multiple-core machines. Next-generation power grid applications should seek to develop new methods that maximally leverage the power of parallel computing and cloud computing, especially focused on small and medium size computational platforms, and leverage the fast changing computer hardware industry.[85]

  Task 4.3.4: Demonstrate the application of parallel and distributed computing algorithms on existing (multi-processor, multi-core, and GPU) and emerging (many-core and co-processors) computational platforms to significantly improve the performance of applications and methods proposed in Tasks 4.3.1 – 4.3.3 at speeds an order of magnitude faster than is possible presently. [FY19-20]

4.4 Activity 4: Develop Enhanced Power Flow Control Device Hardware

Enhanced power flow control in a modern grid will benefit the entire system and create important new value streams that are unachievable within the traditional system design. Eliminating transmission constraints and providing the ability to control power flow is equally important. Increasing congestion and loop flows at both the transmission and sub-transmission levels increase energy prices, prevent full infrastructure use, and degrade system reliability. Other diverse benefits include reduced transmission losses, fewer outages, and enhanced asset utilization.

The development of low cost power flow control devices will be critical to enabling improved controllability and greater flexibility of the electrical grid. In particular, one of the most important key crosscutting technology areas to enable this will be significant performance and cost improvements in high voltage power electronics devices.

Power electronics are already widely used in various power system apparatus, with applications including:[86]

[85] J. Eto and R. J. Thomas, "Computational Needs for the Next Generation Electric Grid proceeding", April 19-20, 2011. Available on line: http://www.doe.gov/sites/prod/files/FINAL_CompNeeds_Proceedings2011.pdf

[86] Di Wu, Chunlian Jin, Patrick Balducci, and Michael Kintner-Meyer, "An Energy Storage Assessment: Using Optimal Control Strategies to Capture Multiple Services", PNNL -23039, available online.

- Flexible Alternating Current Transmission System (FACTS) devices
- High-voltage direct current (HVDC) transmission facilities
- Static VAR compensators (SVC)
- Fault current limiting devices
- Solid-state distribution transformers
- Transfer switches and solid-state circuit breakers

The distribution networks of the future will also require modernization to incorporate elements of power flow control to meet the challenges of increasing levels of variable distributed generation, and changing load characteristics. Cost effective and reliable solution will be needed to increase hosting capacities of distribution feeders for distributed generation along with advanced protection schemes and smart metering. All of these application areas would benefit from a technology development campaign that reduces the risk associated with further implementation of high-power solid-state devices.

- **Topology Optimization using Power Flow Control Devices** – Enable network topology optimization under a variety of operating conditions.

  Task 4.4.1: Implement methods and tools for robust adaptive topology control to optimize asset utilization, wind and solar curtailment reductions, and increased reliability. [FY16-18]

  Task 4.4.2: Develop validated models of various power flow control devices for use in simulation models for grid integration studies, long-term planning and daily operations. [FY19-FY20]

- **Low-Cost Power Flow Control Technologies** – New materials, devices, and concepts to reduce the cost of power flow control devices that will allow the fine adjustment of power flow and multi-directional flows.

  Task 4.4.3: Develop advanced controls, communication protocols, and computational methods to enable the real-time coordinated dispatch of many power flow control devices. [FY16-17]

  Task 4.4.4: Enhance capabilities of inverter-coupled technologies (wind, solar, energy storage) through the development of control strategies for coordinated control of distributed resources to accomplish global system objectives such as power flow control and provision of ancillary services to the grid. [FY17-19]

  Task 4.4.5: Investigative application of wide-band gap devices in power systems; and demonstrate high-performance low-cost applications. [FY18-FY20]

- **Prototype Development, Testing, and Demonstration in Laboratory and Utility Environments** – The cost-effective deployment of reliable technology will be critical for ensuring success of this activity.

  Task 4.4.6: Demonstrate through testing and simulation the operational and economic impacts of lower cost and highly reliable power flow controllers, fault current limiters, FACTS, AC/DC converters, solid state-transformers, and other newly developed power flow controller technologies. Publish report detailing the potential operational and economic impact of advanced power electronic devices on a modernized grid. [FY16-18]

  Task 4.4.7: In partnership with appropriate external stakeholders (e.g., utilities and vendors), build prototypes and conduct laboratory and field demonstrations of selected technologies that show promising results. [FY19-20]

4.5 Links to Other Grid Modernization Technical Areas

Efforts in framing approaches to deliver full system transparency through advanced sensing, measurement and communications have significant connections across the GMLC technical teams.

- Development of low cost transmission and distribution system sensors that are accurate across most off-normal system events will depend upon new architecture and control concepts (**System Operations, Power Flow, and Control**) and will inform the **Devices and Integration Systems Testing** team regarding testing standards for future grid control systems as well as interoperability requirements for monitoring systems and grid load devices. Development of low cost building sensors will inform the **Design and Planning Tools** and **Institutional Support** teams regarding costs and performance opportunities for designing and evaluating new ancillary grid services as well as market structures for rates and ancillary services markets.
- Development of next generation communications constructs requires an understanding of likely new demands on communications driven by new architecture and control concepts from the **System Operations, Power Flow, and Control** group. These communications specifications must be informed by cyber and disaster recover needs from the **Security and Resilience** team. Finally, the **Institutional Support** team efforts in examining future market and regulatory options that engage broad consumer engagement with grid services will dictate communications requirements of the modernized grid as well.
- New approaches for situational awareness visualization and data analytics must integrate seamlessly with the emerging EMS/DMS/BMS operator tool frameworks developed by the **System Operations, Power Flow, and Control** group. They must also be informed by requirements for security issues and needs of future emergency response needs as developed by the **Security and Resilience** technical team.

4.6 Links to Existing DOE Portfolio

The proposed work in System Operations, Power Flow, and Control builds upon the existing activities of the various Program offices within the DOE, in the following manner:

- The *DOE-OE AMGR* program is leading the effort to apply new classes of algorithms and other advancements from mathematical and computational sciences to power system software and to develop improved and validated models which are amenable to coupling across a variety of temporal and spatial scales. Over the past year, the AMGR program has fostered and engaged a multidisciplinary community with diverse perspectives and collectively through meetings and workshops evaluated the current efforts, identified the gaps, and re-calibrated the vision towards ongoing and additional research topics that should be pursued. Technologies being developed associated with AMGR program projects are envisioned to be well-aligned with the activities that will be developed associated with the Grid Modernization Initiative.
- Various system integration studies associated with the *EERE Building Technologies, Wind Energy, Solar Energy,* and *Hydrogen and Fuel Cell Technologies* programs support the goals and objectives of this GMI technical area. Specifically, interconnecting EMS, DMS, and BMS aligns well with the building technology office and accommodating distributed energy resources is an objective that cuts across many areas of the EERE landscape.

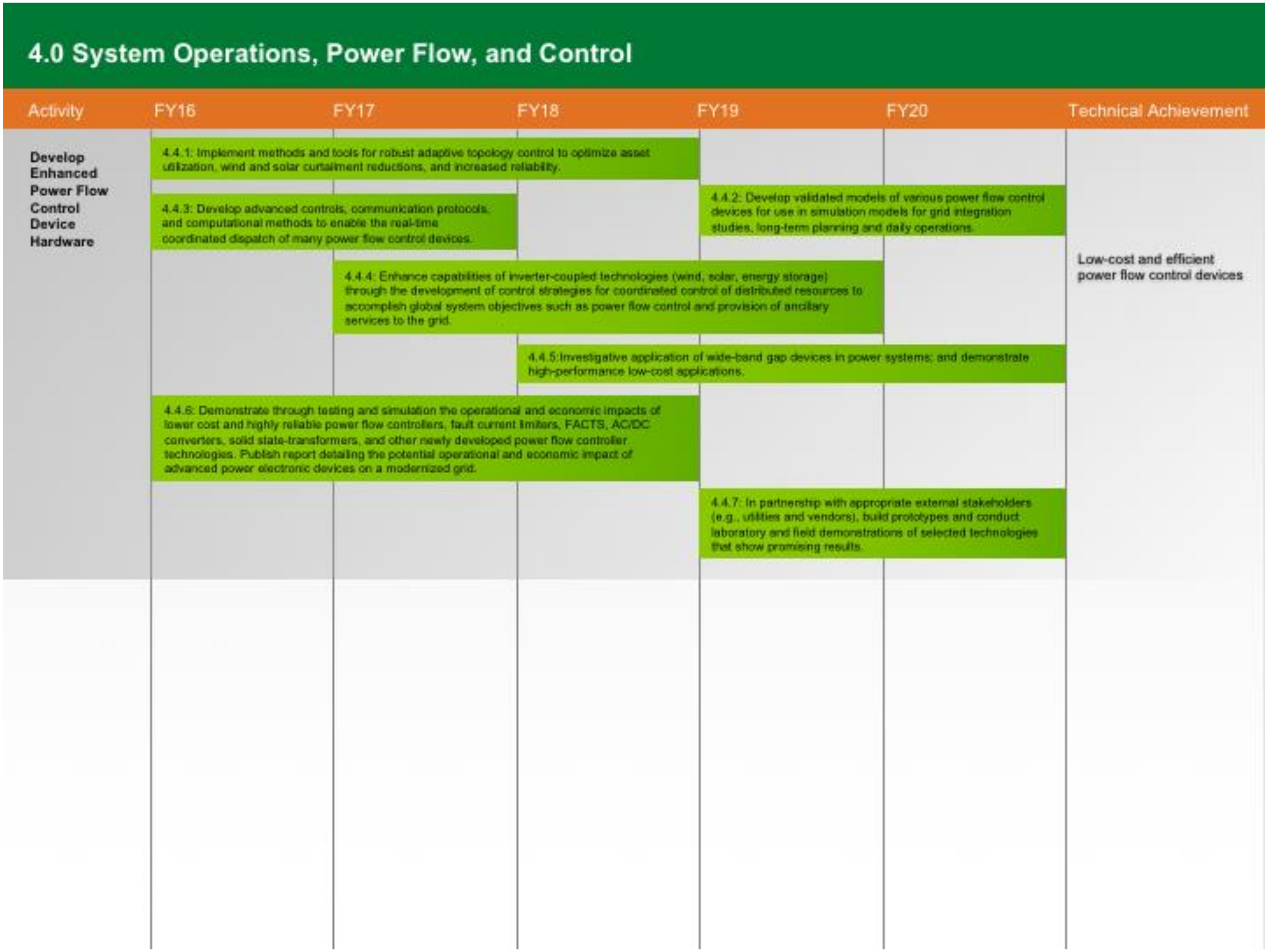
Table 6 contains specific details on the existing funding streams supporting FY15 System Operations, Power Flow, and Control projects conducted at the DOE National Laboratories. The Briefing Papers contained in Appendix C specifically map our proposed future work in this technical area to the goals and objectives of the individual participating DOE Programs.

TABLE 6. EXISTING NATIONAL LABORATORY SYSTEM OPERATIONS, POWER FLOW, AND CONTROL PROJECTS

Activity	Existing Major DOE Funded GMLC Projects in FY15
Develop Architecture and Control Theory ***12 Projects***	• OE – Advanced Grid Modeling Program • EERE – Building-Grid Integration Program • OE CERTS Program • OE/NSF CURENT • OE Transmission Reliability and Renewables Integration Program • OE Smart Grid Program • OE Energy Systems Predictive Capability Program
Develop Coordinated System Controls ***14 Projects***	• EERE – Building-Grid Integration, Wind, Solar Programs • OE – Smart Grid and Advanced Grid Modeling Program • OE Transmission Reliability and Renewables Integration of Synchrophasor Technology Program • OE/NSF CURENT
Improve Analytics and Computation for Grid Operations and Control ***12 Projects***	• OE – Advanced Grid Modeling Program • EERE – Wind and Water Power Technologies Office
Develop Enhanced Power Flow Control Device Hardware ***5 Projects***	• EERE – Wind, Solar • EERE – Advanced Manufacturing Office (e.g. PowerAmerica, Manufacturing Innovation Institute on Next Generation Power Electronics • OE – Advanced Grid Modeling Program • ARPA-E – GENI
Total: 43 Projects	

4.0 System Operations, Power Flow, and Control

Activity	FY16	FY17	FY18	FY19	FY20	Technical Achievement
Develop Architecture and Control Theory	4.1.1: Develop a modern grid system architecture with internal and external stakeholder input to be used as the shared vision of future grid structure and to provide a unifying framework for the Grid Modernization Initiative activities. This effort will also seek adoption by more than 10 key industry players including utilities, vendors, and regulators as a start toward widespread industry acceptance.					Architectural model and wide-area control strategies developed
	4.1.2: Develop control theory that accommodates distributed architecture that is highly scalable and flexible, able to accommodate a diverse range of devices, and capable of coordinating two orders of magnitude more device and subsystem controls than is possible presently.					
			4.1.3: Validate that control theory achieves defined control performance objectives through testing in a realistic demonstration environment.			
Develop Coordinated System Controls	4.2.1: Develop a prototype next generation grid-level EMS that has the fast and automated control mechanisms and allows the grid to be operated reliably without the N-1 criterion with large-scale system use cases; and develop DMS and BMS that operate interactively for use cases involving high penetration of DER or microgrids.					Frameworks for integrating next-generation control platforms
		4.2.2: Investigate and incorporate probabilistic risk-based approaches into the next generation EMS/DMS/BMS that shifts from a traditional contingency analysis model to a stochastic model. The risk-based control system will be demonstrated with the ability reduce the mitigation costs and minimize security violation risk compared to deterministic approaches in large-scale use cases.				
	4.2.3: Develop open framework approaches for coordinating and integrating EMS, DMS, and BMS among themselves and with other local energy network controllers, such as microgrid controllers, etc. The integrated platform will be demonstrated on a large-scale use case with more than 15,000 transmission substations and involving high penetration of DER or microgrids (more than 50 percent). This will require extensive external stakeholder engagement.					
Improve Analytics and Computation for Grid Operations and Control	4.3.1: Develop applications that incorporate uncertainty and integrate with sensor data to provide decision support for control room automation applications. Examples include making better operational decisions with real-time information and more precisely managing risk associated with potential future conditions.					Enhanced analytics to support better decision support technologies
	4.3.2: Develop new stable, efficient, and accurate numerical methods for stochastic systems to push the state-of-the-art from a deterministic analysis to a stochastic one. Demonstrate the applicability of these algorithms on medium and large-scale use cases. These demonstrations will need to establish the value of stochastic methods and how they augment and enhance decision support tools based on traditional methods.					
			4.3.3: Develop efficient linear, mixed-integer, and nonlinear mixed-integer optimization solution techniques customized for stochastic power system models, novel bounding schemes to use in branch and bound, and structure exploiting algorithms. Demonstrate the cost-benefit achieved by these techniques relative to existing ones.			
				4.3.4: Demonstrate the application of parallel and distributed computing algorithms on existing and emerging computational platforms to significantly improve the performance of applications and methods proposed in Tasks 4.3.1 – 4.3.3 at speeds an order of magnitude faster than is possible presently.		


4.0 System Operations, Power Flow, and Control
Activity
FY16
FY17
FY18
FY19
FY20
Technical Achievement
Develop Enhanced Power Flow Control Device Hardware
4.4.1: Implement methods and tools for robust adaptive topology control to optimize asset utilization, wind and solar curtailment reductions, and increased reliability.
4.4.2: Develop validated models of various power flow control devices for use in simulation models for grid integration studies, long-term planning and daily operations.
4.4.3: Develop advanced controls, communication protocols, and computational methods to enable the real-time coordinated dispatch of many power flow control devices.
4.4.4: Enhance capabilities of inverter-coupled technologies (wind, solar, energy storage) through the development of control strategies for coordinated control of distributed resources to accomplish global system objectives such as power flow control and provision of ancillary services to the grid.
4.4.5: Investigative application of wide-band gap devices in power systems; and demonstrate high-performance low-cost applications.
4.4.6: Demonstrate through testing and simulation the operational and economic impacts of lower cost and highly reliable power flow controllers, fault current limiters, FACTS, AC/DC converters, solid state-transformers, and other newly developed power flow controller technologies. Publish report detailing the potential operational and economic impact of advanced power electronic devices on a modernized grid.
4.4.7: In partnership with appropriate external stakeholders (e.g., utilities and vendors), build prototypes and conduct laboratory and field demonstrations of selected technologies that show promising results.
Low-cost and efficient power flow control devices

5.0 Design and Planning Tools

Planning and design tools are used within the grid community to support policy development, economic assessments, engineering design, and risk and vulnerability analysis impacting billions of dollars of capital investments and operational costs. These tools are embodied in the numerous modeling, simulation, and analysis software packages used for planning and design performing such technical functions as capacity planning, production cost modeling, contingency analysis, modeling dynamic response, and transient stability analysis.[87] Unfortunately, existing tools will not keep pace with increasing complexity resulting from the rapid changes in the electric grid.

The technology gaps for tools focus on increasing resolution and fidelity, modeling across grid domains and infrastructure, handling uncertainty, and modeling extreme events (e.g., physical or cyber-attack, storms, earthquakes, electro-magnetic pulse (EMP), geo-magnetic disturbances (GMD)). Current tools rely on simplifying the underlying physics of power systems. Transmission and distribution are modeled separately and at significant lower complexity as compared with the as-built grid systems. With the rapid increase in distributed generation sources, energy storage, and sophisticated control technologies, detailed interactions between the transmission, distribution, and communication systems are not adequately captured with current tools. Planners grapple with the inherent uncertainties in renewable resources, loads, extreme events. The current use of deterministic approaches lead to overly conservative analysis and designs. Finally, the volume of scenarios required to support thorough cost-benefit trade-offs overwhelms current tools and computational resources.

The above gaps drive a concomitant need for computational solutions that are thousands of times faster than today. Major advances in numerical methods in optimization algorithms, non-linear solvers, and differential algebraic equations will be required to support these improvements. Increases in modeling complexity will outstrip current validation methodologies and require a new generation of statistical and data analytic tools to ensure models produce accurate results. Utilities, ISOs, RTOs, and PUCs are increasingly seeking assistance for more complex analysis requiring large volumes of computations and data and enhancements to existing tools. Such requirements will not be met with today's approach of using desktop or small servers with existing modeling software designed for PCs. While grid tools developers are adding increasingly more capabilities to the tools, they do not take full advantage of modern computing architectures to address emerging grid needs.

To address these challenges, the GMLC will pursue research and development to develop the next generation of such tools. This R&D is organized into three areas that represent tools usage and foundational challenges. The first area will be *economic assessment* tools required for policy analysis, expansion planning, and day-ahead to long-term planning. Such tools answer the basic questions of "How do I build out and operate the grid in the most cost-effective manner?" The second will be tools for *reliability and resilience*, which will address such questions as "given an expansion plan or operations change, how do I ensure that power is delivered to customers reliably and securely?" The third will be the *advancing computational technologies and infrastructure* required to produce detailed and timely answers to support grid modeling under the grid modernization plan.

The vision for planning and design tools is to drive the industry and research community to develop the next generation of capabilities that address the needs of the rapidly evolving future grid. Currently, there are a large

[87] Note that while tools under System Operations, Power Flow, and Control have some commonalities with this chapter, they support very different workflows and users, therefore driving separate research plans. For example, planning and design tools are typically stand-alone software packages used by analysts and engineers over timeframes from a single day to multiple years. Operational tools are integrated into robust management software used by grid operators to make real-time decisions.

number of planning and design tools that are successfully used within the grid industry.[88] Our strategy will be to partner with the software vendor community, utilities, ISO, RTOs, and academia to identify gaps and develop a research roadmap. Research will support the development of open source math libraries, analytic tools, and prototype planning and design software. The GMLC will work with software vendors to help integrate new methods and algorithms techniques into commercial and open source products. In addition, the GMLC and research partners will work with utilities, ISOs, RTOs, and PUCs to demonstrate the value of the advanced computational methods on relevant stakeholder problems. The benefit of this research will be to substantially improve investment and operation decisions, reduce costs, avoid stranded assets, and response to extreme events.

TABLE 7. ACTIVITIES AND TECHNICAL ACHIEVEMENTS FOR PLANNING AND DESIGN TOOLS

Activity	Technical Achievements by 2020
1. Scaling Tools for Comprehensive Economic Assessment	• Enhance performance of stochastic production cost modeling from 100 to 10,000 transmission nodes; expand to include distribution system. • Easy-to-use decision support tools based upon complex HPC results that incorporate new technologies such as demand response and energy storage and enable cost-benefit analysis for policy and regulatory analysis. • Improve scaling of stochastic tools to model electric and gas system inter-dependencies from 1,000 to 60,000 electric and 100 to 1,000 gas nodes.
2. Developing and Adapting Tools for Improving Reliability and Resilience	• Scalable simulation framework that couples transmission, distribution, and communications systems for integrated modeling at regional scale. • Data-driven tools to automate construction and validation of models of devices, loads, generation, and customer behavior. • Improve performance of contingency analysis tools by 500x to capture extreme events; enable automated analysis of cascading events.
3. Building Computational Technologies and High Performance Computing (HPC) Capabilities to Speed up Analyses	• Scalable math libraries and tools for enhanced analysis; co-simulation frameworks to support coupling of tools and models, uncertainty quantification, and systems optimization. • Federation of five computational centers established to provide access to high performance computing systems, host grid software, provide grid data sets for model development and validation, support comprehensive policy analyses • Six "prototype-to-practice" projects conducted every year to drive adoption of new tools research into industry.

The activities in the Design and Planning Tools technical area will deliver Technical Achievements for each Activity area (see Table 7) as well as support the three "Integrated Regional Demonstrations" outlined in Chapter 8.0. Research in Design and Planning Tools will serve as the means to provide much more complex, accurate, and comprehensive system design and analysis. For example, novel grid system architectures explored for "Lean Reserve Margin Grid Bulk Power Systems" demonstration will be designed and analyzed using coupled dynamic transmission, distribution and communications modeling tools to ensure secure and reliable grid operations. Cost-

88 Existing tools include commercial and open source software packages such as GE's PSLF, MARS, and MAPS; Energy Exemplar's Plexos; ABB's GridView; Powerworld Simulator; Siemens's PSS/E; Commonwealth's Transmission Grid Analytics™; Electrical Distribution Design's DEW; Cooper Power Systems / Eaton's CYME; EPRI's OpenDSS, PSERC's Matpower; PNNL's GridLab-D.

benefit trade-offs required to develop economically viable "Clean Distribution Systems" will be performed using new advanced production cost modeling capabilities that covers generation across both transmission and distribution. Finally, the vision for an "Advanced Modern Grid Planning & Analytics Platform" will be realized through all area of Design and Planning Tools. For instance, access to high performance computing systems will enable comprehensive analyses and optimization for policy analysis. Tools to automatically generate component models from data will enable analysts to more rapid build and validate systems models.

5.1 Activity 1: Scaling Tools for Comprehensive Economic Assessment

A wide spectrum of tools are used for grid economic assessments, from day-ahead planning, through mid-term hydro-thermal coordination, and up to long-term procurement of generation and transmission. At their core, these tools identify the most cost-effective approaches for capital and technology investments, operational approaches, and market designs to meet desired operational and economic performance objectives. A future grid with a far greater number of interacting devices and increased variability and uncertainty will require significant improvements in design and planning tools that enable them to accurately represent system stochasticity, and significantly higher spatial and temporal resolution. [89,90]

- **Scalable transmission and distribution planning with uncertainty** – Develop next generation tools for production cost modeling and expansion planning. Current approaches for modeling that integrate wind/solar generation are extremely computationally intensive and primarily limited to the transmission system. Key research challenges include improving time and spatial resolution, modeling uncertainty, reducing time-to-solution, and distribution system modeling.

    Task 5.1.1: Improve computational performance of production cost modeling for year-long sub-hour time resolution by decreasing run times from 2+ weeks to less than 1 day for (1) stochastic transmission (from 100 to 10,000+ nodes) and (2) deterministic combined transmission-distribution (from 1 to 10-million distribution and 100 to 1000 transmission nodes). [FY16-FY20]

    Task 5.1.2: Develop methods for integrating distribution into system-wide planning, including data management, integration of balanced and unbalanced power-flow, retail market models, models of load, validation methodologies and distributed energy resources—including distributed generation, demand response, electric vehicles, and energy storage. [FY16-FY19]

    Task 5.1.3: Develop advanced capacity expansion planning for generation, transmission, and distribution that captures operational flexibility, long and short term uncertainties, distributed energy technologies, market and policy impacts, and coupled network and generation optimization. Increase planning horizon from 10 to 50 years, scale from 100 to 5000 nodes and temporal resolution from tens to thousands of annual time periods. [FY16-FY20]

- **Model development and valuation** – Build models and valuation methodologies for existing and emerging grid technologies. New technologies such as demand response and energy storage frequently lack accurate validated models. Research is required to develop common physics, math, and economic representations suitable for assessments.

[89] Pacific Gas and Electric led utility / vendor / DOE laboratory working group that reviewed grid planning tools. "Collaborative Review of Planning Models", April 18, 2014. (http://www.cpuc.ca.gov/nr/rdonlyres/ece43e97-26e4-45b7-aaf9-1f17b7b77bce/0/combinedlongtermprocure2014oir_report_collaborativereview.pdf)

[90] EPRI research in integrated planning tools for cost-benefit trade-offs: http://integratedgrid.epri.com/

Task 5.1.4: Identify and classify data sources, define templates, and develop databases for new grid technologies, generation, load, and other components that compatible with modeling for high performance computers. [FY16]

Task 5.1.5: Develop valuation methods and mathematical models for new energy technologies such as energy storage, customer behaviors and communications. [FY17-FY18]

- **Integrated energy systems modeling –** Conduct research in methodologies that couple electric grid models with other external drivers such as gas infrastructure, weather events, and communications. Current approaches utilize deterministic methods and employ substantial simplifications. Work required in this task area includes development of advanced statistical techniques to incorporate heterogeneous and incomplete information, common repository and interface to external datasets, and scalable coupling methods for power grid models and external drivers.

Task 5.1.6: Improve tools for analyzing dependencies between electric and gas infrastructures by increasing scale from 1000 to 30,000-60,000 electric and 100 to 1000 gas nodes and addition of parametric uncertainty. [FY16-FY18]

Task 5.1.7: Increase resolution by 10x and include integrated risk assessment and extensibility to other infrastructures and drivers (e.g. water, weather, climate, communications, and emissions). [FY18-FY20]

- **Decision support tools** – This task area will focus on tools that 'scale down' results from high-fidelity simulations into actionable and easily understandable economics-based decision tools. Currently, results from HPC tools are neither integrated nor compatible with desktop solutions and are frequently too complex for use by policy analysts. Proposed work in this task area includes methods for reducing model complexity, techniques to quantify errors in simplification processes, tools to perform sensitivity analysis and cost-benefit trade-offs, and perform multi-objective optimization to identify most promising options.

Task 5.1.8: Develop methodologies and tools to produce simple-to-use desktop computer models from HPC-generated simulations and economic analysis. [FY16-FY17]

Task 5.1.9: Demonstrate approach on at least three important policy analysis problems by first using HPCs to perform large-scale and detailed analysis, then reduce results into simple desktop software tools. [FY18-FY19]

5.2 Activity 2: Developing and Adapting Tools for Improving Reliability and Resilience

Due to the increasing complexity of the grid, its reliability and resilience will not be sufficiently addressed with existing grid design and planning tools. These tools are used for a wide class of engineering functions including ensuring fault tolerance, design of protection systems, diagnosis of faults and blackouts, and impact assessment of high consequence events such as electromagnetic pulses (EMP), geomagnetic disturbances (GMD), and cyber-physical attacks. Key research in this area involves coupling across grid domains, planning under uncertainty, incorporation of distributed resources that enhance resilience, such as energy storage, and the use of data analytics.[91,92]

- **Dynamic Modeling of Integrated Transmission, Distribution, and Communications** – Develop an **i**ntegrated model framework to couple dynamic transmission/distribution/ communications models that run on a range of computer architectures (from desktop to HPC systems). Current tools model transmission, distribution, or communications separately, which prevents modeling interactions across grid domains. Research includes developing scalable coupling frameworks and methodologies and adapting existing commercial and academic modeling software packages integration into this coupling framework.

  Task 5.2.1: Develop scalable integration framework for dynamic modeling and simulation tools across transmission, distribution and communications for evaluation and design (e.g., system stability, protection schemes) from millisecond to seconds time resolution. [FY16-FY18]

  Task 5.2.2: Scale modeling framework to the regional level. Develop associated models for load, distributed generation, energy storage, and controls to enable the design and evaluation of future EMS/DMS/BMS architectures and novel wide-area sensor-control networks. [FY18-FY20]

- **Modeling for Extreme Events** – This activity area will develop tools and methods that automate the analysis of high consequence events, including automating analysis of cascading events, modeling of partitioning and intentional islanding, and understanding impact of extreme weather, EMP, and coordinated cyber and physical attacks. Current tools used for dynamic analysis require 1 minute of calculation time to model a transient time window of 15 seconds. Renewable generation is one example that expands the required window to 10 minutes with model uncertainty, which will increase compute requirements by a factor of approximately 100. Tools for modeling cascading events are extremely labor intensive and do not simulate the actions of protective device conveniently. This work will include improving the speed of time domain solvers, probabilistic methods, and modeling distributed energy resources.

  Task 5.2.3: Develop methodologies to simulate cascading events and protection systems and improve solution times by 500x via scalable computational math algorithms and automation techniques. Include probabilistic approaches in N-k contingency analysis.[93] [FY16-FY18]

  Task 5.2.4: Develop tools needed to perform interconnection level analysis of extreme events such as weather, EMP, GMD, and cyber and physical attacks. [FY18-FY20]

- **Big Data for Building and Validating Models** – Research algorithms and data-driven methods for automating the process of constructing and validating models for loads, components, subsystems, and systems. Current methods involve labor-intensive processes for collecting various circuit, component, load, and environmental data and synthesizing this information for use in design and planning tools. This results in over-simplification and inaccurate simulations. Necessary research includes approaches to speed up this process using automation, measurement data, and other computing technologies to develop and validate models.

[91] Bonneville Power Association roadmap includes planning and design tools needs: "BPA Collaborative Transmission Technology Roadmap), March 2014. http://www.bpa.gov/Doing%20Business/TechnologyInnovation/Documents/2014/Collaborative-Transmission-Technology-Roadmap-March-2014.pdf

[92] APRA-E funded report reviewing planning tools for distribution: E. M. Stewart, S. Kiliccote, C. McParland, "Software-Based Challenges of Developing the Future Distribution Grid", Lawrence Berkeley National Laboratory Report, July 2014.

[9393] N-k rule: N components can always work in order, whenever any k components suffer contingency.

Task 5.2.5: Develop open source tools to extract information for model development and validation from large and streaming datasets such as PMUs, smart meters, line sensors and SCADA. Develop data-driven model construction techniques with 5 percent accuracy of circuit models and cover as small as one device, to one distribution feeder, to as large as 90 percent of a region. [FY16-FY18]

Task 5.2.6: Develop automated tools and mathematical algorithms to build complex data-driven models, to include nonlinear conditions such as during major voltage and frequency events. [FY19-FY20]

5.3 Activity 3: Building Computational Technologies and High Performance Computing (HPC) Capabilities to Speed up Analyses

Rapidly advancing computational power is essential to addressing the increasingly complex, interactive, uncertain, and dynamic power system of the future. New algorithms and tools will be required to develop modeling and analytic applications to take advantage of new technologies such a cloud computing, high performance computers, multi-core and GPU processors, and data analytic architectures.[94,95] The main goals for this activity are to reduce the time for solving complex grid modeling problems, to substantially extend the complexity and volume of scenarios analyzed, to provide data repositories for analysis and code development, and to enhance the performance of existing tools.[96]

- **High Performance Computing and Data Infrastructure** – Provide access to HPC and data-analytic systems with 10,000 to 100,000 processors for computation to support collection and archiving of grid data, development of new tools, conduct policy analysis, host commercial and open source software applications, develop and validate new grid modeling algorithms, and test novel computer configurations. Currently, most grid modeling is performed either on desktops or small servers, which inhibits detailed analysis. Work includes include establishing federated HPC centers that leverage existing supercomputer centers, establishing procedures to protect and share data, storing validated data sets of loads, weather scenarios, etc. to support development and analysis.

  Task 5.3.1: Establish prototype regional HPC/data center, including computing systems, data archives, access controls, and selected commercial grid software to support institutional analysis and tools research. [FY16-FY17]

  Task 5.3.2: Establish four additional HPC/data centers for grid modernization support, with protocols and procedures to share data, resources, and expertise to support geographically dispersed users. [FY18-FY19]

- **Comprehensive Benchmark Data** – Develop a suite of benchmark test cases for use by algorithm and software developers. Test cases would range from open datasets for basic research to restricted-release information supporting risk analysis of critical infrastructure. Current approaches use benchmarks that are too small to be of interest to industry, larger databases are proprietary and closely held. Work includes establishing a methodology for developing test cases that represent current and future grid topologies and scenarios, support for the integrated analyses such as transmission/distribution/communications and grid/gas test cases.

[94] D. Callahan et al., 2nd Workshop on Challenges in Next- Generation Analytics for the Future Power Grid Workshop Report. Pacific Northwest National Laboratories, 2014.

[95] "Advanced Data Processing and Computing Technologies at Control Centers", EPRI Report 1021752, December 2011. http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001021752

[96] J. H. Eto & R.. J. Thomas (Eds.), "Proceedings on the Computational Needs for the Next Generation Electric Grid", April 19-20, 2011. http://energy.gov/sites/prod/files/FINAL_CompNeeds_Proceedings2011.pdf

Task 5.3.3: Establish methodologies for developing benchmark systems and cases to validate and test scaling of new tools. Develop ten benchmarks from which co-simulation, open source and commercial transmission and distribution simulation software and frameworks can be validated. [FY16]

Task 5.3.4: Create and maintain repository of open and restricted benchmark datasets. Select five tools/frameworks to be benchmarked and process for validating models and results. [FY17-FY20]

- **Scalable Libraries and Computing Frameworks** – Create scalable math libraries for use by software packages for grid planning and design tools. Most current planning and design tools do not take advantage of advances in scalable algorithms, libraries, and computer architectures, missing the opportunity for significant performance enhancements. There are no frameworks to link HPC results to visualization tools and sensitivity analysis to understand uncertainty in results are not performed due to a lack of tools. Objectives of this research area include the development of scalable libraries of algorithms, solvers, and statistical modules for use by grid modeling tools on HPC systems; tools and frameworks to manage job launch, support systems studies with uncertainty quantification and optimization, and manage hierarchies of models; and frameworks for computational/analytical processes to enable coupling of advanced simulation tools with data and visualization technologies.

Task 5.3.5: Develop and distribute advanced libraries of algorithms, solvers, uncertainty quantification, and stochastic optimization modules. [FY16-FY20]

Task 5.3.6: Develop computing frameworks that enable the coupling of advanced computation tools, data, and visualization technologies with easy workflow management. [FY16-FY20]

- **Technology Transfer and Adoption** – Establish collaborative technology transfer program to drive adoption of planning and design tools and technologies into practice by ISO's, RTO's, utilities, vendors, and policy makers. Currently, there is no grid-specific program that offers this capability. The key aspect of this effort is to accelerate the transition of advanced computational technologies from proof of principle to deployment through demonstrations and collaborations.

Task 5.3.7: Implement "prototype to practice" program. Competitive process will be used to solicit important challenge problems, form teams comprised of GMLC members and problems owners (e.g., IOU, ISO, vendors) to solve challenge problems, and then transition solutions into practice. (For example, grid software vendors might propose challenge problem of integrating advanced math libraries for HPCs into their planning tools to address important state policy issue.) Complete one pilot program to develop processes and demonstrate value. [FY16-FY17]

Task 5.3.8: Establish "prototype to practice" program as a continuing activity, maintaining six GMLC-partner projects per year. [FY18-FY20]

5.4 Links to Other Grid Modernization Technical Areas

Efforts in framing approaches to deliver next generation high performance planning and design tools have significant connections across the GMLC technical teams.

- The development of high performance, high resolution production cost planning tools will coordinate with the **System Operations, Power Flow, and Control** team in the development of advanced solvers and algorithms that underlay tool platforms developed by both teams. Similar dependencies exists between these teams in developing co-simulation and other techniques that will link transmission, distribution, and load simulations for both time domains (less than 1 day, and greater than 1 day).

- The design and planning tools targeted for the future distribution system will have significant linkage to the **Institutional Support** and **Devices and Integrated Systems Testing** teams in its development of DER valuation analytics and metrics. This effort will dictate model requirements back to the **Design and Planning** team regarding model attributes necessary to enable analysis of new grid attributes and business/market models.
- **Security and Resilience** team will shape emergency response strategies that must be reflected in new tools. For example, tools developed for dynamic modeling across transmission, distribution, and communications systems would be used to design resilient cyber defenses. Research in modeling extreme events will be critical for supporting more timely and comprehensive analysis for disaster response and recovery.

5.5 Links to Existing DOE Portfolio

The proposed work in Planning and Design Tools builds upon the existing activities of the various Program Offices within DOE. Examples are described below:

- Research in *Scaling Tools for Comprehensive Economic Assessments* will be supported by existing and ongoing DOE research in solar, wind, and water power integration. Methodologies developed under DOE's Solar Energy Technology Office (SETO) to estimate the value of solar deployments will be used as a basis for valuation of emerging technologies. GMLC research will also build on SETO efforts for detailed distribution simulation and data conversion, Wind and Water program work in integrated T&D simulation. Research in stochastic mixed-integer linear programming methods under the DOE OE Advanced Grid Modeling Research program will be used to develop next-generation production cost modeling tools. HPC-based approaches for production costing will also build on past DOE EERE funded efforts for large-scale renewable integration studies. Efforts under the *OE Energy Storage* in establishing the cost-benefit analysis of energy storage deployments will enable storage to be effective represented in future planning and design tools. Important DOE studies (e.g., NREL Renewable Futures study) would help motivate research topics in this area.
- Projects in *Developing Tools for Improving Reliability and Resilience* will build upon existing and ongoing DOE work in computational science and grid modeling software application development. For example, under the DOE OE AGM Program, research in parallel differential algebraic equation solvers will be used to support modeling system reliability. Research under the EERE Solar Energy program to model distribution and communication will support the development of coupled transmission, distribution, and communication models.
- Research under *Develop Computational Technologies and High Performance Computing (HPC) Capabilities to Speed-up Analysis* will rely on basic and applied research in parallel computational methods and library development. Advances under the DOE Office of Science *Mathematics for Complex Systems program* will serve as the basis for research in highly scalable techniques and methods for stochastic optimization and non-linear solvers. Work under the OE AMG GridPACK project to build scalable math libraries for future HPC systems will support developing tools for modeling extreme events and coupled transmission, distribution, and communication systems. HPC infrastructure will leverage existing Office of Science and EERE funded HPC facilities by including strategic investments tailored to grid simulation (e.g. higher memory nodes) and providing coordinated grid-focused data.

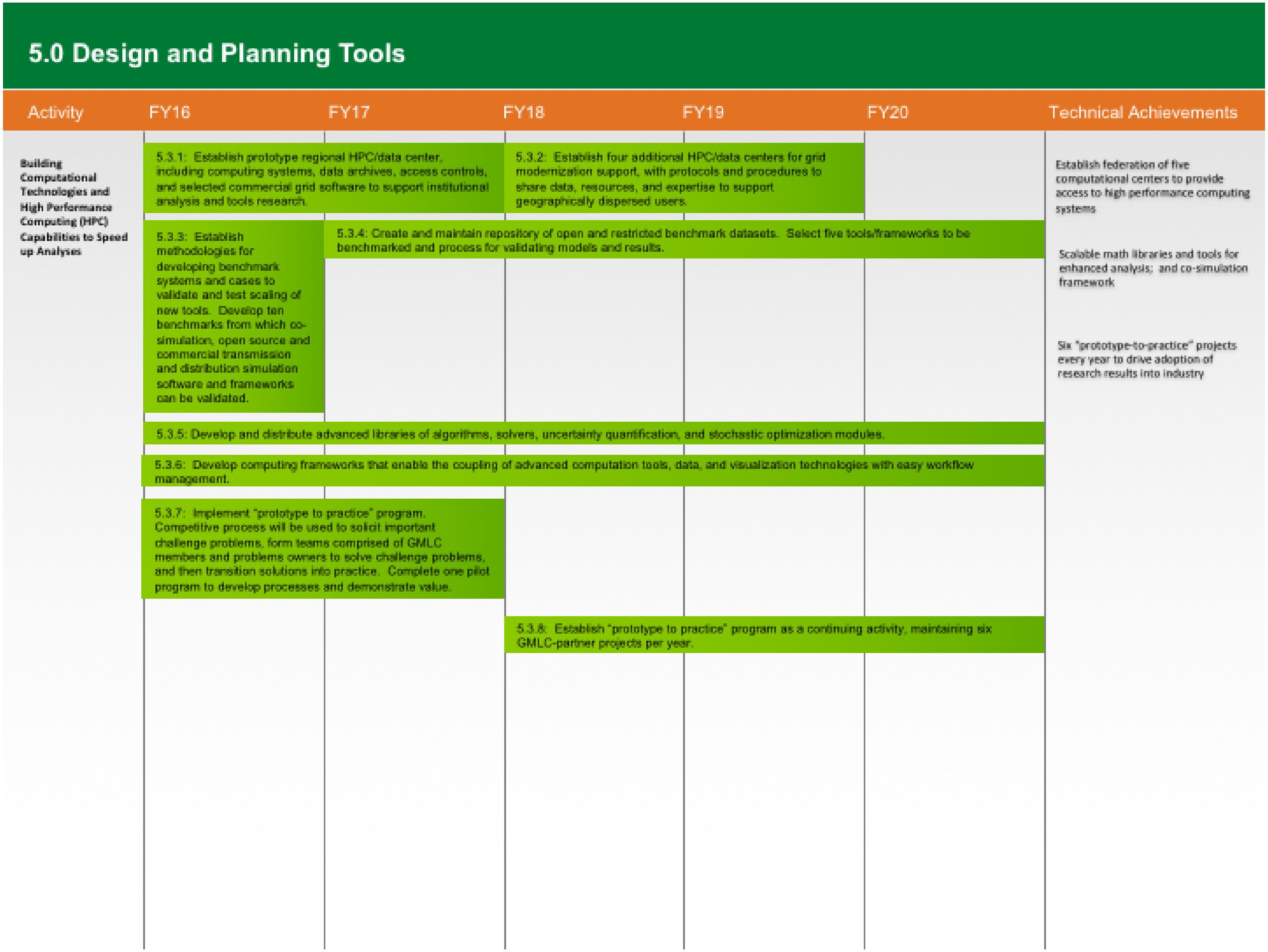
Table 8 contains specific details on the existing funding streams supporting FY15 Planning and Design Tools projects conducted at the DOE National Laboratories. The Briefing Papers contained in Appendix C specifically map our proposed future work in this technical area to the goals and objectives of the individual participating DOE Programs.

TABLE 8. EXISTING NATIONAL LABORATORY PLANNING AND DESIGN TOOLS PROJECTS

Activity	Existing Major DOE Funded GMLC Projects in FY15
Tools for Economic Assessment ***25 Projects***	• EERE/Solar – Design and assessment tools to enable high PV penetration of solar deployment • OE/AGMR – Numerical optimization methods required for probabilistic unit commitment and economic dispatch • EERE/BTO – Commercial Building Agent Based Modeling and OpenStudio • OE/Storage – Use-case analysis, algorithms for optimized dispatch, integration of economic dispatch into GridLab-D, methodologies for revenue forecasting based upon storage technologies • EERE/Wind&Water – Tools and techniques for market assessment and large-scale production costing with high Wind penetration; hydro modeling and forecasting
Tools for Reliability and Resilience ***22 Projects***	• EERE/Solar – Modeling tools for high penetration solar deployment and distribution circuits • OE/AGMR – Stochastic Planning Tools; contingency analysis; co-simulation of transmission and distribution; probabilistic methods • OE/Smart Grid – Microgrid, infrastructure resilience, extreme events • EERE/Wind&Water+Solar – Large-scale disturbance performance with high renewable penetration
Computational Infrastructure and Technologies ***16 Projects***	• Office of Science – Math for Complex Systems; Extreme Scale Computing, stochastic algorithms • OE/AGMR – GridPACK, advanced math libraries, models of uncertainty, parallelization techniques • EERE/Solar – Transmission analysis using GridLab-D, solar radiance modeling, analysis of regulation • EERE/ESIF – HPC center supporting simulation and analysis for grid research
Total 63 Projects	

5.0 Design and Planning Tools

Activity	FY16 – FY20	Technical Achievements
Scaling Tools for Comprehensive Economic Assessment	5.1.1: Improve computational performance of production cost modeling for year-long sub-hour time resolution by decreasing run times from 2+ weeks to less than 1 day for (1) stochastic transmission and (2) deterministic combined transmission-distribution.	Improve scaling of stochastic tools to model electric and gas system inter-dependencies from 1,000 to 60,000 electric and 100 to 1,000 gas nodes
	5.1.2: Develop methods for integrating distribution into system-wide planning, including data management, integration of balanced and unbalanced power-flow, retail market models, models of load, validation methodologies and distributed energy resources—including distributed generation, demand response, electric vehicles, and energy storage.	Enhance performance of stochastic production cost modeling from 100 to 10,000 transmission nodes
	5.1.3: Develop advanced capacity expansion planning for generation, transmission, and distribution that captures operational flexibility, long and short term uncertainties, distributed energy technologies, market and policy impacts, and coupled network and generation optimization. Increase planning horizon from 10 to 50 years, scale from 100 to 5000 nodes and temporal resolution from tens to thousands of annual time periods.	Easy-to-use decision support tools based upon complex HPC results
	5.1.4: Identify and classify data sources, define templates, and develop databases for new grid technologies, generation, load, and other components that compatible with modeling for high performance computers.	
	5.1.5: Develop valuation methods and mathematical models for new energy technologies such as energy storage, customer behaviors and communications.	
	5.1.6: Improve tools for analyzing dependencies between electric and gas infrastructures by increasing scale from 1000 to 30,000-60,000 electric and 100 to 1000 gas nodes and addition of parametric uncertainty.	
	5.1.7: Increase resolution by 10x and include integrated risk assessment and extensibility to other infrastructures and drivers .	
	5.1.8: Develop methodologies and tools to produce simple-to-use desktop computer models from HPC-generated simulations and economic analysis.	
	5.1.8: Demonstrate approach on at least three important policy analysis problems by first using HPCs to perform large-scale and detailed analysis, then reduce results into simple desktop software tools.	
Developing and Adapting Tools for Improving Reliability and Resilience	5.2.1: Develop scalable integration framework for dynamic modeling and simulation tools across transmission, distribution and communications for evaluation and design from millisecond to seconds time resolution.	Scalable framework to couple coupling transmission, distribution, communications models for integrated analysis at regional scale
	5.2.2: Scale modeling framework to the regional level. Develop associated models for load, distributed generation, energy storage, and controls to enable the design and evaluation of future EMS/DMS/BMS architectures and novel wide-area sensor-control networks.	
	5.2.3: Develop methodologies to simulate cascading events and protection systems and improve solution times by 500x via scalable computational math algorithms and automation techniques. Include probabilistic approaches in N-k contingency analysis.	Improve of performance of contingency analysis tools by 500X to capture extreme events
	5.2.5: Develop open source tools to extract information for model development and validation from large and streaming datasets such as PMUs, smart meters, line sensors and SCADA. Develop data-driven model construction techniques with 5 percent accuracy of circuit models and cover as small as one device, to one distribution feeder, to as large as 90 percent of a region.	Data-driven tools to automate construction and validation of models of devices, loads, generation, and costumer behavior
	5.2.4: Develop tools needed to perform interconnection level analysis of extreme events such as weather, EMP, GMD, and cyber/physical attacks.	
	5.2.6: Develop automated tools and mathematical algorithms to build complex data-driven models, to include nonlinear conditions such as during major voltage and frequency events.	


5.0 Design and Planning Tools
Activity
FY16
FY17
FY18
FY19
FY20
Technical Achievements
Building Computational Technologies and High Performance Computing (HPC) Capabilities to Speed up Analyses
5.3.1: Establish prototype regional HPC/data center, including computing systems, data archives, access controls, and selected commercial grid software to support institutional analysis and tools research.
5.3.2: Establish four additional HPC/data centers for grid modernization support, with protocols and procedures to share data, resources, and expertise to support geographically dispersed users.
5.3.3: Establish methodologies for developing benchmark systems and cases to validate and test scaling of new tools. Develop ten benchmarks from which co-simulation, open source and commercial transmission and distribution simulation software and frameworks can be validated.
5.3.4: Create and maintain repository of open and restricted benchmark datasets. Select five tools/frameworks to be benchmarked and process for validating models and results.
5.3.5: Develop and distribute advanced libraries of algorithms, solvers, uncertainty quantification, and stochastic optimization modules.
5.3.6: Develop computing frameworks that enable the coupling of advanced computation tools, data, and visualization technologies with easy workflow management.
5.3.7: Implement "prototype to practice" program. Competitive process will be used to solicit important challenge problems, form teams comprised of GMLC members and problems owners to solve challenge problems, and then transition solutions into practice. Complete one pilot program to develop processes and demonstrate value.
5.3.8: Establish "prototype to practice" program as a continuing activity, maintaining six GMLC-partner projects per year.
Establish federation of five computational centers to provide access to high performance computing systems
Scalable math libraries and tools for enhanced analysis; and co-simulation framework
Six "prototype-to-practice" projects every year to drive adoption of research results into industry

6.0 Security and Resilience

The security and resilience of the modern electric grid may be defined as the functional preservation of the electric grid operations in the face of natural and man-made threats and hazards. Complementing the notion of operational reliability, the grid must proactively act in securing itself and be resilient in spite of an ever-changing threat landscape. Recent extreme weather events such as super-storm Sandy, the sniper attack on PG&E Corporation's Metcalf Transmission Substation, and the growing number of cyber-attacks on utilities all serve to highlight the vulnerabilities and the urgency for action. In light of such events, Presidential Policy Directives 8 (PPD-8) and 21 (PPD-21) and Executive Order 13636 (EO13636)[97,98,99] were developed. The *Security and Resilience* component of this MYPP builds upon the intent of these documents and current DOE activities to secure the power grid as one of the U.S. critical infrastructures.

"WEATHER RELATED OUTAGES HAVE INCREASED FROM 5 TO 20 EACH YEAR IN THE MID-1990S TO 50 TO 100 PER YEAR IN THE LAST FIVE YEARS. A MORE RESILIENT GRID WILL HELP BOTH LESSEN AND ADAPT TO THIS CHALLENGE."

Melanie Kenderdine, Director for the Office of Energy and Policy Analysis

This MYPP defines five key grid DOE Grid Modernization thrust areas, based on the NIST cybersecurity framework,[100] that will be pursued to advance the security and resilience of the US power grid in alignment with DOE strategies in the Infrastructure Security and Restoration (ISER) Program and the Cybersecurity for the Energy Delivery Systems (CEDS) Program. As these programs update their roadmaps and strategies, we recommend that the NIST cybersecurity framework and other relevant frameworks be taken into consideration. Additionally, acknowledgement and recognition of current efforts by the private sector in security and resilience is essential. These actions align with the Nation's policy framework for protecting critical infrastructure through the development of high-priority solutions for maintaining predictive state awareness and an accepted level of operating normalcy in response to disturbances, including threats and hazards of an unexpected and malicious nature. The resulting solutions will measurably increase the resilience of the cognitive, cyber-physical grid systems against all hazards, including high-impact and low-frequency events such as Geomagnetic Disturbance (GMD) and more frequent physical threats and hazards such as devastating weather events. The five key thrust areas and the targeted technical achievements in these areas are shown in Table 9.

[97] The Whitehouse, "Presidential Policy Directive/PPD-8: --National Preparedness", March 30, 2011, www.dhs.gov/xlibrary/assets/presidential-policy-directive-8-national-preparedness.pdf

[98] The Whitehouse, "Presidential Policy Directive -- Critical Infrastructure Security and Resilience," February 12, 2013, www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil

[99] Government Printing Office, "Executive Order 13636—Improving Critical Infrastructure Cybersecurity," www.gpo.gov/fdsys/pkg/FR-2013-02-19/pdf/2013-03915.pdf

[100] National Institute of Standards and Technology, "Framework for Improving Critical Infrastructure Cybersecurity," February 12, 2014, http://www.nist.gov/cyberframework/upload/cybersecurity-framework-021214.pdf

TABLE 9. ACTIVITIES AND TECHNICAL ACHIEVEMENTS FOR SECURITY AND RESILIENCE

Activity	Technical Achievements by 2020
Improve Ability to Identify Threats and Hazards	• An all hazards approach (e.g. standards and guidelines) for threat identification and emergency response planning and preparation, which is accepted and implemented by the energy sector.
Increase Ability to Protect Against Threats and Hazards	• Standards, methods, testing and evaluation procedures for physical and cybersecurity enabled designs. • Development, demonstration, and field validation of novel energy device (e.g. energy storage), communications, and control system models and logistical optimization techniques. • Grid components which are inherently protective of grid services to all-hazards (e.g. energy storage).
Increase Ability to Detect Potential Threats and Hazards	• Advanced cyber-physical data analytics and cognitive learning, spanning time scales and data sources across the system lifecycle, to enable proactive and real-time information flow as demonstrated in regional exercises by the end of FY20.
Improve Ability to Respond to Incidents	• Methodologies and architecture frameworks that assess system degradation to all hazards, provide diverse attack recognition, and mixed-initiative response on multiple timescales, and optimize operational efficiencies/priorities to reduce incident response time for the power grid.
Improve Recovery Capacity/Time	• Advanced substation, transformer and support technology (e.g., energy storage) designs and standards that facilitate improved portability and rapid substation recovery from storms and natural disasters. • Hardened fail-safe and wireless communications capabilities and devices for grid control systems that resist impacts from cyber, geomagnetic disturbance, and electromagnetic pulse events.

The activities in the Security and Resilience technical area will deliver Technical Achievements for each Activity area (see Table 9 above) as well as support the three "Integrated Regional Demonstrations" outlined in Chapter 8.0. The first activity to identify threats and hazards will be central to the first two demonstrations, "Lean Reserve Margin Grid Bulk Power Systems" and "Clean Distribution Systems", through threat situational awareness and device design to ensure threat resilience. The cyber-physical data analytics from activity three will be integral to the design of the new control and operator analytics used in these demonstrations as well. The fifth activity dealing with improved recovery capacity/time will inform transformer and substation design utilized in the demonstrations for these demonstrations areas as well. The fourth activity to improve emergency response supports the third Integrated Regional Demonstration of "Advanced Modern Grid Planning & Analytics Platform" in helping regulators and planners evaluate the cost benefits of new investments in cyber and natural disaster risk mitigation. Descriptions of each activity area follow.

6.1 Activity 1: Improve Ability to Identify Threats and Hazards

In order to improve the grid designers' and operators' ability to identify threats and hazards, this first set of activities under the Security and Resilience technical area is targeted at anticipating threats and hazards while gaining understanding of vulnerabilities and potential consequences to all hazards (including cyber). The ultimate goal of this activity is to develop and establish an all hazards approach for threat identification, mitigation, and emergency response, which will be accepted and implemented by the energy sector. Towards that end, the R&D within this activity area focuses on risk management from a business and critical needs perspective, improving and sharing threat and hazard anticipation and understanding, characterizing system vulnerabilities, accelerating state awareness, predicting potential consequences, and determining event response needs and capabilities. DOE can then use this wide breadth of knowledge to establish an effective approach to anticipate and mitigate threats and hazards. The specific actions within this activity are listed below.

- **Communication and Outreach** – **Develop new tools and expand existing tools that provide** consistent, thorough communication to key stakeholders to improve system security and risk posture to all hazards, specifically the Cybersecurity Capability Maturity Model (C2M2) and Risk Management Plan (RMP), with benchmarking and analytics supported by an established data repository for information sharing, a consistent framework considering all hazards for users, and feedback to inform R&D and incident management activities.

  Task 6.1.1: Expand the C2M2 model and best practices to include All Hazards (including physical) over the first year. Plan an annual update to capture new practices each year while maintaining the original best practices. Enhance the Risk domain of ES-C2M2 to include threat anticipation practices. Convene RMP participants to update RMP to align with C2M2 and add all hazards in the second year. [FY16-17]

  Task 6.1.2: Validate the new ES-C2M2 model with piloted on-site assessments and use the feedback to improve the model before publishing. Create an internet platform to house the tools and support anonymous analytics. Define annual requirements for trainers. Train private industry parties to perform assessments. [FY17]

  Task 6.1.3: Update analytics to support the new model which will allow stakeholders to understand their security posture and compare to peers. Develop risk management tools to support C2M2 and RMP. [FY17-18]

- **Industry Support and Ownership** – Increase industry engagement in grid security technology improvement and reporting after an incident through the Electric Emergency Incident and Disturbance Report (Form OE-417)[101] and wider participation in the Cybersecurity Risk Information Sharing Program (CRISP).

  Task 6.1.4: Define and hold annual cybersecurity vendor interoperability tests. [FY16-20]

  Task 6.1.5: Create analytic capability for CRISP sites. [FY17-20]

- **Tool Development** – Enhanced sensing and analytic functions for CRISP and interoperability tested solutions in the market with emphasis on risk assessment and management strategy tools that are effective and useful to industry.

  Task 6.1.6: Create enhanced sensor technology for information sharing devices in CRISP. Create enhanced CRISP analytics with external entities. Define contents, security, and usability of a security data repository. [FY16-17]

  Task 6.1.7: Create a security data repository with rules tools for use. [FY18-20]

6.2 Activity 2: Increase Ability to Protect Against Threats and Hazards

The variety of and escalation in extreme weather events and other natural disasters, emerging concerns about cybersecurity, aging components, and the proliferation of new technologies associated with smart systems and renewable energy resources further increases the difficulty in planning, design, and operational decisions related to the grid. A modern grid that is secure and resilient, from generation to load, will require that these diverse

[101] https://www.oe.netl.doe.gov/oe417.aspx

challenges be addressed holistically throughout all phases of the planning, design, and operation of the grid system. Through Activity 2, effective protection and resilience of the grid will be achieved by developing standards for analyzing component and system resilience, creating and disseminating tools for resilient planning, hardening components, and instituting an inherently resilient communications system. The activities detailed below will advance the design and use of new emerging security and resilience technology through significant research and development efforts. The ultimate result of this advancement will be the development, demonstration, and field validation of novel energy, communication, and control system models and logistical optimization techniques for the assured protection of the electric grid. We will direct the modern grid towards greater resilience and security by promoting grid technologies that are inherently secure and resilient while also providing utilities and other stakeholders the predictive analytic tools to cost effectively optimize their utilization. In so doing, we will support objectives in each element of the MYPP as well as the overall objectives of the MYPP.

- **Security and Resilience Standards** – Develop standards, methods, testing, and evaluation procedures for improved security-driven real-time device management. Develop an inherently resilient communications standard that includes a cyber-enabled design and supports the measureable determinism required of all networks supporting operational technologies (OT).

  Task 6.2.1: Issue a FOA to award a multi-lab, university, and industry consortium to lead communications infrastructure R&D and develop and evaluate all-hazards probabilistic damage models for grid components. [FY16

  Task 6.2.2 Develop resiliency metrics, models, and evaluation tools to help vendors, integrators, decision makers and operators with resiliency based designs, infrastructure investment decision making, and operations. [FY17]

- **Hardened and Resilient Components** – Design and test grid components that are inherently protective of grid services to all- hazards.

  Task 6.2.3: Demonstrate a cyber upgrade on a legacy OT that can respond to and withstand a cyber-attack. Develop tight integration between interdependency predictive models and network optimization tools for creating and deploying technology integration and system response planning. [FY18]

- **Optimal Planning, Design, and Operations Tools for System Resilience/Recovery** – Develop decision support tools that will enable power system designers to discover and prioritize cost-effective system upgrades and expansions so the utility can predictively minimize the size and duration of future outages to customers through improved, cost-effective designs.

  Task 6.2.4: Develop grid architectural alternatives and response and restoration logistical optimization techniques to minimize outage durations (with and without priority load requirements) for system recovery planning. Examples include adaptive islanding, special protection schemes, and microgrids. [FY19]

- **Inherently Resilient Communications Infrastructure** – Develop and evaluate advanced communication systems that can monitor the broad spectrum of cyber and physical threat vectors to grid components, operations, and services and rapidly alert utility operators of any emerging concerns. Extend current cyber and physical resilience techniques and methods to improve resilience against cyber-physical threats and all-hazards on systems that use conventional communications technologies to avoid large utility investments and extensive equipment replacement programs.

Task 6.2.5: Develop an energy and communications interdependencies model for the energy sector including optimization techniques to enable utilities to discover and prioritize cost-effective system upgrades and expansions. [FY16-18]

Task 6.2.6: Conduct a series of demonstrations to validate the seamless completion of scanning and patching activities of grid devices, without disruption to normal device operations and service. Tests will include multiple scales of grid operation (building, facility, utility). [FY20]

6.3 Activity 3: Increase Ability to Detect Potential Threats and Hazards

To increase the ability to detect potential threats and hazards, DOE will address system status characterization, machine learning and high-throughput analytics, and dissemination for the entire grid lifecycle from planning and design all the way to operations to proactively call out system vulnerabilities or attacks be they man-made or naturally caused. This applies to cyber as well as the physical infrastructure, with specific focus on the "cyber-physical" intersections between the two. This activity also considers the cognitive, human-in-the-loop components, providing a paradigm shifting approach to status characterization and prioritization of required responses by operators and support toolkits. Through the three main focus areas below, this activity will lead to the design and development of advanced analytics to detect cyber-physical threats and hazards spanning multiple time scales, across the system lifecycle, incorporating improved baseline grid operation descriptions and data exchange.

- **Improve data capture and exchange** – Develop a robust data and generalized state identification and exchange scheme that can scale to include different components of the cyber-physical lifecycle from planning, design, to operations.

  Task 6.3.1: Establish a secure and efficient data ingest and dissemination framework from devices and data sources (e.g. sensors, intelligent electronic devices, energy management systems, etc.) critical to the cyber-physical integrity of the full grid system lifecycle, including planning, design, and operations. [FY16-17]

- **Create baseline operating profiles** – Design constructs and tools for utilities and vendors to create and publish "core" operating profiles applicable across utilities[102] so that cyber-physical anomalies can be rapidly identified and investigated to proactively take action where necessary.

  Task 6.3.2: Create baseline operating profiles of grid operations from a cyber-physical standpoint for the full system lifecycle including planning components (e.g., siting and transmission planning), design components (e.g., control protocols and architecture), and operational state (e.g., transmission and distribution status). Build modeling/simulation capabilities to approximate full-system operating profiles prior to production implementation. [FY17-18]

- **Enable early and rapid detection through data analytics** – Instantiate resilience and anomalous activity evaluation frameworks that link and expose the vulnerabilities and emerging threats and hazards with the root-cause across multiple time-scales be it in the supply chain, design methodology, or real-time operational system.

  Task 6.3.3: Enable early detection of cyber threats and natural/physical hazards through cyber-physical data fusion and analytics leveraging the previously developed and vetted baseline operating profiles and data sources. Solutions will address multiple time scales (e.g. slow and stealthy cyber-attacks or a sudden earthquake or storm) and apply across the system lifecycle from planning to design to operations. [FY17-20]

[102] A role no single utility can undertake by itself.

Task 6.3.4: Conduct two region-based exercises in coordination with state and local governments and asset owners/operators to demonstrate an integrated real-time cyber-physical state awareness and early detection of threats and hazards. [FY20]

6.4 Activity 4: Improve Ability to Respond to Incidents

Power grid operations include many cyber-physical dependencies and interdependencies, leading to the potential of a high impact negative event to be initiated from a random event. Power grid operations are based primarily upon operational technologies (OT), which unlike information technologies (IT), are comprised of real-time devices that provide for the reliable monitoring and control. As a result, any latencies or data corruption arising from cyber-physical attack or failure to OT can lead to cascading failures of the power grid. To counter this impact, DOE will improve the industry's ability to mitigate and respond to incidents. This activity focuses on improving the power grid's ability to predict, adapt and respond to all hazards and threats, which is a paradigm shift from the current design and operation of the grid. The role of the distribution system in light of the growth in distributed generation, smart loads (e.g., devices that self-regulate power use), energy storage, and other distribution-based technologies must be addressed in this context. Most resiliency and security guidelines have been traditionally focused on the transmission system, not the distribution system. Given the dependence of the power grid upon OT, the ability of the OT to optimally recognize and adapt to degradation of these assets is a fundamental enabler to achieving resilience. Ultimately, Activity 4 will result in the development of methodologies and architectures frameworks which assess degradation, advance prognostic preparation and transform system behavior to maintain operation to all hazards. These frameworks will provide diverse and predictive cyber-physical attack recognition and mixed-initiative response on multiple timescales, and optimize operational efficiencies/priorities for the power grid. Towards that end, the key activities and tasks planned in this area are listed below.

- **Develop degradation aware architectures** – Integrate and holistically evaluate/prognosticate degradation within cyber-physical architectures and then mitigate, which is a fundamental first step to advancing more autonomous architectures that achieve greater efficiencies of operation and threat-resilience.

  Task 6.4.1: Develop a common infrastructure degradation assessment framework and demonstrate/vet/deploy promising prototypes, which identify cyber-physical security attacks and failures and adapts OT behavior to maintain critical energy operations. [FY16-20]

- **Improve human-in-the-loop response** – Optimize the benign human interaction within OT to achieve reproducibility of response, regardless of experience, achieving greater human resilience in response to threats and hazards.

  Task 6.4.2: Develop a common cyber-physical data fusion framework and demonstrate/vet/deploy human system visualization prototypes which adapt the presentation of actionable information based upon the situational context and role to ensure a desired human response. [FY16-20]

- **Improve cybersecurity response** – Integrate a multi-layer spectrum of cybersecurity technologies, including physical indicators for OT, which provide the basis for adapting the response of OT to threats and hazards and place defenders on an equal footing to malicious actors.

  Task 6.4.3: Develop a common cyber feedback framework and demonstrate/vet/deploy promising prototypes that use intelligent, diverse cyber detection and autonomous feedback mechanisms for recognition and agile response to attack. [FY16-20]

- **Develop resilient architectures** – Establishing distributed architectures that enable an adaptive and agile framework to recognize, prognosticate, isolate, if possible, and respond to threats and hazards, stabilizing disturbances at the local level while maintaining a global optimum in performance.

  Task 6.4.4: Formulate an adaptive and agile OT framework and demonstrate/vet/deploy prototypes, that optimize stability and efficiencies of operation while accommodating high penetration of distributed, renewables generation, smart loads and energy storage [FY16-20]

6.5 Activity 5: Improve Recovery Capacity/Time

The improvements in the recovery capabilities of system and community grid operations will reduce the potential for longer-term economic and public health and safety impacts and improve overall infrastructure resilience from an all-hazards and -threats perspective. Activity 5 includes developing and implementing activities to maintain plans for resilience and to restore any capabilities or services that are impaired within the electric sector and impact other interdependent infrastructures following an all-hazards event. Activities include preparedness and recovery planning, but these rely on on-going, reliable, and resilient advanced communications and device security methods to maintain critical data streams among substations and central control centers following damages or disruptions to normal grid operations. Recovery further requires developing measurable hardening and advanced recovery standards for grid devices, components, and communications medium. The end result of this technical area activity will be the development of advanced substation and large power transformer (LPT) designs and standards, improvement of substation criticality selection, implementation of SCADA systems, networks and devices, and advancements in GMD and EMP device hardening that facilitate improved transformer portability, rapid substation recovery, and robust grid communications devices and control. The following activities are targeted in this area to lead to enable these results.   We will develop the materials, cooling techniques, and designs for solid state transformer modules such that any transformer on the U.S. Grid could be rapidly replaced by the assembly of the solid state modules including transmission scale.

- **Develop Advanced Substation and LPT Designs and Standards** – Advance and specify substation and LPT standards; develop modular impedance matching equipment and/or other means to improve transformer portability among substations of the same voltage class and capacity rating;, and, in the longer term, specify and develop modular solid-state transformers, scalable from distribution to transmission, to replace conventional designs, increase grid resilience, and minimize substation and equipment restoration efforts.

  Task 6.5.1: Establish and advance the application of standard impedance LPT and prototype modular impedance matching equipment and validate the design and implementation of modular impedance matching equipment using a traditional LPT or prototype standard impedance transformer in the laboratory. [FY16-17]

  Task 6.5.2: Evaluate the applicability of existing substation footprint, layout, and connection standards relative to applications using standard impedance transformers and modular impedance matching equipment and define revisions to substation standards to accommodate applications using these advanced technologies that mitigate existing portability and operational challenges to improve resilience. [FY17-19]

  Task 6.5.3: Design and construct solid-state distribution (10-kV and 50-kV) and transmission (100-kV and 345-kV) transformers based on scalable power modules in the laboratory, and deploy a modular 345-kV solid-state transformer on the grid using revised substation standards. [FY16-20]

- **Improve Substation Criticality Selection and Recovery Planning** – Improve the critical electric infrastructure asset selection process through advanced selection metrics and criticality ranking methods (e.g., outage extent from n-k contingencies, population impacted, and other lifeline infrastructure impacts) to complement existing and proposed spare LPT inventory activities and improve recovery planning.

  Task 6.5.4: Specify advanced critical asset selection and criticality ranking methods and develop asset response and recovery plans to assure efficient restoration following an all-hazards event. [FY16-18]

- **Advance SCADA System and Network Recovery** – Design ultra-secure, low-power, self-healing wireless networks capable of bypassing compromised network components, while preserving sufficient bandwidth to maintain minimal essential connectivity to critical grid assets, preserving fail-safe operation of essential SCADA and sensor elements and devices, and improving overall grid communications, operations, and resilience. Design the capability to initiate the failsafe mode across the US Grid within minutes of a cyber-attack.

  Task 6.5.5: Develop requirements for ultra-secure, low-power wireless devices and networks designed for minimal essential communications that encompasses requirements for fail-safe devices for critical grid elements, and design, demonstrate, and evaluate a prototype wireless network employing fail-safe prototype devices. [FY16-17]

- **Advance Recovery from GMD and EMP Events** – Collaborate with other organizations to further assess the potential impacts of GMD and EMP events on critical electrical equipment by using advanced multi-physics modeling capabilities and reduced- and full-scale physical equipment testing.

  Task 6.5.6: Specify, evaluate, and validate the requirements of advanced hardened devices that withstand an EMP in a highly interconnected environment and demonstrate and test hardened devices in the laboratory. [FY16-18]

6.6 Links to Other Grid Modernization Technical Areas

Efforts in framing approaches to Security and Resilience that are robust against all hazards have significant connections across the GMLC technical teams.

- Efforts to support expansion and enhancement of cyber information sharing tools and practices can inform tools development for visualization and data analytics (**Sensing and Measurements**) and in the enhancement of EMS/DMS/BMS operating software such that detection, prediction and recovery from system problems are substantially improved.
- The development of new threat detection and prediction modeling tools can benefit from the advanced solvers and algorithms (HPC) being developed in **Design and Planning Tools** and in **System Operations, Power Flow, and Control**. Similarly, the need for high volume, high velocity data stream management in real-time for enhanced security situational awareness can leverage the **Sensing and Measurements** team efforts in advanced data analytics and communications.
- New approaches for managing risk and recovery need to be coordinate with the **Institutional Support** team to provide information that guides cost/benefit tools development to help regulators identify investment strategies at the state and local level related to enhance resilience and security.

6.7 Links to Existing DOE Portfolio

The proposed work in Security and Resilience builds upon the existing activities of the various Program Offices within DOE, in the following manner:

- Projects in *Improve Ability to Identify Threats and Hazards* work are currently an area of focus in OE's Cybersecurity for Energy Delivery Systems (CEDS) program. The Energy Savings Performance Contracts (ESPC) also funds some risk work in this area. OE's Infrastructure Security and Energy Restoration (ISER) program primarily addresses physical security threats and hazards to the power grid. We will build upon existing work and expand for all hazards threat identification.
- Work in *Improve Ability to Protect against Threats and Hazards* spans several program areas with the biggest investment in cybersecurity by OE's CEDS program and the remaining investment by EERE's ESPC and OE's ISER, Smart Grid R&D, Advanced Grid Modeling Research, and Transmission Reliability which invest in a variety of activities to improve grid reliability and resiliency. Activities proposed in this MYPP will expand the work in these programs to develop robust communication systems and inherently security devices and systems.
- Ongoing and existing work in *Increase Ability to Detect Potential Threats and Hazards* is centered in OE's CEDS program and is strictly focused on cybersecurity. We propose development of physical-cyber based tools threat detection and analytics tools.
- There are currently no DOE funded projects in *Improve Ability to Respond to Incidents* area. A variety of activities are proposed to fill the needs in more resilient architectures, response tools, and human-in-the-loop response optimization.
- Activities in *Improve Recovery Capacity/Time* are funded by OE's CEDS and ESPC. CEDS is funding design of a resilient self-healing cybersecurity framework for the power grid and ESPC is funding post disruption event methods and models. We propose investment in modular transformer technology to rapidly replace critical large power transformers, development of requirements for a minimum essential communication network, and advancing requirements for EMP hardening of critical grid elements.

Table 10 contains specific details on the existing funding streams supporting FY15 Security and Resilience projects conducted at the DOE National Laboratories. The Briefing Papers contained in Appendix C specifically map our proposed future work in this technical area to the goals and objectives of the individual participating DOE Programs.

TABLE 10. EXISTING NATIONAL LABORATORY SECURITY AND RESILIENCE PROJECTS

Activity	Existing Major DOE Funded GMLC Projects in FY15
Improve Ability to Identify Threats and Hazards *11/12 Projects*	• OE – CEDS (7 projects) – C2M2, Supply Chain Integration (3), Digital Forensics, Source Code Theft, Configuration Management and Monitoring, • OE – ESPC (3 projects) – Pre-Event Methods/Models, Risk & Reliability Methods/Models; • OE – ISER – Physical Security Engagements
Increase Ability to Protect Against Threats and Hazards *13/20 projects*	• OE – CEDS (5 projects) – Quantum Security, Dynamic Defense, ARMORE • OE – ESPC (2 projects) – Industry Outreach, Interdependent Infrastructures; • OE – ISER (3 projects) – Risk Management, Global Security Engagement (2) • OE – Smart Grid – Grid Resilience • OE – TRRI – Reliability Technology Issues • OE – AGMR –Large-scale Power Grid Optimization

Activity	Existing Major DOE Funded GMLC Projects in FY15
Increase Ability to Detect Potential Threats and Hazards *6/8 projects*	• OE – CEDS (6 projects)– NSTB Project Outreach, CRISP, Advanced Monitoring (3), Characterization and Information Response, SIEGate
Improve Ability to Respond to Incidents *0/1 projects*	N/A
Improve Recovery Capacity/Time *2/4 projects*	• OE – CEDS – Resilient, Self-Healing Cybersecurity Framework for Power Grid • OE – ESPC – Post-Event Methods and Models
Total: *32/45 Projects*	

6.0 Security and Resilience

Activity	FY16	FY17	FY18	FY19	FY20	Technical Achievement
Improve Ability to Identify Threats and Hazards	*Task 6.1.1:* Expand the C2M2 model and best practices to include All Hazards (including physical) over the first year. Plan an annual update to capture new practices each year while maintaining the original best practices. Enhance the Risk domain of ES-C2M2 to include threat anticipation practices. Convene RMP participants to update RMP to align with C2M2 and add all hazards in the second year.					All hazards approach for threat identification and emergency response, which is accepted and implemented by the energy sector
		Task 6.1.2: Validate the new ES-C2M2 model with piloted on-site assessments and use the feedback to improve the model before publishing. Create an internet platform to house the tools and support anonymous analytics. Define annual requirements for trainers. Train private industry parties to perform assessments.				
		Task 6.1.3: Update analytics to support the new model which will allow stakeholders to understand their security posture and compare to peers. Develop risk management tools to support C2M2 and RMP.				
	Task 6.1.4: Define and hold annual cybersecurity vendor interoperability tests.					
		Task 6.1.5: Create analytic capability for CRISP sites.				
	Task 6.1.6: Create enhanced sensor technology for information sharing devices in CRISP. Create enhanced CRISP analytics with external entities. Define contents, security, and usability of a security data repository.		*Task 6.1.7:* Create a security data repository with rules tools for use.			
Increase Ability to Protect Against Threats and Hazards	*Task 6.2.1:* Issue a FOA to award a multi-lab, university, and industry consortium to lead communications infrastructure R&D and develop and evaluate all-hazards probabilistic damage models for grid components.	*Task 6.2.2:* Develop resiliency metrics, models, and evaluation tools to help vendors, integrators, decision makers and operators with resiliency based designs, infrastructure investment decision making, and operations.	*Task 6.2.3:* Demonstrate a Cyber upgrade on a legacy OT that can respond to and withstand a cyber-attack. Develop tight integration between interdependency predictive models and network optimization tools for creating and deploying technology integration and system response planning.	*Task 6.2.4:* Develop grid architectural alternatives and response and restoration logistical optimization techniques to minimize outage durations for system recovery planning. Examples include adaptive islanding, special protection schemes, and microgrids.	*Task 6.2.6:* Conduct a series of demonstrations to validate the seamless completion of scanning and patching activities of grid devices, without disruption to normal device operations and service. Tests will include multiple scales of grid operation.	Resilient grid components, supplemented by security procedures and optimization techniques
	Task 6.2.5: Develop an energy and communications interdependencies model for the energy sector including optimization techniques to enable utilities to discover and prioritize cost-effective system upgrades and expansions.					

6.0 Security and Resilience

<table>
<tr><th>Activity</th><th>FY16</th><th>FY17</th><th>FY18</th><th>FY19</th><th>FY20</th><th>Technical Achievement</th></tr>
<tr><td rowspan="3">Increase Ability to Detect Potential Threats and Hazards</td><td colspan="2">Task 6.3.1: Establish a secure and efficient data ingest and dissemination framework from devices and data sources critical to the cyber-physical integrity of the full grid system lifecycle, including planning, design, and operations.</td><td></td><td></td><td>Task 6.3.4: Conduct two region-based exercises in coordination with state and local governments and asset owners/operators to demonstrate an integrated real-time cyber-physical state awareness and early detection of threats and hazards.</td><td rowspan="3">Advanced cyber-physical data analytics spanning time scales across the system lifecycle enabling real-time response</td></tr>
<tr><td></td><td colspan="2">Task 6.3.2: Create baseline operating profiles of grid operations from a cyber-physical standpoint for the full system lifecycle including planning components, design components, and operational state. Build modeling/simulation capabilities to approximate full-system operating profiles prior to production implementation.</td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Task 6.3.3: Enable early detection of cyber threats and natural/physical hazards through cyber-physical data fusion and analytics leveraging the previously developed and vetted baseline operating profiles and data sources. Solutions will address multiple time scales (e.g. slow and stealthy cyber attacks or a sudden earthquake or storm) and apply across the system lifecycle from planning to design to operations.</td></tr>
<tr><td rowspan="4">Improve Ability to Respond to Incidents</td><td colspan="5">Task 6.4.1: Develop a common infrastructure degradation assessment framework and demonstrate/vet/deploy promising prototypes, which identify cyber-physical security attacks and failures and adapts OT behavior to maintain critical energy operations.</td><td rowspan="4">Methodologies and architectures frameworks which assess system degradation to all hazards, provide diverse attack recognition and mixed-initiative response on multiple timescales, and optimize operational priorities for the power grid</td></tr>
<tr><td colspan="5">Task 6.4.2: Develop a common cyber-physical data fusion framework and demonstrate/vet/deploy human system visualization prototypes which adapt the presentation of actionable information based upon the situational context and role to ensure a desired human response.</td></tr>
<tr><td colspan="5">Task 6.4.3: Develop a common cyber-feedback framework and demonstrate/vet/deploy promising prototypes that use intelligent, diverse cyber detection and autonomous feedback mechanisms for recognition and agile response to attack.</td></tr>
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<tr><td rowspan="6">Improve Recovery Capacity/Time</td><td colspan="2">Task 6.5.1: Establish and advance the application of standard impedance LPT and prototype modular impedance matching equipment and validate the design and implementation of modular impedance matching equipment using a traditional LPT or prototype standard impedance transformer in the laboratory.</td><td></td><td></td><td></td><td rowspan="6">Advanced substation and transformer designs and standards , Hardened fail-safe and wireless communications capabilities and devices</td></tr>
<tr><td></td><td colspan="3">Task 6.5.2: Evaluate the applicability of existing substation footprint, layout, and connection standards relative to applications using standard impedance transformers and modular impedance matching equipment and define revisions to substation standards to accommodate applications using these advanced technologies that mitigate existing portability and operational challenges to improve resilience.</td><td></td></tr>
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</table>

7.0 Institutional Support

State policymakers, regulatory agencies, and regional planning organizations play a critical role in shaping both the direction and pace of grid modernization. However, many of these organizations face significant challenges today, including small staff size and high staff turnover, significant budget constraints that limit training opportunities and access to technical experts, and, in some areas, insufficient technical expertise and experience. As a result, many state regulatory agencies are hard pressed to address the complex technological, policy, regulatory, and market issues related to grid modernization and deployment of distributed energy and intermittent renewable resources.[103] Potential new environmental regulations that require cooperation with other state officials (e.g., air quality regulators) and possibly regional compliance strategies that involve multiple states working together may also pose new challenges. Finally, many state regulators are also assessing whether existing cost of service regulatory models are sufficient to meet the needs and challenges facing utilities over the next decade or two. Thus, the demand for objective technical assistance (TA) and information on grid modernization topics from state regulatory agencies and regional planning organizations is high and likely to increase as the urgent and evolving needs of the modernizing grid gains momentum.[104]

> "THE PRIVATE SECTOR AND STATE REGULATORS ARE GOING TO DO MUCH OF WHAT HAS TO HAPPEN… [BUT] DOE CAN HELP, AND ITS ASSISTANCE WILL BE ESSENTIAL IF THE ENERGY SYSTEM IS TO MAKE THE NECESSARY ADVANCEMENTS."
>
> *Dr. David Danielson, Assistant Secretary for Energy Efficiency and Renewable Energy*

In the *Institutional Support* area, the DOE Grid Modernization Initiative will take advantage of the technical expertise, analytical tools, models, and data at National Laboratories, academic institutions, and the private sector to:

- Directly address high priority grid modernization challenges and needs identified by electric power industry stakeholders, with particular emphasis on state policymakers and regional planning organizations;[105]
- Convene key grid stakeholders as an honest-broker for collaborative dialogues around grid modernization and create an over-arching ongoing suite of grid-related "institutional" analysis, workshops, and dialogues to highlight challenges and explore options for transforming the grid, focusing on key policy questions related to new technologies, regulatory practices, and market designs.

Historically, various DOE offices (e.g. DOE OE NED and EERE) have funded *Institutional Support* activities often in response to requests for technical assistance from states and regional planning organizations.[106] DOE also recognizes that it is critical to work with and obtain input from key national and regional organizations and electric industry organizations and draw upon expertise from academic and public research organizations that focus on electricity markets and policy and/or offer training to state regulators (see Figure 3).[107]

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103 For example, state regulators generally have focused on planning and review of utility generation and transmission investments, with less emphasis on distribution system planning. State regulators have often addressed barriers to DER as well as their financial impacts on utilities on a piecemeal basis, which may be sub-optimal with greater penetration of DER.

104 Technical assistance can be defined as provision of technical expertise, information, analysis, and tools on electricity grid-related issues.

105 DOE OE Electricity Advisory Committee, "Expanding and Modernizing the Electric Power Delivery System for the 21st Century," Sept. 2014. http://energy.gov/sites/prod/files/2014/10/f18/ModernizingElectricPowerDeliverySystem.pdf

106 As part of Institutional Support activities, national laboratories have also prepared information and analysis products targeted at state policymakers and regulators on grid modernization topics. See http://energy.gov/oe/services/doe-grid-tech-team

107 Figure 3 provides a cross-section of national, regional and academic/public institutions; it is not meant to be comprehensive. Academic institutions that offer training and educational programs targeted to state regulators are shown with an asterisk in Figure 3. As an example, Rocky Mountain Institute (RMI) eLab includes thought leaders and decision makers from across the U.S. electricity sector and focuses on

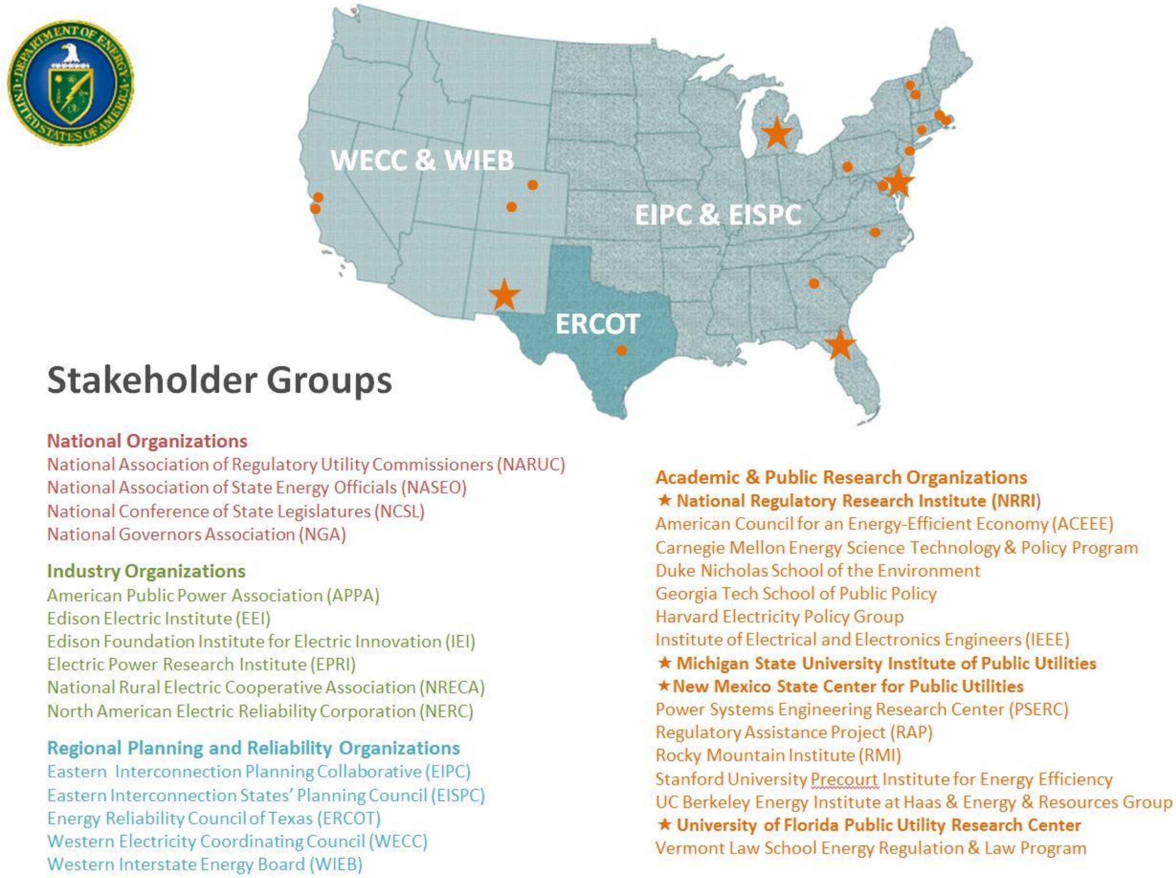

FIGURE 3. EXAMPLES OF NATIONAL, REGIONAL AND INDUSTRY ORGANIZATIONS AND ACADEMIC AND PUBLIC RESEARCH ORGANIZATIONS THAT ARE ACTIVE IN INSTITUTIONAL SUPPORT AREA

The ongoing collaborative engagement with a broad group of stakeholders under the Grid Modernization Initiative's Institutional Support technical area will strengthen and better inform the Grid Modernization R&D technical areas and may facilitate industry adoption of key R&D results (see Figure 4). Furthermore, the Institutional Support technical area will provide a valuable and transparent platform for collaborative dialogue and engagement with key electric power industry stakeholders as they seek to address their own grid modernization challenges. DOE will also strive through the DOE Grid Modernization Initiative to provide greater coordination, transparency, and a stakeholder-service orientation among the various DOE offices and National Laboratory staff and other TA partners in responding to TA requests from stakeholders.

collaborative innovation to address institutional, regulatory, business, economic, and technical barriers to the deployment of distributed resources. See http://www.rmi.org/elab

FIGURE 4. INSTITUTIONAL SUPPORT: TECHNICAL AND POLICY ASSISTANCE TARGETED AT KEY STAKEHOLDERS

Table 11 summarizes key planned DOE Grid Modernization Initiative activities and technical achievements for the Institutional Support area through 2020. The first two activity areas focus on expanding efforts to provide high-quality technical assistance (which includes objective, "honest broker" analysis and studies), primarily targeted to state energy agencies (e.g., public utility commissions, energy offices), tribal governments, consumer groups, regional planning organizations and utilities. The third activity area focuses on activities that analyze the potential impacts of (and barriers faced by) emerging technologies on grid operations and markets and develops analytic methods and tools to value distributed energy resources. The fourth activity area focuses on research on the future of electric utility regulation, which is critical for a grid modernization initiative whose success may depend on adapting the existing regulatory system to give load-serving entities the opportunity to create sustainable business models while incorporating emerging technologies that provide value-added energy services to customers and the nation.

TABLE 11. ACTIVITIES AND TECHNICAL ACHIEVEMENTS FOR INSTITUTIONAL SUPPORT

Activity	Technical Achievements by 2020
Provide Technical Assistance to States and Tribal Governments	• Technical assistance to all states and tribes to inform their electricity policy decision making and that accelerate policy innovation in at least 7 states (e.g., DR programs and resources in a post-FERC order 745 world, innovative strategies to acquire all cost-effective efficiency, policy, regulations and market designs that facilitate deployment of energy storage technologies) . • Technical analysis results to at least 10 states that allows them to establish formal processes to review utility distribution system plans, including guidance on how to consider Non-Wires Alternatives,[108] distributed energy resources, and advanced grid components and systems. • At least 10 other states have developed comprehensive energy system plans.

[108] Non-Wires Alternatives (NWA) can be defined as any action or strategy that could help defer or eliminate the need to construct or upgrade a transmission system and/or distribution system sub-stations and include, but are not limited to, demand response, dynamic retail pricing, distributed generation, energy efficiency, alternative power dispatch options, and application of technologies to expand the capacity of the system. [DOE OE Electricity Advisory Committee, "Recommendations on Non-Wires Solutions," Oct. 17, 2012.

Activity	Technical Achievements by 2020
Support Regional Planning and Reliability Organizations	• Regional planning & reliability organizations develop institutional frameworks, standards, and protocols for integrating new grid-related technologies, supported by DOE funding. • Facilitated long-term regional planning in each U.S. interconnection (e.g., conduct studies of potential clean energy zones in Eastern Interconnection; analyze impacts of market design changes in a region, such as Energy Imbalance Market in the West). • Coordinated regional long-term planning process in states that uses standardized, publicly available databases of transmission and regional resource data and planning assumptions.
Develop Methods and Resources for Assessing Grid Modernization: Emerging Technologies, Valuation, and Markets	• New methods for valuation of DER technologies (including energy storage) and services that are defined and clearly understood by stakeholders and enable informed decisions on grid investments and operations. • Analysis tools and methods that facilitate states' and tribes' integration of emerging grid technologies into decision-making, planning, and technology deployment. • New Grid Modernization performance and impact metrics and data collection methods, which are used by states and tribes to track Grid Modernization progress.
Conduct Research on Future Electric Utility Regulations	• 3-5 states have adopted fundamental changes and 8-10 states have adopted incremental changes to their regulatory structure that better aligns utility interests with grid modernization and clean energy goals.

The activities in the Institutional Support technical area will deliver Technical Achievements for each Activity area (see Table 11 above) as well as support the three "Integrated Regional Demonstrations" outlined in Chapter 8.0. Efforts in the first two activities of technical assistance to states and tribes and regional planning support provide the foundation for the third demonstration: "Advanced Modern Grid Planning & Analytics Platform". The activities in developing new valuation approaches for DER concepts, energy storage, and framing future alternative utility regulatory structures will inform the design and evaluation of the first two regional demonstrations: "Lean Reserve Margin Grid Bulk Power Systems" and "Clean Distribution Systems". They will identify new performance metrics relevant to modern grid constructs and identify data requirements for the demonstrations that will better inform regulatory analysis. Descriptions of each activity area follow.

7.1 Activity 1: Provide Technical Assistance to States and Tribal Governments

The primary goal of this activity is to provide independent and unbiased grid modernization related technical assistance (TA) (e.g., information, analysis, tools, and stakeholder-convened discussions) to state and tribal policymakers on existing and emerging policy, technology, regulatory, and market issues in the electricity sector. Historically, DOE's TA efforts have primarily been directed at state utility regulators, energy offices, and tribal governments.[109] DOE-sponsored technical support has focused on such topics as utility resource planning, policies, and programs related to energy efficiency, DR, renewable resources, and smart grid implementation issues (e.g., deployment of advanced metering infrastructure (AMI), time-based rates, and customer engagement and privacy

[109] Tribal entities include federally recognized Indian Tribes, bands, nations, tribal energy resource development organizations, and other organized groups and communities—including Alaska Native villages or regional and village corporations. The DOE Office of Indian Energy (IE) Policy and Programs and the EERE Tribal Energy Program currently support tribal TA assistance activities, which have focused primarily on planning and implementation of energy efficiency and clean energy generation projects.http://apps1.eere.energy.gov/tribalenergy/technical_assistance.cfm

concerns).[110] Looking out to 2020, with declining technology costs, changes in resource mix, and greater demands on the electric grid, we expect that state policymakers, regulators, utilities, and stakeholders will request technical assistance from DOE on a broader range of issues (see Table 12).[111]

TABLE 12. TECHNICAL ASSISTANCE TO STATES: EXAMPLES OF TOPICS AND ISSUES (NEW ISSUES SHOWN IN ITALICS)

Topic Area	Issues (New Issues Shown in Italics)
Cross-cutting Issues	• Resource valuation and cost/benefit analysis • *Market designs and rules that enable development and appropriate valuation of clean energy resources* • *Modeling and analysis for inter-jurisdictional coordination and multi-infrastructure interdependencies* • Future electric utility regulation (see activity area 4) • *Early-stage planning for electrification of transportation*
Energy Efficiency	• EERE Policy frameworks (e.g., EERS, requirements to acquire all cost-effective efficiency, IRP) • DSM planning processes and administration options for: program design, cost-effectiveness screening, potential studies, EM&V, strategies for financing EE • State-administered programs: energy-saving performance contracting, building codes, benchmarking and disclosure
Demand Response	• *Demand Response programs and resources in a post-FERC Order 745 world* • Policy and market barriers to DR providing ancillary services; DR as enabler for higher levels of variable generation • Design and evaluation of time-varying pricing and DR programs with customer enabling technologies
Distributed Generation *and Micro-grids*	• Policies such as net metering, feed-in tariffs, bi-directional tariffs, CHP solicitations, RPS carve-outs, state tax credits, rebates, utility ownership or leasing, and multi-party micro-grids • Treatment in Integrated Resource Planning, distribution and transmission system planning • Valuation, including locational- and time-based benefits and costs • Interconnection standards/procedures and standby rates • *Interactions and coordination with utility distribution systems under normal and emergency operating conditions*
Energy Storage	• Policies, regulations, and market designs that support energy storage; treatment in utility resource and T&D planning • *Valuation and compensation strategies, including providing ancillary services and increased flexibility* • *Role in supporting critical service providers (e.g., hospitals and fire stations) and as enabling technology for higher levels of renewable resources* • *Monitoring and providing technical information on demonstration projects and incentive programs*
Utility-Scale Renewable Resources	• State policies (e.g., RPS and renewable energy credits) • Treatment of utility-scale renewable resources in resource planning and procurement • Flexibility metrics for resource planning and acquisition
Fossil Fuel and Nuclear Resources	• *Role of natural gas, including as a flexibility resource* • *Role of nuclear power, including as a clean energy resource* • *Role of coal, including carbon capture and sequestration* • *Impacts of potential environmental regulations on system reliability and fuel diversity* • *Treatment of potential future environmental regulations in planning and acquisition of generation resources and analysis of potential power plant upgrades*
Distribution System	• *Planning to enable two-way flows of energy and information, including integration of advanced monitoring, controls, volt/VAR optimization, IT management, and communications systems* • *Optimizing voltage and reactive power on distribution systems*

[110] See DOE OE (http://energy.gov/oe/technical-assistance-topics) and DOE EERE (http://energy.gov/eere/services/states-and-local-communities) and DOE Smart Grid (https://www.smartgrid.gov/) and NARUC (http://www.naruc.org/grants/default.cfm?page=2).

[111] Technical assistance is also provided on request to rural electric cooperative boards and municipal utilities.

Topic Area	Issues (New Issues Shown in Italics)
Planning and Operation	• *Integration of non-wires solutions, including geo-targeting* • *Adapting state utility regulations to changes in distribution system operations* • *Avoiding adverse effects of distribution-level technologies on the transmission system*
Transmission System Planning and Operation	• Treatment of transmission in utility integrated resource planning • Integration of utility resource planning and sub-regional/regional transmission planning • *Integration of energy efficiency, DR, DG, variable generation, and energy storage in utility transmission planning* • Reliability, security, and resiliency

- **State Institutional Support for Reliability and Assurance Planning** – DOE will support states that want to develop more comprehensive energy system plans as part of grid modernization.

  Task 7.1.1: Provide technical assistance to all states and tribes to inform their electricity policy decision making and that accelerate policy innovation in at least seven states [FY16-FY20]

  Task 7.1.2: Administer and implement a new program that will provide grants to states, localities, and tribal entities for electricity transmission, storage, and distribution reliability and resilience plans. [FY16-FY18]

- **Expanded Technical Assistance –** With additional resources, DOE will provide TA on a broader set of topics (see Table 12) as well as target additional actors. TA efforts will be critically important to help state policymakers, regulators, utilities and stakeholders make more informed decisions to address the challenges of grid modernization.

  Task 7.1.3: Provide technical support to at least ten states to allow them to establish formal processes to review utility distribution system plans, including guidance on how to consider non-wires alternatives, distributed energy resources (including energy storage), and advanced grid components and systems. [FY16-FY20]

- **TA to Tribal Entities** – Tribal governments tend to be underserved with respect to electric service; widespread grid modernization could exacerbate this service gap. [112]

  Task 7.1.4: As requested, DOE will provide technical support to analyze impacts of grid modernization on tribal entities. [FY16-FY17]

7.2 Activity 2: Support Regional Planning and Reliability Organizations

Grid modernization and rapid deployment of emerging technologies require greater regional coordination in both grid operation and expansion planning. Regional planning and reliability organizations (RP&ROs) will continue to play a central role in coordinating long-term transmission planning for the bulk power system[113] [114], provide favorable institutional and market conditions for the development of clean energy resources on a regional scale

[112] Federal engagement on tribal lands is distributed across several agencies. Projects on tribal lands can be costly to develop and build and project financing can be difficult to obtain.

[113] Eastern Interconnection Planning Council, *EIPC final DOE Statement of Project Objectives*, http://www.eipconline.com/uploads/SOPO_14Jul10_DE-OE0000343.pdf (July 14, 2010).

[114] Eastern Interconnection States' Planning Collaborative has funded numerous white papers and studies on transmission planning and support issues located at: *Publications – NRRI Knowledge Communities* http://communities.nrri.org/web/eispc/publications (June 2012 - April 2015)

(e.g., energy zones)[115], and ensure that the grid is resilient and reliable[116]. These entities include regional planning organizations comprised of state policymakers and regulators (e.g., the Eastern Interconnection States Planning Council and Western Interstate Energy Board), regional reliability planning organizations (WECC, Eastern Interconnection Planning Collaborative, ERCOT, and regional reliability coordinators), regional grid operators (ISO and RTOs) and national reliability organizations (NERC).

RP&ROs have varying technical capabilities, resources, and responsibilities and face a number of challenges, including (1) limited information sharing and communications among different planning entities across regions; (2) challenges in coordinating and developing physical and cybersecurity standards and protocols, (3) difficulties developing institutional support and removing barriers for integration of new technologies and modernization of electric grid, and (4) coordinating planning and operation of the electricity sector and other infrastructure sectors (e.g. gas and water). Regional policymaker organizations generally have had limited technical expertise and funding; thus, DOE has focused technical support on key issues faced and requested by their members.

The primary goals of this activity are to: (1) provide unbiased information, analysis, tools and resources that help RP&ROs develop their capabilities to address key policy, regulatory, program, and market issues and (2) provide technical expertise that supports development of institutional frameworks, standards, protocols, and enhanced modeling tools for integration of new technologies into the grid.

Activities in this activity area include:

- **Facilitate long-term regional planning at the inter-connection level.**

    Task 7.2.1: Coordinate regional long-term planning process in the Western Interconnection that uses standardized, publicly available databases of transmission and regional resource data and planning assumptions. [FY16-FY20]

    Task 7.2.2: Analyze regional market design issues, such as the Energy Imbalance Market in the Western Interconnection, and other options that may provide greater flexibility to the power grid. [FY18-FY20]

    Task 7.2.3: Conduct studies of potential clean energy zones and new energy corridors within the Eastern Interconnection to assist in coordinated regional resource and transmission planning. [FY16-FY18]

    Task 7.2.4: Conduct studies of electric sector interdependencies with other infrastructure sectors (e.g., natural gas, water, transportation) that will facilitate increased coordination in operation and planning of different infrastructures resulting in greater reliability and resilience. [FY16-FY20]

- **Assist regional planning and reliability organizations in developing institutional frameworks, standards and protocols for integrating emerging technologies as well as for the physical and cybersecurity of the grid.**

    Task 7.2.5: Provide technical support for developing design requirements for enhancing existing tools or for developing new analytical tools to model and simulate integrating emerging smart grid and DER technologies (including energy storage) in the grid at the interconnection level. [FY17-FY19]

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[115] EISPC, ANL, NREL, ORNL, DOE, *EISPC EZ Mapping Tool* https://eispctools.anl.gov (April 2015). Since its public release in April 2013, over 1,200 users have registered for the EZ Mapping Tool, including federal and state energy planners, energy regulatory agencies, public utility commissions, grid operators, utilities, non-governmental organizations, universities, and researchers.

[116] Eastern Interconnection Planning Collaborative, *Phase II Final Report*, http://www.eipconline.com/Phase_II_Documents.html (Dec. 22, 2012)

7.3 Activity 3: Develop Methods and Resources for Assessing Grid Modernization - Emerging Technologies, Valuation, and Markets

This activity focuses on providing analyses, case studies, and tool development for decision makers to facilitate stakeholder engagement and address the challenges posed by increased deployment of emerging technologies on the electric grid, particularly more DER.[117] The overarching goal of this activity is to reduce risks and better inform investment decisions regarding emerging technologies enabled by grid modernization.

The primary programmatic objectives of this activity are to: (1) enable state regulators and utilities/grid operators to manage large -scale integration of emerging technologies and integrate physical and cybersecurity into decision-making, planning, and technology deployment and (2) sufficiently define opportunities for consumers to participate in the energy market.

Research projects in this activity area include:

- **Valuation of DER** – Widely accepted, quantifiable methods to value the potential benefits and costs of DER are a high priority for state regulators (e.g., prices to be paid to customers that have installed distributed PV or other DER including energy storage). DER valuation methods will facilitate development and standardization of emerging grid-related products and services and help clarify potential roles and opportunities for consumers.

  Task 7.3.1: Develop an analytical framework and tools for valuing potential benefits, costs, and impacts of distributed energy resources on grid functions and services that are well-defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations. [FY16-FY18]

  Task 7.3.2: Develop and implement informational activity targeted at regulators, policy makers, consumers and utilities on valuation of DER technologies: annual workshops, periodic reports, and ongoing TA. [FY17-FY20]

- **Mitigate market barriers** – Analyze emerging technologies to identify current and future market barriers and alternatives in order to reduce market entry impediments and characterize the potential market impacts of customers' technology choices.[118]

  Task 7.3.3: Perform two to three focused analyses per year of emerging technologies to characterize the barriers posed by existing market structures and identify options to reduce market entry impediments. [FY16-FY20]

- **Metrics that measure progress toward a safer, more resilient, efficient, low-carbon electric infrastructure that enables services innovation** – The complex nature of the Grid Modernization Initiative—including RD&D,

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[117] These DER technologies are deployed behind the substation, either within the distribution system or more prevalently on the customer-side of the meter and include renewable resources with variable power generation (e.g., solar PV, and community wind), energy storage, electric vehicles, microgrids, and demand response, including consumers' price-responsive connected devices. Stanton Hadley, Alan H. Sanstad, *Impacts of Demand-Side Resources on Electric Transmission Planning*, ORNL/TM-2014/568, Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory, http://energy.gov/epsa/downloads/report-impacts-demand-side-resources-electric-transmission-planning (January 2015).

[118] New York Independent System Operator (NYISO), *A Review of Distributed Energy Resources. New York Independent System Operator*, 2014, URL: http://www.nyiso.com/public/webdocs/media_room/publications_presentations/Other_Reports/Other_Reports/A_Review_of_Distributed_Energy_Resources_September_2014.pdf; U.S. Energy Information Administration, *Electricity storage technologies can be used for energy management and power quality,* 2011. URL: http://www.eia.gov/todayinenergy/detail.cfm?id=4310

technology transfer, market development, industry investment, and institutional support—necessitates a well-developed set of metrics to assess research and policy tradeoffs and to measure and quantify progress.[119]

Task 7.3.4: Work with policymakers and key stakeholders to develop a set of grid modernization performance and impact metrics, data collection methods and a common methodology to quantify metrics in order to track grid modernization progress.[120] [FY16-FY18]

- **Advanced Grid Concepts** – Disseminate information on advanced grid concepts (e.g., novel grid architectures) and their potential implications on the design of market structures and business models in leading states.

7.4 Activity 4: Conduct Research on Future Electric Utility Regulations

Given the capital investment requirements of a modernized grid and the emergence of new, potentially disruptive technologies, many state regulators are re-examining their existing regulatory structures.[121] Specifically, whether existing cost-of-service (COS) regulatory models align well with state and federal policy goals and meet the needs of and challenges facing utilities and customers over the next decade or two.[122]

Key challenges for state policymakers and regulators in this activity area include the following:(1) enlisting utilities as partners in grid modernization, (2) balancing the interests of customers and utilities with achievement of grid modernization goals, and (3) determining whether and how to change regulatory models and identify evolving roles and responsibilities for utilities and other service providers in that process, recognizing that regulatory oversight and governance varies among utilities (e.g., investor-owned utilities, rural electric cooperatives, and publicly-owned utilities).

The primary objectives in this activity area are to provide analysis and modeling tools and technical assistance to state regulators, utilities, and industry stakeholders to support analysis of key issues facing state PUCs considering proposals for incremental or fundamental changes to existing regulation and to facilitate customer choice and engagement in the electricity system.[123] Figure 5 provides examples of key analysis activities for those utilities considering pathways to new business models (e.g., developing performance mechanisms that incent utilities to create value for customers as part of a performance-based regulation approach).[124]

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[119] An excellent discussion on the need for a national metric framework to assess resilience can be found in The National Academies, *Disaster Resilience: A National Imperative* (Washington, DC: The National Academies Press), 2012.

[120] Metrics and data collection could be developed for such grid characteristics as impacts to cost, reliability, grid flexibility, resilience, efficiency, carbon intensity, and criteria emissions. This would also include economic valuation of metrics which are not typically reported in monetary value such as reliability, emissions, and worker and public safety.

[121] New York State Department of Public Service, *Reforming the Energy Vision: Staff Report and Proposal* (Albany, NY, 2014).

[122] Elisabeth Graffy, Steven Kihm, "Does Disruptive Competition Mean a Death Spiral for Electric Utilities?" *Energy Law Journal* 35:1 (2014): 1-44; see Peter Kind, Energy Infrastructure Advocates, *Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business*. (Washington, D.C.: Edison Electric Institute, 2013).

[123] DOE OE Electricity Advisory Committee, "Recommendations regarding Emerging and Alternative Regulatory Models and Modeling Tools to assist Analysis, Sept. 2014. See http://energy.gov/sites/prod/files/2014/10/f18/Recs-EmergAltRegModels-Tools.pdf

[124] Key issues include: (1) financial impacts of DER on utility shareholders and customers; (2) efficacy of alternative ratemaking and regulatory approaches; and (3) transition strategies and design options for performance-based regulatory approaches that tie utility earnings to meeting particular outcomes See Peter Fox-Penner, *Smart Power: Climate Change, the Smart Grid, and the Future of Electric Utilities* (Washington, DC: Island Press, 2010 and 2014). James Newcomb, Virginia Lacy, Lena Hansen, *New Utility Business Models for the Distribution Edge: The Transition from Value Chain to Value Constellation* (Boulder, CO: Rocky Mountain Institute, 2013).

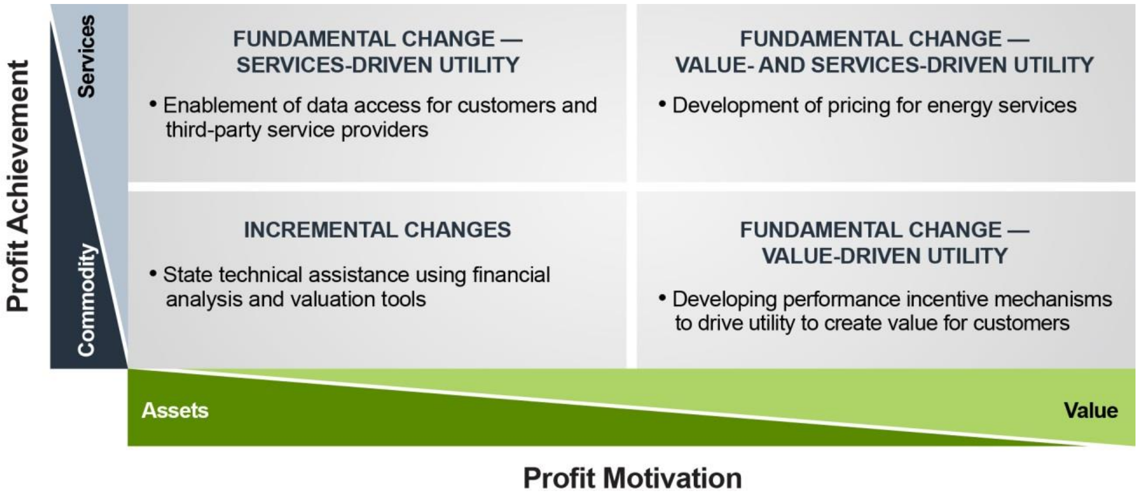

FIGURE 5. ELECTRIC UTILITY BUSINESS MODELS: KEY ACTIVITIES

Activities in this area include:

- **Development and Support of Utility Financial Analysis Modeling Tools**

  Task 7.4.1: Support utility financial analysis modeling tools to address regulatory and utility business model issues to enable assessments of impacts of alternative regulatory and ratemaking approaches on utility shareholders and customers. [FY16-FY19][125]

- **Technical Assistance and Analysis**

  Task 7.4.2: Provide TA to at least eight state PUCs and utilities on ratemaking alternatives to existing regulation (e.g., shareholder incentive mechanisms, lost revenue recovery mechanisms, and rate design changes) using DOE-supported utility financial analysis modeling tools, other analytic resources and/or stakeholder-convened discussions. [FY16-FY20]

  Task 7.4.3: Provide TA to at least three "leading" states and utilities that are considering fundamental changes to their existing regulatory model (e.g., performance incentive mechanisms that align utility profitability with state clean energy and grid modernization policy goals). [FY16-FY17] and to five states (and utilities) by FY20 [FY18-20][126]

  Task 7.4.4: Provide TA to at least five states that are considering policy guidelines on third party access to customer hourly interval load data and pricing of value-added services, which facilitates development of energy services markets and customer choice and engagement. [FY16-FY20]

7.5 Links to Other Grid Modernization Technical Areas

The proposed activities in the Institutional Support area will be coordinated with other Grid Modernization Initiative technical areas to maximize the value of the entire initiative and will create a pathway for state, regional, tribal governments, and other stakeholders to give guidance to the other R&D areas on tools and analyses that will

[125] Andy Satchwell, Andrew Mills, Galen Barbose, Ryan Wiser, Peter Cappers, Naim Darghouth, *Financial Impacts of Net-Metered PV on Utility and Ratepayers: A Scoping Study of Two Prototypical U.S. Utilities* (Berkeley, CA: Lawrence Berkeley National Laboratory, 2014).

[126] Melissa Whited, Tim Woolf, Alice Napoleon, Synapse Energy Economics, Inc., *Utility Performance Incentive Mechanisms: A Handbook for Regulators* (Denver, CO: Western Interstate Energy Board, 2015).

be of use in the electricity sector. The other technical areas can use the activities in Institutional Support to broadcast their capabilities, tools, and analyses to stakeholders so that DOE-funded research capabilities can be more effectively used. These pathways of links are shown in Figure 4 at the beginning of the Institutional Support chapter. Examples of such linkages are:

- Activity 7.1 will involve working with state and tribal government entities on incorporating the latest information on grid **Security and Resilience**, **Design and Planning Tools**, and modernized equipment and **Sensing and Measurements** devices into their regulations and policies.
- Activity 7.2 brings in the larger multi-state entities into the research being conducted on grid modernization. These stakeholders have an increasingly critical role in effective implementation of the modernization efforts on grid **Devices and Integrated Systems; System Operations, Power Flow, and Control**; **Sensing and Measurements** and communications; and grid **Security and Resilience**.
- Activity 7.3 includes analysis, case studies and tool development primarily designed to support policy makers. The **Institutional Support** team will work with policymakers and key stakeholders to obtain input on design requirements and use cases, which will be shared with the **Design and Planning Tools** research team.
- Activity 7.4 looks at the broader future of electric sector regulation. The **Institutional Support** team will include and draw upon advances in emerging technologies, grid architecture and design, data availability, and simulation to inform discussions among policymakers and key stakeholders on transition strategies and alternatives to existing regulatory models (and policies). Information will be drawn from the **System Operations, Power Flow, and Control**; **Sensing and Measurements; Design and Planning Tools; and Devices and Integrated Systems Testing** technical areas.

7.6 Links to Existing DOE Portfolio

The proposed work in Institutional Support builds upon the existing activities of the various Program offices within the DOE in the following manner:

- *Technical Assistance to State and Tribal Governments (TA 7.1)* work in the DOE OE Electricity Policy Technical Assistance Program focuses on technical support to states and tribes on their electricity-related policies.[127] Technical assistance activities supported by the DOE EERE Solar and Strategic Programs offices focus on renewable integration issues and overcoming barriers to distributed PV. The DOE EERE State Energy Program's competitive financial assistance program awards grants to state/local governments in focused areas to test innovative policy approaches and programs that incentivize energy efficiency and renewable energy technology deployment at the state level. The DOE EERE Tribal Energy Program and the DOE Office of Indian Energy Policy and Programs focus on technical assistance on renewable energy assessments and micro-grids for tribal communities. The OE Energy Storage program provides assistance to states and regional entities in the siting, commissioning, and evaluation of energy storage systems deployed on the grid. We will also provide technical assistance on a broader set of topics as well as target additional industry stakeholders (e.g. utilities, consumer groups).
- *Support Regional Planning and Reliability Organizations (TA 7.2)* work in DOE OE focuses primarily on technical support on high priority projects identified by regional planning organizations at the interconnection level.

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[127] Topics of interest include, but are not limited to: transmission and electric system resource planning; reliability and resiliency; demand response and smart grid; regulated utility business models; integrating variable generation; rate-payer funded energy efficiency; electric sector interdependencies (e.g., gas-electric, water, transportation); environmental regulations; and resource diversity. http://energy.gov/oe/services/electricity-policy-coordination-and-implementation/electricity-policy-technical

Technical resources are limited at present; an expanded technical support activity will enable regional planning organizations to address key grid modernization issues (see Activity 7-2). Projects supported by various DOE OE and EERE offices also support regional governmental associations, international smart grid partnerships, collaborations, and technical exchanges on grid integration support and analysis.

- *Resources and Methods for Assessing Grid Modernization* projects (TA 7.3) supported by the DOE EERE Solar Energy, Wind Energy Geothermal, and Strategic programs primarily focus on grid and market implications for specific technologies. We will build on this work by developing more comprehensive approach to valuation of DER, by developing grid modernization performance and impact metrics and data collection methods that can track progress, and by analysis of barriers in existing market structures (and options for mitigating barriers) faced by emerging technologies.
- *Research on Future Electric Utility Regulations* projects (TA 7.4) supported by DOE OE focus on technical assistance and financial analysis tools that support state regulators, utilities and stakeholders in assessing proposed changes to ratemaking or existing regulatory models. EERE Wind and Solar program projects focus on developing a framework for solar policy and market development and disseminating policy analysis and implementation strategies to decision makers. We will build upon this work by enhancing utility financial analysis modeling tools to support analysis of emerging regulatory policy issues and by supporting industry dialogues and workshops on future regulatory and utility business models drawing primarily from a series of DOE-supported “concept papers” on issues and models for regulating electric utilities and achieve grid modernization goals. These activities will support states seeking to make incremental and fundamental changes to their regulatory model.

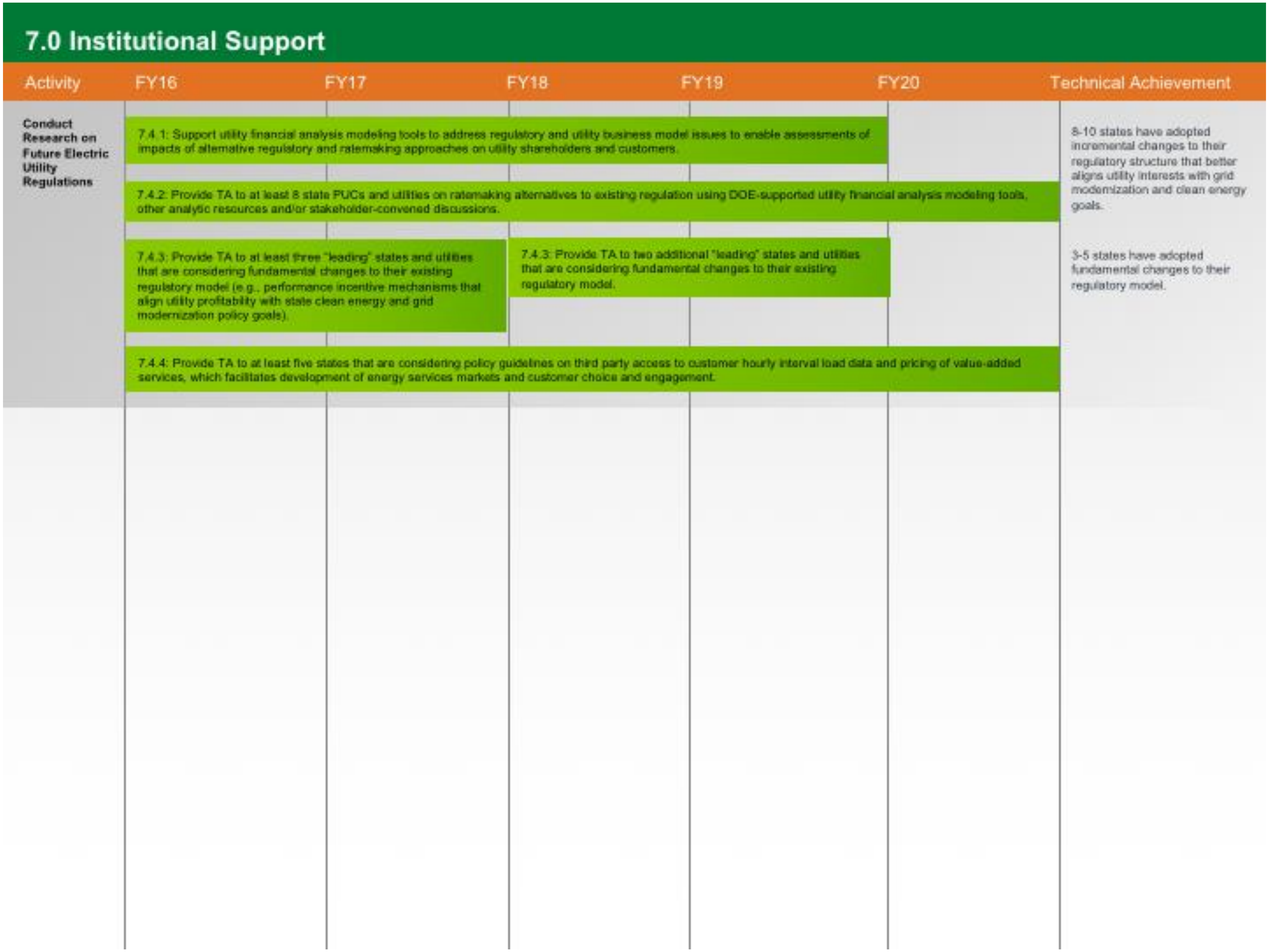
Table 13 includes additional details on existing program activities supporting FY15 projects in the Institutional Support area. The Briefing Papers contained in Appendix C map our proposed future work in this technical area to the goals and objectives of the individual participating DOE programs.

TABLE 13. INSTITUTIONAL SUPPORT: EXISTING PROGRAM ACTIVITIES AND FUNDING

Activity	Existing Major DOE Funded GMLC Projects in FY15
Technical Assistance to States and Tribal Governments ***14 Projects***	• EERE Solar/Water – Renewable Integration, Strategic Stakeholder Engagement, Distributed PV, Codes and Standards • OE – Energy Efficiency and Renewable Energy Policy and Programs, Smart Grid Implementation Issues • OE – Energy Storage – State storage efforts in WA, OR, CA, HI, VT. • DOE Office of Indian Energy (IE) Policy and Programs – TA to Alaska Tribal Governments on microgrid and renewable energy implementation issues • EERE VTO – Codes /Standards support
Support Regional Planning and Reliability Organizations ***18 Projects***	• EERE Wind/Solar – Grid Integration Support, Comparative Grid Integration Analysis (International Partnerships) • OE – Physical Security Engagements, EISPC Mapping Tool & Analysis, WIEB Utility Resource Planning, Smart Grid International; Energy-water Nexus
Develop Resources and Methods for Assessing Grid Modernization: Emerging Technologies, Valuation and Markets ***7 Projects***	• EERE Solar, Wind, Geothermal, and Strategic Analysis Program – Demand Response and DER Valuation, Grid and Market Implications for Specific Technologies, Vehicle-to-Grid Modeling; Understanding Inefficiencies in Electric Market Operations; Geothermal Power & Intermittent Generation
Conduct Research on Future Electric Utility Regulations ***7 Projects***	• OE – Regulatory Utility Business Models, Financial Analysis Model Tool: Impacts to Utility Earnings • EERE Solar and Wind – Innovative Policy Stacking and Grid Operations: Market Impact Analysis
Total: 46 Projects	

7.0 Institutional Support

Activity	FY16	FY17	FY18	FY19	FY20	Technical Achievement
Provide Technical Assistance (TA) to States and Tribal Governments	7.1.1: Provide technical assistance to all states and tribes to inform their electricity policy decision making and that accelerate policy innovation in at least 7 states					At least 7more states have developed comprehensive energy system plans
	7.1.2: Assist states, localities, and tribal entities with electricity transmission, storage, and distribution reliability and resilience plans. [FY16-FY18].					At least 10 states establish formal processes to review utility distribution system plans
	7.1.3: Provide technical support to at least ten states to allow them to establish formal processes to review utility distribution system plans, including guidance on how to consider non-wires alternatives, distributed energy resources, and advanced grid components and systems.					At least 10 other states have developed comprehensive energy system plans
	7.1.4: As requested, DOE will provide technical support to analyze impacts of grid modernization on tribal entities.					
Support Regional Planning and Reliability Organizations (RP&RO)	7.2.1: Coordinate regional long-term planning process in the Western Interconnection that uses standardized, publicly available databases of transmission and regional resource data and planning assumptions.					
			7.2.2: Analyze regional market design issues, such as the Energy Imbalance Market in the Western Interconnection, and other options that may provide greater flexibility to the power grid.			Each U.S. interconnection has an established long-term regional plan
	7.2.3: Conduct studies of potential clean energy zones and new energy corridors within the Eastern Interconnection to assist in coordinated regional resource and transmission planning.					RP&RO have integrated emerging technologies into their institutional frameworks, standards and protocols
	7.2.4: Conduct studies of electric sector interdependencies with other infrastructure sectors that will facilitate increased coordination in operation and planning of different infrastructures resulting in greater reliability and resilience.					
		7.2.5: Provide technical support for developing design requirements for enhancing existing tools or for developing new analytical tools to model and simulate integrating emerging smart grid and DER technologies in the grid at the interconnection level.				
Develop Methods and Resources for Assessing Grid Modernization: Emerging Technologies, Valuation and Markets	7.3.1: Develop an analytical framework and tools for valuing potential benefits, costs, and impacts of distributed energy resources on grid functions and services that are well-defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations.					New performance and impact metrics and data collection methods which are used by states to track Grid Modernization progress.
		7.3.2: Develop and implement informational activity targeted at regulators, policy makers, consumers and utilities on valuation of DER technologies: annual workshops, periodic reports, and ongoing TA.				
	7.3.3: Perform two to three focused analyses per year of emerging technologies to characterize the barriers posed by existing market structures and identify options to reduce market entry impediments.					Stakeholders are enabled to make informed decisions on grid investments and operations.
	7.3.4: Work with policymakers and key stakeholders to develop a set of grid modernization performance and impact metrics, data collection methods and a common methodology to quantify metrics in order to track grid modernization progress.					


7.0 Institutional Support
Activity
FY16
FY17
FY18
FY19
FY20
Technical Achievement
Conduct Research on Future Electric Utility Regulations
7.4.1: Support utility financial analysis modeling tools to address regulatory and utility business model issues to enable assessments of impacts of alternative regulatory and ratemaking approaches on utility shareholders and customers.
7.4.2: Provide TA to at least 8 state PUCs and utilities on ratemaking alternatives to existing regulation using DOE-supported utility financial analysis modeling tools, other analytic resources and/or stakeholder-convened discussions.
7.4.3: Provide TA to at least three "leading" states and utilities that are considering fundamental changes to their existing regulatory model (e.g., performance incentive mechanisms that align utility profitability with state clean energy and grid modernization policy goals).
7.4.3: Provide TA to two additional "leading" states and utilities that are considering fundamental changes to their existing regulatory model.
7.4.4: Provide TA to at least five states that are considering policy guidelines on third party access to customer hourly interval load data and pricing of value-added services, which facilitates development of energy services markets and customer choice and engagement.
8-10 states have adopted incremental changes to their regulatory structure that better aligns utility interests with grid modernization and clean energy goals.
3-5 states have adopted fundamental changes to their regulatory model.

8.0 DOE Integrated Regional Demonstrations

Technical achievements both within and across the DOE Grid Modernization Initiative's six technical areas will provide the tools and technologies necessary to achieve the Initiative's vision of a modernized grid that provides a platform for innovation and economic growth and that is resilient, reliable, secure, affordable, flexible, and sustainable.

However, success can only occur when the tools and technologies are combined together to provide real-world solutions. Consequently, DOE has developed frameworks for three types of Integrated Regional Demonstrations that will each demonstrate the attributes of a modernized grid described above.

1. Lean Reserve Margin Grid Bulk Power Systems,
2. Clean Distribution Systems, and
3. Advanced Modern Grid Planning and Analytics Platform.

"UTILITIES ARE NOT GOING TO CREATE THIS FUTURE ALONE... OUR ROLE IS GOING TO BE ABOUT PROVIDING THE MEANS TO INTEGRATE ALL OF THIS INNOVATION."

Anthony Earley, President and CEO of Pacific Gas & Electric

The following sections describe the Integrated Regional Demonstrations and highlight the MYPP activities required to bring them to fruition. These will be accomplished through research, development, demonstration, and validation in laboratory and virtual environments, and ultimately in a portfolio of ten or more field demonstrations that will be awarded competitively to Regional Grid Partnerships (RGPs). These major demonstrations will begin in the 3rd and 4th year of the current MYPP and will continue past FY20.

The Regional Grid Partnerships will build on DOE work with states, regions, and other stakeholders. They will incorporate features from all the technology, policy, regulatory, and business efforts DOE and its partners perform. The RGPs will also build on work done in the Smart Grid grants and demonstrations, in state funded projects like the NY PRIZE awards, and by the utility sector. The goal is to collectively pull from the best work to date and demonstrate the most advanced grid projects and activities in the world.

8.1 DOE Integrated Regional Demonstration 1: Lean Reserve Margin Grid Bulk Power Systems

Description: Emerging capabilities that allow complete visibility of the power system from real-time sensor networks (across transmission and distribution) enables new approaches to system design, control, operations, protection, and optimization. The GMI proposes to demonstrate a reliable and affordable power system with a substantially reduced system reserve capacity (generation and delivery); thereby substantially improving the economic productivity of the modernized grid and utilizing more distributed resources.

Value Proposition/Success Metrics:

By 2020, the Grid Modernization Initiative will develop and initiate public-private demonstrations in three to four regions across the country with the following properties.

1. **Reliable:** Modernized grid design framework (architecture and controls) to meet reliability criteria with 10 percent reserve margin at the regional reliability area level, and validate regional reliability and cost performance based on simulated testing.
2. **Affordable:** New operations capability for grid operators to safely run system closer to grid edge for increased asset utilization and leverage distribution-level grid services that require less generation reserve.

3. **Secure:** Advanced physical and cybersecurity measures for the integration of large numbers of devices, and predictive operations tools to detect and mitigate risk in real-time.
4. **Sustainable:** Real-time tools improve operator ability to manage transmission systems with higher penetration of variable renewable generation, enable higher transmission asset utilization, and reduce need for transmission expansion.
5. **Resilient**: Outages reduced by orders of magnitude with improved prediction, detection, and distributed controls.
6. **Flexible:** Advanced approaches to controlling consumer demand such as transactive control coupled with T&D control tools allows for higher levels of renewable generation and more complex consumer loads.

Integrated Approach (FY16 – FY20)

Successful demonstration of reliable operations with reduced system reserve margin will require integration of advances from all six technical areas of the MYPP.

FY16 – FY17:

- Develop a grid architecture view of system with full transparency and capacity to control entire system scope (centralized to distributed). This establishes the framework for control of demand side assets to enhance reserve margins.
- Develop a new class of sensors (at the transmission, distribution, and building scale) and real-time communications (at the interconnection scale) that are robust across a range of systems conditions.
- Develop a platform for advanced EMS/DMS/BMS software that leverages both centralized and decentralized control capabilities; thus enabling real-time coordination of assets at all scales sufficient for reliable operations.
- Develop an integrated T&D stochastic planning tool to enable high resolution testing of new control and protection systems.
- Develop testing and interoperability standards for loads, storage, and DER power electronics that enable reliable distributed demand response control.

FY18:

- Conduct simulated testing of protection, control, and restoration activities of the “lean reserve” system approaches at component levels working with industry.

FY19:

- Model system performance at reliability region and interconnection levels that are representative of main attributes in current U.S. operations by utilities.
- Work with regional planning entities and regulators to examine necessary institutional innovations and establish cost benefit approaches to establish evaluation basis for FY20 – FY25 demonstrations.

FY20 – FY25:

- Develop public/private demonstrations in three to four regions.
- Monitor and document operations.
- Help industry adopt best practices.

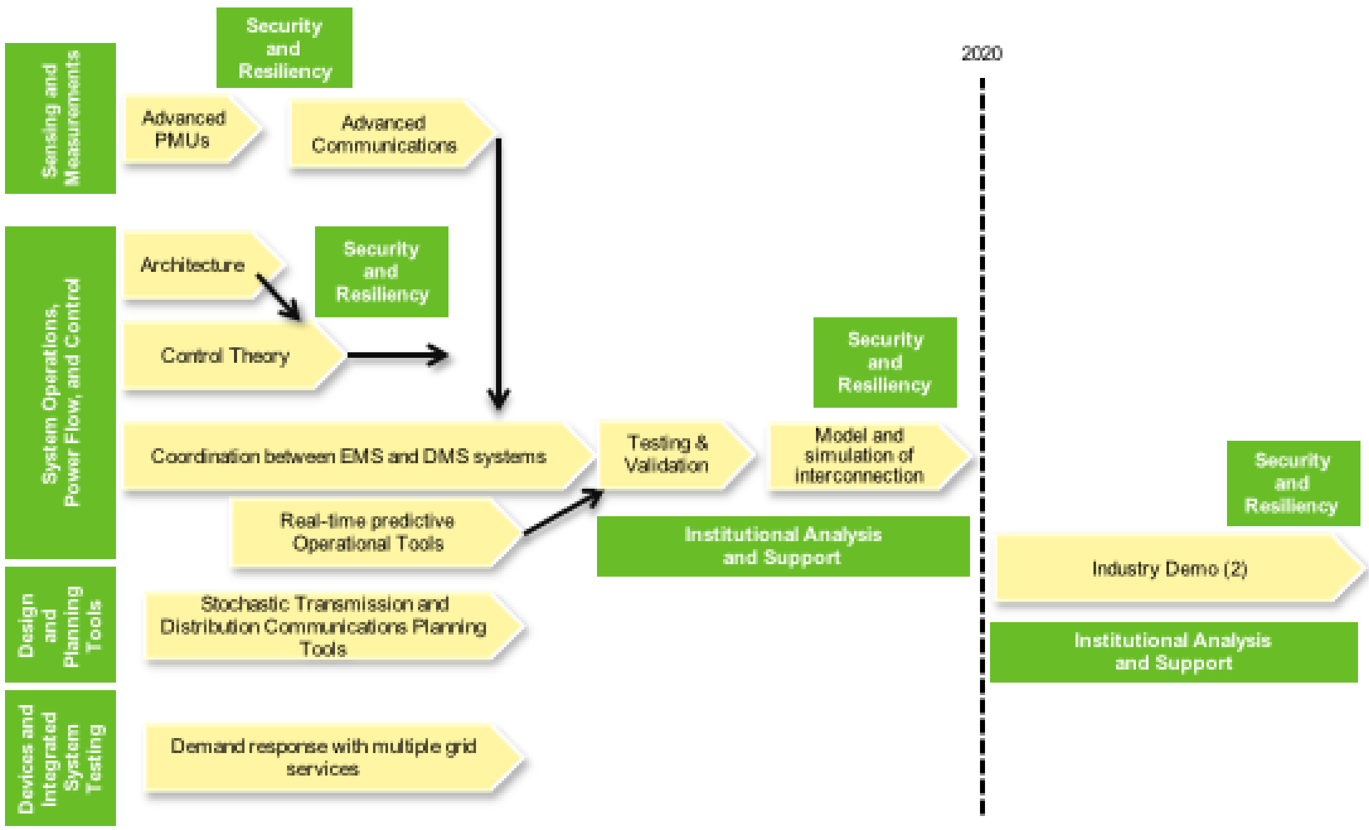


FIGURE 6. LEAN RESERVE MARGIN GRID BULK POWER SYSTEMS

8.2 DOE Integrated Regional Demonstration 2: Clean Distribution Systems

Description: New paradigms for the design of resilient distribution feeders with a high percentage of low carbon distributed resources are possible due to many new grid developments including the following: a) advances in real-time system monitoring; b) emergence of policy incentives for high penetration of clean, distributed generation; c) emergence of energy storage resources; and d) proliferation of smart consumer end-use devices on the customer side of the meter. New approaches for distributed control, engagement with bulk system reliability management, and coordination across local intelligent assets (including multiple microgrids) offer the potential for enhanced economic performance, resilience to all hazards, and support of new consumer-focused innovation. The GMI proposes an integrated approach to design, test, and demonstrate a range of feeder innovations that meet changing consumer expectations and traditional demand for reliability, resilience, and affordability.

Value Proposition/Success Metrics:

By 2019, the Grid Modernization Initiative will initiate demonstration of 6-10 resilient distribution feeders with high percentage of low carbon DER (50 percent) in regions across the country with the following properties.

1. **Flexible:** Advanced architecture and distributed control enhances local power electronics contribution to flexible response to voltage changes from DER resources, and energy services definition and standards maximize potential contribution from DERs.
2. **Sustainable:** Greater than 50 percent of the loads on the distribution feeder can be supplied by clean, renewable energy resources such as solar, fuel cells, distributed wind, and other DERs; and building efficiency systems are engaged interactively.
3. **Resilient:** Coordinated microgrids control reduce recovery time by 50 percent.

4. **Reliable:** Coordinated microgrids control reduce outages by 20 percent.
5. **Affordable**: Distributed, hierarchical control for consumer engagement, economic innovation, and control support to bulk grid operations.
6. **Flexible**: Advanced architecture and distributed control enhances management of DER resources including better use of power electronics to mitigate voltage changes, and definition of new energy services enable new value streams for emerging smart grid technologies.

Integrated Approach (FY16 – FY20)

Successful demonstration of a range of advanced, resilient distribution feeders with high percentage of low carbon DER (50%) feeder configurations will require integration of advances from all six technical areas of the MYPP.

FY16 – FY17:

- Develop full architectural representation of high DER penetration feeders with capacity to deliver local control with DR, energy storage, advanced inverters, and transactive energy market constructs.
- Establish new sensor suites and strategies for visibility required to implement resilient distributed control and coordination with bulk system control systems.
- Deliver a platform to enable grid operations utilizing assets across transmission, distribution, and buildings systems that leverage system visibility and intelligent resources end-to-end.
- Develop T&D planning tools that reflect stochastic behavior of distribution feeders with high penetrations of renewables and include resilient communications networks requisite for reliable coordination and control.

FY 17:

- Develop representative feeder models for high resolution modeling of new feeder control, protection, and restoration paradigms.
- Develop hardware models and interoperability standards requisite to enable full engagement of emerging load, clean generation, storage, and power electronics controls likely in modern feeders.
- Design public/private funding opportunity announcements (FOAs) to conduct demonstrations of highly resilient, distribution feeders utilizing high penetrations of clean distributed generation (>50 percent) in representative regions across the U.S. meeting the "success metrics" stated above.

FY18:

- Model on 6-8 different feeder configuration types representative of national system to validate performance and set specifications for field demonstrations.
- Develop new resilience cost recovery approaches to be evaluated in the field demonstrations
- Frame suite of alternate standards and market approaches and concomitant cost/benefit tools to enable full evaluation of new approaches

FY19 – FY25:

- Develop 6-10 public/private field demonstrations.

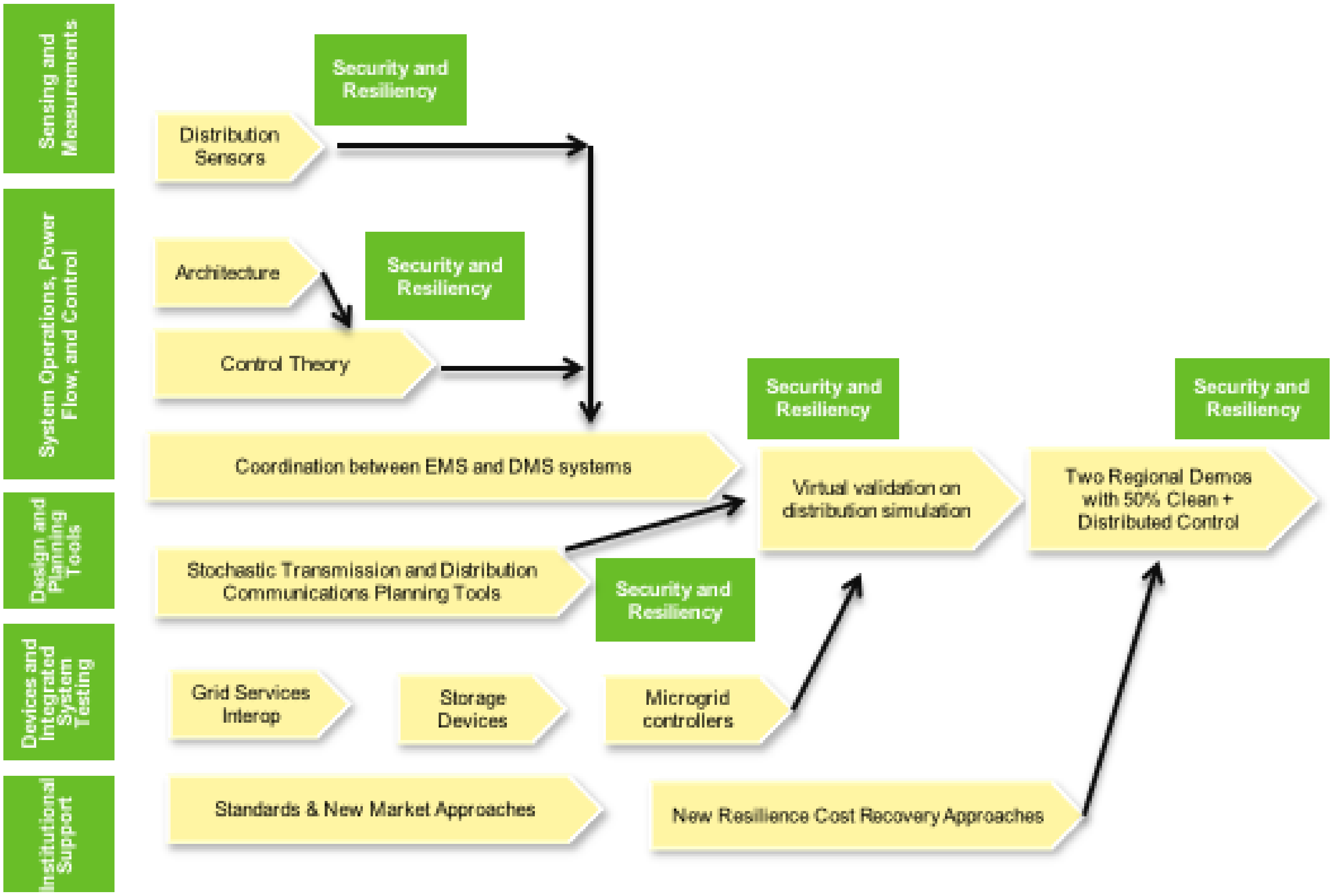


FIGURE 7. CLEAN DISTRIBUTION SYSTEMS

8.3 DOE Integrated Regional Demonstration 3: Advanced Modern Grid Planning & Analytics Platform

Description: Emerging trends in grid system generation and consumer demand are driving the need to improve planning and design tools to support states, system planners, and industry operators. Boundaries between transmission and distribution are blurring driving the need for increased coordination between these two domains. Models need to be coupled so that the increasing coordination across the transmission and distribution boundaries can be modeled and addressed in new system design. The advent of smart grid technologies increases the importance of communications networks to future smart grid systems and markets. Communications models require integration with traditional transmission and distribution power flow modeling tools. Finally the increased complexity of alternative policy options for renewables and DER requires substantial improvement in the fidelity and speed of analytics tools. For example, California proposed policies for high use of PV that created a multi-year backlog of system studies for the California utilities.

Existing transmission and distribution planning tools are inadequate for wide-area planning and to meet the challenge of renewables integration.[128] Therefore, the GMI proposes a platform of integrated high performance tools that couple transmission, distribution, and communications tools with the capacity to reflect uncertainty. This

[128] Massachusetts Institute of Technology, *The Future of the Electric Grid: An Interdisciplinary MIT Study*, 2011.

advanced planning and analytics platform will dramatically improve the accuracy, speed, and capacity at which planners and regulators can evaluate future grid alternatives such as emerging grid business models. This tools platform will be made available for integration with vendor products and leveraged into on-going DOE technical assistance with states and regions.

Value Proposition/Success Metrics:

By 2018-20 the GMI will begin delivering a platform of high speed production cost modeling tools that incorporate uncertainty and couple transmission, distribution, and communications models with the following properties.

1. **Reliable**: Use coupled T&D grid planning models with 1000x speed of computation to address grid power quality and outage issues.
2. **Affordable**: Rapidly evaluate new business models and impacts of policy decisions working with states.
3. **Secure:** High-level cybersecurity for all data-driven and operational models.
4. **Sustainable**: New data-driven approaches, technology models, and analysis frameworks for DER valuation and market design.
5. **Flexible:** Foundational metrics research will deliver new metrics and planning tools to help states and utilities establish regulatory approaches to enhanced system flexibility.
6. **Resilient:** New analytics tools to better evaluate resilience impacts of grid modernization options and support cost benefit analysis related to enhanced system resilience to all hazards.

Integrated Approach (FY16 – FY20)

Successful demonstration of a platform for advanced modern grid planning and analytics tools will require integration of advances from all six technical areas of the MYPP.

<u>FY16 – FY17:</u>

- Develop high performance production cost modeling framework that couples T&D and communications.
- Enhance production cost tools to handle uncertainty, new and emerging technologies, and system dynamics.
- Develop alternative system architecture and distributed control constructs that enable consumer and policy aspirations in clean generation, distributed generation, and consumer engagement.

<u>FY18:</u>

- Enhance valuation tools to examine benefits of device interoperability standards that enable device access to multiple grid service value streams
- Develop enhanced regional data sets and a common set of representative modern feeders to enhance the productivity and accuracy of modern grid analytics

<u>FY19:</u>

- Develop resilience modeling tools and metrics to the analytics platform tools to support state and local cost/benefit analysis of investment in resilience improvements (all hazards).

FY20 – FY25:

- Transition the integrated analytics tools platform into the on-going DOE technical outreach efforts with states, regions and tribes.
- Monitor and document operations
- Help industry and regulators adopt best practices

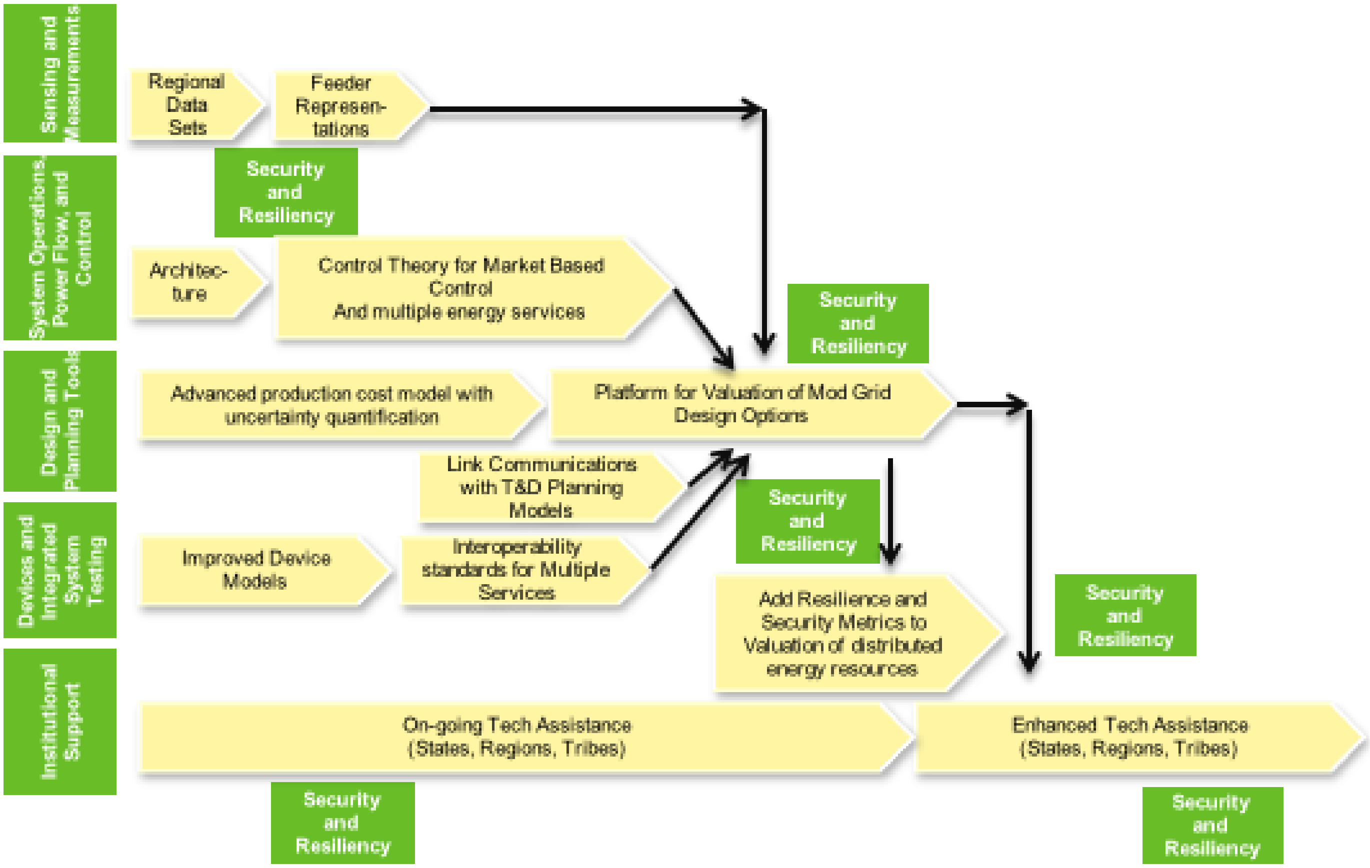


FIGURE 8. ADVANCED MODERN GRID PLANNING & ANALYTICS PLATFORM

8.4 Delivering DOE Major Technical Achievements through Regional Grid Partnership Demonstrations

The Grid Modernization Initiative team believes that rigorous integrated demonstrations at meaningful scales across different regions are vital to private sector acceptance and incorporation in utility and state investment plans for grid infrastructure modernization. This is due to five main reasons:

- The demonstrations integrate efforts across all six technical areas.
- They simultaneously demonstrate success across the six desired attributes of the system (reliable, flexible, affordable, secure, resilient, and sustainable).
- Utilities and regulators want validation in their own regions to ensure that regional intricacies are incorporated.

- The low utility industry R&D investment rates, combined with the small size of the grid energy management software markets, hampers grid industry-based R&D innovation and large scale demonstration.
- State regulators are cautious in embracing cost recovery approvals for many new grid technologies because the cost-benefit analyses are lacking credible data which depends upon quality demonstrations; thus hindering utility innovation.[129]

To successfully execute on these important capstone demonstration projects, the DOE Grid Modernization Initiative's MYPP plans to develop Regional Grid Partnerships early to gather necessary feedback on needs and interests of crucial stakeholders such as utilities, vendors, public utility commissions and others. Regional workshops will be held in 2016 to continuously improve the MYPP and to identify candidate RGPs. In 2016 the National Laboratories will work with states to identify key state-level activities that will inform a DOE FOA for cost-shared demonstrations that would be competitively placed in the third and fourth year of the initiative. The intent is for the RGPs to commit to structured demonstrations at relevant scales to help achieve the Initiative's vision of a modernized grid that is reliable, flexible, affordable, secure, resilient, and sustainable. Further detail on the regional partnership plans are summarized in Chapter 9.0, Stakeholder Engagement.

[129] The Smart Grid Investment Grant and American Recovery and Reinvestment Act experiences of the past five years have developed numerous examples of dramatically accelerated engagement of private sector capital and attention in demonstrations that resulted in dramatically accelerated utility adoption of new commercial innovations.

9.0 Grid Modernization Initiative Management and Stakeholder Engagement

Successfully implementing the six Technical areas of the Grid Modernization Initiative (GMI) and Integrated Regional Demonstrations outlined in Chapter 8.0 requires careful planning and management by DOE and the Labs. It also requires substantial engagement with industry, academia, public officials, and other stakeholders. Chapter 9.0 presents the general management approach for the DOE GMI Initiative, addressing the integrated planning and management of all DOE grid program areas (including RD&D providers in academia and industry), and coordination with the Grid Modernization Laboratory Consortium (GMLC) Labs supporting grid modernization. This chapter also addresses how vital engagement with industry, states, regions, and other stakeholders will be achieved.

"THE ELECTRIC UTILITY INDUSTRY IS COLLABORATING WITH TECHNOLOGY COMPANIES, CONSUMER ADVOCATES, AND GOVERNMENT STAKEHOLDERS TO DEVELOP OPTIONS FOR INTEGRATING NEW TECHNOLOGIES. AND THE INDUSTRY IS CONTINUING TO WORK WITH FEDERAL AND STATE GOVERNMENTS TO ADDRESS CRITICAL CYBER SECURITY ISSUES. SIMILARLY, COLLABORATION IS IMPORTANT WITH REGARD TO INTEROPERABILITY STANDARDS, WHICH WILL ALLOW DIFFERENT TECHNOLOGIES TO COMMUNICATE WITH EACH OTHER."

Tom Kuhn, President of the Edison Electric Institute

The GMI MYPP represents an integrated and comprehensive plan for research, development, demonstration, institutional support, and stakeholder engagement across DOE and the National Laboratory complex. This is the inaugural version of the MYPP and is intended to be a living document that will be updated as needed. The MYPP provides guidance for all grid modernization activities. It reflects:

- strategic input provided by the Quadrennial Energy Review and the DOE 2015 Quadrennial Technology Review (QTR 2.0) released in September 2015;
- new and on-going programmatic efforts in program offices across OE, EERE, EPSA, IE, FE, NE, ARPA-E and SC/ASCR (see
- Figure 9); and
- work conducted by the National Laboratories, academia, industry, and other stakeholders in support of both DOE and other funders of grid modernization research.

Implementation will occur through multiple channels including directed Annual Operating Plans (AOPs) to National Labs; FOAs to academia, industry, and Labs; and CRADAs with industry, National Labs, and other federal agencies.

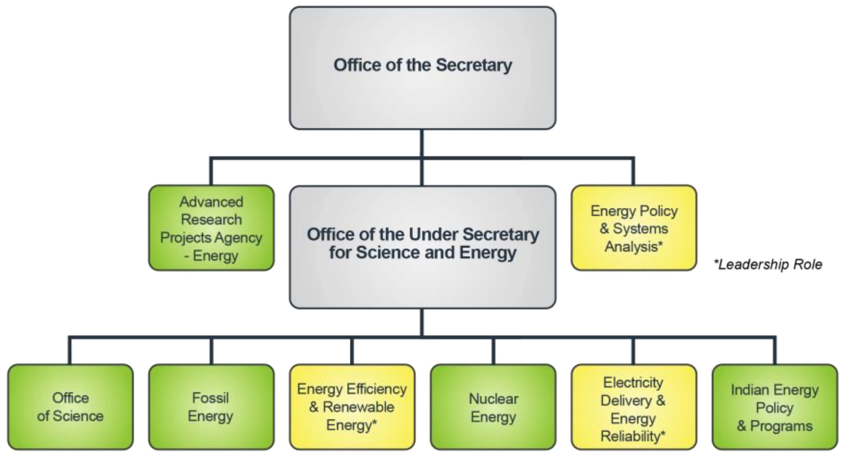


FIGURE 9. DOE ORGANIZATIONS INVOLVED IN THE GRID MODERNIZATION INITIATIVE

9.1 GMI Portfolio Management Approach

The DOE Grid Modernization Initiative mission and goals (outlined in Chapter 1.0) are based on national goals, legislation, administrative priorities (such as those derived from the QER), DOE and strategic goals and priorities (e.g. the QTR), and new and on-going programmatic efforts in program offices across DOE (in particular, OE, EERE, and EPSA). Combining these with an understanding of market needs and technical scenarios leads to the definition of GMI targets that are consistent with government objectives.

The GMI developed the Multi-Year Program Plan (MYPP) with activities needed to accomplish these targets. The MYPP will be used to guide ongoing activities and development of the GMI portfolio of activities through 2020 and beyond, and will be updated as required to reflect the current state of advances, priority needs, and resources availability.

To meet its targets and address the associated barriers, the GMI manages its portfolio based on a two-prong approach: (a) national laboratory participation through the Grid Modernization Laboratory Consortium (GMLC) and (b) RD&D provided by industry, academia, and other stakeholders through traditional DOE funding and contracting mechanisms. These activities are all coordinated by the program offices in conjunction with the executive leadership team of the GMLC consisting of the Undersecretary of Science, Director of the Office of Energy Policy and Systems Analysis, Assistant Secretary of Electricity Delivery and Energy Reliability, and Assistant Secretary of Energy Efficiency and Renewable Energy.

Technology transfer will be an integral element of the GMLC effort because the actual modernization of the nation’s infrastructure will be done through investments by the utility industry (public and private) as well as through consumer investments via commercial offerings. Technology transfer will occur primarily through GMI functions designed explicitly for collaboration with industry (utilities, vendors, and service providers) and demonstration partners and traditional federal RD&D mechanisms.

The GMI will carry out performance assessments on multiple levels to monitor performance and evaluate the Initiative’s progress as activities are implemented. For example, assessments, led by DOE managers from the participating program offices, will evaluate baseline schedule, scope, and costs quarterly. Peer reviews, conducted annually or biennially, will influence decision making on future funding and direction. Stage-gate and comprehensive project reviews will be conducted at the individual project level to assess technical, economic, environmental, and market potential, as well as risk. In large-scale demonstration projects involving public-private partnerships, independent expert analysis, stage-gate decision making, and DOE internal evaluation contribute to project risk assessments and go/no-go decisions.

9.1.1 Managing National Laboratory Participation in the Grid Modernization Initiative

DOE called for a new model to coordinate and enhance the contribution of the National Laboratory system in support of the Grid Modernization Initiative. In response, the Grid Modernization Laboratory Consortium (GMLC) was launched in November 2014. The GMLC provides coordinated program planning and peer review for those grid modernization activities delivered by the National Laboratories via a DOE AOP. Based on the MYPP, the Department intends to annually develop a single DOE-wide National Laboratory AOP for the GMLC that is consistent with and guided by Congressional appropriations through the traditional funding lines within DOE’s program offices (OE, EERE, etc.). The first comprehensive lab call was released in July 2015 with awards planned for November 2015. The GMLC anticipates that industry and academic partners will be included in laboratory work to ensure the highest level of scientific and technical capability is delivered on the Laboratory research portfolio.

This GMLC AOP will serve each year as the foundation for the implementation of highly coordinated grid-related annual work plans by the Program Offices specifically with the National Laboratory complex. The GMLC will ensure that the Laboratory system is delivering a high level of integration, coordination, quality, and impact, leveraging the best available assets from the regionally dispersed National Laboratory System (see Figure 10).

FIGURE 10. NATIONAL LABORATORY SYSTEM

Implementation by the Labs will be coordinated by the Laboratory Consortium governance mechanisms as specified in the GMLC organizational and governance model (Figure 11 and Appendix A). The Labs will develop proposals that bring the best available lab system assets to bear, conduct progress reviews, and interact with external stakeholder technical advisory groups while performing research.

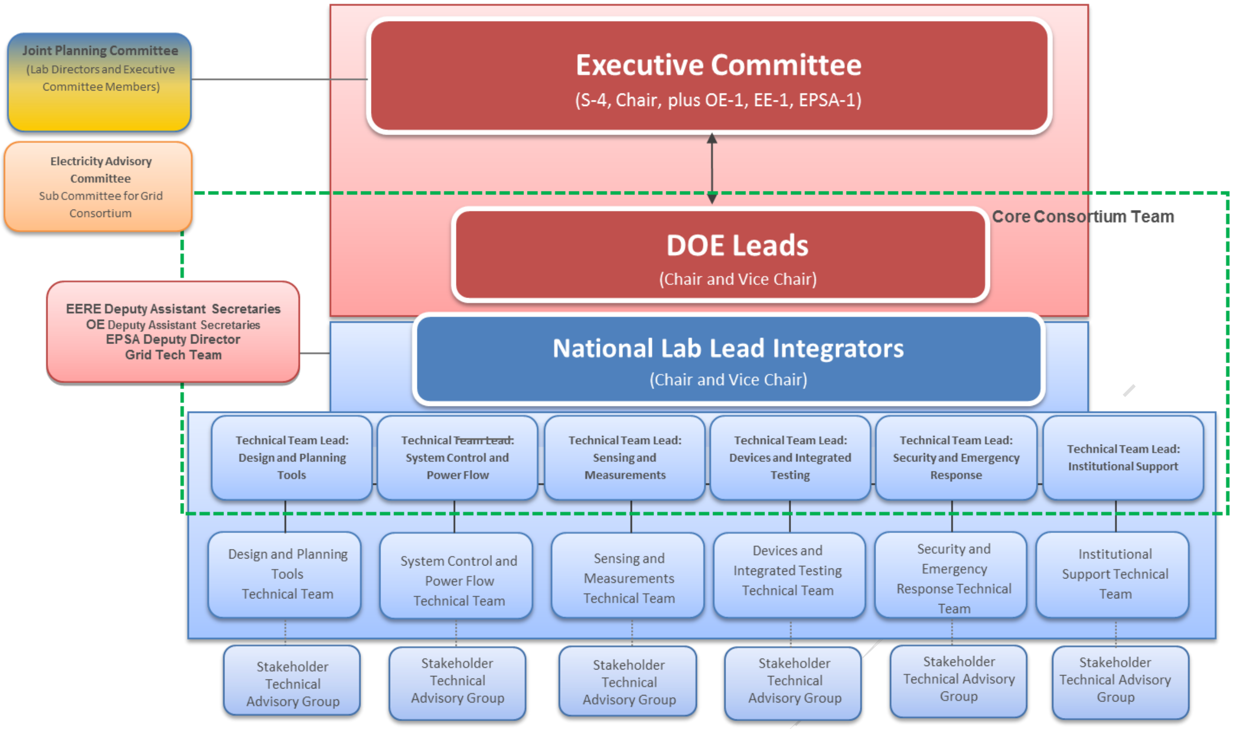


FIGURE 11. GMLC GOVERNANCE MODEL

The GMLC Chairs and Technical Team Leads will establish processes for developing integrated proposals, program plans, assembling project teams, and conducting peer reviews of research results. In the Joint Planning Committee, Laboratory senior management will review annual performance and plans and provide annual assessments to the Executive Committee regarding progress, quality, impact, and issues meriting attention.

9.1.2 Managing RD&D Provided by Industry, Academia, and Other Stakeholders for the Grid Modernization Initiative

Significant portions of the Grid Modernization effort defined in the MYPP will continue to be directed by the DOE Program Offices to academia, industry (utilities and vendors), state and regional entities. DOE will continue to utilize traditional contracting mechanisms such as competitive funding opportunity announcements (FOAs), CRADAs, and grants. Work will be monitored for quality using existing approaches of DOE oversight and peer review established by the DOE Program Offices, the GMI DOE Chairs, and the Assistant Secretaries. National Labs may be able to support university and industry teams in pursuit of competitive solicitations similar to current practice as well.

One of the goals is to increase the impact and effectiveness of the overall DOE grid portfolio through integration and collaboration across all programs and all research providers (academia, National Labs and industry). An integrated program planning (MYPP) and delivery model (AOP for the National Lab work) is designed to enhance overall DOE impact and effect and to encourage collaboration with academia and industry.

DOE recognizes that it will be utilities, vendors, service providers, and consumers who will ultimately invest in the nation's electricity infrastructure. Technology transfer to these entities will be crucial for the success of the GMI vision of a modernized grid and will occur primarily through two mechanisms: (1) traditional federal RD&D mechanisms and (2) National Lab research designed explicitly for collaboration with industry and demonstration partners.

Traditional technology transfer mechanisms are associated with existing contracting approaches used with universities, industry, and the Labs. Intellectual property developed using federal funds is made available for licensing and commercialization consistent with the RD&D contracts used by DOE. In addition, industry can access knowledge and know-how through joint contracts such as CRADAs to accelerate industry benefit from R&D advances.

Additional pathways to encourage rapid transfer of grid modernization innovations include the following:

- Development of open source tools platforms (software, testing facilities, etc.) that aggregate advances from the participating National Laboratories and work with vendors to enable them to leverage these tool sets into their proprietary tool offerings. These tool platforms can include packaged algorithms, middleware software constructs, advanced data handling, and visualization frameworks.
- Development of open testing and computational test beds that enable vendors and researchers to utilize specialized federal scientific and engineering capabilities customized to support grid modernization efforts. These test beds can include special data types, computational platforms not readily available to utilities, and specialized interoperability testing facilities.
- Development of state and regional demonstrations of innovations to enable rapid test and evaluation of concepts under real system conditions in all regions of the U.S.

9.1.3 Performance Assessment

Performance monitoring, as well as program and project evaluation, provides the means to measure relevant outputs and outcomes to evaluating decisions, goals, and approaches, and track the actual progress. The assessment processes will include input from other government agencies, stakeholders, and independent expert reviewers, as appropriate, on the effectiveness and progress towards GMI goals.

External input will come from Federal Advisory Committee Management groups, authorized to provide recommendations to DOE, Stakeholder Technical Advisory Groups that will support each of the six Laboratory technical teams, and the programmatic peer review processes utilized by the DOE program offices. In addition, AOP directed work undertaken by the National Labs will have peer review from within the Lab community and from external peer reviewers.

DOE has an established Electricity Advisory Committee (EAC) that serves as an external FACA (under the Federal Advisory Committee Act) advisory body. It has three meetings annually and offers recommendations to DOE regarding its portfolio performance and future issues meriting DOE attention. It includes members representing industry, academia, and regulators with experience in all facets of power system planning, operation, regulation, and policy. The EAC is represented on the GMLC governance model (Figure 11) and will engage and advise the GMI effort with an emphasis on the adequacy, rate of progress, and quality of results for the overall process.

Portions of the Grid Modernization Initiative portfolio will be directed to the GMLC for coordinated National Lab proposal and delivery of RD&D. GMLC management will review the progress of these efforts and report progress to the Executive Committee. GMLC management will also carry out annual reviews, and will include DOE program office representatives in these reviews.

DOE programs have structured peer review processes for their FOA recipients, CRADA providers, and the National Lab efforts that result from FOAs. These will continue to serve as the primary peer review function for program specific DOE grid RD&D activities under solicitations, CRADAs, and grants.

9.2 Stakeholder Engagement

Modernization of the nation's electric power infrastructure involves many stakeholders including consumers, the utility industry, vendors, labor, state and federal regulators, state and federal policy makers, research institutes, and others (see Figure 12).

FIGURE 12. STAKEHOLDER ENGAGEMENT AND PARTNERSHIPS FOR IMPLEMENTATION

The Grid Modernization Initiative will engage stakeholders from the outset, and stakeholders will have opportunities to provide input and participate in Initiative forums, solicitations, and tech transfer efforts. Seven pathways for stakeholder engagement are:

- Issue competitive research funding opportunities (discussed in Section 9.1.2)
- Engage in technology transfer from DOE programmatic advances (discussed in Section 9.1.2)
- Carry out ongoing peer review (discussed in Section 9.1.3)
- Conduct regional dialogues to gather input on grid modernization needs and priorities
- Hold Grid Modernization Initiative progress summits
- Expand technical assistance to states, regions and tribes
- Develop partnerships to define and develop regional demonstrations

9.2.1 Regional Dialogues and Grid Modernization Summits

DOE will update the MYPP as needed and solicit external comments via multiple venues to ensure strong stakeholder contribution. DOE expects to conduct stakeholder meetings and workshops and use other media (website, webinars, teleconferences, etc.) to gather external input. During stakeholder engagement, DOE and the National Labs will learn what the key stakeholder priorities and issues are, and then use the knowledge to help refine RD&D and technical assistance, and shape demonstration solicitations. Examples of organizations that will be regularly engaged in the GMI process include state agencies and PUCs, industry trade associations, NERC, reliability councils, regional transmission planning groups, the ISO community, and academia. Individual utilities and technology vendors will also be engaged as appropriate. A likely product of these stakeholder interactions will be roadmaps for each the MYPP technical area that translate the grid modernization plans into structure programmatic activity that detail roles, responsibilities, schedules, etc. Additionally, DOE is planning to host a Grid Modernization Summit in 2016 to share progress and hear from the regions on lessons learned and priorities related to grid modernization. These summits will likely be held annually, but frequency will be determined on stakeholder need and other considerations.

9.2.2 Expanded Technical Assistance to States, Regions, and Tribes

DOE will offer substantial technical assistance to states, regions, and tribes in support of stakeholder electric system policy analysis, planning, and regulatory developments. Historically, these efforts included grants to stakeholders, support from National Laboratories and experts on multi-party efforts (typically DOE-funded or directly funded by stakeholders), and development of tools and data sets to facilitate effective stakeholder analysis and other activities. The Grid Modernization MYPP has a technical team focused on Institutional Support and intends to build on past institutional support efforts to develop new tools and analytic frameworks that will better inform state, regional, and tribal grid analysis and planning efforts.

9.2.3 Regional Partnerships

Federal investment in grid modernization RD&D can develop the tools, techniques, and knowledge needed to demonstrate the feasibility and value of modernized grids, but most of the actual deployment will be conducted by the private sector. Only the private sector can mobilize the resources necessary for grid modernization at a pace and scale that can meet future system requirements driven by technology advances, consumer demand, and policy.

In addition to the stakeholder engagement outlined above, the Grid Modernization Initiative expects to utilize integrated regional demonstrations in the evaluation and validation of new grid modernization concepts and technologies. DOE will continue and potentially expand its current portfolio of partnerships with states, and regions (including interconnections) to facilitate stakeholder input into the MYPP updates and identify partners for the demonstrations vital to the success of the initiative. These partnerships are intended to serve as principal agents for ultimately transferring technology and knowledge from the Grid Modernization Initiative focus areas to the private sector. This state/regional/interconnection focus takes into consideration the unique grid-related challenges and opportunities available in different regions of the country as a result of different

> "THE SOLAR INDUSTRY CAN AND SHOULD WORK IN CLOSE COLLABORATION WITH THE UTILITY INDUSTRY TO DRAW CLEAR PARALLELS BETWEEN THE SMART GRID AND THE ABILITY TO MEET RENEWABLE ENERGY STANDARDS."
>
> *Julia Hamm, CEO of the Solar Electric Power Association*

technology mix, fuel supply, demographics, and other region-specific factors. This approach will foster regional economic development and job creation to support grid modernization activities in any particular region.

One or more DOE National Laboratories will support each of these collaborations involving local electric utilities, energy providers, grid operators, state and/or local authorities, universities, vendors, manufacturers, entrepreneurs, financial institutions, and non-profit organizations. Collaborations that progress to demonstrations are expected to provide cost share to matching federal investment.

In FY16, DOE envisions launching systematic state and regional engagements to identify stakeholder interest and needs. This would establish ongoing dialog to keep all parties informed of needs, plans, and progress of the initiative. In addition, DOE plans to release an FY16 Request for Information (RFI) to identify potential industry and state partners to organize and express their interest in forming Regional Grid Partnerships (RGPs) that will support the eventual demonstration of DOE results at the state, regional, and/or interconnection level. Using the tools, technologies, and knowledge developed by the Grid Modernization Initiative, RGPs will model the grid infrastructure of their candidate sites to determine the best options for accomplishing one or more of the three Integrated Regional Demonstrations (see Chapter 8.0) in their region by 2025. By 2017, DOE expects to have achieved substantial technical advancements for potential demonstration in RGPs. At this point, RGPs will bid for competitive demonstration projects directed at helping achieve the goals and vision of the Initiative. DOE anticipates to run an open competition between the various RGPs to select the sites deemed most likely to accomplish the goals of one or more of the Integrated Regional Demonstrations. Selected RGPs would be eligible to receive sustained, multi-year funding awards from DOE for construction, operation, and validation of their detailed demonstrations.

The activities of the selected RGPs will result in the demonstration of a commercially viable modernized grid simultaneously on a campus, community, or industrial scale (50-100+ MW) by 2025. By translating DOE-sponsored RD&D into private sector-sponsored action, the RGPs will provide the important intermediate step to realizing Grid Modernization Initiative goals of improving the affordability, reliability, resiliency, security, and clean energy attributes of our nation’s grid.

Appendix A: GMLC Charter

Grid Modernization Laboratory Consortium Governance Structure

1 - Context

A modernized grid is essential to successfully implement the "all of the above" clean energy strategy in the President's Climate Action Plan, to provide a secure, resilient infrastructure for economic prosperity, and to reduce environmental impacts.

Today's legacy electricity grid must be transformed to meet the consumer, economic, environmental, and security priorities of the 21st century.

> *DOE Vision Statement: The future grid provides a critical platform for US prosperity and energy innovation in a global clean energy economy. It must deliver reliable, affordable, and clean electricity to consumers where they want it, when they want it, how they want it.*

The Grid Modernization Laboratory Consortium (the "Consortium") is a strategic partnership between the U.S. Department of Energy (DOE) and its National Laboratories that is focused on achieving DOE's Grid Modernization Program vision, goals and outcomes. The Consortium defines an integrated approach by DOE and the National Laboratories to ensure that DOE-funded studies, across multiple DOE offices and national laboratories, are appropriately integrated and efficiently coordinated to deliver on the outcomes described in the DOE Grid Modernization Multi-Year Program Plan (MYPP).

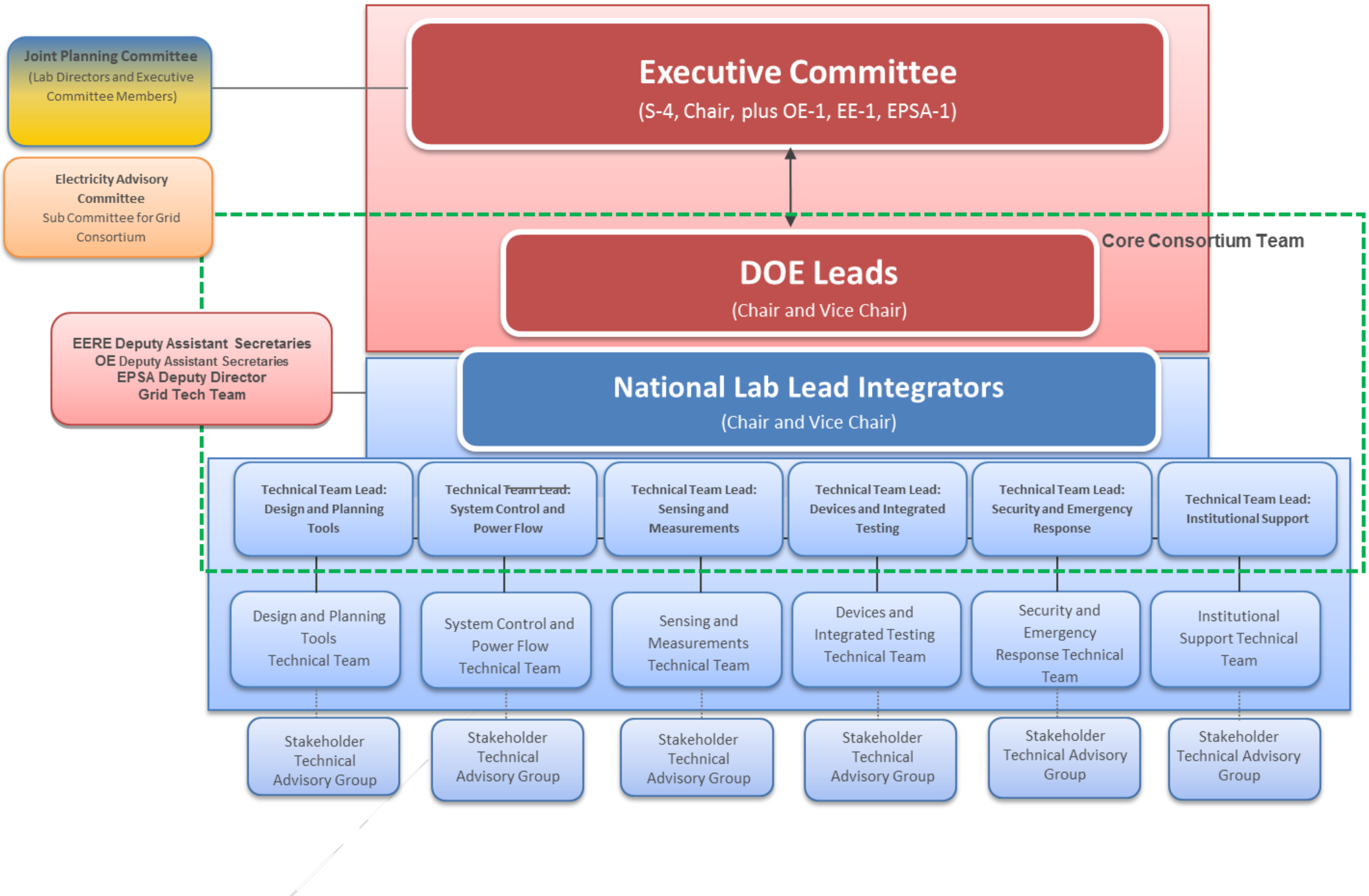
This document describes a governance model designed to establish processes and a management structure to allow key decisions to be made during the life cycle of the Consortium that will ensure that the benefits and outcomes of the program are achieved.

The Department of Energy, working through this Consortium of DOE Program Offices and National Laboratories, must become a resource and convener for the diverse and fragmented set of stakeholders including the electricity industry, state and local governments, and other federal agencies. This role is increasingly important as we recognize the difference between the grid we have and the grid we need.

2 - Consortium Definition and Role

The Consortium will be comprised of DOE representatives from the Office of Electricity Delivery and Energy Reliability (OE), Office of Energy Efficiency and Renewable Energy (EERE), Office of Energy Policy & System Analysis (EPSA), and the National Laboratory enterprise. Coordination among these Offices will be achieved through the Grid Tech Team and liaisons with the other offices, such as the Office of Science, ARPA-E, the Office of Fossil Energy and the Office of Nuclear Energy.

The objective of the governance model, as shown in Figure 1, is to clearly describe roles, responsibilities, accountabilities and authorities among participants in the Consortium. Desired attributes of the governance model include: simpler is better, clear accountability, transparency of decision making,



Joint Planning Committee
(Lab Directors and Executive Committee Members)
Electricity Advisory Committee
Sub Committee for Grid Consortium
EERE Deputy Assistant Secretaries
OE Deputy Assistant Secretaries
EPSA Deputy Director
Grid Tech Team
Executive Committee
(S-4, Chair, plus OE-1, EE-1, EPSA-1)
DOE Leads
(Chair and Vice Chair)
Core Consortium Team
National Lab Lead Integrators
(Chair and Vice Chair)
Technical Team Lead: Design and Planning Tools
Technical Team Lead: System Control and Power Flow
Technical Team Lead: Sensing and Measurements
Technical Team Lead: Devices and Integrated Testing
Technical Team Lead: Security and Emergency Response
Technical Team Lead: Institutional Support
Design and Planning Tools Technical Team
System Control and Power Flow Technical Team
Sensing and Measurements Technical Team
Devices and Integrated Testing Technical Team
Security and Emergency Response Technical Team
Institutional Support Technical Team
Stakeholder Technical Advisory Group
Stakeholder Technical Advisory Group
Stakeholder Technical Advisory Group
Stakeholder Technical Advisory Group
Stakeholder Technical Advisory Group
Stakeholder Technical Advisory Group

conflict resolution, clear budget authority, open communication between DOE and national labs, and engagement of industry.

There are four main components of the Governance Model: the Executive Committee, Joint Planning Committee, the Core Consortium Team and the Laboratory Technical Teams. The roles, responsibilities, authorities, and accountabilities for these components are described in the following sections.

Figure 1 provides a visual illustration of the Consortium structure.

2.1 - Executive Committee

The Executive Committee consists of the Deputy Under Secretary for Science and Energy, the Assistant Secretaries from EERE and OE, and the Director of EPSA. The Executive Committee is accountable to the Secretary of Energy for overall performance of the Consortium and is chaired by the Deputy Under Secretary for Science and Energy.

Through meeting at least quarterly, the Executive Committee will be responsible for:

1. Articulating a unified and integrated vision of the DOE Grid Modernization Program to external stakeholders (Congress, States, Industry, etc.)
2. Establishing a relationship with the Electricity Advisory Committee, which will interface with the Consortium
3. Ensuring budget requests and programmatic activities are coordinated across EERE, OE and EPSA through an integrated MYPP for grid modernization
4. Approving and updating this charter
5. Coordinating with other government agencies (including FERC, DHS, DOI, and states) as appropriate
6. Ensuring that individual DOE program offices support the Consortium
7. Approving notable performance outcomes that would be established in National Laboratory Performance Evaluation and Measurement Plans (PEMPs)

The Executive Committee will meet at least semiannually with the Core Consortium Team to:

1. Evaluate progress and performance of the Consortium
2. Determine current and future year priorities
3. Resolve conflicts regarding scope, funding, and personnel within DOE and among the National Laboratories
4. Assess DOE core capabilities related to grid modernization

The Chair of the Executive Committee will:

1. Convene and preside over meetings of the Executive Committee
2. Lead and organize the Consortium to deliver the MYPP
3. Provide overall oversight and decision authority for the Consortium
4. Develop a transparent process with the Executive Committee to assign and evaluate the performance of the DOE Leads and Laboratory Integrators

5. Deliver oral and written briefings to keep the Secretary of Energy apprised of Consortium activities and outcomes
6. Negotiate and resolve budgetary and other differences among members of the Executive Committee

2.2 - Joint Planning Committee

The Joint Planning Committee consists of members of the Executive Committee as well as Laboratory Directors participating in the Consortium. The purpose of the Joint Planning Committee is to advise the Executive Committee on long-term planning for Grid Modernization and provide an opportunity for Laboratory Directors to address challenges or concerns concerning implementation of the Consortium with the Executive Committee members.

While the duties of the Executive Committee members are detailed above, National Laboratory Executive Members will have the following responsibilities:

1. Represent all National Laboratories involved in grid activities to the Joint Planning Committee
2. Ensure coordination among all Laboratories participating in the Consortium
3. Coordinate a group of National Laboratory representatives (one from each laboratory) that meets at least once a year with the DOE Leads and the Laboratory Lead Integrators
4. In coordination with the Executive Committee, communicate priorities and assess capabilities throughout the Laboratory complex and with external stakeholders
5. Report progress, review results and resolve national lab conflict through the National Lab Directors Council

2.3 - Electricity Advisory Committee Subcommittee on the Grid Consortium

The leadership of the Electricity Advisory Committee (EAC), a FACA established to support OE, will assign responsibility for detailed review of specific Consortium activities, as appropriate, to an existing or newly-created subcommittee. The selected EAC subcommittee will conduct an annual independent assessment of the Consortium and provide associated feedback.

2.4 - Core Consortium Team

The Core Consortium Team is comprised of the DOE Leads (a Chair and Vice Chair), Laboratory Lead Integrators (a Chair and Vice Chair), Deputy Assistant Secretaries of EERE and OE or their designees, the Deputy Director of EPSA or their designee, co-chairs of the Grid Tech Team, and the National Laboratory Technical Team Leads.

As a whole, the Core Consortium Team Members are responsible for:

1. Providing input into the MYPP
2. Aiding the DOE Leads with determining priorities across the National Laboratory Technical Teams
3. Evaluating the outcomes from the Consortium's National Laboratory Technical Teams

4. Providing policy advice (through the EPSA Core Consortium Member) and ensuring alignment of activities with policy

In addition, the DOE members (and not the National Laboratory members) of the Core Consortium Team are responsible for:

1. Coordinating DOE Office budget requests
2. Aiding the DOE Leads with determining budgeting priorities across the National Laboratory Technical Teams

The Core Consortium Team will meet on at least a quarterly basis.

The DOE Leads (Chair and Vice Chair) are Federal employees who are technical leaders with proven technical management track records and stakeholder recognition in grid RD&D. The DOE Leads must have extensive knowledge of DOE grid-related programs and National Laboratory capabilities and possess demonstrated ability to work within DOE and the National Laboratory Enterprise in a cooperative manner.

The DOE Leads (Chair and Vice Chair):

1. Are accountable to, and selected by, the Executive Committee Chair with input from the Executive Committee
2. Are accountable for implementing the Consortium's Multi-Year Program Plan
3. Are accountable for the entire range of the Consortium's activities

The Chair of the DOE Leads will maintain their supervisor of record but will receive input into their annual performance review from the Under Secretary for Science & Energy and the Assistant Secretary of EERE. The Vice Chair of the DOE Leads will maintain their supervisor of record but will receive input into their annual performance review from the DOE Lead (Chair), and the Assistant Secretary of OE.

The DOE Leads (Chair and Vice Chair) are responsible for:

1. Providing to the Executive Committee an integrated five year MYPP for approval
2. Providing a semiannual update to the Executive Committee on status and progress of the Consortium
3. Establishing an open and transparent process, with the Laboratory Lead Integrators, to determine leaders of the National Laboratory Technical Teams[1]
4. Establishing clear expectations of National Lab Technical Team Integrators
5. Providing technical leadership and integration across all National Laboratory Technical Teams
6. Determining priorities and funding across the National Laboratory Technical Teams
7. Evaluating performance of each National Laboratory Technical Team
8. Resolving any disputes among the National Laboratory Technical Teams

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[1] Key criteria for Technical Team Integrators will be documented and demonstrated technical expertise, reputation and proven ability to deliver on technical goals

9. Approving the proposed scope in each National Laboratory Technical Team
10. Developing a competitive proposal review process

The DOE Lead Chair retains overall accountability for ensuring the responsibility enumerated above are completed. The DOE Lead Vice Chair will work with the Chair in all matters pertaining to those responsibilities. The Chair has the authority to delegate specific responsibilities to the Vice Chair on a mutually-agreed upon basis.

The Laboratory Lead Integrators (Chair and Vice Chair) are senior technical leaders with proven technical management track records and stakeholder recognition in grid RD&D. The Laboratory Lead Integrators must have extensive knowledge of DOE grid-related programs and National Laboratory capabilities and possess demonstrated ability to work with the National Laboratory Enterprise in a cooperative manner.

The Laboratory Lead Integrators are accountable to their respective Laboratory Directors for the following:

1. Coordinating all Laboratory activities under the Consortium
2. Organizing semiannual meetings with Laboratory Associate Directors from all laboratories working in the Consortium to discuss progress, issues and overall laboratory participation
3. Delivering results on the integrated Multi-Year Program Plan
4. Supporting the DOE Leads on communication with stakeholders
5. Formal communication between the DOE Leads and the National Laboratory Technical Teams
6. Providing a multi-year, integrated Annual Operating Plan (AOP) for out-year planning
7. Supporting performance evaluation of National Laboratory Technical Team members
8. Providing technical leadership and integration across all National Laboratory Technical Teams
9. Establishing an open and transparent process, with the DOE Leads, to determine National Laboratory Technical Team members[2]
10. Working as a collaborative team with the DOE Leads in terms of coordinated planning and execution of Consortium activities.

The Laboratory Lead Integrator Chair retains overall accountability for ensuring the responsibilities enumerated above are completed. The Lead Laboratory Integrator Vice Chair will work with the Chair in all matters pertaining to those responsibilities. The Chair has the authority to delegate specific responsibilities to the Vice Chair on a mutually-agreed upon basis.

The DOE Leads and Laboratory Lead Integrators will meet with the program manager's across the DOE offices to:

1. Coordinate the development of the MYPP
2. Coordinate the development of the grid AOP

[2] Key criteria for National Laboratory Technical Team members will be demonstrated technical expertise and reputation and proven ability to deliver on technical goals

3. Discuss activities at the National Laboratories
4. Discuss other Grid Modernization activities

National Laboratory Technical Team Leads are accountable to the Laboratory Lead Integrators. Technical Team Integrators are responsible for:

1. Implementing a "best team" approach to meet the goals and outcomes for each technical area
2. Providing input to the MYPP for each technical area
3. Work with the Laboratory Integrator and other Laboratory Lead Integrators to ensure the MYPP for each technical area is integrated well with the MYPP for the other technical areas
4. Work with the Laboratory Integrator in the development of a grid AOP
5. Integrating and utilizing the combined capabilities across the National Laboratory system and universities to deliver program outcomes
6. Defining a fair and transparent process for evaluating technical capabilities at all technical institutions
7. Ensuring proper coordination between projects in tightly focused topical areas and to serve as a technical resource
8. Delivering on technical outcomes
9. Maintaining a working knowledge of state of the art, on-going technology developments, and forward looking technical needs in focused areas that fall within the scope of the team
10. Holding Principal Investigators accountable for participating in coordination activities within focused technical topic areas

2.5 - National Laboratory Technical Teams

National Laboratory Technical Teams will be staffed by personnel from the National Laboratories participating in the Consortium.

National Laboratory Technical Team members will:

1. Be nominated by the national laboratories based on technical knowledge and abilities
2. Maintain a working knowledge of state of the art, on-going technology developments, and forward looking technical needs in focused areas that fall within the scope of the team
3. Draft or coordinate the drafting of informational white papers and technical documents for consumption by consortium leadership or others
4. Actively help in coordination of all ongoing DOE National Laboratory work in smaller and technically focused topical areas
5. Convene proposal review committees which are subject to approval by the Lead Laboratory Integrators

2.6 - Stakeholder Assessment Panels

There will be a stakeholder assessment panel for each of the National Laboratory Technical Teams.

The Stakeholder Assessment Panels are responsible for:

1. Holding a yearly technical prospective and retrospective assessment of each technical area

2. Providing independent feedback to the DOE Lead and Lab Integrator on the relevance and quality of current and proposed R&D
3. Recommending changes of scope and projects within each technical area

The Stakeholder Assessment Panels will consist of representatives who are not Federal employees or employees of the National Laboratories. Members of the Stakeholder Assessment Panels will be selected jointly by the National Laboratory Technical Assessment Team Leads and the Laboratory Lead Integrators.

10/29/14	10/30/14
Michael Knotek — Date Deputy Under Secretary for Science and Energy	Melanie Kenderdine — Date Director Office of Energy Policy and Systems Analysis
10/30/14	10/29/14
David Danielson — Date Assistant Secretary Office of Energy Efficiency and Renewable Energy	Patricia Hoffman — Date Assistant Secretary Office of Electricity Delivery and Energy Reliability

TABLE 14. LAB TEAM INFORMATION

Lab	Lab Team Lead	Lab Team Members
Devices and Integrated Systems Testing	Benjamin Kroposki (NREL)	Brian Kelly (LLNL), Mary Ann Piette (LBNL), Peter Schwartz (LBNL), Sean Hearne (SNL), Kurt Meyers (INL), John McIntosh (SRNL), Rob Pratt (PNNL), Keith Hardy (ANL), Teja Kuruganti (ORNL), Jae Sung Jung (BNL), Rod Borup (LANL), Mark Kemp (SLAC), Bo Chen (ANL)
Sensing and Measurements	Thomas King (ORNL)	Phil Top (LLNL), Steven Lanzisera (LBNL), Paul Ohodnicki (NETL), Chip Fisher (SRNL), Jeff Taft (PNNL), Mike McElfresh (ANL), Mike Villaran (BNL), Bri-Mathias Hodge (NREL), Abe Ellis (SNL), Manajit Sengupta (NREL)
System Operations, Power Flow and Control	Jeffery Dagle (PNNL)	Liang Min (LLNL), Joseph Eto (LBNL), Cesar Silva-Monroy (SNL), Scott McBride (INL), Shrirang Abhyankar (ANL), Burak Ozpineci (ORNL), Shawn Wang (BNL), Vahan Gevorgian (NREL), Scott Backhaus (LANL)
Design and Planning Tools	John Grosh (LLNL)	Sila Kiliccote (SLAC), Ross Guttromson (SNL), Rob Hovsapian (INL), Landis Knnberg (PNNL), Mihai Anitescu (ANL), Yilu Liu (ORNL), Meng Yue (BNL), Marissa Hummon (NREL), Russell Bent (LANL), Bryan Palmintier (NREL)
Security and Resilience	Juan Torres (SNL)	Sean Peisert (LBNL), Craig Rieger (INL), Joe Cordaro (SRNL), Paul Skare (PNNL), Jim Kavicky (ANL), Arjun Shankar (ORNL), Stephanie Hamilton (BNL), Jim Cale (NREL), Tim McPherson (LANL), Chris Strasburg (AMES), Jamie Van Randwyk (LLNL)
Institutional Support	Charles Goldman (LBNL)	Tom Edmunds (LLNL), Charles Hanley (SNL), Robert Turk (INL), Steve Bossart (NETL), Michael Kintner-Meyer (PNNL), Vladamir Koritarov (ANL), Stan Hadley (ORNL), Bob Lofaro (BNL), Gian Porro (NREL), Alan Bershield (LANL)

Appendix B: Calculation of Potential Cost Savings for Grid Modernization

1. Reliability/Resilience/Security

The Grid Resiliency Report prepared by OE for the White House in August 2013 (http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf) estimated an annual average impact of weather-related outages to the U.S. economy between $18 - 33 billion. We take the midpoint and assume (conservatively) that this $25B number includes both physical and cyber-related outages. **If achieved through Grid Modernization, a 10% reduction in frequency, duration, and impact of outages could therefore result in a $2.5B annual savings to the economy.**

2. Clean

The NREL Eastern Wind Integration and Transmission Study (http://www.nrel.gov/docs/fy11osti/47078.pdf) estimated the cost of wind integration as $3.1-$5.1 per MWh for a 20% wind penetration (225 GW) in the Eastern Interconnect by 2024 (see p. 46). In its 2011 Energy Resource Plan filing Xcel/PSCo (https://www.xcelenergy.com/staticfiles/xe/Regulatory/Regulatory%20PDFs/PSCo-ERP-2011/Attachment-2.13-1-2G-3G-Wind-Integration-Cost-Study.pdf) found a $4/MWh integration cost for 3 GW of wind on its system or roughly 20%. We assume $4/MWh then for wind integration costs. PacifiCorp's April 2013 IRP filing found costs closer to $2.5/MWh but we assume this would be expected given the nearby hydro present for low-cost balancing for their Washington and Oregon State resources (see p.89, Fig H.1.; http://www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Integrated_Resource_Plan/Wind_Integration/2012WIS/2013IRP-AppendixH-2012WindIntegrationStudy_4-30-13.pdf).

For solar PV, an October 2013 ANL/LBNL/NREL study of PV integration costs on the Arizona Public Service system in 2027 (http://emp.lbl.gov/sites/all/files/lbnl-6525e.pdf) found those to be $1.8 - $3.8/MWh where solar PV was 9% - 18% of system energy. Black and Veatch did a similar study for APS in November 2012 (http://variablegen.org/wp-content/uploads/2013/03/BV-FINAL-PV-Reserve-Report-2012-11-11.pdf) and found PV solar integration costs to be $1.5 - $2.0/MWh in 2020 at 6.5% of system energy, and $2.4 - $3.0/MWh in 2030 at 7.9% of system energy. Therefore, we assume a cost of $2.5/MWh for PV integration costs in 2025.

From EIA's Annual Energy Outlook 2014 Reference Case (http://www.eia.gov/forecasts/aeo/), U.S. net electric generation to the grid in 2025 is projected to be 4416 TWh. We assume 20% of system energy coming from wind (at $4/MWh integration cost) and 10% of system energy coming from solar PV (at $2.5/MWh integration cost) and get total variable renewables integration costs of roughly $4.6B per year. **If achieved through Grid Modernization, a 50% reduction in wind and solar integration costs could therefore result in a $2.3B annual savings to the economy.**

3. Affordable

PacifiCorp's 2015 IRP has a draft Planning Reserve Margin study (http://www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Integrated_Resource_Plan/2015IRP/2015IRPStudy/2015IRP-Appendix%20I_DRAFT-PRM_2014-10-28.pdf) that looks at the total system cost impacts of maintaining different reserve margin levels from 10% to 20%. After running through a variety of scenarios they identified their preferred optimal reserve margin at 13% taking cost and reliability into account. Table I.4 on page 8 shows a $35M cost benefit to PacifiCorp if they could operate at 10% reserve margin rather than the 13% they have chosen. In 2012, PacifiCorp was only 1.7% of the total retail sales of electricity in the U.S. (per EIA Electric Power Annual 2012; see http://www.eia.gov/electricity/sales_revenue_price/xls/table10.xls). **If comparable savings were achieved for every U.S. retail seller of electricity through Grid Modernization, a 3-point reduction in average planning reserve margin could therefore result in a $2B annual savings to the economy.**

Appendix C: GMLC Briefing Papers to DOE Programs

The GMLC Lab Teams and DOE Programs conducted several meetings during which alignment of goals and activities between the Grid Modernization Initiative (GMI) and the Programs was an important topic of discussion. The papers that follow show where there is consistency between the goals and activities of the GMI and the Programs, wand where the GMI and the Programs are complimentary.

Buildings Technology Office Briefing Paper

Within the DOE Office of Energy Efficiency and Renewable Energy (EERE), the DOE Buildings Technology Office (BTO) works to accelerate energy efficiency in buildings by targeting technology performance improvements and cost reductions, and supporting increased deployment rates that enhance energy savings and benefits to building owners and occupants. Inside the BTO, the Research and Development (R&D) area spearheads the development of new, energy efficient technologies that reduce home and commercial building energy use in new and existing commercial buildings. It also collaborates with industry and states to increase the rate of deployment of such technologies. Recently, BTO has recognized that *smart building technology* is a significant new opportunity for energy efficiency. Smarter buildings utilize information technology to identify energy efficiency opportunities, as well as manage distributed generation (e.g. photovoltaic solar, building cooling-heating-power systems, and backup generation systems), thermal and electrical storage systems, and electric vehicle charging systems developed by other offices within EERE and elsewhere within DOE. Smarter buildings not only bring about benefits to building owners in terms of reduced energy bills, but also can offer a significant contribution to a more reliable and cost-efficient electrical power grid that can take advantage of the flexibility offered by loads and other distributed resources connected behind the building meter. This not only helps the power grid increase its flexibility and hence become more accommodating to higher levels of renewable generation, the financial incentives the grid provides for such response helps pay for making building systems 'smarter', with resulting benefits for both energy efficiency and increasing levels of renewables penetration.

The DOE Grid Modernization (GM) Initiative is a cross-cutting, coordinated program of activities to help set the Nation on a cost-effective path to an integrated, secure, and reliable grid system that is flexible enough to provide an array of emerging services while remaining affordable to customers.

The anticipated proliferation of smart, connected equipment (controllable generation, storage, and load) in buildings that can cost-effectively participate in grid operations emphasizes the need for timely, simple, and reliable equipment integration procedures, accurate prediction of buildings controllable resources, and measurement and verification of proper operation. Moreover, harnessing the benefits of engaging the flexibility of buildings equipment on the performance and reliability of transmission and distribution power systems is becoming of greater value. Table C- 1 maps BTO and GM high level areas and goals. This shows good alignment of goals in five of the six GM areas.

Table C- 1. BTO High Level Activity and Goal Mapping

BTO Areas and Goals	Grid Modernization Areas and Goals
BTO Buildings Modeling and Design Tools • Incorporating the value of grid services in buildings energy modeling tools, so such services can be considered as an added value feature of smart buildings during building design and rennovation. • Accurate models of device and system performance based on measured performance need to be incorporated in such tools. • The value streams that can be obtained by providing such services to the grid, and to energy efficiency, from	**Design and Planning Tools** • Incorporate uncertainty and system dynamics into reliability planning tools to accurately capture effects of renewable generation • Coupling grid transmission, distribution, and communications models to understand cross-domain effects • Advanced production cost modeling used to understand cost-benefit tradeoff of the mix and location of storage and solar

BTO Areas and Goals	Grid Modernization Areas and Goals
deployment of smart grid technology need to be accurately reflected in building energy modeling and design tools.	
Controls, and Transactional Network • Control strategies to address the integration and optimization of homes and commercial buildings with the nation's energy grid are critical. • Develop fundamental concepts and capabilities for transaction-based energy systems, so that buildings are effectively rewarded for providing grid services, and the transactional capability can be leveraged to support other services that enhance other energy-related services to the consumer and society.	**System Control and Power Flow** • Deliver an architecture, framework, and algorithms for controlling a clean, resilient and secure power grid • Develop software platforms for decision support, predictive operations & real-time adaptive control
Smart Buildings Equipment Initiative • Characterize the response characteristics of connected buildings and other behind-the-meter equipment so that their performance can be accurately predicted and other services they can support can be evaluated. • Align the buildings community with analytic methods and testing procedures that enable a credible means to assess grid-readiness of appliances/equipment/controls and the performance/efficiency implications of engaging these devices with the grid and for energy efficiency	**Devices and Integrated System Testing** • Develop and enable a wide range of grid connected devices (e.g. PV inverters) to provide energy services • Coordinate and support the development of validated test procedures and standards to provide energy services
Sensors • Promote enhanced sensing capbilities with virtual intelligent sensing that supports automated commissionging and diagnostics in equipment and systems, and the ability to forecast energy efficiency performance and the provision of grid services. • Advance low-cost, self-powering wireless sensors and sensor networks are essential for accompilshing this objective.	**Grid Sensing and Measurement** • Develop low-cost building and DG sensors & communication for grid services engagement • Develop real-time data management and data exchange framework that enables analytics to improve prediction and reduce uncertainty • Develop next generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resiliency
Grid security and resilience is not a primary objective or focus area for BTO. As described above, technologies under its purview can play a significant role in providing resources for resilience during an emergency. Cybersecurity and consumer privacy, while not a primary focus for BTO technology development, needs to be built into all smart building solutions developed by BTO and will systematically encourage, engage, and industry must be to include it in building products.	**Grid Security and Resilience** • Holistic grid security and resilience, from devices to systems • Inherent security designed into components and systems vice security as an afterthought
BTO Market Stimulation • State and regional stakeholder engagement. • Training and education for stakeholders ranging from energy professionals, state energy offices, and public utility commissions. • Estimate the value of grid and energy services that can supplied by smart buildings, systems, and equipment, and work with states to adopt polices recongizing such values in utility planning processes and building codes.	**Institutional Support and Alignment** • Technical support for states that want to evaluate changes to their regulatory model that better aligns utility and consumer interests with grid modernization and/or clean energy policy. • Methods for valuation of DER technologies and services are defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations

Leveraging Opportunities

The DOE Grid Modernization Initiative is a cross-cutting effort that spans multiple DOE Program Offices. Based on our review of existing national lab projects/activities funded by various DOE offices, there may be additional opportunities that can be leveraged to meet BTO objectives and work collaboratively with other Program Offices. Table C- 2 identifies some current BTO activities and activities to be included in the Grid Modernization MYPP.

TABLE C- 2. BTO ACTIVITIES TO BE INCLUDED IN THE GRID MODERNIZATION MYPP

BTO Activities	Potential Activities in the Grid Modernization MYPP
Design and Planning Tools • Buildings Energy Modeling (BEM) calculates energy use from description of assets & operations • EnergyPlus whole-building energy simulation • OpenStudio middleware & Software Development Kit (SDK) • Develop an archive of validated models of equipment and systems performance.	**Design and Planning Tools** • **OE AGM** – Modeling and Stat Estimation • **WWPO** - WWSIS and ERGIS tool development • **OE SG** – Smart grid communication modeling • **SETO** – Integrated modeling of high pen PV
System Control and Power Flow • VOLTRON agent-based platform supports buildings-to-grid and building control opportunities and the capabilitities needed to support the transactions invovled. • Transactive control strategies within buildings to support energy efficiency and the provision of grid services. • Enhanced home- and building-energy management systems.	**System Control and Power Flow** • **OE AGM** – grid architecture and control theory development • **OE/NSF CURRENT** - data architecture and control theory development • **OE AGM** – advanced EMS/DMS systems • **OE AGM** – Advanced Analytics and Computations for Grid Operation and Control • **ARPA-E GENI** – Power Electronics Development • **SETO** – solar forecasting and operational models
Devices and Integrated System Testing • Develop and promulgate grid-responsive equipment characterization procedures. • Develop analytic methods and testing procedures that enable an impartial, technically credible means of assessing the grid-readiness of the next generation of appliances/equipment/controls and the performance/efficiency implications of engaging these devices with the grid.	**Devices and Integrated System Testing** • **SETO** – developing interconnection and interoperability standards for PV inverters, development of inverter with advanced functionality, high pen demonstrations • **VTO** – developing interoperability standards and power electronics for EV • **FCTO** – evaluating Solar/Wind/Electrolyzers integrated systems • **WWPO** – evaluation of wind turbine power electronics for grid services • **OE SG** – updating interconnection standards for DER • **OE SG** – developing interoperability standards for DER • **OE ES** – battery and power electronics development

BTO Activities	Potential Activities in the Grid Modernization MYPP
Sensing and Measurement • Develop data taxonomies and standard communication protocols that enable building equipment to engage the larger electric system. • Data/communication/interoperability protocols/standards for device engagement and control as part of a demand management strategy • Equipment health monitoring with virtual intelligent sensing • Low-cost, non-intrusive power metering to augment existing sensor sources • An integrated power disaggregation fault identification system based on signal unmixing techniques • (3) a capability to deliver diagnosis information to building managers with impact of fault on energy efficiency for rapid response • Low-Cost, Self-Powering Wireless Sensors and Sensor Networks: develop the sensor node and network via engineering and integration of existing technologies, including high-efficiency mechanical energy harvesting, and ultralow-power integrated circuits (ICs) for sensing and wireless communication.	**Grid Sensing and Measurement** • **SETO** – development of distribution level monitoring and visualization for High Pen PV • **OE TR** – Transmission sensors and asset monitoring
Grid Security and Resilience – Buildings-to-Grid Technical Opportunities • Coordinating strategies and activities with stakeholders to address the integration and optimization of homes and commercial buildings with the nation's energy grid. • Promote the embedded cybersecurity features of VOLTTRON, an open platform for bulding energy services and buildings-to-grid services applications.	**Grid Security and Resilience** • **OE CEDS** – Supply Chain • **OE CEDS** – Quantum Security • **OE CEDS** – Advanced Monitoring • **OE CEDS** – self healing cybersecurity framework • **OE CEDS** – CRISP • **OE CEDS** – ES-C2M2
Institutional Support and Alignment • Help communities improve efficiency through the Better Buildings Neighborhood Program. • Promote the adoption of energy efficient technologies and methods in new homes through the DOE Zero Energy Ready Home program. • Encourage building owners and operators to commit to an energy savings pledge with the Better Buildings Challenge. • Improve commercial retail, real estate, and health care buildings through Better Buildings Alliance. • Help grow new technologies through awareness programs like Solid-State Lighting. • Inspire the next generation of builders and architects through the U.S. Department of Energy Solar Decathlon. • Give engineers, architects, and designers improve insight into building energy use through modeling software for programs such as EnergyPlus and OpenStudio Plug-in for SketchUp.	**Institutional Support and Alignment** • **OE SG** – Smart grid implementation • **OE NED** – Regulatory utility business models • **SETO** – State and Regional stakeholder engagement

CEDS Program Office Briefing Paper

The Cybersecurity for Energy Delivery Systems (CEDS) program assists the energy sector asset owners (electric, oil, and gas) by developing cybersecurity solutions for energy delivery systems through integrated planning and a focused research and development effort. CEDS co-funds projects with industry partners to make advances in cybersecurity capabilities for energy delivery systems. The CEDS program emphasizes collaboration among the government, industry, universities, national laboratories, and end users to advance research and development in cybersecurity that is tailored to the unique performance requirements, design and operational environment of energy delivery systems. The aim of the program is to reduce the risk of energy disruptions due to cyber incidents as well as survive an intentional cyber assault with no loss of critical function.

The DOE Grid Modernization (GM) Initiative is a cross-cutting, coordinated program of activities to help set the Nation on a cost-effective path to an integrated, secure, and reliable grid system that is flexible enough to provide an array of emerging services while remaining affordable to customers.

Cybersecurity is a serious and ongoing challenge for the energy sector. Cyber threats to energy delivery systems can impact national security, public safety, and the national economy. Because the private sector owns and operates most of the energy sector's critical assets and infrastructure, and governments are responsible for national security, securing energy delivery systems against cyber threats is a shared responsibility of both the public and private sectors. Table C- 3 maps CEDS and GM high level areas and goals. This shows potential alignment of goals in all six GM areas.

Table C- 3. CEDS High Level Activity and Goal Mapping

CEDS Program Areas and Goals	Grid Modernization Areas and Goals
Manage Incidents • Energy sector stakeholders are able to mitigate a cyber incident as it unfolds, quickly return to normal operations, and derive lessons learned from incidents and changes in the energy delivery systems environment.	**Design and Planning Tools** • Incorporate uncertainty and system dynamics into reliability planning tools to accurately capture effects of renewable generation • Coupling grid transmission, distribution, and communications models to understand cross-domain effects • Advanced production cost modeling used to understand cost-benefit tradeoff of the mix and location of wind plants
Develop and Implement New Protective Measures to Reduce Risk • Next-generation energy delivery system architectures provide "defense in depth" and employ components that are interoperable, extensible, and able to continue operating in a degraded condition during a cyber incident.	**System Control and Power Flow** • Deliver an architecture, framework, and algorithms for controlling a clean, resilient and secure power grid • Develop software platforms for decision support, predictive operations & real-time adaptive control
Develop and Implement New Protective Measures to Reduce Risk • Next-generation energy delivery system architectures provide "defense in depth" and employ components that are interoperable, extensible, and able to continue operating in a degraded condition during a cyber incident.	**Devices and Integrated System Testing** • Develop and enable a wide range of grid connected devices (e.g. PV inverters) to provide energy services • Coordinate and support the development of validated test procedures and standards to provide energy services
Assess and Monitor Risk • Continuous security state monitoring of all energy delivery system architecture levels and across cyber-physical domains is widely adopted by energy sector asset owners and operators.	**Grid Sensing and Measurement** • Develop real-time data management and data exchange framework that enables analytics to improve prediction and reduce uncertainty • Develop next generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resiliency

CEDS Program Areas and Goals	Grid Modernization Areas and Goals
Sustain Security Improvements • Collaboration between industry, academia, and government maintains cybersecurity advances.	**Grid Security and Resilience** • Holistic grid security and resilience, from devices to systems • Inherent security designed into components and systems vice security as an afterthought
Build a Culture of Security • Cybersecurity practices are reflexive and expected among all energy sector stakeholders.	**Institutional Support and Alignment** • Technical support for states that want to evaluate changes to their regulatory model that better aligns utility and consumer interests with grid modernization and/or clean energy policy Methods for valuation of DER technologies and services are defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations

Leveraging Opportunities

The DOE Grid Modernization Initiative is a cross-cutting effort that spans multiple DOE Program Offices. Based on our review of existing national lab projects/activities funded by various DOE offices, there may be additional opportunities that can be leveraged to meet CEDS objectives and work collaboratively with other Program Offices. Table C- 4 identifies some current CEDS Program activities and activities to be included in the Grid Modernization MYPP.

TABLE C- 4. CURRENT CEDS PROGRAM ACTIVITIES AND ACTIVITIES FOR THE GRID MODERNIZATION MYPP

CEDS Activities	Potential Activities in the Grid Modernization MYPP
Design and Planning Tools • Risk assessment and mitigation tools • Cyber forensic analysis tools	**Design and Planning Tools** • **OE AGM** – Modeling and Stat Estimation • **WWPO** - WWSIS and ERGIS tool development • **OE SG** – Smart grid communication modeling • **SETO** – Systems integration • **OE ES** – battery storage safety • **BTO** – Commercial Building agent based modeling
System Control and Power Flow • Cyber-secure architectures and devices	**System Control and Power Flow** • **OE AGM** – grid architecture and control theory development • **OE/NSF CURRENT** - grid architecture and control theory development • **OE AGM** – advanced EMS/DMS systems • **OE AGM** – Advanced Analytics and Computations for Grid Operation and Control • **ARPA-E GENI** – Power Electronics Development • **BTO** – Building-grid coordinated control
Devices and Integrated System Testing • Cybersecurity devices and techniques for building in inherent security	**Devices and Integrated System Testing** • **BTO** – developing characterization procedures for building technologies to provide grid and other services • **FCTO** – evaluating Solar/Wind/Electrolyzers integrated systems • **WWPO** – evaluation of wind turbine power electronics for grid services • **OE SG** – updating interconnection standards for DER • **OE SG** – developing interoperability standards for DER • **OE ES** – battery and power electronics development
Grid Sensing and Measurement • Cyber event detection tools that evolve with the dynamic threat landscape • Real-time security monitoring	**Grid Sensing and Measurement** • **BTO** – Building and Customer Communications • **OE TR** – Transmission sensors and asset monitoring

CEDS Activities	Potential Activities in the Grid Modernization MYPP
Grid Security and Resilience • Expand cybersecurity to all renewables and energy efficiency programs as well as to energy storage program	**Grid Security and Resilience** • **OE CEDS** – Supply Chain • **OE CEDS** – Quantum Security • **OE CEDS** – Advanced Monitoring • **OE CEDS** – self healing cybersecurity framework • **OE CEDS –** CRISP • **OE CEDS –** ES-C2M2
Institutional Support and Alignment • Incident reporting guidelines • Federally funded partnerships and organizations focused on energy sector cybersecurity become self-sustaining • Mature, proactive processes to rapidly share threat, vulnerabilities, and mitigation strategies are implemented throughout the energy sector	**Institutional Support and Alignment** • **OE SG** – Smart grid implementation • **OE NED** – Regulatory utility business models

Energy Infrastructure Modeling and Analysis Briefing Paper

The DOE-OE Energy Infrastructure Modeling and Analysis (EIMA) Division (OE-40) supports the development of a reliable, secure, resilient, and advanced U.S. energy infrastructure through a range of activities, including electric system modeling, synchrophasor-based tool development, transmission reliability research, reliability assessments, energy security modeling and visualization, and energy infrastructure risk analyses. The Clean Energy Transmission and Reliability program develops the monitoring, analytical decision support, and control capabilities necessary to operate and plan the grid in the Transmission Reliability and Advanced Grid Modeling Research programs. The Advanced Grid Modeling (AGM) program that is leading the effort to apply new classes of algorithms and other advancements from mathematical and computational sciences to power system software, and to develop improved and validated models which are amenable to coupling across a variety of temporal and spatial scales.

The DOE Grid Modernization (GM) Initiative is a cross-cutting, coordinated program of activities to help set the Nation on a cost-effective path to an integrated, secure, and reliable grid system that is flexible enough to provide an array of emerging services while remaining affordable to customers.

Technologies and projects associated with the EIMA Program is envisioned to be well aligned with the projects envisioned to be part of the GM Initiative, particularly in the areas of System Operations, Power Flow, and Control, as well as the Design and Planning Tools area. Moreover, the impact of advanced grid modeling on the performance and reliability of transmission and distribution power systems is becoming a larger challenge in the coming years. Table C- 5 maps EIMA Program and GM Initiative high level areas and goals. This shows good alignment of goals several of the GM areas.

Table C- 5. EIMA High Level Activity and Goal Mapping

EIMA Program Areas and Goals	Grid Modernization Areas and Goals
Models and Simulation • Research highlights a new class of fast, high fidelity capabilities that underpin better grid operations and planning in a large-scale, dynamic and stochastic environment. Reliability and Markets/Load as a Resource • Research addresses grid operations and planning guided by wholesale markets, including explicit treatment of network constraints and uncertainty	**Design and Planning Tools** • Incorporate uncertainty and system dynamics into reliability planning tools to accurately capture effects of renewable generation • Coupling grid transmission, distribution, and communications models to understand cross-domain effects • Advanced production cost modeling used to understand cost-benefit tradeoff of the mix and location of storage and solar
Mathematical Methods and Computation • Effort addresses emerging mathematical and computational challenges arising in power systems, developing software libraries and demonstrating applications of new algorithms for the power system, leveraging the latest mathematical advancements by the Office of Science. Advanced Applications R&D • Research involves data collection/processing, analysis, visualization, monitoring and alarming, and decision support for grid operators. Many of the applications rely on high time-resolution and time-synchronized grid monitoring technologies.	**System Control and Power Flow** • Deliver an architecture, framework, and algorithms for controlling a clean, resilient and secure power grid • Develop software platforms for decision support, predictive operations & real-time adaptive control

EIMA Program Areas and Goals	Grid Modernization Areas and Goals
No formal work in Devices and Integrated System Testing Devices and integrated system testing, while not a primary focus for EIMA, should be taken into consideration when understanding implementation issues that will be important following the technology development and demonstration phases.	**Devices and Integrated System Testing** • Develop and enable a wide range of grid connected devices (e.g. PV inverters) to provide energy services • Coordinate and support the development of validated test procedures and standards to provide energy services
Data Management & Analytics • These activities focus on the way data is collected, used, stored, and archived (i.e. data architecture) to improve applicability of large, multi-source datasets for real-time operations and off-line planning studies. Synchrophasor Technology Initiatives • These activities encompass a variety of technical support, R&D, and pre-commercialization activities involving industry-led initiatives stemming from DOE's ARRA-funded investments in the deployment of high time-resolution and time-synchronized grid monitoring technologies ("synchrophasors") to enhance grid reliability and economics.	**Grid Sensing and Measurement** • Develop real-time data management and data exchange framework that enables analytics to improve prediction and reduce uncertainty • Develop next generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resiliency
No formal work in Security and Resilience EIMA programs to not have a primary focus on grid security and resilience. Cybersecurity activities within OE are primarily coordinated through CEDS and ISER, depending on whether it is an R&D or operational focus.	**Grid Security and Resilience** • Holistic grid security and resilience, from devices to systems • Inherent security designed into components and systems vice security as an afterthought
No formal work in Institutional Support and Alignment Institutional support, while not a primary focus for EIMA, is normally considered within the context of implementing EIMA-developed technologies and understanding broader stakeholder adoption strategies.	**Institutional Support and Alignment** • Technical support for states that want to evaluate changes to their regulatory model that better aligns utility and consumer interests with grid modernization and/or clean energy policy Methods for valuation of DER technologies and services are defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations

Leveraging Opportunities

The DOE Grid Modernization Initiative is a cross-cutting effort that spans multiple DOE Program Offices. Based on our review of existing national lab projects/activities funded by various DOE offices, there may be additional opportunities that can be leveraged to meet EIMA Division objectives and work collaboratively with other Program Offices. Table C- 6 identifies some current EIMA activities and activities to be included in the Grid Modernization MYPP.

TABLE C- 6. CURRENT EIMA ACTIVITIES AND ACTIVITIES FOR THE GRID MODERNIZATION MYPP

EIMA Program Activities	Potential Activities in the Grid Modernization MYPP
Design and Planning Tools • Modeling and State Estimation	**Design and Planning Tools** • **WWPO** - WWSIS and ERGIS tool development • **BTO** – Commercial Building agent based modeling • **OE SG** – Smart grid communication modeling
System Control and Power Flow • Grid Architecture and control Theory Development	**System Control and Power Flow** • **OE/NSF CURRENT** - grid architecture and control theory development • **BTO** – Building-grid coordinated control • **OE AGM** – advanced EMS/DMS systems • **OE AGM** – Advanced Analytics and Computations for Grid Operation and Control • **ARPA-E GENI** – Power Electronics Development
Devices and Integrated System Testing	**Devices and Integrated System Testing** • **BTO** – developing characterization procedures for building technologies to provide grid and other services • **VTO** – developing interoperability standards and power electronics for EV • **FCTO** – evaluating Solar/Wind/Electrolyzers integrated systems • **WWPO** – evaluation of wind turbine power electronics for grid services • **OE SG** – updating interconnection standards for DER • **OE SG** – developing interoperability standards for DER • **OE ES** – battery and power electronics development
Grid Sensing and Measurement • Data Management and Analytics	**Grid Sensing and Measurement** • **BTO** – Building and Customer Communications • **OE TR** – Transmission sensors and asset monitoring
Grid Security and Resilience	**Grid Security and Resilience** • **OE CEDS** – Supply Chain • **OE CEDS** – Quantum Security • **OE CEDS** – Advanced Monitoring • **OE CEDS** – self healing cybersecurity framework • **OE CEDS** – CRISP • **OE CEDS** – ES-C2M2
Institutional Support and Alignment	**Institutional Support and Alignment** • **OE SG** – Smart grid implementation • **OE NED** – Regulatory utility business models

Fuel Cell Technology Office Briefing Paper

The DOE Fuel Cell Technology Office (FCTO) address the full range of barriers facing the development and deployment of hydrogen and fuel cells with the ultimate goals of decreasing our dependence on oil, reducing carbon emissions, and enabling clean, reliable power generation. Hydrogen and fuel cells offer a broad range of benefits for the environment, for our nation's energy security, and for our domestic economy, including reduced greenhouse gas emissions, reduced oil consumption, expanded use of renewable power (through use of hydrogen for energy storage and transmission), highly efficient energy conversion, fuel flexibility (use of diverse, domestic fuels, including clean and renewable fuels), reduced air pollution, and highly reliable grid support. Fuel cells also have numerous advantages that make them appealing for end-users, including quiet operation, low maintenance needs, and high reliability while providing grid compatible power. Electrolyzers can also be used as controllable loads to provide advanced grid services.

The DOE Grid Modernization (GM) Initiative is a cross-cutting, coordinated program of activities to help set the Nation on a cost-effective path to an integrated, secure, and reliable grid system that is flexible enough to provide an array of emerging services while remaining affordable to customers.

Table C- 7 maps FCTO and GM high level areas and goals. This shows good alignment between FCTO and GM areas in Devices and Integrated Systems Testing and Design and Planning Tools.

TABLE C- 7. FCTO HIGH LEVEL ACTIVITY AND GOAL MAPPING

FCTO Areas and Goals	Grid Modernization Areas and Goals
FCTO modeling • Modeling of fuel cells and electrolyzers to demonstrate high value grid services that EE and RE technologies can provide holistically at a variety of scales (e.g. building, distribution, transmission). • Planning tool to optimize stationary fuel cell integration and control with thermal and electrical storage as well as applicability and system optimization of innovative approaches such as trigeneration.	**Design and Planning Tools** • Incorporate uncertainty and system dynamics into reliability planning tools to accurately capture effects of variable generation • Coupling grid transmission, distribution, and communications models to understand cross-domain effects • Advanced production cost modeling used to understand cost-benefit tradeoff of the mix and location of storage and DER
FCTO will leverage system controls and software/tools for real-time adaptive control/software platforms that will be developed in other programs.	**System Control and Power Flow** • Deliver an architecture, framework, and algorithms for controlling a clean, resilient and secure power grid • Develop software platforms for decision support, predictive operations & real-time adaptive control
FCTO Device and Integrated Systems • Reduce the cost and improve the durability of electrolyzers and fuel cell systems. • Real time testing, analysis, and quantification of the power quality impacts of distributed electrolyzers • Integration of large scale electrical power network models in real time environment between NREL-ESIF and INL-ESL facilities • Power-to-Gas: Electrolytic H2 from renewables with blending into natural gas pipelines and distributed solar H2 production and onsite storage for FCV • Demonstrate the capability of large-scale (250 kW+) electrolyzers and fuel cells to support the grid and increase hosting capacity (i.e., penetration) for variable renewable generation resources.	**Devices and Integrated System Testing** • Develop and enable a wide range of grid connected devices (e.g. FCs and Electrolyzers) to provide energy services • Coordinate and support the development of validated test procedures and standards to provide energy services

FCTO Areas and Goals	Grid Modernization Areas and Goals
No formal work	**Grid Sensing and Measurement** • Develop real-time data management and data exchange framework that enables analytics to improve prediction and reduce uncertainty • Develop next generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resiliency
FCTO will leverage system controls and software/tools for real-time adaptive control/software platforms that will be developed in other grid-cross cut activities.	**Grid Security and Resilience** • Holistic grid security and resilience, from devices to systems • Inherent security designed into components and systems vice security as an afterthought
Development of financial tools for end users to determine payback. Engagement of codes and standards communities. As fuel cell/energy storage market penetration increases, FCTO will increase state and utility engagement.	**Institutional Support and Alignment** • Technical support for states that want to evaluate changes to their regulatory model that better aligns utility and consumer interests with grid modernization and/or clean energy policy • Methods for valuation of DER technologies and services are defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations

Leveraging Opportunities

The DOE Grid Modernization Initiative is a cross-cutting effort that spans multiple DOE Program Offices. Based on our review of existing national lab projects/activities funded by various DOE offices, there may be additional opportunities that can be leveraged to meet FCTO objectives and work collaboratively with other Program Offices. Table C- 8 identifies some current FCTO activities and activities to be included in the Grid Modernization MYPP.

TABLE C- 8. LEVERAGING OPPORTUNITIES

FCTO Activities	Potential Activities in the Grid Modernization MYPP
Design and Planning Tools • Modeling of high penetration FC and Electrolyzer scenarios at bulk-system and distribution system levels	**Design and Planning Tools** • **OE AGM** – Modeling and Stat Estimation • **WWPO** - WWSIS and ERGIS tool development • **BTO** – Commercial Building agent based modeling • **OE SG** – Smart grid communication modeling • **SETO** – Integrated modeling of high pen PV
System Control and Power Flow	**System Control and Power Flow** • **OE AGM** – grid architecture and control theory development • **OE/NSF CURRENT** - grid architecture and control theory development • **BTO** – Building-grid coordinated control • **OE AGM** – advanced EMS/DMS systems • **OE AGM** – Advanced Analytics and Computations for Grid Operation and Control • **ARPA-E GENI** – Power Electronics Development • **SETO** – solar forecasting and operational models

FCTO Activities	Potential Activities in the Grid Modernization MYPP
Devices and Integrated System Testing • Developing and characterizing electrolyzers and fuel cell technologies to provide grid services • Developing new inverter technologies • Integrated testing capabilities across laboratories	**Devices and Integrated System Testing** • **SETO** – developing interconnection and interoperability standards for PV inverters, development of inverter with advanced functionality, high pen demonstrations • **BTO** – developing characterization procedures for building technologies to provide grid and other services • **FCTO** – evaluating Solar/Wind/Electrolyzers integrated systems • **WWPO** – evaluation of wind turbine power electronics for grid services • **OE SG** – updating interconnection standards for DER • **OE SG** – developing interoperability standards for DER • **OE ES** – battery and power electronics development
Grid Sensing and Measurement	**Grid Sensing and Measurement** • **BTO** – Building and Customer Communications • **OE TR** – Transmission sensors and asset monitoring • **SETO** – development of distribution level monitoring and visualization for High Pen PV
Grid Security and Resilience	**Grid Security and Resilience** • **OE CEDS** – Supply Chain • **OE CEDS** – Quantum Security • **OE CEDS** – Advanced Monitoring • **OE CEDS** – self healing cybersecurity framework • **OE CEDS –** CRISP • **OE CEDS –** ES-C2M2
Institutional Support and Alignment • Stakeholder Engagement - C&S groups, both within the industry and government.	**Institutional Support and Alignment** • **OE SG** – Smart grid implementation • **OE NED** – Regulatory utility business models • **SETO** – State and Regional stakeholder engagement

Smart Grid Program Briefing Paper

The DOE-OE Smart Grid Program is leading DOE's efforts to realize the benefits that pervasive communications and information technology can bring to the operation and control of power grids from the distribution level down to the level of the customer systems and other devices connected at the "edge" of the grid. The Smart Grid Program has focused its efforts on

- developing overarching architectures and frameworks for smart grids, and information interoperability standards,
- developing simulations and analyses of smart grid designs, operation, technologies, and benefits
- developing smart grid technologies and applications, and advancing them into the marketplace including field demonstrations and deployments (primarily $4B in ARRA Smart Grid Investment Grants and Demonstrations)
- fostering innovation in policies, regulation, and outreach with a broad range of stakeholders.

The historical Smart Grid Program now consists of a number of individual programs focused on specific aspects of smart grid: 1) Microgrids for reliability, resiliency, and the provision of grid services, 2) Advanced Distribution Management Systems (ADMS), and 3) Transactive Systems for the integration of distributed assets. Also included in the discussion below is a significant portion of DOE-OE's Storage program (i.e., that lies beyond the materials science aspects), specifically 4) the standards, control, modeling, simulation, and analysis of costs and benefits of electrical storage technologies.

The DOE Grid Modernization (GM) Initiative is a cross-cutting, coordinated program of activities to help set the Nation on a cost-effective path to an integrated, secure, and reliable grid system that is flexible enough to provide an array of emerging services while remaining affordable to customers.

Technologies and projects associated with the Smart Grid Program are well aligned with the projects envisioned to be part of the GM Initiative, particularly in the areas of Design and Planning Tools, System Control and Power Flow, and Grid Sensing and Measurement. Moreover, the impact of advanced grid modeling on the performance and reliability of transmission and distribution power systems is becoming a larger challenge in the coming years. Table C- 9 maps Smart Grid and GM Initiative high level areas and goals. This shows good alignment of goals several of the GM areas.

TABLE C- 9. SMART GRID HIGH LEVEL ACTIVITY AND GOAL MAPPING

Smart Grid Program Areas and Goals	Grid Modernization Areas and Goals
Models and Simulation • Smart grid technologies and operational strategies must be accurately represented in design and planning tools with high fidelity in order for them to be properly considered as options for design of grid systems. • The value of distributed energy resources must be reflected at both the transmission and distribution levels for smart grid approaches to be fully recognized. • The performance and value of microgrids in both islanded and grid connected operation also needs to be fully understood and recognized.	**Design and Planning Tools** • Incorporate uncertainty and system dynamics into reliability planning tools to accurately capture effects of renewable generation • Coupling grid transmission, distribution, and communications models to understand cross-domain effects • Advanced production cost modeling used to understand cost-benefit tradeoff of the mix and location of storage and solar

Smart Grid Program Areas and Goals	Grid Modernization Areas and Goals
Control, Coordination, and Operational Strategies • Develop an overarching architecture and framework for smart grid systems. • Develop coordination strategies for large populations of diverse distributed assets that provide the smooth, stable, predictable response required at the time, location, and duration needed to provide grid services. • Develop microgrid control strategies and embed them in controllers. • Maximize value of batteries by developing optimal dispatch algorithms for providing grid services. Remove barriers and lower costs for linking disparate operational tools into comprehensive distribution system management. • Understand and define the need for information sharing between transmission and distribution management systems.	**System Control and Power Flow** • Deliver an architecture, framework, and algorithms for controlling a clean, resilient and secure power grid • Develop software platforms for decision support, predictive operations & real-time adaptive control
Validated Models of Smart Grid Devices and Systems • High-fidelity models of smart grid devices such as batteries, gensets, microturbines, fuel cells, inverters, and customer end-use devices and systems must be created and validated. • Models of integrated systems for voltage and frequency control, distribution network reconfiguration, and short-circuit protection must be validated. • Microgrid controls and operations must be tested and validated. • Standard performance metrics are need for batteries and microgrids.	**Devices and Integrated System Testing** • Develop and enable a wide range of grid connected devices (e.g. PV inverters) to provide energy services • Coordinate and support the development of validated test procedures and standards to provide energy services
Communications Interoperability and Standards • Smart grid devices and systems are, by definition, dependent on communications, so interoperability standards and testing are an essential requirement.	**Grid Sensing and Measurement** • Develop real-time data management and data exchange framework that enables analytics to improve prediction and reduce uncertainty • Develop next generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resiliency
Smart Grid Systems Cybersecurity • Cybersecurity for smart grid devices and systems is absolutely critical to protect grid integrity and consumer privacy. Resilience and Smart Grid Systems • Microgrids are central to distribution-level resiliency. • Many mart grid approaches designed to enhance reliability also contribute to grid resiliency. • Smart grid systems must be designed to fail gracefully.	**Grid Security and Resilience** • Holistic grid security and resilience, from devices to systems • Inherent security designed into components and systems vice security as an afterthought
Smart Grid Stakeholder Engagement • Regular stakeholder engagement meetings are critical for smart grid. • Policy makers and regulators must make informed choices that enable smart grid.	**Institutional Support and Alignment** • Technical support for states that want to evaluate changes to their regulatory model that better aligns utility and consumer interests with grid modernization and/or clean energy policy Methods for valuation of DER technologies and services are defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations

Leveraging Opportunities

The DOE Grid Modernization Initiative is a cross-cutting effort that spans multiple DOE Program Offices. Based on our review of existing national lab projects/activities funded by various DOE offices, there may be additional opportunities that can be leveraged to meet Smart Grid Program objectives and work collaboratively with other Program Offices. Table C- 10 identifies some current Smart grid activities and activities to be included in the Grid Modernization MYPP.

TABLE C- 10. CURRENT SMART GRID ACTIVITIES AND ACTIVITIES FOR THE GRID MODERNIZATION MYPP

Smart Grid Program Activities	Potential Activities in the Grid Modernization MYPP
Design and Planning Tools • The open-source GridLAB-D simulation platform was developed by DOE-OE and is supported as a tool to examine and develop the performance of smart grid control and coordination strategies, device technologies, and associated communications networks. • It is also used to develop and promulgate methods for consideration of smart grid approaches in grid design tools and processes, and to "flight test" demonstrations and deployments before going to the field and extrapolate results from them after they are conducted. • GridLAB-D's capabilities have been extended by linking it with models of network communications transmission and market systems. • Prototypical feeders representative of U.S. distribution systems have been developed as a basis for analysis. • The DER-CAM model is being constructed as a design tool for microgrids (it includes GridLAB-D).	**Design and Planning Tools** • **WWPO -** WWSIS and ERGIS tool development • **BTO –** Commercial Building agent based modeling
System Control and Power Flow • The GridWise Architecture Council focuses on architectural issues and frameworks such as transactive energy systems. • The Transactive Systems program is developing transactive coordination methods, theory, valuation methods, and test cases and simulation platforms for evaluating and developing them. • The ADMS program will construct advanced control for applications that integrate distributed assets and smart inverters into distribution voltage control, reconfiguration, and short circuit protection schemes. • The Microgrid program is constructing and testing microgrid controllers. • The Storage program is developing optimal battery dispatch algorithms.	**System Control and Power Flow** • **OE/NSF CURRENT -** grid architecture and control theory development • **BTO –** Building-grid coordinated control • **OE AGM –** advanced EMS/DMS systems • **OE AGM –** Advanced Analytics and Computations for Grid Operation and Control • **ARPA-E GENI –** Power Electronics Development
Devices and Integrated System Testing • Results from ARRA grants and demonstrations are being analyzed and published. • Microgrid testbeds are under construction and field tests are underway. • The ADMS program will be testing the performance of integrated systems including SCADA, DMS, AMI, outage management, asset management, workflow management, and customer information systems.	**Devices and Integrated System Testing** • **BTO –** developing characterization procedures for building technologies to provide grid and other services • **VTO –** developing interoperability standards and power electronics for EV • **FCTO –** evaluating Solar/Wind/Electrolyzers integrated systems • **WWPO –** evaluation of wind turbine power electronics for grid services

Smart Grid Program Activities	Potential Activities in the Grid Modernization MYPP
Information Interoperability • The ADMS program will focus on developing open source approach for integrating the many disparate applications across the utility enterprise that must be combined to form an ADMS. • The Smart grid program is regularly engaged in the Smart Grid Interoperability Panel activities at a variety of levels from board and steering committee membership to participation in several technical working groups.	**Grid Sensing and Measurement** • **BTO –** Building and Customer Communications • **OE TR –** Transmission sensors and asset monitoring
Grid Security and Resilience • DOE-OE policy is to require that cybersecurity be built in to any smart grid project it funds deployed in the field. • DOE-OE assists utilities in examining their cybersecurity systems and policies. • The smart grid program is assisting in the rethinking of distribution systems operations in New York (one of the primary objectives is resiliency. • The microgrids program is fundamentally focused on provided resiliency. • The smart grid program is actively planning to spin out an independent resiliency program.	**Grid Security and Resilience** • **OE CEDS –** Supply Chain • **OE CEDS –** Quantum Security • **OE CEDS –** Advanced Monitoring • **OE CEDS –** self healing cybersecurity framework • **OE CEDS –** CRISP • **OE CEDS –** ES-C2M2
Institutional Support and Alignment • The GridWise Alliance is a co-convener with DOE-OE for stakeholder engagement and policy/regulatory outreach. • Smart grid program regularly interacts with NARUC at their meetings. • The GridWise Architecture Council is also a key instrument to inform policy makers and regulators • DOE=OE prepares the bi-annual Smart Grid Systems (status) Report to Congress required by EPACT legislation.	**Institutional Support and Alignment** • **OE NED –** Regulatory utility business models

Grid Energy Storage Program Briefing Paper

The DOE OE Grid Energy Storage Program is designed to develop and demonstrate new and advanced energy storage technologies that will enable the stability, resiliency, and reliability of the future electric utility grid as it transforms into a resilient grid utilizing greater clean energy sources. The Energy Storage program focuses on accelerating the development and deployment of energy storage in the electric system through directly addressing the four principal challenges identified in the 2013 DOE Strategic Plan for Grid Energy Storage: cost competitive energy storage technology, validated reliability and safety, equitable regulatory environment, and industry acceptance. The program develops, tests and demonstrates energy storage technologies, devices, and systems, develops analytic tools enabling improved design and optimal utilization of energy storage, and facilitates codes and standards development for grid storage. R&D includes development of new electrochemical and power conversion technologies, materials development and analysis, collaborative testing (controlled test-bed and field), performance monitoring and development of component and systems-level of technical and economic analysis tools.

The DOE Grid Modernization (GM) Initiative is a cross-cutting, coordinated program of activities to help set the Nation on a cost-effective path to an integrated, secure, and reliable grid system that is flexible enough to provide an array of emerging services while remaining affordable to customers.

Table C- 11 maps the OE Grid Storage Program (OE-GS) and GM high level areas and goals.

TABLE C- 11. GS HIGH LEVEL ACTIVITY AND GOAL MAPPING

OE Grid Storage Areas and Goals	Grid Modernization Areas and Goals
OE-GS modeling • Modeling of battery electrochemical behavior, components, and systems (including manufacture) • Modeling of storage integration into the grid, with use-case development and economically optimal dispatch	**Design and Planning Tools** • Incorporate uncertainty and system dynamics into reliability planning tools to accurately capture resiliency/reliability impacts and effects of variable generation. • Coupling grid transmission and distribution models to understand cross-domain effects and use-case valuation • Advanced production cost modeling and local use-case economics to understand cost-benefit tradeoff for storage for bulk and local system operations
OE-GS control • Development of optimal dispatch and control algorithms • Analysis of field performance regarding control or use-case value capture, and local reliability functions	**System Control and Power Flow** • Deliver an architecture, framework, and algorithms for controlling a clean, resilient and secure power grid • Develop software platforms for decision support, predictive operations & real-time adaptive control
OE-GS Device and Integrated Systems • Development of electrochemical storage devices at scales ranging from button cells to multi-kW devices • Development of storage-specific power conversion devices at small scale • Testing up to 1MW electric energy storage systems • Safety-relevant testing • Development of performance and safety test protocols, and codes and standards	**Devices and Integrated System Testing** • Develop and enable a wide range of grid connected devices (e.g. storage components and systems, incl. power converters) to provide grid services • Coordinate and support the development of validated test procedures and standards to provide grid services
OE-GS Sensing and Measurement • State of charge and state of health monitoring for electrochemical storage systems • Safety-relevant monitoring	**Grid Sensing and Measurement** • Develop real-time data management and data exchange framework that enables analytics to improve prediction and reduce uncertainty • Develop next generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resiliency

OE Grid Storage Areas and Goals	Grid Modernization Areas and Goals
OE-GS Security and Resilience • Incorporation of reliability/resilience use-cases in optimal dispatch and control	**Grid Security and Resilience** • Holistic grid security and resilience, from devices to systems • Inherent security designed into components and systems vice security as an afterthought
OE-GS Institutional Support and Alignment • Common use-case characterization, modeling, and monitoring as basis for economic assessment, and value stream recognition and monetization • Codes and standards development for evaluating performance, safety and facilitating deployment	**Institutional Support and Alignment** • Technical support for states that want to evaluate changes to their regulatory model that better aligns utility and consumer interests with grid modernization and/or clean energy policy • Methods for valuation of DER technologies and services are defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations

Leveraging Opportunities

The DOE Grid Modernization Initiative is a cross-cutting effort that spans multiple DOE Program Offices. Based on our review of existing national lab projects/activities funded by various DOE offices, there may be additional opportunities that can be leveraged to meet OE-GS program objectives and work collaboratively with other Program Offices. Table C- 12 identifies some current OE-GS program activities to be potentially included in the Grid Modernization MYPP.

TABLE C- 12. LEVERAGING OPPORTUNITIES

OE-GS Activities	Potential Activities in the Grid Modernization MYPP
Design and Planning Tools • Modeling of storage integration into the grid, with use-case development and economically optimal dispatch	**Design and Planning Tools** • **OE AGM** – Modeling and State Estimation • **OE SG** – Smart grid & microgrid modeling & distribution planning • **WWPO** - WWSIS and ERGIS tool development, PSH for grid services • **BTO** – Commercial Building advanced EMS development, • **SETO** – Integrated modeling of high pen PV
System Control and Power Flow • Development of optimal dispatch and control algorithms • Analysis of field performance regarding control or use-case value capture, and local reliability functions	**System Control and Power Flow** • **OE AGM** – Grid architecture and control theory development, advanced EMS/DMS systems, advanced analytics and computations for grid operation and control • **OE SG** – Advanced distribution system management, microgrid control • **WWPO** – PSH control for grid services • **BTO** – Building-EMS & grid coordinated control • **ARPA-E GENI** – Power electronics development • **SETO** – solar forecasting and operational models
Devices and Integrated System Testing • Development of electrochemical storage devices at scales ranging from button cells to multi-kW devices • Development of storage-specific power conversion devices at small scale • Testing up to 1MW electric energy storage systems • Safety-relevant testing • Development of performance and safety test protocols, and codes and standards	**Devices and Integrated System Testing** • **SETO** –development of inverter with advanced functionality • **BTO** – developing characterization procedures for building technologies to provide grid and other services, building EMS evaluation • **FCTO** – Regenerative H2 fuel cells • **VTO** – Automotive battery pack design & battery development • **WWPO & SETO**– variable renewable power electronics for grid services • **OE SG** – updating interconnection & interoperability standards for DER • **ARPA-E AMPED, GRIDS, BEEST, RANGE** –Storage technology development • **ARPA-E GENI, SWITCHES** – Power electronics development

OE-GS Activities	Potential Activities in the Grid Modernization MYPP
Grid Sensing and Measurement • State of charge and state of health monitoring for storage systems • Safety-relevant monitoring	**Grid Sensing and Measurement** • **SETO** – development of distribution level monitoring • **VTO –** Battery status and health monitoring
Grid Security and Resilience • Incorporation of reliability/resilience use-cases in optimal dispatch and control	**Grid Security and Resilience** • **OE SG –** microgrid and smart grid architectures, and outage management • **OE SER** – Integrated planning for reliability and resilience
Institutional Support and Alignment • Common use-case characterization, modeling, and monitoring as basis for economic assessment, and value stream recognition and monetization • Codes and standards development for evaluating performance, safety and facilitating deployment	**Institutional Support and Alignment** • **OE SG** – Smart grid implementation • **OE NED** – Regulatory utility business models • **OE-SER** – Regulatory reforms for storage

Solar Energy Technology Office Briefing Paper

The DOE Solar Energy Technology Office (SETO) works to accelerate the market competitiveness of solar energy by targeting cost reductions and supporting increased solar deployment. Inside the SETO, the Systems Integration (SI) area supports strategies to dramatically increase solar penetration in the nation's electrical grid and enable safe, reliable, cost-effective, and widespread solar deployment.

The DOE Grid Modernization (GM) Initiative is a cross-cutting, coordinated program of activities to help set the Nation on a cost-effective path to an integrated, secure, and reliable grid system that is flexible enough to provide an array of emerging services while remaining affordable to customers.

The anticipated proliferation of solar power at the centralized and distributed scales emphasizes the need for timely and cost effective interconnection procedures, accurate prediction of solar resources, and monitoring and control of solar power. Moreover, the impact of solar energy on the performance and reliability of transmission and distribution power systems is becoming a larger challenge. Table C- 13 maps SETO and GM high level areas and goals. This shows good alignment of goals in five of the six GM areas.

TABLE C- 13. SETO HIGH LEVEL ACTIVITY AND GOAL MAPPING

SETO Areas and Goals	Grid Modernization Areas and Goals
SI Grid Performance and Reliability • Maintain and enhance the efficiency and reliability of electric transmission and distribution systems in a cost-effective, safe manner with hundreds of gigawatts of solar generation deployed onto the nation's power system	**Design and Planning Tools** • Incorporate uncertainty and system dynamics into reliability planning tools to accurately capture effects of renewable generation • Coupling grid transmission, distribution, and communications models to understand cross-domain effects • Advanced production cost modeling used to understand cost-benefit tradeoff of the mix and location of storage and solar
SI Dispatchability • Ensure that solar power is available on-demand, when and where it is needed and at the desired amounts, in a manner that is comparable to or better than conventional power plants.	**System Control and Power Flow** • Deliver an architecture, framework, and algorithms for controlling a clean, resilient and secure power grid • Develop software platforms for decision support, predictive operations & real-time adaptive control
SI Power Electronics • Develop intelligent devices that maximize the power output from solar power plants and interface with the electric grid (or end use circuits), while ensuring overall system performance, safety, reliability, and controllability at minimum cost	**Devices and Integrated System Testing** • Develop and enable a wide range of grid connected devices (e.g. PV inverters) to provide energy services • Coordinate and support the development of validated test procedures and standards to provide energy services
SI Communications • Create infrastructure that is used to inform, monitor and control generation, transmission, distribution and consumption of solar energy effectively under broad temporal and spatial scales	**Grid Sensing and Measurement** • Develop real-time data management and data exchange framework that enables analytics to improve prediction and reduce uncertainty • Develop next generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resiliency
No formal work in Security and Resilience Cybersecurity, while not a primary focus for SunShot, should be taken into consideration when designing communication solutions.	**Grid Security and Resilience** • Holistic grid security and resilience, from devices to systems • Inherent security designed into components and systems vice security as an afterthought

SETO Areas and Goals	Grid Modernization Areas and Goals
SETO Soft Cost • Empowering state and local decision-makers through timely and actionable resources, peer networks, and technical assistance • Training an innovative solar workforce to enable the solar industry to meet growing demand • Developing solar finance and business solutions to expand access to capital and accelerate market growth	**Institutional Support and Alignment** • Technical support for states that want to evaluate changes to their regulatory model that better aligns utility and consumer interests with grid modernization and/or clean energy policy Methods for valuation of DER technologies and services are defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations

Leveraging Opportunities

The DOE Grid Modernization Initiative is a cross-cutting effort that spans multiple DOE Program Offices. Based on our review of existing national lab projects/activities funded by various DOE offices, there may be additional opportunities that can be leveraged to meet SETO objectives and work collaboratively with other Program Offices. Table C- 14 identifies some current SETO activities and activities to be included in the Grid Modernization MYPP.

TABLE C- 14. LEVERAGING OPPORTUNITIES

SETO Activities	Potential Activities in the Grid Modernization MYPP
Design and Planning Tools • Integrated T&D Modeling for High Pen PV • WWSIS and ERGIS tool development • Distribution Modeling Tools for High Pen PV • Bulk-System Stochastic Modeling for PV	**Design and Planning Tools** • **OE AGM** – Modeling and Stat Estimation • **WWPO** – WWSIS and ERGIS tool development • **BTO** – Commercial Building agent based modeling • **OE SG** – Smart grid communication modeling
System Control and Power Flow • Solar Forecasting • Solar Operational Analysis, Models, and Tool Improvement	**System Control and Power Flow** • **OE AGM** – grid architecture and control theory development • **OE/NSF CURRENT** - grid architecture and control theory development • **BTO** – Building-grid coordinated control • **OE AGM** – advanced EMS/DMS systems • **OE AGM** – Advanced Analytics and Computations for Grid Operation and Control • **ARPA-E GENI** – Power Electronics Development
Devices and Integrated System Testing • Updating interconnection standards for PV inverters • Developing PV inverters with new grid support functionality • Module Level Power electronics testing and standards • PV inverter testing • Integrated PV/Storage System Testing • High Pen Testing and demonstrations	**Devices and Integrated System Testing** • **BTO** – developing characterization procedures for building technologies to provide grid and other services • **VTO** – developing interoperability standards and power electronics for EV • **FCTO** – evaluating Solar/Wind/Electrolyzers integrated systems • **WWPO** – evaluation of wind turbine power electronics for grid services • **OE SG** – updating interconnection standards for DER • **OE SG** – developing interoperability standards for DER • **OE ES** – battery and power electronics development
Grid Sensing and Measurement • Development of distribution level monitoring and visualization for High Pen PV	**Grid Sensing and Measurement** • **BTO** – Building and Customer Communications • **OE TR** – Transmission sensors and asset monitoring

SETO Activities	Potential Activities in the Grid Modernization MYPP
Grid Security and Resilience	**Grid Security and Resilience** • **OE CEDS** – Supply Chain • **OE CEDS** – Quantum Security • **OE CEDS** – Advanced Monitoring • **OE CEDS** – self healing cybersecurity framework • **OE CEDS –** CRISP • **OE CEDS –** ES-C2M2
Institutional Support and Alignment • State and Regional Stakeholder Engagement • Training and Education	**Institutional Support and Alignment** • **OE SG** – Smart grid implementation • **OE NED** – Regulatory utility business models

Vehicle Technology Office Briefing Paper

The DOE Vehicle Technology Office (VTO) develops and deploys efficient and environmentally friendly highway transportation technologies that will enable America to use less petroleum. These technologies will provide Americans with greater freedom of mobility and energy security, while lowering costs and reducing impacts on the environment.

The DOE Grid Modernization (GM) Initiative is a cross-cutting, coordinated program of activities to help set the Nation on a cost-effective path to an integrated, secure, and reliable grid system that is flexible enough to provide an array of emerging services while remaining affordable to customers.

Electrification of the vehicle fleet can increase the overall energy efficiency of vehicles and decrease the use of petroleum. Transitioning to a light-duty fleet of HEVs and PEVs could reduce U.S. foreign oil dependence by 30-60 percent and greenhouse gas emissions by 30-45 percent, depending on the exact mix of technologies. Table C- 15 maps VTO and GM high level areas and goals. This shows good alignment between VTO and GM areas with a majority of work covered in three areas: devices and Integrated Systems Testing, Sensing and Measurement, and Institutional Support and Alignment.

TABLE C- 15. VTO HIGH LEVEL ACTIVITY AND GOAL MAPPING

VTO Areas and Goals	Grid Modernization Areas and Goals
VTO EV modeling • Modeling of high pen EV deployments	**Design and Planning Tools** • Incorporate uncertainty and system dynamics into reliability planning tools to accurately capture effects of variable generation • Coupling grid transmission, distribution, and communications models to understand cross-domain effects • Advanced production cost modeling used to understand cost-benefit tradeoff of the mix and location of storage and DER
No formal work	**System Control and Power Flow** • Deliver an architecture, framework, and algorithms for controlling a clean, resilient and secure power grid • Develop software platforms for decision support, predictive operations & real-time adaptive control

VTO Areas and Goals	Grid Modernization Areas and Goals
VTO Device and Integrated Systems • Advanced battereis - Reducing the cost, volume, and weight of batteries, while simultaneously improving the vehicle batteries' performance (power, energy, and durability) and ability to tolerate abuse conditions. • Secondary use of EV batteries • Assessment of potential battery performance and life degradation due to Fast Charging • EV and PHEV testing - energy demands, charging profiles, communications, and charging profiles as a function of drive cycles to support vehicle to grid benefits analyses • Support the development and verification of standards and technology for plug-in vehicle-grid connectivity and communication; Direct support to SAE and ISO/IEC standards committees with expertise and laboratory facilities support. • Explore feasibility and benefits of wireless power transfer (WPT) grid integration service concepts and siting environments • development of EV communication standards; identifying high value renewable, energy storage, utility, EV / EVSE use cases that require communications; developing and demonstrating control strategies; and evaluating bridging options between SEP2.0 equipped and SEP2.0 not equipped vehicles with currently implemented utility communications.	**Devices and Integrated System Testing** • Develop and enable a wide range of grid connected devices (e.g. PEVs, EVSEs) to provide energy services • Coordinate and support the development of validated test procedures and standards to provide energy services
VTO Sensor Development • Development of end-use measurement devices (smart sensors) • Electric Fuel Measurement Device	**Grid Sensing and Measurement** • Develop real-time data management and data exchange framework that enables analytics to improve prediction and reduce uncertainty • Develop next generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resiliency
VTO Cybersecurity • Conduct cybersecurity and efficiency testing of OE-funded Smart Grid EVSE	**Grid Security and Resilience** • Holistic grid security and resilience, from devices to systems • Inherent security designed into components and systems vice security as an afterthought
VTO Institutional Support • Support the development and enhancement of various grid-related Codes and Standards (C&S) via the testing of the end-of-the-grid charging infrastructure required for plug-in electric vehicles (PEV) and its interoperability with PEVs, and the development of testing reports that are relayed to C&S groups, both within the industry and government. • Participating in CPUC/CAISO Vehicle Grid Integration Roadmap Initiative, contributing to the development of UL/IEEE/SAE V2G-related operations and testing standards, and collaborating with utilities on V2G vehicle interconnection rules and requirements review	**Institutional Support and Alignment** • Technical support for states that want to evaluate changes to their regulatory model that better aligns utility and consumer interests with grid modernization and/or clean energy policy • Methods for valuation of DER technologies and services are defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations

Leveraging Opportunities

The DOE Grid Modernization Initiative is a cross-cutting effort that spans multiple DOE Program Offices. Based on our review of existing national lab projects/activities funded by various DOE offices, there may be additional opportunities that can be leveraged to meet VTO objectives and work collaboratively with other Program Offices. Table C- 16 identifies some current VTO activities and activities to be included in the Grid Modernization MYPP.

Table C- 16. Leveraging Opportunities

VTO Activities	Potential Activities in the Grid Modernization MYPP
Design and Planning Tools • Modeling of high penetration EV scenarios at bulk-system and distribution system levels	**Design and Planning Tools** • **OE AGM** – Modeling and Stat Estimation • **WWPO** - WWSIS and ERGIS tool development • **BTO –** Commercial Building agent based modeling • **OE SG** – Smart grid communication modeling • **SETO** – Integrated modeling of high pen PV
System Control and Power Flow • N/A	**System Control and Power Flow** • **OE AGM** – grid architecture and control theory development • **OE/NSF CURRENT** - grid architecture and control theory development • **BTO** – Building-grid coordinated control • **OE AGM** – advanced EMS/DMS systems • **OE AGM** – Advanced Analytics and Computations for Grid Operation and Control • **ARPA-E GENI** – Power Electronics Development • **SETO** – solar forecasting and operational models
Devices and Integrated System Testing • Developing new battery technologies • Developing new inverter technologies • Developing interoperability standards and power electronics for EV • Developing interconnection standards for EVs • Integrated EV testing capabilities across laboratories	**Devices and Integrated System Testing** • **SETO** – developing interconnection and interoperability standards for PV inverters, development of inverter with advanced functionality, high pen demonstrations • **BTO** – developing characterization procedures for building technologies to provide grid and other services • **FCTO** – evaluating Solar/Wind/Electrolyzers integrated systems • **WWPO** – evaluation of wind turbine power electronics for grid services • **OE SG** – updating interconnection standards for DER • **OE SG** – developing interoperability standards for DER • **OE ES** – battery and power electronics development
Grid Sensing and Measurement • Development of end-use measurement devices (smart sensors) • Electric Fuel Measurement Device (NIST HB44)	**Grid Sensing and Measurement** • **BTO** – Building and Customer Communications • **OE TR** – Transmission sensors and asset monitoring • **SETO** – development of distribution level monitoring and visualization for High Pen PV
Grid Security and Resilience • Conduct cybersecurity and efficiency testing of OE-funded Smart Grid EVSE	**Grid Security and Resilience** • **OE CEDS** – Supply Chain • **OE CEDS** – Quantum Security • **OE CEDS** – Advanced Monitoring • **OE CEDS** – self healing cybersecurity framework • **OE CEDS –** CRISP • **OE CEDS –** ES-C2M2
Institutional Support and Alignment • Stakeholder Engagement - C&S groups, both within the industry and government. • CPUC/CAISO Vehicle Grid Integration Roadmap Initiative, contributing to the development of UL/IEEE/SAE V2G-related operations	**Institutional Support and Alignment** • **OE SG** – Smart grid implementation • **OE NED** – Regulatory utility business models • **SETO** – State and Regional stakeholder engagement

Wind and Water Program Office Briefing Paper

The DOE Wind Program works to enable rapid expansion of clean, affordable, and reliable domestic wind power to promote national security, economic vitality, and environmental quality. The Wind Program works with electric grid operators, utilities, regulators, and industry to create new strategies for incorporating increasing amounts of wind energy into the power system while maintaining economic and reliable operation of the grid.

The program's goal in advanced grid integration is to remove barriers to wind energy grid integration and accelerate deployment to enable 20 percent of the nation's electricity to come from wind. This can be accomplished through integration studies, modeling, demonstrations, and assessments at both the transmission and distribution levels.

The DOE Grid Modernization (GM) Initiative is a cross-cutting, coordinated program of activities to help set the Nation on a cost-effective path to an integrated, secure, and reliable grid system that is flexible enough to provide an array of emerging services while remaining affordable to customers.

The anticipated proliferation of Wind power emphasizes the need for timely and cost effective interconnection procedures, accurate prediction of wind resources, and monitoring and control of wind power. Moreover, the impact of wind energy on the performance and reliability of transmission and distribution power systems is becoming a larger challenge. Table C- 17 maps Wind and Water Program and GM high level areas and goals. This shows good alignment of goals in five of the six GM areas.

TABLE C- 17. WWPO HIGH LEVEL ACTIVITY AND GOAL MAPPING

Wind and Water Program Areas and Goals	Grid Modernization Areas and Goals
Wind Forecasting • Improve forecasting for mitigating wind variability and uncertainty—by providing data for forecast verification, improving forecast accuracy, and evaluating methods for presenting forecast data to system operators. Wind Plant Performance Characterization • Provide wind turbine component electrical models for use in interconnection studies. Support analysis of how best to determine the power curve for wind farms, help improve wind forecasts, and help better evaluate how turbine wake effects can impact power production. Grid Planning and Analysis • Inform power systems planners on how to best represent the characteristics of wind power.	**Design and Planning Tools** • Incorporate uncertainty and system dynamics into reliability planning tools to accurately capture effects of renewable generation • Coupling grid transmission, distribution, and communications models to understand cross-domain effects • Advanced production cost modeling used to understand cost-benefit tradeoff of the mix and location of wind plants
Control and Ancillary Services • Integrate forecasting tools into energy management systems • Ensure stable and reliable system operation at the turbine generator and operate in coordination with grid power electronics, e.g. HVDC and FACTS devices • Integrate new control capabilities into AGC systems	**System Control and Power Flow** • Deliver an architecture, framework, and algorithms for controlling a clean, resilient and secure power grid • Develop software platforms for decision support, predictive operations & real-time adaptive control
• Evaluation of wind turbine power electronics for grid services	**Devices and Integrated System Testing** • Develop and enable a wide range of grid connected devices (e.g. PV inverters) to provide energy services • Coordinate and support the development of validated test procedures and standards to provide energy services

Wind and Water Program Areas and Goals	Grid Modernization Areas and Goals
• High Performance Computing and Information Challenges • Sensors, and architectures to allow variable generation to operate with energy storage, demand response as reliably as dispatchable generation • Algorithms, computing architecture, and information management to support increasing use of sensors and PMUs	**Grid Sensing and Measurement** • Develop real-time data management and data exchange framework that enables analytics to improve prediction and reduce uncertainty • Develop next generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resiliency
	Grid Security and Resilience • Holistic grid security and resilience, from devices to systems • Inherent security designed into components and systems vice security as an afterthought
Market Design for High Penetration Variable Generation • Design of competitive markets to better support variable generation • Wind participation and dispatch in locational marginal price markets • Value of wind generation and storage for long term generation forecasts	**Institutional Support and Alignment** • Technical support for states that want to evaluate changes to their regulatory model that better aligns utility and consumer interests with grid modernization and/or clean energy policy Methods for valuation of DER technologies and services are defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations

Leveraging Opportunities

The DOE Grid Modernization Initiative is a cross-cutting effort that spans multiple DOE Program Offices. Based on our review of existing national lab projects/activities funded by various DOE offices, there may be additional opportunities that can be leveraged to meet Wind and Water objectives and work collaboratively with other Program Offices. Table C- 18 identifies some current Wind and Water Program activities and activities to be included in the Grid Modernization MYPP.

TABLE C- 18. CURRENT WIND AND WATER PROGRAM ACTIVITIES AND ACTIVITIES FOR THE GRID MODERNIZATION MYPP

Wind & Water Activities	Potential Activities in the Grid Modernization MYPP
Design and Planning Tools • Wind forecasting • Wind plant performance modeling and characterization • Grid planning and interconnection studies	**Design and Planning Tools** • **OE AGM** – Modeling and Stat Estimation • **WWPO** - WWSIS and ERGIS tool development • **OE SG** – Smart grid communication modeling
System Control and Power Flow • System control and Energy Management • Integration with AGC systems	**System Control and Power Flow** • **OE AGM** – grid architecture and control theory development • **OE/NSF CURRENT** - grid architecture and control theory development • **OE AGM** – advanced EMS/DMS systems • **OE AGM** – Advanced Analytics and Computations for Grid Operation and Control • **ARPA-E GENI** – Power Electronics Development
Devices and Integrated System Testing • Wind turbine compatibility with other grid power electronics	**Devices and Integrated System Testing** • **FCTO** – evaluating Solar/Wind/Electrolyzers integrated systems • **WWPO** – evaluation of wind turbine power electronics for grid services • **OE SG** – updating interconnection standards for DER • **OE SG** – developing interoperability standards for DER • **OE ES** – battery and power electronics development

Wind & Water Activities	Potential Activities in the Grid Modernization MYPP
Grid Sensing and Measurement • Sensors, algorithms, and computing architectures for wind plant management in tandem with grid	**Grid Sensing and Measurement** • **OE TR** – Transmission sensors and asset monitoring
Grid Security and Resilience	**Grid Security and Resilience** • **OE CEDS** – Supply Chain • **OE CEDS** – Quantum Security • **OE CEDS** – Advanced Monitoring • **OE CEDS** – self healing cybersecurity framework • **OE CEDS** – CRISP • **OE CEDS** – ES-C2M2
Institutional Support and Alignment • Value of wind • Market design for variable generation	**Institutional Support and Alignment** • **OE SG** – Smart grid implementation • **OE NED** – Regulatory utility business models

Appendix D: Sources Consulted

Chapter 2: Devices and Integrated System Testing

Power Electronics Research and Development Plan, April, 2011: http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/OE_Power_Electronics_Program_Plan_April_2011.pdf

US Department of Energy, DOE SunShot Vision Study: http://energy.gov/eere/sunshot/sunshot-vision-study

US Department of Energy, DOE Solar FOA: SUNSHOT NATIONAL LABORATORY MULTI-YEAR PARTNERSHIP (SUNLAMP) https://eere-exchange.energy.gov/#FoaId54a44ce1-eaa5-4f50-9c19-54702253559b

US Department of Energy, DOE Wind Vision Study: http://energy.gov/eere/wind/wind-vision

US Department of Energy, DOE Fuel Cell Technologies Office MYPP: http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

US Department of Energy, DOE EV EVERYWHERE GRAND CHALLENGE ROAD TO SUCCESS Report: http://energy.gov/eere/vehicles/downloads/ev-everywhere-grand-challenge-road-success

US Department of Energy, DOE Grid Energy Storage Report: http://energy.gov/oe/downloads/grid-energy-storage-december-2013

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