Electricity Advisory Committee

TO: **Honorable Patricia Hoffman, Assistant Secretary for Electricity Delivery and Energy Reliability, U.S. Department of Energy**

FROM: **Electricity Advisory Committee (EAC)**
Richard Cowart, Chair

DATE: **September 30, 2015**

RE: **Grid Modernization: ARRA Accomplishments and Recommendations for Moving Forward**

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1 Background and Purpose

The U.S. Department of Energy (DOE)'s smart grid portion of the American Reinvestment and Recovery Act (ARRA) was a bold, robust attempt to advance the technology of the U.S. electrical grid by driving adoption of, and demonstration of, innovative smart grid technology. The program was undeniably successful in launching new technology in the field. This paper is a retrospective assessment of the value of this program in encouraging the industry to take a substantial technical step forward. It is also a prospective look at the future of the smart grid and DOE's role going forward.

Further, this paper sets forth the EAC's recommendations for building on the ARRA smart grid-related accomplishments to continue the Nation's efforts to develop a smarter, more resilient grid. The timeframe of the prospective view is the next 15 years, which corresponds with the planning horizon of many utilities. This timeline also spans the electric industry drivers and performance conditions that support responsible societal development and growth. The purpose of this report is to provide input to the 2016 Smart Grid Systems Report that will include recommendations for State and Federal policies and actions that could help facilitate the transition to a smarter grid. Additionally, the report highlights opportunities and challenges

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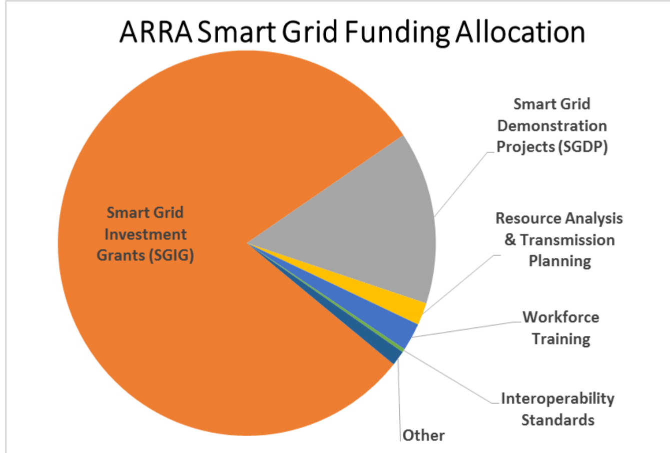
presented by the smart grid, the current status of grid deployment, including key factors driving and influencing that status, and recommendations for realizing the full potential of the grid.



Over the last five years, through a public-private partnership, approximately $9B has been invested under the ARRA to support 131 smart grid projects. Funding was distributed across a range of projects and programs with the majority going toward smart grid investment grants (SGIG) and smart grid demonstration projects (SGDP). Workforce training, resource assessment and transmission planning, and interoperability standards also received support (see Figure 1). This paper is *not* intended to provide a full summary of project evaluations and quantitative results related to the deployment of technologies under the SGIG, SGIP, or other projects. A detailed evaluation of those projects can be found in the Case Studies on the DOE's Smart Grid Portal (DOE, 2015) and in the summary materials from the 2014 conference *The Smart Grid Experience: Applying Results, Reaching Beyond* hosted by DOE and the Electric Power Research Institute (EPRI, DOE 2014).

As a result of the ARRA investments, the rate of smart grid technology adoption has accelerated, technology penetration has increased, and the power sector's understanding of the costs and benefits of smart grid enhancements has matured. The challenge now is to identify avenues through which the nation can best capitalize on past accomplishments to continue advancing grid modernization in a cost-effective manner.

2 Power System Transformation

A fundamental shift is occurring in how power markets and electricity delivery systems operate; they are increasingly required to support an integrated grid that includes more distributed energy resources (DER) and distributed control. This shift is changing how electricity is generated, moved, and used. It is driven by trends in the energy landscape, enabling technologies, increased consumer participation, and market competition. The traditional model of the grid, with large plants supplying power through a mostly passive, unidirectional distribution system, is changing to one in which more renewables, distributed generation, load controls, storage, voltage and volt-ampere reactive power optimization (VVO) management technology and other technologies must be integrated and coordinated in a dynamically controlled system. This will allow power to flow in multiple directions (rather than in one direction, as it is currently designed) and help the balance between supply and demand of electricity to be maintained. The smarter grid must be able to seamlessly and dynamically incorporate, manage and balance each of these components. Therefore, technical innovation needs to go well beyond being "automation capable" to be designed for true interoperability.

Grid operators will need improved information management, communications and control systems and increased awareness into the real-time status of these distributed components, e.g., variable DER, in order to make certain the distribution network remains balanced. The fundamental shift to the grid of the future will require technologies that enable productivity, reliability and increased efficiency. It is within this space that the ARRA has played a crucial role, lending much needed support to the innovators and creators that are developing the tools and technologies necessary to spearhead the transition from the traditional grid of today to the smarter grid of the future.

Additionally, major shifts in the broader energy landscape are occurring. For example, hydraulic fracturing technology has unlocked untold supplies of natural gas causing energy prices to decline. This supply trend is expected to continue; the US Energy Information Administration projects U.S. natural gas dry production will increase an average of 1.4% annually until 2040. Production will increase to 35.4 trillion cubic feet in 2040 from 24.4 trillion cubic feet in 2013, a 45% increase. At these rates, the U.S. will become a net exporter of natural gas before 2020 (EIA 2015, Table A13.) As a result, opportunities could likely emerge for alternative energy vehicles and the infrastructure to support them, including supply, storage and delivery mechanisms for electric vehicles and natural gas powered cars. Convergence of coordinated energy flows and markets between the natural gas network and electricity network will increase over time.

These power system changes are occurring against the backdrop of increasingly severe climate change (IPCC, 2014), a top-rated threat according to the majority of participants in a 40 nation Pew Research Center survey conducted in 2015. Leaders around the globe are taking action. Late in 2014, President Obama accelerated his national climate goal to reduce greenhouse gas emissions and in August 2015 the EPA announced the final Clean Power Plan to reduce carbon pollution from the power sector by 32% below 2005 levels by 2030 (EPA, 2015) and many states have instituted ambitious renewable portfolio standards (NREL, 2013). European Union (EU) leaders have committed to transforming Europe into a highly energy-efficient, low carbon economy and the region is working successfully towards meeting its progressive greenhouse gas emissions reduction goals by 2050 (ECF, 2015). Similar movements are occurring in many other global regions. In China, leaders announced plans to cut the carbon intensity of GDP by 60-65% below 2005 levels by 2030, and to peak CO_2 emissions by 2030 or before (China INDC, 2015).

Increased interest in managing emissions has put a spotlight on renewable generation development. With rapid cost reductions and continued support through subsidies and policies, renewables are forecasted to account for one-third of global power generation by 2040 (IEA, 2014). The share of renewables in power generation increases will be led by China, India, Latin America and Africa. The price of wind turbines has dropped 20% - 40% since 2008, a recent

DOE report found (DOE 2014). Similarly, solar prices have declined, leading to accelerating rates of adoption (Barbose, et al., 2014). Much of this generation is located at its point of consumption, making it very distributed in nature. Large sources of power serving many customers are being replaced with many smaller sources serving – and often owned by – a single customer or small group of customers. This movement presents opportunities in renewable generation technologies and facilitating renewables' interconnection with the grid.

The recent recession and slow recovery have forestalled load growth and, in some circumstances, led to declines in load, but renewed economic growth and continued electrification in developing economies is expected to drive global electricity demand. The International Energy Agency (IEA) forecasts that global energy demand will grow 37% by 2040, but the rate of global demand growth will slow from above 2% per year over the last two decades to 1% per year after 2025 (IEA, 2014). Growth in U.S. electricity use is expected to remain modest with an average rate of growth of 0.8% from 2013 through 2040. (EIA, 2015).

Distributed generation is expected to demonstrate the opposite trend; DG is forecasted to grow from less than 2% in the U.S. today to approximately 10% by 2025 (EIA 2015). In the decade ahead, it will also be likely that emerging DG technologies, such as battery storage, fuel cells, rooftop solar installations and microgrids will continue to grow. Increasing penetration of renewable DG will make both operations and long-term planning more complex due to the fact that they will be providing highly-variable power into the grid from distributed locations.

At the same time, the profile, level, and flexibility of demand could benefit from the falling cost of using smart devices to manage cooling, heating, water heating, electric vehicle charging and other flexible loads. If appropriately facilitated, the application of smart devices to provide virtual storage and improve efficiency could accelerate over the next decade. Potential studies suggest that such technologies could significantly reduce peak demand, facilitate the integration of variable resources, and provide significant energy and cost savings. (NETL 2011; Mathieu 2012).

These combinations of potential assets, oftentimes referred to as distributed energy resources (DERs) that will both consume and provide energy in unconventional ways at the distribution level will require a more configurable network to better manage load flow and maintain power quality. Further, it will require implementing innovative solutions for large-scale distributed generation adoption and more strategic planning of upgrades, with increased emphasis on network flexibility. As distributed energy resources grow as a market force, the grid must evolve into a more distributed, digital and dynamic system that is capable of providing two-way management of both information and power flow between consumers, distributed resources, and the utility.

Experience from the ARRA investment was pivotal and a critical preparatory step for grid transformation. It helped ready the workforce (which is fundamental to facilitating the smart grid transition), advanced the conversation on codes and standards (which is necessary for successfully sustaining advanced interoperability for a smart grid), set the stage for introducing the technology components that are the key building blocks to the optimized grid's functionality and efficiency, and advanced cybersecurity practices and capabilities.

3 Current Status of Smart Grid Deployment and Lessons from ARRA Program

Smart grid penetration has grown substantially since the initiation of the ARRA program; however, the advent of distributed energy resources will usher in an age of grid transformation with respect to how it is operated. The following section highlights several of the key factors enabling this growth and development, the current status of the smart grid industry, and key outcomes from the ARRA program, including lessons learned, noteworthy successes and best practices to bear in mind going forward.

3.1 Factors Driving Grid Modernization & Status of Current Transformations Underway

Grid modernization has been driven by a variety of conditions and trends. Some of these are common across the utility landscape while others are unique to particular regions and markets. Several of the most notable types of drivers are discussed here: business models, technological change, new product development, and the Internet of Things as well as smart cities phenomena. Smart cities phenomena will permit the effective integration of various infrastructure networks. The influence that these drivers have had in shaping the current market is discussed as well. Further, a brief overview of the current status of smart grid deployment, as pertains to each category, is provided throughout.

3.1.1 Business Model Drivers

The business model of electric utilities has changed little since their inception in 1883, but relentless improvement in technology and operations have taken electricity from a luxury product to the inexpensive, ubiquitous lifeblood of modern society. Today, there are numerous challenges to the business model including the need to replace an aging infrastructure in the face of flat to declining revenue and the prospect of further decreases in revenue as users generate some of their own power and invest in energy efficiency (EPRI, 2014; Kind, 2013).

Traditionally, the grid has been built to handle peak demands yet these rarely occur, meaning that the grid seldom operates at the peak of its design limits. Distributed energy resources (DER) can exacerbate peak demand management challenges and make planning difficult, depending on how and where DER is deployed and operated. New technologies, such as virtual storage from management of flexible demand and energy storage, are, or are on the cusp of, becoming commercially viable (with policy driven storage adoption being implemented in California). These technologies have the potential to help address several of the issues associated with peak demand management in the face of increasing DER expansion, yet regulatory models struggle to properly provide incentives and to handle storage ownership and financial payback logistics.

Though the current industry structure is complicated by competing approaches (investor-owned vs. customer-owned, vertically integrated vs. functionally segregated, and issues unique to each region) there are commonalities in the current market structure that can be summarized as follows:

- The aging infrastructure needs to be replaced,[1] and upgraded with technologies that will serve the user of the future. When demand is stagnant and an increasing proportion of generation is close to the load, as is expected in the future, business models supporting forthcoming investments must be different than historical investment structures.

- Electricity prices are already expected to rise in most regions and they would experience further upward pressure with expanded investment in the grid.

- Renewable penetration will increase and generation mix will be altered to address climate change objectives.

- The grid must to be optimized for these new industry realities.

- The business case that supports the importance of grid modernization needs to be better communicated to all stakeholders so more informed decisions can be made regarding the costs and benefits of building a smarter, more optimized grid to serve future needs.

- Electricity service is essential to the health and economic welfare of all Americans. The need to ensure reliable, universal, affordable electricity service continues to be paramount.

- The number of service interruptions involving large numbers of electric customers has increased over the last twenty years and the grid is seen as increasingly at risk for service interruptions from severe weather and security events.

- As society becomes increasingly digitized there is escalating dependency on reliable power and a strong linkage to economic vitality. This has led to a growing recognition of the importance of having a power grid that will be both reliable under normal circumstances and resilient in the face of greater challenges.

- Momentary interruptions and outages are increasingly costly to an economy that is fueled by electricity and critical functions simply do not work without connectivity.

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[1] *See examples such as: http://www.marketwatch.com/story/capital-spending-soars-at-us-utilities-2015-04-20*

This last point, the notion that even millisecond interruptions in electricity service have noticeable repercussions (economic and otherwise) is taken very seriously by both system operators and utility industry experts, especially as they work to incorporate an increasing number of novel devices onto a grid that is inexperienced at handling them all. Technologies and other applications to better facilitate maintaining uninterrupted electric service are available, however the financial justification for them is often difficult to parse out, including the allocation of cost responsibility between those customers who require the very highest levels of reliability and costs required to provide an optimal level of service to the system as a whole. Updating the Department of Energy's Interruption Cost Estimation would serve to better quantify the cost of outages and power quality events to customers and help to drive the business case for investments by individual customers and by utilities in improving resiliency and reliability of service. These cost estimation recommendations were outlined in a previous EAC paper: *Recommendations Regarding Emerging and Alternative Regulatory Models and Modeling Tools to Assist in Analysis, (DOE 2014).*

This same paper also provided a robust discussion and overview of many of the ongoing and regulatory/business model initiatives happening on both a national and international scale. Recommendations for white papers and further evaluation were highlighted. The paper served to provide the DOE with a snapshot of ongoing efforts and future opportunities.

3.1.2 Technology Driven Change

Rapid technological change has been a key factor in spurring smart grid deployment; without it, many of the fundamental components and value added opportunities provided by a smart grid would be impossible. Key developments include a suite of transmission-oriented technologies, a similar set of distribution-oriented tools, new customer-friendly products, and the application and advancement of information and communications technology (ICT) for grid applications (discussed in section 3.1.3).

The rates of development and adoption of grid technologies are rapidly accelerating. Advanced sensors, advanced switches, VVO technology, improved power electronics, Advanced Metering Infrastructure (AMI), and other technologies underpin the transformation of the electric power system to a network that is much more agile and actively managed, but correspondingly more complex and immensely dependent on a vastly larger body of data. For example, current AMI capabilities can help utilities cut costs (through improved outage detection, remote metering and service management) and improve customer relationships (through specialized optional pricing schemes, abnormal bill alerts and enhanced communications), in addition to other benefits. Advanced sensors allow system operators to monitor the condition of transmission and distribution lines in real-time and improved power electronics provide a wide range of opportunities for increasing the efficiency and optimization of grid components. The ARRA projects demonstrated these technologies, proving viability and unforeseen benefit streams.

Lessons are being shared throughout the industry which is serving to build communities and accelerate acceptance of technical advancements.

Continued implementation and effective utilization of these key technological drivers will depend wholly on utility's adoption rates which are highly dependent upon the oversight and approval of regulators, including state regulatory commissioners and the boards of public power and cooperative utilities. When planning for a new physical asset, utilities do not size their project solely for the current requirements; they size and deploy infrastructure for projected future requirements. The same investment principles should apply to smart grid technology investments. Moreover, some smart grid investments provide a platform that could enable multiple applications, making it important to consider initial investments in the context of a longer-term roadmap for modernizing the utility's system. In many cases, this may require a reconsideration of the regulatory framework to facilitate an efficient level of investment that provides greater value to customers.

High levels of DER penetration will require fundamental changes in the planning and operation of the grid, especially at the distribution system level. Utilities and regulators will need new distribution planning approaches and tools to effectively integrate DERs into the grid and understand the benefits and costs to develop forward-looking investment plans. For example, they will need to understand how DER adoption will either offset or require additional grid upgrades, including planning for the requisite information management and communication systems, as well as understanding the relationships and responsibilities associated with asset ownership, grid function and the maintenance of both markets and reliable service. Informing both utilities and regulators with consistent approaches and best practices for addressing this transformation will be crucial to the cost-effective implementation of the advanced grid. These approaches and practices will need to consider options for grid design, market formation, utility business models, and regulatory mechanisms, as well as requirements for the control and coordination of grid functions with the establishment of interoperability standards.

3.1.3 New Product Development Drivers

The development of new products – especially those at the customer level – have further enabled smart grid deployment. Technologies and devices such as rooftop solar, electric vehicles, smart thermostats, and storage capabilities have put pressure on the grid to develop more rapidly in order to handle all of these emerging devices. The rapid deployment of this equipment coincides with the increasing interest of some consumers in having control over, and input into, their own energy use and management decisions. As additional customer-centric products come online, the growing trend toward increasing self-generation and demand-side management resources will accelerate. Greater migration toward distributed generation seems likely.

An important question is how and to what degree distributed generation will integrate with utility systems. The answer will vary by location and over time. Currently, utilities and grid owners are grappling with how to manage the growing prevalence of DER in a way that does not contradict their traditional business model, or, that permits them a make a reasonable transition to a profitable new model. The distributed environment could prove to have great value if it is effectively integrated into the larger electricity system, especially as a way to increase the efficiency and resilience of the grid, as well as promote customer-based solutions. However, if it develops in an independent silo the value will not hold up over time and the resulting technologies and processes will be much more difficult to integrate. This would suggest that new product developments should not just be automation capable but should be designed for interoperability as well. There is considerable work being done on smart grid interoperability standards and it remains a critical aspect of ensuring true, long-term success of an optimized grid.

To ensure continued benefits of these new product developments and distributed resources, grid owners must "get out in front" on integration of solar, storage and microgrid technologies so that the grid can adequately absorb these new technologies at a large scale, and will be prepared to manage their impact on shared infrastructure. Similarly, the use of storage has many benefits that cut across all aspects of grid and market operations. As a nascent product with multifaceted advantages, it is difficult to classify storage into any existing asset class – distribution, transmission, or generation. Therefore, to ensure the benefits are correctly and fully valued, storage will need to evolve into its own asset class.

3.1.4 Internet of Things and Smart Cities Initiatives (ICT infrastructure)

Each of the aforementioned drivers for change has helped to perpetuate – either directly or indirectly – the "Internet of Things (IoT)" concept and the smart cities movement that has emerged as an intimately linked by-product. Intricately connected to the advent of the IoT is the evolution of information and communications technology (ICT), which will need to be advanced and integrated effectively to support the required grid functions and the convergence of infrastructure networks. ICT includes advanced sensing and control technologies needed to monitor and manage grid functions with real-time capability. These factors have in turn helped drive the modernization of the grid and put pressure on both public and private sector actors to ensure that the grid is prepared to handle the pivot towards these two trends.

By creating a network of physical objects that are able to wirelessly interoperate with other devices, taking advantage of cloud-based data analytics to optimize their operation consistent with individual customer preferences, and be remotely controlled by owners, manufacturers, system operators and others, IoT and ICT could improve the efficiency, economic return, and flexibility of a number of diverse products at the consumer-level. These products may include, for example, home automation, energy management, smart vehicle charging, and security systems. On a broader level, the IoT has spurred the development of Smart Cities – cities that incorporate a number of these remotely-controlled, more efficiently managed, and interoperable devices in a strategic, comprehensive way for the betterment of the city and its residents. These efforts may help to increase efficiency of municipal-wide operations, monitor and control critical infrastructure, improve response times for vital services (e.g. for firefighters and emergency medical responders), reduce negative environmental impacts, and even increase citizen satisfaction and participation in city-led initiatives.

As the IoT/ICT develops and smart cities become more prolific – they are already appearing in a number of cities from South Korea to Spain to the US – the grid will be increasingly relied upon to handle multidirectional communications between many different entities and to balance the innovations that already have, and will continue, to develop. The grid's integral role in the success of both IoT and smart cities is already helping to drive research and development of the advanced grid, and will continue to do so.

3.1.5 Understanding the Common Drivers

Different utilities have different adoption rates of distributed energy resources, distribution automation, competition, and customer costs per kWh, among other industry components. While there are certainly differences, there are also noteworthy commonalities. As the process continues from the original grid to the enhanced grid of today, which embraces the technologies that were demonstrated in the ARRA, the next logical progression is to work toward an optimized grid.

Elements of an optimized grid could include the following:

- Greater reliance on high-value or multi-purpose and distributed assets.
- Sensing, communications and control networks equipped with the security elements necessary to allow migration deep into the network.
- Improved resilience that helps prevent outage events and the ability to quickly recover after events that do occur.
- Ability to integrate, control and optimize high-level city and regional systems operations.
- Collaborative in nature and able to facilitate energy and financial exchanges from multiple sources on the transmission and distribution network.
- Customer-centric with active customer participation at multiple points along the system.

While the elements of an optimized grid can be debated, there is no dissension around utilities' interest in obtaining cost recovery around those investments and regulators' needs to make prudent investments. Nor is there debate regarding consumers' interest in maintaining reliable service at a reasonable cost. The timeline and the degree related to business model evolution for the industry is also debatable; however, a repository of information that addresses policy, regulatory, technical, and business cases (for example that result in "no regrets" decisions for some of the necessary capex investments in the migration to an optimized grid) would be useful because progress in each of these areas differs by state and region.

Reviewing multiple "success cases" presents an opportunity to draw upon collective experiences and develop best practices. Forums can be established to socialize these business cases to gain reaction and insight from the state regulators, featuring the highly successful and less successful experiences. The DOE should make these cases more visible, provide technical assistance to policymakers to keep them informed of best practices and lessons learned, brief them on the application of emerging technologies and associated costs and benefits, and assess emerging issues such as new rate policies to address DER integration and ownership.

3.2 Lessons Learned from the ARRA Program and Noteworthy Outcomes

The aforementioned market drivers and the subsequent advancements in smart grid deployment were facilitated by the ARRA Program, which provided $9 billion in public-private partnership funding for 131 smart grid projects deployed across the nation. This section highlights a number of lessons that can be drawn from the program, particularly in the areas of technology and institutional development, as well as ancillary benefits.

3.2.1 Technology and Economic Developments

Advancing technological deployment was a key focal point within the ARRA program and is a critical component of successful smart grid operability and continued market expansion. The ARRA's support helped spur penetrating technology that is the foundation for grid modernization, thereby accelerating technology learning curves and reducing technological-related costs. Additionally, demonstrations of smart grid technology, and the opportunities provided by those resources, helped to expedite adoption of the technologies and to build confidence in their functionality and value added capabilities. For example, feeder automation to self-heal and improve reliability is shown to provide the best short-term value.

A previous EAC paper, *Smart Grid Systems Report (DOE 2014),* outlined in great detail the technology improvements achieved with ARRA support. They include, but are not limited to, AMI development to enhance operational efficiency and help customers better manage energy use; customer-based technologies such as programmable, communicating thermostats; integration of sensing, communications, and control technologies; and advanced sensors in conjunction with high-speed communications networks on transmission systems to monitor and control operations.

Technology developments spurred by the ARRA also helped to advance the understanding of the value proposition. Several case studies are available to further this and "rules of thumb" were developed; for example, it was determined that 1% voltage reduction can provide .8 – 2.3% kW reduction. Additional smart grid technology applications and benefits are listed in the Table 1 below.

Table 1

Benefits	Smart Grid Technology Applications					
	Consumer-Based Demand Management Programs (AMI-Enabled)	Advanced Metering Infrastructure (AMI) Applied to Operations	Fault Location, Isolation and Service Restoration	Equipment Health Monitoring	Improved Volt/VAR Management	Synchrophasor Technology Applications
	• Time-based pricing • Customer devices (information and control systems) • Direct load control (does not require AMI)	• Meter services • Outage management • Volt-VAR management • Tamper detection • Back-Office systems support (e.g., billing and customer service)	• Automated feeder switching • Fault location • AMI and outage management	• Condition-based maintenance • Stress reduction on equipment	• Peak demand reduction • Conservation Voltage Reduction • Reactive power compensation	• Real-time and off-line applications
Capital expenditure reduction – enhanced utilization of G,T & D assets	✓			✓	✓	✓
Energy use reduction	✓	✓	✓		✓	✓
Reliability improvements		✓	✓	✓		✓
O&M cost savings		✓	✓	✓		
Reduced electricity costs to consumers	✓				✓	
Lower pollutant emissions	✓	✓	✓		✓	✓
Enhanced system flexibility – to meet resiliency needs and accommodate all generation and demand resources	✓	✓	✓	✓	✓	✓

Source: US Department of Energy Office of Electricity Delivery and Energy Reliability

On a macro level, investments from ARRA funding and matching support from utilities and the private sector in the SGIG and SGDP were valued at $2.96 billion (as of March 2012) but generated at least $6.8 billion in economic output. Further, for every $1 million[2] of direct spending on smart grid investments, the GDP increased by $2.5 to $2.6 million, depending on the scenario evaluated. Additional details on these figures can be found in the paper *Economic Impact of Recovery Act Investments in the Smart Grid, (DOE 2012).*

The *Economic Impact Report 2012* also notes that roughly 47,000 full time equivalent jobs were supported by ARRA investments and the number of jobs increased as smart grid deployments continued through 2015. Through the Workforce Training subsection of the program, workers received training and developed the skills and process understanding necessary to design, build, operate and maintain critical smart grid technology and other components. Industry participants, and the industry as a whole, learned how to integrate these new technologies with existing infrastructure, a key factor in effectively transitioning to an optimized grid. Case studies on the results of the workforce development programs are evident on the national level and in the experiences of Pennsylvania, Vermont, and California, among many other examples (DOE 2011; DOE 2012).

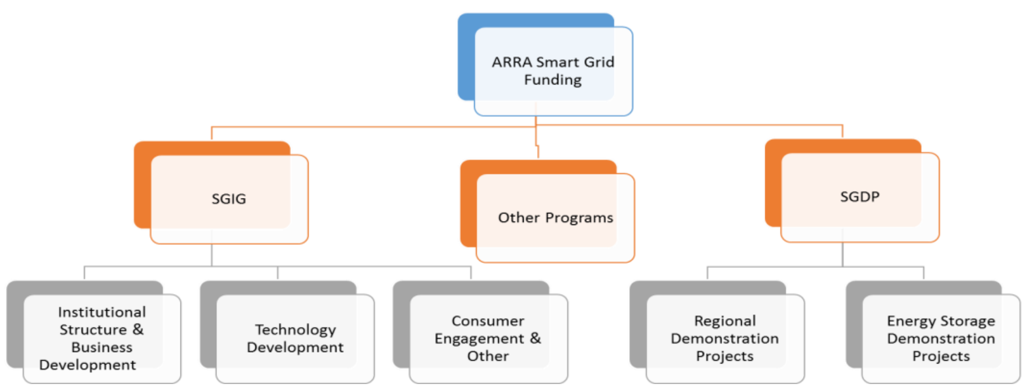
[2] *Includes ARRA funds and private sector matching*

3.2.2 Institutional Developments

From an institutional development and market adoption standpoint, the ARRA project has created enthusiasm for smart grid technology adoption among power companies and many other industry stakeholders. This is a crucial, albeit often under-acknowledged, component in initiating and ensuring the continued growth of grid optimization. Furthermore, the project has helped build a community that more readily shares information and best practices regarding smart grid deployment and associated topics.

Key to the successful growth of any nascent industry or broad-ranging initiative are clear and well-articulated standards. The ARRA program has facilitated the continued development of smart grid standards which serve to advance grid developments, enable interoperability, and support efficiency in the process. The Smart Grid Investment Grant Program (SGIG) noted in Figure 1, helped established a framework, brought standards development organizations together, and advanced activity supporting priority action plans. Continued regulatory and policy support for standards development is crucial for ensuring mass adoption and implementation of a smart grid.

Figure 1



The Smart Grid Demonstration Program (SGDP), noted in Figure 1, helped to further this cause as well. By providing financial assistance to merit-chosen candidates[3], the SGDP has helped demonstrate new and more cost-effective smart grid technologies and tools. The Regional Demonstration portion of this program was particularly important for advancing the institutional structure surrounding smart grids; the demonstration projects sought to quantify costs and benefits of the smart grid, validate new smart grid business models at scales to promote replication, and verify smart grid viability.

While slightly more innovation-oriented, the other portion of the SGDP (Energy Storage Demonstration Projects) has also played an important role in furthering market adoption of

[3] *Selected candidates received up to 50% of the project's costs in the form of a cooperative agreement, as opposed to an outright grant provided by the SGIG.*

essential smart grid components. Examples include demonstrating the technical and economic performance of voltage soothing, ramping control, load shifting, frequency regulation, and the integration of renewable resources. Taken together, the ARRA-supported Smart Grid Investment Program and Demonstration Program have helped drive and advance a much needed discussion on the institutional realities and the value proposition of the future smarter grid.

3.2.3 Unanticipated Benefits

Several best practices emerged from the ARRA smart grid projects, resulting in a range of unanticipated benefits including workforce safety benefits and efficiency gains. By providing enhanced communications information on equipment conditions and workforce location, accidents were prevented; workers could "see" that lines were hot, and planners could "see" that areas were not clear of workers.

The fundamental value of the smart grid lies in better coupling of state measurement with modeling of agile and precise controls through improved analytics. While ARRA smart grid projects were directed at specific objectives, general improvement in these three core capabilities lead to applications beyond the specific, immediate objective. For example;

- An AMI system was installed for better meter reading and better outage management, but showed value beyond these functions. In one instance during an outage, most meters correctly reported loss of power, but one meter showed "green". The utility discovered that there was a backup generator that was not correctly isolated from the grid. It was energizing the lines in the neighborhood, presenting a potentially lethal hazard to the linemen.

- In another instance, a thermal sensor in a residential smart meter alarmed. Upon investigation, the utility crew discovered a short in the house (not the grid) and alerted the homeowner, preventing a potential fire.

- Several utilities have taken advantage of voltage data from smart meters to plan strategies for conservation voltage reduction (CVR) and to turn CVR systems in real time.

- In Georgia, one utility is using advanced smart-feeder switching to manage two (smart) connected feeders using only communications between their respective substations, with no central control.

- By connecting the automatic vehicle location system to their outage management system through their GIS, one utility is improving lineman safety by automatically verifying the location of line crews before any section is re-energized.

4 Recommendations and Future Steps Necessary to Realize Full Potential of Smart Grids

While smart grid deployment has expanded markedly, due in part to significant ARRA support, there are many opportunities for further advancement and there is remaining work to be done to fully capitalize on advanced grid potential. Future action steps can be grouped into five categories: capability enhancement, technology performance improvements, business case development, system integration, and regulatory standards. Each is discussed in detail below.

4.1 Capability Enhancement

The distribution grid must be significantly more flexible and agile to accommodate the increasing distributed activity and distribution operations. The DOE has been developing the transactive energy model that envelops the economic control and balance of the grid through advanced financial and technological integration. The DOE and others are developing and testing collaborative controls that allow devices to work together rather than under central control (ARPA-E, 2015). Work is needed to continue to develop and demonstrate this more nimble and dynamic approach. Similarly, gaining industry support and securing the confidence of the market is imperative for the continued growth of this method. Specifically, the DOE can facilitate this process by:

- Continuing to demonstrate smart grid technologies. In particular, control and coordination of distributed energy resources is needed to advance integrated systems, better ascertain costs and benefits, and work out interoperability standards requirements. Demonstrations would greatly promote the adoption of the advanced systems needed to meet the efficiency and resilience objectives of state and federal programs.

- Demonstrating and helping to develop the tools still needed. Specifically, the tools to plan and operate distributed generation, two way power flow, power-quality management, and optimized automation schemes, among other devices.

- Supporting Information and communications technology (ICT) development. ICT with concomitant advancement in sensor and control technologies is needed to support a range of application needs to enhance efficiency, facilitate technology optimization and effectively integrate new devices across the entire grid.

- Participating in codes and standards development. While some standards are beginning to emerge, additional standards development is needed, especially to unleash the capability of power electronics to dynamically provide for a range of voltage grid needs.

4.2 Technology Performance Improvements

As previously noted, ARRA support helped fuel advancements in technology performance. Still, opportunities remain in this area. Specifically, while the concept of micro-grids was advanced, work remains to develop controllers that accommodate balancing of the system. Improvements are also needed in coordinating micro-grid operation with other micro-grids and the traditional grid itself.

Additionally, several research, development and demonstration (RD&D) needs and target areas were identified by the EAC in a March 2015 report *Recommendations on Smart Grid Research and Development Needs.* EAC continues to support these recommendations, which include continued/increased DOE support for:

- Integrating new and legacy technologies.
- Providing power quality for the digital economy.
- Optimizing the use of intelligent devices at different points along the grid.
- Making appropriate use of open standards.
- Investment at the distribution level (especially with distribution automation).
- Advancing next generation grid operating systems and electric energy storage.

Energy storage is still widely considered amongst the "holy grail" of the energy industry. Bringing down costs of energy storage and determining the most effective way to integrate it into the grid is very much needed and would provide a major breakthrough in smart grid utilization opportunities.

Specific recommendations regarding energy storage and DOE's future involvement in its development can be found in a previous EAC paper *Storage Plan Assessment Recommendations for the U.S. Department of Energy (DOE 2014).* EAC continues to support the recommendations that DOE focus on supporting:

- Applications for storage interconnecting at the distribution level.
- Developing the tools that could lead to improved energy storage operation, resource assessment and decision making.
- An overarching strategy for codes and standards design.

Building from ARRA demonstrations of feasibility of automating load to respond to real-time price signals, an additional near-term priority should be to facilitate the application of smart technologies for managing flexible demand so as to alter the timing of power use and provide virtual storage without compromising customer service.

4.3 Further Development of the Business Case and Institutional Support

Development of an investment decision framework is needed to better link business decisions to societal objectives to support the reliability, resiliency, efficiency, sustainability and affordability needs of the 21st century. This will require market and technology developments along with metric advancement. In particular, linking societal benefits into short and long term investment decisions is key. The SGIG and SGDP efforts under the ARRA were helpful in demonstrating and quantifying the business case for smart grid development; efforts of this nature should continue. Additionally, DOE should support the following business and institutionally-focused efforts:

- Convene policy makers, utilities and relevant stakeholders to ascertain the system requirements needed for the effective design and integration of markets, business models, regulations, and control systems for advanced operation.

- Facilitate coordination between diverse organizations working on different aspects of business case and institution development.

- Development of a new generation of planning tools to support bi-directional energy flows and a more probabilistic view of both load and supply, including methods to appropriately value and weigh the costs and benefits of advanced grid technologies and DERs.

- Provide assistance to policy makers to develop approaches that incentivize performance against efficiency, reliability, and affordability objectives.

- Provide assistance to develop approaches that ensure, through new pricing policies, that proper incentives and compensation are provided to stakeholders that invest, own, operate and maintain the asset. This may also include facilitating discussions on the future of energy storage in so far as it relates to the possibility for storage to evolve into its own asset class.

- Support jurisdictional and market development to fully unleash the value for distributed energy storage to both customers who install storage and to the utility system as a whole.

- Recognize that the value of DER can vary significantly between time intervals, distribution circuits, and locations on a given distribution feeder, the development of an institutional and technology roadmap and the necessary tools for distribution system operators to develop and operate, within distribution systems, security constrained, real-time markets based on principles of Locational Marginal-cost Pricing for real energy, reactive power, and reserves.

- Ensure that these efforts are not conducted in a silo; they should be part of a broader, comprehensive scheme to implement smart grid technologies and devices in a way that captures long-term economic benefits for all parties along the business chain.

- Develop a repository of information that addresses policy, regulatory, technical, and business cases (for example that result in “no regrets” decisions for some of the necessary capex investments in the migration to an optimized grid). This initiative would be particularly useful because progress in each of these areas differs by state and region.

- Provide technical assistance to policymakers to keep them informed of best practices and lessons learned, brief them on the application of emerging technologies and associated costs and benefits, and assess emerging issues.

One example that provides a valuable case study and should serve as a reference for future initiatives is the Duke Energy experience (DOE 2014). ARRA funds – through the SGIG – helped Duke Energy introduce a comprehensive effort to implement a range of technologies across multiple service areas. Devices included AMI with an upgraded meter data management system, distribution automation, integrated voltage/VAR control, a new distribution management system, electric vehicle charging stations, a customer web portal, and customer pricing pilots. These efforts led to significant cost savings for the utility: an estimated 20-year net present value of $382.8 million (according to a third-party evaluation from the Public Utilities Commission of Ohio). The majority of savings came from avoided operating and maintenance costs from continuous voltage monitoring and reduced meter reading labor. Now, not only is Duke Energy enjoying economic benefits from its investments but it is drastically better positioned to capitalize on future technology changes or to implement legislative policy requirements.

4.4 Systems Integration

As micro-grids, self-healing distribution, distributed renewable integration, storage, and increased consumer involvement develop, it is changing traditional system practices and design philosophy. Integrated demonstrations will be required to understand how these components will need to interact with real-time capabilities. To further enable progress in this area the Department should invest in:

- Advancing the architecture of ICT to enable the effective integration of distribution system components.

- Identifying the data requirements needed at grid-to-grid and device-to-grid interfaces to enable true interoperability leading to standards development and prioritization.

- Testing platforms to better understand the effect of potentially disruptive technologies.

- Development of models, algorithms and simulation tools to enable predictive and real-time analysis of grid conditions (complex system behavior) for operators.

- Enhanced tools for developing indicative price forecasts that could enable the positioning of DER and grid topology to efficiently respond to emerging conditions.

- Advancing market mechanisms and consumer education to encourage consumer participation and enable them to take full advantage of new tools, products, and services.

- Supporting interfaces between Generation and Delivery as well as Delivery and the Consumer to bridge the consumer environment with a range of voltage utility grid needs.

- Developing standards, planning tools, testing methodologies, operational tools, and resource optimization capabilities at the distribution level.

- Fully integrating the individual islands of technology to leverage information and control capability in a holistic system approach (this is being aided by the Common Information Model that maps together protocols such as ModBus, DNP3, and the Smart Energy Profile for example).

- Continuing to ensure the cyber and physical security of the power system.

Work is also needed as the electrical infrastructure becomes increasingly interdependent with other infrastructures such as transportation, water, heat and buildings. Challenges for research include the following and DOE should support research efforts in these areas:

- Understanding tradeoffs of central / distributed choices.

- Planning for interdependent infrastructures.

- Metrics and valuation to connect infrastructure investment to economic vitality.

- Standards to facilitate interoperability with legacy systems.

- Mechanisms for incorporating customer solutions into the optimization mix and workforce competency development.

Tools for planning and dynamic operations are also needed along with guidance on how to utilizing large amounts of data, methods to assess reliability of increasingly complex systems and ongoing guidance to overcome emerging cyber and physical security threats.

4.5 Development of Standards and Policies (Interoperability Standards Requirements)

While standards development did occur and continues to do so, work remains in order to achieve complete plug-and-play vision, especially as it crosses traditional boundaries between medium and low voltage. DOE could support the following noteworthy areas:

- Facilitating large[4] penetrations of DER in terms of making them dispatchable, managing the ramp rates, and avoiding cascading system conditions.
- Improving voltage management and coordinated islanding.
- Overcoming market and regulatory challenges for DER investment and deployment.
- Gaining state and federal level support to enable full DER integration.
- Determining how to incorporate open-source technology and support related standards development.
- Weaving the functionality of smart inverters into the general grid operations to fully benefit from their capability.
- Establishing standards, market mechanisms and testing protocols, and additional demonstrations, to build confidence and adoption of inverters as a grid resource.

5 Summary

The ARRA has lent unprecedented support to smart grid development initiatives, providing the foundation upon which smart grid deployment has grown significantly in the last few years. ARRA funding has fueled a host of advancements, including digital technology innovation such as AMI development and deployment, customer based technologies, integration of sensing communications and control technologies, and the deployment of advanced sensors, among others.

Additionally, the ARRA has spurred economic growth both inside and outside the smart grid industry; from $2.9 billion invested by the ARRA and private matching as of March 2012, $6.8 billion was generated in economic output according to a DOE Smart Grid Investment Economic Impact Report (DOE 2012). The reports also notes that the success extends to job development as well, with more than 47,000 jobs being supported by ARRA and partners, and countless others being peripherally touched. Through the Workforce Training programs, workers developed advanced skills and digital technology training. Moreover, these efforts have created a community of workers with new expertise, forward-thinking mentalities and a willingness to embrace and spearhead the transition to a smarter, more digitized grid. They will be key champions for the implementation of smart grid improvements throughout the electric industry.

[4] *Large penetrations in this context are considered to be 20% or more.*

Further, through the SGIG and SGDP grants and demonstrations, the ARRA funding has laid the groundwork for, and ignited, a much needed, frank conversation on the business case for smarter grid development: a discussion that, finally, can be rooted in real-time examples, first-hand experiences and quantifiable outcomes. Hand-in-hand with a clearer value proposition for the smarter grid is the institutional structure necessary to support its development, another area in which the ARRA support has achieved success. ARRA initiatives have helped advance interoperability by convening standards organizations and supporting priority action plans.

Still, work remains to fully develop the codes and standards necessary for complete interoperability. To achieve “plug-and-play” in the smarter grid, seamlessly introduce additional DER, and effectively transition to the smarter grid of the future, additional policy, market and regulatory standards must be developed. The DOE can play an important role in this process and in facilitating effective systems integration.

Continued technology development is still needed as well. Specifically, DOE should continue to support efforts in distribution automation, transmission line power flow, AMI-services, and phasor measurement unit systems, among other smart grid technologies. DOE can also capitalize on the opportunity to support technologies still in R&D phase, such as development of electric energy storage, next generation grid operating systems, and next generation distribution integration.

As the technological functionality of these and other products improve, and economies of scale help to bring down prices, the business case for smart grid deployment will correspondingly improve. In the meantime, DOE should continue its ongoing efforts of highlighting the economic benefits of embracing these products that is currently being enjoyed by recipients of SGIG grants. There are extraordinary efficiency and efficacy gains to be made by transitioning to a smarter grid and DOE is uniquely positioned to broadcast the positive experiences of those who are already taking steps in that direction.

While there is still much work to be done to ensure a seamless transition, the ARRA smart grid program has sparked innovation, development and debate of the fundamental components necessary for a full transition to a smarter grid. The ensuing technology creations, standards frameworks, economic output, business case studies, and idea creation all serve to move the process forward and bring the country significantly closer to full grid optimization. Above all, the program has generated a ripple effect of excitement and enthusiasm for smart grid deployment across multiple facets of the industry that will persist beyond the end of the project funding.

6 Appendix I

Results of DOE EAC Survey on Smart Grid Development Support Areas

In conjunction with the development of this work product, the Electricity Advisory Committee conducted an informal survey of its membership to help determine areas in which DOE could continue its support of the development of a smarter, more resilient grid. The survey was intended to gauge the members' views on potential focus areas and funding priorities that warrant DOE support. The survey addressed a range of various future opportunities that pertain to achieving full realization of an optimized grid. In total, 71% of the 31 committee members completed the survey.

The results indicate that, in broad terms, support for the various opportunity areas is evenly distributed. This trend is shown in the figures below by the similar mean values and fairly clustered standard deviations for most responses. This suggests that the diverse professional backgrounds and perspectives of the various stakeholders who participated in the survey inform their opinions as to which opportunity areas deserve prioritization, and that those priorities are quite diverse. Further, it indicates that achieving grid optimization is a complex issue that requires a multidimensional approach, a key point for DOE to bear in mind going forward.

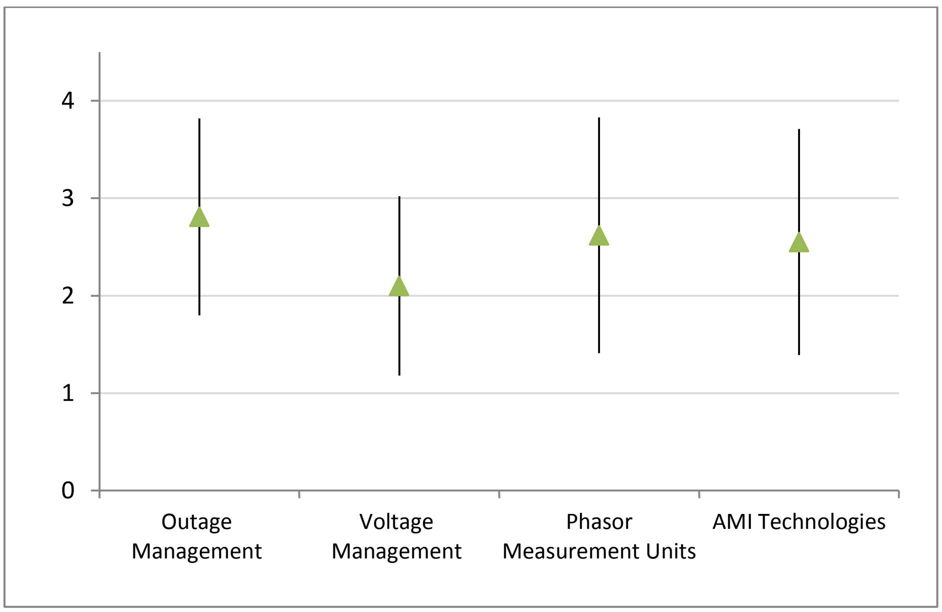
Still, several conclusions can be drawn from the survey.[5] First, there appears to be an emphasis on support for technology development, particularly as a percentage of the funding potentially available for smart grid development and deployment (see question #3). Second, research and education were seen as being more substantially improved as a result of ARRA funding, compared to workforce training (see question #4). Research and education are also seen as important foci for DOE funding in the future (see question #5). Additionally, there was a rough consensus on DOE supporting codes and standards development, particularly interoperability standards (see questions #6 and #9); however, the large standard deviations on these responses and the diverse feedback regarding prioritization of the *types* of codes and standards (see question #7) indicate a wide range of opinions in this area.

The full text of each question is presented below along with a visual representation of the results.

[5] *Please note, these trend conclusions are qualitative only and not based on rigorous statistical analysis*

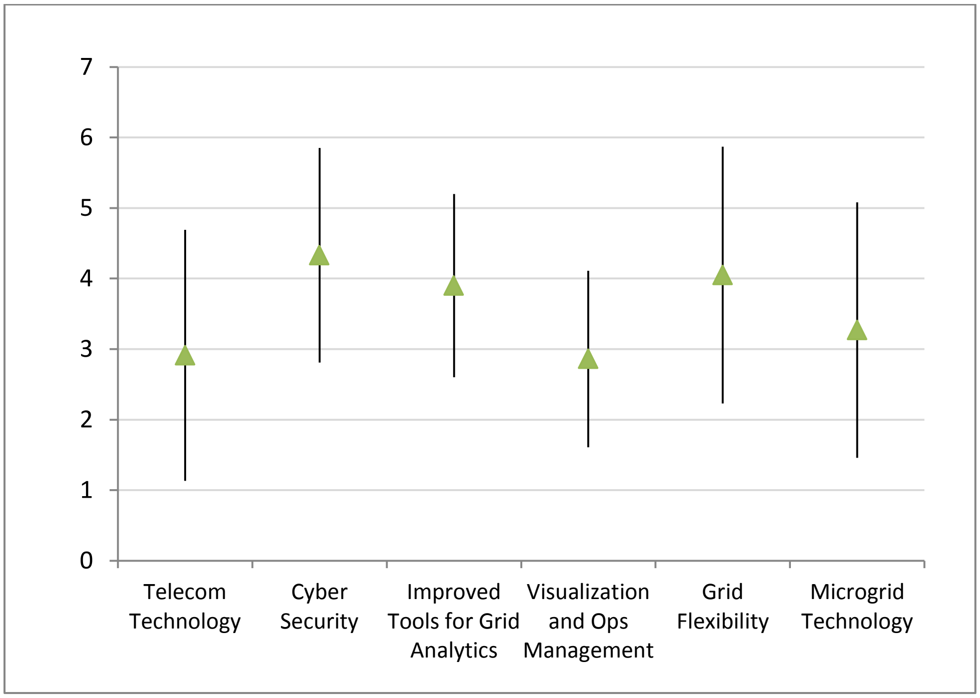
1. Under the ARRA Program, significant investment has been made in demonstrating and deploying new technologies to further the realization of the Smarter Grid. Which of the following was ARRA most successful in advancing? Rank from highest (most successful = 4) to lowest (least successful = 1).

   - Outage management technologies (i.e. to quickly identify disruptions, restore service)
   - Voltage management technologies/systems (i.e. to reduce peak energy consumption)
   - Phasor Measurement Units (PMUs) and data utilization and management (i.e. to give transmission operators visibility into the state of the system)
   - AMI technologies/services (i.e. two way meters, in-home displays, programmable control thermostats)



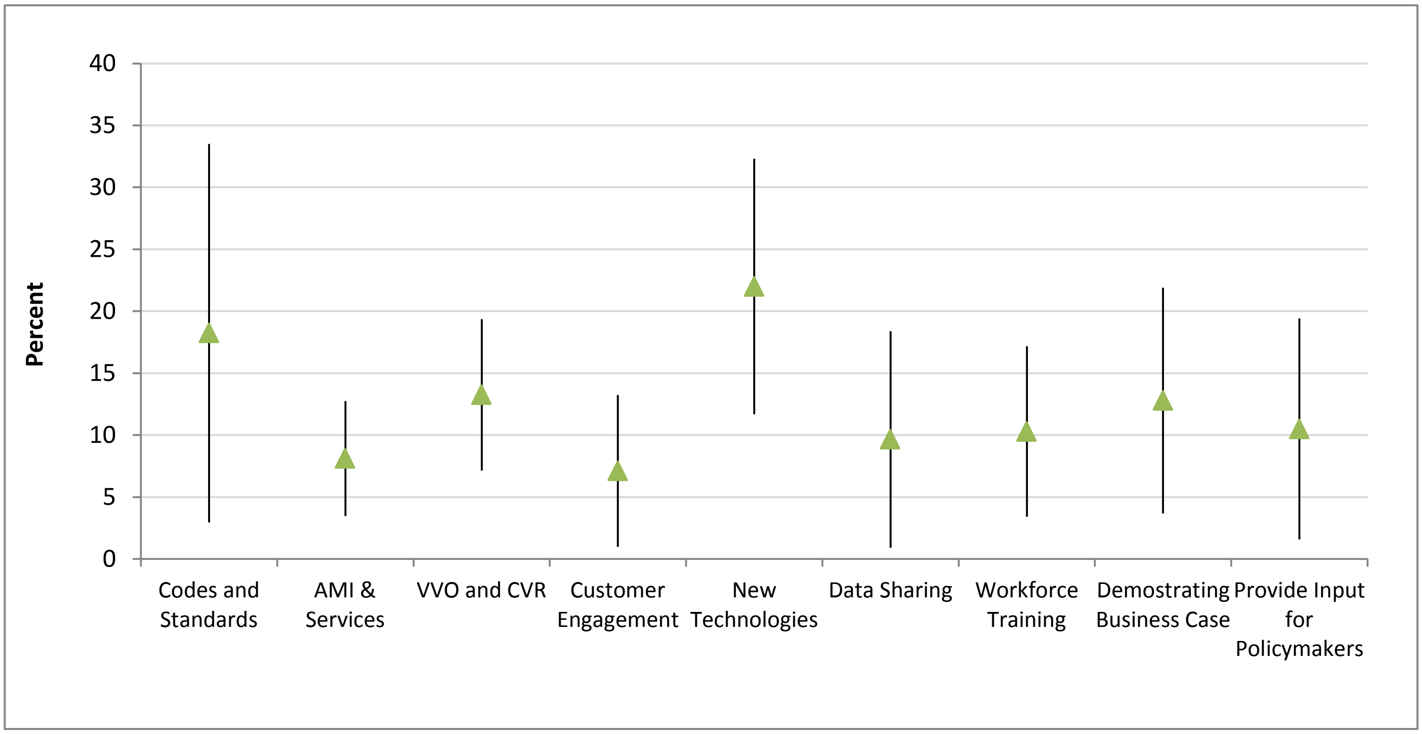
2. Additional support for new technologies is still needed to fully realize the benefits of the Smarter Grid. Several technology areas have been identified as target areas. How would you prioritize the following in terms of receiving continued DOE support? Rank from highest (should receive most support = 6) to lowest (should receive least support = 1).

- Telecommunications technologies
- Cyber security protections and technologies
- Improved tools for grid analytics (i.e. to obtain usable information from vast quantities of data)
- Visualization and operations management tools
- Tools and technologies to further enhance grid flexibility and facilitate integration of variable energy resources on the transmission and distribution systems
- Microgrid technologies



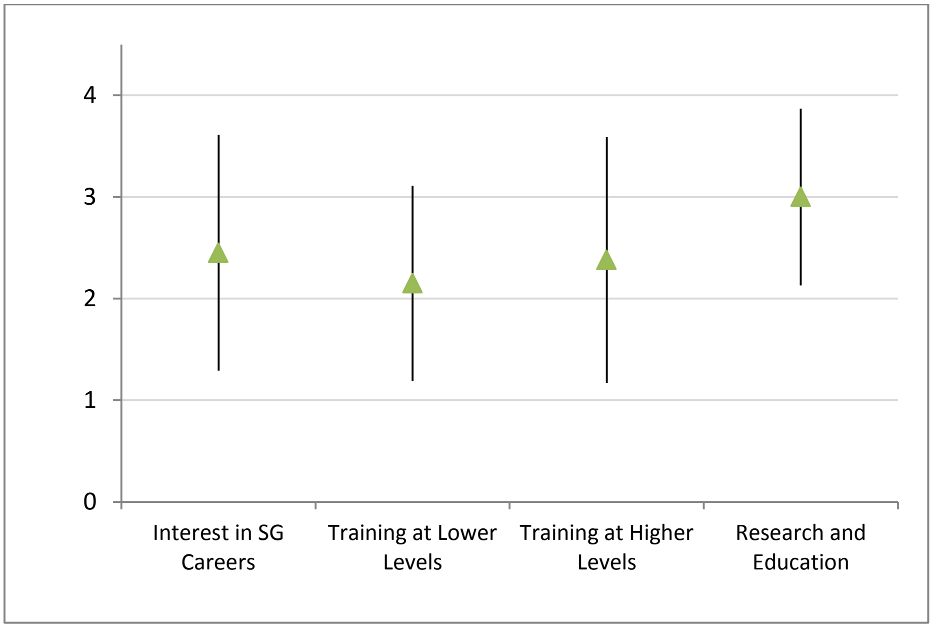
3. What percentage of the DOE budget potentially available for smart grid development and deployment should be allocated to the following general areas (should total 100%).

- Improving codes and standards to improve interoperability
- Enhancing AMI and AMI services
- Improving Volt/VAR Optimization (VVO) and Conservation Voltage Reduction (CVR)
- Increasing customer engagement
- Supporting new technologies
- Data sharing agreements and capabilities
- Workforce training
- Demonstrating the business case for smart grid deployment (and individual components)
- Providing any necessary and relevant input to inform state and federal policy makers on legislation that can support the Smarter Grid



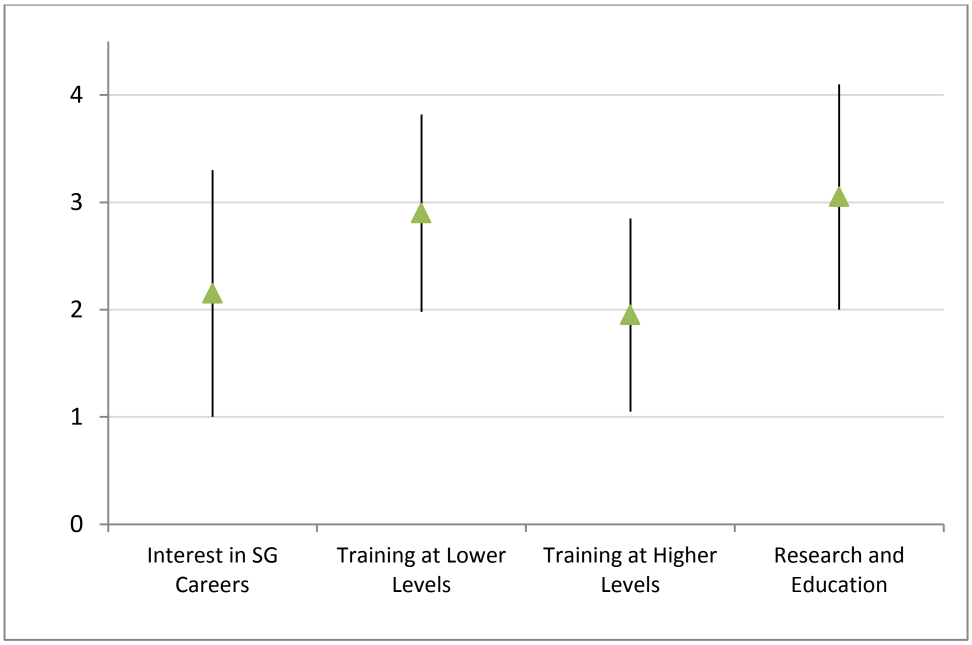
4. <u>Workforce Training</u> is one area that received ARRA support. The efforts were centered on several key goals. Which of the following areas was most improved/advanced from ARRA support? Rank from highest (improved the most = 4) to lowest (improved the least = 1).

- Increased awareness of and interest in electric utility and Smarter Grid careers
- Training of professionals at the lower levels of utilities (i.e. maintenance and service professionals) to implement, maintain and advance future Smarter Grid innovations (i.e. demand response, distributed generation, energy utilization/optimization)
- Training of professionals at the highest levels of utilities (i.e. CEO's and upper level management) to implement, maintain and advance future Smarter Grid innovations (i.e. demand response, distributed generation, energy utilization/optimization)
- Promoting research and education in electric power systems and Smarter Grids



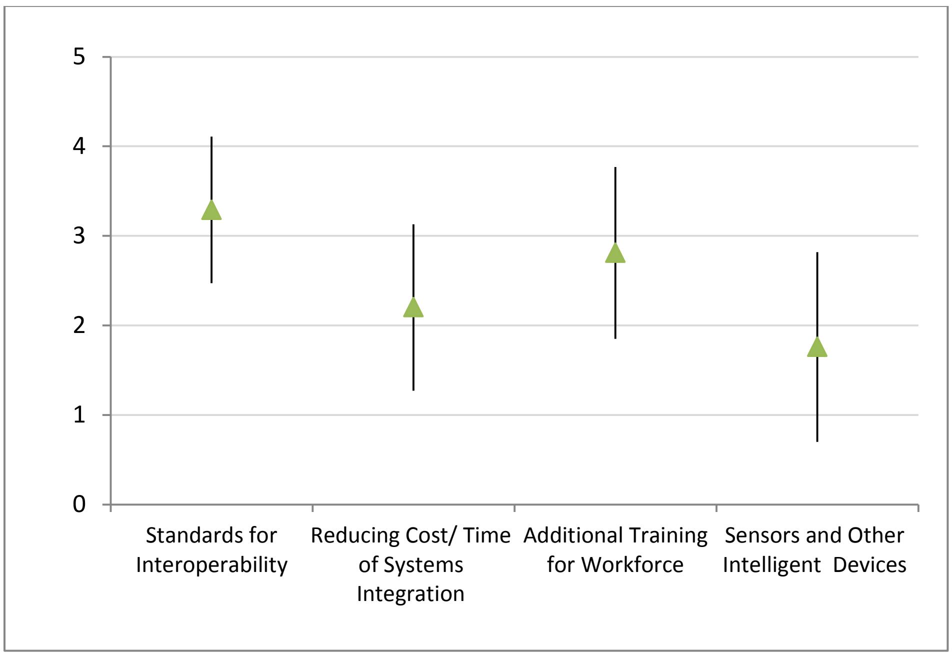
5. Going forward, which areas of Workforce Training should receive continued DOE support? Rank from highest (should receive most support = 4) to lowest (should receive least support = 1).

- Increased awareness of and interest in electric utility and Smarter Grid careers
- Training of professionals at the lower levels of utilities (i.e. maintenance and service professionals) to implement, maintain and advance future Smarter Grid innovations (i.e. demand response, distributed generation, energy utilization/optimization)
- Training of professionals at the highest levels of utilities (i.e. CEO's and upper level management) to implement, maintain and advance future Smarter Grid innovations (i.e. demand response, distributed generation, energy utilization/optimization)
- Promoting research and education in electric power systems and Smarter Grids



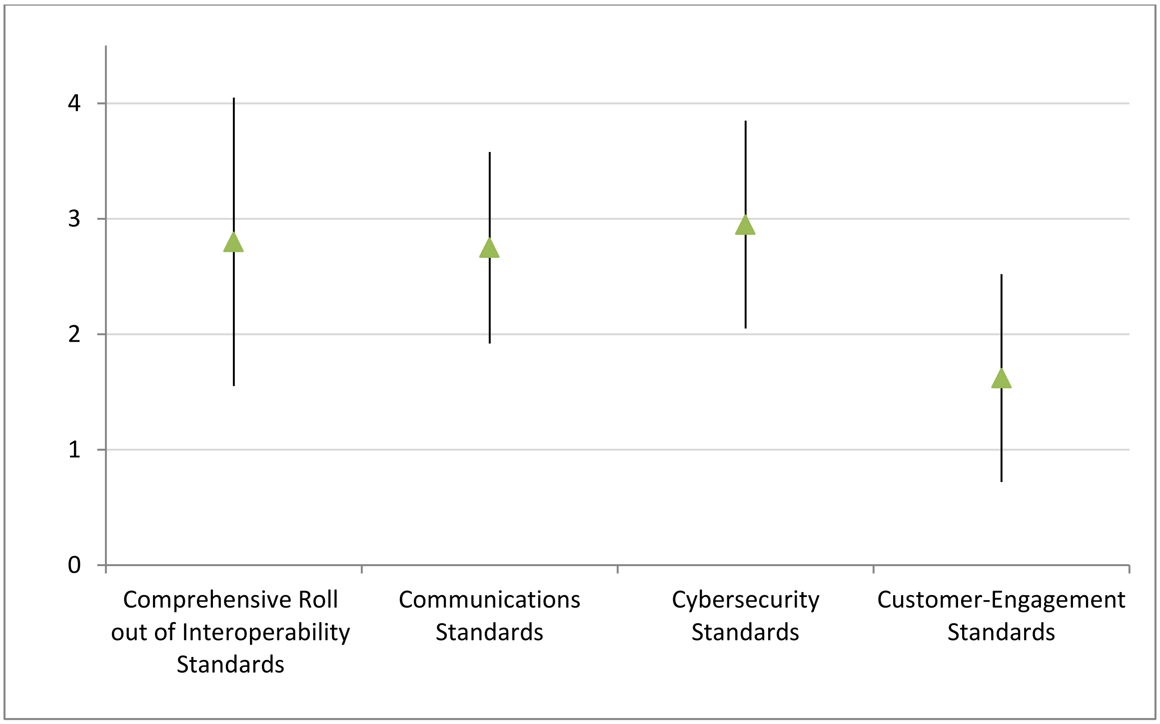
6. Systems integration is a key component in moving toward a Smarter Grid but remains a challenge for many utilities. Which of the following would be most beneficial for furthering and advancing systems integration? Rank from highest (would have most beneficial impact = 4) to lowest (would have least beneficial impact = 1).

- Improving industry standards for interoperability
- Reducing the cost and time associated with accomplishing systems integration (i.e. reducing the cost to 10% of project's total cost from the 20% it currently constitutes)
- Reducing transition challenges associated with integrating new products with existing equipment (i.e. data management, cybersecurity, communication/control challenges)
- Additional training for the workforce on how to manage systems integration



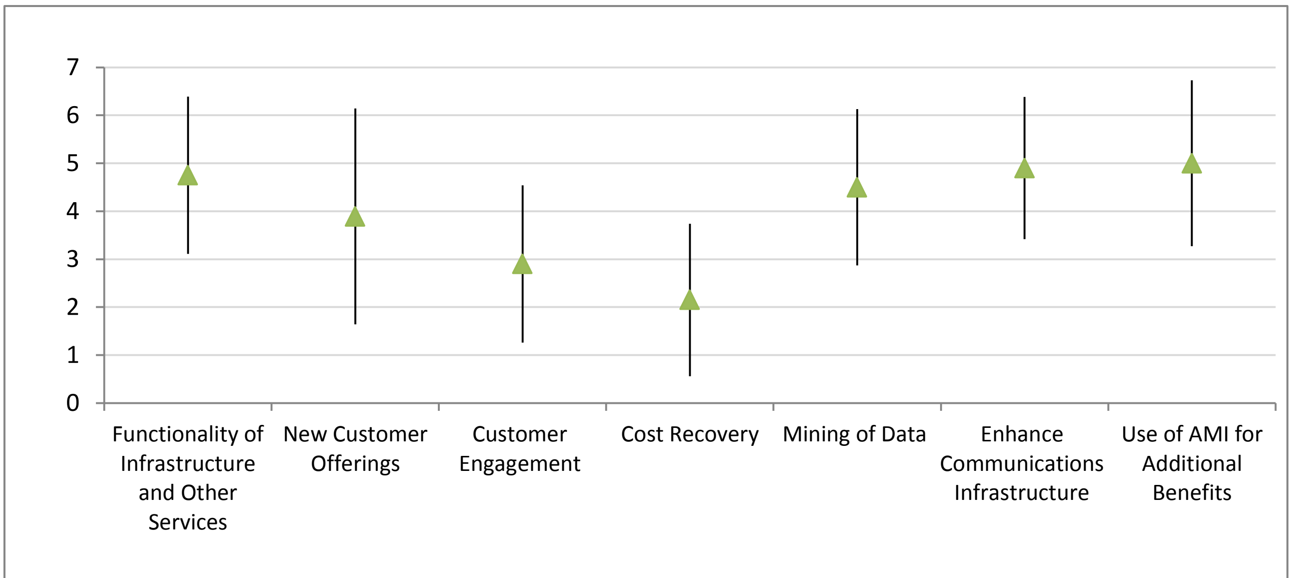
7. Codes and standards are considered a key factor in fully realizing the Smarter Grid. How would you prioritize future DOE support for advancing the following codes/standards? Rank from highest (should receive most support = 4) to lowest (should receive least support = 1).

- Comprehensive roll out of interoperability standards for every aspect of the Smarter Grid (i.e. across all functional and technological areas and engaging all stakeholders)
- Communications standards (i.e. protocols, data definitions, control strategies)
- Cybersecurity standards (i.e. best practices and sharing practical applications)
- Customer-engagement standards (i.e. how utilities interact with customers)

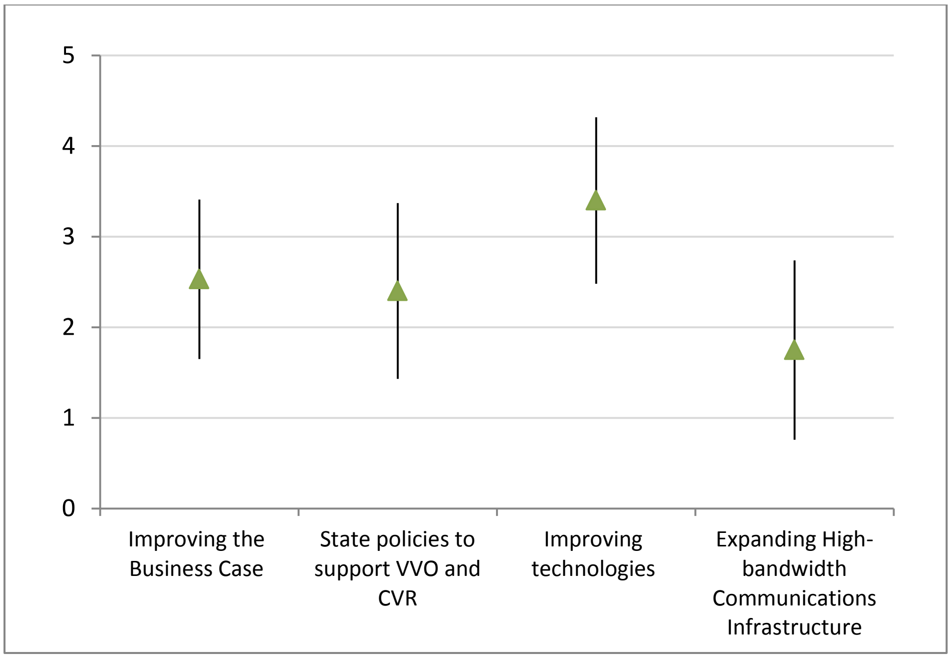


8. Advanced Metering Infrastructure (AMI) and AMI-related services are key components to fully capitalizing on the opportunities provided by the Smarter Grid. Advances have been made in these areas with ARRA support but there are still many opportunities for continued emphasis on AMI and AMI-services. How would you prioritize future DOE support for the following? Rank from highest (should receive most support = 7) to lowest (should receive least support = 1).

   - Functionality of the infrastructure, outage management and repair dispatch (i.e. precise location identification of outage area and speed of response)
   - New customer offerings (i.e. time-based rates, web portals, advanced bill alerting)
   - Customer engagement and buy-in (i.e. increasing frequency of customer activity and comprehensive acceptance of AMI/smart meters)
   - Clearer paths to, and methods for, cost recovery
   - Mining of data collected on AMI devices and improved utilization of data (i.e. to improve customer serves, boost effectiveness of voltage controls)
   - Use of AMI for additional benefits (i.e. power quality monitoring and support for Distribution Automation or Conservation Voltage Reduction)
   - Enhance communications infrastructure and AMI to facilitate greater integration of distributed energy resources (DER)

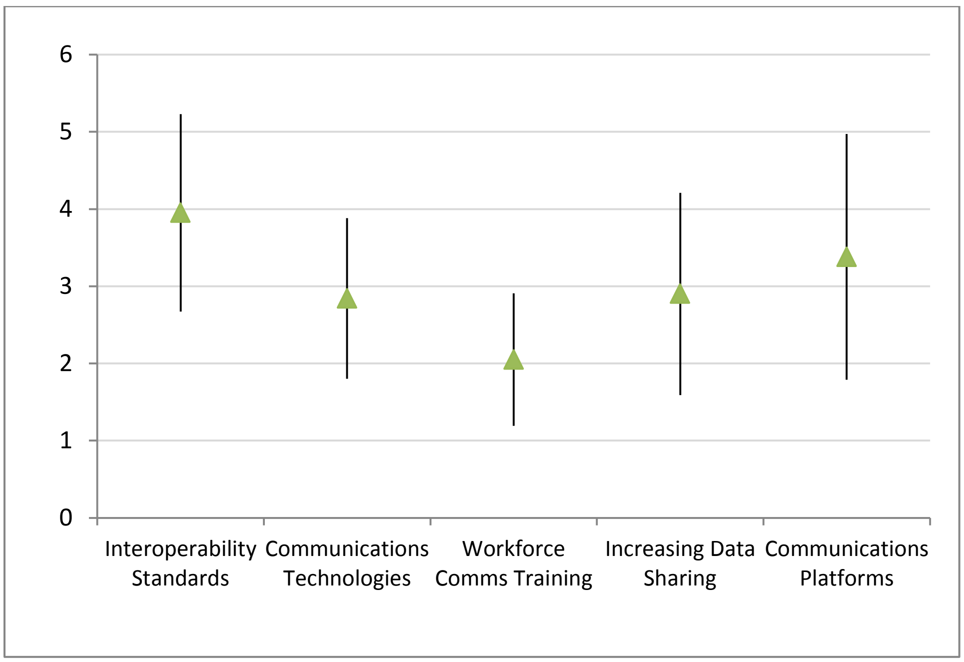


9. Voltage and Volt-Ampere Reactive Power Optimization (VVO) has been shown to help reduce line losses and improve energy efficiency. Attention is being directed at how to further Conservation Voltage Reduction (CVR) techniques to capitalize on these savings. Which of the following would best help to further VVO and CVR techniques? Rank from highest (would be most helpful = 4) to lowest (would be least helpful = 1).
    - Improving the business case to enable a more certain path to cost recovery
    - State policies to support VVO and CVR (i.e. energy efficiency resource standards)
    - Improving technologies and control schemes (i.e. distributed and centralized controls)
    - Deploying, improving and expanding high-bandwidth communications infrastructure



10. Effective communications networks and related systems are critical to ensuring an effective and reliable smart grid. How would you prioritize the following components of effective communications networks in terms of where DOE should lend its support? Rank from highest (should receive most support = 5) to lowest (should receive least support = 1).

- Interoperability standards
- Communications technologies
- Workforce/operator training on communications
- Increasing data sharing
- Communications platforms to support particular services (i.e. increased penetration of DER)



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