Testimony of Dr. Peter Littlewood
Director, Argonne National Laboratory
before the
U.S. Senate Committee on Energy and Natural Resources
March 17, 2015

Chairman Murkowski, Ranking Member Cantwell, and members of the Committee, thank you for the opportunity to appear before you today to discuss the state of technological innovation related to the electric grid.

A reliable, efficient, and secure electrical grid is essential to the United States' prosperity, competitiveness, and innovation. It delivers the power that drives our economy, lights our homes and enables the near ubiquity of the Internet in our daily lives. It is essential for meeting the needs of our growing digital society and a clean energy economy. To achieve a reliable, resilient, and clean electric power sector, our nation must pursue the vision of a Future Grid in which all the parts communicate with one another and deliver reliable, affordable and clean electricity to consumers where they want it, when they want it, and how they want it.

While modern communication networks would have been unimaginable to Alexander Graham Bell, the current electrical grid would be much more familiar to Thomas Edison. That reflects the persistence of expensive physical investment and is a reminder that the grid we build today will be with us for many decades. As we exploit the convergence of information networks with physical transport networks for infrastructure – not only the electrical grid, but also gas, water, and transportation – we must build in the flexibility to support unheralded developments both in technology and in the needs of society. A future grid will likely need to support distributed generation from renewables, support an electrified transportation network, entwine with other physical distribution networks, and be embedded in a complex information-rich, sensorized environment.

This will not be an easy task, but it is a challenge we must meet head on. It will require investment, cooperation and technological innovation on a grand scale. It will require a concerted effort over decades, akin to the development of our interstate highway system – another driver of the United States' economic might. The competitive greatness of this country was built on the quality of its infrastructure, and we must once again rise to meet the challenge in order to ensure our future prosperity.

Our existing electrical grid struggles to accommodate the new economy that is emerging as the nation and the world shift to clean energy and digital technology. Much of the current electric grid was designed and built using technologies and organizational principles developed decades ago to serve vertically integrated markets with large-scale generation sources located dozens of miles from consumers; they were designed to use centralized control schemes that deliver a one-way flow of power to customers who have minimal opportunity to provide feedback. The emerging national economy needs a flexible modern grid that accommodates the two-way flow of electricity and information; provides strong protection against physical and cyber risks and the impacts of natural disasters; and integrates widely distributed, variable energy sources, such as solar and wind energy, that produce electricity intermittently, depending on the weather.

Our nation's electricity delivery systems face complex challenges as power companies, equipment manufacturers, federal and state regulators, electricity consumers, and other stakeholders evaluate alternative technologies, systems, and investment strategies for modernization. To succeed, grid modernization must incorporate intelligent technologies, next-generation components with "built-in" cybersecurity protections, advanced grid modeling and applications, and innovative control systems. The Electric Power Research Institute's 2011 report, *Estimating the Costs and Benefits of the Future Grid*, estimated that realizing these goals will require between 300 and 500 billion dollars of new investment over the next 20 years.

Today, we lack a good picture of how all the pieces of the grid fit and work together. The existing grid is not a single system, but a patchwork of thousands of independent generators, transmitters, and distributors that range from large regional utilities to rooftop solar collectors to backyard wind generators. The grand challenge is to understand the entirety of the grid and its interoperability, then to use game-changing technology to shape it effectively into that vision of a Future Grid that is both reliable and resilient.

Argonne National Laboratory is a DOE Office of Science laboratory with a long and distinguished history in power grid R&D. We recently joined 13 other DOE laboratories in the Grid Modernization Laboratory Consortium (GMLC), a new initiative started last November by Energy Secretary Ernest Moniz. The GMLC is developing a vision and a plan for moving forward and has already identified three specific goals that can be achieved through a coordinated national effort to modernize the grid:

- A 10 percent reduction in the societal costs of power outages.
- A 33 percent reduction in the cost of utilities' reserve margins, while maintaining reliability.
- A 50 percent reduction in the cost of integrating distributed energy sources with the grid.

The GMLC estimates that achieving these three goals would save the nation's economy an estimated $7 billion a year. In addition, a coordinated national grid modernization effort would help ensure the Future Grid is a flexible platform for innovation by entrepreneurs and others who can develop tools and services that empower consumers and businesses, helping them make informed energy decisions.

The GMLC has identified significant opportunities and needs in six broad technical areas that are critical to the establishment of the Future Grid:

- Sensing and measurement
- Devices and integrated systems
- System operations and power flow
- Design and planning tools
- Security and resilience
- Support for utilities and regulators

I agree with the GMLC list. I would also like to emphasize the need for advanced energy storage systems (included under integrated systems above) that are critical to integrating intermittent electricity sources with the grid and to building a national fleet of electric vehicles. The Secretary has recently stressed the need for us to consider grid and storage as an integrated activity. An excellent example of this integration is DOE's Joint Center for Energy Storage Research (JCESR), which leverages and expands current investments in energy storage research and is a vital component of an overarching grid strategy.

Sensing and measurement

Sensing and measurement are critical to enabling the millions of pieces of the Future Grid to communicate and interact effectively. A Future Grid needs miniature, low-cost sensing and measuring devices to gather and report real-time data from as many components as we can monitor. The ability to monitor and understand the state of the grid and all its parts in real time will provide enormous potential benefits. We could instantaneously detect and respond to changes in supply and demand by rerouting transmission or adjusting generation. We could not only detect system failures and outages instantly, but could develop modeling and simulation systems that predict future failures and allow us to stop them before they happen. By designing a system made of components that communicate with one another, we could create new self-healing systems that automatically adjust to minimize the scale and duration of outages and bring power back online quickly.

Many of these "distributed automation" systems have begun to appear in the field in recent years. In the past, when lightning tripped a switch at a transmission station, a worker had to visit the site to see if it was safe to reset the switch. Today, automated systems in the field communicate to reset switches automatically when it's safe.

Industry has been a leader in placing smart meters in homes and businesses, which presents new, as-yet-untapped opportunities to run the electrical grid more efficiently, more economically, and with less environmental impact. At the consumer level, we can let meters in homes and businesses save energy by communicating with utility systems to, for example, charge electric vehicles when electricity rates are low or to cut back on air conditioning and turn off unused equipment when rates are high.

Devices and integrated systems

Essential to this vision of the Future Grid is the need to develop and integrate devices that talk to one another over the Internet, allow customers to make decisions about their energy use, and implement those decisions remotely. This movement is already well under way in the form of products that use smartphone apps to control home thermostats and turn lights on and off from the other side of the world. Industry is also pursuing this vision by integrating systems and devices in our homes and automobiles to save time, money, energy, and lives. Examples include smart thermostats that sense when no one is home and turn down the temperature, car systems that reset home thermostats so the house is warm when the driver arrives, smoke alarms that flash bedroom lights when triggered in the middle of the night, and carbon monoxide detectors that communicate with smart light bulbs that flash red to alert home owners. The Future Grid promises to raise this vision to an entirely new level and unleash new realms of entrepreneurial opportunity.

Argonne is helping make hybrid and electric vehicles Future-Grid friendly by working with the automotive and electric supply industries to develop and test systems and technologies that let electric vehicles communicate with grid operators to enable ‘smart’ charging and discharging, depending on the condition of the grid. Smart charging will ensure that electric vehicles recharge their batteries when they can take advantage of excess power, low-cost electricity, or power from solar or wind. Smart discharging will return electricity from electric vehicle batteries to the grid when customers benefit, such as during a power outage. The long-term goal is to develop standard, industry-wide systems and interoperable connections that let anyone plug in and charge any car, anytime, anywhere in the world. Achieving this goal requires a coordinated world-wide effort and close collaboration with industry to develop, test, and validate devices and communications protocols that are secure, reliable, and robust.

System operations and power flow

The Future Grid will need advanced control technologies that enhance its reliability and optimize its transmission and distribution systems. While utilities install smart meters and similar devices around the nation, the research community lacks the analytic and diagnostic capabilities to take full advantage of data from these devices. Today's grid relies primarily on control rooms and centralized operations. The Future Grid calls for distributed controls that use computers to analyze data in real time and shift the flow of electrical power to meet changing conditions.

Distributed controls will give customers greater decision-making power over how and when they consume electricity.

We also need systems that are predictive and can alert human operators to developing concerns before they result in failures or outages. Today's grid is largely reactive, responding to failure and outages after they happen. Developing predictive systems and algorithms for the Future Grid will require collaboration in both fundamental and applied research by computer scientists, systems analysts, and engineers in a variety of specialized disciplines.

An underlying challenge is the grid's increasing use of microprocessors. While they provide many benefits, microprocessors make a system more complex and can slow it down. If a system grows too complex; it can behave in unexpected ways. We need fundamental research in the mathematical and computing sciences to understand this phenomenon and mitigate it.

Design and planning tools

We need a new generation of design and planning tools to accommodate the changing nature of the grid. The existing tools were created for a grid in which electricity was generated, transmitted, and delivered in one direction only–from the utility to the customer. This one-way model is breaking down with the rapid spread of distributed electricity generation based on renewable energy and the ability of customers to sell electricity back to utilities. Driven by rapid improvements in green energy generation, this practice will continue to grow, and we will need analytical methods to optimize its integration into the Future Grid.

Better design and planning tools are also needed to calculate accurate cost-benefit tradeoffs for the two-way flow of electricity between utilities and customers and to ensure reliable design and deployment of intermittent or variable electricity sources, such as wind and solar, which are not deployable on demand because their availability depends on the weather. To capture the complexity, uncertainty, and dynamics of growing renewable generation, we need new computational tools, methods, and software libraries that improve analysis and design capabilities a thousand-fold.

Security and resilience

The Future Grid must also be secure and resilient in the face of disruptive threats that range from natural disasters to terrorist attacks. Security and resilience need to be designed into all Future Grid systems and components from the start. Too much of the safety and resilience in today's grid was added as an afterthought—necessarily so, since much of today's grid was built decades ago. For tomorrow’s grid we need to build security and resilience into both emerging and legacy grid technologies.

Resiliency research is a particular strength at Argonne National Laboratory, for the grid and for the rest of the nation's infrastructure. The grid is arguably our most important infrastructure and certainly one of the most complex.

Argonne is currently developing a concept for a national Resilient Design User Facility, which would give researchers from industry, universities, government, and national laboratories access to Argonne's physical science and computing facilities to test and simulate the resiliency of key infrastructure systems. The goal is to develop new knowledge, tools, and technologies to help communities mitigate the impacts of disasters and recover more quickly.

The starting point for infrastructure resiliency analysis is always the impact of a potential disaster on the local electrical grid. Those impacts are then analyzed to understand how they will cascade out to the region and nation, and what additional threats come into play as the impact spreads. For example, any prolonged power disruption is a danger to local economies, public health, and safety. Power disruptions can quickly cascade across interdependent infrastructures and adjacent regions, triggering disruptions in transportation services, wastewater processing, and other critical services. Although advanced control systems have improved automated outage responses, they can also expose the power grid to new cyber risks as digital components proliferate and create new points of entry.

Key threats to grid security include electromagnetic pulses (EMP) and geomagnetic disturbances (GMD) that could injure the grid so badly that outages last weeks or months and the damage takes years to fully repair. The Security and Resilience Committee of DOE's Grid Modernization Laboratory Consortium considers EMP and GMD threats to have low probabilities, but extremely high potential impacts. Historically, utilities have been most concerned with physical threats to infrastructure and more recently with cyber threats. The Security and Resilience Committee sees cybersecurity becoming an increasingly critical challenge as we move to the Future Grid with millions of components communicating in real time and more operating decisions made by computer.

We also need to develop methods for prioritizing which grid infrastructure assets need protection. Large transformers at substations are particularly vulnerable assets because they are custom-made and their replacement lead time is typically 12 to 18 months. The Department of Homeland Security has spearheaded work to develop modular transformers with standardized designs that can be quickly assembled and delivered. We might further minimize replacement time by developing standardized transformers in key high-voltage classes. A good deal of research has been done on solid-state transformer design that could aid this effort, but the focus has been on small-scale, low-voltage transformers. More research and development is needed to scale up to the larger transformers of interest to utilities.

The DOE labs, specifically Pacific Northwest National Laboratory, National Renewable Energy Laboratory, Los Alamos National Laboratory, Sandia National Laboratories, and Argonne National Laboratory, have developed the beginnings of a foundational key to the secure grid—a National Power Grid Simulator. Such a simulator would serve two functions. First, it would analyze the state of the grid in real time to provide broad situational awareness and to communicate important information to the grid's various operators. Faced with a threat to the grid, the real-time simulator would help operators understand the scope and progression of events, and would suggest control and mitigation strategies. Second, the simulator would include an offline component that would operate as a national user facility where researchers from industry, universities, government, and national laboratories would run virtual experiments to test potential vulnerabilities and mitigations, develop responses to various types of attack, and understand the impacts of new technologies—a capability of particular importance to the Future Grid and all the new technologies it will bring online.

Support for utilities and regulators

Utilities and regulators need better decision-making tools to provide the best information possible to guide and coordinate their planning and investment decisions. As the grid becomes smarter, better integrated, and more complex, the importance of good, rapid decision making will extend beyond the local level and have increasing regional and national impact.

The rapid growth of distributed energy sources, such as solar energy and wind energy, is changing the game in many ways. In the previous century, an electrical utility's biggest operating challenge might have been how to provide power for all the region's air conditioners on the hottest day of the year—a relatively easy challenge to anticipate. But how do you anticipate and quickly ramp up supply when a cloud bank suddenly blocks the sun and cuts off all the electricity the grid is receiving from solar collectors on neighborhood rooftops?

Better decision-making tools will help the states adjust their regulatory models to align utilities' interests with grid modernization and clean-energy goals. These tools will also provide methods for evaluating distributed energy technologies and services so all stakeholders understand them better and can make informed decisions on grid investments and operations.

Advanced battery research

Advances in energy storage are critical to modernizing the nation’s aging electrical grid—and integrating clean, renewable energy sources such as wind and solar power into our electricity supply. Breakthroughs in battery technology are also needed to reduce our dependence on petroleum through broader use of electric vehicles.

Across our energy economy, effective storage of energy holds the key to the flexible energy sourcing and delivery required to diversify our energy portfolio, renovate our energy infrastructure, and alleviate the growing environmental costs and risks of continued reliance on fossil energy as our primary energy source. For the grid, advanced battery technologies are the key to storing energy from intermittent sources so we can release it later when we need it. The best solar tracking technologies have average capacity factors only just above 20 percent, and even in the windy plains, the median annual capacity factor of wind generators was only about 33 percent last year. (Plant capacity measures how much electricity a generator actually produces compared to the maximum it could produce at continuous full power operation during the same period.)

Fundamental research at our national laboratories and universities has yielded significant improvements in batteries and energy storage over the past 20 years. But we are still far short of comprehensive solutions for the grid and transportation.

Benefits of grid modernization

Grid modernization will provide the nation with a reliable and secure system that delivers increasingly clean electricity to businesses and residences in ways that optimize customers' ability to control how, when, and where they consume energy. Grid modernization also assures a system that remains resilient to a range of threats and vulnerabilities. Success will not only save the nation billions of dollars annually, it will also create new suites of advanced technology, such as:

- A new grid architecture that enables controllability across a system that consists of multiple microgrids, millions of distributed energy sources, and a wide variety of end-use devices, most of which are still emerging.
- Next-generation sensing and data management platforms that make the full system transparent and enable quick, adaptive responses over wide areas.
- New control theory and algorithms that speed system restoration by basing decisions on real-time analysis of real-time measurements.
- Contingency tools that predict outages in real-time in the face of threats and go beyond today's contingency tools, which consider only single-point failures, to analyze the impacts of multiple failures.
- New devices and methods to manage the flow of power transmission and distribution and reduce the need to expand transmission systems.
- Integration of high-performance computing to mitigate the uncertainty inherent in a system as complex as the Future Grid.
- Real-time control systems based on ultra-fast (less than one second) measurement and estimation of the state of the grid.

- Validation of algorithms and computer models to make the system work.
- Demonstrations of developing technology and systems, in cooperation with utilities, to verify developing concepts and strategies, such as reconfiguring grid connections in real time to minimize the size and duration of an outage.

A focused national effort to modernize the grid will fundamentally alter the way our electric grid and transportation systems function, enabling the creation of entirely new approaches to satisfy the increasing electricity needs of our country. It will inevitably create new technologies, new businesses and entrepreneurial opportunities, and new high-value jobs with the potential to power the American economy for decades to come.

Thank you for your time and attention to this critically important topic. I would be pleased to respond to any questions that you might have.

###