Review of National Laboratory Capabilities to Support the Department of Energy's Grid Modernization Initiative

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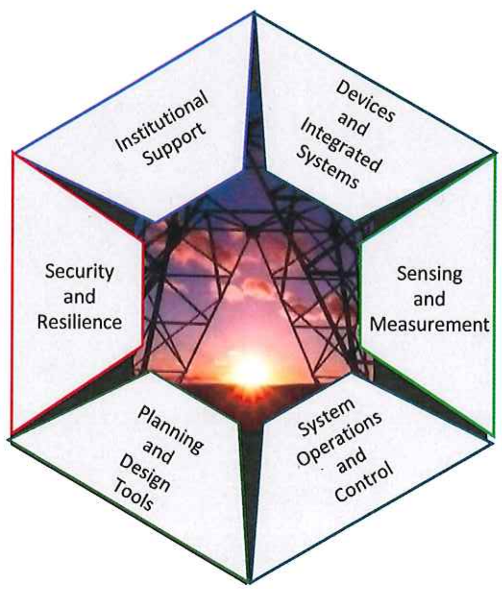

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Review of National Laboratory Capabilities to support DOE's Grid Modernization Initiative

Executive Summary

In 2015, the Department of Energy (DOE) formed the Grid Modernization Initiative (GMI) to focus efforts on creating an adaptive and resilient U.S. electric grid. As part of the initiative, a National Laboratory consortium comprised of thirteen National Laboratories was formed called the Grid Modernization Laboratory Consortium (GMLC). The purpose of the GMLC is to integrate and coordinate "Laboratory expertise and facilities to best advance DOE Grid Modernization goals."

In October 2015, DOE commissioned an independent review of the staff and physical facilities of these thirteen Laboratories as those capabilities pertain to GMI goals. The review was conducted by three retired senior National Laboratory officials through on-site meetings and interviews with all the thirteen National Laboratories involved in the GMLC.

The review generated several findings and associated recommendations that are summarized below. A more detailed discussion of the findings and recommendations as well as specifics on each technical area and individual Laboratories' capabilities in each area are contained in the body of the report.

First Finding and Recommendation:

Finding: The National Laboratory system's capabilities (the thirteen laboratories that were visited) are well suited for the current GMI program goals. In fact, the review team believes that the capabilities exceed those required for the program as defined today. Additionally, the noted presence and enthusiasm of cadres of younger scientists and engineers in almost all of the laboratories will be critical in sustaining the continued excellence and evolution of the GMI in response to external developments that go to 2025 and beyond.

Recommendation: The review team acknowledges that DOE and their laboratories spent a considerable amount of time and effort in obtaining input from other sectors. However, the review team recommends that DOE should more aggressively work with technology providers, utilities, and state regulators to develop a more externally driven set of goals and framework to better structure the program to address external realities and to encourage greater innovation. This framework should provide a clearer basis for understanding the value of specific capabilities, especially physical infrastructure, contained in the National Laboratory system, and any needed expansion. To accomplish this modified approach, an external advisory group, consisting of technology providers, end-users, and regulators, should be formed (or expanded from previous interactions) under the leadership of DOE.

Second Finding and Recommendation:

Finding: A number of specific technical areas in the Grid Modernization program could benefit from a coordinated approach to both developing and using capabilities. Also, it was not clear that the existing capabilities, especially physical test beds and computational facilities, were being viewed as shared resources and/or were being used to get the best outcomes for the program.

Recommendation: DOE should charter a number of specific activities within grid modernization in order to address certain cross-cutting capability issues, including but not limited to: test beds as user facilities, cyber security, and coordinated approaches to modeling and simulation.

Third Finding and Recommendation:

Finding: With respect to the leadership capability of the GMLC, there was almost unanimous consensus that the co-leaders at PNNL and NREL are leading the overall program in a reasonably transparent manner and are trying to be fair, in as much as the construct allows. Just as significant was the unanimous consensus that the approach being used by DOE must be given time to succeed.

Recommendation: DOE should give this approach time to work effectively. This requires that the current approach will carry forward into the new administration through FY 2017 and beyond. Additionally, the DOE and GMLC leadership must develop fair and transparent mechanisms for consolidating appropriate projects in fewer laboratories on an as-needed basis.

Fourth Finding and Recommendation:

Finding: Consistent effective leadership from DOE/Headquarters is critical for the future wellbeing of this effort. The review team recognizes that there are significant issues with the current approach. The review team recognizes that the current funding approach, which essentially applies funds from existing activities in program offices in DOE/EERE and DOE/OE to this effort, can lead to programmatic funding conflicts.

Recommendation: The fundamental recommendation is for DOE to propose line item(s) to Congress that can more appropriately meet the programmatic needs of the integrated nature of the GMI. If that is not possible, the overall GMLC program should more closely align and explicitly integrate its project activities with those of the individual EERE and OE program offices that are participating and funding the GMLC activities, while taking into account industry and regulatory requirements and initiatives.

These recommendations are intended for use by DOE to examine the longer-term needs of and opportunities for the aggregated National Laboratory system. Periodic analyses, incorporating input from a variety of external entities, should be conducted to assess the needs of the evolving electricity grid. That is, there may be transformative and/or disruptive technological and societal changes that will require significant contributions and funding for the development of new facilities and the enhancement of scientific and engineering human resources to address these needs. At the same time, these changes may render less important, or even obsolete, some laboratory capabilities that will no longer require continued investments.

1.0 Introduction

This report is an overview and assessment of the capabilities, both staff and physical facilities, of DOE's National Laboratories to support the DOE Grid Modernization Initiative (GMI). This report was based on multiple in-person interviews with each of the Laboratories, using targeted questions about their capabilities and site visits to assess their strengths using criteria set by the review team with concurrence from DOE. The report summarizes findings and provides recommendations.

The review was developed by a team comprised of three retired National Laboratory senior officials. The members were Abbas Akhil, David Hill, and Terry Surles. Biographies are to be found in Appendix A. Since each of the team members has historical connections with one or more of the National Laboratories, care was taken to avoid any bias or potential conflict. The approach to this concern is also discussed in Appendix A.

1.1 Grid Modernization Multi-Year Program Plan (MYPP)

The focus of the review was based on the Grid Modernization Multi-Year Program Plan (MYPP) developed by DOE Headquarters with substantive input from the various participating National Laboratories. The MYPP states that success could be seen in the following outcomes; 10% reduction in the economic costs of power outages by 2025, 33% decrease in cost of reserve margins while maintaining reliability by 2025, 50% decrease in the net integration costs of distributed energy resources by 2025.

These proposed target achievements would lead to:

Lean Reserve Margin Grid Operations
Clean, Resilient Distribution Feeders
Advanced Modern Grid Planning and Analytics Platform

The proposed outcomes and achievements are consistent with key attributes of the future national electricity grid, which will lead to improvements in:

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

To address these goals and attributes, the Grid Modernization program focused on six interdependent technical areas that are:

- Device and Integrated Systems Testing
- Sensing and Measurements
- System Operations, Power Flow, and Control
- Design and Planning tools
- Security and Resilience
- Institutional Support

It should be noted that the inherent integrated systems approach that was being utilized led to a level of overlap between the six areas. The review team acknowledges this fact in its findings and believes that the overlap is consistent with the integrated systems approach that is being utilized.

By encouraging the National Laboratories to work across disciplinary lines and to have substantive working relationships with one another, technology developers, and end users, the results can lead to:

- Functional, optimized distribution controls linked to overall system controls
- System architectural concepts and platforms for planning and operating a new grid
- Automatic system operations that predict system operational direction and self-correct when sensing anomalies
- Regional flexibility to reflect state and local policies and desires as well as regional resource options
- Ubiquitous consumer engagement.

The box and text below, emphasis added, from the MYPP, defines the roles and responsibilities within DOE and the expectations of the Grid Modernization Initiative.

Through a coordinated Grid Modernization program, DOE's leadership is expected to provide:

- Catalyze Private-Sector Innovation— DOE and its National Laboratories can use their RD&D expertise in collaboration with other key stakeholders to help establish the technological foundation for grid modernization. Federal RD&D across National Laboratories, universities, and industry can complement the RD&D being currently carried out by power generation and delivery entities and their vendors. Federally sponsored R&D can (i) de-risk technologies that could provide significant value to the nation; (ii) reduce the cost of such technologies; and (iii) promote innovation and encourage broader investment. With knowledge and tools ranging from technology development to computational expertise to field experience, DOE is well suited to lead and facilitate partnerships among states, regions, tribes, research institutes, non-profits, and private industry. This kind of collaboration is especially important for small municipal and cooperative utilities that have limited resources to conduct R&D.

- Regional Breadth—America's regions vary significantly in their readiness for grid transformation, energy resources, access to transmission, vulnerability to natural disasters, and a wide array of other factors. DOE, in partnership with the National Laboratories, and states can combine knowledge of new technology capabilities, analytical tool-sets, and understanding of unique regional issues to deliver collaborative partnerships and initiatives that are tailored to regional needs yet able to deliver national benefits.
- Convening Power[1]—DOE can listen, synthesize, and help communicate, without being prescriptive. Using its convening power as an honest-broker, DOE can help identify and replicate best practices and avoid duplication or unproductive technology pathways. DOE's leadership can help other stakeholders recognize and respond to the urgency of the need for investment. DOE's assembling efforts were successful in the ARRA funded interconnection wide planning efforts, significantly supporting states and the private sector in interconnection wide planning scenarios.[2] DOE can bring together the multiple actors and influencers to find common visions and identify activities that benefit all parties.

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

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

Grid Modernization Roles and Responsibilities within The Department of Energy

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

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

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

This report is a review of the capabilities of the National Laboratory system and its system-wide and individual laboratory ability, not only to carry out the necessary research, but also to behave as a system in order to effect *"...more efficient use of resources and reduced duplication of efforts; shared networks improving learning and preservation of knowledge; enhanced Lab coordination and collaboration across traditional programmatic "silos"; and regional perspective and relationships with local stakeholders and industry.."* To carry out this charge the review team had to visit and, at least qualitatively, evaluate individual Laboratory capabilities against the programmatic goals.

It is important to note at this juncture that the review was not of the MYPP itself, rather a review of the capabilities resident within the National Laboratories for executing the MYPP. However, the nature of the review, coupled with substantial commentary from the various laboratories, led the review team to make certain comments, findings, and recommendations about the MYPP.

Coincident with this report, DOE was reviewing and down-selecting in order to make awards in the first phase of the competitive proposals under the Grid Modernization Initiative. This review did not influence the outcome of that selection process.

1.2 Review Approach

The review team used the proposed goals, outcomes, and results of the MYPP to determine how effective the laboratory system would be in meeting these end points. To this end, the team also considered, on an as-needed basis, the National Laboratories value from the standpoint of the recent Congressional Commission on National Laboratories, as summarized in "Securing America's Future: Realizing the Potential of the DOE National Laboratories: Final Report of the Commission to Review the Effectiveness of the National Energy Laboratories." Key attributes in that report were: (1) maintaining alignment and quality; (2) maximizing impact; and (3) ensuring lasting change.

1.3 Review Logistics

A schedule of the site visits to National Laboratories conducted for the review can be found in Appendix B.

NREL and PNNL are charged by DOE/OE and DOE/EERE offices as co-leads for the GMLC. Thus, it was important that the review team visit those institutions first. After those visits the order of visits was governed by travel limitations and prior team member commitments.

2.0 Findings and Recommendations

2.1 First Finding and Recommendation

➤Finding: The National Laboratory system's capabilities (the thirteen laboratories that were visited) are well suited for the current GMI program goals. In fact, the review team believes that the capabilities exceed those required for the program as defined today. Additionally, the noted presence and enthusiasm of cadres of younger scientists and engineers in almost all of the laboratories will be critical in sustaining the continued excellence and evolution of the GMI in response to external developments that go to 2025 and beyond.

It is also noted that based on each laboratory's individual strengths, the definition of "grid modernization" was slightly different among the various laboratories. Thus, there were very few "surprises" in terms of what the laboratories were doing differently from what they had been doing. That said, it is clear that almost all of the laboratories have continued to develop strengths in their respective areas of expertise. Section 3 provides a detailed commentary of laboratory strengths in each program area of the MYPP.

The review team also noted and appreciated the significant number of younger staff in leadership positions during the visits to the laboratories. This cadre of younger staff will be critical in sustaining the continued excellence and evolution of GMI in response to external developments that occur in future years.

The review team believes that the laboratory system's combined resources can match well to an enhanced program as we expect the capabilities to evolve with the program. In addition, our current brief review noted a number of areas that could be brought to bear, such as the specialized fabrication facilities at two of the laboratories. However, these are outside the current focus of the GMI. This observation, however, would need to be validated by existing and future external partners of the laboratories.

There was a limited amount of time available for the current review of the laboratories only. As a follow-on activity, we believe it is extremely important to systematically and substantively engage external organizations, such as utilities, system operators, end users, and regulators.

Recommendation: The review team acknowledges that DOE and their laboratories spent a considerable amount of time and effort in obtaining input from other sectors. However, the review team recommends that DOE should more aggressively work with technology providers, utilities, and state regulators to develop a more externally driven set of goals and framework to better structure the program to address external realities and to encourage greater innovation. This framework should provide a clearer basis for understanding the value of specific capabilities, especially physical infrastructure, contained in the National Laboratory system, and any needed expansion. To accomplish this modified approach, an external advisory group, consisting of technology providers, end-users, and regulators, should be formed (or expanded from previous interactions) under the leadership of DOE.

DOE should seek stakeholder (utilities, technology developers-including selected developers of potentially game-changing products, state and federal regulators, end-users) to better shape GMI goals and objectives. The stakeholders could include: utilities, technology developers-including selected developers of potentially game-changing products, state and federal regulators, end-users. This requires creating an advisory group to advise DOE and the laboratories in enhancing the goals and framework of the GMI. Input provided by this advisory group will better align the GMI to the technological and regulatory changes that will shape the future electric grid. International participants should be included to inform about activities in other countries that may be advancing the concept of grid modernization more rapidly than in our country. This group could consist of some members of the current Electricity Advisory Council with additional new members based on their potential for substantive contributions.

The charge to this advisory group should be to recommend short-, mid-, and long-term objectives. A primary benefit of DOE's leadership is a two-way communications stream to allow for the development and deployment of innovative, disruptive, and transformative technologies. The increased accessibility between the private sector and the laboratories will enhance these sets of goals and objectives.

The advisory group recommendations will be of critical importance, as the program offices will, by the nature of the Congressional line items, fund projects specific to their program area. However, the intrinsic nature of grid modernization requires a systems approach that allows for integrated incorporation of new technologies that build on each other's capabilities and strengths.

Also noteworthy is the recognition that grid modernization will lead to new business models for legacy utilities. Eventual users of new technologies may not be utilities, but end users or other suppliers of electricity. Including regulators on the advisory group is important as state regulatory agencies are, in a number of cases, forcing the legacy utilities to think in terms of new business models. To this end, a government agency such as DOE cannot **create** new business models to be used by the private sector. However, proper approaches in working across public/private sectors can allow DOE to **enable** new business models.

2.2 Second Finding and Recommendation

➤Finding: A number of specific technical areas in the Grid Modernization program could benefit from a coordinated approach to both developing and using capabilities. Also, it was not clear that the existing capabilities, especially physical test beds and computational facilities, were being viewed as shared resources and/or were being used to get the best outcomes for the program.

One key benefit expected of the work of the GMLC is "...more efficient use of resources and reduced duplication of effort..." Our observations led the review team to conclude that there was still substantial duplication of effort, especially in the use of LDRD and other discretionary resources. This is a difficult area to address since the use of LDRD is an internal laboratory decision, made with Field Office concurrence.

The review team observed well thought out utilization of LDRD in an effort to enhance existing capabilities or apply existing capabilities from other programmatic areas to that of grid modernization. The review team also observed apparently less well thought out use of LDRD and other discretionary investments where the goal seemed to be to either enter an area where an institution had no capability or to create a duplicative (from the laboratory system perspective) physical infrastructure. In the first of these two examples, partnership with more expert institutions might make more sense and in the second case investment might be justified if access to existing capabilities at other institutions was limited in some way.

While there should not be external (DOE) direction of LDRD, institutions should be encouraged to use the GMLC construct to engage in a dialogue around specific subjects to allow them to make better, fully-informed, decisions on the allocation of scarce discretionary resources so that they and the program can reap maximum benefits.

This recommendation's intent is to explicitly address potential duplicative, less well thought out, investments identified in this cursory review. The MYPP identifies coordinated approaches to both computing and testing (GMLC-TN) as specific goals of the program. The review team supports those goals but recommends a more aggressive approach to recognizing system-wide legitimate facilities and capabilities and coordinating their future development. Implementation of this recommendation would also ensure that DOE management could treat the various laboratories' test beds and computational capabilities and facilities as an integrated shared system. In this way, the facilities' use can be maximized to the overall benefit of GMI.

Recommendation: DOE should charter a number of specific activities within the grid modernization in order to address certain cross-cutting capability issues, including but not limited to: test beds as user facilities, cyber security, and coordinated approaches to modeling and simulation.

2.3 Creating a Competition of Ideas (not Institutions): Commentary on the First Two Findings and Recommendations

The basic idea behind the GMLC approach is to minimize wasteful inter-laboratory competition and coalesce the capabilities of the aggregate set of national laboratories as a system with, for grid modernization, a single programmatic purpose. The review team believes that such an approach will ultimately be successful only if a competition of ideas is encouraged and rewarded.

The GMLC approach has made progress towards this end-state but there are significant issues that need to be addressed. Specifically;

- *The current process seems to encourage incremental change at the expense of innovative projects. There needs to be greater scope for innovation in the program. Laboratories – both in terms of staff and test beds – need to be flexible in response to innovative, transformative, and disruptive technological change.*
- *Duplication of large and medium scale facilities should be actively discouraged. Existing large and medium-scale test facilities should be treated as system-wide shared resources, where the best ideas are tested independent of their source.*
- *Smaller facilities at different laboratories are useful, but can have hidden costs – for example requiring hiring new laboratory staff to run them. Therefore, their support should be considered carefully from a national viewpoint.*
- *In general, the review team found that the laboratories now have a better understanding of each other's capabilities and programmatic history, which helps reduce duplication and inform investment. Sometimes, however, this understanding was limited to a smaller number of labs, usually those with technical leadership roles.*

In conclusion, despite initial efforts, redundancy remains and the GMLC approach has not yet attained the goal of a true Competition of Ideas.

2.3 Third Finding and Recommendation

➢**Finding: With respect to the leadership capability of the GMLC, there was almost unanimous consensus that the co-leaders at PNNL and NREL are leading the overall program in a reasonably transparent manner and are trying to be fair, in as much as the construct allows. Just as significant was the unanimous consensus that the approach being used by DOE must be given time to succeed.**

A major concern of the laboratories is that this program will not continue long into the future. There is a unanimous opinion among the laboratories that the programmatic concept and aggressive Headquarters support for a truly integrated multi-laboratory program must continue over a number of years in order to demonstrate the efficacy of the integrated approach to the overall program. The consensus opinion of the laboratory leadership is that the multi-disciplinary and integrated nature of grid modernization requires extensive cooperation and sharing of facilities and staff expertise and experience between the laboratories. Industry members that have attended review team meetings are also in agreement on this point.

In all of the review team meetings, there was agreement that having only one or two years for this type of approach will be insufficient to prove the worth of the laboratory system in addressing this area. Worse, if this effort is truncated and business as usual becomes the operating model, real damage will have been done to mutual trust and working relationships at the labs.

One concern raised by most of the laboratories is the current approach to "over-inclusiveness" in developing project teams within the overall GMLC set of activities. Too many laboratories are involved in some of the projects. Thus, some laboratories are almost certainly of marginal value to a given project. Further, the transaction costs (communications, meetings, etc.) cut into the ability of each project group to do substantive work.

The over-inclusiveness is probably necessary as a starting point for the program but cannot be maintained for the long run in a healthy program. Furthermore, there are some responsibilities that are inherently federal and cannot be delegated to laboratory staff, such as removal of underperforming entities or reallocation of resources. These observations lead to the second recommendation.

The review team strongly believes that engaged DOE leadership is essential to balance the cooperative program management in place today and perform inherently federal functions. For many reasons, it would be preferable to see that authority invested in a single person.

Recommendation: DOE should give this approach time to work effectively. This requires that the current approach will carry forward into the new administration into FY 2017 and beyond. Additionally, the DOE and GMLC leadership must develop fair and transparent mechanisms for consolidating appropriate projects in fewer laboratories on an as-needed basis.

2.4 Fourth Finding and Recommendation

➤**Finding: Consistent effective leadership from DOE/Headquarters is critical for the future wellbeing of this effort. The review team recognizes that there are significant issues with the current approach. The review team recognizes that the current funding approach, which essentially applies funds from existing activities in program offices in DOE/EERE and DOE/OE to this effort, can lead to programmatic funding conflicts.**

There is also unanimity among the laboratories in their appreciation for how the DOE leadership (the Secretarial level, the Under Secretary, Assistant Secretaries, and the integrated program leadership within DOE/OE and DOE/EERE) has been coordinated to support this collaborative initiative. The laboratories recognize that this is not a trivial effort as the individual program offices within DOE/OE and DOE/EERE have their Congressionally-mandated activities to support. Laboratory leadership is supportive of the continuation of this effort.

Recommendation: The fundamental recommendation is for DOE to propose line item(s) to Congress that can more appropriately meet the programmatic needs of the integrated nature of the GMI. If that is not possible, the overall GMLC program should more closely align and explicitly integrate its project activities with those of the individual EERE and OE program offices that are participating and funding the GMLC activities, while taking into account industry and regulatory requirements and initiatives.

2.5 Recommended Use of This Report

These recommendations are intended for use by DOE to examine the longer-term needs of and opportunities for the aggregated National Laboratory system. Periodic analyses, incorporating input from a variety of external entities, should be conducted to assess the needs of the evolving electricity grid. That is, there may be transformative and/or disruptive technological and societal changes that will require significant contributions and funding for the development of new facilities and the enhancement of scientific and engineering human resources to address these needs. At the same time, these changes may render less important, or even obsolete, some laboratory capabilities that will no longer require continued investments.

3.0. Capability Assessments

Using the site visits and one-on-one interactions with the Laboratory management and staff, the team focused on the six technical areas of the Grid Modernization Initiative as detailed in the MYPP. The objective was to evaluate the staff, facilities, and related capabilities to determine how well each Lab was situated to meet the desired targeted technical achievements for 2025.

As an overall finding related to our visits, the team was pleasantly surprised with the presence and enthusiasm of younger scientists and engineers in almost all of the laboratories. This cadre of younger staff will be critical in sustaining the continued excellence and evolution of the GMI in response to external developments that go to 2025 and beyond.

As observed earlier, the six technical areas are too broad and overlapping for specific separation of individual labs, determining a rank order in each area. We have chosen to address the program at the activity level defined in the MYPP and attempted to provide commentary on those laboratories whose capabilities stand out.

The following sections present the teams findings grouped into each of the six technical areas.

3.1. Devices and Integrated System Testing

The electrical grid is fundamentally comprised of devices physically connected together and linked by control systems and markets, and form integrated systems that provide specific functions that in aggregate enable the electrical power to operate effectively as a whole. Much of the future grid flexibility required for managing variable generation and enhancing reliability and resiliency will be obtained from new and often distributed devices and systems and the functions that they can perform. These devices must have proven performance as controllable assets when integrated into new and existing systems.

Four activities and the corresponding technical achievements that will be reached by 2020 are shown in Table 1 for the Devices and Integrated Systems technical area. These efforts will develop devices and integrated systems that interoperate with each other and with grid sensors developed in the Sensing and Measurements

Technical Area and control systems developed in the System Operations, Power Flow and Control Technical Area. These devices will interconnect to maintain stable grid operations, while providing grid and local energy services.

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

Activity	Technical Achievements by 2020
1. Develop Advanced Storage Systems, Power Electronics, and other Grid Devices	• Develop power electronics-based converters for renewable, distributed energy and energy storage systems that can provide grid services, self-optimize around the market and energy environment and meet specific DOE applications' targets. • Decrease the system costs of deployed grid-scale, energy storage system to under \$300/kwh by establishing grid-scale storage systems' metrics for safety, reliability and performance, and through new energy storage technologies development. • Enable buildings, large building loads (e.g. HVAC systems, refrigerator systems) and EV charging systems to: 1) diagnose if they are functioning properly, 2) forecast their energy needs over the next day or several days, 3) characterize their available flexibility, and 4) have embedded control and decision-making tools to provide capacity, energy and ancillary services to the electrical grid and other valuable services to system owners. • Develop innovative grid infrastructure technologies that improve electrical grid efficiency and reliability by 10 percent.
2. Develop Standards and Test Procedures	• Updated standards and test procedures that characterize the ability of devices (50% of building loads and all new generation and storage) to provide a full range of grid services and accelerate the uptake of these devices in the market. Codes and standards are also necessary to ensure deployed technologies are safe and effective. • Development of standards and test procedures for microgrids and other systems that reduce customer outages by 10%.
3. Build Capabilities and Conduct Device Testing and Validation	• The Grid Modernization Laboratory Consortium - Testing Network (GLMC-TN) provides test facility integration and optimization, testing frameworks, and component model libraries managed and operated by National Laboratories, universities, and industry groups. • Development of methods to couple hardware-in-the-loop (HIL) devices with advanced simulations including high performance computers (HPC) systems for evaluating systems at a variety of scales. • Characterization of a wide variety of technologies to validate individual devices can provide a full range of grid services using a variety of techniques including HIL.
4. Conduct Multi-scale Systems Integration and Testing	• Validated multi-scale systems that enable integration of 100% renewable energy at the local level and 35% at the bulk system while reducing reserve margins and interconnection costs. • Validated transactive control constructs that coordinate distributed generation, storage and controllable loads to reduce reserve margins by 33%. • Validated 10% outage reductions by using advanced distribution system configurations (including microgrids) and fault location, isolation and service restoration (FLISR) systems. • Field demonstrations of energy storage providing multiple grid services cost effectively.

Activity 1: Develop Advanced Power Electronic Interfaces, Energy Storage Systems, Controllable Loads and other Grid Devices.

This activity encompasses three separate sub-areas and expertise in each sub-area is dispersed among multiple labs. The primary expertise in power electronics lies both at SNL and ORNL. SNL has a more visible presence because it has been awarded five R&D 100 awards in a row and has successfully collaborated with academia. ORNL also has a significantly strong capability in power electronics and collaborates with academia and industry.

SNL has the lead capability in energy storage with activities that span fundamental science to systems-level capability in developing and testing energy storage systems, especially battery systems. A secondary, but, well-established capability in component development and testing resides at PNNL. ORNL's energy storage activity is focused on secondary use of EV batteries in stationary applications.

ANL's lead role in the energy storage hub is also noted as a complementary capability for the GMLC.

Building loads investigation and characterization capability resides at LBNL, PNNL and ORNL. These labs have active programs and well-established expertise in this sub-area. The capability to use vehicles as controllable grid loads is resident at both INL and ANL. INL has a strong legacy capability that is being leveraged and developed to reflect advances in electric vehicle technology. It is noted however, that stronger coordination and collaboration is needed between INL and ANL and expanded to include a lesser capability that exists at NREL.

Activity 2: Develop Standards and Test Procedures.

While capabilities to support this activity are existent in several labs, PNNL is the key lead lab assisted by SNL. These two labs have already launched an initiative to gather existing relevant codes and standards and develop those that are needed. INL and NREL participate and contribute expertise in interconnection and interoperability standards and test procedures as needed.

Additional capabilities are resident at ORNL and SRNL for NIST standards-based testing of high and low voltage and current devices.

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

Both SRNL and the NREL WTC have unique facilities to test components of large, multi-megawatt wind turbines, with SRNL having a higher MW test capability than those at NREL.

Testing and validation capability for lower megawatt-rated components for commercial and residential photovoltaic systems exists both at SNL and PNNL test facilities.

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

Multi-scale testing capability in wind and solar exists at NREL and power electronics for solar power exists at SNL. NREL capability of testing wind systems and components is evident through the large investments at the Wind Technology Center (WTC). More recent substantive investments have created an impressive facility at the Savannah River National Laboratory/Clemson University facility in Charleston, SC. SNL capabilities of testing inverters for PV systems is similarly evident at the Distributed Energy Technologies Laboratory (DETL).

SNL also has a dedicated storage system test capability at the DETL, where stand-alone or grid-tied storage systems from kW to megawatt scale can be tested. A similar parallel capability is being developed at NREL's WTC, and closer coordination between the two is needed to avoid duplication of capabilities and test programs.

Specific high voltage testing for power line conductor and other high voltage component test capability exists at ORNL, which is different and unique from the capabilities at other Labs.

Similarly, the large electric grid comprised of over 100 miles of transmission and distribution lines operated by INL within the boundaries of the laboratory offers unique capabilities to test infrastructure vulnerabilities.

3.2 Sensing and Measurements

The activities in this technical area are geared to assess the grid's health in real time, predict behavior and potential disruptions, and quickly respond to events. Devices such as smart meters and synchrophasors have been and continue to be deployed. However, very little visibility is currently available at and below the distribution level. This lack of visibility limits the integration of distributed systems and utilization of end-user loads from their full potential. The activities in this area address this gap by leveraging sensors developed in Devices and Integrated Systems to enhance visibility across multiple spatial scales - from generation to the end-user load - and at multiple time scales spanning microseconds to hours and days.

The six activities and desired technical achievements by 2020 are shown in Table 2 below.

Table 2. Activities and Technical Achievements for Sensing and Measurements

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

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

ORNL has a strong resident capability in developing low-cost sensors drawing on their well-established capability in this area. Their direct-write sensor development has the potential of deploying ubiquitous, low cost sensors in buildings and other infrastructures including the electric grid. Secondary capabilities for developing low cost sensors resides at SNL's Microsystems Engineering Sciences & Applications (MESA) Facility and at NETL.

LBNL has strong capabilities in characterizing and real-time control of buildings and other commercial loads through end-use controls and agents that will allow these grid-edge loads to participate as a resource in the grid.

Activity 2: Enhance Sensing for Distribution System.

The capability to sense the state-of-health at the distribution level is being developed at multiple labs including ORNL, PNNL and LBNL. ORNL's capability focuses on reducing the size and cost, whereas PNNL and LBNL are deployment and data gathering efforts. LBNL is developing low cost micro-synchrophasers for sensing and control of the distribution system.

Activity 3: Enhance Sensing for the Transmission System.

PNNL has a strong capability in this area represented by the North American Synchrophasor Initiative (NASPI) as part of their transmission reliability program. Tools developed by the CERTS program managed by LBNL are also part of the PNNL transmission reliability program. Parallel capabilities for transmission line sensing reside INL and NETL. Additionally, NETL has capabilities in developing sensors for central stations to better respond to voltage and frequency fluctuations resulting from the variability of renewable systems.

Activity 4: Develop Data Analytic and Visualization Techniques.

Strong foundational data analytics capability for the grid exists at ANL, and applied analytics capabilities exist at PNNL and SNL, with emphasis on transmission reliability and resiliency.

Data visualization capabilities exist at multiple labs with significant capabilities at ORNL, with geo-spatial and temporal display methodology, at NREL's ESIF, with 3-D visualization and modeling tools, and at PNNL's National Visualization Analytics Center (NVAC). The NVAC is primarily operated for the Department of Homeland Security, but its' capability can also be leveraged for grid modernization data analytics and visualization.

Activity 5: Demonstrate Unified Grid-Communications Network.

A unified grid-communications network has not been demonstrated at any of the labs, although capabilities to develop it exist at multiple labs including INL, PNNL and SNL.

Both INL and PNNL have collaborated with NREL to show low latency communication capability of geographically separated devices located remotely at each lab.

3.3 System Operations, Power Flow, and Control

The MYPP anticipates increased use of distributed and wide-area control, incorporation of uncertainty, and the development and leveraging of new power electronics devices. The underlying capabilities are fundamental control theory, mathematical solvers, data analytics, and other enabling technologies such as material science for power electronics. Individual concepts and technologies such as transactive control, microgrids, probabilistic methods, and advanced wide-area controls may play a role in certain areas.

The four activities and respective technical achievements are shown in Table 3 below.

Table 3. Activities and Technical Achievements for System Operations, Power Flow, and Control

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

This area of work draws upon multiple capabilities, some of which are already embedded in the historical grid research agenda (e.g. power electronics, transmission system modeling, test ranges) and others which are being imported from specialized fields of mathematics and computation to allow historical capabilities to be extended (e.g. stochastic optimization, modern control theory). Similarly, the historical transmission grid operational paradigm and modeling capabilities must be expanded and modified to the whole grid, including distribution networks and other elements. This requirement introduces other sets of capabilities. As such, this area is too varied to be simply defined by a few leading capabilities, it is better characterized by a broader set of specialized capabilities at a wide variety of laboratories.

Activity 1, Architecture and Control Theory, is the best example of this diversity of expertise since it spans mathematics, data architectures, and application all the way to test ranges. The necessary mathematical expertise to modernize the control approaches seems to be resident primarily at LANL, the OE/NSF center at UTK and ORNL (CURENT) is providing data analytics, specific applications of new architectures is being addressed by PNNL, SNL and ORNL, while ultimate validation on large scale test ranges is addressed at INL.

Activity 2, Coordinated System Controls, is the province of fewer laboratories drawing on the leading capabilities of LBNL in the application of synchrophasor technology. Others that are important contributors here are NREL, via their capabilities in renewable integration, PNNL in microgrid dynamics and ORNL through the CURENT center.

Activity 3, Analytics and Computation for Grid Operations and Control, provides a clear example of a leading capability. The laboratory that stands out in this area is PNNL. Their expertise in transmission grid modeling is widely acknowledged and they are taking steps to bring in the expertise in control theory and stochastic optimization from other experts in this domain, specifically LANL and ANL. The PNNL-developed tool GRIDPACK is the vehicle of choice for grid operational modeling and future modeling enhancements are based upon this model.

Activity 4, Power Flow Control Device Hardware, draws upon fundamentally different capabilities, that of material sciences, device fabrication and testing as well as a modest amount of computational modeling aimed at understanding how new devices might operate in a system context. The leading lab in this area is ORNL, with a long history of device design and fabrication. Sandia could also contribute in the future. Modeling of power controls in a system falls largely to NREL and PNNL.

Overall, the following provide basic capabilities for this program element; the historical capability in transmission modeling at PNNL and its modernization with the help of key partners such as LANL and ANL, the CURENT capability at ORNL, the efforts on renewable integration and synchrophasors at LBNL, also involving NREL and PNNL, as well as the material science expertise at ORNL.

Test bed capabilities at INL as well as SNL, ORNL and NREL provide the applications testing environment that will underpin the introduction of new tools and technologies into application.

3.4. Design and Planning Tools.

The three activities in this technical area are shown in Table 4 below.

TABLE 4. ACTIVITIES AND TECHNICAL ACHIEVEMENTS FOR PLANNING AND DESIGN TOOLS

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

The National Laboratories listed as the "best" have activities on-going in all of the activity areas that are listed above.

The first laboratory in this section is ANL. ANL has a long history of developing and utilizing analytical modeling tools that are used by a broad range of clients. These include ENPEP, EMCAS, and GTMax. Among other things, these models are used to optimize power system operations. These involve sub-second ("faster than real time") dynamic models examining transient stability, hour/day operational models that examine economic dispatch, unit commitment, and stochastic analyses. Where necessary, commercial models are used or improved upon (PSLF, PLEXOS). ANL has utilized the mathematics division to further develop reliance models (EPFast, ERAP-D, EGRIP, and M2ACS) in which high performance computational capabilities are also incorporated. Many of these models/systems are being utilized by the private sector and other laboratories.

The other laboratory in this category is PNNL. PNNL has developed a number of models and analytical tools that are being utilized by a number of other laboratories and the private sector. These include GridPACK, VOLTTRON, and GridLab-D. VOLTTRON, as an applications platform is being used at many of the other laboratories. PNNL has provided the grid analytics to, among other things double the speed of the GE PSLF model and has done a considerable amount of development and deployment of graphical contingency analysis and stochastic forecasting.

The next two laboratories should be considered just slightly below the expertise and capabilities listed for the first two laboratories. SNL has a number of advanced simulation tools, such as SCEPTRE, Xyce, and Grid-PV for doing simulations on the grid. These models, as well as WSTAT, etc., are being used in the western United States by WECC, EPRI, and the California utilities.

ORNL has a number of tools that are used by utilities and the Eastern Interconnect (EI). These tools include FNET/Grideye, which monitors the "health" of the US grid and the EI in particular. ORNL, through CURENT and the University of Tennessee, has a uniquely funded partnership involving communities, a National Laboratory, and a university that is co-funded by NSF and DOE. Expertise also includes wide area dynamic modeling and data management simulation.

The next three laboratories have good modeling capabilities, but in specific areas, reflecting their backgrounds. LBNL has strong modeling skills, part of which stems from their excellent leadership for CERTS. The key model, DER-CAM, is focused on distributed energy systems and distributed markets. DER-CAM is being used at a number of the other laboratories. Other models include Modelica and VirGIL (an integrated design and planning tool. Lastly, LBNL is also working with NREL on development and utilization of a generation and transmission model.

NREL, based on its leadership as the premier renewable energy laboratory in the DOE system, is focused on models that address the insertion of renewable energy systems into the grid. For example, PSCAD is considered the standard for evaluation of PV inverter dynamics. MAFRIT is the multi-area frequency response integration tool that examines insertion of increasing percentages of renewable energy systems into the grid, which also uses the IESM (Integrated Energy Management Simulator).

LLNL has invested considerable effort and LDRD into development of advanced modeling techniques based on the strong laboratory capabilities in high performance computing (HPC). As such, they should be seen as leaders in HPC for the GMLC. However, the review of the actual programs has raised some issues that the focus of the actual model development may be a bit misplaced. This laboratory's activities in this area may benefit from a review from other laboratories that are working in the same or similar program area.

3.5. Security and Resilience

A review of the relevant parts of the MYPP and discussions with the labs active in this area serve to identify the broad set of capabilities required to execute the program. However, this technical area has some special characteristics that lead to corresponding difficulties in assessing the capabilities. In particular, the field of physical, cyber, and cyber-physical, challenges to many critical infrastructures is already a substantial program, funded by other agencies such as DHS and largely operating in the classified domain. Nonetheless, these programs have led to the creation of key capabilities that can be used in the Grid Modernization arena.

Table 5 shows the expected technical achievements in this program element.

Table 5. Activities and Technical Achievements for Security and Resilience

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

A modern grid that is secure and resilient requires that these diverse challenges be addressed holistically throughout all phases of the planning, design, and operation of the grid system. It is important to remember that, given the dependence of the power grid upon operating technologies (OT), the ability of the OT to optimally recognize and adapt to degradation of these assets is a fundamental enabler to achieving resilience. That is to say the cyber/resilience problem is one that is both an information technology and an operating technology problem and must be treated as such from a capability standpoint.

The capabilities required to execute this work is highly dependent upon staff expertise and relevant experience with relatively few, but very important, physical infrastructure capabilities - the latter being mostly about having a safe and secure environment in which to carry out full scope, real world, testing without endangering real transmission and distribution system performance for consumers. Without this past investment in deep background it is difficult for any laboratory to develop the necessary breadth of experience to provide a meaningful contribution or be a credible representative to industry in the outreach efforts. In fact, we saw internally-funded efforts at some laboratories that seemed naïve and possibly wasteful.

Not surprisingly we find the bulk of the relevant specific capability to reside at those labs already heavily invested in the WFO programs, specifically; INL, PNNL and SNL, and those with useful large-scale physical infrastructure that can be used for testing and validation of ideas; INL and ORNL. Where capability (expertise) does exist elsewhere we recommend that it be encouraged, through this program, to establish working relationships with one or more of the leading laboratories so that the program can ensure that any work is at the cutting edge.

The program does seek to invest in models and use modern optimization techniques and it does appear that there is adequate modeling and algorithmic capabilities at labs such as LANL and LLNL. What is not clear to the reviewers is the distinction between this component and those funded under the modeling program element,

Several laboratories commented that the Grid Modernization program, as a whole, appears to not address the critical issue of communications with as much depth as it does the power flow issues even though the MYPP identifies the issue as one of concern.

3.6 Institutional Support

Table 6 shows the four expected technical achievements in this program element.

Table 6. Activities and Technical Achievements for Institutional Support

Activity	Technical Achievements by 2020
Provide Technical Assistance to States and Tribal Governments	• Technical assistance to all states and tribes to inform their electricity policy decision making and accelerate state policy innovation in at least 7 states (e.g., DR programs and resources in a post-FERC order 745 world, innovate strategies to acquire all cost-effective efficiency, policy, regulations and market design that facilitate deployment of energy storage technologies. • Technical analysis results to at least 10 states that allows them to establish formal processes to review utility distribution system plans, including guidance on how to

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

All of the laboratories have activities on-going in many of the sub-areas listed above. The review did not find any laboratory that was doing nothing in this area. The following qualitative commentary allows for the categorization of the "best" and the "better" within the laboratory system. As with all of the previous sections, the categorization should not be seen as explicitly definitive, rather as a guide to the relative strengths of the laboratories in this area.

The one laboratory that stands out in the area of institutional support is LBNL. They have maintained a level of excellence in energy, environmental, and economic analysis and support over the years. This includes working with regulatory agencies, such as the California and Hawaii Public Utility Commissions, regional transmission authorities, such as CAISO and PJM, and government policy organizations, such as WECC and California Energy Commission (CEC), as well as other activities. In particular, their efforts for Activity 7.4 (conducting research on future energy regulations), should be highlighted. Lastly, the ecumenical approach LBNL provided for the leadership of CERTS can serve as a positive example for the GMLC effort.

Other laboratories can also be listed highly because of the work they are doing in this area on both a regional and national level. These are PNNL, ORNL, and BNL. Brief comments on each laboratory follow.

PNNL is providing insight and leadership to a number of organizations. They work closely with Bonneville Power Authority and WECC. In this sense they fill a critical role in examining impacts of grid modernization in the Pacific Northwest. They are also involved in working in other parts of the country, such as with CEC and PJM.

ORNL is very strong in the Southeastern United States. As such, they are involved in truly innovative projects with Southern Company, Duke Power, Tennessee Valley Authority, and the City of Chattanooga. The laboratory also works in other regions, such as with PJM.

BNL is a unique case among the laboratories. They are relatively new to programmatic activities in the overall area of grid modernization. However, they are in a unique position due to their presence as the only Northeastern National Laboratory and their presence in New York. Because of their significant interaction with New York State Energy Research and Development Authority (NYSERDA), they are substantively involved in the Re-inventing the Energy Vision (REV) for NY State program. REV activities are significantly re-vamping the electricity grid of the future as it pertains to New York and to the RGGI (Reduction of Greenhouse Gases Initiative) states. In this manner, they have involved other laboratories, including LBNL, PNNL, ANL in analyses related to proposed changes to the grid.

The previous listing enumerates the reasons for listing the four laboratories as "best." Other laboratories that should be considered "better" follow in this paragraph. With one exception, the descriptions of what these laboratories are doing to support this observation are not listed. These laboratories are ANL, SNL, INL and SRNL.

It is important to describe the activities of the NREL in this category. NREL does do substantial work in a number of areas that the other laboratories do as well. However, they do not appear to have the substantive input, which laboratories such as PNNL, ORNL, and LBNL have. What they do have is the most significant visibility on an international level. Thus, on an anecdotal level, NREL is known and has interactions with many of the countries, for example in the Asia-Pacific Economic Consortium (APEC). Many APEC energy professional and governmental organizations have an on-going set of communications with NREL.

To conclude, all of the laboratories, even those not listed here, are involved in at least some aspect of institutional support.

3.7 National Laboratory Test Beds for Distributed Energy Systems

This Phase 1 report is based on discussions with national laboratory staff; we did not verify information with industry (technology providers, utilities, etc.) or gather other external inputs from regulators and regional transmission organizations. As a result, some aspects of how national laboratory facilities can be utilized by industry have not been discussed.

However, one member of the team addressed the National Research Council as part of its meeting in support of the DOE Quadrennial Energy Review in February 2016. It was pointed out that the national laboratory system had a number of facilities that could be used – not as simulators – but as hardware to be utilized on an actual grid. The examples used in the presentation are shown in Table 7.

TABLE 7. FACILITIES FOR HIGH VOLTAGE AND HIGH POWER TESTS

Facilities
• INL: 100+ miles of transmission and distribution network on site can test various grid components such as transformers and advanced switchgear for geomagnetic disturbances, high voltage electromagnetic interference and electromagnetic pulses. • ORNL: Outdoor Powerline Conductor Accelerated Testing (PCAT) facility tests and evaluates advanced power transmission technologies with the potential to increase the capacity and the reliability of the U.S. transmission and distribution network. The technologies being characterized include new and conventional conductors, advanced sensors and controls, and power electronics. • NREL: Electrical Systems Integration Facility (ESIF) in which HECO has successfully tested advanced inverters. • SNL: The Distributed Energy Technologies Lab (DETL) can test PV components and inverters up to 1 MW, and energy storage systems also up to 1 or 2 MW in a grid-tied or islanded model • SRNL: NIST-Approved facility for very high current testing and an indoor wind turbine component test facility, which can test wind turbine drive trains and tied into a 23.9kV utility bus from a utility owned substation to support two test stands of 7.5MW and 15MW.

There are a large number of facilities within the national laboratory system that are being utilized for testing and validation of distributed generation/storage systems. DOE currently funds the operation of all of these facilities. Table 8 lists these facilities and their test capability in MWs. These facilities exist now and are operational. The capabilities of these facilities can be enhanced with additional investment in hardware and human resources. However, as funding is not currently planned and with limited involvement of industry and utility stakeholders, it is premature to highlight the possible expansion of these test facilities or development of new test facilities.

TABLE 8. EXISTING DISTRIBUTED SYSTEM TEST BEDS AT NATIONAL LABORATORIES

National Laboratory and Test Bed Name	Power Capability (MW)	Grid Connected
National Renewable Energy Laboratory (NREL) National Wind Technology Center (NWTC)	8 MW	Yes
Sandia National Laboratories (SNL) Energy Storage Test Pad (ESTP)	1 MW Islanded 2 MW Grid Connected	Yes
Idaho National Laboratory (INL) Energy Systems Lab (ESL)	1 MW	Yes
Pacific Northwest National Laboratory (PNNL) Systems Engineering Building	1 MW+	Yes
Oak Ridge National Laboratory (ORNL) Distributed Energy Control and Communication Facility (DECC)	1 MW	Yes
Argonne National Laboratory (ANL)	1 MW	No
Brookhaven National Laboratory (BNL) Northeast Solar Energy Research Center (NSERC)	1 MW	Yes
Idaho National Laboratory (INL) Test Grid**	50 MW	Yes
***The INL Test Grid is comprised of 61 miles of 138 kV transmission loop with several substations and multiple distribution feeders for a total of 111 miles of transmission and distribution, with 3 independent commercial feeders.)*		

As can be seen from Table 8, the national laboratory system possesses considerable distribution-level testing capability in a number of facilities. Their purpose is to provide technology developers and utilities with invaluable and impartial assessments of how these systems would perform in a wide range of operating environments.

DOE has sustained these test facilities over a long period of time despite, at times, limited funds. They have served industry needs with considerable success thus far. However, we note that changes in the electric industry spurred by evolving technology and changing regulatory environments require significantly greater industry engagement to direct the mission and activities of these test facilities to keep them relevant and up-to date to meet these rapidly evolving needs.

Again, we did not incorporate industry (technology providers, utilities, etc.) and other external inputs from regulators and regional transmission organizations, into this report. As a result, some aspects of how national laboratory test facilities can be utilized by industry have not been discussed. With all this existing capability, the question that must be asked is whether *additional* facilities might be useful to technology developers and utilities. Without substantive discussions with these external organizations, additional expenditure on new test beds should be held until further evaluation.

4.0 NEXT STEPS: Review Mechanisms for Addressing Industry and Regulatory Opinions, Needs, and Requirements

There was a limited amount of time to focus on the many substantive National Laboratory activities that relate to the DOE GMI. As a result, while visits were made to thirteen laboratories, the team was not able to incorporate input from industry. It is requested that this review continue into a second phase in order that necessary external input can be incorporated and the report updated. The information gained from industry, other government organizations, and end-users will be useful to DOE in allowing them to consider:

1. Nearer-term funding allocations based on external observations and innovative requirements
2. Longer-term directions based on perceptions and developments that may be transformative and disruptive

By integrating input from a variety of external sectors, DOE can be in a better position to plan for the future. This planning requires an understanding of the trajectory of future technological and societal developments. The planning would entail:

1. What human resources (scientific, engineering, and other fields) need to be nurtured and developed for future changes?
2. What new test beds, models, and computational facilities need to be developed to address these future changes?
    a. How can these facilities become better integrated with one another to maximize their benefits to the National Laboratory system as a whole?
    b. Where and when does duplication of facilities (with modifications to address different specific issues) become a cost-effective alternative?
3. What test beds and other facilities become obsolete as changes to the grid lead to their irrelevance?

The review team believes that the laboratory system's capabilities can match well to an expanded and re-calibrated program. The review team recognizes that changes proposed by external advisory groups could challenge the capabilities of the laboratories. However, by recognizing these challenges and working with industry, DOE can request funding for various enhanced capabilities in order to meet the nation's future grid requirements. This observation would need to be validated by current external partners of the laboratories. As noted in the first finding and recommendation, the DOE GMI program would be enhanced with a concerted attempt to engage industry of every type in providing guidance to the program. Below are some simple questions we believe should be directed towards industry in the proposed follow-on activity:

1. *How well are the National Laboratory system capabilities being utilized by your organization?*
2. *How can the overall capabilities available in the laboratory system address your organizations' nearer term issues?*
3. *Do the labs possess the capabilities to address innovative, transformative, and disruptive technologies?*
4. *Since everyone/no one owns the grid, parts of the GMI program are necessarily incremental due to the overall disaggregated nature of the grid. – Is this program useful to industry and others in its current form?*
5. *Do external partners expect larger scale change and prefer a more forward-looking program?*
6. *Are there industry leaders who choose not work with DOE and the labs? Why?*
7. *Conversely, are there external partners who work with the labs only because it "looks good"?*

Appendix A: Fact sheet for National Laboratory visits

Department of Energy Independent National Laboratory Grid Modernization Capability Assessment

Summary

The Department of Energy, Office of Electricity and Office of Energy Efficiency and Renewable Energy have commissioned an independent review and assessment of the National Laboratory capabilities in related to Grid Modernization initiatives and projects. The reviewers will visit all National Labs currently performing Grid Modernization tasks or receiving funds toward future work in the Grid Modernization area. The reviewers will conduct in-person interview, asking specific questions about Laboratory capabilities in order to characterize each capability and assess its strengths. *This effort is uncoupled from the GMLC Lab Call and proposal process.* A final report will be provided at the conclusion of the independent review and delivered to OE and EERE.

Reviewers:

Terry Surles, Ph.D.

Dr. Terry Surles worked as the ALD for Energy Programs at LLNL from 1998-2000. Prior to joining LLNL, Dr. Surles worked at various positions within ANL and served as General Manager for Environmental Programs from 1993-1997. Dr. Surles has also worked as Deputy Secretary for Science and Technology at Cal/EPA. In addition, Dr. Surles has worked in high-level positions at a number of research organizations including the California Energy Commission, the Pacific International Center for High Technology Research, Electric Power Research Institute, the Hawaii Natural Energy Institute and the Desert Research Institute. Dr. Terry Surles holds a Ph.D. in Analytical Chemistry from Michigan State University.

David Hill, Ph.D.

Dr. Hill is widely experienced in all aspects of nuclear energy, domestically and internationally, with special emphasis on safety, severe accidents, fuel cycle issues and proliferation. Dr. Hill held the position of Deputy for Science and Technology at Idaho National Laboratory from November 1, 2005 to December 2012. Dr. Hill is a Fellow of the American Nuclear Society and previously held senior positions at both Oak Ridge National Laboratory and Argonne National Laboratory. Dr. Hill holds a Ph.D. in Mathematical Physics from London University, Imperial College of Science and Technology

Abbas Akhil, MS

Mr. Akhil worked at SNL as a Senior Member and then Principal Member of Technical Staff from 1989 – 2011. Prior to joining SNL, he worked as a Senior Energy Conversion Engineer for the Public Service Company of New Mexico. Mr. Akhil was a Lead Author on the DOE/EPRI 2013 Electricity Storage Handbook. In addition, Mr. Akhil was extensively involved in the Hawaii Clean Energy Initiative serving as the technical lead for Lanai and

Kauai Islands and conducting the first electricity storage study for Kauai Island Utility Co-op. Mr. Akhil currently provides consulting services to industry clients on energy storage ventures and projects. In addition, Mr. Akhil has expertise in electricity utility system planning and regulation, conventional and advanced microgrids, distributed generation and PV generation. Mr. Akhil holds an MS in Industrial Engineering from New Mexico State University.

Mitigating Conflicts of Interest

All three reviewers have connections with Labs reviewed, through one or more past employments, current contracts, close prior working relationships, etc. It is of obvious value to have reviewers who are well versed in individual laboratories and the system of Laboratories as a whole, yet it does raise the question of potential conflicts of interest. Where a conflict might be presumed, mitigating measures were applied. For example, at INL, where one reviewer was previously employed as Deputy Director for Science and Technology, that reviewer did attend the visit, but did not participate in any judgments about the capabilities other than to provide a factual resource. In another case where the spouse of a reviewer was employed, that reviewer did not attend or otherwise participate in that review.

Appendix B: Schedule of National Laboratory Visits by Review Team

The team carried out site visits as follows:

National Laboratory	Dates (2015)	Review Participants
PNNL	October 28-29	Akhil, Hill and Surles
NREL	November 9-10	Akhil, Hill and Surles
INL	November 17-18	Akhil, Hill and Surles
NETL	November 19	Surles
ANL	November 20	Akhil, Hill and Surles
LBNL	November 23	Akhil, Hill and Surles
LLNL	November 24	Hill and Surles
Sandia	November 30-December 1	Akhil, Hill, and Surles
ORNL	December 3	Akhil, Hill and Surles
SLAC	December 4	Hill (Videoconference)
LANL	December 7	Akhil and Hill
SRNL/Clemson	December 9-10	Surles
BNL	December 11	Akhil and Surles

Appendix C: List of Laboratory Acronyms

PNNL	Pacific Northwest National Laboratory
NREL	National Renewable Energy Laboratory
INL	Idaho National Laboratory
NETL	National Energy Technology Laboratory
ANL	Argonne National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
SNL	Sandia National Laboratory
ORNL	Oakridge National Laboratory
SLAC	Stanford Linear Accelerator Center
LANL	Los Alamos National Laboratory
SRNL/Clemson	Savannah River National Laboratory/Clemson University
BNL	Brookhaven National Laboratory