U.S. DEPARTMENT OF ENERGY

Action Plan Addressing the Electricity Transmission System

~Draft~

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INTRODUCTION

Access to reliable, cost-effective electricity underpins nearly every aspect of modern society. It powers our nation's homes, businesses, and everything in between. Sustained energy security is critical to continued economic growth and prosperity. Yet, current trends towards clean energy resources and increased consumer participation are adding stress to an already aging electric power infrastructure. For example, the deployment of wind and solar energy on the bulk power system has introduced some level of increased variability. Likewise, the adoption of roof-top photovoltaics (PVs) and plug-in electric vehicles (PEVs) onto distribution systems has had significant impacts on transmission system operations and planning.

The complex and pervasive nature of the electric power system means that no single entity will be able to overcome the myriad challenges associated with grid modernization. As an illustration, numerous stakeholders must be involved in the permitting and siting process for transmission projects that span multiple states and broad jurisdictions. This introduces several layers of complexity on top of an already complicated system. Based on this understanding, the Department of Energy (DOE) proposes a strategy centered on engagements with various stakeholder communities. The purpose is to identify priorities, national goals, and critical research and development targets that will improve technologies and specific processes to meet the challenges of a 21st century electricity transmission system.

Due to the scale of this overall effort, this paper and its associated workshop will, together with other inputs, inform the development of a technical roadmap focused on modernizing the electricity transmission system. The workshop will also help identify the DOE's potential role in addressing key challenges in this space. The DOE is seeking input from industry, policy, and regulatory experts that will shape the development and execution of a five-year research plan. This document in its current form serves as a preparatory guide for the Transmission Workshop and the subsequent development of a detailed technology R&D roadmap.

The Grid Tech Team

The DOE recognizes the enormous complexity of modernizing the electric grid, especially with the many challenges associated with integrating technologies, policies, and systems together in the face of rapid technological and institutional changes. There are tremendous opportunities for improvements in the physical dimensions of the grid, which include generation, transmission, distribution, and end users. There are also opportunities to enhance the system dimensions of the grid, namely its interfaces, connectivity, operations, and planning. There are also innumerable challenges posed by uncertainties in technical, regulatory, policy, and market conditions at the local, state, and federal levels. Understanding that a holistic systems perspective is needed to address this complexity, the Grid Tech Team (GTT) was established to coordinate and synchronize all grid-related activities across the DOE.

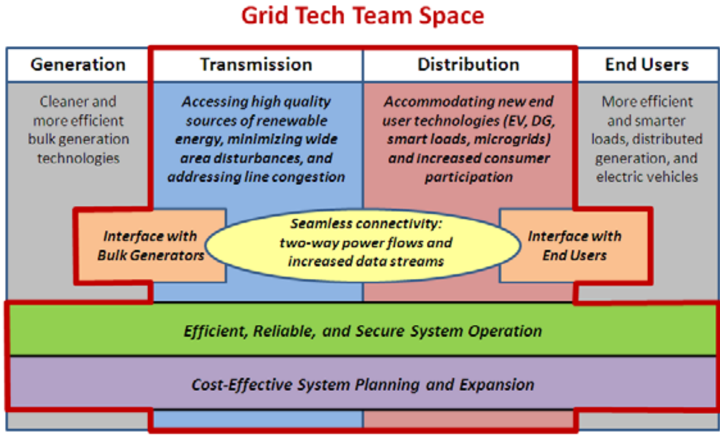

Figure 1 – Systems Perspective of Grid Challenges and the GTT Space

The DOE has many offices and programs that specialize in research and development, spanning generation through end-use technologies. These offices include (but are not limited to) Fossil Energy (FE), Electricity Delivery and Energy Reliability (OE), The Office of Science (SC), ARPA-E, and Energy Efficiency and Renewable Energy (EERE). While these offices have long been working on research projects associated with various aspects of the grid, much of the work has been focused within their respective realms. The GTT was established to implement a holistic systems approach across these efforts to coordinate activities and develop recommendations for future R&D. As shown in Figure 1, the GTT is primarily concerned with transmission, distribution, and the systems aspects of the grid. Generation and end-use technologies are outside the purview of the GTT. Nevertheless, the interfaces and connectivity of those technologies with the transmission and distribution systems requires careful consideration to ensure the efficient, reliable, and secure operation of the grid as well as cost-effective system planning and expansion.

Focus on Transmission

A modernized transmission grid must be able to accommodate the challenges associated with integrating and accessing a variety of generation resources and new technologies in a highly dynamic and changing environment. Planning and operation of the system must consider new resources, such as wind and solar, in concert with traditional forms of generation[1], emerging capabilities[2], and growing uncertainties.[3] This holistic approach is essential to maintaining reliability, resiliency, security, and cost-effectiveness across the grid. In facing these challenges, grid operators and planners are currently ensuring that these changes do not compromise reliability. Initial discussions indicate that there are two overarching areas that technology can help address:

1. Availability of Adequate Transmission Capacity
   Approaches to planning, building, and paying for new transmission facilities and/or better utilization of existing capacity to access the best resources is critical.

2. Reliably Balancing Electricity Generation and Load
   To accommodate increased variability and uncertainty, operators must ensure that there are sufficient reserves from available resources. This equates to broader system flexibility from technologies such as gas turbines, energy storage, or demand response to keep the system in balance.

[1] e.g., nuclear, coal, gas, hydro
[2] e.g., demand response, energy storage, improved visibility
[3] e.g., extreme weather events, cyber-attacks

The growing interdependency between the natural gas and electricity sectors, as well as concerns about cyber and physical security will also have significant impacts on operations and planning. Technological advances in computation, modeling, power electronics[4], materials science[5], bulk energy storage, and sensors[6] (among others) have the opportunity to transform the transmission system. There is great potential for the application and integration of such technologies to meet the challenges of a modernized grid. Harnessing these implications to achieve the power system of the future will require a holistic systems perspective.

Additionally, the transmission system must be able to accommodate the rapid changes occurring on distribution systems with the adoption of distributed energy resources[7], plug-in electric vehicles, energy storage systems, transactive residential, commercial and industrial building loads, microgrids, and other technologies. These topics, including some of the interactions of the distribution system with the transmission system, were discussed at the DOE Distribution Workshop held in September, 2012. A full summary of these discussions can be found in the draft workshop report, located on the Grid Integration Workshop website[8].

DOE has made substantial investments in technologies leading to innovations in the electric power system. Many of these innovations, however, have targeted discrete technologies without a broad, integrated perspective of the whole system. As a result, more consideration of a systems perspective is needed in order to address the numerous opportunities and challenges of integrating these different technologies into the grid. A coherent, holistically designed, and efficient transmission system that is seamlessly connected with distribution systems is needed to increase deployment of clean energy technologies and unlock efficiency potentials across the system.

Roadmap Goals

The DOE intends to work closely with various stakeholder communities to establish a clear, comprehensive vision for a 21st century transmission system as well as a corresponding DOE research and development roadmap. The GTT would like to identify opportunities and challenges for the integration of current and future technologies into the transmission system and their associated R&D needs. A critical step in the development of a DOE R&D roadmap is identifying key priorities and research directions that can help overcome these challenges and realize the opportunities of a modern transmission system. To help realize the vision, the roadmap will identify barriers to the development of a fully integrated power system, set goals, and lay out plans for the next five years.

[4] e.g., HVDC, FACTS
[5] e.g., HTSC, nano-composites
[6] e.g., weather forecasting, synchrophasors
[7] e.g., rooftop PV, fuel cells, CHP
[8] http://apps1.eere.energy.gov/grid_integration_workshop

PROCESS OVERVIEW

The GTT has developed a draft vision which describes a future electricity system and lists several key attributes of that system. Reactions to the draft vision have been positive, and it will continue to be further refined as the GTT engages with the broader stakeholder community. This vision is:

A seamless, cost-effective electricity system, from generation to end-use, capable of meeting all clean energy demands and capacity requirements, while allowing consumer participation and electricity use as desired:

- **Significant scale-up of clean energy (renewables, natural gas, nuclear, fossil with CCUS)**
- **Universal consumer participation and choice (including distributed generation, demand-side management, community storage, electrification of transportation, and energy efficiency)**
- **100% holistically designed (including regional diversity, AC-DC transmission and distribution solutions, microgrids, energy storage, and centralized-decentralized control)**
- **Accommodates two-way flows of energy and information**
- **Reliable, secure (cyber and physical), and resilient**

This vision accommodates the diversity and uncertainty of future demands and generation portfolios, recognizing the inherent regional differences in needs, goals, and available resources. The GTT supports the significant scale-up of clean energy but is also sensitive to the impacts on consumer costs and economic prosperity. To allow for 100% consumer participation and choice in every aspect of the system, including everything from using electric vehicles to producing and selling electricity, for example, the future grid will need to accommodate two-way flows of energy and information. It will also require a combination of AC-DC hybrid transmission and distribution solutions. The system must also balance between centralized and decentralized control, which applies to microgrids. Through all these changes and increasing interdependencies and complexities, the grid must remain reliable and secure against cyber and physical threats while, at the same time, it becomes much more resilient to disruptions and outages.

There are many challenges and opportunities associated with achieving the vision stated above. Through stakeholder discussions, the DOE is very focused on capturing these challenges and opportunities pertaining to the transmission system. This paper is meant to provide context for participants in the Electricity Transmission Workshop and for any other parties interested in contributing to the DOE roadmapping process. Interested parties are encouraged to: (1) review this paper and provide written comments; (2) participate in the workshop and identify key opportunities and challenges for holistic grid integration and extend or question those that are identified in this document; and (3) provide additional feedback on DOE's R&D roadmap when it is available for public comment.

Building on this paper and the inputs from workshop participants, in addition to other sources of information[9], DOE will develop a comprehensive draft roadmap for grid integration, gather further public input on the draft roadmap, and finalize the results. This includes distilling clear action items and expected outcomes. DOE decision-makers are relying on stakeholder inputs, which are utterly crucial to developing a comprehensive list of R&D priorities for the next five years.

[9] e.g., DOE documents, industry reports

SYSTEMS PERSPECTIVE

There are numerous technological advances, policy incentives, and market changes that are impacting the operations, planning, and expansion of the transmission system. The integration of these various new technologies into a legacy system and the interactions between them, all within a complex regulatory and market environment, pose many challenges as well as opportunities for synergies. For example, the increased deployment of variable energy resources (VERs) can be cost-effective and efficient if they are properly coupled with the judicious expansion of transmission lines and other assets. They could also be enhanced by operational improvements to address increased variability, new market mechanisms that value attendant ancillary services, and the development of complementary technologies.

Ultimately, the electric power system will need to improve its: (1) visibility of grid and ability to forecast weather conditions across space and time; (2) understanding of the status of the grid and how to respond to system events and variability; and (3) flexibility of the grid to quickly respond (or initiate action) appropriately to events and dynamic conditions. These three characteristics define the grid's ability to adapt and respond to changes and uncertainties. Due to the complex and interconnected nature of the system, grid modernization will require many innovations and advancements to occur simultaneously and successfully.

The GTT proposes a strategic framework (Figure 2) that organizes technology options into three interrelated domains: informational, knowledge, and physical. These represent the systems nature of the grid. Each of these domains corresponds to a strategic focus area that aims to increase the visibility, understanding, and flexibility of the electric power system. This framework will help guide discussions during the Transmission Workshop to inform specific R&D activities and initiatives needed to modernize the transmission system. Furthermore, in addition to the interconnectedness of these three technical focus areas, there are many institutional factors (markets, regulations, policies, standards, etc.) that influence the success of R&D activities. Consideration of the numerous institutional challenges associated with specific technologies must be recognized in addressing the activities in the three strategic focus areas.

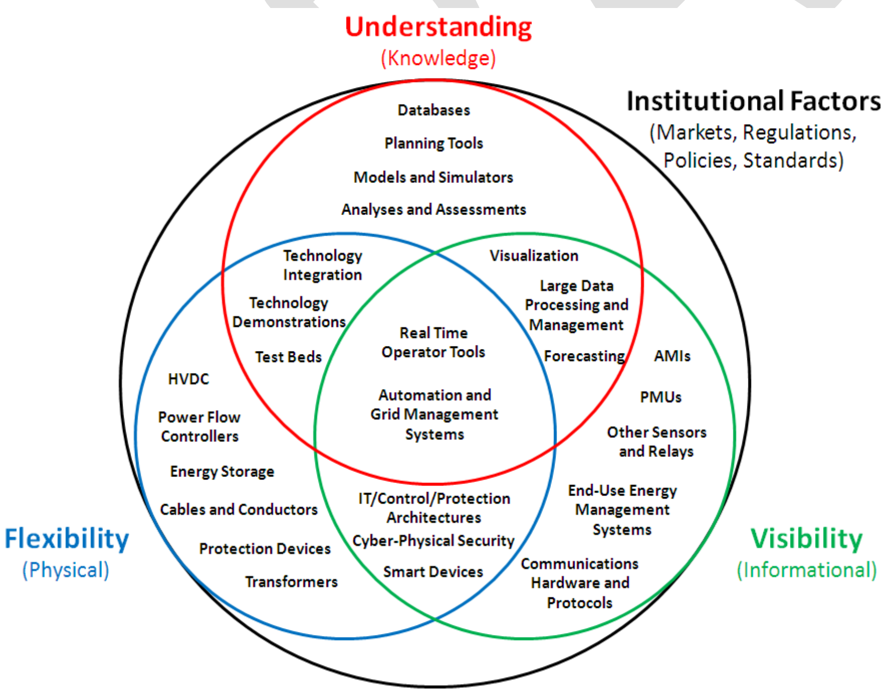

Figure 2 – Strategic Framework for Grid Modernization

Grid Visibility

Grid visibility focuses on the challenges and technology opportunities in the informational domain of the power system. These technologies and issues span the measurement[10] and the transfer of data/information[11]. It also includes the processing and handling of data to improve system understanding[12], which will help with planning and operations. Finally, the interdependencies between information streams and the physical system[13] will be critically important to ensure system security, reliability, and resiliency as the power system transforms.

Key Challenges & Opportunities

The lack of situational awareness of grid conditions has been a significant contributor to large-scale power disruptions and outages. Notable examples include the Northeast blackout in 2003 and the Southern California blackout in 2011. Information that is important to the safe and resilient operation of the transmission system spans multiple scales in space[14] and time (from microseconds to days). Recent deployment of variable generation and end-use technologies has increased visibility requirements. This entails gathering information from across larger distances, deeper into the distribution system, and at a much faster rate. Advances in sensor technologies[15] enable observation of grid conditions with significantly higher spatial and temporal resolutions needed to handle increased variability and changing system dynamics. Next-generation sensors may also be needed to provide information on the condition of grid assets or new relays that can adapt to changing conditions for improved resiliency.

With the explosion of data coming from the deployment of PMUs, AMIs and other sensors, large data management and processing have become critical issues. Some data will be needed for short periods of time (hours to days) while other types may be needed for much longer (months to years). Methods and mechanisms to filter, aggregate, distill, and store essential information will be needed in the near future. The growing importance of sensor data to the operation of the transmission system will require advances in communication architectures, hardware, and protocols to meet the accuracy, latency, and cyber security requirements of potential grid applications. Additionally, cyber attacks on grid management systems[16] and the impacts on reliability are areas that are not well understood.

Ultimately, data should inform a system operator or an automated application to perform a control action. System operators exist in a world where they must make decisions quickly in order to maintain system reliability. There needs to be significant improvements in visualization and operator tools that will translate the data into actionable intelligence. One example is weather forecasting to support the integration of VERs. Current installed systems provide either a jumbled display of forecast outputs or a spectrum of probabilities, both of which deviate from simple, deterministic options that are familiar to operators.

[10] e.g., sensors, relays, AMIs, PMUs
[11] e.g., communication protocols, hardware, end-use energy management systems
[12] e.g., visualizations, large data management, weather/load forecasting
[13] e.g., IT/control architectures, cyber-physical security
[14] e.g., facilities, service areas, regions, interconnections
[15] e.g., PMUs and AMIs
[16] e.g., SCADA, DMS, EMS

Questions for Consideration

What challenges in the informational domain[17] impede the improvement of visibility and controllability of the grid? What are the characteristics and functionalities needed to address the challenges identified and at the same time ensure a safe, reliable, cost-effective system? What are the metrics? More specifically:

- To ensure reliability, what are the requirements for the measurement and communication of data associated with the various technologies being integrated into the grid?
- Are there fundamental improvements in communication hardware and protocols necessary to ensure data is accurate, timely, and secure?
- How can forecast information be presented in a clear way while maintaining some of the probabilistic nature of the information?
- What technology advances are needed to ensure seamless connectivity between component technologies, transmission operators, and end-users?
- How do we ensure that the information, control, and protection architectures are well integrated and aligned?
- If the information is wrong and/or communication fails, what will be the impact to the power system? What can be done to mitigate adverse impacts?

Grid Understanding

Grid understanding focuses on the challenges and technology opportunities in the knowledge domain of the power system. Models and simulation tools need to better understand the impact of technologies interacting both with one another as well as with the power system at large. Improving these models requires knowledge of the physical and performance characteristics of the technologies operating in various conditions[18]. It also requires accurate databases to conduct simulations that are realistic and credible. Improved models, tools, and databases will support real-time operations and automated controls. Additionally, analyses and planning tools that build off these technologies can help explore what is technically possible and will inform the value proposition of upgrades and investments.

Key Challenges & Opportunities

Increased visibility is only of value if it can improve system understanding. Therefore, data captured from the system must be converted into useful information that supports knowledge and awareness. To improve controls and future applications, the system needs operational and planning tools that can derive actionable intelligence from the full range of data available across multiple scales in space[19] and time (from microseconds to decades). It may be possible to link existing tools that were

[17] e.g., sensors and relays, AMIs, PMUs, end-use energy management systems, communications hardware and protocols
[18] e.g., demonstrations, integration efforts, test beds
[19] e.g., facility, feeder, service area, state, region, interconnections

originally designed for a subset of the data scales. This may enable comprehensive, system-wide situational awareness and control. Alternatively, it may be more practical to develop new grid simulator capabilities to improve broader planning and more efficient operations. Lastly, fundamental advances in computational methods and algorithms are needed to process the large data streams. This will also enable "faster-than-real-time" applications that can address uncertainty over wide areas.

There are currently many models for emerging and deployed technologies that are being used in planning tools, operational tools, and simulations. Due to the dynamic nature of new technologies interacting with the power system, existing models may no longer be accurate enough to reproduce what was observed, let alone predict what will happen. An effort to develop accurate and valid tools is needed to ensure that system operators and planners will have confidence in model outputs. New models and simulation tools can be used to create realistic environments for operator training.

The enhancement and integration of databases must play a key role in a modernized transmission system. Numerous databases are utilized to support real-time operations, day ahead planning, power system analyses, and long-term regional, interconnection-wide, and national grid planning. Multiple entities have their own databases for various applications despite the interconnectivity between them. Furthermore, the information in these databases are neither comprehensive nor are they in a standardized format that is broadly applicable[20]. Tools, analyses, and decisions that rely on these databases will be hindered by the quality and the completeness of the data. Although tremendous efforts have been made to develop robust datasets for interconnection-wide studies, more work in this area is certainly needed.

Questions for Consideration

What challenges in the knowledge domain[21] impede enhanced understanding and controllability of the grid? What are the characteristics and functionalities needed to address the identified challenges? What are the metrics? More specifically:

- What are the data priorities and requirements that are needed for databases? What are the physical characteristics that capture the dynamics of the system for today and tomorrow?
- What additional databases, such as load, weather, technology deployment, distribution system layout, and others, will be needed to support operations and planning?
- How do we ensure that models of various technologies are accurate and that simulations produce credible results?
- How do we develop tools and simulators that can span the multiple scales and various dimensions of the power system?
- What advances in mathematics and computation (e.g., stochastics, parallel processing) can be leveraged in the development of tools?
- How do we ensure that the large amounts of data from increased visibility can be accessed in real time without overwhelming monitoring tools and detracting from grid operations?

[20] e.g., naming convention, physical parameters, performance metrics
[21] e.g., databases, planning tools, models and simulators, analyses and assessments

Grid Flexibility

Grid flexibility focuses on the challenges and technology opportunities in the physical domain of the power system. The technologies and issues associated with this aspect of the grid include transformers, cable and conductors, switches, and protection devices that directly interact with the electricity in the power system. It also includes power electronic systems[22] and energy storage devices[23] that can improve controls, asset utilization, and operational efficiency of the system. These technologies, along with generators[24] and loads[25] can also provide flexibility through ancillary services[26] to support grid operations. Finally, new system architectures and associated protection and control schemes[27] can also increase system flexibility.

Key Challenges & Opportunities

VERs pose significant challenges to modernizing the grid. The inclusion of more VERs on the bulk transmission system (as well as distribution systems) is introducing increased variability, reduced inertia, and faster dynamics in the power system. In order to meet reliability requirements, reserves and ancillary services must also increase. These can be provided by multiple sources, including new controls on traditional generation sources, inverters in solar and wind farms, energy storage devices, FACTS[28] devices, and even loads. How to properly coordinate and control these resources is not well understood. Similarly, the large-scale impacts that VERs will have on the system also remains uncertain. Recent advances in wide band-gap semiconductors present significant opportunities for new power electronic solutions that can improve reliability and resiliency.

Another key challenge is overcoming geography and variability. High-quality renewable resources are typically located far from load centers and may not be well correlated with peak demand. This causes underutilization of transmission assets in some areas, congestion in others, and large fluctuations and differences in locational marginal prices. Technologies that can optimize asset utilization and increase operational efficiencies have the potential to decrease overall system costs. Advances made in HVDC, power flow controllers, energy storage devices, cable and conductors, and control concepts[29] require further investigation to demonstrate their efficacy.

As the grid evolves to accommodate all the changes on the transmission and distribution systems, new system architectures, controls, and protection schemes will be needed. The next generation of energy management systems and operator tools that can connect all these various technologies[30] is a critical area that requires significant attention.

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[22] e.g., HVDC, FACTS devices, inverters, solid state transformers
[23] e.g., flywheels, CAES, batteries, thermal, pumped-hydro
[24] e.g., fast ramping resources, wind curtailment
[25] e.g., demand response, EV charging
[26] e.g., VAR support, voltage control, frequency response, regulation, ramping, energy shifting
[27] e.g., microgrids, next generation EMS, intentional islanding, dynamic reconfiguration
[28] Flexible AC Transmission Systems
[29] e.g., dynamic reconfiguration
[30] e.g., visibility from new sensors, understanding from new models, and flexibility from new controllers

Questions for Consideration

What challenges in the physical domain[31] impede the increase of flexibility and controllability of the grid? What are the characteristics and functionalities needed to address the identified challenges while ensuring a safe, reliable, and cost-effective system? What are the metrics? More specifically:

- How do you characterize, benchmark, and quantify the amount of flexibility needed to support the integration of new technologies?
- What changes in the system architecture will be needed to improve resiliency? What is the role of hierarchical distributed controls?
- What new functionalities and capabilities, including protection, will be needed in the energy management system of the future?
- How do energy storage devices, FACTS devices, demand response, and other options for ancillary services compete with one another? How can these approaches be valued for making operational decisions?
- What control algorithms are needed to prioritize, coordinate, and aggregate resources to form virtual power plants or microgrids?
- What efficiency gains and performance improvements can be obtained from utilizing more HVDC lines? What is the value of being able to route transmission lines underground?

Institutional Factors

Although it is outside the scope of the Transmission Workshop, it is important to recognize that institutional factors are an integral part of the three technical focus areas described in the previous sections. The success of a particular technology option can be impeded by market, policy, or regulatory conditions. Policy incentives, market changes, or regulatory rules can completely alter the viability of business models. Public utility commissioners and regulators must also be empowered to make educated decisions on the adoption of new technologies including cost allocations and equity of payments. Additionally, the lack of appropriate and universal standards can prevent technology interoperability or present unnecessary burdens to vendors.

Institutional factors underpin most of the key challenges and opportunities highlighted in this paper. For example, increased situational awareness requires collaboration, cooperation, and data transparency among grid operators and planners. Concerns over regulatory fines and economically sensitive information impede the ability to share important information. Privacy of end-user data and the security implications of shared operational data are also difficult challenges. Furthermore, the successful development of a comprehensive database will require consensus to standardize naming conventions and other data fields. It will also require vested cooperation from all participating entities to maintain and update the data.

[31] e.g., component technologies, inverters, power flow controllers, transformers, cable and conductors, protection devices, etc.

Markets, policies, and regulations play a crucial role in the system's flexibility. Non-technical solutions already exist to increase the system's capacity to handle variability and uncertainty. There are, however, ways for these non-technical conditions to improve. For example, it may be possible to develop faster markets (e.g., 5-minutes) to enable more frequent adjustments of existing generation assets. Accessing more resources by sharing reserves between balancing areas is another option that has been readily utilized and can be expanded. Market changes that value and allow non-traditional technologies[32] to provide ancillary services is another institutional factor that is actively being explored.

POINT OF DEPARTURE

Approaching the Workshop

The purpose of this DOE Action Plan is to continue the process of developing a comprehensive research roadmap for grid integration at the transmission level. This process involves engaging key stakeholders to identify challenges and opportunities, R&D needs, and priorities for action spanning the near-, mid-, and long-term.

The Transmission Workshop is a critical step in the development of a roadmap that accurately targets these key challenges and opportunities. The advice and proposals gleaned from the workshop will assist the DOE in making decisions on how to refine and implement a research roadmap, which will likely be released in a draft form for further inputs from interested stakeholders. The results of the workshop and the road mapping process will help reinforce the broader efforts of the Grid Tech Team and enable DOE to support research and development of critical solutions to achieve a 21st century electric power system.

[32] e.g., PEV charging, DR, storage