National Electric Delivery Technologies Roadmap

Transforming the Grid to Revolutionize Electric Power in North America

January 2004

United States Department of Energy
Office of Electric Transmission and Distribution

NATIONAL ELECTRIC DELIVERY TECHNOLOGIES ROADMAP

— DESIGNING "GRID 2030" ARCHITECTURE —
— DEVELOPING CRITICAL TECHNOLOGIES —
— ACCELERATING ACCEPTANCE OF ADVANCED TECHNOLOGIES —
— STRENGTHENING ELECTRIC MARKETS —
— BUILDING PARTNERSHIPS —

Based on the Results of the
National Electric Delivery Technologies Roadmap Workshop
Washington, DC

July 8-9, 2003

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United States Department of Energy
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Creating the Future

The electric grid is an essential part of American life. For a variety of reasons, America has been under-investing in the electric grid and in research and development to create advanced electric delivery technologies. Most of the existing infrastructure of wires, transformers, substations, and switchyards has been in use for 25 years, or more. The aging of this infrastructure, and the increasing requirements placed on it, have contributed to market inefficiencies, electricity congestion, and reduced reliability in several regions. These conditions could lead to higher prices, more outages, decreased power quality, and less efficient use of energy and financial resources. Jobs, environmental protection, public health and safety, and national security are at risk.

This Roadmap provides a framework for all of the stakeholders that comprise the electric industry to work together to achieve common aims.

In recognition of this, President Bush has asked the U.S. Department of Energy to lead a national effort to modernize and expand the electric grid. The newly formed Office of Electric Transmission and Distribution has been given that assignment. The assignment involves research and development, technology transfer, modeling and data analysis, and policy analysis. Getting the job done will involve time, investment, and unprecedented levels of cooperation among the electric power industry's many and diverse stakeholders. **Neither government nor industry can get the job done alone.**

This Roadmap contains an **action agenda** for moving forward. We are grateful to the 250 electric industry professionals – and the organizations they represent – who participated in the *National Electric System Vision Meeting* on April 2 and 3, 2003, and the *National Electric Delivery Technologies Roadmap Workshop* on July 8 and 9, 2003. On August 14, 2003, a widespread blackout in the Great Lakes region affected 50 million people in 8 states and 2 Canadian provinces. The ideas and priorities contained in this Roadmap reflect the contributions made by the workshops, as well as suggestions provided afterward, including some regarding the blackout.

This Roadmap provides a framework for all of the stakeholders that comprise the electric industry to work together to achieve common aims. We plan to use it to guide our multi-year program planning and to help strengthen existing partnerships and promote new ones. By addressing national problems in a more coordinated manner we hope to be able to address certain risks and uncertainties that interfere with effective electricity planning and market operations. In this way, together, we can create a more prosperous, efficient, clean, and secure electricity future for America.

We consider this Roadmap to be "version 1.0" of an ongoing process. Your continuing participation and support is vital as we "move out" to leverage resources and maintain a "critical mass" of enthusiasm and commitment. Additional suggestions are always welcome.

Jimmy Glotfelty, Director
Office of Electric Transmission and
Distribution, U.S. Department of Energy

Executive Summary

On February 6, 2003, President Bush underscored a point raised in several key energy policy documents[1]: America needs to "…modernize our electric delivery systems…it is needed for economic security…it is needed for national security."

Recognizing that the federal government cannot carry out the President's electricity policies alone, the U.S. Department of Energy convened two meetings with electric industry stakeholders to discuss what needs to be done to modernize America's electric delivery systems:

> **Vision of the Future Electric System**
>
> "Grid 2030" energizes a competitive North American marketplace for electricity. It connects everyone to abundant, affordable, clean, efficient, and reliable electric power anytime, anywhere. It provides the best and most secure electric services available in the world.

- On April 2 and 3, 2003, more than 60 senior executives and policy makers attended the *National Electric System Vision Meeting* to develop a common "vision" of the future for electric delivery in North America.[2]

- On July 8 and 9, 2003, almost 200 electricity professionals attended the *National Electric Delivery Technologies Roadmap Workshop* to build consensus on the needs and priorities for achieving the vision.[3]

This Roadmap – which is based on ideas raised at the workshop and afterward – outlines the key issues and challenges for modernizing the grid and suggests paths that government and industry can take – both separately and together – to build America's future electric delivery system. In addition to the items discussed on the following page, grid modernization development will need to take many ideas into consideration, including the impact new technologies will have on the marketplace and the costs versus benefits of all alternative or possible scenarios.

1 The *Report of the National Energy Policy Development Group* (May 2001), the *National Transmission Grid Study* (May 2002), and the *Report of the Secretary's Electricity Advisory Board* (September 2002). These documents can be downloaded from www.energy.gov.
2 The Proceedings of the *National Electric System Vision Meeting* and the vision document, "Grid 2030 – A *National Vision for Electricity's Second 100 Years*", can be downloaded from http://www.energetics.com/meetings/electric/pdfs/electric_vision.pdf.
3 The Proceedings of the *National Electric Delivery Technologies Roadmap Workshop* can be downloaded from http://www.energetics.com/meetings/electric/pdfs/electric_vision.pdf.

Action Agenda

1. Design the "Grid 2030" Architecture.

- The grid is a legacy network that was not designed to support wholesale or competitive retail markets for the sale of electric power. As we invest in grid modernization and create compatible electric market designs, we need to ensure that the architecture of the future grid is both flexible and robust. Flexibility is necessary to accommodate variations in technology choices, resource mixes, market rules, customer services, and regional characteristics. Robustness is necessary to ensure that the grid of the future is at least as reliable as today's, if not more so. Mechanisms need to be built into the design that decreases substantially the possibility of cascading regional outages, such as the one that occurred in August 2003. Cost is another critical factor to properly account for in the design to ensure that the grid of the future provides affordable as well as reliable power.

Under the auspices of this Roadmap, a new public-private effort is needed to develop and test alternative design concepts for the architecture of the vision for "Grid 2030."

- It is premature to commit to a single design for the architecture of the "Grid 2030" vision. There are too many unknowns with regard to the ultimate requirements of the future grid, and the expected progress of research and development. For example, as discussed in the vision document, having the ability to move bulk power across the country could be an extremely valuable capability. However, there is no compelling reason to determine today whether this capability should be provided by dedicated power lines, networks of power lines, or combinations of both. Specific "down-select" decisions of this type – ones that involve choosing from among alternative technology pathways – can wait until the relative merits of the alternatives are more thoroughly understood.

- Under the auspices of this Roadmap, a new public-private effort is needed to develop and test alternative design concepts for the architecture of the vision for "Grid 2030." This would involve the development of two or more design concepts for each of the three major "Grid 2030" elements: national electricity backbone, regional interconnections, and local distribution. Modeling and analysis to identify the relative costs and benefits of alternative grid architectures is needed to identify the most promising technology pathways. Research, development, field testing, and demonstrations of the alternative design concepts need to be carried out to ensure both technical and economic feasibility.

This design effort needs to proceed for the next five years before industry, government, and market forces determine the most promising architecture of the "Grid 2030" system. Designers need to build a certain amount of flexibility into the architecture so that it will be able to address changing markets, policies, and technologies.

2. Develop "Critical" Technologies.

- There is a small portfolio of technologies that crosscut the electric transmission and distribution system which will be needed no matter what architecture evolves for the grid of the future. New components will need to be transitioned into the system and made to properly function with the existing grid and new architecture. These so-called "critical" technologies include advanced conductors; high temperature superconducting materials and equipment; large- and small-scale electric storage devices; distributed sensors, intelligence, smart controls, and distributed energy resources; and power electronics. Public-private efforts to develop these technologies need to be accelerated and expanded.

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- Specifically, **advanced conductors** are needed that are lighter weight, lower cost, and have higher current densities. **High temperature superconducting (HTS)** materials are needed that have low price-performance ratios compared to conventional conductors (such as copper) and that can be produced in sufficiently high volumes to meet the needs not only for power cables, but also for other grid electrical equipment including transformers, generators, synchronous condensers, fault current limiters, and other devices. Large- and small-scale **electric storage** devices are needed that have lower costs and are more durable and reliable. Information technologies for **distributed intelligence, sensors, smart systems, controls, and distributed energy resources** need to be designed, field tested, standardized, and integrated with market operations of electric transmission and distribution systems, and customer operations. Lower cost and more durable and reliable **power electronics** devices are needed for controlling bulk power flows on the transmission system and for managing electric distribution and customer operations. The integration of these components into the system, and the management of the components during times of emergency is necessary in order to achieve reliability while operating the grid near system limits.

3. Accelerate Acceptance of Advanced Technologies.

- Even if progress is made in developing critical technologies, there is the likelihood that they will not be widely deployed unless ways are found to speed up their acceptance in the marketplace. The technology transfer process by which advanced electric delivery technologies move from the laboratory and into the "tool kit" of transmission and distribution system planners and operators is too slow. Part of the problem is that the useful economic lives of embedded electric assets are 25 years, or more. In addition, the embedded "inertia" of legacy systems and business practices is hard to overcome. For example, today's regulatory framework fosters a business environment that is known to discourage risk taking and entrepreneurial activities. Ways need to be found for equipment manufacturers, and other technology developers and suppliers to the electric industry, to support more collaborative product development and deployment, and to reduce restrictions to the sharing of information when proprietary issues are not involved.

  While the Federal Energy Regulatory Commission is the primary regulatory body for the nation's interstate transmission system, the distribution system is operated by investor-owned utilities, municipalities, or cooperatives and regulated by the various state public utility commissions. Effort is needed to encourage federal and state regulators to work together to identify promising grid technologies and support more rapid testing and implementation. Regulatory and market-based mechanisms need to be identified to encourage innovation and prudent risk sharing.

More effective regulations and business practices are needed to spur innovation and increase testing of new technologies and techniques.

- Clearly, technology transfer practices must be improved. More effective regulations and business practices are needed to spur innovation and increase testing of new technologies and techniques. A federal role in this endeavor is crucial for facilitating partnerships and spearheading long-term, high-risk research. A key role for the states involves providing greater focus in their research and development programs on grid and other technologies that produce greater electric reliability, better electric services, or lower electric costs. Investors need to become better educated about the risk-reward profiles of grid modernization technologies. Technology developers need to ensure that they provide the proper information to decision makers and the investment community. Electric transmission and distribution planners and operators need to employ business practices that more aggressively include consideration of new concepts and approaches.

Effort is needed to assess market operations and evaluate the relative merits of alternative proposals for bringing greater certainty and lower financial risks to electric market transactions.

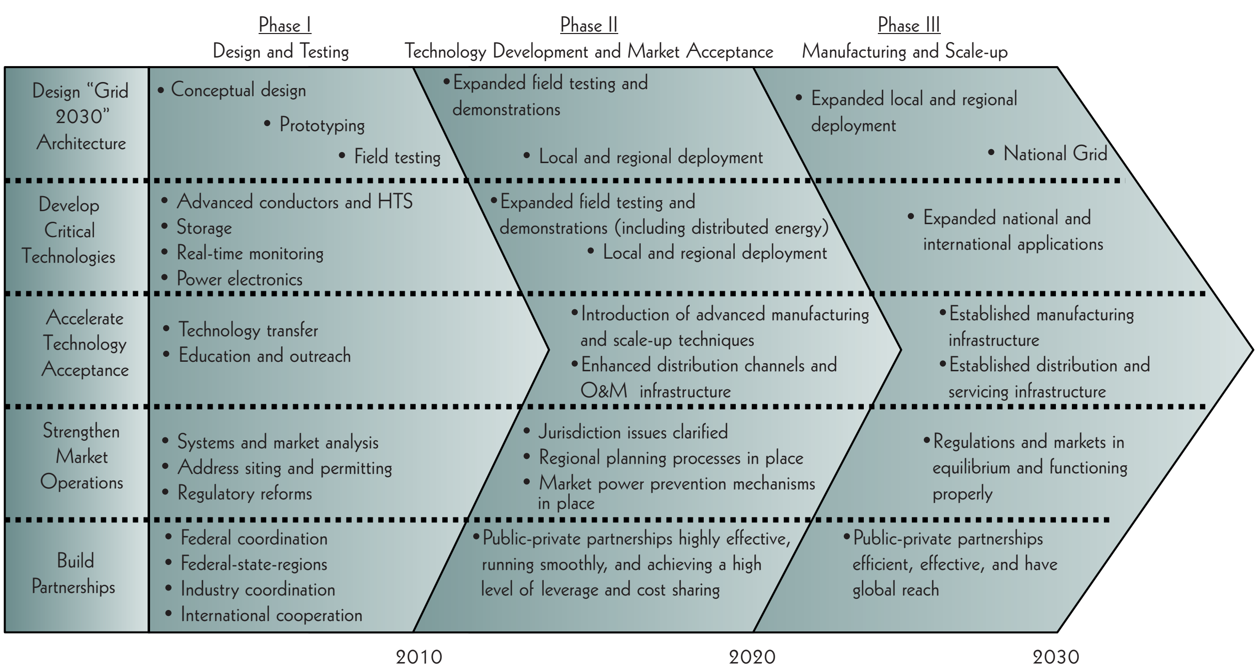
4. Strengthen Electric Market Operations.

- The regulatory frameworks governing the electric delivery system are not consistently producing socially beneficial results in all regions of the country. As a result, some electric markets are not functioning well enough for grid modernization to occur properly.

  For example, even if cost-effective critical technologies gain market acceptance, investment capital will not necessarily flow in their direction, siting and permitting will not automatically be more streamlined, and cost recovery will not necessarily be more certain. In addition, unintended consequences from previous agreements from consenting institutions has caused federal-state jurisdiction to inhibit certain projects from moving forward.

- Effort is needed to assess market operations and evaluate the relative merits of alternative proposals for bringing greater certainty and lower financial risks to electric market transactions. Modeling and analysis is needed to identify ways for reducing or eliminating barriers to greater economic efficiency, competition, and market forces.

Exhibit 1. Overview of the National Roadmap for Modernizing America's Electric Delivery System



5. Build Public-Private Partnerships.

- The resources needed to complete the job of modernizing the electric grid are vast. This is a big job that affects every region of the country and every segment of the industry. Government and industry will need to coordinate research and development efforts to make progress.

  To apply leverage, actions to modernize the grid need to proceed through multi-year, public-private partnership(s). The amount of coordination is enormous. The federal government needs to provide leadership to facilitate these partnerships and make sure that focus is kept on long-term as well as near-term objectives.

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- To make progress, the U.S. Department of Energy needs to re-invigorate existing and create new public-private partnerships. Key partners include:

  - Electric and gas utilities including regional transmission organizations and independent system operators
  - International agencies and trading partners (particularly Canada and Mexico but also in other industrialized nations)
  - Other federal agencies including the Departments of Defense, Commerce, Agriculture, and Homeland Security, and the Federal Energy Regulatory Commission
  - Regional, state, and local government agencies
  - Electric equipment and information technology manufacturers and systems developers
  - National laboratories, universities, and research institutions
  - Public interest organizations, environmental groups, and labor unions
  - Investors

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1 Introduction and Overview of the Roadmap

The significance of electricity to the U.S. economy is enormous. The total value of electric generation and distribution assets in America is estimated to exceed $800 billion. America's annual "electric bill" exceeds $240 billion. Electricity's significance includes the protection of the economy, environment, public health and safety, and national security. Blackouts serve as a powerful reminder of the critical role electricity plays in people's everyday lives. Billions of dollars were lost during the August 14, 2003, blackout. Public health and safety were jeopardized. America cannot afford to let its electric system degrade and potentially fall short of meeting the economy's growing needs for electric power[4].

The significance of electricity to the U.S. economy is enormous ... its significance includes the protection of the economy, environment, public health and safety, and national security.

In fact, for a variety of reasons, electricity has steadily become one of the preferred forms of energy in America. For example, in 1940, making electricity accounted for about 10% of total U.S. energy consumption. Today it accounts for about 40%. Most energy forecasters think an even larger percentage of U.S. primary energy resources will go into making electricity in the future. After all, electricity is the only form of energy capable of running computers and telecommunications systems, the very lifeblood of the 21st century "information age." The effects of the August 14, 2003, blackout underscore electricity's importance to the economy.

For these reasons, the Bush Administration is committed to keeping America's electricity sector strong. The *Report of the Energy Policy Development Group*, the Bush Administration's National Energy Policy (May 2001), contains 13 recommendations for strengthening the electric delivery system. The *National Transmission Grid Study* (May 2002) contains 51 recommendations. The *Transmission Grid Solutions Report* (September 2002) of the Secretary's Electricity Advisory Board provides further suggestions for improving the physical and financial state of the nation's electric infrastructure. The President's Council of Advisors on Science and

August 14, 2003, Blackout

1 Canadian Province affected

3 deaths attributed to the blackout

8 U.S. states affected

12 airports partially or completely closed

259 power plants shut down

700 flights cancelled nationwide

9,266 square miles affected

61,800 MW of power lost

1.5 million Cleveland residents without water

50 million people affected

$4.5-12 billion in lost economic activity

[4] The Interim Report: Causes of the August 14th Blackout in the United States and Canada can be downloaded from http://electricity.doe.gov/news/blackout.cfm?section=news&level2=blackout.

Technology's *Report on Energy Efficiency* (April 2003) calls for "…the Nation to proceed with the development of the 21st Century electricity grid."

Some of the aims of this Roadmap are to provide an organizing framework to address the recommendations in these reports, to implement the President's electricity policy priorities, and to include input from stakeholders. The Roadmap can also serve as a management tool for measuring progress and ensuring accountability.

A number of studies have been done over the past decades that call attention to the need to modernize America's electric grid. For example:

- In **July 1974**, the Federal Power Commission published the *National Power Survey – Advisory Committee Report on Research and Development for the Electric Utility Industry*.
- In **January 1980**, the U.S. Department of Energy's Office of Utility Systems published the *National Power Grid Study*.
- In **May 1986**, the National Research Council of the National Academy of Sciences published *Issues in Electric Energy Systems – a Review of the DOE R&D Program*.

Each of these documents contained recommendations for accelerating research and development and dedicating more resources to grid modernization and expansion. This Roadmap can be reviewed every year or two to determine the pace of progress toward completion of key actions. It provides a mechanism that was not available with the other studies to help ensure that actions are taken and that results are produced.

Vision of the Future Electric System

"Grid 2030" energizes a competitive North American marketplace for electricity. It connects everyone to abundant, affordable, clean, efficient, and reliable electric power anytime, anywhere. It provides the best and most secure electric services available in the world.

National Electric Systems Vision Meeting

The *National Electric Systems Vision Meeting* was held on April 2-3, 2003, in Washington, DC.[5] Participants included more than 60 senior business executives and public policy leaders from federal, state, and regional agencies. The U.S. Department of Energy initiated the meeting to identify a common vision for the future electricity grid.

[5] The Proceedings of the *National Electric System Vision Meeting* can be downloaded from www.energetics.com/electric.html.

Major findings and conclusions from the vision meeting include:

- America's electric system is aging and congested—substantial investment will be needed over the next several decades to modernize it.
- The revolution in information technologies that has transformed other industries has yet to fully take hold in the electric power business.
- Greater use of distributed intelligence, smart controls, and distributed energy resources, including demand response, will play an increasing role in addressing the needs of the electric grid.
- Unprecedented levels of uncertainty about future regulatory and market conditions have raised concerns about the ability of the industry to attract sufficient capital to accomplish grid modernization properly.
- The regulatory framework governing electric power markets is under stress and needs to be strengthened. For example, the voluntary rules among the utilities for ensuring grid reliability need to be made mandatory.
- Siting and permitting of new electric facilities needs to be streamlined.
- The "technology readiness" of certain electric systems needs to be accelerated, including high temperature superconducting materials and applications, advanced conductors, electric storage, multiplicity of field sensors, distributed intelligence and smart power systems, and power electronics.

Uncertainty about future regulatory and market conditions have raised concerns about the ability of the industry to attract sufficient capital to accomplish grid modernization properly.

The vision document, "Grid 2030 – A National Vision of Electricity's Second 100 Years," outlines the characteristics of a modernized electric grid and explains that the transition process could take several decades to achieve.[6]

National Electric Delivery Technologies Roadmap Workshop

The *National Electric Delivery Technologies Roadmap Workshop* took place on July 8-9, 2003, in Washington, DC. Approximately 200 technical experts and industry practitioners from public and private organizations participated in the meeting (a list of the participating organizations is located in Appendix B).

[6] The vision document can be downloaded from www.energetics.com/electric.html.

During the workshop, participants divided into eight breakout sessions to discuss four specific topics related to the vision:

- National Electricity Backbone
- Regional Interconnections
- Local Distribution
- Regulatory Framework for Electric Market Operations

The purpose of the Roadmap workshop was to identify targets, technical challenges, and research, development, and demonstration activities to achieve the vision.

There are significant technical challenges to overcome to achieve the targets and accomplish the vision.

Targets. There are major milestones to achieve between now and 2030 for the vision to be accomplished. The architecture of the national electricity backbone needs to be developed and technologies for accomplishing cost-effective, long-distance power exchanges need to be identified, tested, and demonstrated. Upgrade of existing and construction of new transmission systems needs to proceed for regional interconnections to reduce congestion and improve wholesale market operations. More rapid integration of distributed energy technologies and smart systems for optimizing customer and local distribution system operations needs to occur. Uncertainty about future regulations and market conditions needs to be reduced by settling jurisdictional problems to attract capital and foster a stronger financial climate for the electric power sector.

Technical Challenges. There are significant technical challenges to overcome to achieve the targets and accomplish the vision. Progress is particularly needed in the following areas:

- Advanced conductors (for long-distance transmission of electricity) and superconducting cables (for short- and long-distance applications)
- Electricity storage to lower costs and improve reliability and performance
- Distributed intelligence, smart systems, controls, and distributed energy resources to integrate electric system operations from end-users to generators and optimize the flow of both information and electric power – in real time, and give customers a greater opportunity for involvement in electric markets

- Electricity market modeling and analysis and in educating electricity policy officials in identifying structural improvements to traditional utility regulations and opportunities for greater reliance on competition and market forces wherever it can be demonstrated that there are real consumer benefits

Research Development & Deployment Needs. There is an "action agenda" to address the technical challenges, achieve the targets, and accomplish the vision. The top priority research, development, demonstration, modeling, analysis, and technology transfer needs include: designing the architecture for the "Grid 2030" vision, advancing the "commercial readiness" of certain critical electricity technologies, accelerating the acceptance of advanced technologies by electric system planners and operators, taking steps to strengthen electric market operations, and strengthening existing and building new public-private partnerships for implementing the action agenda and ensuring proper coordination and accountability.

Exhibit 2. National Electric Delivery Technologies Roadmap At-A-Glance

Vision

"Grid 2030"…

…energizes a competitive North American marketplace for electricity. It connects everyone to abundant, affordable, clean, efficient, and reliable, electric power anytime, anywhere. It provides the best and most secure electric services available in the world.

Targets

By 2010

- Architecture for "Grid 2030" vision defined and accepted
- Lower cost, more reliable, and field-tested
  - Data visualization
  - Point-of-use deployment of power quality enhancing systems
- Barriers eliminated to acceptance of advanced electric T&D technologies
- Uncertainty about regulations and market operations reduced
- Investments in electric infrastructure and TD&D sufficient to meet the needs

By 2020

- Local and regional deployment of "Grid 2030" architecture
- Expanded installations of advanced electric technologies for grid modernization
- Continued flow of capital into grid modernization projects
- Measurably more efficient market operations and consumer benefits

By 2030

- Intercontinental power transfers accomplished
- Real-time information flow from consumers (and appliances) through system for greater operational efficiency and control
- Near-zero economic losses from power outages and disturbances
- Openly competitive markets in all segments of the electric industry where consumer benefits can be demonstrated

Technical Challenges

- Lack of technically feasible and commercially viable designs for the architecture of the "Grid 2030" vision.
- Relatively high costs and mostly unproven reliability, performance, and manufacturability for certain advanced conductors, HTSC materials and equipment, electricity storage systems, distributed sensors and intelligence, smart systems and controls, and power electronics devices.
- Lack of data and modeling capabilities for assessing grid congestion problems and implementing real-time solutions and controls.
- Relatively slow capital stock turnover and institutional "inertia" interfere with introducing new electric delivery technologies into the "tool kit" of transmission and distribution planners and operators.
- Insufficient interest in power systems careers among the "next generation" of engineering students and lack of support for training opportunities and curricula development for electric system technicians, state utility commissioners and staff, and state and local code officials.

Action Agenda

Designing "Grid 2030" Architecture

- Design National Electric Backbone
- Design Regional Interconnections
- Design Local Distribution

Developing Critical Technologies

- Advanced conductors RD&D
- HTS RD&D
- Electric Storage RD&D
- Distributed intelligence, smart systems and controls RD&D including distributed energy systems
- Power electronics RD&D

Accelerating Acceptance of Advanced Technologies

- Strengthen technology transfer
- Expand education and training

Strengthening Electric Market Operations

- Assess markets, planning and operations, and bottlenecks
- Improve siting and permitting
- Address regulatory framework

Building Partnerships

- Federal coordination
- State coordination
- Public-private partnerships
- International cooperation

2 DESIGNING "GRID2030" ARCHITECTURE

"Grid 2030" is envisioned to be a fully automated power delivery network that is able to monitor and control electricity flows to every customer and node, ensuring two-way flow of electricity and real-time information between the power plant and appliance, and every point in between. It is envisioned to consist of three major elements:

- The national electricity backbone for enabling intercontinental transfers of bulk power.
- Regional interconnections for enabling regional power grids to operate both independently and as part of a unified, North American system.
- Local distribution for enabling retail customers to play an active role in regional and national wholesale markets.

Building a North American electric grid with the functionality of the "Grid 2030" concept is a multi-step process.

Building a North American electric grid with the functionality of the "Grid 2030" concept is a multi-step process. Incremental deployment and integration of new technologies will begin in the near-term and help strengthen the electric system as modernization continues. As research, development, and demonstrations of new technologies are being conducted, work will be done to determine how instrumentation, sensors, control systems, communications, and modeling can help industry make the most out of the existing grid.

The multi-step process begins with the architectural design phase. This is expected to be a five- to ten-year process during which design concepts will be developed and evaluated, existing systems will be evaluated, and prototype technologies will be built and field tested. During this process it will be necessary to clearly define which parties will regulate, own, and operate each portion of the grid.

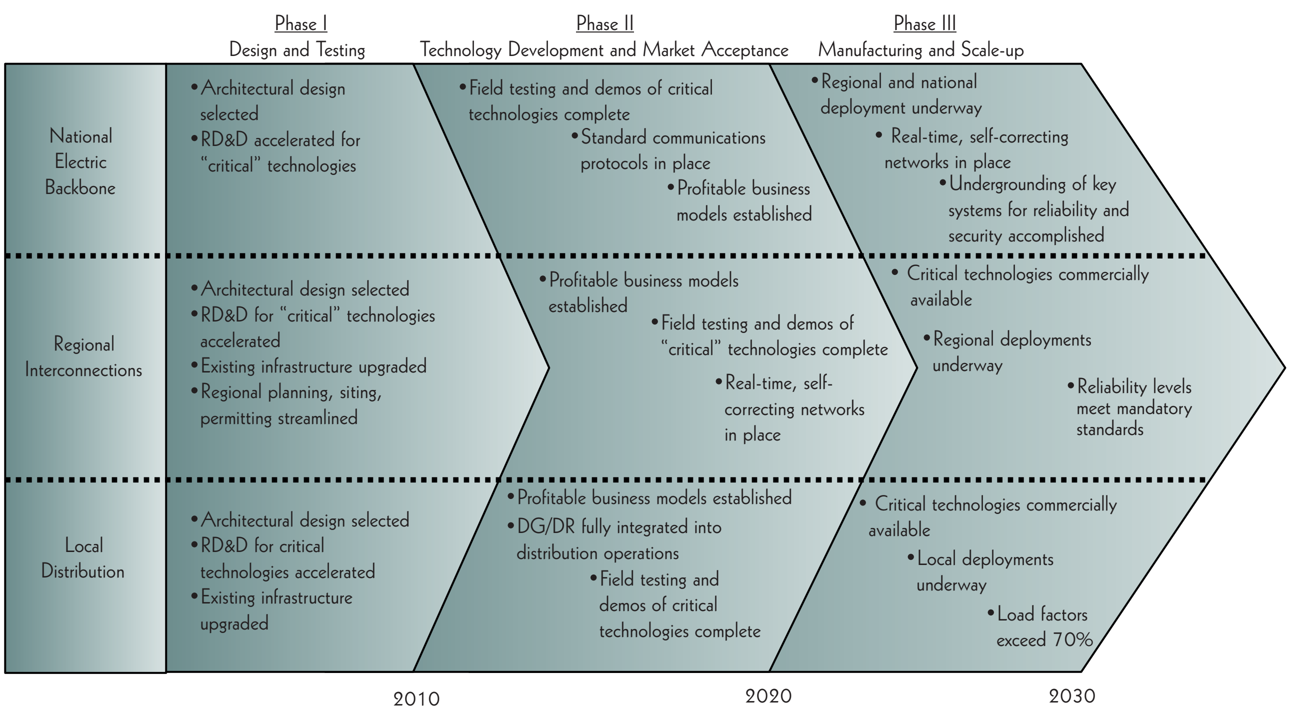
The next phase is market acceptance. This is expected to be a five- to ten-year process during which technology field tests and demonstrations are expanded and local and regional deployment of certain segments of the architectural design begins, probably including the integration of both existing and new technologies. During this second phase, it is expected that utilities, manufacturers, regulators, customers, and the financial community will gain confidence in the technologies and the architectural design; as a result, investors should have greater interest and financing for construction projects should be easier to attract. It is also necessary that government and industry collaborate to establish a universal system of codes and standards to allow greater ease in connecting new technologies to the grid.

The third phase is manufacturing and scale-up. This is expected to be a ten-year process, or more, during which local and regional segments will be knit together to form a national grid.

National Electricity Backbone

Having the ability to transmit power over long distances provides grid operators with access to potentially lower cost energy resources, perhaps from other regions. It can help balance supply and demand, leading to increased utilization of assets and/or reduced congestion, depending on system requirements and economics. A national electricity transmission backbone could provide important national benefits: it could help to balance electricity supply and demand on a national basis and provide "continental access" to electricity supplies from a wide variety of generation sources. The national benefits from this capability could be substantial, but need to be fully explored. Such a system does not currently exist, nor do the technologies (both hardware and software) and know-how required to build, operate, control, and maintain it. Analysis is needed to assess the financial, technological, and regulatory requirements to build, operate, control, and maintain a national electricity backbone.

EXHIBIT 3. ROADMAP FOR DESIGNING THE "GRID 2030" ARCHITECTURE



The development of a future national electricity backbone that provides continental interconnectivity and improved reliability would likely incorporate both "evolutionary" and "revolutionary" technical approaches. An evolutionary approach will be needed to upgrade and expand the existing inter-regional transmission infrastructure; a revolutionary approach will involve the permitting and construction of new, high-capacity, long-distance superconducting/high voltage transmission lines and control systems along existing or new rights-of-way.

Technical Challenges. Whether a national backbone develops along a predominantly evolutionary or revolutionary path, there are a number of technical challenges that must be addressed in the design of the architecture of the system through research, development, and demonstration projects.

The most urgent challenge to address is the lack of analytical tools, as well as an organizational research infrastructure, to properly model the nation's entire electric grid. Such tools will be needed to develop conceptual designs and system requirements. Improved tools are also needed to simulate and analyze the alternative technology pathways for the national electricity backbone, including the design and costs and benefits. Other important challenges include:

- Lack of suitable cryo-cooling technology (high Carnot efficiency, large size, ultra-high reliability, affordable)
- Lack of a manufacturing infrastructure for next generation technologies
- Lack of techniques for overlaying next generation technologies onto the existing grid

Paths Forward. Addressing these technical challenges will require a systematic approach that moves from system analysis/requirements definition, to research and development on enabling technologies and components, to simulation, to real-world demonstrations. As a first step, it will be necessary to study and model the technical and economic feasibility of a national electricity backbone. The models should explore alternative system architectures, configurations, topologies, etc., to focus future investments in R&D. System requirements and impacts, including those related to social, economic, security, reliability, and environmental performance, must be defined to guide these analyses.

Technology development must include demonstrations of the equipment *on the grid* in order to validate performance and reliability. Technical, financial, regulatory, and political risks will need to be mitigated during testing. Demonstration programs will be one of the keys to future utility acceptance of new technologies. A research infrastructure must be in place to make this all happen – to provide the "critical mass" of knowledge and expertise to conduct the fundamental feasibility and scoping studies, to educate future power engineers and materials scientists, to perform the R&D, to offer test facilities for equipment testing, and to develop standards and protocols.

Regional Interconnections

The interconnection of regional networks is an integral part of the "Grid 2030" vision. A key aspect is effective regional planning and mechanisms for greater market transparency for loads and energy resources, both within and across regions. Real-time, wide-area monitoring and control, along with the implementation of techniques for intelligent networks, adaptive relaying, and controlled islanding will be needed to address security concerns and enhance system reliability.

Technology development must include demonstrations of the equipment on the grid in order to validate performance and reliability.

Environmental issues related to electricity transmission and distribution will have to be addressed by involving the public in regional transmission planning; by determining the health, safety, and environmental impact of advanced transmission technologies; and by exploring non-transmission alternatives to specific transmission technologies, such as distributed energy resources which can offer a fast, comparably inexpensive source of supplementary power to end users and distribution systems.

Technical Challenges. There are several technical challenges that must be addressed. For example, large scale, load-leveling technologies (such as, bulk electricity storage, distributed generation, demand-side management) are either too expensive, too unreliable, or too unproven for widespread bulk power applications. To benefit regional systems, technologies must reach cost and reliability targets to entice utility investment and installation.

Real-time analysis, controls, and sensor and measurement technologies are not generally ready for the marketplace. These systems typically are too high in cost and lack standard and wide-area communications networks that would enable them to operate across large geographic areas that involve multiple load centers and sources of generation.

Substation and auxiliary equipment must be modernized in order to efficiently operate at the many different voltage levels required on a modernized electric grid.

Another barrier to streamlining interconnection systems is the lack of consistent codes and standards. For example, distributed energy interconnection onto the utility grid is hindered because there is no defacto standard for anti-islanding. In order to solve this problem, codes and standards must be established so that research and development on anti-islanding technologies can follow accordingly.

There are also workforce issues to address. There is a cohort of skilled electric transmission and distribution engineers and technicians that is approaching retirement age. There is no cohort of replacement staff on the horizon.

Paths Forward. Specific research, development, and demonstration is required in the near-, mid-, and long-term to overcome these challenges. As with the design of the national electricity backbone, the architectural design of the regional interconnections needs to begin with modeling and simulation for studies on wide area protection and control; to evaluate issues, benefits, and costs of different technical approaches; and to enable real-time models for tracking system dynamics of the grid's physical and market responses. Analysis tools will also be needed to provide more accurate end-of-life predictions of aging existing equipment and regional transmission infrastructure.

Research in the basic sciences must also continue in the long-term search for "breakthrough" paradigms in control theory, thermodynamics, and materials.

Research in the basic sciences must also continue in the long-term search for "breakthrough" paradigms in control theory, thermodynamics, and materials. Research and development of hardware for the grid must also be continued. Small, light weight, efficient transformers with high temperature and voltage management capacity would ensure reliable and efficient voltage and current change at high power levels.

Local Distribution

Local distribution systems will need to evolve substantially to meet the requirements of the "Grid 2030" vision. The biggest challenge for the distribution system of today is aging infrastructure and finding cost effective ways to integrate new technologies into the nation's legacy systems. Reliability will need to become more customized so that customers will be able to choose the level that best suits their individual needs. Asset utilization will increase so that 75% of distribution capacity is employed on average.

Distributed energy resources will play a larger role in providing local reliability services. Pricing will need to become more transparent and flexible so that customers can better manage their electricity costs.

Security threats will need to be addressed and systems will need to be in place to eliminate outages and downtime, including "ride-through" capabilities for end-use appliances and equipment. In addition, to suit customer needs and growing awareness, environmental impacts will need to be smaller and the physical footprint of distribution systems much less noticeable.

Several technical challenges need to be addressed. First and foremost is overcoming the inertia caused by legacy systems and procedures in the power distribution business.

Technical Challenges. Several technical challenges need to be addressed. First and foremost is overcoming the inertia caused by legacy systems and procedures in the power distribution business. The existing infrastructure involves long-lived assets and well-honed ways of system planning and operations. These will have to evolve, over time, for the "Grid 2030" vision for local distribution to be realized.

In addition, many of the critical advanced distribution devices are not ready for the marketplace. They cost too much and do not have proven performance, reliability, and durability. These include dispersed intelligent agents, interconnection devices for distributed energy resources, electric storage and distributed energy devices, protective relaying for two-way power flow, and techniques for identifying and locating faults.

Similar to the plans for regional interconnections, there are other limitations. The workforce needs more training and tools to install and maintain advanced systems properly. There is also difficulty attracting financial resources to distribution system investments. And, the existing suite of distribution system computer models and analysis tools fall short of providing the information that future planners and operators will need to integrate customers with the distribution network and allow flow-through decision making for participation in transmission and generation markets.

Paths Forward. More effort is needed in research, development, and demonstration to overcome these challenges and achieve the vision for "Grid 2030" for local distribution. Improving the performance of the existing distribution network is also a key aspect in doing so. Retrofitting low-cost monitoring, control, and communications applications on the existing grid is necessary to improve its efficiency, performance, and reliability. Further development is needed to lower the cost and improve the reliability of power electronics devices, including converters/inverters, solid state current limiters, static voltage regulators, and solid state transformers. Lower cost electricity storage devices are needed for the customer's side of the meter and for key feeders and substations. Lower cost distributed energy resources are needed to provide on-site power sources and with combined heat and power to improve the efficiency of power generation. More complete integration of distributed energy resources into the distribution system could enable customers to implement their own tailored solutions, thus boosting profitability and quality of life.

Further effort is needed to develop smart systems and controls. Communications protocols and standards are needed to establish an effective architecture for integrating distribution system operations with customer activities and transmission and generation markets. Control systems are needed for integrating demand response, distributed energy, and "grid-friendly" appliances into distribution planning and operations. Protocols for advanced metering are needed. New curricula need to be developed for training the "next generation" of distribution engineers and for training technicians in the proper design, installation, and maintenance of advanced equipment. For progress to be made, federal and state governments must collaborate with industry, universities, and national laboratories.

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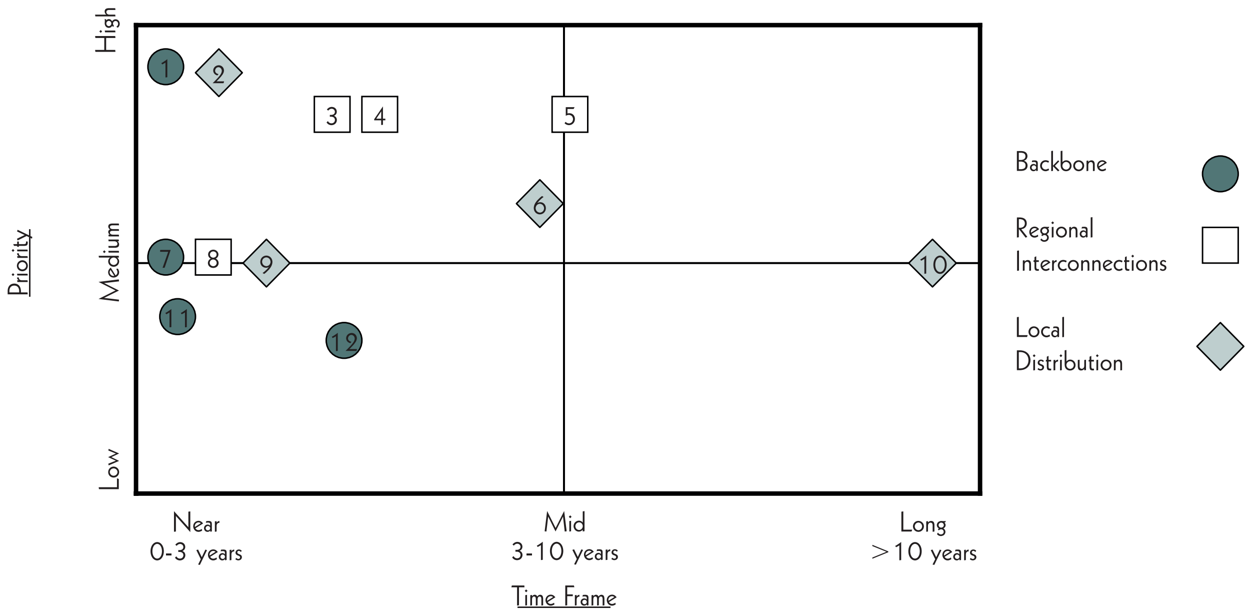
Priorities and Time Frame

There are a number of key activities to accomplish in designing the "Grid 2030" architecture. Priorities and time frames are shown in the exhibit that follows.

Exhibit 4. Grid Architecture Priorities and Time Frame Matrix



1. Candidate architectures for "Grid 2030" evaluated.
2. Industry-wide protocols/standards for the integration of distributed energy resources into the "Grid 2030" concept established
3. High speed, high accuracy analysis and control algorithms developed for distributed control and protection systems
4. Root-cause analysis of power control systems break ups determined and conceptual design for the use of self-correcting architecture determined
5. Critical technologies (advanced conductors, high temperature superconductors, electric storage, distributed sensors and intelligence and smart controls, power electronics) demonstrated
6. Standard distribution system models for urban, suburban, and rural locations developed
7. Requirements for "Grid 2030" specified
8. Tools and techniques for fast network evaluation planning, operation, stability, and reliability developed
9. New protection scheme for two-way power flow developed
10. Alternative distribution system concepts such as DC grids, high voltage, multi-frequency explored
11. Study completed life extension methods for existing T&D equipment completed
12. Grid impacts of expanded installations of distributed generation devices verified

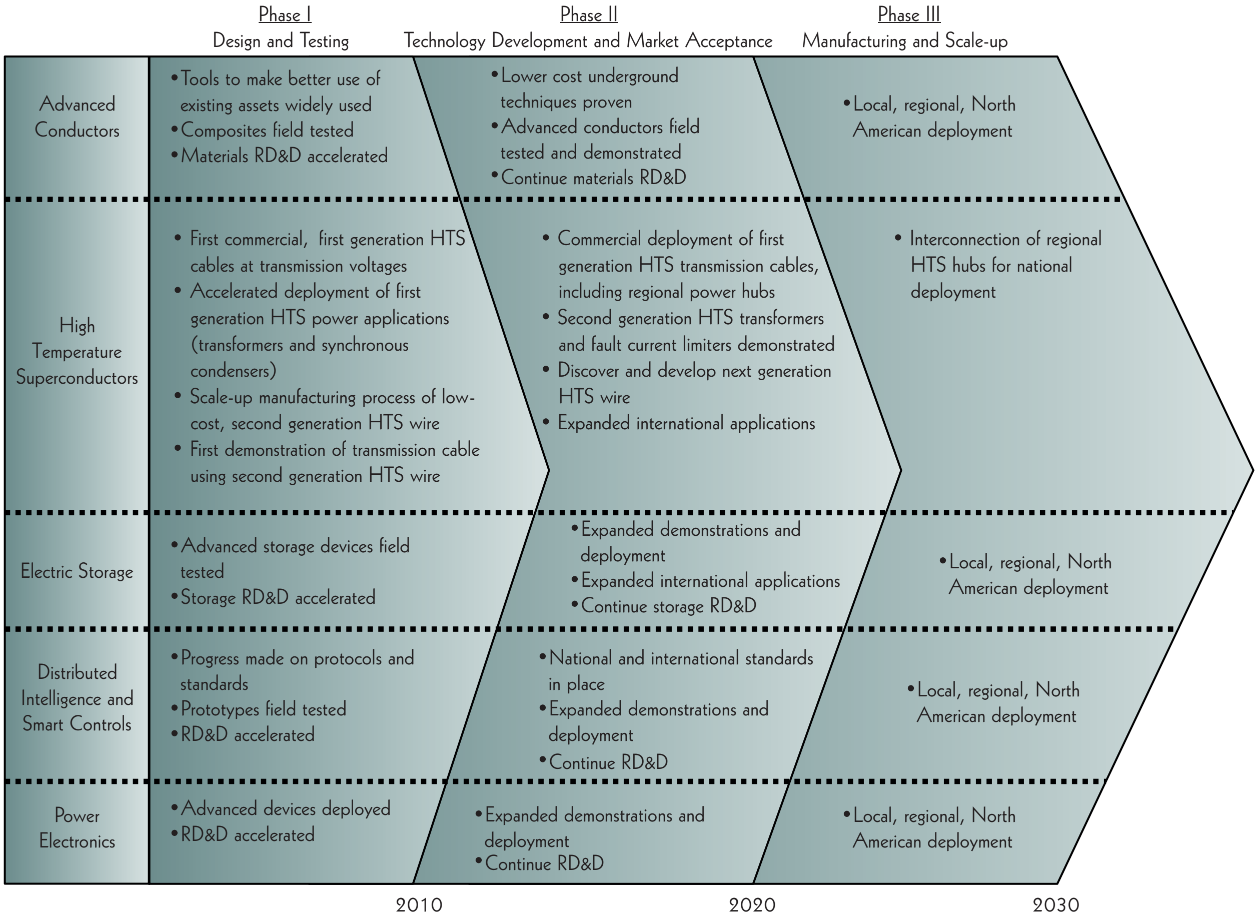
3 Developing "Critical" Technologies

The architectural design for the "Grid 2030" vision will support expanded functional requirements with enhanced capabilities beyond what current electric equipment can provide. Systems, subsystems, and components will need to deliver higher levels of performance at competitive, market-based costs. This will require greater efforts in research, development, field testing, and demonstration of basic devices that comprise the electric delivery network: cables and conductors, transformers, capacitors, switchgear, circuit breakers, sensors, communications, control apparatus, including substation and auxiliary equipment.

Systems, subsystems, and components will need to deliver higher levels of performance at competitive, market-based costs.

One of the keys to achieving the Administrations goals of reducing greenhouse gas emissions and reducing the nation's dependence on foreign fuel sources is to modernize our current energy delivery system and reduce inefficiencies so that we can get more usable power from our existing generation facilities. Another priority to improving the efficiency of the grid is to reduce the duration and frequency of power outages. Fortunately, there are technologies available today as well as those being developed that can help to reduce the likelihood of future outages. These technologies include devices for outage prevention, detection, response, and restoration. Technologies can be applied proactively to decrease the likelihood of a reliability event occurring and, if one does occur, to keep it from cascading. For example, advanced conductors and tower designs can increase the capacity of transmission lines in congested corridors with little environmental impact. Sensors for detecting line-sag can identify priority areas for tree trimming. Better planning tools, data visualization techniques, and training programs can assist grid operators to identify anomalies and take steps to prevent them from expanding or jeopardizing grid reliability. Monitoring and data acquisition systems can catalog information on system conditions at various points on the grid; using visualization tools, that data can be transformed into actionable information. Distributed generation, energy storage, and demand response techniques can be used to reduce peak demands and stress on the grid during times of system need. In the future, with more research and development to lower costs and increase durability, technologies can be used to improve grid operations and efficiency and reduce the likelihood of outages and their economic consequences.

Exhibit 5. Roadmap for Developing "Critical" Technologies



Five "critical" technologies have been identified by industry stakeholders and will be the basis for making these efficiency improvements to the grid, including advanced conductors; high temperature superconducting materials; electric storage; distributed sensors, intelligence, smart controls, and distributed energy resources; and power electronics. The five critical technologies emphasized in this roadmap are crosscutting technologies that have applications throughout the electric delivery network from the generator busbars through transmission and distribution networks to end users. Accelerating their development will benefit the electric grid no matter what architecture emerges for the electric system of the future. Investments in these technologies will help us on our way to making the grid more efficient, reliable, and less vulnerable to security threats.

Advanced Conductors

Conductors are wires, or combinations of wires, that carry electric current, including both alternating and direct current. Existing conductors deliver electricity at voltage levels ranging from several volts

Exhibit 6. Advanced Conductors – Technical Challenges and RD&D Needs

Key Technical Challenges	Top Priority RD&D Needs
• Increasing current-carrying capacities • Reducing manufacturing and installation costs • Reducing line losses • Increasing durability • Reducing weight • Increasing corrosion resistance • Reducing line sag	• Develop advanced conductor materials using alloys and composites of aluminum, copper, polymers, carbon, dialectrics, magnets, supercapacitors, and others • Develop advanced conductor designs for high-current-carrying capacity, low line losses, low-cost manufacturing, installation, and maintenance • Develop lower cost construction and installation techniques for re-conductoring existing and building new facilities, for both overhead and underground • Test lines before they are installed on grid

of direct current to hundreds of thousands of volts of alternating current. Conductor designs range from a single copper wire to cables consisting of several types of wires, including conventional copper and aluminum and newly designed high strength, light weight composites. Cable manufacturing includes wire wrapping and the use of insulators and dielectric materials.

Conductors are components of larger transmission and distribution systems. These systems include combinations of engineered conductors, insulators, towers, conduits, breakers, switches, and other devices that are needed for operating power systems efficiently, safely, and cost effectively. The art of advanced conductor design involves the integration of new materials with existing materials and other components and subsystems to achieve better technical, environmental, and economic performance, e.g., higher current-carrying capacity, lighter weight, greater durability, lower line losses, and lower installation and operation and maintenance costs.

The "ideal" conductor is said to have the conductivity of high-purity copper, the light weight of aluminum, and the strength and durability of hardened steel. To achieve these characteristics, research is needed to explore new materials, composites, and alloys for conductors. This involves basic materials science to characterize the electrical and mechanical properties as well as the long-term stability and resistance to degradation of the candidate conductors. New materials need to be manufactured in commercial lengths and field tested to demonstrate technical feasibility and market readiness. Modeling and analysis are needed to assess manufacturing scale-up from test batches at the laboratory to mass production at the factory. By making these improvements, conductor capabilities will decrease inefficiencies on both the transmission and distributions systems.

Effort is needed to design advanced conductors to improve performance and take advantage of breakthroughs in the development of new materials. Use of supercomputers for design simulations need to be applied to the design of advanced conductors. Advanced designs can reduce tower height, enable longer spans, and reduce sagging, thus alleviating some of the concerns in siting and permitting new facilities, as well as in re-conductoring existing rights-of-way.

A premium is placed on being able to expand carrying capacity without the need for new real estate or rights-of-way.

Improved conductors will increase grid capacity and relieve congestion, thereby lessening the need to site new transmission lines. The real estate for installing power lines and cables is highly constrained, costly, and subject to time-consuming permitting processes. As a result, a premium is placed on being able to expand carrying capacity without the need for new real estate or rights-of-way. It is estimated that 8-10 years are needed today for planning, siting, and constructing new overhead transmission lines, at a cost of approximately $2 to $8 million per mile for overhead lines and $5 to $15 million per mile for underground lines (depending on location, terrain, and right-of-way characteristics).

Further research and development is needed to improve DC-DC technologies. By improving DC-DC conductor technologies, electric isolation is possible, thus reducing the likelihood of cascading blackouts. Testing and demonstration of these technologies is strongly recommended in the National Transmission Grid Study. Efforts to develop advanced DC technologies, including DC transmission replacement of AC transmission, where cost effective and appropriate, should begin as soon as possible.

As with any new technology, product, or service, cost competitiveness is paramount. Underground installation is an important area of development, particularly for urban areas, but is increasingly an issue for long-distance transmission, too. High temperature superconducting cables, for example, require underground installation. Effort is needed to research new techniques for underground installations that are less environmentally intrusive and lower in cost. Better machines are needed for digging, assembling, and wiring. Better training is needed for installers and operators.

High Temperature Superconducting Materials

One of the more significant breakthroughs in advanced materials for electric power is the emergence of high temperature superconductors (HTS). For more than a decade, there has been an extensive public-private research development and deployment partnership to develop and test high temperature superconducting materials for transmission cables, transformers, motors, generators, fault-current limiters, and storage systems. High temperature superconductivity technology has come a long way since its inception in 1988. Not only is superconductivity vitally important to the future of the electric transmission system, but there have also been developments for medical and defense applications.

High temperature superconducting materials can replace existing grid segments with greatly enhanced capabilities, thereby giving the grid more flexibility, reliability, and efficiency, which would mean less electricity losses and less primary energy use, thus lowering the environmental impacts of power production.

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First generation high temperature superconducting wires are formed by packing high temperature superconducting materials in silver tubes, which are rolled, heat treated, and converted into tapes. First generation wires created under this process have been successfully introduced into prototype electric systems. Private U.S. companies have validated the manufacturing process of first generation wires and have ramped up to commercial production. The cost and performance characteristics of this wire make it applicable for a significant range of applications. However, in order to meet necessary cost goals for the broadest range of power applications, lower cost materials and manufacturing must be developed and commercialized, which is the opportunity for second generation wire.

Second generation high temperature superconducting wires, also known as coated conductors, are created by depositing thin films of high temperature superconducting materials (a few microns) on a nickel, or nickel alloy, metal strip. Major support for this program originated with the U. S. Congressional authorization of the Accelerated Coated Conductor Initiative to accelerate the development, commercialization, and application of second generation HTS wire. Los Alamos and Oak Ridge National Laboratories have been tasked with leading this effort.

Exhibit 7. High Temperature Superconducting Materials – Technical Challenges and RD&D Needs

Key Technical Challenges	Top Priority RD&D Needs
Lower cost manufacturing methods for mass production Lower cost, more durable and reliable equipment Lower cost and better performing cryogenic equipment Better designs for wires and cables to increase current-carrying capacities Easier field repair, maintenance, and remote diagnostics for cables and wires	Continue investment in the manufacturing scale-up of second generation HTS wire while using the best available first generation HTS wire in immediate applications to ready the market Develop HTS cables, conductors transformers, and fault-current limiters (and other devices such as generators and electric storage) for improving power flows and optimizing grid operations Develop HTS enabling equipment such as cryocoolers, cryopumps, and cryostats Continue basic research to identify higher temperature superconducting materials Continue investment in the scale-up of second generation HTS wire

Virtually all of the high temperature superconducting wires that have been produced have been used for experiments, tests, and prototype demonstrations of electric devices, including wires, cables, generators, motors, transformers, synchronous condensers, fault-current limiters, and flywheel energy systems. These demonstrations need to be expanded, particularly in the area of high voltage AC and DC transmission cables, in order to accelerate acceptance of high temperature superconducting applications by the electric utility industry. In addition, the adoption of second generation wire in these applications should be encouraged to take place as soon as feasible, thereby providing more incentive for the private investments that will be required to develop and commercialize a second generation wire that can have a price-performance ratio below that of first generation wire.

Advanced, cost-effective manufacturing techniques need to be developed, validated, and scaled up. For example, in going from high temperature superconducting wires (individual tapes) to cables, it is necessary to address the special characteristics of layering and coating brittle ceramic materials with other materials on buffered metallic substrates. All of these layers combine to a thickness of only a few microns. For this technology, analysis and testing is needed to evaluate using scalable deposition techniques from the semiconductor industry for the manufacture of high temperature superconductors. For this and other examples of high temperature superconducting devices, prototype coated conductor production processing lines need to be built, field tested, and demonstrated.

Further progress needs to be made for all of the electric devices that can use high temperature superconducting materials to improve their performance: wires, cables, transformers, fault-current limiters, synchronous condensers, motors, generators, and storage systems. Costs need to be brought down and current carrying capacities need to be increased at longer lengths. For this, effort is needed to improve engineering design. More prototypes need to be engineered and field tested. More "vertical" partnerships are needed involving national laboratories, manufacturers, and end users, particularly electric utilities.

Further progress needs to be made for all of the electric devices that can use high temperature superconducting materials to improve their performance.

A critical subsystem for high temperature superconductors is refrigeration. Achieving and sustaining liquid nitrogen temperatures of -196° C (77K) in a cost-effective and environmentally sustainable manner is a key step on the critical path toward expanded use of high temperature superconducting materials in the electric system and industrial, defense, and medical applications. Costs for cryogenic devices need to be lower. Engineering designs need to be improved to enable lower operating and maintenance costs. Low cost and durable sensors for detecting problems need to be developed. Remote diagnostic systems and remote maintenance and repair systems need to be developed, field tested, and demonstrated. Opportunities to leverage cryogenic research in superconducting applications with those of other energy research areas, such as the liquefaction of hydrogen, need to be explored.

Efforts at universities and at laboratories need to continue to explore the physics and chemistry of materials and identify mechanisms for materials to exhibit superconducting properties at even higher temperatures. The dream of developing room temperature superconductors should not be lost. Advances in nanotechnology needs to be pursued and tools for evaluating the microstructure of materials at the atomic level need to be applied to research in superconducting properties. The Department of Energy Superconductivity Program, in partnership with national laboratories and industry, is focused on developing the best available materials into practical high temperature superconductivity conductors for electric power applications. For progress to be made, federal and state governments must continue to collaborate with industry, universities, and national laboratories.

Electric Storage

Low-cost, flexible, and reliable electric storage devices could revolutionize electric markets by flattening load curves and boosting asset utilization of generation, transmission, and distribution facilities. The three types of storage most commonly in use throughout the electric system are:

Low-cost, flexible, and reliable electric storage devices could revolutionize electric markets by flattening load curves and boosting asset utilization of generation, transmission, and distribution facilities.

- Customer, small-scale storage, such as batteries in appliances and uninterruptible power supply units
- Distributed, medium-scale storage such as battery storage facilities in distribution utility applications and power supply units in distribution systems
- Bulk, large-scale storage as in pumped hydroelectric dams for wholesale power generation

Other types of electric storage devices include flywheels, compressed air, capacitors, and superconducting magnetic energy storage systems.

There is approximately 22 GW of pumped hydro at 150 facilities in 19 states; there is a 110-MW compressed air facility in Alabama; there is more than 70 MW of battery storage in use by utilities in 10 states; there is 30 MW of superconducting magnetic energy storage in facilities in 5 states; and there is a small number of demonstration flywheel units being tested.

Exhibit 8. Electric Storage – Technical Challenges and RD&D Needs

Key Technical Challenges	Top Priority RD&D Needs
• Achieving dramatic reductions in capital, installation, and O&M costs in all size ranges • Improving efficiency and performance in the charging and discharging of various storage devices • Improving the design of storage systems to improve customer acceptance, reduce footprint, and achieve plug&play operations	• Conduct design and simulation studies of manufacturing processes for all types of storage devices to identify opportunities to develop tools and techniques for lowering costs and improving performance • Develop, field test, and demonstrate storage devices in all size ranges and application areas, including advanced batteries, flywheels, capacitors, and superconducting magnetic energy storage • Explore novel electric storage systems

Reducing electric storage costs is one of the keys to more widespread utility adoption. Effort is needed to assess opportunities for new manufacturing processes to reduce the costs of energy storage devices. For both large- and small-scale systems, opportunities need to be explored for substituting lower cost materials without sacrificing technical performance. Advances in the design of storage systems are needed, especially for batteries, flywheels, and capacitors, to evaluate trade-offs in features and performance to lower manufacturing costs.

Greater effort is needed to develop, field test, and demonstrate advanced storage devices. Advanced batteries such as flow battery systems need to accumulate more operating data and experience to verify technical performance and address market acceptance. Further progress is needed on flywheel storage devices to develop more durable and reliable systems and verify safety and performance. Efforts to develop lower cost superconducting magnetic energy storage systems need to be accelerated for large-scale applications.

Greater effort is needed to develop, field test, and demonstrate advanced storage devices.

More effort is needed in the fundamental sciences to expand opportunities for advanced materials to be explored for electricity storage. Advances in nanotechnology need to be used to identify promising new materials and approaches for storing electrons. Efforts to leverage resources through coordination with related energy research, development, and deployment programs should be exploited, including those investigating technical solutions for storing hydrogen. For progress to be made, federal and state governments must collaborate with industry, universities, and national laboratories.

Distributed Sensors, Intelligence, Smart Controls, and Distributed Energy Resources

Installing sensors, data acquisition devices, and control algorithms more extensively in the electric network can improve grid operational efficiency, enable real-time fault detection and system restoration, and control the devices working together to run the grid. A low-cost, flexible standardized communications architecture needs to be developed and overlaid on today's power delivery system. With the appropriate communications architecture in place, devices can be designed to talk with one another and automate a variety of functions that currently require manual controls. The flow-through of real-time information about system conditions and prices can contribute to reductions in grid congestion through better demand management. A robust distributed intelligence and controls system for the electric grid could support the deployment of new technologies, enhance the performance of end use devices, and enable customer connectivity so that those who are willing to reduce their consumption in peak periods could participate in resource decision making through demand bidding in wholesale and retail markets.

Additional research, development, and demonstration is needed for automation systems, which are needed to provide high levels of power security, reliability, and power quality throughout the electricity value chain of the near future. To a consumer, automation may mean receiving hourly electricity price signals, which can automatically adjust home thermostat settings via a smart consumer portal. To a distribution system operator, automation may mean automatic "islanding" of a distribution feeder with local distributed energy resources in an emergency. To a power system operator, automation means a self-correcting, self-optimizing smart power delivery system that automatically anticipates and quickly responds to disturbances to lessen their impact, minimizing or eliminating power disruptions altogether.

Development is needed to improve distributed energy generation and combined heat and power systems that could expand the number of installations by industrial, commercial, residential, and community users of electricity. Devices such as fuel cells, reciprocating engines, distributed gas turbines and microturbines can be installed by users to increase their power quality and reliability, and to control their energy costs. They can lead to reduced "upstream" needs for electric generation, transmission, and distribution equipment by reducing peak

Exhibit 9. Distributed Intelligence, Smart Controls, and Distributed Energy Resources – Technical Challenges and RD&D Needs

Key Technical Challenges	Top Priority RD&D Needs
• Lowering the cost and increasing the reliability of dispersed intelligent agents and sensors • Having the capability to remotely identify the location and cause of faults • Having common communications protocols for integrating loads with distributed energy devices and electric grid operations • Achieving effective controls for wide area systems	• Develop hardware and software, sensors and algorithms, and data acquisition and management tools for accomplishing real-time communications and controls for transmission, distribution, and customer operations • Develop data management systems for achieving two-way flow of information between grid operators and electricity devices, including distributed energy resources • Undertake collaborative effort to develop communications standards/protocols for interoperability of distributed energy and grid interconnections

demand. Prices will need to come down on these devices in order for them to be cost effective.

Effort is needed to develop data management systems for achieving two-way flow of information, in real time, between grid operators and electricity devices – including distributed energy resources – and all of the key nodes in between. These systems are needed to provide decision makers with information on key decision variables, including electricity prices, weather conditions, voltages and frequencies, demand and energy levels, and equipment status. Information management systems need to be designed to acquire and analyze data over small and wide geographic areas for local, regional, and eventually national grid operations. They need to be able to simulate grid operations in real time and provide predictive capabilities for identifying potential weaknesses (including identifying and locating faults) in the network before they become disturbances or outages. Research and development of WiFi applications on the grid may be useful in achieving these goals.

Effort is needed to develop data management systems for achieving two-way flow of information, in real time, between grid operators and electricity devices.

Once communications and electricity infrastructures are integrated, electricity consumers will need to be connected more fully with electronic communications. The portal could sit between consumers' "in-building" communications network and wide area "access" networks. It could enable two-way, secure, and managed communications between consumers' equipment and energy service and/or communications entities. Performing the work closely related to routers and gateways, the portal could add management features (e.g., expanded choice, real-time pricing, detailed billing and consumption information, wide area communications, and distributed computing) to enable energy industry networked applications. Data management and network access based on consumer systems could consist of in-building networks and networked equipment that integrate building energy management, distributed energy resources, and demand response capability with utility distribution operations.

Effort is also needed to develop lower cost and more reliable sensors, controllers, and other equipment for operating transmission and local distribution systems more efficiently. The sensor and the system that produces the corrections have to be closely integrated. Design, development, field testing, and validation activities are needed. Devices for interconnecting distributed energy resources between the customer's site and the electric grid are needed. Equipment is needed to upgrade distribution systems and enable two-way power flow between customers and utility systems and ensure safe operations when larger numbers of distributed energy are installed. Accelerated development and deployment of fault current limiters is also needed. Fault current limiters provide adequate protection to the grid and reduce the need for more costly, higher capacity protection devices.

A key enabler for developing smarter electric systems is a greater degree of standardization among software platforms and equipment. For example, the goal of having "plug&play" capabilities for new distributed energy devices cannot be readily achieved if equipment from different manufacturers cannot communicate with each other easily. In a world where electric grid operations are becoming increasingly complex and interconnected, common communications protocols are essential. Effort is needed for manufacturers, utilities, and customers to continue to develop industry standards for advanced grid technologies.

Power Electronics

Faults in the grid are typically detected by protective relaying and resolved by circuit breakers or fuses. This electromechanical process often takes too long to accomplish, thus raising the likelihood of outages and power quality disturbances. Solid state devices such as switches, converters, inverters, static VAR compensators, and fault current limiters have faster response times and can be coupled with real-time monitoring and control systems to automate the grid's response to changes in customer needs, generation conditions, or weather patterns. These power electronics devices can be used for flexible alternating current transmission systems (FACTS), and in the conversion of alternating to direct current, and direct to alternating current. Improvements in power electronics technologies will allow the existing grid to manage larger capacity current, thereby reducing the need for increases in power generation.

Effort is needed to develop lower cost and more reliable power electronics for the safe and effective interconnection of distributed energy devices with the grid, including AC/DC conversion devices for distributed energy devices that produce only direct current electricity such as photovoltaics, battery storage, and fuel cells.

Exhibit 10. Power Electronics – Technical Challenges and RD&D Needs

Key Technical Challenges	Top Priority RD&D Needs
Lowering the cost of manufacturing and installing power electronics devices Improving the efficiency, durability, and current-handling capacity Finding better materials for improving performance and lowering costs Decreasing the cost and increasing the efficiency and reliability of distributed energy resources	Develop power electronics devices for integrating distributed energy resources into grid operations for safe, two-way power flows Develop power electronics devices for distribution system operations including switches, transformers, and power conditioning Develop power electronics devices for transmission system operations including switchgear, fault current limiters, and static VAR compensators Develop advanced materials for power electronics devices to increase durability, efficiency, and reliability, and to lower costs Develop distributed energy devices and combined heat and power systems for customer and utility applications

Lower cost and more reliable power electronics for enabling more effective automation of distribution system operations need to be developed. For example, lower cost and more reliable power electronics controllers and static VAR compensators can produce reactive power to support voltage levels in distribution systems. Effort is needed to explore the concept of direct current "micro and mini grids" as an advanced means of power delivery for power parks and urban areas with specialized electricity needs.

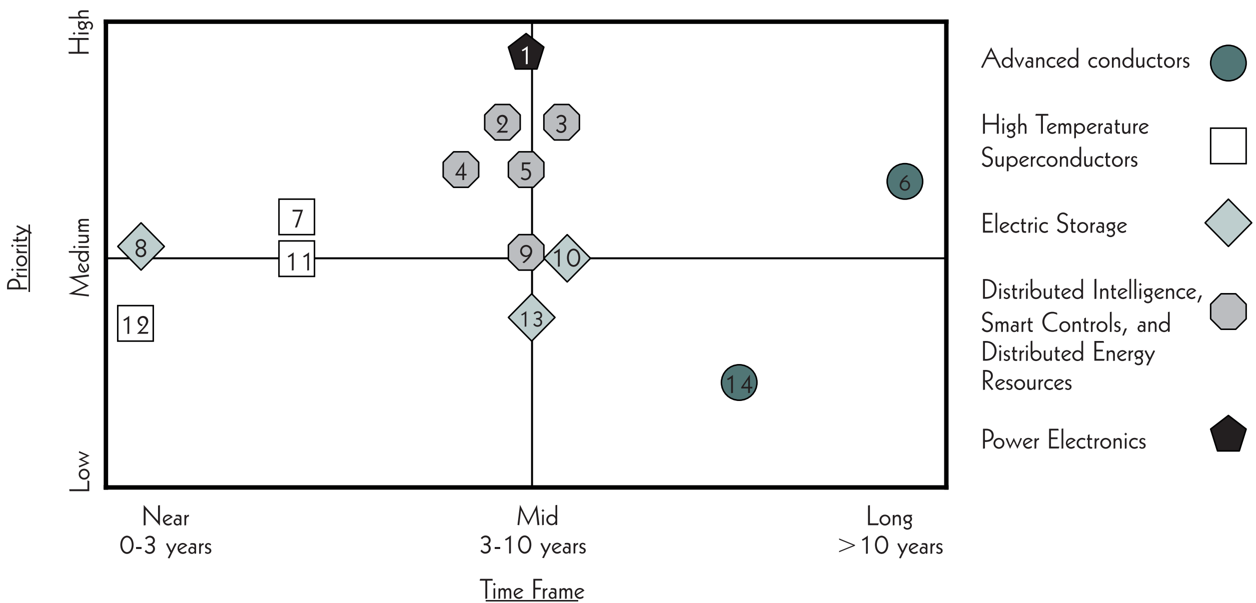
Lower cost and more reliable power electronics for transmission system operations need to be developed. Efforts underway to develop flexible alternating current transmission systems (FACTS) need to be accelerated and more opportunities for field testing and demonstrations need to be found. Further field testing and demonstrations need to be conducted on dynamic voltage support devices for injecting reactive power into key portions of transmission systems in order to help maintain voltage levels, keep line sagging to a minimum, and avoid potential under or over voltage situations, which can lead to cascading system failures if not addressed in a timely manner. These activities are underway within the industry, and testing and demonstrations need to be increased.

Effort is needed to develop advanced materials for power electronics devices which result in lower costs, higher efficiency, higher current-carrying capacities, and higher temperature operations. High temperature semi conducting materials (e.g., silicon carbide) need to be developed and tested and used in power electronics devices. These semi conducting materials are better able to operate efficiently in harsh environments, have higher thermal conductivity, and can operate effectively at higher frequencies.

Priorities and Time Frame

There are a number of key activities to accomplish in developing critical electric delivery technologies. Priorities and time frames are shown in the exhibit that follows.

Exhibit 11. Priorities and Time Frame Matrix for Critical Technologies



1. Low-cost, high capacity power electronics available that are modular, multi-level high voltage power conversion systems
2. Intelligent reconfiguration control systems and prototype technologies for robust, self-correcting controls developed
3. Control systems for automated end use devices developed
4. Distributed energy resources improved and grid interconnection policies and devices developed and in place
5. Intelligent sensors developed
6. Environmentally friendly, economically efficient dielectric materials developed
7. Multi-kilometer, AC HTS cable at transmission voltages completed (includes intermediate cooling station, PAR, and second generation section)
8. Lower cost energy storage system components such as batteries, flywheels, ultra-capacitors, power converters, and controls demonstrated
9. Systems to integrate demand response resources into SCADA for assessment, control, and deployment developed
10. New devices for large-scale, bulk energy storage designed and tested and incorporated into Grid 2030 architecture
11. DC HTS cable (hundreds of meters), including power electronic converters demonstrated
12. Cryo-technology refined to ensure size/scale, high efficiency, affordability
13. Storage for all relevant scales developed: bulk (hours) and grid stability (minutes)
14. New materials for advanced conductors developed (beyond composite, alloys, and high temperature superconductors)

4 ACCELERATING ACCEPTANCE OF ADVANCED TECHNOLOGIES

Even if progress is made in designing the "Grid 2030" architecture and developing critical technologies, there is the likelihood that they will not be put into practice properly unless ways are found to accelerate their acceptance in the marketplace. The technology transfer process by which advanced electric delivery technologies move from the laboratory and into the "tool kit" of transmission and distribution system planners and operators is too slow.

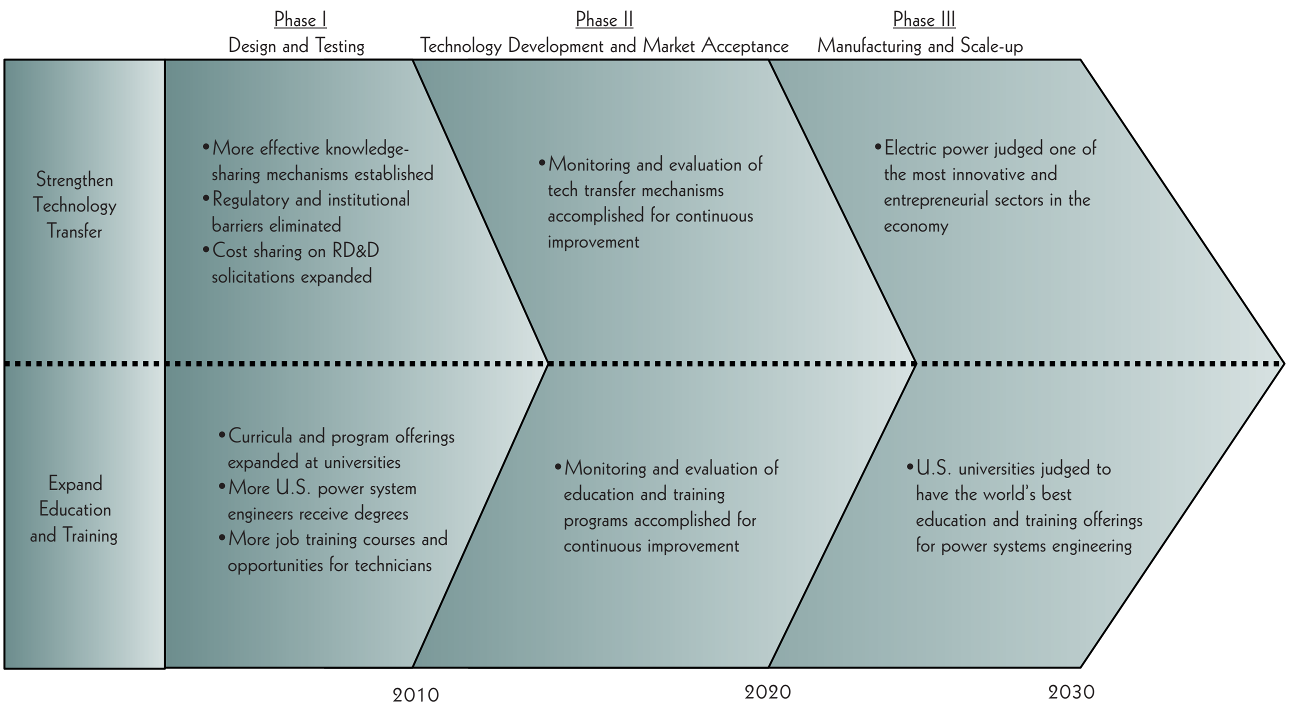
The technology transfer process by which advanced electric delivery technologies move from the laboratory and into the "tool kit" of transmission and distribution system planners and operators is too slow.

Part of the problem is that the electric power assets and infrastructure are relatively long lived. The economic lives of transmission and distribution systems can last 25 years, or more. In addition, the embedded "inertia" of legacy systems and business practices is hard to overcome. For example, today's regulatory framework fosters a business environment that is known to discourage risk taking and entrepreneurial behavior.

Equipment manufacturers and technology developers face difficulties convincing potential users to invest scarce capital in technologies that have not been fully proven. Potential users have concerns about the lack of training and the availability of skilled technicians to operate, maintain, and repair advanced technologies, for which the servicing infrastructure may not be fully developed. Ways need to be found for sharing the risks of new product development among the key participants – e.g., utility companies, equipment manufacturers, financiers, customers, and federal and state agencies – to encourage innovation and spur the introduction and acceptance of new technologies.

Clearly, technology transfer practices must be improved and companies, regulators, investors, and the federal government will need to share risk. More effective regulations and business practices need to be established to spur innovation and increase testing of new technologies and techniques. A federal role in this endeavor is crucial for facilitating partnerships and spearheading a comprehensive research and development portfolio. Federal and state regulators need to work together to identify promising grid technologies and support more rapid testing and implementation. Regulatory and market-based

Exhibit 12. Roadmap for Accelerating Acceptance of Advanced Technologies



Commercialization plans must be considered an integral part of the research and development process.

mechanisms need to be identified to encourage innovation and prudent risk sharing. Technology developers need to ensure that they provide the proper information to decision makers and the investment community. Electric transmission and distribution planners and operators need to employ business practices that more aggressively include consideration of new concepts and approaches. Education and training opportunities need to be expanded.

Technology Transfer

The process of modernizing the grid with the installation of advanced technologies is a two-way street. Technology developers must have superior products and employ effective techniques for educating potential adopters and investors on the merits of the new technologies and systems. Commercialization plans must be considered an integral part of the research and development process. Potential users must follow business practices that enable product testing and evaluation and have business planning tools that reveal the financial advantages of new technologies and approaches. In regulated industries, federal, state, and local officials must pay attention to regulations, codes, and standards and ensure they do not unnecessarily penalize appropriate risk-taking and entrepreneurial actions.

Well-publicized and properly documented evidence of the technical, financial, and environmental benefits of advanced electric delivery technologies is one of the best ways to address the concerns of wary investors and public policy officials. Yet, attracting financing for technology demonstration projects is difficult, and purely private assessments have the disadvantage of limited dissemination of project results. Cost-shared demonstrations in which federal and state investments are highly leveraged with private capital can be used to evaluate the relative merits of advanced technologies. For example, the Tennessee Valley Authority is working to develop a technology in which high temperature, diamond materials could be used to replace silicone in conductoring materials. The diamond materials have proven capable of carrying ten times more current, conducting heat four times better than copper, and operating at higher temperatures and voltage levels. Proving the manufacturability of this development could revolutionize the transmission grid. If the demonstration projects are targeted to areas of the country where the transmission and distribution system needs are greatest, their impacts and public benefits can be maximized.

A national approach to electric delivery project demonstration requires a test plan that provides directions and priorities and leverages federal, state, and private monies.

A national approach to electric delivery project demonstration requires a test plan that provides directions and priorities and leverages federal, state, and private monies. The plan needs to outline the testing criteria and information and monitoring requirements.

In addition to the "critical" technologies discussed in Chapter 3, the demonstrations need to include the full range of distributed energy resources. The use of distributed generation and demand-side management on the customer side of the meter to reduce requirements

Exhibit 13. Key Challenges and Technology Transfer Needs

Key Challenges	Top Priority Technology Transfer Needs
• Lack of regulatory support for risk taking and investment in new technologies • Insufficient financial resources for RD&D • Unclear roles and responsibilities in transmission planning, siting, and permitting • Lack of electric distribution planning and budgeting techniques that reveal financial advantages of new technologies	• Expand the number of industry-led demonstration projects for evaluating advanced electric delivery projects, including distributed energy resources • Develop profitable business models for capturing the financial advantages of advanced electric delivery systems • Encourage more effective integration and coordination on a pre-competitive basis among technology developers, equipment manufacturers, and potential users • Assess models in other markets

on the electric delivery system needs to be more fully evaluated. Testing of single units or small numbers of devices is well underway. It lacks demonstrations of large numbers of distributed energy systems either concentrated in local areas or aggregated across wider geographical areas. Demonstrations of distributed energy systems by electric utilities to support transmission and distribution operations also need to be expanded.

Providing timely information to decision makers in formats they can easily use is one of the key ingredients to accelerating the adoption of advanced technologies.

Part of the technology demonstration process should include the evaluation of potential revenue streams from services that are currently "bundled" in existing cost structures and rate designs. Profitable business models are needed to increase the incentives for new technologies and the development of new markets for products and services. For example, real-time and location-specific pricing could boost the economics of installing new electric delivery and distributed energy technologies to specific areas of the grid. A more thorough understanding of the costs of outages and power quality disturbances enable equipment manufacturers and project developers to uncover revenue streams that improve the favorability of project economics. Steps to remove regulatory and institutional barriers to siting and permitting new technologies could lower installation costs and boost financial attractiveness. In most states, distributed energy development is not stifled by inhibiting factors, but rather a lack of incentives.

The research and development process itself could benefit from greater coordination and integration. The concept of using integrated project teams consisting of manufacturers, universities, national laboratories, and electric utilities throughout the research, development, and demonstration process increases commitment and the likelihood that effective commercialization plans will be put in place. Federal and state cost sharing can be used to encourage integrated teams and to increase the level of coordination to ensure information is developed and disseminated in a more comprehensive manner.

Education and Training

Providing timely information to decision makers in formats they can easily use is one of the key ingredients to accelerating the adoption of advanced technologies. Uncertainties about performance and cost need to be reduced before potential users will be able to justify investments. To bring about changes in the marketplace, information dissemination efforts need to be carefully targeted. Different audiences require different types of information, presented at different levels of detail.

Providing expanded opportunities for professional education and training in power systems is another key ingredient to accelerating the adoption of new technologies. The existing workforce consists of professionals that have been on the job and gaining experience for several decades. For a variety of reasons, there are questions about the availability of the next generation of engineers and technicians.

An information campaign is needed to inform decision makers at several levels in a variety of organizations located across the country. The purpose of this campaign is to raise awareness about the need to modernize the electric grid and the various solutions that are available for solving problems, both in the near and long terms. A major issue that needs to be addressed is educating state and local policy makers on the customer and utility system benefits of distributed energy resources, including distributed generation, demand-side management, and energy storage systems. Near-term efforts should focus on known bottlenecks in the transmission of electricity and congested electric distribution systems, which are located primarily in urban areas. Long-term efforts should focus on developing support for sustaining multi-year research and development programs.

A major issue that needs to be addressed is educating state and local policy makers on the customer and utility system benefits of distributed energy resources.

The development of state of the art simulators is critical for training federal, state, and local emergency response personnel to deal with crisis and malicious attack conditions.

Effort is needed at the nation's colleges, universities, and professional and trade schools to strengthen engineering programs in power systems, including the development of new curricula to include expanded coverage of advanced technologies. Support of research in top universities could facilitate changes in curricula and attract more students to pursuing careers in power systems. A student's ability to conduct research as an undergraduate is often what attracts the very best students to the field. Effort is also needed to develop training programs to expand the capabilities of the workers who are on the job today.

Exhibit 14. Key Challenges and Education and Training Needs

Key Challenges	Top Priority Education and Training Needs
• Aging electric transmission and distribution workforce • Difficulties in attracting new electrical engineering students to major in power systems curricula • Lack of job training program opportunities for engineers and technicians on advanced electric delivery technologies • Frequent turnover of pubic utility commissioners and staff • Lack of awareness of senior utility executives about the relative merits of advanced electric delivery technologies	• Raise awareness among utility industry executives, public utility commissioners, public interest organizations, and investors about the costs and benefits of new electric delivery technologies and distributed energy resources • Develop new curricula in line with the vision for electrical engineering programs to attract students majoring in power systems • Build better training programs for installing, operating, and maintaining advanced electric delivery technologies and distributed energy resources • Develop state-of-the-art simulators for crisis training and malicious attack conditions

5 Strengthening Electric Market Operations

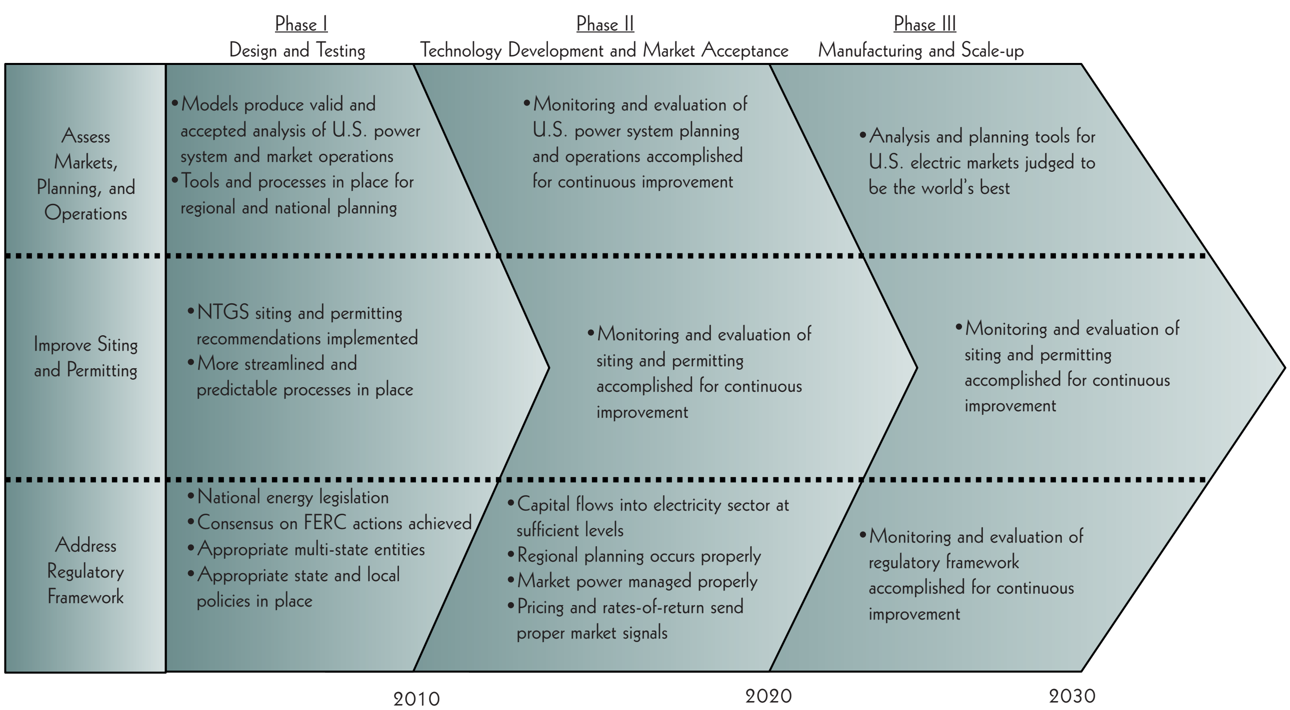
The regulatory frameworks governing the electric delivery systems are not consistently producing socially beneficial results in all regions of the country. As a result, some electric markets are not functioning well enough for grid modernization to occur properly.

For example, even if cost-effective “critical” technologies gain market acceptance, investment capital will not necessarily flow in their direction, siting and permitting will not automatically be more streamlined, and cost recovery will not necessarily be more certain. Lack of clarity in federal-state jurisdiction is interfering with certain projects moving forward. Rate freezes in some areas have put cost recovery in jeopardy for certain types of capital expenditures.

Effort is needed to assess market operations and evaluate the relative merits of market-based approaches for bringing greater certainty and lower financial risks to electric market transactions. Modeling and analysis is needed to identify ways for reducing or eliminating barriers to greater economic efficiency, competition, and market forces.

Even if cost-effective “critical” technologies gain market acceptance, investment capital will not necessarily flow in their direction, siting and permitting will not automatically be more streamlined, and cost recovery will not necessarily be more certain.

Exhibit 15. Roadmap for Strengthening Electric Market Operations



Assessments of Market Operations

Timely, accurate, and widely available information is paramount for markets to function efficiently. Electric delivery systems are complex and information is needed for decision making in two primary dimensions: planning and operations. Planning involves evaluating future conditions and possibilities to determine the electricity requirements of consumers and simultaneously assessing the relative merits (from financial, environmental, security, and health and safety standpoints) of alternative resource portfolios to meet the forecasted needs. Operations involve the analysis of system conditions on a real-time basis to manage the flow of electricity through the grid and ensure that the resource portfolios available to meet the needs are dispatched in an orderly, cost-effective, safe, and secure manner, while protecting the environment. Better and more accurate data, computer models, and analytical tools are needed to support these functions. These data and tools can be used to help identify and assess load management opportunities for customers to participate more fully in grid operations by reducing consumption during times of system need.

Exhibit 16. Key Challenges and Market Assessment Needs

Key Challenges	Top Priority Market Assessment Needs
• Lack of easy-to-use models to simulate electric delivery system operations (physical and financial) on local, regional, and national basis • Lack of models to simulate bid-based and other wholesale market designs to evaluate costs and benefits and assess market power • Lack of location-specific data on the marginal costs of delivering electricity to any point in the system • Lack of data on the market value of non-traded products and services: e.g., ancillary services, outage prevention, power quality, environmental improvements • Lack of analysis tools and data for grid operators to manage system logistics in real time	• Develop, verify, and validate engineering and economic models of electric delivery system operations and disseminate to grid operators • Develop and use planning models to forecast local, regional, and national electric delivery resource requirements and provide planning studies to industry and public officials • Develop information management systems for collecting and disseminating large volumes of real-time data on grid operating conditions

In addition, relevant agencies, including state regulatory commissions, regional transmission organizations, independent system operators, and others, should evaluate how the new infrastructure might affect natural gas pipelines, railroads, roads, and waterways that can transport energy sources like natural gas, liquified natural gas, coal, and oil to satisfy the economy's needs for energy.

Grid operators need support in managing system logistics in real time. With improved sensors, power electronics, and automated controls, grid operators will have the physical assets in place to manage electric delivery more efficiently and in a manner that reduces the likelihood of outages and power-quality disturbances. However, information management and analysis tools need to be developed, verified, and validated to monitor grid operations in real time and support decision making using visualization techniques, simulation modeling, and other approaches. Industry, government, universities, and national laboratories need to work together in data and model development to ensure greater consistency of methodologies and assumptions so that results can be shared more easily between grid control centers across states and regions.

Robust electric delivery planning tools need to be developed to assist in the assessment of resource requirements to identify least-cost pathways for meeting consumer needs.

Robust electric delivery planning tools need to be developed to assist in the assessment of resource requirements to identify least-cost pathways for meeting consumer needs. These planning tools are needed to support local, state, and regional planning processes that involve extensive public inputs and consensus building. Industry, government, universities, and national laboratories need to work together on the development of planning models to ensure consistency of methodologies, data, and assumptions; to ensure greater degrees of agreement; and to help focus public planning processes on issues that can be quantified, to the maximum extent possible.

Effort is needed to develop information collection and management and visualization tools that are capable of processing and summarizing large volumes of data in real time to provide a stronger, fact-based foundation for grid operations and planning. These tools will require communications systems to link them with sensors and physical assets (e.g., power plants, power lines, switchyards, substations, transformer banks, and customers) located throughout the system, region, and country.

Siting and Permitting

There are well-documented problems with siting and permitting new transmission lines. There are private and public land use concerns, federal and state jurisdictional issues, and “not-in-my-backyard” attitudes to address. The *National Transmission Grid Study* and the *Transmission Grid Solutions Report* of Secretary Abraham’s Electricity Advisory Board document a series of recommendations aimed at accelerating the siting and permitting of needed transmission facilities.

The *National Transmission Grid Study* contains eight specific siting and permitting recommendations. They instruct the U.S. Department of Energy, the Federal Energy Regulatory Commission, utilities and state utility commissions, the national and regional governors' associations, the National Association of Regulatory Utility Commissioners, the Council on Environmental Quality, and the U.S. Congress to conduct joint studies, form collaborative enterprises, remove unnecessary barriers, implement new guidelines and regulations, and pass laws to increase electricity throughput on existing rights-of-way and increase construction of new facilities. These recommendations should be implemented as soon as possible.

The *Transmission Grid Solutions Report* identifies a number of actions to improve market operations. These include:

- Identifying "national interest" bottlenecks on the transmission system and taking steps to increase capacity in those areas
- Considering enactment of legislation to give the federal government "backstop" authority to approve applications to build transmission facilities to relieve DOE-identified bottlenecks, in instances when the states or other authorities are unable to act
- Highlighting the importance of Regional Transmission Organizations to facilitate grid expansion and the efficient operation of wholesale power markets
- Encouraging infrastructure enhancements through merchant transmission
- Developing advanced electric delivery technologies
- Encouraging cost-effective demand response and distributed generation
- Enhancing physical and cyber security
- Implementing mandatory reliability rules

Progress should be made in moving these actions forward.

Regulatory Framework

The regulation of electric delivery in America is aimed at vital public purposes: consumer and environmental protection, public health and safety, and economic and energy security. Efforts over the past decade to restructure the regulatory framework and open certain segments to competition and market forces have involved federal and state policies and legislation. These efforts have not resulted in a unified approach, thus many issues remain unresolved. For grid modernization to proceed, the level of private investment must increase. This means there needs to be a more attractive investment climate in the electric power sector than there is today. Federal and state electricity and environmental regulators can contribute to improving investment conditions by streamlining siting and permitting processes for new electricity facilities and using market-based mechanisms wherever feasible for setting rates and rates-of-return. Innovative approaches are needed to achieve these policy goals while at the same time ensuring both consumer and environmental protection.

Federal and State electricity and environmental regulators can contribute to improving investment conditions by streamlining siting and permitting processes for new electricity facilities and using market-based mechanisms wherever feasible for setting rates and rates-of-return.

Effort is needed at the federal level to implement laws and regulations that clearly assign responsibility for grid reliability. These efforts need to include monitoring performance and holding the responsible parties accountable for both successes and failures. They need to involve enforceable mandatory reliability standards, followed by complementary provisions at the regional, state, and local levels. Federal legislation to provide a clear legal foundation for such actions was first proposed in 1996, and is included in the pending comprehensive federal energy bill. If the proposed reliability provisions are not enacted into law, federal officials (at the Federal Energy Regulatory Commission in particular) should work with electric reliability organizations and the industry to make reliability requirements mandatory and enforceable under existing federal authorities.

Effort is needed at the state level to evaluate alternative regulatory mechanisms for ensuring reliability and efficient market operations. The relative merits of regulatory approaches like performance-based ratemaking, price caps, revenue caps, and enforcement of anti-competitive trade practices, at the state level, need to be thoroughly assessed. State-level mechanisms for providing financial incentives and penalties for ensuring grid reliability need to be explored and tested.

Effort is also needed to use new regulatory approaches to encourage innovation and prudent risk taking for investments in advanced grid technologies. The relationship between those aspects of current business practices that discourage innovation, and state and federal energy, economic, and environmental regulations, need to be analyzed. Effort is needed to find ways to encourage greater levels of spending by the electric industry on research, development, and demonstrations for grid reliability technologies. The vast majority of state spending on energy research has been focused on energy efficiency and renewable energy through public benefits funds. These are important public investments. Effort is needed to explore how these state funds could be expanded to include financial incentives for grid reliability research.

Regulatory and institutional barriers currently interfere with the installation of distributed energy devices by customers. The lack of uniform grid interconnection standards is being addressed by the state and federal agencies that are considering the adoption of the interconnection guidelines recently published by the Institute of Electric and Electronic Engineers. Building, fire, and safety code officials need better information on the technical parameters of distributed energy so that local ordinances can be revised. Environmental siting and permitting rules need to be streamlined so that developers do not have to wait unnecessarily for permission to install distributed energy systems. Net metering provisions need to be assessed to determine their effectiveness in encouraging safe, reliable, and cost-effective, on-site generation. Regulatory incentives need to be evaluated for encouraging distribution utilities to upgrade distribution facilities and achieve reasonable cost recovery to accommodate greater use of distributed energy devices.

Exhibit 17. Key Challenges and Regulatory Framework Needs

Key Challenges	Top Priority Regulatory Framework Needs
• Lack of clarity about the relative roles of federal and state government agencies in regulating electric grid planning and operations and ensuring grid reliability • Overcoming uncertainties about future regulations and achieving a more stable business climate for attracting private investment capital • Establishing multi-state entities that have the ability to regulate certain aspects of regional electric market operations • Enabling market-based price signals that reflect marginal costs to be used by producers and consumers through rate design • Sustaining public purpose programs such as research and development in more competitive market designs	• Encourage national energy legislation and regulations that achieve the proper balance between federal and state jurisdiction in assigning responsibility for grid reliability • Conduct studies and simulations to assess the relative merits of alternative regulatory approaches to efficient and reliable market operations such as performance-based regulations, price and revenue caps, and market power penalties • Encourage federal and state restructuring efforts that provide incentives to encourage technological innovations • Encourage state and local regulators and code officials to eliminate unnecessary barriers to the expanded use of advanced electric grid technologies, including distributed energy resources and demand side management

6 Building Public-Private Partnerships

The resources needed to complete the job of modernizing the electric grid exceed what stakeholders separately have available. This is a big job which affects every region of the country and every segment of the industry. It is simply more than the government or industry can handle separately.

To apply leverage, actions to modernize the grid need to proceed through multi-year, public-private partnership(s). The amount of coordination is enormous. The federal government needs to provide leadership to facilitate these partnerships and make sure that focus is kept on long-term, as well as near-term objectives.

To apply leverage, actions to modernize the grid need to proceed through multi-year, public-private partnership(s).

To make progress, the U.S. Department of Energy needs to re-invigorate existing and create new public-private partnerships.

Federal Coordination

Effort is needed to achieve greater coordination among all of the federal agencies who participate in or are affected by grid modernization efforts. The Department of Energy is encouraged to expand its partnership activities with other federal agencies, including perhaps a stronger inter-agency approach. Within the Department of Energy, greater coordination is needed in developing research and development plans and strategies among the Offices of Electric Transmission and Distribution, Energy Efficiency and Renewable Energy (including distributed energy, hydrogen, energy efficiency, and renewable energy technologies), Fossil Energy, Nuclear Energy, and Energy Assurance. The Department of Homeland Security along with the Federal Energy Regulatory Commission, for example, are developing cyber-security approaches that will be a critical aspect of grid modernization activities. The grid crosses international boundaries so it is likely that modernization efforts will require greater levels of coordination with the energy ministries of Canada and Mexico.

Another key aspect involves oversight and appropriations provided by Congress. Greater effort is needed to expand communications between the Executive and Legislative branches to achieve a common understanding of aims so that focus can be fixed on sustaining an appropriate federal role.

Exhibit 18. Key Roadmap Partners

Federal	Regional	State and Local	Industry	Other
Department of Energy Department of Defense Department of Homeland Security Department of Commerce Department of Agriculture (Rural Utility Service) Federal Energy Regulatory Commission	Multi-State Utilities (TVA, Southern Co., etc.) Power Marketing Administrations Regional Transmission Organizations Independent Systems Operators	States National Governors Association National Conference of State Legislatures National Association of Regulatory Utility Commissioners National Association of State Energy Officials Local Governments	Electric and Gas Utilities Independent Power Producers Electric Equipment Manufacturers IT Providers Financial Institutions	Universities Public Interest Groups Environmental Organizations Labor Unions National Laboratories International Organizations Electric Research Institutions

Coordination with Regions and States

Federal responsibilities include several regional organizations that currently play key roles in grid planning and operations. These include the Tennessee Valley Authority and the Power Marketing Administrations (Bonneville, Western, and Southwestern). Ties between these agencies and private regional organizations, such as independent system operators, are strong but will likely need to be expanded for grid modernization to occur properly.

Coordination between federal and state agencies on grid issues is extensive. The Federal Energy Regulatory Commission and state public utility commissions are involved in many proceedings related to grid modernization. Clarification of jurisdictional issues could be achieved if national energy legislation is enacted. This could improve the likelihood of greater cooperation and collaboration and reduce the instances of inaction caused by unclear roles and responsibilities. State organizations such as the National Governors Association, the National Conference of State Legislatures, the National Association of Regulatory Utility Commissioners, and the National Association of State Energy Offices are critical partners for reaching state officials and harmonizing federal, regional, state, and local policies for grid modernization.

Industry Coordination

There is a natural diversity of opinions and interests among the many companies and non-governmental organizations that comprise the electric power industry and its suppliers. It is not reasonable to expect agreement and consensus on every aspect of grid modernization. For grid modernization to occur smoothly, it is useful to reach general agreement on a common vision and to establish ground rules, and a roadmap, for getting there.

A key partner in grid modernization is the consumer. They will be the beneficiaries of a more reliable grid. Through the prices they pay for electricity, and the taxes they pay for public services, they will be the primary source of revenues to energy and equipment suppliers, grid operators, financiers, and others who risk capital to achieve a more modern and expanded grid. Effort is needed to reach consumers – industrial, commercial, residential, and governmental – and provide unbiased information on costs and benefits.

There is a natural diversity of opinions and interests among the many companies and non-governmental organizations that comprise the electric power industry and its suppliers.

Consumers have varying needs for electricity, and differing "willingness-to-pay" for the services electricity provides, including, for example, electric reliability, power quality, industrial productivity, indoor comfort, and convenience. This presents a significant challenge for the designers of the future grid to map out a course for modernization that is able to take diverse consumer perspectives into account.

Effort is needed among the non-governmental organizations, trade associations, professional societies, and interest groups to identify ways to communicate better on grid modernization issues.

7 Next Steps

This roadmap outlines an extensive set of activities that need to be accomplished for grid modernization to occur. It is by no means a complete and comprehensive set of activities. Many of the details as to how the activities will be accomplished, the timelines, and the resource requirements are not included. These implementation plans are up to the stakeholders to develop and pursue.

The U.S. Department of Energy, Office of Electric Transmission and Distribution is developing a multi-year program plan which will elaborate its role in the roadmap implementation process. This roadmap is intended to support a broad-based coalition of organizations who want to participate in a national effort to modernize and expand the electric grid. It is considered to be "version 1.0," meaning that comments and suggestions are welcome and that updates will be produced, as the need arises.

This roadmap is considered to be "version 1.0," meaning that comments and suggestions are welcome and that updates will be produced, as the need arises.

The Office of Electric Transmission and Distribution's website, www.electricity.doe.gov, will include periodic updates on roadmap activities and copies of roadmap materials. Accessing this website is the best way to keep abreast of roadmap implementation activities, including information on solicitations, conferences, and workshops.

Appendix A summarizes the research, development, and deployment needs to be completed by 2010, covering grid architecture, critical technologies, accelerating acceptance of advanced technologies, and strengthening electric market operations.

Appendix B lists all of the organizations and individuals who participated in the Vision Meeting and the Roadmap Workshop. These people, along with countless others, have had the opportunity to review this roadmap, and the vision, and provide suggestions and comments. The Department of Energy is counting on the continued participation and support of these individuals and organizations to ensure that the key provisions of this roadmap are implemented. They, along with others in the industry, states, and interest groups, are invited to join the vast public-private partnership that this roadmap is meant to support.

Appendix C lists contact information for the U.S. Department of Energy's Office of Electric Transmission and Distribution. You are encouraged to follow up if you have questions, problems, or concerns.

A Summary of RD&D Needs to be Completed by 2010

"Grid 2030" Architecture

Backbone

- Evaluate and select architectural design
- Accelerate RD&D for "critical" technologies
- Develop a manufacturing infrastructure for next generation technologies
- Develop techniques for overlaying next generation technologies onto the existing grid
- Address security threats to eliminate outages and downtime
- Demonstrate use of new technologies on the grid to validate performance and reliability
- Develop suitable cryo-cooling technology (high Carnot efficiency, large size, ultra-high reliability, affordable)

Regional Interconnection

- Develop tools and techniques for fast network evaluation planning, operation, stability, and reliability
- Develop standard distribution system models for urban, suburban, and rural locations
- Determine conceptual design for the use of self correcting architecture
- Determine root cause analysis of power control systems break ups
- Update existing infrastructure
- Make critical technologies commercially available
- Lower cost and improve reliability of power electronics including converters/inverters, solid state current limiters, static voltage regulators, and solid state transformers
- Develop new protection scheme for two-way power flow
- Develop high speed, high accuracy and control algorithms for distributed control and protection systems
- Explore alternative distribution system concepts such as DC grids, high voltage, and multi frequency

Local Distribution

- Develop "ride-through" capabilities for end-use appliances and equipment
- Update existing infrastructure
- Develop standard distribution system models for urban, suburban, and rural locations
- Develop "ride-through" capabilities for end-use appliances and equipment
- Make critical technologies commercially available
- Integrate lower cost distributed energy resources into the distribution grid
- Develop new protection scheme for two-way power flow
- Depend on distributed energy for backup to distribution system for reliability services
- Explore alternative distribution system concepts such as DC grids, high voltage, and multi frequency

Critical Technologies

Advanced Conductors

- Develop new materials for advanced conductors (beyond composite, alloys, and high temperature superconductors)
- Develop advanced conductor materials using alloys and composites of aluminum, copper, polymers, carbon, dialectrics, magnets, supercapacitors, and others
- Develop advanced conductor designs for high-current-carrying capacity, low line losses, low-cost manufacturing, installation, and maintenance
- Develop lower cost construction and installation techniques for re-conductoring existing and building new facilities, for both overhead and underground
- Develop advanced conductors to reduce line sag and line losses
- Increase corrosion resistance of advanced conductors
- Develop environmentally friendly, economically efficient dielectric materials
- Test lines before installation on grid

High Temperature Superconductivity (HTS)

- Develop and demonstrate HTS cables, conductors, transformers, and fault current limiters (and other devices such as generators and electric storage) using the best available HTS wire for improving power flows and optimizing grid operations
- Develop HTS enabling equipment such as cryocoolers, cryopumps, and cryostats
- Develop fabrication techniques for mass producing commercial quantities of HTS materials, components, and equipment
- Refine cryo-cooler technology to ensure size/scale, high efficiency, and affordability
- Manufacturing scale-up of second generation HTS wire with a lower price-performance ratio than first generation HTS wire
- Multi-kilometer, AC HTS cable at transmission voltages completed
- DC HTS cable (hundreds of meters), including power electronic converters demonstrated
- Continue basic research to identify higher temperature superconducting materials

Electric Storage

- Conduct design and stimulation studies of manufacturing processes for all types of storage devices to identify opportunities to develop tools and techniques for lowering costs and improving performance
- Develop, field test, and demonstrate storage devices in all size ranges and application areas, including advanced batteries, flywheels, capacitors, and superconducting magnetic energy storage
- Explore novel electric storage systems
- Demonstrate lower cost energy storage system components such as batteries, flywheels, ultra-capacitors, power converters, and controls
- Design new devices for large-scale, bulk energy storage for incorporation on "Grid 2030"
- Complete development of storage for all relevant scales

Critical Technologies
Distributed Intelligence & Smart Controls • Develop intelligent sensors • Develop intelligent reconfiguration control systems and prototype technologies for robust, self-correcting controls • Develop distributed energy devices and combined heat and power systems for customer and utility applications • Develop control system for automated end use devices • Improve distributed energy resources • Develop and implement distributed energy interconnection policies and devices • Develop systems to integrate demand response resources into SCADA for assessment, control, and deployment • Improve technologies such as data visualization to address near-term monitoring and control issues on the existing transmission grid **Power Electronics** • Develop power electronics devices for integrating distributed energy resources into grid operations for safe, two-way power flows • Develop power electronics devices for distribution system operations including switches, transformers, and power conditioning • Develop power electronics devices for transmission systems operations including switchgear, fault current limiters, and static VAR compensators • Develop advanced materials for power electronics devices to increase durability, efficiency, reliability, and to lower costs • Make available low cost, high capacity power electronics that are modular, multi-level high voltage power conversion systems

Accelerating Acceptance of Advanced Technologies

Technology Transfer

- Expand the number of industry-led demonstration projects for evaluating advance electric delivery projects, including distributed energy resources
- Develop profitable business models for capturing the financial advantages of advanced electric delivery systems
- Encourage more effective integration and coordination on a pre-competitive basis among technology developers, equipment manufacturers, and potential users
- Assess models in other markets
- Encourage regulatory support for reasonable risk taking and investment in new technologies
- Clarify roles and responsibilities in transmission planning, siting, and permitting
- Demonstrate electric distribution planning and budgeting techniques that reveal financial advantages of new technologies

Education needs

- Raise awareness among utility industry executives, public utility commissioners, public interest organizations, and investors about the costs and benefits of new electric delivery technologies and distributed energy resources
- Develop new curricula in line with the vision for electrical engineering programs to attract students majoring in power systems
- Build better training programs for installing operating, and maintaining advanced electric delivery technologies and distributed energy resources
- Develop state-of-the-art simulators for crisis training and malicious attack conditions

Strengthening Electric Market Operations
• Develop, verify, and validate engineering and economic models of electric delivery system operations and disseminate to grid operators • Develop and use planning models to forecast local, regional, and national electric delivery resource requirements and provide planning studies to industry and public officials • Develop information management systems for collecting and disseminating large volumes of real-time data on grid operating conditions • Encourage national energy legislation and regulations that achieve the proper balance between federal and state jurisdiction in assigning responsibility for grid reliability • Conduct studies and simulations to assess the relative merits of alternative regulatory approaches to efficient and reliable market operations such as performance-based regulations, price and revenue caps, and market power penalties • Encourage federal and state restructuring efforts that provide incentives to encourage technological innovations • Encourage state and local regulators and code officials to eliminate unnecessary barriers to the expanded use of advanced electric grid technologies, including distributed energy resources and demand side management

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