Modern Grid v2.0
Powering Our 21st-Century Economy

THE MODERN GRID INITIATIVE

Conducted by the National Energy Technology Laboratory
for the U.S. Department of Energy
Office of Electricity Delivery and Energy Reliability
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Office of Electricity
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Reliability

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Throughout the 20th century, the U.S. electric power delivery infrastructure served our nation well, providing adequate, affordable energy to homes, businesses and factories. This once state-of-the-art system brought a level of prosperity to the United States unmatched by any other nation in the world. But a 21st-century U.S. economy cannot be built on a 20th-century electric grid.

Between now and 2020, more than $200 billion will be spent to maintain and expand our electricity transmission and distribution infrastructures, according to projections by the Energy Information Administration.

But without a modern grid perspective much of this money will be spent based on 20th century technology. Under a business-as-usual scenario—without a modern grid perspective—that would be like expanding the nation's telecommunications system without taking advantage of today's digital and wireless technologies.

This is why the decisions to modernize the grid are so vital. Will our nation follow a business-as-usual pathway? Or will we step up to the challenge of modernizing the grid?

With this massive investment comes a once-in-a-century opportunity to invest wisely—to not merely shore up America's infrastructure but to revolutionize its capabilities. With a coordinated and comprehensive modernization framework, the nation can invest more wisely and, over time, save billions of dollars.

A modernized system will mean value-added services and major benefits for consumers. Over the next two decades, consumers could look forward to:

- Near-zero wide-area blackouts.
- Rare localized interruptions and rapid recovery when interruptions do occur.
- Higher-quality power for sensitive electronics and complex computer applications.
- Greater consumer choice in how electricity is purchased and used, with price signals and other economic incentives like demand response (DR) to decide if and when to purchase electricity and whether to produce or store it using a distributed energy resource (DER).
- Increased ability to transfer low cost power.
- More efficient system operations.
- The plug-and-play integration of control systems, power electronics, and distributed resources.

- Improved resilience to terrorist attack and natural disasters.
- A cleaner environment

Each of these choices has already been demonstrated to provide numerous benefits to multiple parties. Technologies such as advanced metering and communications, smart thermostats and appliances, distributed generation and energy storage, have already been proven. They provide new abilities and tools to utilities, system operators, retail marketers, electricity consumers and policy makers - new tools for achieving their mutual and separate objectives.

This document describes the Modern Grid Initiative—its scope, stakeholder roles and responsibilities, project plan and timeline. It begins to explain why America needs to modernize its grid, as well as some of the associated challenges and opportunities. It also offers readers an opportunity to engage in the process of refining these concepts into a national plan for modernizing the grid.

Creating the modern grid will take a monumental effort by all stakeholders. With a clear vision, we can generate the alignment needed to inspire passion, investment and movement toward that vision.

To achieve this, your input is needed to more clearly define the vision of the modern grid. Your acceptance—which will ultimately lead to stakeholder alignment—is essential to getting traction and making progress toward achievement of the modern grid. Stakeholders can provide their input on defining and creating the modern grid by responding to the "Call to Action" at the end of this document.

INTRODUCTION

America's challenge is to transform the current grid structure into a modern grid that generates and distributes electricity more effectively, economically and securely and meets the demands of a changing society.

Within the U.S. Department of Energy (DOE), the Office of Electricity Delivery and Energy Reliability (OE) is taking up that challenge. In July 2003 and January 2004, DOE sponsored two stakeholder meetings that produced "Grid 2030" and the "National Electric Delivery Technologies Roadmap." These two documents crystallized the Department's vision of a modernized national electric system and, combined with industry guidance, led to the creation of the GridWise and GridWorks programs. Both of these programs focused on improvements to the reliability of the electric infrastructure through the research and development of key grid systems and components.

Throughout 2005 and 2006 DOE has sponsored the Modern Grid Initiative (MGI, the subject of this document) under the direction of the National Energy Technology Laboratory (NETL). MGI's mission is to develop and reach national consensus on a detailed vision and plan for grid modernization.

The Modern Grid Initiative is creating a shared national vision of a modern grid's principal characteristics and key technology areas. The Initiative is analyzing performance and technology gaps, developing a national concept of the modern grid, encouraging industry consensus and coordinating regional technology integration projects. It complements OE's mission, as well as industry efforts led by EPRI's Intelligrid, the Galvin Electricity Initiative, the GridWise Architecture Council, GridApps Consortium and others that have focused on raising national awareness about the need to radically improve grid performance, reliability and security.

For the fiscal year 2007 budget, DOE proposed the Visualization and Controls program, by folding GridWise, GridWorks and other related programs together. In addition, OE is funding an initiative at the National Energy Technology Laboratory (NETL) to further develop the ideas first laid out in "Grid 2030" and "National Electric Delivery Technologies Roadmap" in addition to its continued funding of the Modern Grid Initiative.

The National Energy Technology Laboratory has developed and will continue to develop a series of publications with details about the concepts and planned actions of the MGI. These documents include a technical description of the proposed national vision of the modern grid, a plan for conducting regional demonstrations of integrated technologies and processes, and a comprehensive set of brochures, white papers and presentations.

All of these documents provide a foundation for integrating stakeholder input and creating a common vision for the grid. Efforts continue to actively engage stakeholders in the Initiative through additional regional meetings, national meetings, working groups and the interactive website (www.TheModernGrid.org).

CHALLENGES AND OPPORTUNITIES

There are many reasons a modern grid is not emerging more quickly. Fundamentally, no single business owns or operates the grid. Individual players have little incentive to risk major change. With so many players in the grid system, finding a common interest in or vision for change is difficult.

A government-industry partnership is needed to recognize and account for the broad public and private benefits of modernizing the nation's electricity grid. The benefits are so broad and far reaching that only government can account for the cumulative value. Businesses are willing to make small improvements to parts of the system but they lack the long-term financial incentives to make changes that will improve the overall power system for decades.

Many challenges exist today and more will arise before the vision is realized. Some of the challenges the U.S. faces now include:

- Stakeholder involvement—Numerous stakeholders have an interest in creating a vision for the modern grid, but they differ in their ideas of what the vision is and how it should be achieved. Modernizing the grid will be a long and arduous journey; without stakeholder consensus, it will be nearly impossible.
- Regulatory impacts—The nation's uncertain regulatory climate has helped dampen grid modernization. Causes include incomplete industry restructuring, federal and state regulatory agencies' unfamiliarity with needed technologies and processes, varying phases of state-to-state deregulation, inconsistent setting of rates and investment recovery by state public utility commissions, and frequently unclear and inconsistent interfaces between these commissions and the Federal Energy Regulatory Commission.
- Human resources and training— America is fast losing the human skills to deal with advanced power systems and information technology needed to support a more modern grid. This is being driven by utility downsizing, retirement without replacement and low student enrollment in power engineering training programs.
- Other issues include:
  - Physical and cyber security threats will become progressively more sophisticated.
  - Many regions in the United States see generation shortages on the 10-year horizon, yet have limited plans to expand generation and transmission facilities.
  - Long approval times make transmission additions difficult.
  - Some areas depend on natural gas for up to 70% of their power generation while the supply, availability, and cost of natural gas over the long term is uncertain.

  - Programs for substantial increases in "green" power are impeded by inadequate delivery capacity.
  - While the focus of the policy community is on transmission issues, 90% of the outages and power quality problems initiate at the distribution level. Priorities may need to be adjusted.

These challenges are daunting but they can be overcome. In fact, they provide an opportunity to:

- Articulate a vision for the next generation of researchers, professionals and policy makers. Create a common understanding and a shared purpose regarding the most urgent modernization needs and each participant's ability to contribute to the solutions.
- Continuously engage stakeholders through modern grid summits, working groups and communication vehicles, and interactions with Modern Grid Initiative team members. Quickly engage and focus the best minds in government, industry, academia, national laboratories and research and development (R&D) organizations.
- Identify needed technologies and spur their development.
- Rectify the mutil-faceted regulatory environment through a balanced mix of legislation, policy, standards and incentives.
- Identify the true costs of poor reliability, inefficiency, uncertain power quality and other underperforming grid parameters. Create integrated physical-economic models that accurately predict the system impacts of various technologies and process improvements.
- Encourage investments that are consistent with the modern grid vision to realize net societal benefits.
- Promote the electric power industry as a desirable career path.

Through the Modern Grid Initiative, the OE and NETL will work objectively with all stakeholders to find acceptable solutions to the issues faced—federal, state, and local government, utilities, vendors, policy and regulation agencies, advocacy groups, consumers and others.

THE MODERN GRID INITIATIVE

The intent of the Modern Grid Initiative is to accelerate the nation's move to a modern electric grid by creating a flagship partnership between industry and DOE that invests significant funds in demonstration projects.

Projects to demonstrate advanced technologies will establish the value and feasibility of developing an integrated suite of technologies and processes that move the grid toward modernization. They will address key barriers and establish scalability, broad applicability and a clear path to full deployment for solutions with compelling benefits.

These projects will involve a full spectrum of national and regional stakeholders and multiple funding parties. The size, structure and goals of the regional projects will vary to maximize value to the participants and the regions in which the projects are located.

Following each project, results and lessons learned will be shared among regional participants, with on-going stakeholder activity to synthesize these results in formats that can be broadly discussed and disseminated.

It is envisioned that this program will consist of 10–15 projects carried out over five years. These will ultimately produce a set of modern grid design specifications for the nation. They will also support the creation of standards and guidelines for the utilities, consumers, vendors, regulators, researchers and trade associations that make up the electric grid industry.

ROLES AND RESPONSIBILITIES

The intent of OE is to engage all stakeholders in developing a shared vision of the modern grid and to help achieve that vision by conducting regional tests of integrated technologies and processes. Therefore in fiscal year 2005, OE asked NETL to explore the possibility of creating this coordinated national program to facilitate the modernization of the U.S. power system.

At NETL, these efforts have evolved into the Modern Grid Initiative, which is focusing DOE's related efforts into a long-term program. A successful effort will require coordination among OE, NETL and grid stakeholders. Specific personnel assignments, roles and responsibilities will be determined as the Initiative moves forward, and the following broad roles have been identified:

DOE OE:

- Provide project sponsorship, guidance, and direction.

- Integrate and coordinate with related DOE and federal government programs.
- Represent DOE in working with stakeholders.
- Provide partial project funding.

DOE NETL:

- Coordinate modern grid conceptualization.
- Facilitate stakeholder outreach.
- Define and manage advanced technology projects.
- Facilitate technology integration.
- Provide technical expertise.

Stakeholders:

- Review grid documentation and provide content and technical expertise.
- Participate in advanced technology projects.
- Provide partial project funding.
- Participate in Modern Grid Initiative working groups.

Federal, state and local governments will play a significant part in championing the broad societal benefits of a modern grid. As a neutral third party, government is uniquely positioned to convene the nation's top talent—academia, industry, national laboratories, consumer advocates and research organizations. Working together they will define a shared vision, develop innovative solutions and speed the adoption of new technologies and processes. It is also government's role to ensure that its appropriate stakeholders continue to be involved as the fully modern grid emerges.

DOE must play a major role in developing national programs that provide focused, systematic methods of examining the multi-faceted nature of the grid. Government-sponsored programs must provide new incentives for utilities and others to invest in transforming the grid.

The Modern Grid Initiative is providing the national leadership and the visibility needed for modern grid development. Working as a neutral broker with every stakeholder, the Modern Grid Initiative will accelerate our nation's achievement of the modern grid vision.

PROJECT PLAN

The following figure and text describe how the Modern Grid Initiative plans to move forward with a framework for accelerating the nation's progress toward the modern grid.

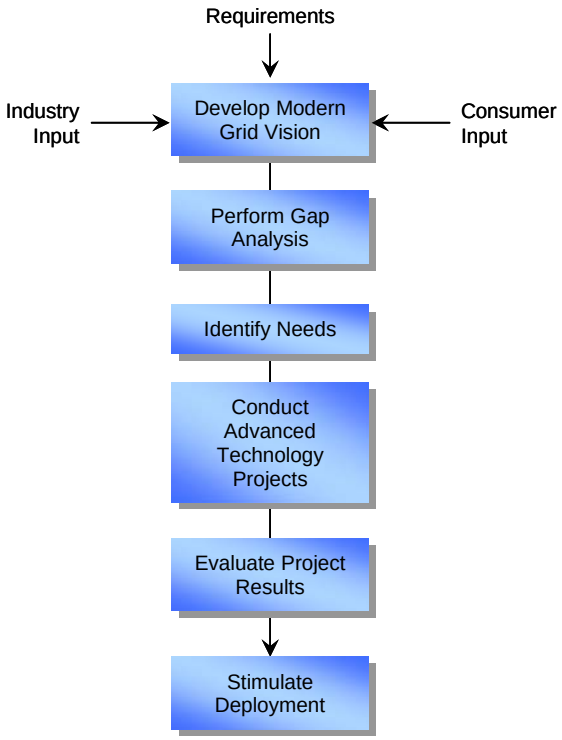

Figure 1: The Modern Grid Initiative project plan will provide the necessary framework to accelerate the nation's progress toward achieving the modern grid vision.

- **Develop a Vision of the Modern Grid**—Create the vision and define it through the grid's principal characteristics and key technology areas.
- **Perform Gap Analysis**—Determine the technology and research gaps preventing realization of the modern grid.
- **Identify Needs**—Identify technologies and processes needing assistance in widespread deployment and areas of research that require increased focus.
- **Conduct Advanced Technology Projects**—Demonstrate integrated technologies and processes that have the potential to achieve the modern grid principal characteristics.
- **Evaluate Project Results**—Appraise project results and benefits at the local or regional level and then extrapolate to the national level.
- **Stimulate Deployment**—Turn lessons learned from projects into modern grid business cases that include societal benefits and provide position papers to stimulate action.

Develop Modern Grid Vision

The U.S. power delivery system has the potential to make the kinds of leaps in capabilities and cost efficiencies seen in telecommunications and most other industries during the past decade. Similar advances will be made in power delivery capabilities

and efficiencies by implementing modern information technologies, along with other technologies and processes now emerging from the laboratory.

Investing in a coordinated national plan will be less costly and more beneficial than business-as-usual approaches. But widespread adoption and integration is seriously lagging. Various stakeholders have developed and implemented new technologies and devices over the past few years but these activities have been conducted with limited scope.

New technologies allow us to rethink grid design and operations. For example, a modernized grid will detect and address emerging problems before they impact service. Protective relaying will be the *last* line of defense, not the *only* defense as it often is today.

The modern grid will know much more about any emerging broad system problems and will respond to both local and system-wide inputs. This "self-healing" characteristic is one of seven principal modern grid characteristics identified, defined and proposed, all based on broad industry consensus.

The seven principal grid characteristics are the focal point for developing new strategies for grid research, technology development, regulation, integration, operation, maintenance and asset management. They can be briefly described as follows:

- Self-heals—The modern grid will perform continuous self-assessments to detect, analyze, respond to, and as needed, quickly restore grid components or network sections. Self-healing will help maintain grid reliability, security, affordability, power quality and efficiency.
- Motivates and includes the consumer—Consumers' active participation in electricity markets brings tangible benefits both to the individual consumer and to overall system reliability.
- Resists attack—Security requires a system-wide solution that will reduce physical and cyber vulnerabilities and recover rapidly from disruptions.
- Provides power quality for 21st-century needs—The modern grid will provide the quality of power desired by today's users, as reflected in emerging industry standards.
- Accommodates all generation and storage options—The modern grid will seamlessly integrate many types of electrical generation and storage systems with a simplified interconnection process analogous to "plug-and-play."
- Enables Markets—This characteristic is particularly important because open-access markets expose and shed inefficiencies. Therefore, the modern grid's information technology will provide detailed awareness of the factors that affect the supply and demand in electrical energy markets. The modern grid will also improve the connectivity between buyers and sellers of electricity.

- **Optimizes assets and operates efficiently**—The modern grid's assets and its maintenance will be managed toward one goal: to deliver desired functionality at minimum cost.

Five key technology areas emerge that support the achievement of the principal characteristics and ultimately the desired performance of the modern grid.

A focus on technology and innovation is required to achieve the functional specifications of the principal characteristics. The key technology areas proposed are the following:

- **Integrated Communications**—High-speed, fully integrated, two-way communications technologies will make the modern grid a dynamic, interactive "mega-infrastructure" for real-time information and power exchange. Open architecture will create a plug-and-play environment that securely networks grid components to talk, listen and interact.
- **Sensing and Measurement**—These technologies will enhance power system measurements and enable the transformation of data into information. They evaluate the health of equipment and the integrity of the grid and support advanced protective relaying. They eliminate meter estimations and prevent energy theft. They enable consumer choice and demand response, and will help relieve grid congestion.
- **Advanced Components**—Advanced components play an active role in determining the grid's behavior. The next generation of these power system devices will apply the latest research in materials, superconductivity, energy storage, power electronics and microelectronics. This will produce higher power densities, greater reliability and improved real-time diagnostics.
- **Advanced Control Methods**—New computer-based algorithms will be applied to monitor and control essential components and systems, enabling rapid diagnosis and timely, appropriate response to any event. They will also support market pricing and enhance asset management.
- **Improved Interfaces and Decision Support**—In some situations, the time available for operators to make decisions has shortened to seconds. Thus, the modern grid will require wide, seamless, real-time use of applications and tools that enable grid operators and managers to make decisions quickly. Decision support with improved interfaces will enhance decision making at all levels of the grid, including at the consumer level.

The Modern Grid's principal characteristics and key technology areas were identified by taking a systems approach. This approach led to the determination of the root issues facing today's grid and to a model that addresses these issues comprehensively.

The Modern Grid Initiative continues to engage in an on-going stakeholder outreach effort to further refine these concepts and

identify and address key regional and national issues. The Initiative is planning for a national meeting in early 2007, building on the series of stakeholder summits held during fiscal year 2006. This planning is being done in collaboration with GridWise Alliance, a key industry stakeholder group also committed to grid modernization.

Perform Gap Analysis

A gap analysis compares how an organization, process, or system is currently functioning compared with how stakeholders envision it functioning in the future. The analysis helps define the gaps—areas of improvement—that must be addressed to move to the future state.

The Modern Grid Initiative is following the gap analysis process as shown:

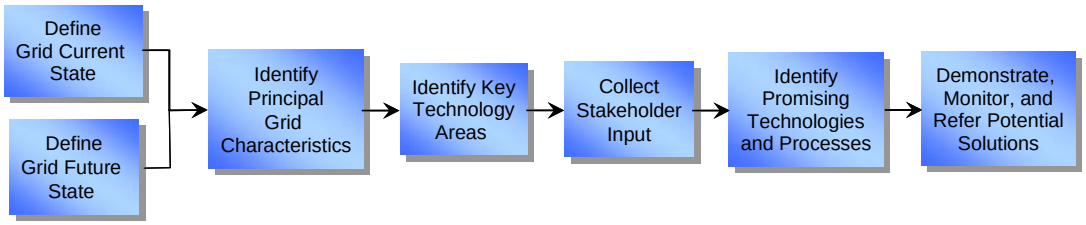

Figure 2: Modern Grid Initiative gap analysis process

The gap analysis will drive modern grid R&D strategies and regional demonstrations of integrated technologies, plus identify the processes to accelerate the effective development of the grid. This approach will optimize existing R&D successes and initiate new R&D efforts by ensuring a consistent relationship among evaluated needs, integrated technologies and processes, and R&D planning.

Identify Needs

From the gap analysis, technology and process needs and promising solutions are identified. These include technologies that are through their R&D phase and are ready for demonstration, or current R&D that deserves attention and possible acceleration, or areas of potential R&D that require increased emphasis. The following figure illustrates this examination:

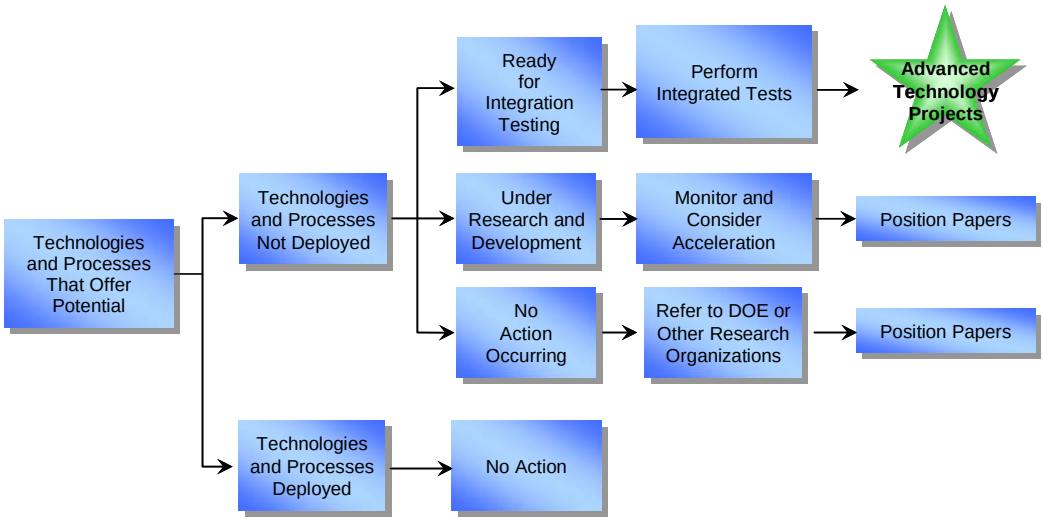

Figure 3: Modern Grid Initiative technology and process gap analysis

Technologies and processes in need of development fall under three categories:

- **Ready for integration testing**—These approaches have been successfully developed but they have yet to be demonstrated. Technologies and processes under this category will be evaluated for advanced technology projects.
- **Under research and development**—These approaches are currently in R&D but are not yet ready for integration testing. They require increased emphasis and perhaps funding. The Modern Grid Initiative will bring attention to these technologies to accelerate R&D and move them into demonstration and ultimate deployment.
- **No action occurring**—These approaches are not currently in R&D but they hold promise. Again, the Modern Grid Initiative will direct the attention of DOE or other research organizations toward these technologies and processes to accelerate R&D.

Conduct Advanced Technology Projects

The next step within the Modern Grid Initiative will be to design and perform regional advanced technology projects based on the developed vision, gap analysis and identified needs. The first step in this process will be smaller scale developmental field tests that will aid in the understanding of specific issues involved in creating successful regional projects.

As the initiative expands, NETL expects to launch fully integrated suites of promising technologies and processes in various locations around the country. Each project will address the specific needs of the region and will establish enhanced performance, scalability, broad applicability and a clear path to the full deployment of a suite of solutions that show compelling benefits. The size,

structure, and goals of each project will vary to maximize impact to the participants and the region in which the project is located.

These projects will involve a full spectrum of national and regional stakeholders, as well as multiple funding parties where DOE's contribution represents up to 50%. Project teams will share results and lessons learned among regional participants and make both available for dissemination and broad discussion.

This program is expected to:

- Measure the regional impact and benefits of applying new, integrated technologies and processes to the grid in six targeted key success areas:
  - Reliability
  - Security
  - Economy
  - Efficiency
  - Environmental friendliness
  - Safety
- Demonstrate the broad applicability of these technologies and processes and, using modeling and simulation, project their benefits at the national level.
- Analyze and demonstrate scalability.
- Enhance technology transfer and commercialization.
- Maximize cooperative funding.
- Leverage grid refurbishment needs (existing plans).

The fundamental steps of the program are:

- **Program Definition**—The needs identified through the gap analysis of technologies and processes will provide input to program definition. Stakeholder input will fully define regional needs and the scope and objectives of the projects.
- **Program Funding**—A significant level of non-DOE participation in these projects is expected by grid owners and operators, utilities, local and regional governments, and vendors. Funding will be determined as part of the program definition and planning process.
- **Program Plan**—The program plan will contain objectives and metrics, design specifications, and other technical requirements needed to implement the projects. It will include modeling and simulation analyses being performed to predict the program's outcome. Also through modeling and simulation, expected program benefits will be extrapolated to predict their impact on grid performance at the national level.
- **Project Management and Deployment Assistance**—A project team will be chosen for each demonstration project to include personnel from the appropriate stakeholder groups. Project

teams will be responsible for project execution and the communication of interim and final test results.

The program will significantly enhance the likelihood that the tools, technologies, processes and systems needed for a fully modern grid will be deployed. The program includes objective analysis and quantification of results, the effective coordination and communication of results across regions and stakeholders. The results become a credible basis for new policies, standards and incentives.

The program reduces modernization costs to individual participants through cost-sharing. DOE's investment is expected to catalyze a much greater investment by program participants and industry in general.

What a typical advanced technology project might look like

A 3-year project with $5 million from DOE and $10 million from non-DOE partners builds benefits on a communications backbone. It includes wireless or broadband over power lines as well as smart technologies such as diagnostics, digital controls, load control and remote switching. It also includes a spectrum of decision-making support tools such as smart agents, data mining and visualization, advanced models and simulators, and rapid detection.

During the life of the project, many or all of these and other tools and technologies are operated on an actual transmission and distribution system with quantified and analyzed benefits to regional transmission organizations, utilities and consumers.

Evaluate Project Results

NETL, in cooperation with project funders, participants, and interested stakeholders, will collect, analyze, trend and evaluate the results of the regional projects. These evaluations will consider technical results and financial implications, both of which will be extrapolated to the national level using modeling and simulation technologies.

Using these results, business cases will be developed that consider both the societal benefits and benefits to investors. These business cases are expected to lead to the identification of the technologies and processes that are most important to achieving the modern grid vision. Specific actions needed to stimulate their deployment will be identified.

Communication to all stakeholders will be broadly implemented through the Modern Grid Initiative website, working group interfaces, presentations, white papers and other communication vehicles.

Stimulate Deployment

The business cases are expected to identify specific areas where aggressive deployment is needed. In addition, specific barriers to widespread deployment will be identified. Actions needed to remove these barriers and enable widespread deployment will be identified and sponsored by NETL and OE.

Some of the areas in which assistance might be solicited include:

- Rule changes—Legislative actions may be needed to correct statutes that are inconsistent with the vision of the modern grid.
- Regulatory changes—Revision to federal and state regulations may be needed to resolve interstate inconsistencies among public utility commissions and improve alignment between the Federal Energy Regulatory Commission and the states.
- Standards adoption—New and revised standards that simplify deployment may be necessary to facilitate the deployment of modern grid technologies by the appropriate stakeholders.
- Financial incentive—Financial incentives funded by state and federal government may be needed to stimulate deployment, particularly for the solutions that have significant societal benefit.
- Consumer involvement—Consumers are expected to become increasingly involved as they receive information about demonstration results that hold promise for investment, cost-saving opportunities and improvements in lifestyles.
- Investment opportunities—Focus on deployment is expected to create new opportunities for investors, vendors, consumers, utilities and other stakeholder groups.

TIMELINE

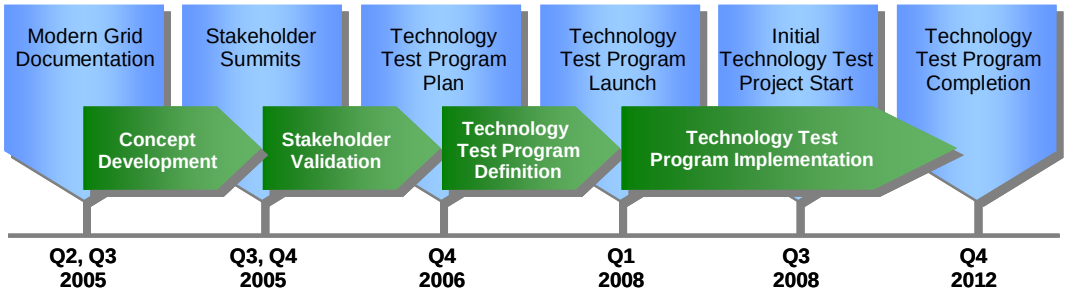

Figure 4: The Modern Grid Initiative timeline showing development at a high level view

The goal of the Modern Grid Initiative is to reach the stage where the nation has a set of detailed modern grid design specifications. This achievement will enable a consistent vision and set of standards throughout the utilities, consumers, vendors, regulators, researchers and trade associations that together constitute the electric grid industry.

To achieve a national set of detailed modern grid design specifications, it is important to prove and demonstrate the design and integration concepts. This will be accomplished through these advanced technology projects.

CALL TO ACTION

Creating the modern grid will take a monumental effort by all stakeholders. With a clear vision, we can generate the alignment needed to inspire passion, investment and movement toward that vision.

To achieve this, your input is needed to more clearly define the vision of the modern grid. Your acceptance—which will ultimately lead to stakeholder alignment—is essential to getting traction and making progress toward achievement of the modern grid.

To take action in support of the Modern Grid Initiative, please provide feedback to what you've read. You can do this through:

- Regional summit meetings of the Modern Grid Initiative, where you can personally provide your input.
- The Modern Grid Initiative website, where you can interact with team members to resolve questions and issues.
- Your leadership as a working group member, in which you can take an active role in the implementation of the Modern Grid Initiative.

We want your thoughts. Visit our website at www.TheModernGrid.org to find out when and where you can attend a stakeholder summit, how to speak directly with a team member and how to become involved in a working group.

For more information

This document is part of a collection of documents prepared by The Modern Grid Initiative team. For a high-level overview of the modern grid, see "A Systems View of the Modern Grid." It is available for free download from the Modern Grid Web site.

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