Five-Year Program Plan
for
Fiscal Years 2008 to 2012
for
Electric Transmission and Distribution Programs

A Report to the United States Congress
Pursuant to Section 925
of the Energy Policy Act of 2005

AUGUST 2006

U.S. Department of Energy

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1.0 INTRODUCTION

The Office of Electricity Delivery and Energy Reliability (OE) is the primary organization within the U.S. Department of Energy (DOE) for research, development, demonstration, technology transfer, and policy development activities for the electric transmission and distribution system. OE has prepared this program plan pursuant to the requirements of Section 925 of the Energy Policy Act of 2005 (EPACT), as outlined below. This plan delineates research directions and priorities.

1.1 Energy Policy Act of 2005

Title IX, Subtitle B of EPACT addresses distributed energy and electric energy systems. Section 925 calls for the U.S. Department of Energy (DOE) to "…establish a comprehensive research, development, and demonstration program to ensure the reliability, efficiency, and environmental integrity of electric transmission and distribution systems." Section 925 calls for the Secretary of Energy to submit to Congress a five-year program plan to guide activities in 11 areas[1]:

- Advanced energy delivery technologies including energy storage technologies, materials, and systems
- Advanced grid reliability and efficiency technologies
- Technologies contributing to significant load reductions
- Advanced metering, load management, and control technologies
- Technologies to enhance existing grid components
- High temperature superconductors
- Integration of distributed power systems including combined heat and power
- Small-scale distributed and residential based power generators
- Advanced grid design, operations, and planning tools
- Other infrastructure technologies
- Technology transfer and education

Within these areas, Section 925 calls for the Secretary of Energy to establish initiatives that:

- "…specifically focus on power delivery using components incorporating high temperature superconductivity, " and
- "…specifically focus on tools needed to plan, operate, and expand the transmission and distribution grids."

Subtitle B contains four other sections addressing technology development for distributed energy and electric energy systems:

- Section 921 authorizes appropriations for Fiscal Years 2007, 2008, and 2009 in the amounts of $240 million, $255 million, and $273 million, respectively.

[1] See Appendix A for a table that shows where these 11 areas are discussed in this plan. Appendix B contains a copy of EPACT Title IX, Subtitle B.

- Section 922 calls for the Secretary of Energy to "…establish a comprehensive research, development, demonstration, and commercial application to improve the energy efficiency of high power density facilities, including data centers, server farms, and telecommunications facilities."
- Section 923 calls for the Secretary of Energy to "…make competitive, merit-based grants to consortia for the development of micro-cogeneration energy technology." However, residential micro-cogeneration activities were completed in Fiscal Year 2006 following the completion of Phase 1 and no funds are in the Fiscal Year 2007 budget request for this area of activity.
- Section 924 says the Secretary of Energy "…may provide financial assistance…for demonstrations designed to accelerate the use of distributed energy technologies…"

This plan includes OE's approach to EPACT Sections 922, 923, 924, and 925. The plan is not resource constrained. In reality, resources are limited, and the Administration prioritizes activities annually in the President's Budget. Therefore, it is unlikely that all the activities included in this Plan will be undertaken.

Additional provisions in EPACT affect the scope and potential results of the activities outlined in this plan. For example, EPACT Section 1211 calls for the development of an "Electric Reliability Organization" (ERO) and implementation of mandatory and enforceable electric reliability standards. These standards are likely to affect investment decision-making by utilities and their assessments of the relative merits of advanced transmission and electric system reliability upgrades. EPACT Section 1221 calls for DOE to study transmission congestion and possibly designate constrained areas as national interest electric transmission corridors. Areas of transmission congestion that are identified in the study could be used to target locations for field testing and demonstrations of advanced distributed energy and electric systems.

EPACT Section 1223 defines nineteen advanced transmission technologies and calls upon the Federal Energy Regulatory Commission (FERC) to encourage their deployment, as appropriate. OE coordinates with FERC on a variety of technology, policy, and market issues, including the activities outlined in this plan, and will support their efforts to encourage the deployment of advanced transmission technologies.

EPACT Subtitle E contains amendments to the Public Utility Regulatory Policies Act (PURPA). Section 1251 calls for the adoption of standards for net metering; these can impact the interconnection of distributed energy systems with the electric grid. Section 1252 contains standards for smart metering and time-based pricing which affects electricity demand response programs and electric system resource planning and operations. Section 1254 calls for the adoption of standards for interconnection of distributed energy systems and calls for states to consider using the Institute of Electrical and Electronic Engineering (IEEE) Standard 1547 as the basis under which the states offer interconnection services. IEEE 1547 involves a set of standards (1547.1–1547.6) that IEEE requires be reaffirmed every five years.

1.2 Administration Guidance

The *National Energy Policy* (NEP) was published in May 2001. The NEP highlights the need for the Nation to address electricity transmission and distribution issues, expand investment in new technologies, tools, and techniques, and study the national transmission system. The NEP also highlights and specifically encourages the Federal Government to work with State and local Governments in implementing combined heat and power (CHP) and other distributed energy systems.

The *National Transmission Grid Study* (NTGS) was published in May 2002 and contains recommendations for research, development, demonstration, technology transfer, and policies for strengthening the Nation's electric transmission system. The NTGS calls for the creation of a new office in DOE focused on electric transmission and distribution issues. As a result, the Office of Electric Transmission and Distribution (OETD) was created in August 2003. One of OETD's first actions was the development of a national vision and technology roadmap for electric transmission and distribution. These efforts brought together more than 200 experts from electric utilities, equipment manufacturers, Federal and State Government agencies, national laboratories, and universities to develop a vision of the future for electric power in North America and chart technology, market, and policy pathways for getting there.[2]

The office was re-organized by Congress in May 2005 to include infrastructure security activities and was renamed the Office of Electricity Delivery and Energy Reliability (OE). (The Distributed Energy Program was transferred from DOE's Office of Energy Efficiency and Renewable Energy to OE in Fiscal Year 2006.)

The *Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations* was published in April 2004 and addressed the regional blackout that affected eight states in the Midwest and Northeast and one province in Canada. The U.S.-Canada Power System Outage Task Force was created to identify the root causes of the blackout and recommend solutions. The interim (November 2003) and the final (April 2004) reports of the Task Force contained recommendations for data analysis and visualization tools to improve the situational awareness of grid operators and improve communications to better detect, prevent, and respond to problems and keep them from cascading into regional outages.

The Fiscal Year 2007 budget request for OE seeks funding for high priority program activities. This five-year plan reflects funding requirements up to the authorization levels in Section 921, which is significantly higher than the President's Budget request for these programs. This plan will be used to help guide the future direction of OE's program activities; annual budget requests will take into account funding limitations and priorities.

1.3 Stakeholder Consultations

EPACT Section 925 states that in preparing this plan the Secretary shall consult with:

- Utilities

[2] U.S. Department of Energy, OETD "Grid 2030 – A national Vision for Electricity's Second 100 Years" July 2003 and "national Electric Delivery Technologies Roadmap" January 2004. These documents can be downloaded from www.oe.energy.gov

- Energy service providers
- Manufacturers
- Institutions of higher education
- Other appropriate State and local agencies
- Environmental organizations
- Professional and technical societies

OE routinely consults with these and other stakeholder organizations in a continuous effort to ensure that funded activities are relevant to the reliability and security of the Nation's electric grid and electricity consumers, and that they address critical problems in electric transmission and distribution planning and operations. These consultations involve both formal and informal workshops, conferences, and program review meetings.

For example, OE regularly reviews its activities so that they can be adjusted to respond to changing needs and opportunities. Peer reviews evaluate the technical and economic merit of activities. These reviews are conducted at least once every two years. Portfolio and risk analysis reviews assess program directions and priorities. The purposes, processes, and expected outcomes of these reviews are discussed in more detail in Section 10 of this document.

In preparing this plan, several meetings were used as opportunities for obtaining stakeholder inputs to guide research directions and priorities. For example:

- October 2005 – About 30 people from utilities, universities, equipment manufacturers, national laboratories, and professional and technical societies met to discuss research and development opportunities to assist with replacing electric transmission and distribution systems that were destroyed as a result of Hurricanes Katrina and Rita.
- December 2005 – More than 100 people from across the country including representatives of utilities, energy service providers, information technology companies, telecommunications services providers, universities, State and local agencies, national laboratories, and professional and technical societies met to discuss future architectures for the Nation's electric system and the integration of information, visualization, controls, and communications into grid operations.
- February 2006 – More than 100 people from across the country including utilities, energy service providers, manufacturers, universities, State and local agencies, and professional and technical societies met to discuss OE research and development activities and to provide inputs for this program plan.

EPACT Section 925 also calls for this plan to be prepared in consultation with other appropriate Federal agencies. Federal agency consultations include the Federal Energy Regulatory Commission, Department of Homeland Security, and the Department of Defense.

1.4 Federal Role

With the advent of more openly competitive markets for electric power, particularly at the wholesale level, utilities have the incentive to seek locally-optimized solutions which may not lead to the safety, security, and reliability needed regionally or nationally. Through collaborative research and development, DOE can facilitate the adoption of advanced technologies, tools, and techniques that address both local and national needs.

In general, DOE's principal tool for advancing technology is investing in high-risk, high-value energy research, development, and demonstration that the private sector does not have the financial incentive to develop on its own, given the competitive pressures of our market-based electric system. In addition, the Federal Government can help spur innovation and invention by developing new ideas and concepts, promoting information sharing and technology transfer, and facilitating collaborations among industry groups.

OE's strategy is to emphasize highly-focused projects that achieve aims vital to the electric system and the consumers it serves that will not be addressed by the private sector or the states without Federal support. Focus is placed on technology development that addresses the long-term needs of the power system but that also has the capability to contribute to today's critical challenges. Projects are selected as part of a broader strategy that involves partnerships with key stakeholders, particularly those who can influence and change conditions and circumstances that the Federal Government may be unable to influence and change on its own. These partnerships enable OE to leverage its resources and capabilities by conducting joint planning, information exchange, and cost-shared research, development, and demonstration projects with other Government agencies, national laboratories, universities, and the private sector. OE plays catalytic and facilitative roles since more than 80% of the Nation's energy infrastructure is owned and operated by the private sector.

1.5 Potential Benefits

A resilient, reliable, and secure electric transmission and distribution grid is paramount for the success of the economy and the public health and safety of citizens and businesses. Much of the system that is in place today was designed and constructed more than 40 years ago. These systems were not designed for the high-level and random nature of electric power transactions that occur today under competitive markets, nor were they designed to provide the high levels of reliability and power quality that many consumers demand today. In fact, the reliability-based power flows that result from competitive markets often result in grid congestion because of generation re-dispatch.

In this *"Information Age,"* growing levels of automation and computer controls require an electric grid that is far more capable than the one we have today. It requires real-time response; far fewer outages and power quality disturbances; more transmission and distribution capacity; better use of existing capacity; less grid congestion; and enhancements that enable new power supplies, both central-station and distributed energy resources, to be brought on-line to deliver electricity for meeting the growing requirements of the economy.

Activities outlined in this plan are designed to strengthen the reliability, energy efficiency, system efficiency, and security of the Nation's electricity delivery system. They seek to:

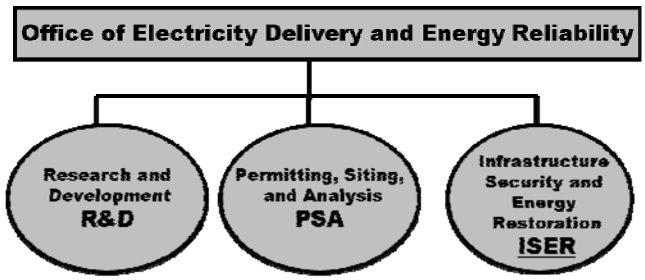
- Strengthen grid stability and reduce the frequency and duration of operational disturbances
- Increase efficiency of the electric delivery system through reduced energy losses
- Reduce peak demands and electricity price volatility

- Increase transmission and distribution asset utilization
- Improve access to new electricity supplies (including both those that require transmission such as new nuclear power plants or wind energy farms, and those located close to end-users such as combined heat and power systems and photovoltaic arrays)
- Harden grid operations systems so they are better able to detect, prevent, and mitigate energy supply disruptions from physical or cyber attack
- Accelerate restoration of services after energy supply disruptions occur

2.0 PROGRAM MANAGEMENT

The activities described in this plan are managed by DOE's Office of Electricity Delivery and Energy Reliability (OE). OE was formed in May 2005 when the activities of the Office of Electric Transmission and Distribution were combined with those of the Office of Energy Assurance. In Fiscal Year 2006 the Distributed Energy Program from DOE's Office of Energy Efficiency and Renewable Energy was transferred into OE.

OE consists of three operating divisions as shown in Figure 1:



R&D is focused on developing "next generation" technologies to modernize an electric transmission and distribution system operating under competitive markets. Key technology areas include: visualization tools and controls, grid reliability and market interactions, power electronics and enabling materials, distributed systems integration, and high temperature superconducting materials and devices. The activities outlined in this plan are managed by the R&D division. **PSA** is focused on developing market, institutional, and regulatory measures to modernize the electric transmission and distribution system and streamline siting and permitting of new electric transmission lines. **ISER** is focused on developing measures for enhancing the security and reliability of the energy infrastructure, including natural gas pipelines and storage facilities, oil and coal delivery systems, and the electric transmission and distribution system.

2.1 OE Mission and DOE Goals

OE's mission is to lead national efforts to modernize the electric grid, enhance security and reliability of the energy infrastructure, and facilitate recovery from energy supply disruptions.

As shown in the table below, OE's mission directly supports DOE's Energy Security Goals, especially Energy Security Goal 1.3.[3]

DOE's Energy Security Goals	Strategies to Reach DOE's Energy Security Goal 1.3 – Energy Infrastructure
1.1 Energy Diversity – "…increase energy options…reduce dependence…reduce vulnerability…increase flexibility"	▪ Develop advanced wires and coils to increase the capacity, efficiency, and reliability of the electric system. ▪ Advance real-time visualization and control tools to improve the reliability

[3] U.S. Department of Energy "Energy Security Section of the Draft Strategic Plan," Draft May 23, 2006

1.2 Environmental Impacts of Energy – "…reduce greenhouse gas emissions and other environmental impacts…" **1.3 Energy Infrastructure** – "…more flexible, secure, reliable, efficient, and higher capacity energy infrastructure…" **1.4 Energy Productivity** – "Cost-effectively improve the energy efficiency of the U.S."	and efficiency of the Nation's electric delivery system by increasing the utilization of transmission and distribution assets. ▪ Integrate advanced technologies, including distributed generation, storage, and load management on a constrained distribution utility feeder. ▪ Provide technical assistance to State and regional officials on policies and emergency response options to forge concerted actions to modernize the Nation's electricity grid.

2.2 OE Goals for Modernizing the Electric Grid, Enhancing Energy Infrastructure Security and Reliability, and Facilitating Recovery from Disruptions in Energy Supplies

The electric grid encompasses the transmission and distribution system itself and the rules, regulations, and business practices for planning and operations.

OE's strategic goal for modernizing the electric grid is to increase the efficiency, reliability, and security of the electric transmission and distribution system to meet the needs of the 21st century.

Modernizing the electric grid encompasses a broad set of activities aimed at improvements to technologies, markets, and policies. OE's strategy for electric grid modernization is to partner with other Federal, State, and regional agencies and the private sector to develop "next generation" transmission and distribution systems, to develop information systems and visualization tools to enhance grid operations and manage congestion, to create new planning processes for regional resource adequacy, and to help develop strategies that encourage innovation and technology change.

OE's strategic goal for enhancing security and reliability of the energy infrastructure is to mitigate the effects of natural disasters and man-made disruptions, including protection, prevention, detection, and information sharing.

The energy infrastructure includes electric transmission and distribution, natural gas pipelines and storage facilities, and oil and coal delivery systems. OE's strategy for enhancing energy infrastructure security and reliability, while modernizing the grid, is to partner with other Federal, State and regional agencies and the private sector to assess vulnerabilities and to develop strategies to manage risks; foster information exchange; facilitate planning processes; and to test and implement strategies for critical infrastructure protection.

OE's strategic goal for facilitating recovery from energy supply disruptions is to plan for and respond to supply disruptions by providing expertise and support to the Department of Homeland Security and to coordinate DOE activities.

Disruptions in energy supplies can be caused by acts of nature and by both deliberate and accidental acts of people. OE's strategy for facilitating recovery from disruptions in energy supplies is to partner with other Federal, State and regional agencies and the private sector to coordinate DOE's response to energy emergencies; and to assist all affected parties to recover from energy supply disruptions as rapidly as possible.

2.3 R&D Priorities

Innovation and the development of new technologies are critical for OE to achieve its mission and goals. This program plan is an "innovation blueprint" to bring the next generation of electric transmission and distribution technologies out of the laboratory and into the marketplace. It describes a set of activities that are currently underway in close coordination with key stakeholders including several of the Nation's most innovative electric utilities, State energy research and development agencies, equipment manufacturers, universities, national laboratories, trade associations, and research organizations.

Consultations with industry have led to a diverse portfolio of research, development, demonstration, and technology transfer projects. Priorities include the following areas of activity:

- Transmission and Distribution Grid Planning and Operations (Visualization and Controls)
- High Temperature Superconductors
- Distributed Systems Integration
- Power Electronics and Enabling Materials

In addition, several areas of activity that were authorized in Sections 922, 923, and 925 of EPACT are not included in OE's Fiscal Year 2007 budget request. These include (1) High Power Density Industry (Section 922), (2) Micro-cogeneration Demonstrations (Section 923), and (3) High Voltage Transmission Lines (Section 925g).

All of these areas of activity will be discussed in further detail in subsequent sections of the plan.

2.4 R&D Partnerships

Public-private partnerships will continue to play a critical role in conducting the research, development, demonstration, and technology transfer activities outlined in this plan. Successful R&D partnerships leverage resources through cost-sharing, help keep research directions aligned with industry needs, and provide opportunities for eventual users of the new technologies to learn about their costs and performance from the early stages of the development process.

This is a national program, and partnerships will be encouraged with organizations from all regions of the country, including equipment manufacturers, power companies, private research organizations, trade associations, and professional societies. Regional and State agencies, national laboratories, and universities also are encouraged to participate. Current R&D partners are listed in this plan in the sections that outline linkages to other programs and activities (sections 3.6, 4.6, 5.6, 6.6, 7.6, 8.6, and 9.6).

University centers and national laboratories will also continue to play a critical role. In fact, EPACT Section 925 (f) calls for the "…use of a geographically distributed center, consisting of institutions of higher education and national Laboratories…" to be involved in research, development, demonstration, modeling and analysis, and technology transfer activities outlined in this plan. OE currently works with several universities and national laboratories in conducting research, development, demonstration, analysis, and technology transfer activities.

3.0 Transmission and Distribution Planning and Operations Technologies (Visualization and Controls)

Blackouts, brownouts, reliability and power quality events, and increased congestion along transmission corridors and local distribution systems cost the U.S. economy billions of dollars each year.[4] These problems also jeopardize public health, safety, and well-being, and the productivity and economic performance of U.S. industries. Managing power flows across the grid is a complex challenge, even when supply and demand conditions are within normal operating parameters. With the volume of power transactions across the grid growing each year, managing regional and local power flows has become a greater challenge for system operators than ever before.

The review conducted by the North American Electric Reliability Council of the August 14, 2003, blackout found one of the contributing factors to be that "…system operators did not have access to the information necessary to monitor and understand system conditions." The focus of this area of activity is on the "next generation" of visualization and control systems to enable grid operators to detect deteriorating conditions or potential disturbances and take actions before problems cascade into more serious and costly electric reliability events. The intent is to develop technologies, tools, and techniques that will:

- Improve the response time to system disturbances to reduce the number and spread of outages
- Reduce operating reserve margins and allow the system to operate closer to its loading limits by improving sensing and real-time visualization of the state of the system and implementing advanced operational and control tools for faster and more robust response
- Enhance the cyber security of the transmission system's digital control, communications and automation systems to reduce the threat of energy disruptions and increase reliability
- Be responsive to, and well-coordinated with, the policies, processes, and practices of the ERO, which is to be established pursuant to EPACT Section 1211, to develop and implement mandatory and enforceable electric reliability standards.

This section of the plan outlines a set of activities that address the following topics from EPACT Section 925:

- Advanced energy delivery technologies
- Advanced grid reliability and efficient technologies
- Technologies to enhance existing grid components
- Development of advanced grid design, operation, and planning tools

[4] Lawrence Berkeley national Laboratory "Understanding the Cost of Power Interruptions to U.S. Electricity Consumers" LBNL-55718 September 2004

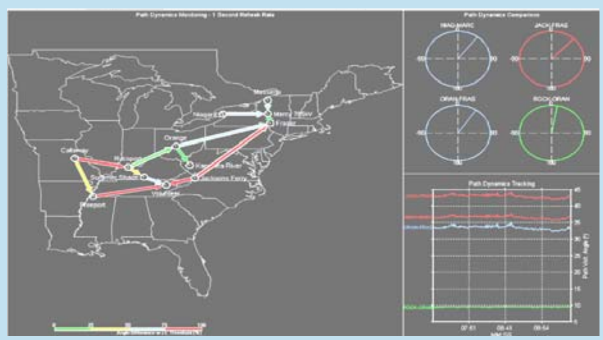
- Technology transfer and education

3.1 Situation Analysis and Current Status of Electric Transmission and Distribution Planning and Operations Technologies (Visualization and Controls)

The North American electric power system was designed, built, and operated as a vertically-integrated system under the control of local utilities. In many parts of the country this system is being used in ways for which it was not designed. Grid operations typically involve extensive communications and coordination among utility control areas and interconnections with neighboring utilities. In some parts of the country, including major load centers in the East, Midwest, and West, regional transmission organizations and independent system operators plan and manage regional electricity markets.

Phasor Measurement Projects

Grid operators can have a "wide area" view of power flows on the system – in near real-time – from the installation of phasor measurement units (PMUs) in key locations across the Eastern and Western United States. Data from the PMUs will provide a consistent framework for grid visualization displays and foster better communications among operators from different control areas to enhance situational awareness and help prevent cascading regional outages such as the one that occurred in the northeastern United States and Canada on August 14, 2003. DOE led a project to install more than 50 PMUs in the Eastern interconnection that provides data to a central data base and visualization system. PMU data can be used for event/disturbance analysis and can improve the speed, accuracy, and robustness of state estimation.



Grid operations typically involve control systems such as Supervisory Control and Data Acquisition (SCADA) systems and Distributed Control Systems (DCS) for monitoring and managing the flow of power across the grid. Energy Management Systems (EMS) incorporate SCADA and DCS data into network analysis tools which grid operators can use for load flow and optimal power flow estimation, stability analysis, state estimation, and contingency analysis.

Operators use contingency analysis, driven by state estimation from data collected by SCADA systems, to anticipate potential problems. Not all control areas have extensive network analysis tools such as state estimation. Existing time scales are too long (typically every five minutes) which restricts operational flexibility and response.

While SCADA/DCS perform vital functions in managing the power grid and maintaining system reliability, these systems are vulnerable to cyber attacks due to growth in:

- connectivity with the internet

- use of new technologies to improve productivity (e.g. wireless communications, advanced meter reading)
- demand from vendors, business operations, and market participants for more systems operational data

At the same time, sophisticated tools to carry out cyber attacks are being developed and are easily available (downloadable on the internet) for potential adversaries who are also becoming more technologically astute and capable of launching attacks that could cause major energy disruptions.

Grid operators are in the midst of a major transition from vertically-integrated markets to regionally-organized markets with “unbundled” generation, transmission, distribution, and power marketing, and from pre- to post-9/11 approaches to cyber-security. Analysis of the August 14, 2003, blackout found that situational awareness, wide area visibility, real-time information and analysis tools, time synchronized data, voltage management, and system modeling to define system states need to be improved if such events are to be avoided in the future.

In general, grid planners and operators need better tools to address unpredictable and unfamiliar load patterns, data overload, time limitations with understanding and reacting to dynamic system behavior, uncertainty about safety margins, grid congestion and bottlenecks, and threats from potential terrorist attacks. With the forthcoming establishment of mandatory and enforceable electric reliability standards, with oversight from the ERO and FERC, the need for better information, tools, and techniques will increase.

3.2 Long-Term Goal

The long-term goal for this area of activity is that by 2014 grid planners and operators will have technologies, tools, and techniques that are not available today to operate an automatic, smart, reconfigurable, and secure electric transmission network that enhances reliability, enables fast restoration from supply disruptions, accommodates decentralized operations and distributed systems, facilitates market operations, and is switchable, flexible, and capable of rapid changes in response to market needs. The underlying control systems will be designed, installed, operated, and maintained with the goal of being able to survive an intentional cyber assault, and other potential damage to cyber or physical assets, without loss of critical functions.

3.3 Key Technical Challenges

Achieving this goal requires that a number of technical challenges for electric transmission and distribution planning and operations technologies be addressed. For example:

- Completing the transition to a power grid that can be operated as a regional network with a hierarchy of control options to ensure greater security and reliability
- Completing the transition to a power grid that relies on market signals for supplies, reserves, and ancillary services and is able to respond automatically while maintaining security and reliability

- User-friendly tools and techniques for grid operators that can accommodate rapidly increasing numbers of market players and transactions and higher levels of system complexity
- Capabilities that can address the vulnerability of electric transmission and distribution to emerging threats from intentional attacks, both cyber and physical, and other extreme events that impact the system

3.4 Fiscal Year 2007 Baseline Activities

Activities in the Fiscal Year 2007 budget request include:

- Expansion of monitoring and control capabilities using GPS-synchronized data
- Development of technical principles for an open-architecture that enables interoperability among multi-vendor products and development of fault location and prevention strategies and devices
- Development of tools and techniques for operators to address localized cyber and physical disturbances
- Development and deployment of time-synchronized measurement technologies and sensors
- Testing and development of advanced approaches to enhance the cyber security of control systems
- Development of substation and ancillary equipment for improving grid operations
- Development of simulators/test beds capable of pre-insertion testing of new wide area control and protection systems

3.5 Key Activities for Fiscal Years 2008 to 2012 and Metrics for Measuring Progress

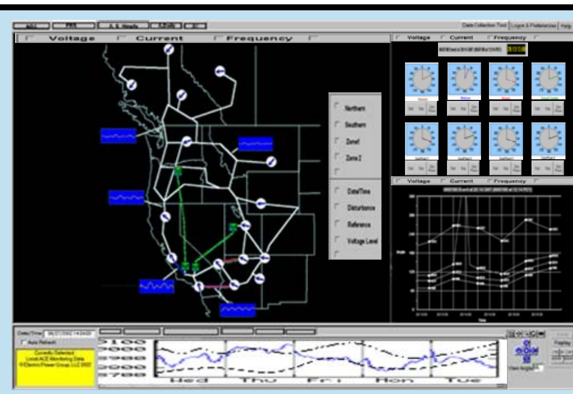
The technology development activities for improving electric transmission and distribution planning and operations include:

- **Sensors** for measuring system conditions involving a variety of physical metrics across the grid
- **System monitoring** to provide analysis tools and models for using measurement data to provide real-time information on grid operating conditions
- **Visualization tools** for portraying real-time information to enable grid operators to identify disturbances before they cascade into serious problems
- **Control systems security** for rapid response to disturbances and coordinated control of real and reactive power flow, frequency, and voltage in an increasingly expansive and complex system under changing market conditions, and reconfiguration, survivability, and restoration for extreme unplanned events
- **Grid architecture** designs for more integrated communications and interoperability of new transmission and distribution technologies
- **Technology Transfer** techniques to encourage innovation and commercialization through expanded field testing, technology showcases, and learning demonstrations

Sensors are an essential "building block" in providing the basic data for equipping system planners and operators with the real-time information they need for achieving the long-term goal of improved electric transmission and distribution planning and operations. Currently, real-time data collection is limited to about 100 sensors throughout the country. This key activity involves working with electric utilities to expand the breadth of coverage of sensors in the transmission systems and the depth of coverage in the distribution system. Sensors included in the deployment could include phasor measurement units (PMUs), new or replacement transmission line relays incorporating PMU capabilities, digital fault recorders with GPS-synchronization, intelligent electronic devices (IED) in substations for time synchronized circuit breaker monitoring, and sensors for dynamic line loading conditions (sag monitors). Activities include assessing the types of sensors, frequencies of measurement, and locations on the grid that will produce information for achieving more reliable grid operations, and developing strategies with electric utilities for their cost-effective deployment across the grid.

The technical objective is to increase deployment of at least 100 transmission-level sensors by 2009 and to initiate deployment of at least 100 distribution-level sensors by 2012. There will be an annual internal assessment, validated every other year by independent peer review, of the number of installations and the accuracy and usefulness of the information they are providing.

Better **system monitoring** is another key activity for utilizing expanded sensor measurements, real-time alarming and reporting, interconnection-wide state estimation, measurement-based sensitivities, and security assessments. Currently, there is a lack of automated reporting capabilities on system conditions; system status/modeling is often inaccurate; data sources have inconsistent data rates; and alarming criteria on high resolution data are mostly undefined. Activities include integration of phasor and SCADA data for state estimation; defining reporting requirements and procedures for early warning and threat analysis; resolving "seams" issues for interconnection-wide state estimation; implementing intelligent alarming; improving data synchronization and aggregation methods for more accurate analysis; creating advanced data fusion and decision-making tools; and accomplishing data acquisition of dynamic line ratings including thermal monitoring, voltage, stability margins, and damping monitoring.



Synchronized Phasor Applications

The technical objective for the activities under system monitoring is to develop by 2014 a family of specific tools and techniques for grid operators to strengthen state estimation capabilities and improve analysis of system dynamics. There will be an annual internal assessment, validated every other year by independent peer review, toward the development of specific tools and techniques. One activity will be the development of a tool for dynamic security by 2009 that will enable real-time assessment of voltage levels. Subsequent activities will involve the development of grid stability alarm systems by 2010 that will enable analysis of characteristic power oscillations; and development of a contingency evaluation tool by 2011 that will enable analysis of the ability of the system to withstand contingencies. If these activities are successfully implemented, this effort will culminate in the development of a set of system protection and control tools for automatic system reconfiguration by 2014 that will enable reactive power control, interruptible load management, and adaptive islanding. In the long run, it may become possible to merge this set of tools into a single suite of solutions based on real-time, large-scale, transient simulations.

Improved **visualization tools** are essential for achieving greater wide-area visibility and display and thus equipping grid operators with expanded capabilities for maintaining reliable and secure systems. Currently there is a lack of knowledge beyond control areas and limited dynamics monitoring capability. With fast-growing phasor networks there is the possibility of overwhelming operators with large volumes of streaming data. To address these issues, activities will include defining real-time, interconnection-wide visualization systems, involving human-factors experts to address visualization needs, and defining summary information displays to present relevant information in an integrated fashion.

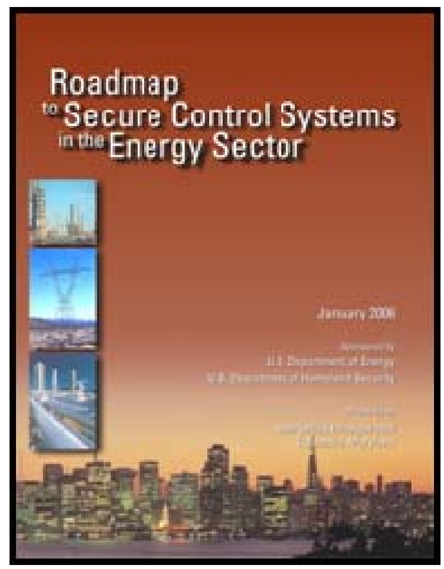
Control Room Displays

A real-time monitoring and visualization system, based on time-synchronized measurement of frequency, voltage and current, will provide visualization screens that display the status of the transmission system over a wide area in real-time. However, to take full advantage of this technology, new software applications must be developed that are fed with these measurements to calculate the "health" of the grid in real-time. The approach will be to first develop the capabilities for real-time data collection and begin to build a baseline for system performance. The next step will be to compare actual system operations to this baseline. This will enable the development of new diagnostics and operator cuing tools. This step will lead ultimately to automatic operation. This process is depicted in the following diagram.

Predictive Modeling → Real-time Data Collection → Diagnostics/Operator Cuing → Automation

The technical objective for visualization tools is to develop by 2014 the technical capabilities for automated system operations. There will be an annual internal assessment, validated every other year by independent peer review, toward the development of specific visualization tools and techniques. One activity will be to produce one diagnostics/operator cuing tool by 2009. Subsequent activities will involve development and refinement of four more additional tools by 2012. If these activities are successfully implemented, this effort could culminate in the development of one fully-automated system by 2014.

Development of enhanced **control systems security** for system protection and automatic control is essential for improved grid management and reliability, and ultimately fully-automated operations. Existing control systems typically lack the ability to mitigate transient stability based on real-time information, address voltage instabilities since they can be solved locally only to a limited extent, or incorporate traditional approaches based on local area measurement which are generally unsatisfactory against inter-area oscillations. More effective control systems are vital to the reliable operation of the grid. A critical issue to address is that there is currently limited ability to measure and address the vulnerabilities of control systems, detect intrusion, implement protective measures and response strategies, and sustain cyber security improvements over time. However, these systems have become more vulnerable to malicious cyber attacks as a result of increased adoption of standardized technologies with known vulnerabilities and the increased connectivity to the internet. The need to improve electric power control systems security is well-recognized by both the private and public sectors.[5]



Activities include facilitating a more comprehensive and national effort to develop secure control systems by working in partnership with industry and developing adequate test beds and new technologies such as low latency link encryption and key management technology to secure legacy systems, cost-effective stronger authentication technologies, and grid status monitoring. Efforts will be directed toward energy infrastructure security in accordance with Homeland Security Presidential Directive #7. Focus will be placed on the security of communications and controls specific to the energy infrastructure, including coordination with the Department of Homeland Security to ensure there is no overlap in efforts. Asset owners often see benefits in sharing certain information with one another to develop lessons learned, but they can also be reluctant to share specific, sensitive information. There is an important role for an unbiased, neutral agency (in coordination with the Department of Homeland Security) to collect and analyze information from the private sector about cyber security vulnerabilities, assist in understanding "lessons-learned," while at the same time protecting the sensitivity of the information.

The technical objective for the activities under control systems is to develop by 2014 the capabilities to evaluate and address threats from cyber attacks. There will be an annual internal assessment, validated every other year by independent peer review, toward the development of specific tools and techniques for making control systems more secure. One activity will be to produce a security evaluation tool by 2011 that will enable analysis of local and area-wide control system cyber vulnerabilities.

[5] The national Research Council identified *"protecting energy distribution services by improving the security of SCADA systems"* as one of the 14 most important technical initiatives for making the Nation safer. This and other reports led the White House to declare that *"securing DCS/SCADA is a national priority"* in *The National Strategy to Secure Cyberspace* (February 2003).

Contributing to the design of **new grid architecture(s)** is another key activity for improving grid planning and operations and achieving interoperability among various systems and subsystems that will comprise the 21st century grid. Currently, communications and controls protocols differ among utilities and equipment manufacturers and thus interfere with the development and deployment of new electric and transmission and distribution software and devices such as distributed intelligence, distributed energy systems, energy storage devices, control systems, and cyber-security protection. Activities include developing common standards, software, and hardware for the interoperability of equipment, developing better models and simulation tools for transmission and distribution planning and operations, and developing software and hardware (including advanced metering infrastructures, communications, and controls) for integrating demand response and distributed energy systems into grid planning and operations.

The technical objective of the activities under the new grid architecture is to use the Federal Government's unique ability to convene national stakeholder groups and support processes for developing common standards and protocols by 2014. There will be an internal annual assessment, validated every other year by independent peer review, of progress toward the development and deployment of grid designs that achieve interoperability of subsystems and components. One activity will be an assessment of baseline conditions in the industry for interoperability. Subsequent activities will assess accomplishments that enable industry to go beyond existing baseline levels.

A major barrier to more effective and modernized grid planning and operations is the relatively slow pace of technological change in the utility sector. Another key activity involves expanded field testing for getting advanced **technologies to the market**. Modular, affordable, and reliable substation and protective equipment is essential for modernizing aging electric system equipment and infrastructure, accomplishing greater energy and economically efficient utilization of grid assets, and enabling more rapid recovery from outages. Currently, there is a lack of hard data about the technical and economic performance of advanced technologies under realistic grid conditions. Utilities interested in such data often have to go overseas to get it. There is a need to develop simulators/test beds that are capable of testing new technologies in a "virtual grid" environment and that can be connected to a real-time system simulator that, in turn, can be linked interactively to a high-power test bed.

Activities include development of "next generation" and cost-effective solid state transformers and fault current limiters and flexible AC transmission system devices and to validate their performance under real-use conditions to mitigate market acceptance risks. There will be extensive coordination with electric utilities and equipment manufacturers to ensure the result is market-ready, robust, reliable, and fully tested and documented systems.

3.6 Linkages to Other Programs and Activities

The successful development and deployment of advanced electric generation systems (e.g., fossil, nuclear, and renewable) will require electric transmission systems for access to markets, particularly when these generation facilities are located far from load centers. One of the lessons from the August 14, 2003, regional blackout involved the operational difficulties encountered in accomplishing orderly and error-free shutdown and restart of the nuclear power plants that were taken off line when the grid went down. More effective and secure grid planning and operations technologies is an essential "enabler" of generation capacity expansions and the delivery of electricity from suppliers to consumers. Coordination on grid-related issues and activities will be accomplished with DOE's programs in fossil, nuclear, and renewable electricity generation.

Coordination will continue with FERC and with the North American Electric Reliability Council, including appropriate committees and subcommittees and the Regional Reliability Councils. Coordination with the activities of the ERO will be a top priority.

Coordination will also be accomplished with research, development, and demonstration activities of regional agencies including independent system operators, regional transmission groups, and multi-state, vertically-integrated power companies. National and regional organizations that are responsible for mandatory and enforceable electric reliability standards will be important stakeholders as well as organizations that represent the various companies that comprise the electric power industry (e.g., the Edison Electric Institute, National Rural Electric Cooperative Association, and the American Public Power Association); State regulatory and policy making agencies (e.g., National Association of Regulatory Utility Commissioners, National Council of State Legislatures, and National Association of State Energy Officials); individual utilities, national laboratories, private research entities (e.g., the Electric Power Research Institute, and the Consortium for Electric Reliability Technology Solutions); equipment manufacturers, and trade groups (e.g., the GridWise Architecture Council).

Coordination will continue with existing university research centers and national laboratories. Efforts to make control systems more secure from cyber and physical attacks will be coordinated with programs at the Department of Homeland Security.

3.7 Summary of the Five-Year Plan for Transmission and Distribution Planning and Operations (Visualization and Controls)

Key Activities	Technical Objectives	Metrics
Sensors	Expanded deployment	Up to 200 installations by 2012
Monitoring	Enhanced capabilities	Up to 3 analysis tools by 2011
Visualization	Enhanced capabilities	Up to 5 visualization tools by 2012
Controls	Enhanced capabilities	At least 1 security tool by 2011
Architecture	Expanded interoperability	Accepted protocol(s) by 2012
Technology Transfer	Faster acceptance	Up to 10 field test demos by 2012

<table>
<tr><th>Key Activities</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th></tr>
<tr><td>Sensors</td><td colspan="5">More extensive real-time information on grid conditions</td></tr>
<tr><td>Monitoring</td><td colspan="5">Faster identification of faults and disturbances</td></tr>
<tr><td>Visualization</td><td colspan="5">Faster and more precise response</td></tr>
<tr><td>Controls</td><td colspan="5">Cyber security protection</td></tr>
<tr><td>Architecture</td><td colspan="5">Interoperability among various systems and subsystems</td></tr>
<tr><td>Technology Transfer</td><td colspan="5">Validating performance to reduce technical risks and increase acceptance</td></tr>
</table>

4.0 High Temperature Superconductivity

High Temperature Superconducting (HTS) power equipment has the potential to become a key twenty-first century technology for improving the capacity, efficiency, and reliability of the electric delivery system. For example, higher capacity HTS power lines could provide a new approach to building transmission and distribution systems that will reduce the footprint and allow additional capacity to be placed in service within existing rights-of-way. When cooled to and operated at liquid nitrogen temperature (77K or -196^{0}C), HTS power equipment offers extremely compact, high-power density designs that offer significant reduction in power losses compared to conventional options.

Significant advances have been achieved in the production of First Generation (1G) HTS wires, which can now be purchased from U.S. as well as overseas manufacturers. Knowledge has been gained in demonstration devices using these 1G conductors. To achieve commercial acceptance as well as broad market penetration, however, the performance of HTS wire has to be improved and the cost has to be drastically reduced. Second Generation (2G) coated conductor has the potential to overcome the market barriers and enable successful commercialization in the electric power sector.

The focus of this area of activity is on applying high temperature superconductivity to the national effort to modernize and expand America's electricity delivery system. Core activities focus on researching and developing viable 2G coated conductor HTS wires that promise high performance at significantly lower cost than today's HTS wire. With strong industry partnerships, first-of-a-kind HTS electric power devices using the best available HTS wire are designed and tested under real-world operating conditions in order to facilitate the introduction of HTS products into the marketplace. Industry will also have the capability to produce HTS power equipment with a significant value proposition compared to conventional equipment, including smaller size, lower electrical losses, reduced environmental impact, enhanced systems impact, or some combination thereof.

This section of the plan calls for high temperature superconductivity activities to involve efforts in the following topics from EPACT Section 925:

- Development of high temperature superconductors to enhance the reliability, operational flexibility, or power carrying capability of electric transmission or distribution systems; or increase the efficiency of electric energy generation, transmission, distribution, or storage systems
- Establishment of a power delivery research, development, and demonstration initiative focused on using HTS components in our electricity delivery system
- Planned activities under the Power Delivery Research Initiative (PDRI) will include:
  - Feasibility analysis, planning, research, and design to construct demonstrations of HTS links in high-power DC and controllable AC transmission systems
  - Establishment of public-private partnerships to demonstrate deployment of HTS cables into test beds simulating a realistic transmission grid and actual grid insertions

4.1 Situational Analysis and Current Status of High Temperature Superconductivity

Twentieth-century power system components were based on traditional conductors using copper and aluminum wires. The opportunity now exists to modernize and expand the Nation's electricity delivery system with equipment using an emerging new capability: practical HTS wires that have 100 times the capacity of conventional wires without energy loss due to electrical resistance. This breakthrough enables a new generation of reliable grid equipment with typically twice the capacity of same-sized conventional equipment with only half the energy losses. Commercial versions of superconducting power cables, fault current limiters, transformers, generators, and motors are now under development and are expected to be available after 2012 – in time to accommodate expected load growth and to replace existing equipment, most of which will exceed its design lifetime during the next 15 to 20 years.

2nd Generation Superconducting Wire

When fully developed, wires made from high temperature superconducting (HTS) materials are expected to conduct 100 times more power than conventional wires of the same dimensions and are nearly 100% efficient. Presently, 1st generation (1G) wires are commercially available and used in several utility cable test sites, in commercial dynamic synchronous condensers to stabilize grid voltages, and in large prototype motors for U.S. Navy ships. Second generation wire is thinner and potentially lower in cost than 1G wire, and is beginning to be available in limited quantities. Using novel processes developed by DOE's national laboratories, 2G wire is under intense development including a recent record-setting accomplishment by DOE's industrial partner SuperPower, Inc. when they achieved 70,518 amp-meters in a 322 meter long 2G HTS wire. This achievement improved upon the previous record set by a Japanese institution by more than 18,400 amp-meters.

For full-scale commercialization of HTS electric power devices, further research and development of HTS wire, cryogenic dielectric materials, and refrigeration systems is needed. While 1G HTS wire is commercial and technically adequate for prototype demonstrations, its present and projected cost is too expensive and its performance is insufficient for large-scale electric grid applications. The properties and performance of 2G HTS wire are improving rapidly but are inadequate for most commercial applications. Short samples of 2G wire, prepared under laboratory conditions, do indeed meet or exceed most requirements for commercial applications. For 2G wire to enter the marketplace, production of kilometer piece lengths that have uniform short sample properties along their entire length is needed. To achieve competitive costs, faster manufacturing processes are needed. By 2015, 2G wire will be available that can carry 100 times the amps per square centimeter of copper wire at or below the price-performance of copper ($/kiloamp-meters) in power grid applications.

HTS applications operate at cryogenic temperatures, typically cooled by liquid nitrogen or gaseous helium. Custom refrigeration systems are required. Refrigeration systems are needed that are reliable, highly efficient and affordable. In addition, cryostat vacuum reliability needs to be improved for long HTS cable applications. There is limited industrial experience in selecting dielectrics that are proven to work well under conditions of high voltage and cryogenic temperatures. This is new territory for equipment manufacturers and electric utilities. Available cryogenic dielectric materials are limited and have not yet been fully characterized, especially in high voltage AC applications with acceptable partial discharge.

There have been public and private cost-shared demonstrations of first-of-a-kind electric power equipment such as cables, transformers, motors, generators, and a flywheel electricity system. Further work is needed to advance the design and operation of HTS components that will lead to the next generation of electric power equipment. While there has been one HTS demonstration cable reliably delivering electrical service to three factories since 2000, there is still limited experience with the operation of HTS devices on the electricity grid. In 2005, Tennessee Valley Authority installed and tested over a full-year timeframe a prototype HTS reactive power generator at a steel mill to support its transmission system. This led to TVA placing the world's first two commercial orders for HTS power equipment. Three other major utilities (American Electric Power, Long Island Power Authority, and National Grid) are installing advanced HTS cables on their grids. These distinctly designed HTS cables will begin operation during FY 2006–2007. In general, utilities still lack sufficient confidence in how HTS components will behave when inserted into conventional networks. Additional research, demonstrations, testing, and modeling can help provide the necessary understanding of how HTS components will behave under both normal and fault situations.

4.2 Long-Term Goal

Superconductivity has the potential for bringing a more fundamental change to electric power technologies than has occurred since electricity use became widespread nearly a century ago. The fiber optic "information superhighway" was constructed by replacing copper wires with a higher capacity alternative. Superconductivity provides an "energy superhighway" that will greatly improve efficiency and capacity. HTS technology has the ability to enhance present segments of our electricity delivery system, greatly increasing stability, efficiency, and reliability. The economic and energy benefits will be substantial due to HTS 2G wires that are a resistance-free alternative to conventional wires while carrying 100 times the amount of electricity; and to electrical equipment that is environmentally compatible, with half the energy losses and half the size of conventional alternatives.

The long-term goal is that by 2016, the use of HTS 2G wire will reduce the footprint for new transmission and distribution infrastructure and reduce energy losses. By 2020, HTS 2G wire will achieve the performance level of 1 million amp-meters (i.e., the capability of carrying 1,000 amps per centimeter width over a 1,000 meter long wire).

4.3 Key Technical Challenges

Achieving this long-term goal for HTS power applications requires 1) solving the difficult problem of manufacturing electrical wires from HTS materials – that require special processing before realizing their ability to carry large currents, and 2) designing super-efficient electrical systems that use these wires for transmission cables, fault current limiters, generators, transformers, and motors.

Fault Current Limiter

To maximize the critical current density, the HTS coating on a 2G wire needs to behave like an infinitely long single crystal. This result can be created if a textured substrate, or template, results in perfectly aligned grains in the deposited superconductor layer. The manufacturing process for this template causes misalignment of the grain boundaries and other microstructural defects.

Conductor research activities continue to expand our capabilities to process long-length conductors. Our objective is to bridge the gap between short-sample, laboratory tape fabrication and wire manufacturing to meet power system requirements. Technical challenges include finding less expensive ways of making the substrate template and faster ways for growing the deposited superconductor on the template, achieving end-to-end uniformity where the amount of current achieved over short lengths is possible over long lengths, and finding methods to enable the current to scale with superconductor thickness.

Conductor research focuses on both rolling-assisted biaxial textured substrates (RABiTS) and ion-beam assisted deposition (IBAD) substrate texturing methods. These methods are both being intensely developed by the national laboratories and their industrial partners.

Pulsed Laser Deposition Unit

At this stage, it is not clear which of several paths to a 2G wire will be most economic. Wire design is such that a substrate thickness of about 50 microns is needed to support a thick film (1 to 5 microns) of superconductor. Inclusion of sufficiently thick stabilizer layers will give a superconductor fraction of between 5% and 10% of the cross-section, compared with the 25%-50% for the first generation conductors made by conventional composite metal-working techniques.

Processing improvements need to be made in both coating and preparation of the underlying metal substrate. Coating improvements include faster processes, thicker films with higher current densities, and improved uniformity in long lengths. In order to improve process control and optimization, process diagnostics need to be developed for *in-situ* and *ex-situ* continuously processed 2G HTS coated conductors.

An exciting possibility is the ability to carry the equivalent of 1000 amps in a 1 cm wide metal tape through an HTS film 5 microns thick–the thickness of a few human hairs. Equipment designs are likely to improve dramatically when this new capability becomes available.

HTS technologies offer new attributes (high capacity, low impedance, ultra-compact footprint, and reduced environmental impacts) and entirely new functionalities (fault current limiting and overload protection). They may make the electricity delivery system more reliable, flexible, controllable, and self-protecting. They also raise new issues that need to be well understood and validated. With strong private sector participation, HTS prototype equipment needs to be designed, built, tested, and demonstrated. Such activities need to include advances in cryogenic dielectric materials and in cryogenic refrigeration systems. Advanced testing capabilities are needed to gain a better understanding of HTS power devices and their operating characteristics under normal and fault situations. Design refinements can be made based on the testing results. This research and development process is a necessary element in obtaining a sufficient level of confidence and acceptance of HTS equipment by electric utilities and other end-users.


Spool of HTS Cable

4.4 Fiscal Year 2007 Baseline Activities

Activities in the Fiscal Year 2007 budget request include:

- Conductor Research
  - Development of deposition processes that will improve the mechanical and electrical properties of 2G wire and will reduce processing times and costs
  - Extension of the ultra-high short-length electrical performance of 2G wire on scaling up to long lengths on the order of a few tens to hundreds of meters using commercially viable methods
  - Development of 2G wires that can carry high currents in the presence of strong magnetic fields
  - Continuation of support of the Department of Defense Title III Program to assure a domestic supply of 2G wires
- Strategic Research
  - Improvement of the understanding of basic HTS issues that will lead to the tailoring of optimal properties at specified fields and temperatures.
  - Simplification of template architecture and development of new metal templates
  - Development of innovative conductor designs to increase current carrying capability, reduce AC losses, and improve stability
- Cryogenic Systems and Dielectrics
  - Research and development of better electrical insulating materials for high-voltage superconducting applications operating at cryogenic temperatures
  - Development of reliable and efficient cryogenic cooling systems
  - Development of reliable, affordable cryostats for longer HTS cable applications
- Component Development and Prototype Testing

- Continuation of on-going prototype demonstration projects, including the three utility HTS cable projects, and an oil-free, easily transportable three-phase power transformer

- Power Delivery Research Initiative (PDRI) Planning
  - Issuance of solicitation and selection of power cable projects to demonstrate advantages of 2G wires and to explore projects such as high-capacity HTS direct current (DC) cable links and very low impedance (VLI) alternating current (AC) cables

4.5 Key Activities for Fiscal Years 2008 to 2012 and Metrics for Measuring Progress

The technology development activities for high temperature superconductivity include:

- Developing **2G HTS wires** that are commercially available
- Developing **reliable and economic refrigeration systems**
- **Researching, developing, and characterizing existing and new cryogenic dielectric materials** and creating design guidelines
- Developing **HTS components** and prototype testing
- Developing **PDRI testing, modeling, and research capabilities** and providing technical leadership for establishing reliability for HTS power applications
- **PDRI verification projects** for HTS power delivery cable systems, fault current limiters, and other electric power equipment

Activities will focus on research and development of the 2G wires–the underlying technology–in order to bring wire performance closer to meeting system requirements, while HTS power devices and systems are currently being developed and tested using the best HTS wires available today. This approach will effectively accelerate commercialization of full-scale HTS systems by the private sector.

Developing commercially viable 2G HTS wires that have high performance, low manufacturing costs, and favorable application characteristics is critical to the success of HTS power systems. Conductor research activities will include increasing the current carrying capacity of 2G wires using commercially selected methods and maintaining this capacity over long kilometer lengths; improving performance in strong magnetic fields using commercially selected methods; developing *in-situ* deposition control and quality assurance methods; reducing AC losses, and developing low-cost, high throughput commercially scalable processes that will achieve the wire cost target.

The technical objective for developing commercially viable 2G HTS wire is to achieve by 2020 a current carrying capability of 1,000 amps over a wire that is 1,000 meters (1 kilometer) long. The price of HTS wire is based on the kiloamp-meter, the cost of one meter of wire capable of transmitting 1,000 amps per centimeter width of electrical current. By 2015, a prototype 2G wire will cost at or below the price-performance of copper ($/kiloamp-meters) in power grid applications and carry 100 times the amps per square centimeter (electrical current across the wire's cross-sectional area) as compared to copper wire. By

2009, 2G wire will achieve 50 times the current carrying capacity of copper and by 2011, 2G wire will achieve a 70 times improvement. The way to achieve this goal is to improve performance and reduce cost.

Current carrying capacity (amps) needs to be raised over longer lengths (meters). By 2010, performance reduction due to scaling up to long lengths will be reduced from the present level of about 60% to a more acceptable level of 25%. By 2012, the current capability reduction with length will decrease to 5%.

Three-in-one HTS Cable System

Primary performance metrics for evaluating progress toward the achievement of these goals are amps per unit width of the conductor, conductor piece length, uniformity of properties along the length, current capacity and AC losses in applied external magnetic fields, and mechanical properties such as tensile stress and strain and bend radius at cryogenic temperatures. Today, the current density of 2G wire decreases by an order of magnitude when operated in perpendicular magnetic fields above 2 tesla at 77K. By 2011, flux pinning defects will be understood to the point of being able to manipulate the shape, size, and distribution of defects and pinning centers to minimize current density decreases under applied magnetic fields.

Primary cost-related metrics are processing speed, deposition rate and production volume. By 2012, cost reductions will be achieved by developing a continuous fabrication technique using simplified conductor architecture, for example with a single or two-level multi-function buffer layer, or significantly accelerated deposition rate compared to present levels.

HTS technologies depend on high-performance, ultra-reliable refrigeration systems. Activities will be focused on **improving cryogenic refrigeration systems** and long cable cryostats to achieve cost, efficiency, and reliability targets.

The technical objective for this activity is to develop by 2020 refrigeration systems that are more efficient, lower cost, and more reliable than current systems. There will be an annual internal assessment, validated every other year by independent peer review, of the progress toward completing the objective using the following milestones: efficiency needs to reach 20% of the ideal Carnot efficiency by 2012; cost should be reduced to $75/watt removed at liquid nitrogen temperatures by 2010 and further reduced to $25/watt by 2020; and system reliability which is 95-99% today and not sufficient for grid applications, should be proven at 99% by 2012, and achieve 99.9% reliability by 2015.

The cryogenic environment is harsh for dielectric materials that will experience thermal and mechanical stresses and high-voltage partial discharge conditions. **Cryogenic dielectric research** will fully characterize existing materials in AC and DC applications and then research, develop, and characterize new dielectric materials that have improved electrical and mechanical properties at cryogenic temperatures. The resulting information will create a database of cryogenic insulation.

The technical objective for this activity is to develop by 2012 a database of cryogenic insulation that can be used to establish design rules for practical HTS grid devices. There will be an annual internal assessment, validated every other year by independent peer review, of the progress toward completing this database. The first activity will be to fully characterize existing materials in AC and DC applications by 2009. Additionally, by 2010, criteria should be established and IEEE testing standards for cryogenic dielectrics at distribution and transmission voltages up to nominal 161 kV. Subsequent activities will be to research, develop, and characterize new dielectric materials that have improved electrical and mechanical properties at cryogenic temperature by 2012.

HTS Refrigeration Subsystem

HTS component development and prototype testing activities include completing the existing portfolio of industry-led 1G-based demonstrations including the three utility-hosted power cable projects. With 2G wire becoming available in useful lengths; it is desirable to pursue device development using 2G wire in non-cable applications. A competitive solicitation where 2G wire will be used will be issued in FY 2007.

The technical objective for this activity is that by 2010 industry will have the capability to produce HTS power equipment at half the size (or twice the power capacity) and half the energy losses of conventional equipment with the same power rating. There will be periodic independent technical readiness reviews and an annual independent peer review.

The following activities are for the **Power Delivery Research Initiative (PDRI)**. PDRI activities will focus primarily on power cable demonstration projects and associated laboratory research and testing as well as modeling and simulation capabilities. The major purpose of PDRI is to accelerate the industrial commercialization of HTS power cables by establishing their performance and reliability.

Utilities require much testing, simulation, and validation in order to gain a complete understanding of new technology and have sufficient confidence before adopting it. A mistake can be catastrophic. Activities during the planning period for PDRI will provide technical leadership for **establishing the reliability of HTS power applications**, including suitable modeling and analysis. Data from research, demonstrations and testing will be used to develop accurate modeling and simulation tools to show how HTS components behave in a grid and interact with conventional elements in both normal and fault situations, especially in conjunction with AC flow control devices such as Flexible AC Transmission Systems (FACTS) or phase angle regulators (PAR).

The technical objective for this activity is to develop by 2012 modeling and simulation tools that can benchmark how HTS components function in the grid. There will be an annual internal assessment, validated every other year by independent peer review, of the accuracy of the tools and their ability to provide value to the resource planning process. The first milestone will be an assessment of existing modeling and simulation tools.

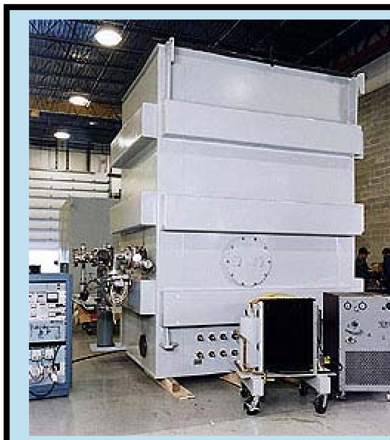
Research and testing efforts will be conducted to advance HTS technologies toward performance and design targets required for broad industry acceptance. **PDRI testing capabilities** will be developed for HTS power applications, in partnership with manufacturers and utilities. Research and testing capabilities will be developed to support fault current testing at transmission and distribution voltages. This will accelerate the industry's understanding of fault current behavior. A cryogenic high-voltage test capability will be established to support testing of high voltage cryogenic dielectrics. Transmission power electronics test capabilities will be needed for AC and DC cable flow control experiments. These capabilities will be made available for joint industry-national laboratory research and testing of AC flow control, DC inverter/converter (power electronics), cable systems, and cryogenics. The technical objective is to have test capabilities in place by 2010.


HTS Motor

PDRI verification projects focused on complete and integrated HTS power cable systems will be initiated. These demonstrations will have a systems research and testing component. The projects will also incorporate feasibility analysis, planning, research and design activities that will support demonstrations of HTS power links and facilitate the commercial transition toward direct current power transmission, storage, and use for high power systems using high temperature superconductivity; and facilitate the integration of very low impedance HTS wires and cables in existing electric networks to improve system performance, power flow control, and reliability. In addition, grid interconnectivity features will be tested and understood. Testing capabilities will reduce technical risks to the overall success of the cable demonstrations. Testing can simulate insertion into a realistic electricity delivery system or a location that most likely will see commercial-scale deployments as well as in-grid insertions.

The technical objective for this activity is that by 2016, the operating characteristics and reliability of high-capacity AC and DC HTS cable systems are understood, predictable, and have reached the threshold of acceptability to the industry and the technology is ready for commercial deployment. The use of HTS wire will reduce the footprint for new transmission and distribution infrastructure and reduce energy losses.

Progress will be evaluated in PDRI power cable development by demonstrating in-grid distributed commercial-grade transmission level HTS cable with cooling stations and controllability by 2012.


5/10 MVA HTS Transformer

4.6 Linkages to Other Programs and Activities

DOE's Superconductivity Program facilitates the integration of industry, national laboratories, other agencies, and universities into a coherent, aggressive program of concurrently developed HTS technology development and system design and demonstration. The program works closely with electric utilities in order to realize the potential benefits. The HTS program has a long history of successful industry participation and collaborative efforts. Private industry is involved in the planning, review, and research aspects of the program in order to develop as many HTS applications as possible. The program greatly leverages funding in order to accelerate the development of HTS electric power equipment.

The Program coordinates its activities with several other Federal agencies. The DOE Office of Basic Energy Sciences makes valuable contributions to the underlying knowledge base needed for the success of HTS technologies. The National Institute of Standards and Technology (NIST) has worked with the program in developing databases of HTS material properties that are used to determine promising processing and fabrication methods. The Department of Defense (DOD) has been a close partner. DOE has coordinated with the Naval Research Laboratory's HTS motor development activities and the Air Force Research Laboratory's HTS research and development activities. Most significantly, the joint support of the DOD Title III activities to fund the private sector's coated conductor pilot production facilities will assure a domestic supply of 2G HTS wire.

Coordination will continue with existing university research centers and national laboratories.

4.7 Summary of the Five-Year Plan for High Temperature Superconductivity

Key Activities	Technical Objectives	Metrics
Develop commercially viable 2G HTS wires	Increase current carrying capability over length and reduce cost	▪ By 2009, achieve 50x current capacity of copper; by 2011, 70x; and by 2015, 100x at or below the price-performance of copper ($/kiloamp-meters) ▪ By 2020, 2G wire can carry 1000 amps per cm width over a 1000 meter long wire at 77K, self field
Develop reliable, economic refrigeration systems	By 2020, develop refrigeration systems that are more efficient, lower cost, and more reliable than current systems	Efficiency needs to reach 20% of the ideal Carnot efficiency by 2012; cost should be reduced to $75/watt removed at liquid nitrogen temperatures by 2010, and further reduced to $25/watt by 2020 and system reliability should be proven at 99% by 2012
Characterize and develop new cryogenic dielectric materials and create design guidelines	By 2012, establish design rules based on the full characterization of mechanical and electrical properties of existing and new dielectric materials at cryogenic temperatures	▪ By 2009, fully characterize existing materials at high voltages and cryogenic temperatures in AC and DC applications ▪ By 2010, establish criteria and IEEE testing standards for cryogenic dielectrics at distribution and transmission voltages up to nominal 161 kV ▪ By 2010, develop design rules based on existing materials ▪ By 2012, fully characterize new

Key Activities	Technical Objectives	Metrics
		dielectric materials at high voltages and cryogenic temperatures ▪ By 2012, develop database of cryogenic dielectric materials and update design rules
Develop HTS components and prototype testing	By 2010, industry will have the capability to produce HTS electric power equipment with one-half the energy losses and one-half the size of conventional units	▪ Complete 1G-based demonstrations including three utility-hosted HTS power cables ▪ Select 2G-based, non-cable projects in FY 2008
Develop PDRI research and testing capabilities	▪ By 2012, develop modeling and simulation tools that can benchmark how HTS components function in the grid ▪ Establish the following world-class research and testing capabilities: high current and high voltage testing for cryogenic dielectric materials; DC power testing; power electronics testing; and energy storage evaluation ▪ During 2008-2011, perform tests of power cables and fault current limiters	▪ Accuracy of tools and their ability to provide value to the resource planning process ▪ Test capabilities available by 2008-2010: ▪ Ability to test HTS grid components operating at 138-161 kV ▪ Ability to test cables up to 100-m long, up to 10,000 A and 15 kV with cryogenic end terminations ▪ Ability to test fault current limiter ▪ Ability to test DC cable
PDRI verification projects for HTS power cable systems	▪ By 2008, establish public-private partnerships to demonstrate grid-connected HTS power cable systems ▪ During 2008-2011, conduct feasibility analysis, planning, research and design activities to support demonstrations and facilitate integration into existing electricity networks	▪ Issue solicitation for public-private cost shared HTS power cable projects ▪ Expand demonstration readiness reviews to incorporate additional analytical studies to facilitate utility confidence and market acceptance ▪ Demonstrate in-grid distributed commercial-grade transmission level HTS cable with cooling stations and controllability by 2012

Key Activities	2008	2009	2010	2011	2012
Develop commercially viable 2G HTS wires	*Improving performance and reducing cost*				
Develop ultra-reliable, economic refrigeration systems	*Meeting cost, efficiency, and reliability targets*				
Characterize and develop new cryogenic dielectric materials and create design guidelines	*Characterizing existing and new materials, developing database and design rules*				
Develop HTS components and prototype testing	*Meeting efficiency, power density (footprint), and reliability targets*				
Develop PDRI research and testing capabilities	*Establishing reliability for HTS power applications*				
PDRI verification projects	*Testing capabilities and expertise developed with industry and Government resource leveraging*				

5.0 Distributed Systems Integration

The focus of this area of activity is on developing secure local energy networks and integrating a portfolio of distributed systems (distributed energy and demand response resources, including certain industrial, commercial, and residential loads) with electric system planning and operations. The integration will (1) improve overall system reliability while providing varying reliability levels to meet individual consumer needs, (2) enhance the resiliency of the system against energy supply disruptions, and (3) reduce vulnerabilities by enabling safe "islanding" of critical infrastructure for faster restoration of service.

This section of the plan outlines a set of distributed systems integration activities that address the following topics from EPACT Section 925:

- Advanced energy delivery technologies and energy storage technologies
- Technologies contributing to significant load reductions
- Advanced metering, load management, and control technologies
- Technologies to enhance existing grid components
- Integration of power systems, including systems to deliver high-quality electric power, electric power reliability, and combined heat and power
- Supply of electricity to the power grid by small-scale, distributed and residential-based power generators
- Technology transfer and education

5.1 Situation Analysis and Current Status of Distributed Systems Integration Technologies

Distributed energy resources encompass a portfolio of fossil and renewable energy generation technologies (e.g., photovoltaic arrays, wind turbines, microturbines, reciprocating engines, fuel cells, combustion turbines, and steam turbines); energy storage devices (e.g., batteries and flywheels); and thermally activated technologies (e.g., chillers and desiccants) that can be combined with generating technologies for combined heat and power (CHP) systems. Also included are demand response (DR) technologies, tools, and techniques.

Distributed energy systems are small-scale (from under 10 kilowatts up to 60 megawatts), modular, designed for locations close to consumers, and are generally not owned and operated by utilities. They can be used periodically when system conditions require emergency power and demand response (tens to hundreds of hours per year), used regularly when fuel sources warrant such as solar and landfill gas (hundreds to thousands of hours per year), or run almost continually for combined heat and power systems (several thousand hours per year). About 4%[6] of the Nation's electric capacity comes from distributed energy systems today, although the majority of this is provided by relatively

[6] Based on EIA data of 962GW of net summer capacity and 35GW of CHP, base load, and peaking DER units sized under 60MW from Resource Dynamics Corporation report *The Installed Base of U.S. Distributed Generation.*

large combined heat and power units serving the pulp and paper and petrochemical industries.

Although distributed energy systems are commercially available, continuing technology advances are needed to lower costs, improve systems integration and interoperability, reduce emissions, and increase fuel flexibility. Despite their commercial availability and increasing capabilities, a wide gulf in market acceptance remains because distributed energy systems are: (1) not typically considered in electric utility resource planning, (2) not consistently assessed for their benefits and costs, (3) not generally facing retail price signals that reflect the marginal costs of electricity supplies, and (4) not being designed for and lack communication and control solutions for integrated applications on the electric distribution grid, such as microgrids and local energy networks.

Integrated Energy System

UTC Power's first generation packaged Integrated Energy System is an ultra-efficient natural gas driven combined cooling, heat, and power system. The PureComfort™ system was developed with DOE support and is capable of satisfying a building's energy needs with or without the grid by providing electrical output, high efficiency, and environmental benefits with 70%+ overall system efficiency. The first skid mounted rooftop system was installed at an A&P Fresh Market in Mt. Kisco, NY (including an optional desiccant dehumidification unit powered by waste heat from the microturbines). Another system installed in Connecticut at East Hartford High School operates during normal hours but can also provide emergency back-up power. PureComfort™ systems are also operating in Simi Valley California at the Ronald Reagan Library.

Through demand response programs, industrial, commercial, and residential consumers and equipment (including distributed generation and storage) can participate in electric markets and contribute to demand-side management to reduce peak demand and enhance system reliability. Interest in demand response programs is increasing following a recent period of relative decline. According to DOE's Energy Information Administration, for example, actual delivered peak demand reductions from demand response resources in 2004 were about 9,000 MW (1.3% of total peak demand), which is about 40% less than the reductions achieved in 1996. The use and effectiveness of demand response is limited by: (1) the lack of transparency in electricity pricing and the limited availability of time-based rates, (2) the lack of communications, control, and optimization technologies and advanced metering infrastructure(s) to facilitate customer responses to price or load control signals (3) the lack of standard methods and definitions for estimating and communicating costs and benefits,

Industrial Advanced Turbine System (ATS)

and (4) the lack of consistent treatment of demand response resources in electric resource planning.[7]

Distributed energy systems can provide voltage regulation support and reactive power. Dynamic reactive power control and local voltage regulation from distributed energy resources can be a significant help to constrained feeders.

5.2 Long-Term Goal

The long-term goal for the future of distributed systems integration is for distributed energy and demand response resources to be fully integrated into local distribution systems to realize their maximum benefits and impacts on reliability, security, affordability, and efficiency of electricity delivery. To achieve this, the intermediate goal is to demonstrate the cost-effective integration of distributed energy and demand response for added system capacity and the enabling information technologies for load responsiveness for a combined effect of a 20% peak-load reduction by 2015, while providing value services and reliability levels required by customers. The enabling integration designs and two-way information and control technologies will be demonstrated in distribution system applications. These applications include: mitigation of congested feeder lines for enhanced reliability and reduced price volatility, and implementation of local energy networks and other innovative operational strategies to protect critical loads in cases of natural or intentional disruptions in energy supplies or to provide premium-level of power quality and reliability as required by customers. With proven technical and economical performance, distributed systems will be properly valued as electric resource options for grid planning and operations, and will evolve to become a critical part of the architecture of the future electric grid.

5.3 Key Technical Challenges

Achieving this vision for the future of distributed systems requires addressing a number of key technical challenges, as follows:

- Making the transition from distributed devices that are designed to serve individual consumers to distributed systems that are designed to serve aggregations of consumers and local utility distribution systems
- Integrating communications and control systems to enable different types of distributed devices and software (e.g., energy storage, distributed generation, and distributed intelligence and controls) to work together and interconnect with local utilities in a seamless manner (interoperability)
- Enabling information technologies to make available the time-varying value of electricity to customers and to empower their participation in demand response
- Enabling control and optimization technologies for industrial, commercial, and residential equipment to respond to price signals and system instability (e.g., under-voltage and under-frequency events, reactive power imbalance, etc.)
- Finding lower cost ways to use distributed systems to manage peak demands and reduce "upstream" congestion on transmission and distribution systems

[7] U.S. Department of Energy "Benefits of Demand Response in Electricity Markets and Recommendations for Achieving Them," February 2006

- Finding lower cost ways to use distributed systems to reduce the costs and inconveniences of power outages and power quality disturbances for consumers
- Finding lower cost ways to boost the utilization of electric distribution assets such as feeder lines, transformer and capacitor banks, and substations
- Developing data, computer models, and analysis tools that estimate the technical and financial value of distributed systems for use by grid planners and operators in resource planning and system operations

5.4 Fiscal Year 2007 Baseline Activities

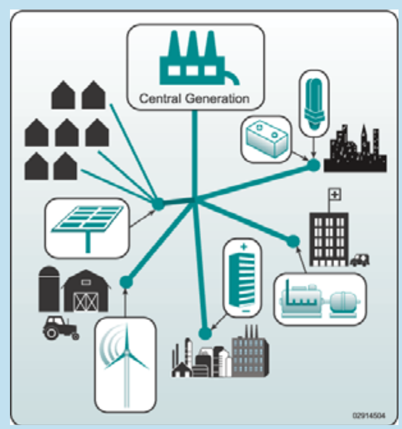
Activities in the Fiscal Year 2007 budget request include:

- Completion of research projects that have successfully improved the energy efficiency, costs, and environmental performance of a portfolio of distributed generation devices, including turbines, microturbines, and reciprocating engines
- Completion of advanced integrated energy system and combined heat and power demonstration projects for healthcare, education, food services, and lodging sectors
- Completion of the EPACT Section 1817 requirement for a "Study of Distributed Generation"
- Continuation of the design and implementation of a framework to enable and guide the development of true interoperable software both within the utility enterprise and across other sectors integral to the electric infrastructure
- Continuation of investigations into distributed generation, combined heat and power, and electric system integration, including interconnection, real and reactive power assessments, and applications in microgrids and local energy networks
- Continuation of technology transfer and education on combined heat and power technologies through regional applications centers
- Continuation of investigations into technology and business issues for advanced operational concepts such as microgrids and local energy networks
- Continuation of collaborative energy storage demonstration projects with the California Energy Commission and the New York State Energy Research and Development Authority for monitoring and data collection of utility-scale applications
- Continuation of development of monitoring and control technologies to enable load management by both utilities and customers
- Development of IEEE 1547 standards for micro-grid operation including islanding and off-grid operation from a systems interconnection functional and testing requirement
- Reaffirmation of IEEE 1547 and IEEE 1547.1 for interconnection systems requirements and testing as required by IEEE

5.5 Key Activities for Fiscal Years 2008 to 2012 and Metrics for Measuring Progress

The key activities for integrating a portfolio of distributed systems with electric system planning and operations include:

- **Distributed systems integration projects** that prove to key stakeholders the benefits of distributed systems integrated with the electric system
- **Advanced operational strategies** such as microgrids or local energy networks that build on experience with multiple distributed energy devices both connected and unconnected to the grid including IEEE 1547 standards development supporting these operational modes
- **Enabling technologies** for real-time load monitoring and load management that will make more cost effective and readily available price-based and incentive-based demand response programs
- **Modeling and analysis** of distributed systems for assessing market barriers and potential impacts on utilities and consumers
- **Energy storage** research to achieve dramatic reductions in capital, installation, and operations and maintenance costs for existing storage systems in a variety of types and size ranges
- **Technology transfer** and education for accelerating technology readiness and market acceptance and development of industry consensus standards through standards development organizations such as the IEEE



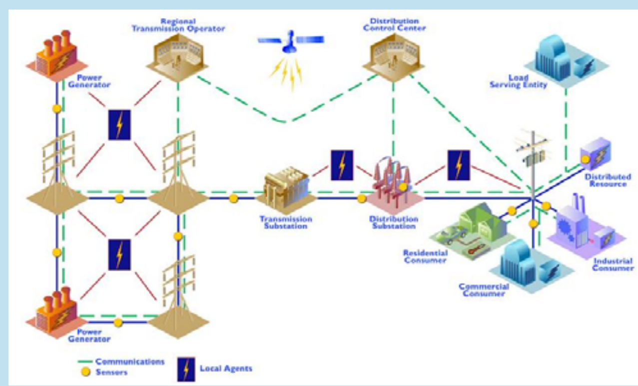
Distributed Systems Interconnection

Distributed systems integration projects will be one of the key activities for addressing technology readiness and market acceptance issues for distributed systems and providing quantitative data on costs, benefits, business models, utility system impacts, and consumer impacts. The integrated demonstration will be conducted in collaboration with utilities; equipment manufacturers; regional, state, and local agencies; national laboratories; and universities. Currently, decision makers are unsure about investments in distributed systems because there is a lack of data about their performance in addressing electric system problems in utility-scale applications. Such information is needed to establish a proven value proposition for distributed energy systems. In addition, there are very few examples of situations where portfolios of distributed systems, (e.g., generation, storage, and price-based demand response) have been installed and expected to work together as integrated systems to meet the capacity and energy needs of utilities and consumers.

Activities include identifying local areas across the country experiencing electricity supply and delivery constraints; soliciting ideas from utilities, states, equipment manufacturers, and consumers about using distributed systems to alleviate grid congestion in those areas; developing local energy network designs, establishing multi-year data collection and analysis plans for measurement of costs, benefits, and utility and consumer impacts to assist in site and system selection; competitively awarding cost-shared agreements to install, operate, test, and evaluate distributed systems in a selected number of constrained areas.

The scope is to encompass a comprehensive evaluation of distributed systems in different regions of the country, in areas experiencing the following different types of grid congestion issues: different market structures (e.g., vertically integrated markets and organized wholesale markets); different mixes of residential, commercial, and industrial consumers; and diverse development patterns and population densities (e.g., urban, suburban, ex-urban, and rural).

The technical objective for the activities under the distributed systems integration projects is to verify and validate by 2015 the application of distributed systems to reduce congestion in areas experiencing electricity supply and delivery constraints and secure critical facilities. There will be an annual internal assessment, validated every other year by independent peer review, of the ability of distributed systems to reduce local peak demand by 20% at a cost competitive with that of the alternative system/capacity upgrades. This assessment will be carried out for each of the integration projects and will include quantitative analysis of costs and benefits for both the utility and the participating consumers. The initial activities will assess baseline values for reducing local peak demands and the associated costs of using distributed systems vs. using traditional utility approaches. Subsequent activities will assess the yearly progression toward the achievement of overall cost of distributed systems competitive with those of system/capacity upgrades.



Distributed Intelligence and Control Systems

Evaluation of the role that **advanced operational strategies** such as local energy networks could play in the new grid architecture will be another one of the key activities for determining feasibility, assessing costs and benefits, and identifying profitable business models. An example of an advanced operational strategy is the concept of a microgrid. A microgrid is an integrated power delivery system consisting of interconnected loads and distributed energy systems, which, as an integrated system, can operate in parallel with the grid or in an intentional "island" mode. Potential applications include: locations experiencing electric supply and/or delivery constraints, remote power (e.g., military installations, rural areas, and Native American reservations), critical infrastructure protection (e.g., police, fire, emergency response, hospitals, and water treatment), and economic development (e.g., industrial parks, commercial centers, and residential development).

Many jurisdictions have interest in developing advanced operational strategies for distributed energy. However, there is limited experience. For example, operational strategies involving district energy systems provide only thermal energy in some cases and are usually aimed at serving consumer and not utility needs. There is also very limited experience with operating multiple forms of distributed systems in an optimized and integrated manner. Activities involve conducting analysis of current and future applications; financial feasibility to identify value propositions and business models; definition of functional requirements and ideas for advanced designs; validation of costs and performance within the context of specific operational strategies; and development of components, platforms, and prototypes to support a wider array of potential applications.

The technical objective for the activities under advanced operational strategies is to verify and validate by 2015 the application of distributed energy systems for the safe, secure, and cost-effective "islanding" of selected portions of the electric grid. There will be an annual internal assessment, validated every other year by independent peer review, of the costs of implementing an advanced operational concept to be cost competitive with today's operational solutions. Initial activities will include an assessment of baseline values and the associated costs of a proposed innovative operational strategy. Subsequent activities will assess the yearly progression toward the goals.

Grid-Friendly Appliance Controller

Improving **enabling technologies** for load monitoring and load management is another one of the key activities for integrating distributed systems into both utility and consumer planning and operations. This integration, through real-time information and control capabilities, will make price-based and incentive-based demand response programs more cost effective and more readily available for electricity consumer participation. Currently, the following capabilities are lacking or not enabled: interoperable software framework for enabling information exchange across different domains within the electric delivery system; small, inexpensive, durable, self-powered, and non-intrusive sensors for accurate and fast measurement of voltages, current, and temperatures for distributed systems; integration of monitoring information for different applications such as power quality, power flow management, equipment diagnostics, and fault locations; mechanisms for real-time and two-way communications from Supervisory Control and Data Acquisition Systems and Energy Management Systems to the lowest level of use such as equipment on the consumer's side of the meter; and control technologies for end-use electrical equipment to respond to system instability.

The wide-scale deployment of advanced metering infrastructure (i.e., meters with the capability of measuring and storing electricity consumption data at intervals of one hour or less, and a communication infrastructure to transmit meter readings as well as other power flow/quality information to support outage management and grid monitoring and management) would be an important step forward for enabling technologies for load management. Activities include assessing utility system-wide deployments of advanced metering infrastructure and determining their impacts on load management and supporting development of better sensors and control devices and their use by both utilities and consumers in monitoring the operational status of consumer appliances and equipment and in controlling their electricity use during times of system need, in coordination with key activities in Transmission and Distribution Planning Operations Technologies as described in Section 3.5.

The technical objective for the activities under enabling technologies for load monitoring and load management is to develop by 2012 data acquisition and two-way communication systems with greater functionality for successfully empowering load management by both the utilities and consumers to serve their respective needs. There will be an annual internal assessment, validated every other year by independent peer review, of the costs of load monitoring and load management systems that are competitive with today's systems. The initial activity will be an assessment of baseline costs. Subsequent activities will assess the yearly progression toward the achievement of reduction in cost.

Enhancing the **modeling and analysis** of distributed systems is another key activity for characterizing technologies, assessing market barriers and potential, quantifying impacts on utilities and consumers, and identifying value propositions and profitable business models. Currently, there are not standardized methods for reporting costs, benefits, and valuation of distributed systems. Development of integrated technical and economical analysis tools for distributed systems will help electric utilities, consumers, state, regional, and Federal agencies to properly assess distributed system capabilities, business cases, and resource plans. Activities include: support for stakeholders to collaborate, develop, and adopt conventions and protocols for estimating the benefits of distributed systems, and where appropriate, to develop standardized tests that evaluate program potential and performance; support for regional planning initiatives to examine how distributed systems are characterized in supply planning models and how those models can be modified to better characterize distributed systems; and support for regional entities and the states to assess the appropriate level of distributed systems for improving the efficiency and reliability of wholesale and retail market operations.

The technical objective for the activities under modeling and analysis is to develop by 2010 data and software tools for grid planners and operators to evaluate the costs and benefits of distributed systems on a consistent basis so they are comparable across states and regions and ready to use in developing local, state, and regional resource plans. There will be an annual internal assessment, validated every other year by independent peer review, of the accuracy of the tools and their ability to be integrated with conventional resource planning models and analysis tools. The initial activities will include an assessment of existing resource planning models and their ability to properly characterize and integrate distributed systems. Subsequent activities will assess the yearly progression toward the achievement of the objective of data and software tools that properly incorporate distributed systems.

Lithium Ion Battery Storage System

Development of new technologies for advancing existing **energy storage** systems (e.g., batteries, flywheels, and capacitors) will be one of the key activities for reducing their capital, installation, and operation and maintenance costs; improving efficiency, durability and performance; and enhancing integration with the electric transmission and distribution system. Greater effort is needed in field testing and demonstration of advanced storage devices to identify technical problems associated with integrating energy storage into electric system planning and operations. For example, advanced batteries, such as flow battery systems, need to accumulate more operating data and experience to verify technical performance and validate their ability to address “real-world” utility problems. Further progress is needed on flywheel systems to develop more durable and reliable systems and verify safety and performance.

The focus of this activity will go beyond traditional energy storage systems and explore the technical verification of alternative battery systems to replace lead acid systems and the deployment of 3rd generation flywheel systems. Activities include data collection and monitoring of field tests and demonstrations of advanced storage systems in conjunction with state agencies and electric utilities, research into improved battery designs and manufacturing techniques, and technical and economic analysis of the relative merits of alternative energy storage devices and applications.

The technical objective for this area of activity is to have lower cost and better performing energy storage systems available to the utility industry by 2011. There will be an independent peer review of the data and analysis from the projects and evaluations of the accuracy and validity of the results. The initial activity will be to establish a new collaborative project for a new energy storage application by 2008 and by 2010 establish at least two additional projects using advanced storage devices for different applications.

Accomplishing **technology transfer and education** is another key activity for accelerating technology readiness and market acceptance. Currently, there are a number of Federal, regional, and state information resources for public and private sector decision makers to access for data on distributed systems. DOE currently supports a network of eight Regional Application Centers across the country to conduct outreach and education activities on combined heat and power, and DOE also supports regional initiatives to effectively deploy distributed systems. Activities include continuation of efforts to disseminate information to states and regions on all aspects of distributed systems, addressing institutional and regulatory barriers in use of distributed systems, and supporting education of key decision makers at utilities and regional and state agencies through educational materials and targeted technical workshops.

The technical objective for the activities under technology transfer and education is to provide necessary information to decision makers when they need it and in forms they can use. There will be an annual internal assessment, validated every other year by independent peer review, of the level of satisfaction expressed by stakeholders in the technology transfer and education services they receive on distributed systems from DOE. Initial activities will assess services provided and the degree to which they meet stakeholder needs.

5.6 Linkages to Other Programs and Activities

Development and demonstration of distributed system integration involve technologies, tools, and techniques that seamlessly integrate distributed energy and demand response into grid planning and operations. Coordination of activities will be needed with the research, development, and demonstration program activities, including those of: DOE’s Office of Energy Efficiency and Renewable Energy that address residential and commercial buildings, industrial facilities and manufacturing plants, and transportation systems; state agencies such as the California Energy Commission and the New York State Energy Research and Development Authority; and utility research and development entities such as the Electric Power Research Institute. Organizations that represent utility companies (e.g., the Edison Electric Institute, National Rural Electric Cooperative Association, and the American Public Power Association) and state agencies (e.g., National Association of Regulatory Utility Commissioners, National Council of State Legislatures, and National Association of State Energy Officials) will be important stakeholders in program activities, as will utility companies, national laboratories, trade groups (e.g., U.S. Combined Heat and Power Association and the GridWise Alliance), equipment manufacturers, and universities.

5.7 Summary of the Five-Year Plan for Distributed Systems Integration

Key Activities	**Technical Objectives**	**Metrics**
Distributed Systems Integration Projects	Expanded deployment	20% peak load reduction on distribution feeders
Advanced Operational Strategies	Enhanced capabilities	20% peak load reduction on distribution feeders
Enabling Technologies	Expanded functionality	20% peak load reduction on distribution feeders
Modeling	Enhanced tools	Accurate and integrated by 2010
Energy Storage	Enhanced performance	Up to 7 projects by 2012
Tech Transfer	Information dissemination	High level of satisfaction by 2012

<table>
<tr><th>Key Activities</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th></tr>
<tr><td>Distributed Systems Integration Projects</td><td colspan="5">Cost-shared projects in grid congested areas</td></tr>
<tr><td>Advanced Operational Strategies</td><td colspan="5">Developing components, platforms, and prototypes</td></tr>
<tr><td>Enabling Technologies</td><td colspan="5">Supporting R&D for sensors and control devices and more</td></tr>
<tr><td>Modeling</td><td colspan="5">Developing more robust tools for properly assessing distributed system capabilities and business cases</td></tr>
<tr><td>Energy Storage</td><td colspan="5">Improving existing energy storage systems for utility applications</td></tr>
<tr><td>Tech Transfer</td><td colspan="5">Disseminating information to states and regions on all aspects of distributed systems</td></tr>
</table>

6.0 POWER ELECTRONICS AND ENABLING MATERIALS

Power electronics devices hold substantial promise for transforming the electric power system. High voltage power electronics allow precise and rapid switching of electric power to support long distance transmission. Power electronics also can be used for distribution level functions including more rapid switching and voltage support and for devices such as transformers and inverters. The speed and precision of these devices will enable the system to respond more rapidly to disturbances and to operate with lower margins and fewer constraints, thereby reducing the need for additional infrastructure, while at the same time improving system reliability and security.

The field of power electronics is an exciting and dynamic area of technology development. Building on advances in semiconductor materials, power electronic building blocks are being created to replace traditional electromagnetic and electromechanical ones. Among the many advantages is the ability to have modular, solid-state power electronics building blocks that can electronically convert electric energy from one form to another quickly and efficiently (e.g., alternating current to direct current and vise versa; higher and lower voltages; higher, lower, and variable frequencies; and real and reactive power), and that can accomplish the functions of traditional equipment (e.g., switches, controllers, capacitors, condensers, and transformers). Greater use of power electronics building blocks can improve electric system reliability, controllability, and stability, and result in greater current-carrying capacities for existing and new transmission lines through existing rights-of-way.

The focus of this area of activity is on power electronics devices, new materials, and building blocks for expanding the functionality, increasing durability, increasing modularity, and increasing response times for a variety of grid components including switches, inverters, transformers, capacitors, cables, and dielectrics.

This section of the plan outlines a set of activities that will address the following topics from EPACT Section 925:

- Advanced energy delivery technologies
- Energy storage technologies, materials, and systems
- Technologies contributing to significant load reductions
- Technologies to enhance existing grid components
- Development and use of high temperature superconductors
- Integration of power systems, including systems to deliver high-quality electric power
- Supply of electricity to the power grid by small-scale, distributed, and residential based power generators
- Technology transfer and education

6.1 Situation Analysis and Current Status of Power Electronics and Enabling Materials Technologies

Substantial investment (public and private) in power electronics for transportation systems, consumer products, and industrial and military applications has occurred and continues today. Much less investment, however, has gone into power electronics for utility-scale applications. While size and weight are key design features of power electronics devices for small-scale, low voltage, and low current applications (e.g., automobiles), large-scale electric system applications require focus on losses, thermal management, durability, and packaging concerns.

High voltage, high current power electronics allow precise and rapid switching of electric power to support long-distance transmission. Power electronics devices with somewhat lower voltage and current levels can be used in substations, feeder lines, and in the interface between customers and the grid. In fact, power electronics are essential for integrating devices such as energy storage, photovoltaic arrays, microturbines, and wind power integration with the local electric distribution system.

More information on the cost and performance of utility-scale power electronics in real-world applications is needed to enable expanded use today. This means more field tests and demonstrations of existing prototypes and equipment. To help utilities and manufacturers get a better understanding of the value proposition for power electronics. Cost may be somewhat higher for power electronics devices, but in many applications these costs can be offset by improved performance and expanded functionality. Field tests are helpful to manufacturers in identifying problems and making corrections in advance of product scale-up. This helps verify and validate product performance and possibly leads to reductions in costs and improvements in reliability.

High Power Converter

The emitter turn-off thyristor (ETO) switch is an advanced power electronics device that uses an innovative control system to allow a conventional gate turn-off thyristor (GTO) switch to operate at 1500-3000 hz rather the normal 50 hz switching frequency. DOE has been working with Virginia Tech University and North Carolina State University since 1998 to develop the device. The ETO combines the high power capability of a GTO with the high switching frequency of a voltage-controlled power transistor. Converter systems made with the ETO will produce high-quality, high power, utility grade AC power with fewer components and lower cost than current systems. The Gen-4 ETO switch is capable of 4000A, 4500V operation. The ETO project team was awarded an R&D 100 Award in 2003. The Bonneville Power Administration has announced plans for the first commercial application where the ETO switch will be installed on a new 10 MW STATCOM device to supply reactive power to stabilize a 64 MW wind farm in Eastern Oregon.

One of the most basic power system devices is the switch. A top priority technology need is the development of power electronics switches with the capability for high voltages, high currents, low losses, and high speeds, with little or no cooling requirements, and a favorable cost-to-value relationship. New approaches and materials (silicon carbide or diamond) that are not used today in power electronics are needed to achieve these aims. Working in the high-voltage, high-current domain requires research in the fundamental properties of advanced materials. Industry is interested in working with Government to explore new materials that “go beyond silicon.” Diamonds and silicon-carbide are promising materials for use in power electronics.

There are several near-term target applications for power electronics. One is the concept of a grid “shock absorber.” This involves applying power electronics devices for the grid to respond better to large power oscillations and achieve better fault current management. Another near-term application is power flow management. This includes devices for changing the phase angle on AC transmission and control methodologies for power converters to address loop flow and other issues.

Power Conversion System

There is also a need to scale-up and bundle power electronics devices from low voltage to high voltage applications, with expanded capabilities to perform a variety of power system functions related to managing power flows across the grid, and incorporating information exchange for detecting and responding to operational problems. Meeting this need will involve development of “building block converter units” that are easy to install in series or parallel, have standardized grid interface and control software, and include communications systems for remote diagnostics and controls by grid operators.[8]

A long-term opportunity is the solid-state transformer. This includes pole-top transformers for electric distribution systems, and larger units for transmission and sub-transmission applications. Such devices would not involve the use of magnetic fields thus having the potential to reduce reactive power requirements substantially. Expanded functionality of solid-state transformers includes direct current power transmission, broadband telecommunications, load control, and automated meter reading.

Because the technologies to store electric energy in a widespread and cost-effective manner do not exist, electric system planners and operators are required to have sufficient capacity in place to meet peak demand, including adequate reserve margins. As a result, utilities invest in peak power plants which operate for several hundred hours per year and sit idle the rest of the time. If more efficient and cost-effective energy storage devices could be implemented the need for peak power plants could be reduced, thus presenting the opportunity to lower overall electricity production costs.

[8] IEEE “Power Electronics Building Block (PEBB) Concepts,” Document Number 04TP170

Advanced Flywheel Storage System

"Smart Energy Matrix" devices developed by Beacon Power for the DOE and its partners (including the CEC, NYSERDA, and PG&E) are being used at sites in New York and California to provide critical services to make the electric grid more reliable and secure. One of the flywheel units, installed in Amsterdam, New York, responds to frequency changes on the grid for regulation support. This device can also provide uninterruptible power for "ride-through" capabilities during momentary outages and reactive power supplies for local voltage and VAR support. The other unit is installed on the PG&E transmission system and is designed to respond to signals for frequency support from the California Independent System Operator over a secure internet link.

Reducing the costs and size of energy storage systems are one of the keys to more widespread use. Effort is needed to assess opportunities for new manufacturing processes to reduce the cost of existing battery storage devices. For all types of systems, effort is needed to explore the possibilities of substituting lower cost materials without sacrificing technical performance. Advances in the design of storage devices are needed for batteries, flywheels, and capacitors, and to evaluate trade-offs in features and performance to lower manufacturing costs.

More effort is needed in the basic sciences to explore opportunities for new materials. For example, advances in nanotechnologies can enable the systematic evaluation of the energy storage properties of various elements and compounds and the development of subsequent nano-formed materials with enhanced energy storage capabilities. Effort is needed to develop high-density, high-capacity battery energy storage based on novel materials and processes.

6.2 Long-Term Goal

The long-term goal for power electronics and enabling materials is that by 2025 there will be a suite of solid-state building blocks that can be cost-effectively installed in both transmission-level (>138kV) and distribution-level (<138kV) applications. The power electronics building blocks of 2025 will be programmable to serve multiple functions (e.g., switches, capacitors, condensers, and transformers), will be able to respond within 1 milli-second, carry up to 20,000 volts at 500 amps (or 50,000 volts at 100 amps), and operate effectively at temperatures up to 4000ºC. These devices will have zero switching and conduction losses, will be light-weight and affordable, and will be able to connect in both series and parallel to achieve higher switch ratings.

The long-term goal for advanced energy storage is to demonstrate by 2030 prototype super-capacitors and/or battery systems with operating voltages that are two-to-three times greater than today' systems or have a five-fold increase in stored energy.

6.3 Key Technical Challenges

Achieving this goal requires that a number of technical challenges be addressed. For example:

- Overall system life-cycle costs for power electronics need to be comparable or lower in cost than existing devices to be more marketable
- Devices need to be able to withstand higher voltages, current levels, frequencies, and power densities
- Advanced topologies are needed for better thermal management
- Detailed information on the proven performance, reliability, and durability of power electronics over a period of time is needed
- Advanced control methodologies and technologies are needed to better coordinate multiple systems
- Lower cost and more modular "building block" converter units that are programmable for multiple functions, and have standardized interfaces are needed for series or parallel installations
- Developing advanced materials with higher density energy storage capabilities, longer cycle lives, and lower costs
- Identifying novel energy storage designs and devices based on nano-formed materials and new processes

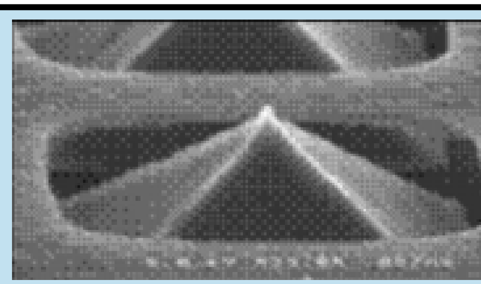
6.4 Fiscal Year 2007 Baseline Activities

Activities in the Fiscal Year 2007 budget request include:

- Completion of full power testing of an emitter-turnoff (ETO) thyristor in collaboration with the U.S. Navy
- Continuation of efforts to refine the cascade inverter concept
- Continued investigations into wide-band-gap semiconductor concepts and electro-optic sensing
- Continued investigations into new high-voltage, high power, wide-band-gap materials such as silicon-carbide composites, diamonds, and diamond-graphite composites

6.5 Key Activities for Fiscal Years 2008 to 2012 and Metrics for Measuring Progress

The technology development activities for improving power electronics and enabling materials technologies include:


Diamond Sensor

- **New materials** for higher voltage, current, frequency, and temperature

- **Advanced power electronics building blocks** with better performance and lower costs
- **Advanced energy storage materials, concepts, and designs** for next generations systems and devices

Development of **new materials** for power electronics building blocks and other grid components and systems will be one of the key activities for gaining higher voltage (>10kV), higher current (>100A), higher frequency (>1 kHz), and higher temperature (>250ºC) operations. The focus will be on investigations that go beyond traditional silicon materials and explore wide-band-gap materials such as silicon carbine, gallium nitride, and diamond-based compounds and composites. Currently, power electronics devices use silicon in traditional solid-state designs that work well for consumer products and in certain vehicle applications; however they cannot meet cost, voltage, current, and frequency targets for power system applications. Activities include studies to characterize the properties of new materials, explore microstructures and nano-scale applications, and to develop better materials processing techniques and packaging materials.

The technical objective for the activities under new materials is to have better performing materials (e.g., silicon carbide, gallium nitride, or diamond) for power electronics devices by 2012 that can operate reliably at voltages above 10kV, temperatures greater than 250ºC, and at power densities that are at least equal to today's levels (knowing that the long-term goal by 2025 is to achieve power densities that are ten times greater than can be achieved with today's materials). There will be an annual internal assessment, validated every other year by independent peer review, of the performance of the new materials with respect to voltage levels and temperatures. The baseline levels for these metrics for silicon-based switches (fully controllable) are 5000 volts at 10 amps at temperatures not to exceed 150ºC. The primary activity is to develop power electronics materials by 2012 that can operate 10,000 volts at 10 amps at temperatures not to exceed 250ºC.


Inverter and Breaker Box

Development of advanced designs that use the new materials for **advanced power electronics building blocks** is another key activity and will be aimed at a variety of power system applications including reactive power control, power flow control, high voltage direct current conversion, and the interface of distributed systems (e.g., distributed generation and energy storage) with the local distribution grid. Current power electronics switches need to have better performance and lower costs. Activities include development of advanced designs for switches, which are one of the fundamental building blocks for power system operations and control. The switches can be subsequently applied to: devices that can convert voltage levels (replacing transformers); devices that can handle fault currents; devices for reactive power control, which is key to voltage stability and the prevention of voltage collapse; and devices for power flow control, which can help keep flow close to contracted paths or relieve heavily loaded lines by switching to less congested lines.

The technical objective for the activities under new power electronics devices will be to have by 2012 advanced designs for cost-competitive switches that have substantially faster response times than conventional mechanical breakers. There will be an annual internal assessment, validated every other year by independent peer review, of the response time. The baseline response time for mechanical breakers is 66 to 100 milli-seconds. The initial activity will involve development of electronic switches by 2010 that have response times of 5 milli-seconds, and 4 milli-seconds by 2012. If these milestones are successfully achieved, this activity could culminate in 1 milli-second response times by 2025.

The primary technology development activity for improving strategic energy storage systems will be investigations into **advanced energy storage materials, concepts, and designs.** These will be aimed at the development of "next generation" energy storage devices for customer, distributed, and bulk storage systems. The focus will be on research to develop more compact, higher capacity, higher energy density, and longer life storage technologies based on investigations into new materials, storage chemistries, and processes, including nanotechnologies. These efforts will be conducted in close coordination with the DOE's Office of Science.

The technical objective for this area of activity will be to develop by 2011 a "next generation" design for an advanced storage system (and a prototype device) that is capable of yielding a 30% improvement in energy storage density, voltage capacity, and lifetime, compared to existing storage systems. Initial activities will focus on investigation into advanced storage chemistries leading to the identification of at least two promising pathways by 2009 and development of advanced designs and prototype devices by 2010. There will be an annual internal assessment, validated every other year by independent peer review, of progress toward achievement of these objectives to eliminate unproductive pathways and down-select efforts for the most promising designs and approaches.

6.6 Linkages to Other Programs and Activities

Coordination of activities will be needed with the research and development programs in DOE's Office of Energy Efficiency and Renewable Energy that address vehicular and transportation applications of power electronics. There are also opportunities to coordinate research activities with DOE's Office of Science in areas such as nano-structured materials for electrodes, ionic fluids for high voltage electrolytes, and investigations involving wide band gap materials such as silicon carbide, gallium nitride, and diamond. Coordination will also be needed with the Department of Defense and their activities in power electronics and enabling materials. Coordination will also be needed with power electronics-related research, development, and demonstration activities of state agencies such as the California Energy Commission and the New York State Energy Research and Development Authority, the electric power industry such as the Electric Power Research Institute and the National Rural Electric Cooperative Association's Cooperative Research Network, universities, and national laboratories.

The successful development of improved and "next generation" energy storage systems involve tackling a number of complex science and engineering challenges. In fact, there may be need for discovery and invention to completely new materials, designs, and processes for the Long-Term Goal of affordable, durable, efficient, and high performing energy storage devices. Coordination on research in fundamental scientific properties of materials and storage chemistries will be accomplished with DOE's Office of Science, universities, and the national laboratories.

Coordination will also be accomplished with energy storage research and development programs in other Federal agencies including the transportation energy storage applications programs in DOE's Office of Energy Efficiency and Renewable Energy and with advanced energy storage programs at the Department of Defense. Coordination will continue with existing university research centers and national laboratories.

6.7 Summary of the Five-Year Plan for Power Electronics and Enabling Materials

Key Activities	Technical Objectives	Metrics
Materials and Devices	Higher voltage levels and temperature	10,000 volts/10 amps/250^{o}C by 2012
Building Blocks	Faster response times	5 milli-seconds by 2012
Advanced Energy Storage Materials	Advanced design and prototype by 2011	30% improvement in energy density, capacity, and lifetime

Key Activities	2008	2009	2010	2011	2012
Materials and Devices	*Gaining higher voltage, higher temperature operations*				
Building Blocks	*Faster response times and "building block" for advanced inverters, fault current limiters, and ultimately transformers*				
Advanced Energy Storage Materials	*Breakthrough research on new storage chemistries*				

7.0 HIGH VOLTAGE TRANSMISSION

The focus of this area of activity is on the design and testing of optimization techniques for power flow through existing high voltage transmission lines. This activity is authorized under EPACT Section 925g but funding for it has not been requested. Section 925g calls for DOE to award a grant to a university research program to design and test, in consultation with the Tennessee Valley Authority, state-of-the-art optimization techniques for power flow through existing high voltage transmission lines.

This area of activity involves efforts in the following topics from EPACT Section 925:

- Advanced energy delivery technologies
- Advanced grid reliability and efficient technologies
- Technologies to enhance existing grid components
- Integration of power systems, including systems to deliver high-quality electric power, electric power reliability, and combined heat and power
- Technology transfer and education

7.1 Situation Analysis and Current Status of High Voltage Technologies

Existing transmission systems are often operated and stressed to the limit of their performance capability in order to maximize asset utilization. To ensure that under these conditions the economical, reliable, and secure operation of the grid is maintained, various aspects of power flow management within the power systems is becoming necessary.

There are several technologies available to optimize the power flow in transmission lines including Flexible AC Transmission Systems (FACTS) devices, synchronous condensers, and distributed energy storage systems. Additionally, phase-shifting transformers, or phase angle regulators, can be used to help control the flow of power on transmission lines and through system interties, and allow, for better utilization of existing networks to address load growth.

FACTS comprise a family of devices that include STATCOMs, static VAR compensators, static synchronous series compensators, and unified power flow controllers. FACTS involve the application power electronics to improve the performance of long distance AC transmission. FACTS devices are commercially available technologies. While the advantages of FACTS have been shown, their integration into the transmission system is not widespread for a number of reasons including:

- High total cost of ownership and the difficulty in establishing dollar value for decreasing congestion or for increasing system capacity or reliability
- Single point of failure yields reliability of 94%, significantly lower than the 99.99% reliability that is typical for the utility system
- The skilled work force required in the field to maintain and operate the system, which is not standard within a utility's core competency, leading to a high cost of ownership

High Voltage DC Transmission (HVDC) is another technology that can provide new dimensions for long distance transmission. Almost 50 GW HVDC transmission capacities have been installed worldwide. Transmission distances over 1,000km to 2,000 km (or even more) are possible with HVDC lines.

7.2 Long-Term Goal

The long-term goal for high voltage transmission is that by 2015 an array of low cost technologies will be available for optimizing power flow through existing rights-of-way. These technologies will be readily available in the marketplace and easily integrated into existing networks. Technical personnel will be intimately familiar with these devices and able to install and maintain them quickly and easily.

7.3 Key Technical Challenges

- Increasing the capacity of conductors while keeping costs constant
- Improving understanding of benefits and applications of transmission devices to stakeholders
- Improving the footprint of VAR support devices so that they can be installed in areas with severe space constraints

7.4 Fiscal Year 2007 Baseline Activities

There are no funds for high voltage transmission lines in the Fiscal Year 2007 budget request for this activity.

7.5 Key Activities for Fiscal Years 2008 to 2012 and Metrics for Measuring Progress

The technology development activities for high voltage transmission lines include:

- **Advanced transmission technologies** that increase transmission capacity, maximize asset utilization, and increase reliability
- **Hybrid AC/DC transmission** systems that can reduce system congestion
- **High-capacity conductors** to increase capacity over conventional wires

The integration of **advanced transmission technologies**, with high voltage transmission, is a key activity area that has the ability to control power flow and ultimately improve asset utilization. The distributed static series compensator module is a type of device that clips onto existing conductors and injects positive or negative impedance to "push" or "pull" current on the line and has the advantage of "smart" and incremental installation. Such technologies have the capability to fully control magnitude and direction of real and reactive power flows, provide dynamic voltage support, and react almost instantaneously to disturbances. Subsequently, these technologies will increase transmission capacity, maximize utilization of transmission systems, and improve overall system reliability and security. Activities include university research programs to work in consultation with the Tennessee Valley Authority to install and test novel devices on the transmission system.

The technical objective for this activity is to develop by 2012 lower cost devices for successfully demonstrating power flow optimization that increases power transfer capability. There will be an annual internal assessment, validated every other year by independent peer review, of the costs of current technologies that are 25% lower than today's systems. The initial activity will be an assessment of baseline costs. Subsequent activities will assess the performance toward the achievement of the 25% reduction in cost.

The use of **hybrid AC/DC transmission systems** consisting of AC and DC interconnections among regional subsystems is another activity that has the potential for being part of the long-term strategy for high voltage transmission. Such interconnected systems have technical and reliability advantages and are being successfully employed overseas. In emerging areas in the United States with increasing power demand, networks will grow quickly, leading to higher voltage levels. Because of the need to transmit power over long distances, application of FACTS and HVDC will play an important role in these areas, leading to hybrid AC/DC systems. Activities include soliciting ideas for the size, scope, and location of the installations and coordinating with utility companies, equipment manufacturers, national laboratories, and universities in construction and operation.

The technical objective for this activity is to demonstrate by 2010 installations where hybrid transmission systems are operating to relieve system congestion. There will be an annual internal assessment, validated every other year by independent peer review, of the costs of hybrid systems that are 20% lower than today's systems. The initial activity will be an assessment of baseline costs. Subsequent activities will assess the progression and value of the verification and validation projects.

The verification and validation of **high capacity conductors** is a key area of activity to improve the capacity of existing transmission lines. Advanced composite conductors can increase capacity over conventional conductors and can be installed on existing rights-of-way without tower modifications. Advanced materials in conjunction with sensors, insulators, and other components of power line systems will lead to an integrated conductor system capable of achieving much greater power flow levels than existing aluminum conductor steel reinforced (ACSR) wires. More widespread implementation of these devices is tempered by higher prices of the conductors and the expensive labor cost of reconductoring existing lines. Activities include design and testing of new conductors over long distance right-of-ways in constrained areas and materials research for lower thermal expansion materials, lighter weight conductors, higher strength conductors, higher operating temperature materials, and second-generation superconducting materials.

The technical objective for this activity is to develop by 2010 overhead conductors that increase the capacity of existing corridors by five times ACSR at current costs. There will be an annual internal assessment, validated every other year by independent peer review, of the costs of current technologies compared to today's systems. The initial activity will be an assessment of baseline costs. Subsequent activities will assess the performance toward the achievement of the increase in capacity while holding costs constant compared to the current baseline.

7.6 Linkages to Other Programs and Activities

Successful development, verification, and validation of power flow optimization through high voltage transmission involves new technologies, tools, and techniques and should be conducted in concert with a multi-faceted team of experts. Coordination will be required with the Tennessee Valley Authority and other Government-funded power authorities, and national laboratories. Leveraging resources with research and development programs within state agencies with transmission issues such as the California Energy Commission and the New York State Energy Research and Development Authority will also be advantageous. Organizations that represent utility companies (e.g., the Electric Power Research Institute, Edison Electric Institute, National Rural Electric Cooperative Association, and the American Public Power Association) will be important stakeholders in the program as well as the utilities themselves.

Coordination will continue with existing university research centers and national laboratories.

7.7 Summary of the Five-Year Plan for High Voltage Transmission

Key Activities	Technical Objectives	Metrics
Advanced transmission technologies	To develop by 2012 lower cost devices for successfully demonstrating power flow optimization that increases power transfer capability	Reduce costs of today's technologies by 25%
Hybrid transmission systems	Demonstrate by 2010 installations where hybrid transmission systems are operating to relieve system congestion	Meeting or exceeding the number of hybrid installations and reducing costs by 10% compared to today's baseline
High capacity conductors	To develop by 2010 overhead conductors that increase the capacity of existing corridors by five times ACSR	Increasing capacity and lower costs

Key Activities	2008	2009	2010	2011	2012
Advanced Transmission Technologies	*Install and monitor power flow optimization devices*				
Hybrid Transmission Systems	*Demonstrate AC/DC transmission systems in congested areas*				
High Capacity Conductors	*Successful testing of high capacity, low-cost conductors over long distances*				

8.0 High Power Density Industry Applications

The focus of this area of activity is on establishing a comprehensive research, development, verification and validation, and commercial application to improve the energy efficiency of high power density facilities.

The program is authorized in EPACT Section 922, but funding for it has not been requested. Section 922 calls for DOE to establish a comprehensive research, development, demonstration, and commercial application to improve the energy efficiency of high power density facilities, including data centers, server farms, and telecommunications facilities. This program is to consider technologies that provide significant improvement in thermal controls, metering, load management, peak load reduction, or the efficient cooling of electronics.

This area of activity involves efforts in the following topics from EPACT Section 925:

- Technologies contributing to significant load reductions
- Technology transfer and education

If funds are appropriated for this area of activity, this section explains how the funds might be used.

8.1 Situation Analysis and Current Status of High Power Density Industry Applications

Data centers, server farms, and telecommunications facilities are predominantly populated with computers, networking equipment, electronic equipment, and peripherals. The equipment installed in these facilities typically serves the continuous operation of mission critical applications. This equipment has special environmental requirements in regards to temperature, humidity, and cleanliness. Careful attention must be paid to these parameters to provide high-quality reliability. This sensitive equipment has the potential for overheating and ultimate failure due to sudden loss of cooling.

Thermal challenges are now widely recognized as being a key barrier to industry's ability to provide continued improvements in device and system performance. Current performance capabilities have advanced to previously unattainable levels. This increased performance created the urgent need for smaller, more capable, and more efficient ways to transport and remove the heat. Technology is continuously changing and therefore data communications equipment is frequently changed or rearranged during the life of a data communications facility.

At a time when thermal issues are actually disrupting product development plans, a number of innovative technologies are emerging at research labs and new business start-ups around the world that have potential to solve the problem of device and package-level cooling and thermal management. Whether for cell phones, laptops, servers, high-brightness LEDs, laser diodes, radio frequency components, micro-electric mechanical systems, power semiconductors, or other similar applications, these new materials and technologies for active and passive cooling promise integral and cost-effective thermal management solutions.

8.2 Long-Term Goal

The long-term goal for the high power density area of activity is that by 2012, data communications equipment will use 20% of the electrical load of today's baseline to power and cool the technology while processing speed and disk storage space continue to grow at a historical pace.

8.3 Key Technical Challenges

Achieving this vision requires that a number of technical challenges will have to be addressed. For example:

- Optimizing cooling performance in data centers, server farms, and telecommunications facilities
- Lowering equipment inlet temperature since air-cooled equipment depends on this air for reliable operation
- Reducing the electrical consumption of high power density equipment
- Having reliable communications and control equipment that can quickly and accurately adjust to facility conditions
- Having sufficiently flexible HVAC systems serving the facility that permit "plug & play" rearrangement of components and expansion without excessive disruption of the production environment
- Having the ability to modify the HVAC system without having to shut down critical systems

8.4 Fiscal Year 2007 Baseline Activities

There are no funds for this activity in Fiscal Year 2007 budget request.

8.5 Key Activities for Fiscal Years 2008 to 2012 and Metrics for Measuring Progress

The technology development activities for high power density industrial applications include:

- Cooling technologies with enhanced capabilities to reduce electric demand of the facility
- Efficient cooling media and application techniques for improving energy efficiency of high power density facilities

Enhancing **performance of cooling technologies** is a key activity for integrating more energy efficient capabilities to reduce the electric demand of the facility. Fans and pumps are some of the largest users of energy in a data center and, as a result, it is critical that these and other technologies are carefully designed. The use of variable speed drives to allow for energy-efficient part-load operation should also be investigated. The electrical consumption of the electronics inside server hardware is growing and activities should be centered on developing novel methodologies for reducing this load. Activities include integrating devices such as advanced chillers and desiccants and adjustable speed drives to optimize power consumption; and developing new server rack configurations that will increase rack cooling effectiveness and ultimately reduce electricity costs.

The technical objective for this activity is to verify and validate by 2010 better overall thermal efficiency in the room using the supply heat index and the return heat index, which, when used together, can provide a measure of the overall thermal efficiency. There will be an annual internal assessment, validated every other year by independent peer review, of the ability of technologies to increase overall thermal efficiency by 20% compared to what can be done today. The initial activity will be an assessment of baseline values for increasing thermal efficiency using advanced technologies and techniques. Subsequent activities will assess the performance toward the achievement of the 20% increase in overall thermal efficiency.

Developing more **efficient cooling media and application techniques** is another key activity for improving the energy efficiency of high power density facilities. With the increase in heat density, the upper limits of air-cooled solutions are being reached. Novel cooling techniques of the equipment cabinets and the electronics should be investigated. Some examples of cooling media include water, refrigerants, high dielectric fluorocarbons, and two-phase fluids such as dielectrics. Activities include studies to characterize the properties of new materials; developing better materials manufacturing techniques; and researching novel and existing cooling techniques such as vapor chamber heat spreader, heat pipes, closed loop water cooling, system with heat rejection to air, liquid jet impingement cooling, and liquid spray cooling.

The technical objective for this activity is to verify and validate by 2012 more effective cooling media and the techniques used for this media to cool equipment. There will be an annual internal assessment, validated every other year by independent peer review, of the ability of cooling media to be two times more effective than what can be done today. This should be achieved while processor clock speeds and disk storage continue to increase at a historical pace. The initial activity will be an assessment of baseline thermal values of cooling media. Subsequent activities will assess the performance toward the achievement of the increase in effectiveness.

8.6 Linkages to Other Programs and Activities

Coordination of activities will be needed with the various telecommunications and data warehousing companies to continue to gather equipment, square footage, and thermal characteristic data. Additional coordination will be needed with the research and development programs in DOE’s Office of Energy Efficiency and Renewable Energy that address commercial buildings. Organizations that represent utility companies (e.g., the Electric Power Research Institute, Edison Electric Institute, National Rural Electric Cooperative Association, and the American Public Power Association) will be important stakeholders in the program as well as the utilities themselves.

8.7 Summary of the Five-Year Plan for High Power Density Industry Applications

Key Activities	Technical Objectives	Metrics
Performance of cooling technologies	Verify and validate by 2010 better overall thermal efficiency in the room using the supply heat index and the return heat index	Overall thermal efficiency increase of 20% compared to today's baseline
Efficient cooling media and application techniques	Verify and validate by 2012 more effective cooling media and the techniques used for this media to cool equipment	The ability of cooling media to be 2 times more effective than today's solutions

Key Activities	2008	2009	2010	2011	2012
Performance of Cooling Technologies	*Novel cooling technology development and improvement*				
Efficient Cooling Media and Application Techniques	*Characterization of new materials and cooling techniques*				

9.0 MANAGING FOR RESULTS

The President's Management Agenda[9] says:

> *"Science and technology are critically important to keeping our Nation's economy competitive and for addressing challenges in health care, defense, energy production and use, and the environment. As a result, every Federal research and development dollar must be invested as effectively as possible."*

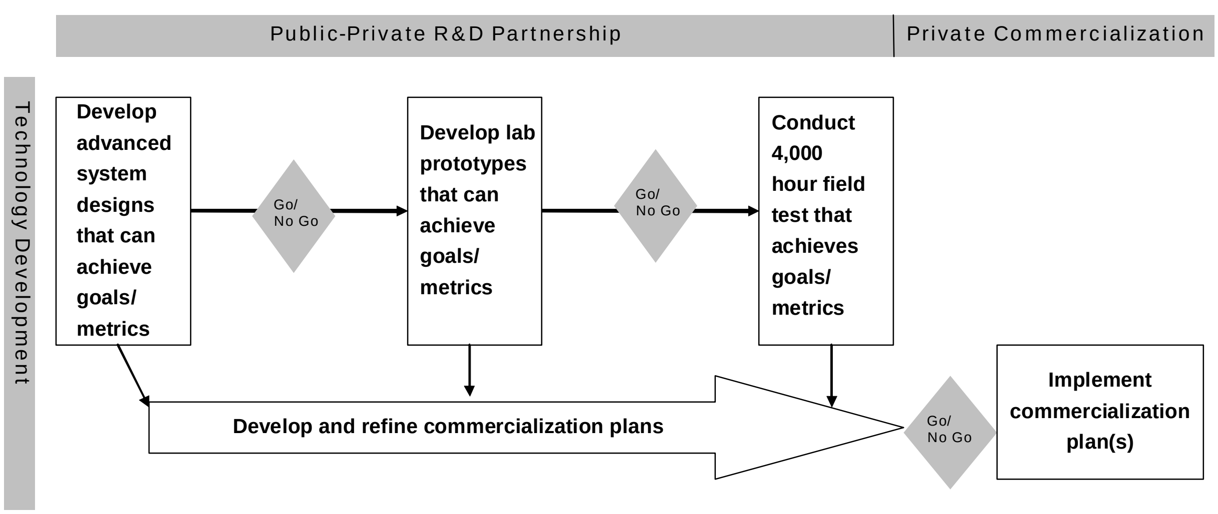
In pursuit of this goal, OE uses several techniques for managing its research, development, demonstration, and technology transfer activities. The activities outlined in this plan will include the following management practices:

- Decision making processes and analysis to improve performance and increase efficiency
- Public-private partnerships to leverage resources and share costs
- Peer reviews to identify less productive projects and re-direct resources toward the most promising technology pathways
- Performance Assessment Rating Tool to evaluate activities and validate directions and priorities
- Portfolio analysis to evaluate research risks and benefits and modify resource allocations to ensure a proper balance among technology activities

9.1 Decision Making Processes and Analysis

Program decision making generally follows the "stage-gate" decision process depicted in the diagram below. This model involves competitive solicitations that require cost sharing, have quantitative technical performance goals, involve multi-year projects with built-in "go/no

Stage-Gate Decision Process



[9] Office of Management and Budget. *The President's Management Agenda*. 2002

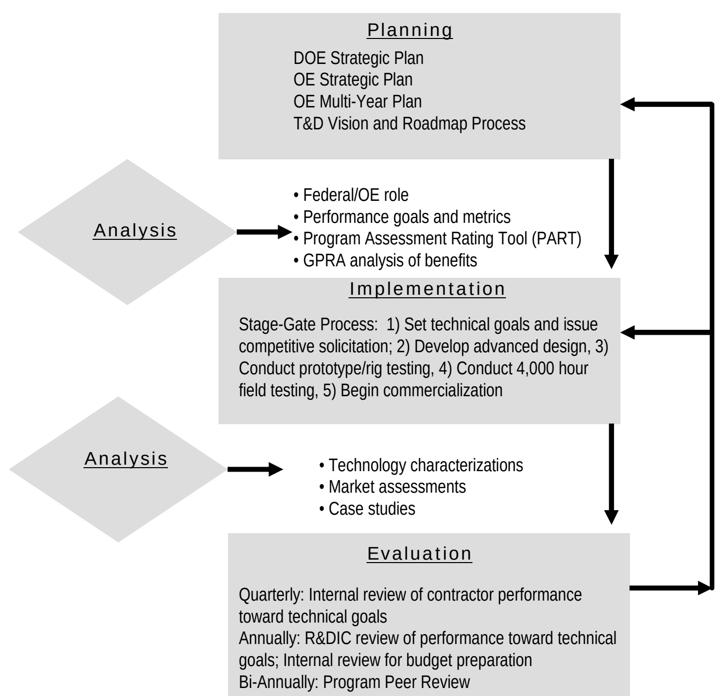
go" decision steps and down selections, build in corporate commitment to commercialization, and include systematic monitoring and evaluation of technical progress at each step of the way.

This means that "go/no go" decisions will be based on internal analysis and independent peer review of progress on a periodic basis to determine if the performance (in meeting technical objectives) of projects, large and small, warrant further Federal funding. In addition, the needs of stakeholders will be assessed to ensure that activities continue to serve industry needs. A certain amount of flexibility is needed in the management of projects to enable objectives to be adjusted in response to changes in the needs of stakeholders, and to levels of appropriated funding.

The first step typically involves a competitive solicitation to develop an advanced technology design (e.g., new grid architectures, energy storage systems, advanced cables and conductors, and high-temperature superconducting devices). The solicitation contains specific technical performance criteria for factors such as energy density, current carrying capacity, durability, or capital cost. Designs which meet the technical criteria can advance to the second step, which is the development of a prototype which undergoes lab/rig testing. After testing, prototypes which meet the technical criteria advance to the third step, which involves the development and field testing of equipment.

Equipment that meets the technical criteria after undergoing at least 4,000 hours (at least) of field testing moves on to commercialization, which is the responsibility of the private sector partner. Commercialization is the ultimate aim of this process. Part of the award criteria in the competitive solicitation for advanced designs includes a commercialization planning component aimed at achieving market readiness and price points that will enable market entry. The private sector partner must demonstrate commitment from senior corporate management for this approach to be effective. Commercialization plans are reviewed at key points in the multi-year process.

Role of Analysis in Planning, Implementation, and Evaluation



Decision making is based on analysis and the diagram to the right describes how analysis is integrated into program planning, implementation, and evaluation. One type of analysis is data development. These efforts are used build better baseline information about the current status of electric transmission and distribution system and the potential opportunities for "next generation" technologies to have an impact. Market assessments are used to evaluate potential technology applications and commercialization strategies. Technology characterizations are used to develop baseline information on the costs and performance of today's technologies and to determine technology performance criteria for solicitations in the design and development of "next generation" systems. Benefits analysis provides information on the impacts of technology investments including reliability, system efficiency, and security.

9.2 Public-Private Partnerships

Collaboration with stakeholders is the primary means for accomplishing the mission and goals for technology development. The likelihood of success in addressing technical barriers and achieving commercial products and services is enhanced when equipment manufacturers, electric utilities, national laboratories, and universities work with OE to identify common technical goals, technical challenges, technology needs, and technology development pathways.

One mechanism for establishing collaboration is through the development of technology visions and roadmaps. In 2003, OE's predecessor office, the Office of Electric Transmission and Distribution, developed a *National Vision for Electricity's 100 Years*[10] and the *National Electric Delivery Technologies Roadmap*[11]. These documents resulted from two workshops where more than 200 stakeholders met to discuss a vision for the future electric grid and technology development needs and priorities for achieving that vision. The strategies discussed in those documents have guided subsequent OE budget requests and have served as the basis for strengthening existing or creating new technology development partnerships.

Partnerships take several forms, depending on the type of stakeholder. Cooperative Research and Development Agreements are used for awards in response to competitive solicitations for technology development projects. These agreements require the award recipient to provide cost sharing to leverage funding and demonstrate corporate commitment. Memorandums-of-understanding (MOUs) are used to establish the scope, activities, and roles and responsibilities of partnerships with state agencies or various R&D consortia. Key on-going MOUs include:

- California Energy Commission for work in energy storage, distributed energy, and microgrids
- New York State Energy Research and Development Authority for work in energy storage
- Consortium for Electricity Reliability Technology Solutions involves universities, utilities, and national laboratories for work in visualization tools and techniques for grid operators
- GridWise Alliance involves utilities, information and telecommunications services providers, and others for work in the integration of distributed energy, demand response, and distributed intelligence into the electric power system

This plan calls for the continuation and possible expansion of these MOUs, as well as possible development of new ones to include other states, consortia, and other technology development activities, depending on interests and opportunities.

[10] U.S. Department of Energy. *national Vision for Electricity's 100 Years*. 2003

[11] U.S. Department of Energy. *national Electric Delivery Technologies Roadmap*. 2004

9.3 Peer Review

Peer review of program activities occurs regularly, at least once every two years. Peer reviews involve using independent experts to evaluate the technical merit of projects, the likelihood of technical success, the likelihood of market success, and the cost-effectiveness of research management. These criteria are drawn from the R&D Investment Criteria that have been developed for DOE in response to the President's Management Agenda.

Recent peer reviews include:

- Distributed Energy – December 2005
- High-Temperature Superconductivity – August 2005
- Transmission Reliability – October 2005
- Electric Distribution Transformation – April 2005
- Energy Storage – October 2005

The results of the peer reviews are used to evaluate the performance of research performers. Within the peer review, experts evaluate each project. Peer reviewers are asked to assess the strengths and weaknesses of each project and to recommend additions or deletions in the scope of work. Feedback is provided to the performers and subsequent funding decisions reflect the peer review evaluations. The peer reviews are used to justify the cessation of funding for unproductive research, and increases in funding for promising research.

9.4 Program Assessment

The Program Assessment Rating Tool (PART) has been developed by OMB to provide a standardized process for evaluating the relative merits of alternative programs. In addition, PART provides an additional perspective for OE managers to judge the efficacy and performance of research directions and priorities. The criteria used for PART evaluations include: program purpose and design, strategic planning, program results, and program management. PART evaluations have been accomplished for:

- High-Temperature Superconductivity (2004)
- Distributed Energy (2004)

Actions taken as a result of the PART evaluation include acceleration of research for second generation high-temperature superconducting wires, and re-direction of distributed energy funding for systems integration efforts with buildings and local energy networks.

9.5 Portfolio Analysis

Portfolio analysis evaluates the efficacy and performance of the entire research portfolio and is not focused on the performance of individual projects. The portfolio analysis process includes evaluation of risk, the number and size of projects, the expected timing of potential impacts, and the life cycle of the technology, partnerships, and level of innovation.

The analysis includes evaluation of different portfolio strategies. These strategies include alternative approaches to the Federal role: technology leader, technology explorer, and technology catalyst. A technology leader strategy is characterized by visible, influential initiatives, relatively large funding levels, and planning horizons that signal long-term commitments. An explorer strategy is characterized by emphasis on leading edge investments in mostly unexplored areas and requires tolerance for relatively high risks. A catalyst strategy uses numerous and relatively small initiatives with the focus to encourage others to complete development. The OE portfolio is balanced to include efforts that involve all three of these strategies.

APPENDIX A. TECHNOLOGY CROSSWALK

Section 925. Electric Transmission and Distribution Programs	Chapter(s) Where Discussed
(1) advanced energy and energy storage technologies, materials, and systems, giving priority to new transmission technologies, including composite conductor materials and other technologies that enhance reliability, operational flexibility, or power-carrying capability;	3, 4, 5, 6, 7, 8
(2) advanced grid reliability and efficiency technology development;	3, 4, 5, 6, 8
(3) technologies contributing to significant load reductions;	5, 6, 9
(4) advanced metering, load management, and control technologies;	5, 6
(5) technologies to enhance existing grid components;	3, 4, 5, 6, 8
(6) the development and use of high-temperature superconductors to— (A) enhance the reliability, operational flexibility, or power-carrying capability of electric transmission or distribution systems; or (B) increase the efficiency of electric energy generation, transmission, distribution, or storage systems;	4
(7) integration of power systems, including systems to deliver high-quality electric power, electric power reliability, and combined heat and power;	3, 4, 5, 6, 8
(8) supply of electricity to the power grid by small scale, distributed and residential-based power generators;	5, 6, 8
(9) the development and use of advanced grid design, operation, and planning tools;	3, 5
(10) any other infrastructure technologies, as appropriate; and	All
(11) technology transfer and education.	All

APPENDIX B. ENERGY POLICY ACT OF 2005 TITLE IX, SUBTITLE B

Subtitle B--Distributed Energy and Electric Energy Systems

SEC. 921. DISTRIBUTED ENERGY AND ELECTRIC ENERGY SYSTEMS.

(a) In General- The Secretary shall carry out programs of research, development, demonstration, and commercial application on distributed energy resources and systems reliability and efficiency, to improve the reliability and efficiency of distributed energy resources and systems, integrating advanced energy technologies with grid connectivity, including activities described in this subtitle. The programs shall address advanced energy technologies and systems and advanced grid reliability technologies.

(b) Authorization of Appropriations-

(1) DISTRIBUTED ENERGY AND ELECTRIC ENERGY SYSTEMS ACTIVITIES- There are authorized to be appropriated to the Secretary to carry out distributed energy and electric energy systems activities, including activities authorized under this subtitle--

(A) $240,000,000 for Fiscal Year 2007;

(B) $255,000,000 for Fiscal Year 2008; and

(C) $273,000,000 for Fiscal Year 2009.

(2) POWER DELIVERY RESEARCH INITIATIVE- There are authorized to be appropriated to the Secretary to carry out the Power Delivery Research Initiative under subsection 925(e) such sums as may be necessary for each of Fiscal Years 2007 through 2009.

(c) Micro-Cogeneration Energy Technology- From amounts authorized under subsection (b), $20,000,000 for each of Fiscal Years 2007 and 2008 shall be available to carry out activities under section 923.

(d) High-Voltage Transmission Lines- From amounts authorized under subsection (b), $2,000,000 for Fiscal Year 2007 shall be available to carry out activities under section 925(g).

SEC. 922. HIGH POWER DENSITY INDUSTRY PROGRAM.

(a) In General- The Secretary shall establish a comprehensive research, development, demonstration, and commercial application to improve the energy efficiency of high power density facilities, including data centers, server farms, and telecommunications facilities.

(b) Technologies- The program shall consider technologies that provide significant improvement in thermal controls, metering, load management, peak load reduction, or the efficient cooling of electronics.

SEC. 923. MICRO-COGENERATION ENERGY TECHNOLOGY.

(a) In General- The Secretary shall make competitive, merit-based grants to consortia for the development of micro-cogeneration energy technology.

(b) Uses- The consortia shall explore--

(1) the use of small-scale combined heat and power in residential heating appliances;

(2) the use of excess power to operate other appliances within the residence; and
(3) the supply of excess generated power to the power grid.

SEC. 924. DISTRIBUTED ENERGY TECHNOLOGY DEMONSTRATION PROGRAMS.

(a) Coordinating Consortia Program- The Secretary may provide financial assistance to coordinating consortia of interdisciplinary participants for demonstrations designed to accelerate the use of distributed energy technologies (such as fuel cells, microturbines, reciprocating engines, thermally activated technologies, and combined heat and power systems) in high-energy intensive commercial applications.
(b) Small-Scale Portable Power Program-
(1) IN GENERAL- The Secretary shall--
(A) establish a research, development, and demonstration program to develop working models of small scale portable power devices; and
(B) to the fullest extent practicable, identify and utilize the resources of universities that have shown expertise with respect to advanced portable power devices for either civilian or military use.
(2) ORGANIZATION- The universities identified and utilized under paragraph (1)(B) are authorized to establish an organization to promote small scale portable power devices.
(3) DEFINITION- For purposes of this subsection, the term `small scale portable power device' means a field-deployable portable mechanical or electromechanical device that can be used for applications such as communications, computation, mobility enhancement, weapons systems, optical devices, cooling, sensors, medical devices, and active biological agent detection systems.

SEC. 925. ELECTRIC TRANSMISSION AND DISTRIBUTION PROGRAMS.

(a) Program- The Secretary shall establish a comprehensive research, development, and demonstration program to ensure the reliability, efficiency, and environmental integrity of electrical transmission and distribution systems, which shall include--
(1) advanced energy delivery technologies, energy storage technologies, materials, and systems, giving priority to new transmission technologies, including composite conductor materials and other technologies that enhance reliability, operational flexibility, or power-carrying capability;
(2) advanced grid reliability and efficiency technology development;
(3) technologies contributing to significant load reductions;
(4) advanced metering, load management, and control technologies;
(5) technologies to enhance existing grid components;
(6) the development and use of high-temperature superconductors to--
(A) enhance the reliability, operational flexibility, or power-carrying capability of electric transmission or distribution systems; or
(B) increase the efficiency of electric energy generation, transmission, distribution, or storage systems;
(7) integration of power systems, including systems to deliver high-quality electric power, electric power reliability, and combined heat and power;
(8) supply of electricity to the power grid by small scale, distributed and residential-based power generators;

(9) the development and use of advanced grid design, operation, and planning tools;

(10) any other infrastructure technologies, as appropriate; and

(11) technology transfer and education.

(b) Program Plan-

(1) IN GENERAL- Not later than 1 year after the date of enactment of this Act, the Secretary, in consultation with other appropriate Federal agencies, shall prepare and submit to Congress a 5-year program plan to guide activities under this section.

(2) CONSULTATION- In preparing the program plan, the Secretary shall consult with--

(A) utilities;

(B) energy service providers;

(C) manufacturers;

(D) institutions of higher education;

(E) other appropriate State and local agencies;

(F) environmental organizations;

(G) professional and technical societies; and

(H) any other persons the Secretary considers appropriate.

(c) Implementation- The Secretary shall consider implementing the program under this section using a consortium of participants from industry, institutions of higher education, and National Laboratories.

(d) Report- Not later than 2 years after the submission of the plan under subsection (b), the Secretary shall submit to Congress a report--

(1) describing the progress made under this section; and

(2) identifying any additional resources needed to continue the development and commercial application of transmission and distribution of infrastructure technologies.

(e) Power Delivery Research Initiative-

(1) IN GENERAL- The Secretary shall establish a research, development, and demonstration initiative specifically focused on power delivery using components incorporating high temperature superconductivity.

(2) GOALS- The goals of the Initiative shall be--

(A) to establish world-class facilities to develop high temperature superconductivity power applications in partnership with manufacturers and utilities;

(B) to provide technical leadership for establishing reliability for high temperature superconductivity power applications, including suitable modeling and analysis;

(C) to facilitate the commercial transition toward direct current power transmission, storage, and use for high power systems using high temperature superconductivity; and

(D) to facilitate the integration of very low impedance high temperature superconducting wires and cables in existing electric networks to improve system performance, power flow control, and reliability.

(3) INCLUSIONS- The Initiative shall include--

(A) feasibility analysis, planning, research, and design to construct demonstrations of superconducting links in high power, direct current, and controllable alternating current transmission systems;

(B) public-private partnerships to demonstrate deployment of high temperature superconducting cable into testbeds simulating a realistic transmission grid and under varying transmission conditions, including actual grid insertions; and

(C) testbeds developed in cooperation with National Laboratories, industries, and institutions of higher education to--

(i) demonstrate those technologies;

(ii) prepare the technologies for commercial introduction; and

(iii) address cost or performance roadblocks to successful commercial use.

(f) Transmission and Distribution Grid Planning and Operations Initiative-

(1) IN GENERAL- The Secretary shall establish a research, development, and demonstration initiative specifically focused on tools needed to plan, operate, and expand the transmission and distribution grids in the presence of competitive market mechanisms for energy, load demand, customer response, and ancillary services.

(2) GOALS- The goals of the Initiative shall be--

(A)(i) to develop and use a geographically distributed center, consisting of institutions of higher education, and National Laboratories, with expertise and facilities to develop the underlying theory and software for power system application; and

(ii) to ensure commercial development in partnership with software vendors and utilities;

(B) to provide technical leadership in engineering and economic analysis for the reliability and efficiency of power systems planning and operations in the presence of competitive markets for electricity;

(C) to model, simulate, and experiment with new market mechanisms and operating practices to understand and optimize those new methods before actual use; and

(D) to provide technical support and technology transfer to electric utilities and other participants in the domestic electric industry and marketplace.

(g) High-voltage Transmission Lines- As part of the program described in subsection (a), the Secretary shall award a grant to a university research program to design and test, in consultation with the Tennessee Valley Authority, state-of-the-art optimization techniques for power flow through existing high voltage transmission lines.