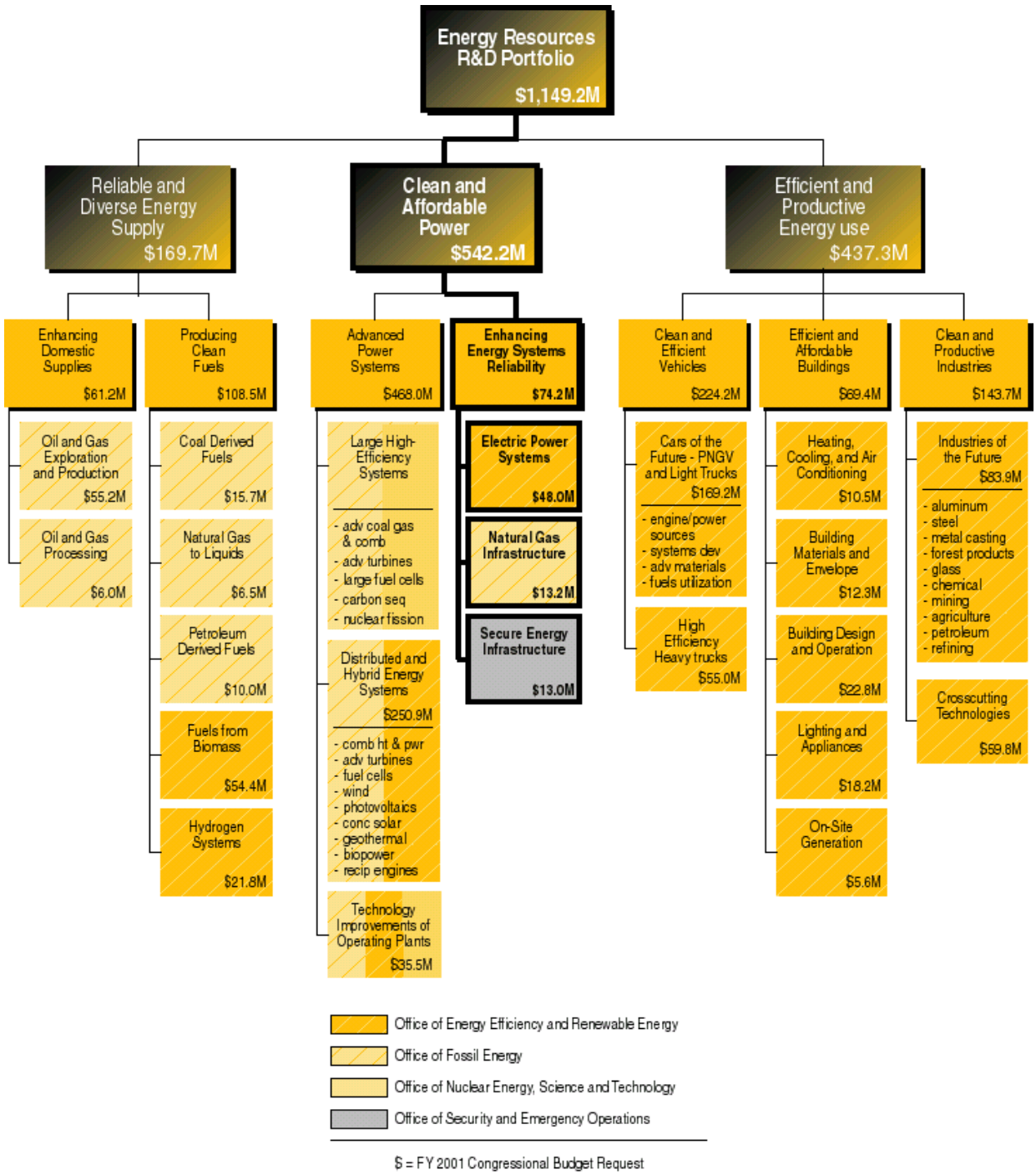
Chapter 6
Enhancing Energy System Reliability



Chapter 6

Enhancing Energy System Reliability

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Overview

Definition of Focus Area

The security, economic prosperity, and social well being of the United States relies on a complex system of interdependent infrastructures. Energy infrastructures are the foundation of American life, upon which the United States is highly dependent. Enhancing energy system reliability encompasses programs to enhance the reliability and security of the Nation's electricity and natural gas infrastructures. The electricity and natural gas infrastructures annually deliver energy services worth over $200 billion and $90 billion, respectively, to U.S. customers.

Electricity also powers other critical national service infrastructures such as telecommunications, oil and gas pipeline systems and water supply systems that are basic to the functioning of U.S. society. The electricity infrastructure consists principally of the transmission and distribution system, but also extends beyond the utility meter on the customer side, and into the power plant on the production side. Customer equipment such as large motors, power quality management, and load control technologies are included, as well as efficient mechanical equipment for generating electricity. As electric industry restructuring revolutionizes the way electric power is produced and consumed, the continued successful development of regional and interregional competitive markets depends upon the availability of a robust, efficient, reliable electricity infrastructure.

Natural gas is delivered to about 175 million U.S. customers through an integrated network of pipelines. From field production to burner-tip, natural gas moves through a complex infrastructure of producing wells, gas gathering systems, natural gas processing centers, natural gas storage facilities, intrastate and interstate pipeline transmission systems, to the city gate delivery points, and finally through the local distribution lines to the customer. A 1.26 million mile network of underground pipe consisting principally of the natural gas gathering lines (50,000 miles), natural gas transmission pipelines (265,000 miles), distribution pipelines (955,000 miles) is owned by the gas utility industry. The natural gas industry is in the midst of unprecedented change. Traditionally regulated energy markets are being transformed into competitive ones, facilitated by changing regulations and new technology.

While the electricity system powers other infrastructures, it will also be increasingly dependent itself on the natural gas system as a fuel source for both central station, and small, distributed generation. The Annual Energy Outlook, 1999 projects that the annual growth for the use of natural gas for electricity generation will be 6.8% from 1996 through 2020. In addition, these energy delivery system are becoming increasingly reliant on telecommunication and computing systems for fast, efficient operation. This reliance increases their vulnerability to deliberate physical and cyber intrusion, and calls for focused measures to counter this threat. Although these two energy systems are interdependent and have reliability issues in common, their operating characteristics are quite different, and the technologies being developed to maintain their reliability under their respective restructuring scenarios are also unique to each system.. Where relevant, some of these differences are noted in the Overview, and expanded upon in the Program sections.

The Enhancing Energy System Reliability sector presents the research and development programs that provide an integrated approach to insuring reliable system operation and efficient markets for the Nations's electric and natural gas infrastructures while assuring their viability under the threat of deliberate disruption. Taken together, these programs comprise the Secretary's Initiative on Energy Grid Reliability.

National Context and Drivers

The Nation's electricity and natural gas systems are being asked to operate in ways for which they were not designed at the same time that new demands for improved performance are being made on them. Restructuring and competition in the electric power and natural gas industry are creating new offerings for energy services, and creating new patterns of demand on energy delivery infrastructures.

- Restructuring within the electric power and the natural gas industries presents the opportunity for companies to develop new businesses and markets. However, uncertainty in receiving a reasonable rate of return, caused by the lack of defined market structures, is preventing industry competitors from investing in R&D that would ensure energy system reliability, flexibility, and infrastructure security.

- Competitive electric markets are operating across far larger geographic areas than the traditional utility service territory. Regional or even national purchase contracts are possible. Wide area competitive electric markets require reliable transmission with capacity for large scale transfers across long distances.

- The integrity of the North American natural gas delivery and storage infrastructure will be critically important in meeting future U.S. energy demands. An average of approximately 2,000 to 2,100 miles of new gas transmission pipeline will be needed each year to achieve a 30 Tcf natural gas marketplace by 2010.

- Future energy delivery systems are likely to use high speed telecommunications and computing in advanced control systems to operate them closer to their limits. These operating conditions, and reliance on electronic controls increases the vulnerability of energy delivery systems to deliberate attack, requiring examination of tools and technologies to determine and mitigate this risk.

- Presidential Decision Directive 63 designates DOE as the lead federal agency for the energy infrastructure to assure the continuity and viability of the nation's critical energy infrastructures, and the elimination of any significant vulnerability of that sector to physical and cyber disruptions.

- The North American Electric Reliability Council (NERC) in its Reliability Assessment (1998-2007) states: "Transmission systems are increasingly challenged to accommodate demands of evolving competitive electricity markets. Market driven changes in usage patterns, the number and complexity of transactions, and the need to deliver replacement

power to capacity-deficient areas are causing new transmission limitations to appear in different and unexpected locations."

- Large power outages are more likely today as power systems operate closer to their limits, and in ways for which they were not planned or designed. The Western outage on August 10, 1996 was such an outage, and its cost in California alone was estimated to be over $1 billion. As a result of the 1996 Western outages, the Secretary of Energy Advisory Board convened a Task Force that recommended that DOE participate in technical studies related to transmission reliability.

- In July 1999, the Secretary of Energy announced a six-point plan to assist utilities with heat-related power outages. Under this plan, DOE expert teams investigated Summer 1999 outages in four areas in the Eastern United States, and will issue a report to the Secretary this Spring that recommends actions the Secretary can take to prevent recurrences. This report will consider the impact of restructuring.

- The required new gas pipeline and storage infrastructure will have to be constructed on existing and new rights of way and facility sites. It is important that the environmental permitting process balance the need for energy and enhanced energy system reliability in a growing economy, against other public interests.

Linkage to CNES Goals and Objectives

Enhancing Energy System Reliability directly supports the five CNES Goals:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems. *(by reducing network and end use losses with superconducting power equipment technologies, and investigating real time control of power systems)*

- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability. (by developing active system controls, storage technologies, and advanced superconducting applications such as the superconducting fault current limiter, and developing advanced technology for natural gas and oil transportation and storage)

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies. *(by developing control and storage technology that could help enable the integration of distributed and renewable resources)*

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options. *(by increasing system capacity, removing bottlenecks, and enabling distributed resource options)*

- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems. (*by working with other countries through the International Energy Agency to promote*

communications and collaborations on an integrated North American natural gas pipeline delivery system that can ensure energy system reliability)

Enhancing Energy System Reliability has four objectives that support the CNES goals that will be achieved through partnerships with industry: (1) provide technical and policy options to enable the operation of large scale, interregional, real time, competitive electricity markets while maintaining system reliability and security; (2) by 2020, develop technologies that could reduce by one-third the approximately 9 percent of electricity lost to network inefficiency and the associated greenhouse gases produced; (3) provide network technology options that would allow the electric and natural gas systems to incorporate market-driven penetration of distributed resources, including renewable generation technologies, of up to 20 percent of new capacity by 2010; and (4) provide technology development for advanced control and monitoring of pipeline and storage facilities to assure the reliability, integrity, and security of the Nation's natural gas delivery systems.

Uncertainties

Technical, regulatory, environmental, and political uncertainties could affect the success of the Enhancing Energy System Reliability programs. Technical challenges (possible barriers to achieving either performance or cost goals) are described in the program planning documents and are summarized in the subsequent R&D challenges sections. Non-technical issues include uncertainty over the nature of incentives for construction of transmission facilities in a competitive marketplace. Without assurance of investment recovery in the regulated natural gas or electric transmission systems, providers may limit involvement in new technologies.

Competition has led many utilities to eliminate or significantly reduce funding for reliability R&D even though R&D needs have increased. Research that enhances reliability through improved market structures or technologies will improve reliability for all. However, due to competition and uncertainty regarding how and when an individual investor will realize a return on his investment in the new restructured industry, no single market participant or entity is generally willing to invest in this research when the benefits will flow equally to all market participants.

An aging U.S. energy infrastructure raises concerns over environmental issues. As local natural gas distribution systems continue to age, the potential for methane leaks and the negative impact of this potent greenhouse gas increases. Uncertainty under restructuring is stifling private sector funding for R&D, including reduction the Gas Research Institute budget, to develop advanced mitigating technologies for this effect, and for capital improvement funds for upgrade of facilities in the natural gas infrastructure.

Investment Trends and Rationale

The FY 1999 DOE investment in the energy system reliability program was $41.7 million, an amount that increases to $44.5 million in FY 2000 and rises to $74.2 million in FY 2001. The FY2001 increase reflects the addition of natural gas and energy security infrastructure programs

to the Secretary's Energy Grid Reliability Initiative, which places unified emphasis on maintaining and enhancing the reliability and energy security of the Nation's electric and natural gas infrastructures.

The Energy Storage Systems program develops storage technologies that enhance power system capacity, power quality, and reliability. Funding for this effort decreased $4.5 to $3.5 million in FY 2000, and is projected to increase to $5.0 million in FY 2001 to increase focus on the contribution of advanced storage technologies such as flywheels and superconducting magnetic energy storage (SMES), and their integration into the electric power system to support the Reliability Initiative.

The Superconductivity in Power Systems program was charged in 1989 with fostering cooperative research and development with U.S. industry to capture the benefits of high-temperature superconductors for power applications. Six new cost-shared, multi-year partnerships designed to produce operating, pre-commercial power equipment using the best available long-length HTS wires will be underway in FY 1999. In addition, to help accelerate the development of wires based on 1996 National Laboratory discoveries, new cooperative research projects will also be initiated with industry. For these partnerships, funding increased in FY 1999 to the $ 32.5 million level, and funding will remain at a relatively constant level in FY 2000 and FY 2001 to enable continued progress at the laboratories and within the industry teams.

Recognizing the need for a program element focused on the development of system technologies to enable competitive markets and maintain reliability in a restructured electricity industry, a new initiative, the Transmission Reliability program was funded in FY 1999 at $2.5 million. This initiative is projected to increase from $2.5 million in FY 2000 to $8.0 million in FY 2001, and, under the Energy Grid Reliability Initiative, focus on development of technologies and policy options to enhance the reliability of the Nation's electric delivery system during the transition to competitive power markets.

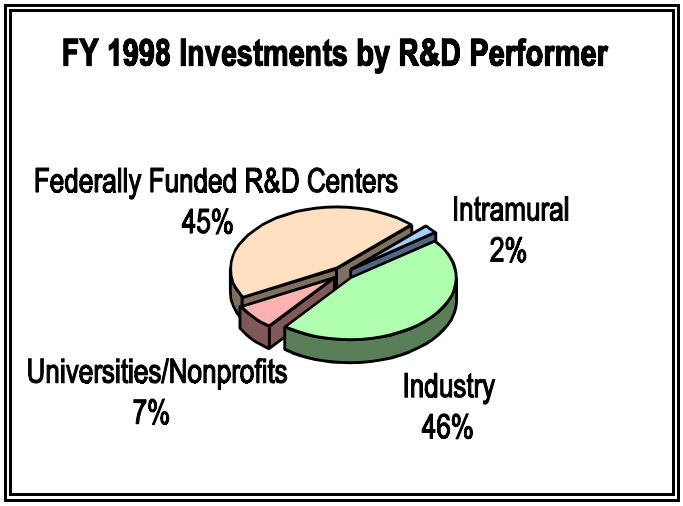
The Distributed Power program conducts R&D to address the technical, institutional, regulatory, and financial issues that are critical to realizing the full potential of distributed generation, energy storage, and demand-side management on the power distribution system. This work was also initiated in FY 1999 at $1,232 million, and is projected to decrease from $3.5 million in FY 2000 to $3.0 million in FY 2001, and focus on completing the utility interconnection standard for distributed generation and storage, and follow-on work to a broad solicitation issued in FY 1999.

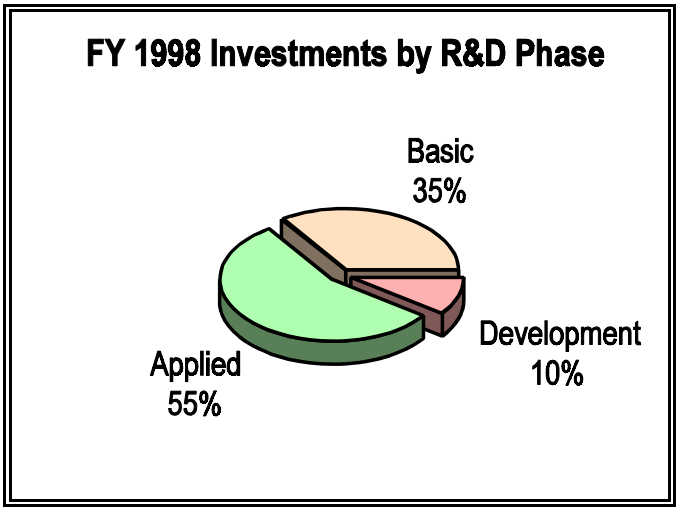
The Natural Gas Infrastructure program is a new initiative in FY 2001 that will enhance reliability and deliverability of the Nation's natural gas pipelines and gas storage facilities. It builds on the gas storage technology program which was funded at $1.0 million in FY 2000. Funding for the new program will increase to $14.0 million in FY 2001 and focus on gas storage technology, pipeline reliability technology research, and international infrastructure integrity research. Research and development activities will concentrate on advanced materials and enabling technology for longer life, high-strength, non-corrosive pipeline; an obstacle detection

systems for horizontal boring applications in distribution pipe; a pipeline leak and intrusion detection system using optical methods; pipeline inspection sensors with an internal leak sealing capabilities; and a portable methane leak detection systems for real-time visualization of gas pipeline systems.

The Secure Energy Infrastructure Program focuses on assuring the continuity and viability of the nation's critical energy infrastructures and the elimination of any significant vulnerability of that sector to physical and cyber disruptions. This is a new program. Funding for FY2000 was only $2.1M, but is projected to increase to $13M for FY2001. Research and Development activities will be concentrated in two areas--analysis and risk management, and protection and mitigation technologies.

The figure below indicates the division of FY 1998 funding between the principle performers of research tasks, and is representative of the current distribution. Industrial firms account for 46 percent of the program's Federal funding, in line with the applied focus of the program and the desire to use partnerships with industry to hasten the development of necessary private manufacturing infrastructure for eventual commercialization. Pre-commercial pilot projects are selected by a competitive process which solicits cost-shared proposals from integrated teams including users, suppliers of materials and/or components, and systems integrators. This process minimizes public funding requirements, and determines the commitment of the marketplace to the technology. Such projects are cost shared with private sector funding at a level at least equivalent to the Federal share. After industry, the most significant performer is the complex of DOE National Laboratories, representing 45 percent of the Federal funding. The emphasis on National Laboratories reflects the need for sophisticated equipment, extensive facilities, concentrated expertise, and the sustained effort required. Though not counted as research performers, industry experts sitting on steering and oversight committees in all program areas provide important reality checks on the progress and future value of research activities.





The figure above shows the division of effort between basic, applied and development activities. In FY 1998, approximately 90 percent of research funding was devoted to basic or applied activities, reflecting the focus of major parts of the program on the long term development of technologies that enable fundamental shifts in concept for electric power equipment design. The relatively low level of development activities reflect the fact that the majority of the technologies under development have commercial horizons of 5 years or more. Development activities are also heavily cost shared with the level of Federal funding rarely exceeding 30 percent of total project cost.

Federal Role

As described under the Uncertainties section above, in the transition to competitive energy markets, the Federal government and State organizations are picking up the critical role of performing energy system reliability technology R&D until market structures and economic incentives are in place for the energy providers to assume this work. In particular, R&D in energy delivery systems and storage systems for electricity and natural gas, and R&D on the integration of distributed energy generation at the customer level are critical activity areas that require long-term Federal involvement. In addition, at the same time these energy delivery systems are converging, their control centers are using advanced communications and computing systems that increase the need for the Federal R&D in infrastructure surety from deliberate physical or cyber attack.

For the electricity infrastructure, maintaining reliable electric service under competitive electricity markets, requires R&D to match generation to load in real time in the most efficient manner. In the near-term, an adequate power delivery system combined with the application of energy storage is essential. In this time frame, the very existence of viable, large-scale markets for electricity depends on the ability to move power over long distances reliably with a minimum of restrictions. In the mid-term, the Distributed Power program will enable energy service choices at the individual customer level through R&D that allows the integration of distributed generation, storage and demand-side management technologies into the distribution system. As

penetration of natural gas-fired distributed generation increases, the interdependencies and synergies of these two energy delivery systems increase dramatically, requiring close coordination through the Energy Grid Reliability Initiative. New technologies that increase the capability of existing systems while maintaining reliability, and that improve the public acceptability of new facilities are needed to maintain progress toward competitive markets in the electric and natural gas industries.

At the same time that the need for new technology increases, incentives for privately funded power and natural gas delivery systems research in the restructured industry are being reduced. While profit opportunities in the competitive marketplace will likely spur generation innovation, the Secretary of Energy Advisory Board (SEAB) Task Force on Electric System Reliability notes that it is " concerned that reliability related R&D with long term focus may be underfunded by market forces." For instance:

- Independent System Operators (ISOs) have been established to take over from utilities the responsibility for reliable operation and planning of the transmission grid while providing equal access to all market players. ISOs have made great strides toward establishing operating arrangements that support competitive markets, but as a result of the transfer of responsibilities, reliability research efforts funded directly by utilities have largely been terminated and not been replaced.

- Historically, the bulk of public interest R&D on system reliability was carried out by research providers like the Electric Power Research Institute (now EPRI), and the Gas Research Institute, research associations funded by the Nation's electric and natural gas utilities. As a result of changes in the business climate of its members, these research associations have seen precipitous declines in their systems research funding. More importantly, these organizations are now more likely to focus their effort on near term, proprietary, commercially viable technology. Projects in longer term strategic research make up decreasing amounts of the total budget, and their public interest value is limited by the proprietary nature of the work.

- State agencies, such as the California Energy Commission (CEC) and the New York State Energy Research and Development Administration (NYSERDA), have funded electric delivery system research and may continue to do so. CEC, with the guidance of the California ISO, funds electric power system reliability research on topics of importance to California consumers. California supports State public benefit research funding through transition charges on electric power sales. However, transition funding usually has a limited duration, focuses on immediate benefits as opposed to strategic research, and may not be available to ISO's that cover multiple States.

- Federal support of electric power and natural gas delivery research is becoming an increasingly important factor. DOE funding of electric and natural gas infrastructure research is necessary to maintain support for activities that are in the national interest, and to sustain adequate levels of long term development necessary to provide the basis for future industry innovations until new market and/or regulatory structures are developed

that provide the incentives for the private sector to assume this work. The realities of energy industry restructuring call for an increased DOE role in energy delivery research with both near term goals to assure reliable systems during the transition to competitive markets, and long range goals to develop advanced, enabling technologies. DOE also has a Federal role in supporting the system integration of the diverse array of DOE-developed distributed technologies, and in providing technically-based policy options, and "third-party" technical expertise to support Federal decision-makers.

- Presidential Decision Directives PDD-62 and PDD-63 define the inherently Federal role of assuring the security of the Nation's energy infrastructures from deliberate attack.

The timeframes used to describe work in this sector are as follows:

- Near Term(< 3 yrs.)
  Execution of the recommendations of the SEAB Task Force for evaluation of risk based analytical tools for reliability assessment, examination of alternatives to central station reactive power supply, and monitoring of private research on reliability technologies to assure that gaps do not develop.

- Mid-Term (3-7 yrs.)
  Development of system control technologies that enhance system stability and market performance, distributed resource integration strategies that enhance the flexibility of energy delivery, and transmission technologies for low cost mitigation of bottlenecks.

- Long Term (7-15 yrs.)
  Development of fundamental and enabling technologies for high capacity transmission.

Key Accomplishments

DOE began investigating synchronized measurements of power system quantities in 1991 through National Laboratory and university research performers. In 1995, the DOE co-sponsored Wide Area Measurement System (WAMS), an advanced satellite-synchronized monitoring system, entered field trials on the western U.S. power grid. During the western system outages of July and August, 1996, this prototype synchronized measurement system proved its worth by dramatically reducing the time needed to understand the causes and progression of the outages.

In recent years, a number of integrated, multi-benefit energy storage systems have been field tested in collaboration with private partners. For instance, a newly-developed R&D 100 Award winning mobile storage system, operating at a Georgia lithography plant, successfully corrected over 90 percent of the plant's power quality events in its first 6 months of operation. A 3.5 MW storage facility at a heavy metals recycling plant in California carries critical emission control loads in the event of a power outage to eliminate environmental noncompliance. A 1.4 MWh storage system recently installed in Alaska improves power quality in an isolated power system

on an Indian reservation. The success of these state-of-the-art systems is helping to address power quality and reliability problems, enable increased use of renewable power generation, and increase the productivity and competitiveness of U.S. industry.

Superconductivity Partnership Initiative (SPI) partners hold world records for high temperature superconducting (HTS) equipment of all types, including fault current limiters, motors, transmission cables, and power transformers. Current-carrying capability of HTS wires has increased 10-fold since 1990, and wire-making costs have decreased substantially as companies gear up for larger orders. A record 6 license agreements have been signed over the last 24 months for industrial use of the innovative second-generation wire technology developed with DOE support. In addition, 4 R&D 100 Awards have been received for Department-sponsored HTS technology.

Transmission Reliability

Budget: FY99-$3.0M, FY00-$2.5M, FY01-$8.0M

Background

The existing electric power grid links nearly 3,500 U.S. utilities operating under the supervision of 150 control areas and 22 security coordinators in 3 functionally and physically independent regional interconnections. It has been characterized as an energy superhighway, though it actually bears more resemblance to the network of two-lane roads that existed before the interstate highway system was built. That system allowed travelers to go from town to town, but those who attempted long distance travel risked delays due to bottlenecks created by local traffic congestion and fragmented, piecemeal routing. Similarly, the electric network has bottlenecks that can become congested and restrict power transfers, while routing for long distance power sales is often fragmented by multiple jurisdictions.

The revolution in system operations resulting from competition has increased pressure to cut costs and to drive the power grids harder, to squeeze as much economic value out of them as possible. Some catastrophic outages in the western system during the summer of 1996 pointed out the fragility of the network in the face of high levels of interregional power transfers. At the same time, the presence of system bottlenecks and the fragmented, independent control structure has made it more difficult for competitive, reliable regional electricity markets and institutions to thrive, and has frustrated attempts to create a national commodity market in electricity.

A major new DOE/industry/university initiative, Transmission Reliability, was funded in FY 1999 to addresses near- and mid-term objectives of the Enhancing Energy System Reliability sector. It supports a National Laboratory/electric industry/universities partnership to conduct electric system reliability research in the context of competitive markets. Technologies that can automatically control networks over large areas at high speed, and that coordinate operation of distributed resources, offer the potential for creating reliable, interregional markets. Incentives that allow markets to provide system upgrades and reliability services, and efficient use of distributed resources can eliminate system bottlenecks at minimum cost. This projected five-year program will be reassessed each year to determine the need for Federal involvement depending

on the nature and implementation needs of new regulations, and the impact of market forces. The Transmission Reliability Program builds on accomplishments from the DOE's earlier program in electric reliability research which was last funded in FY 1995.

Linkage to CNES Goals and Objectives

The research and development program in Transmission Reliability contributes to the following CNES goals and objectives:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems.
- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability.
- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.
- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.

In addition, the Transmission Reliability program supports the Secretary's Initiative on Energy Grid Reliability, and the Secretary's Power Outage Study Team (POST). The Secretary formed POST to investigate major electric power outages, and recommend actions the Department can take to avoid reoccurrences.

Program Description

The Transmission Reliability program collaborates with electric industry stakeholders on a research agenda to develop technologies that promote competitive markets, ensure system reliability (adequacy and security), increase network capacity for large scale, long distance power transfers, and integrate distributed resources, including distributed generation and storage, and demand management, into the electric power grid. The program performs analyses and develops technologies in three program areas: Real Time System Control, Distributed Resource Integration, and Reliability and Markets.

Real Time System Control

Budget: FY99-$1.2M, FY00-$0.9M, FY01-$3.0M

Description, Objectives and Performers. Conventional power system control uses off-line models, planned generation dispatch, and anticipated load patterns to identify secure system configurations. With relatively few configurations to monitor, manual control suffices to maintain the system in the secure state. In a competitive marketplace, with a multiplicity of possible generation and load patterns in a constant state of flux, the number of possible system configurations and potential modeling scenarios could become unmanageably large. Agile competitive markets that permit large numbers of long distance power transactions suggest a

transition from manual control and off-line modeling to automated, on-line strategies that manage the system in real time. The objective of the Real Time System Control program is to develop technologies leading to automated security assessment and control based upon real time system measurements. High speed communications and distributed intelligent controllers would adjust power electronic network management devices and actively suppress disturbances with only limited human supervision. Real time system measurements will also provide information to enable efficient operation of competitive electricity markets.

Since this program element seeks to introduce a completely new paradigm in system control, initial efforts are expected to rely heavily on university and National laboratory performers. Work on wide area synchronized measurements, which can be used in existing systems to more accurately investigate disturbances, would be done in cost shared partnerships with electric industry operations partners.

R&D Challenges. Technical developments that are necessary for successful real time control include:

- Measurement systems that extract information that allow calculation of system states in real time.
- Cost effective communications that securely coordinate high speed data exchange under dynamic circumstances.
- Security assessment models that operate in a distributed environment at high speed using measured system data.
- Autonomous reasoning agents that can carry out secure distributed decision making and issue appropriate control commands.

R&D Activities. Real Time System Control research addresses near- and mid-term research goals of the Enhancing Energy System Reliability sector. Near-term activities include those identified by the Secretary of Energy Advisory Board (SEAB) Task Force on Electric System Reliability, (report published September 29, 1998) while the development of measurement-based, automated system controls supports mid-term objectives. The following R&D activity elements describe tools to meet the challenges.

Wide area synchronized measurements: This program element extends work on system measurements that proved extremely useful in the summer of 1996. The existing network of satellite-synchronized transient data recorders can provide measurements to be analyzed using advanced transient analysis methods, such as wavelet decomposition, and correlated with models of known events. This will both improve the value of existing models, and identify signatures of disturbances that can be used to guide control actions.

On-line measurement-based security assessment models: This element examines modeling algorithms that operate in a distributed environment to both validate measurements and rapidly

screen the hundreds of contingencies represented by the expanded geographic extent of interregional competitive markets.

Adaptive automated control: The advent of power electronics devices capable of actively managing system power flows at high speed creates the need for an automated control capable of coordinating the response of widely dispersed groups of such devices. This research examines development of autonomous reasoning agents that can monitor the state of the system in real time and issue control commands to suppress developing disturbances.

Development of risk assessment planning models for transmission networks: This program element seeks to carry out the SEAB Task Force near-term recommendation by pursuing development of transmission planning models that incorporate real-time control systems and power electronics, as well as extend the accuracy of modeling to larger portions of the grid. Because, in very large systems, conventional deterministic contingency analysis becomes inadequate, the mathematical basis for assessment of transmission capacity through systematic statistical evaluation of a large number of individually unlikely risks will be developed. In order to better define the behavior of very large systems nearing collapse, non-linear modeling methods might also be devised.

Accomplishments. The Transmission Reliability program has published six white papers to identify issues and R&D needs for electric power systems under restructuring. The white paper titled "Real-Time Security Monitoring and Control of Power Systems" outlines the issues, challenges and opportunities in the area of real-time monitoring and control of power systems in the restructured electricity industry. In the earlier research program, in addition to the WAMS project discussed above, which proved its worth during the summer 1996 western system outages, important successes were achieved in initial steps toward automated system control. A neural network-based voltage controller was developed that could simultaneously optimize the voltage profile and minimize system losses using only a single system measurement point. A multi-path fiber optic communications network for distribution system use was developed that could automatically route messages through damaged and reconfigured networks. The system was licensed to a utility who is currently using it as part of a wide area distribution automation scheme.

Distributed Resource Integration

Budget: FY99-$0.9M, FY99-$0.8M, FY00-$2.0M

Description, Objectives and Performers. Distributed resources include a variety of energy production and storage devices, such as microturbine generators , building-integrated photovoltaics, fuel cells, and energy storage systems with capacities from 1 kW to 10 MW. Another distributed resource is direct control of customer load for system and local benefits. Deployment of such resources on distribution networks could both defer investment in distribution and/or transmission facilities, and increase the reliability of power delivery by placing energy sources (either generation or storage) nearer to demand centers. By providing localized reactive power support, distributed resources could improve power quality. By supplementing conventional power delivery systems, distributed generation and storage could offer supply flexibility, including greater use of environmentally benign renewable energy.

This program area will support the integration of distributed resources into the larger power system. Proposed tasks focus on methods to integrate distributed resources into the power system to achieve their full value for reliable system operation, and for operation of efficient competitive markets. In addition, this element addresses redesign of the distribution system to accommodate active distributed power sources. Research will be performed through National laboratories and electricity industry partners. Some of the initial effort will identify the steady-state and dynamic characteristics of active distributed resources, and create scenarios and models for simulating their performance under system loads. National Laboratory and/or university expertise will be utilized to develop the theoretical bases for modeling and control.

R&D Challenges. The principal system integration barriers to large scale deployment of distributed resources are:

- Lack of modeling, monitoring and control methods for planning and operating systems composed of a large number of sources which must be dispatched in accordance with reliable system operation practices, and the economics of the larger marketplace, as well as with consideration for local system constraints.

- Lack of an economic approach to distribution system protection and reliability for distributed resources.

R&D Activities. Research activities under this program area will stretch the new paradigm even further, and require examination of technical, economic, institutional, safety, and other issues. More detailed guidance from stakeholders is continually sought to completely define this program area as distributed resources are developed and introduced. The following elements are proposed as initial areas for investigation in support of near- and mid-term goals. Distributed resources can provide a significant alternative to central station reactive power support, and the evaluation of such options is a near-term recommendation of the SEAB Task Force. In the mid-term, distributed resources offer the potential for increased customer choice and improved reliability of the larger system.

Control and protection of distributed resources: This program element will develop high speed multi-variate constrained optimization strategies for dispatching and control of large numbers of distributed resources. It will also assess the availability of cost-effective communications strategies that can accurately and securely exchange data at high speed to economically control large numbers of dispersed resources. This project will also explore options for protective systems that can be retrofitted to existing distribution systems economically and reliably.

Feasibility case studies: A key recommendation of the SEAB Task Force was the evaluation of alternatives to central station reactive power support. Distributed resources offer an important mechanism for supplying reactive support close to the load. Cooperative efforts with industry will develop case studies assessing the feasibility of distributed resources in specific electric systems. Potential partners would include energy producers, distributors, and users such as commercial building owners as well as equipment manufacturers. Case studies would identify the operational characteristics, reliability issues, control system requirements, and system-related

economic benefits, as well as the potential for reactive power support from distributed generation or storage technologies in an application environment.

Electric and gas systems integration: Most distributed generation is expected to rely on natural gas, at least in the near term. Examples include microturbines and fuel cells, both of which may be applied either as cogeneration in commercial buildings or as stand-alone electricity sources. Gas infrastructure and supply will therefore be as important as electric system issues in determining the success of large-scale application of these technologies. A series of regional studies will be conducted with industry to examine the interactions of the gas and electric delivery systems from the perspective of each as a component of an integrated energy system, with special emphasis on decreasing overall emissions and minimizing the cost of the delivered energy services to the customer. This activity will be closely coordinated with the Department's Distributed Power program.

Accomplishments. The Transmission Reliability white paper, "Interconnection and Controls for Reliable, Large Scale Integration of Distributed Energy Resources" identifies, defines and prioritizes R&D needs for this program area. From DOE's earlier reliability research program, two reports were prepared at the request of Congress that used case studies with actual utilities to determine the potential for integration of renewable resources into the electric power transmission and distribution system. The 1994 report assesses the cost and benefits of integrating wind and solar electric generation resources into the electric power distribution system. A 1995 report assess the capacity of the existing transmission system to accommodate delivery of large blocks of energy generated by renewable resources from remote, resource-rich areas of the country.

Reliability and Markets

Budget: FY99-$1.0M, FY00-$0.8M, FY01-$3.0M

Description, Objectives and Performers. The driving principle underlying restructuring is that markets will make more efficient and more equitable decisions regarding the generation and utilization of electric power than the current system of command and control. Markets for electricity are rapidly developing around the country. Many believe separate markets can and should be created for reliability, and that many reliability and security problems are amenable to market solutions. Yet, electricity has unique physical characteristics (supply and demand must be matched instantaneously, parallel routes may become congested unintentionally, and stability must be maintained in response to disturbances). Traditional approaches to efficient market operation developed for other commodities must be modified to reflect these realities. Early efforts to create markets for a handful of ancillary, reliability-related services in California are not functioning well in their present form. At the same time, many believe that the option of using existing command and control approaches to ensure system reliability protocols are inefficient and inappropriate for the new markets that are being created. The objective of research on Reliability and Markets is to determine the appropriate balance between ideal economic market mechanisms and traditional utility operating practices that will provide inexpensive and reliable energy for consumers. Interdisciplinary research involving power system engineering and market economics is needed. The research must consider both: (1) how market participants will respond to the incentives created under different market structures and the

impacts of these responses on reliability; and (2) how market-based power flows are currently affecting system operation and reliability, and how incorporation of technological advances in real-time system control and distributed technologies might affect future systems. This program area requires a strong Federal role and will be led by National laboratory and university researchers.

R&D Challenges.

- Determine the potential of, methods for, and constraints on increased reliance on market forces to maintain or enhance the reliability of the electric power system
- Determine how the design and operation of electricity commodity markets affect reliability, which aspects of reliability, and to what extent efficient markets for them can be designed and operated
- Rethink system reliability standards and identify what is and what is not amenable to market solutions
- Explore, test, and demonstrate both theoretical and experimental economic approaches that simulate market performance in ways that accurately reflect the physical capabilities and limitations of the electric power system and the risks inherent in linking it to volatile markets

R&D Activities. In a restructured electricity industry, market adoption of new generation, reliability, and end-use technologies will depend on the operation of well-functioning markets that provide meaningful pricing information to all market participants. Markets must be both credible through adequate compliance and monitoring, and transparent in reflecting the true scarcity of resources. This activity will perform R&D to improve the design and operation of markets for the provision of ancillary (reliability) services in a restructured electricity industry. The structures for bulk-power markets have substantial effects on reliability and on consumer costs for electricity (as well as affecting the profitability of generators, power marketers, and other market participants). Ancillary services are provided by the same resources that participate in energy markets, so the markets are inherently linked. Definition of types, pricing and compliance monitoring of ancillary services markets are presenting real challenges for deployment and for system reliability. Timely and reliable ancillary service supplies are key for maintaining system reliability. However, the transition of ancillary service provision from traditional vertically integrated utilities to new energy merchants is making supply difficult to manage, and compliance difficult to track.

Modeling of specific market implementations: Preliminary modeling has shown that conflicting goals significantly complicate the problem of designing market structures. The Independent (transmission) System Operator (ISO) tries to maximize reliability at minimum cost by purchasing a range of services from a fleet of resources. Individual resources try to maximize profits from the sale of a range of services. Even relatively simple market rule sets can result in perverse and unexpected incentives. This activity will utilize both experimental economics and

computer based modeling to determine how market participant behavior changes under different conditions of supply and demand. Actual data will be collected to verify the models and to address current problems in the specific markets. Results will be applicable to other current implementations.

Ancillary service prediction requirements: To complement the broader modeling effort, real time actual and committed ancillary services related data will be identified, collected and archived from the California ISO. California is the first location to operate open ancillary service markets. Consequently, California is the first location to experience the practical problems associated with running real markets. It is also the first location where real economic pressures are influencing operating decisions in a competitive market. The data collected will be used to research and implement ancillary service prediction requirements in near real time and identify the most appropriate user interfaces for reliability monitoring, and efficiently managing ancillary service provision. This will benefit the remainder of the modeling effort but, more importantly, should benefit ISO's directly.

Accomplishments. The Transmission Reliability program white paper "Review of the Structure of Bulk Power Markets" provides an understanding of the needs of a restructured electricity market, and some of the market methods and systems that have developed to address these needs. In addition, the Program, through a National lab, is participating on a NERC Policy 10 Operating Committee to support technology-neutral definitions of ancillary services which would allow for participation of demand-side management in these services.

Distributed Power

Budget: FY99-$1.2M, FY00-$3.5M, FY01-$3.0M

Background

Interest in the use of distributed generation and storage has increased substantially over the last 5 years because of their potential to provide (particularly with customer-sited generation) increased reliability and lower cost of power delivery to the customer. The advent of competition in the electric power industry and customer choice have, in part, been a stimulus for this increased interest. Also contributing to this trend has been the development of small modular generation technologies, such as photovoltaics, micro-turbines and fuel cells. Industry estimates that distributed resources will account for 20 percent of new generation by 2010. The potential environmental benefits of distributed power employing, for example, renewable resources or combined heat and power, are substantial.

Although the application of distributed generation and storage can bring many benefits, the technologies and operational concepts to properly interconnect them with the power system must be developed to realize these benefits and avoid negative impacts on system reliability and safety. The power distribution system was not designed to accommodate active generation and storage at the distribution level, particularly to supply energy to other distribution customers. The technical issues to allow this type of operation are significant. An interconnection standard to allow

distributed generation to deliver energy safely and with acceptable power quality is the high priority issue.

Electricity regulation, zoning and permitting processes, business practices developed under the framework of an industry based on central station generation and ownership of generation facilities by a regulated monopoly can be barriers to the orderly development of market opportunities for distributed power. The institutional and regulatory regimes must be redesigned to accommodate markets for distributed power in a restructured electric power industry.

The Federal government has a interest in the systems aspects of distributed power because of the impact on competition in the electric industry, the reliability and security of the electric power supply and the environment, and because of Federal investments in the distributed generation and storage technologies.

A state public utility commissioner has observed that there will be no true retail competition in the electric industry if there is not significant penetration of distributed power technologies. It is not likely that market power for electricity supply will be concentrated in the hands of a few if there is a robust market for distributed generation, compared to the real possibility that this could occur if self-generation is not a viable option for consumers. Even if the wholesale electricity market is dominated by a few generating companies, the cost of self-generation sets the upper limit for the price consumers need to pay for electricity, if that option is available to them.

The Federal government has and will spend billions of dollars on R&D for distributed generation and storage technologies, photovoltaics, wind, fuel cells, microturbines, combined heat and power, batteries, etc., and would therefore be prudent to invest additional resources to address the systems issues that are fundamental to the large-scale deployment of these technologies.

Finally, the systems issues related to distributed power are national issues that cut across a number of industries. There is a Federal leadership role in bringing together the various stakeholders - hardware manufacturers (photovoltaic, wind, fuel cell, gas turbine, batteries, etc.), utilities, energy service companies, codes and standards organizations, state regulators and legislators, and others, to address the technical, institutional and regulatory barriers to distributed power. These stakeholders have in fact requested the Department to serve this role. States have begun a piecemeal approach to addressing these issues, but neither the states nor industry see this as a satisfactory course of action, and feel a national approach is essential to creating a viable market for distributed power.

Linkage to CNES Goals and Objectives

The research and development program in Distributed Power would contribute to the following CNES goals and objectives:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems.

- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability.

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.

Program Description

Working with its industry and state and local government partners, the Distributed Power program will conduct R&D to address the technical, institutional, regulatory, and financial issues that are critical to realizing the full potential of the use of distributed generation, energy storage, and demand-side management on the power distribution system. The Distributed Power Program focuses on system integration and crosscutting issues that impact several or all distributed power technologies relative to their deployment in the power system, and realization of their full market potential.

The program performs analysis and develops technologies in three program areas: Strategic Research, System Integration, and Regulatory and Institutional Issues.

Strategic Research

Budget: FY99-$0.2M, FY00-$0.5M, FY01-$0.7M

Description, Objectives and Performers. This activity will develop new system operational concepts for distributed power that would be enabled by advanced distribution system control technologies needed to safely interconnect small, modular generation and storage technologies such as fuel cells, microturbines, photovoltaics, batteries and flywheels into the distribution system. Advanced device technologies will be adopted that will lead to development of interconnection devices with advanced capabilities. The potential benefits of distributed power are enhance power system reliability, provide ancillary services, and improve energy efficiency. Strategic research also includes the development of strategies and multi-year R&D plans.

R&D Challenges. The vision for distributed power is of an electric power system substantially different from today's in which the full value of distributed power will be captured in an electricity market in which customers can sell power, load management, and operations support services (ancillary services) as easily as the utility. This will be an automated, adaptive, intelligent electric power system in which distributed power provides 40 to 50 percent or more of the nation's electric energy, increases competition in electric power markets, and enhances the reliability, power quality, security and environmental friendliness of the electric power system. To accomplish this vision, innovative operational concepts and technology solutions will be developed.

R&D Activities. This activity addresses longer-term program objectives. With the limited funding available in FY99, the program's first year, efforts under this activity were limited to initial work by several of the national laboratories, led by NREL, to develop a five-year R&D plan. The plan is expected to be completed in the second quarter FY2000, and is being developed with major stakeholder and industry input through workshops and individual meetings. R&D on advanced operations concepts and innovative device technologies is expected to begin in FY2000 as a result of the competitive solicitation.

Accomplishments.

- Held a workshop with 120 stakeholders on 12/02/99 to identify barriers to distributed power, and determine industry priorities for DOE in addressing these barriers.

- Held a program review and planning meeting in October 1999, attended by over 130 stakeholders.

System Integration

Budget: FY99-$0.7M, FY00-$2.7M, FY01-$2.0M

Description, Objectives and Performers. Interconnection and integration of distributed resources with the power system was identified as the number one near-term priority by industry. The lack of a national interconnection standard and conforming interface devices was stated to be the most important market barrier to distributed power. Much of the program's activities in FY99 have been devoted to initiating efforts to develop an interconnection standard on a fast track.

Working with industry and the national laboratories, system interconnection issues, including safety, reliability, power quality, and environmental issues related to distributed generation and storage, will be identified through modeling and other engineering analyses, case studies and hardware system integration testing and demonstration. Technologies and approaches to address these issues will be developed. The interactions of the gas and electric delivery systems from the perspective of each as a component of an integrated energy system will also be examined.

R&D Challenges. Near-term R&D challenges include development of a national interconnection standard, and testing and certification methodologies and processes for implementation of the standard. In the longer term, in order to realize the full benefits of distributed power, hardware and software for modular, intelligent power system interface units that conform to the interconnection standard will be developed. These interface units will support a plug-and-play environment for automated control and operation of distributed generation and storage across all technologies, i.e., microturbines, fuel cells, photovoltaics, wind, batteries, fly wheels, etc.

R&D Activities. Development through the Institute of Electrical and Electronics Engineers (IEEE) of a national standard for interconnecting distributed generation and storage with the power system has been initiated and will continue through FY 2002 when the standard is expected to be approved and published. At least one revision of the standard, probably in about

FY 2005, will be necessary as substantial amounts of distributed power is deployed and experience with the standard is obtained. Testing and certification activities as well as R&D on interface devices will likely begin in FY 2000 as a result of the competitive solicitation, along with preparation of a plan for demonstration of the integration of distributed power with the grid at the Nevada Test Site.

Accomplishments.

- Initiated development through the IEEE of a national standard for interconnection of distributed power with the electric power system. The initial draft standard has been written, with more than 200 representatives from industry participating in the IEEE working group developing the standard. The program goal, with DOE's continued support and leadership, is to reduce the time to establish the standard in half, and have a standard in place in late 2001.

- NREL issued a competitive solicitation for R&D on interconnection hardware and software, tests and procedures for equipment certification, and modeling and analysis to address technical, regulatory and institutional barriers to distributed power.

Regulatory and Institutional Issues

Budget: FY99-$0.3M, FY00-$0.3M, FY01-$0.3M

Description, Objectives and Performers. The Distributed Power Program works with industry, state legislators, regulators and energy officials, as well as federal agencies to address regulatory and institutional market barriers to distributed power. These barriers include current business practices, planning methodologies, power systems engineering training, policies, regulations, ownership structures.

R&D Challenges. Accelerating the development, adoption, and implementation of regulatory utility policies, technical standards, local codes and permitting processes will allow distributed power to compete fairly in the market without compromising consumer protections, environmental values, health, and safety.

R&D Activities. The Distributed Power Program is working with industry to document the nature and impact of market barriers, particularly related to utility requirements for interconnection of distributed power resources to the grid, including rates and non-technical requirements, and the impact these have on the economic viability of distributed power projects. Several workshops will be held with state legislators and regulators to examine these issues.

Accomplishments.

- Information has been collected on 60 case studies, and will be published in a report which documents the barriers to interconnection due to current utility business practices and interconnection requirements.

- Awarded grant to conduct workshops for state regulators to address regulatory barriers to distributed power, and a grant to the National Conference of State Legislators to conduct a workshop for state legislators on legislative issues impacting distributed power.

Energy Storage Systems

Budget: FY99-$4.5M, FY00-$3.4M, FY00-$5.0M

Background

Competitive electric market pricing structures will stimulate development of new strategies for controlling electricity use and cost. Sophistication of both high-tech and manufacturing industries makes power quality increasingly important to U.S. productivity. As transmission networks more frequently operate at their stability limits, network operators search for means to increase network capacity at minimum cost. Energy storage systems could effectively address all of these issues. In addition, energy storage increases the value of electricity generated by renewable resources by making it available at any time. Accordingly, the Energy Storage Systems (ESS) Program focuses on three technological thrust areas: reliability, renewables, and productivity.

The ESS Program addresses the multi-billion dollar national power quality problem by developing systems that enable electricity providers to correct instantaneously for power variations. Power quality systems can be installed at a customer site or at a utility substation near customers in need of guaranteed quality power. Larger versions can improve stability and selectively increase capacity of the transmission system.

Large electricity users and providers can achieve important productivity gains and increase competitiveness through distributed siting of storage systems. Often, a single storage system can be used for multiple purposes and result in substantial cost savings and improved operational efficiency through avoidance of monthly peak demand charges, power quality-induced equipment failure, and peak period overload of utility equipment.

The President's Committee of Advisors on Science and Technology (PCAST) stated that "if intermittent renewable energy technologies are to make very large contributions to electricity supplies in the longer term. .... technologies are needed that would make it possible to store energy for many hours at attractive costs." The ESS Program works with renewable energy system suppliers to optimize storage systems integrated with Photovoltaics (PV) and wind generators.

Linkage to CNES Goals and Objectives

The Energy Storage Systems program supports the following CNES goals and objectives:

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.

- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems. *(by working with other countries through the International Energy Agency to promote communications and collaborations)*

Focused on the three thrust areas of reliability, renewables and productivity, the ESS Program will continue to team with industry in highly-leveraged agreements to develop improved, integrated, cost-effective storage systems with multiple benefits for electricity providers and users at scales ranging from small remote installations to large industrial facilities.

Application of energy storage technologies will be driven by reduced costs and improved flexibility as the Program develops systems that meet the cost goal of $700 per kW and the energy density goal of 5 kWh per sq. ft. of system footprint while meeting customer needs in the rapidly changing electricity marketplace.

Program Description

Research and development in the ESS Program is organized around three objectives: (1) integration—supporting the near- and mid-term development of complete energy storage systems for diverse applications that make use of modularity, factory integration, and transportability for cost reduction; (2) components—supporting the design, research, and long-term development of batteries, superconducting magnetic energy storage systems (SMES), flywheels, and other advanced energy storage devices along with improved, multi-use power electronics, controls and communications components; and (3) analysis—improving the understanding of application requirements, assisting U.S. industry in identifying high-value energy storage sites through modeling and engineering assessment, and identifying national benefits of storage in a restructured utility industry.

Integration

Budget: FY99-$2.2M, FY00-$1.6M, FY01-$2.5M

Description, Objectives, and Performers. By viewing a storage system as a single product, rather than a custom designed project composed of parts procured from various sources, major savings in construction cost and improvements in performance can be achieved. Benefits include cost savings of 30 to 50 percent through reduction of custom engineering and on-site installation labor, as well as reduced start up times. Standardized components, designed to optimize system performance, offer the potential for further cost reduction and longer life. Integrated hybrid systems, consisting of a renewable generator (PV or wind), storage system, and a diesel generator or gas turbine, offer increased flexibility to meet energy supply needs. Development of multiple integrated systems in a coordinated effort allows the program to leverage private and public resources through coordination of parallel R&D activities.

R&D Challenges. Experience has proven that good integration leads to optimal performance at the lowest cost compared to off the shelf or one-of-a-kind engineered designs. The major obstacle to greater levels of integration is the cost associated with low production volumes. Without further support for high-cost, high-risk prototypes and demonstrations, it will be

impossible to generate the wide-spread interest and support necessary to optimize designs at a low enough cost to reap reliability and productivity benefits.

R&D Activities. *Advanced battery systems:* The ESS Program continues to work on development of zinc-bromine battery systems, which have 4 times the energy density of lead acid batteries. The Advanced Battery Energy Storage System (ABESS) is a high-risk, 3-year, 50-50 cost-shared project with ZBB to develop a transportable, modular zinc/bromine battery storage system, scheduled to begin a multi-year test at a utility or customer site by 2000.

Advanced batter-renewable systems: Another zinc-bromine battery system is being fielded with Powercell Corporation in a community theater project. A 200kWh capacity battery is combined with 70kW of photovoltaic generation, allowing the theater to be a net producer of green power. The ESS program completed a system analysis and will be collecting data from the project.

Renewable generation and storage: The ESS Program works with the photovoltaic and wind industries to improve the compatibility and reliability of hybrid renewable generation and storage (RGS) systems while lowering system cost and maintenance requirements. Studies will define the present and future needs of users of RGS systems, determine their application requirements, and help guide development of integrated system components.

Accomplishments. The PQ2000 system developed by the ESS Program and its industrial partners earned an R&D 100 Award as the first installation of a complete integrated power quality protection system with master control by the electric utility. The system meets the power quality needs of one of Oglethorpe Power Corporation's industrial customers, a lithography plant in Homerville, GA. During the first six months of operation, the system corrected over 90 percent of the plant's power quality events.

A mobile version of the PQ2000 factory integrated battery-based power quality system has been developed in collaboration with Omnion Power Engineering Co. The 2MW/15-second system was tested by the Virginia Power Company, and is now installed at the S&C plastics extrusion plant in Chicago.

A factory integrated 1.4 MWh, multiple benefit storage system by was developed by ESS and an industrial partner. Installed on the Annette Island Reserve, in southeast Alaska, the system absorbs the large load spikes caused by the local lumber mill. By displacing the output of a 3.3 MW diesel engine formerly operated at light load to control power swings, it reduced diesel fuel use by 180,000 gallons and cost by $310,000 in the first 8 months of operation. It greatly improved power quality for the island residents, the 1,700-member Tsimpshian Native American Indian tribe.

A 3.5 MWh storage system co-developed by the ESS Program and GNB provides multiple benefits at a lead-acid battery recycling plant in Vernon, California. The system's primary benefit is its ability to carry critical loads during power outages, ensuring that pollution control equipment remains operational. Additional benefits include peak-shaving and uninterruptible power.

Components

Budget: FY99-$1.4M, FY00-$1.0M, FY01-$1.6M

Description, Objectives, and Performers. The ESS Program works with industry and university partners to carry out fundamental research on advanced storage elements and power conversion equipment components that cost less, have higher performance, are smaller, and are better integrated with the other parts of the system. A great deal of the evaluation of prototype energy storage components is conducted in-house at Sandia National Laboratories. The Program also draws on the expertise and resources of a diverse group of partners including representatives from industry and an industry research association, a utility trade association, two engineering and consulting firms, and several university groups.

R&D Challenges. Materials and processing limit the life, and hence, the cost effectiveness of advanced storage equipment. For example, work must be done to identify electrochemical failure mechanisms in valve regulated lead acid (VRLA) batteries and find ways to delay failure. Key issues include loss of cell seal integrity, loss of conductivity due to changes in separator mechanical characteristics, and sensitivity to temperature extremes. Similarly, successful commercialization of advanced zinc bromine batteries requires improvements in the microporous polyethylene separator, increases in the rate capability of the bromine electrode activation layer, and in the robustness of the electrochemical cell stack.

Research is also needed on SMES, flywheels and power conversion systems. SMES requires low cost materials and cryogenics. Flywheels need high strength composite rotor materials and improved bearings. Power conversion systems require development of advanced, high power, low cost semiconductor switches, hybrid power controller software, and advanced converters.

R&D Activities. *VRLA batteries:* Low-maintenance, spill-proof, and more compact than conventional batteries, VRLA batteries have been commercially available for more than ten years. The ESS Program, using the extensive field data now available, will build on past work with industrial partners by collaborating on a VRLA reliability improvement project with the International Lead Zinc Research Organization. Studies will be conducted to define opportunities in existing VRLA designs for further improvement under typical utility battery operating conditions and use modes. Similar projects are in the planning stages for SMES and flywheels.

Power conversion systems (PCS): The ESS Program is teaming with power electronics firms, universities, and energy research institutions to develop power controller electronics and software for use in several advanced storage applications such as remote backup systems. The ESS Program supports testing at the Arizona Public Service Solar Test and Research Center of a state-of-the-art PV/battery hybrid controller developed by Trace Technologies. Results from the characterization testing will be used to develop operation strategies for village hybrid systems. ESS is also participating with the International Lead Zinc Association in a cost shared effort to develop testing requirements for remote area power systems. This project will greatly improve the reliability of modular renewable energy systems not tied to electric grids.

Accomplishments. Recently, the ESS Program completed development of a prototype 33 kW, 3-hour prototype zinc/bromine battery that exhibits four times the energy density of current lead acid batteries. This highly successful prototype is the basis for the ESS Program's ongoing ABESS project that will result in the development and demonstration of a transportable 300-kW/2-hour integrated system designed to showcase the potential of zinc bromine technology for peak shaving and other customer-side applications.

In 1998, the ESS Program completed an assessment of system configurations, cost, and standards for PCS use in the utility industry with recommendations for future R&D activities. This report will form the basis of future R&D work on a single PCS topology to serve the needs of batteries, flywheels, SMES, and renewable generation sources.

Analysis

Budget: FY99-$0.9M, FY00-$0.8M, FY01-$0.9M

Description, Objectives, and Performers. Projects conducted within the analysis program area are designed to improve the understanding of application requirements and assist industry in identifying high-value energy storage sites using models and engineering assessment tools. This work often forms the basis for R&D projects undertaken by the ESS Program and/or its partners.

R&D Challenges. Currently, the greatest source of uncertainty in the development of energy storage and other distributed resources is the future of the electricity industry. The emergence of a competitive marketplace for electricity will bring about many technological changes in the way electricity is generated, delivered and sold. A restructured electricity marketplace is expected to lead to many opportunities for increased efficiency, resource utilization, flexibility and reliability through energy storage as utilities begin to tap the potential benefits of distributed resources. Understanding how the dynamics of this new marketplace will drive end user needs and quantifying the many potential benefits of energy storage are the major challenges confronting the energy storage community.

R&D Activities. *Transmission Power Quality Project:* The next generation of power quality correction devices is expected to be placed at the substation level. These systems will be large (4-10MW) and will protect entire plants or Premium Power Parks from power quality problems. Most of these customers are fed directly from the transmission grid. This project will measure the power quality of the transmission grid in one region to provide specifications for the substation power quality project. This project will also tie in with the DOE Transmission Reliability Program by producing baseline data on reliability of the current state of the regulated utility network.

Energy storage in a restructured environment: As electric industry restructuring proceeds, it will become increasingly important that electricity providers and related service companies understand the role energy storage can play in maintaining the reliability of the electricity infrastructure. The ESS Program will conduct a quantitative analysis of the impact of energy storage on reliability. This study will help determine the direction of development of integrated energy storage systems for reliability applications.

Non-grid applications: The need for distributed energy storage technology is particularly acute in remote areas not connected to utility grids. Congress highlighted this need in 1998 by requesting that DOE develop and demonstrate cost competitive, modular renewable energy technologies to "focus near-term research on the development of reliable systems for remote applications in occasionally hostile climates." The ESS Program is currently working with the International Lead and Zinc Research Organization on a feasibility study of hybrid photovoltaic/storage systems for use in remote villages in Peru. Results from this study will be used to assist in conducting a series of demonstration projects showcasing this technology.

Accomplishments. Recent progress in the development of both superconducting magnetic energy storage (SMES) and flywheel energy storage has made these technologies increasingly viable energy storage options in the United States. In order to further development of these advanced storage technologies, the ESS Program completed an analytical study that identifies areas of analysis and R&D necessary to advance SMES and flywheel technologies. Included in the study is a modeling tool that links cost and performance of SMES and flywheels over time and an updated definition of application requirements and potential markets.

A recent survey by Arizona State University supported by ESS and the Photovoltaic Program quantified sales of photovoltaic batteries domestically and world-wide in 1995, identifying market weaknesses and information needs. The information contained in the report has helped to improve the information exchange between the various industry groups involved in the development and manufacturing of PV/storage hybrid systems.

Superconductivity in Power Systems

Budget: FY99-$32.1M, FY00-$31.4M, FY01-$32.0M

Background

High temperature superconductivity (HTS) or the ability of some ceramic materials to become lossless carriers of electricity when cooled to the temperature of liquid nitrogen, was discovered in 1986. Materials that become superconducting at the much lower temperature of liquid helium are used in medical applications, but costs of refrigeration have made them unattractive for power equipment applications. HTS not only presents opportunities for constructing compact, high efficiency, high capacity power equipment but also opens possibilities for development of equipment, such as fault current limiters, that offer entirely new capabilities. HTS, in fact, has the potential to impact the production, delivery, and use of electricity as profoundly as fiber optics has impacted communications. Superconducting wires, with 100 times the current carrying capacity of copper wires, will result in transmission cables with five times the capacity of conventional cables. HTS motors, generators, and transformers will have half the energy losses and be half the size and weight of conventional systems. Superconductivity in Power Systems constitutes the principal long-term development effort for the Enhancing Utility Infrastructure program.

HTS offers many national benefits. HTS cables offer an alternative to new rights of way for overhead lines which are difficult to obtain, without the oil spill exposure that limits interest in conventional oil filled cables. Retrofitting HTS cable into existing ducts could increase transmission capacity of rights of way by up to five times with no environmental risks.

HTS motors and generators pack nearly three times the power into the same space as conventional machines and coordinate well with power electronic inverters to provide a double benefit of controllability as well as increased power density.

HTS fault current limiters ameliorate concern for added short-circuit current caused by system growth. Limiting fault currents to lower levels also enhances system stability, reliability, and safety, and improves power quality. The ability to efficiently control currents also offers new operating possibilities for power flow control.

HTS transformers offer utilities oil-free, fire-proof performance and the absence of a thermal aging mechanism, as well as high efficiency. HTS transformers can also be operated for long periods at up to double their rated capacity without loss of life, a capability not available in conventional units. Finally, the HTS transformer will likely have low-impedance, making it easier for utilities to maintain output voltage levels over a wide range of power levels, and they will incorporate fault current-limiting winding concepts to provide additional benefits. HTS transformers truly represent the first major hardware innovation in this mature industry since the development of oriented core steel.

HTS bearings for flywheel systems could be attractive to tomorrow's utilities and large industrial customers seeking diurnal storage efficiencies approaching 90 percent.

HTS magnetic separator technology is important both for the chemical industry and for hazardous waste processing.

The annual world market for HTS power technologies is estimated to be at least $30 billion by 2020. DOE leads the world in superconductor technology development and with the SPI projects described below, DOE and U.S. industry are partnered to move a step closer to being the world leader in sales.

Linkage to CNES Goals and Objectives

The Superconductivity in Power Systems program supports the following CNES goal and objective:

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.

In 1988, DOE mobilized the resources of U.S. industry, National Laboratories and universities to accomplish two major technological goals: (1) solve the difficult problem of manufacturing electrical wires from the family of brittle ceramic superconducting materials discovered in 1986,

and (2) develop practical equipment designs for efficient, pre-commercial electric equipment such as motors, transmission cables, generators, transformers, and current limiters that use these wires.

To accomplish these program objectives, specific goals must be met for superconducting wire, as well as for pre-commercial prototypes of power equipment using the wires. The wire goal is to achieve an operating capacity of 1000 amperes per square millimeter of wire cross-sectional area at a cost of 1 cent per ampere-meter. Goals for equipment are specific to individual technologies, but are met through operational tests of prototypes that prove the technology is ready to provide the specified performance advantages. Generally, devices will have only half the energy losses of conventional alternatives. In addition, it is the goal of the Superconductivity Program that, by 2004, U.S. industry will begin supplying the international electric power sector with the first HTS transmission cables, transformers, motors, and current controllers.

Program goals are achieved through a national effort that partners Federal and State agencies, universities, National Laboratories, and private industry in cost shared, industry led consortia focused on producing marketable products. HTS equipment will achieve market penetration not only based on efficiency, but also on superior performance, small size, and environmental benefits when compared with conventional equipment.

Program Description

The Superconductivity Power Systems program marries the entrepreneurial drive of high-tech companies with the vast technological resources of DOE's National Laboratories to meet the complex research challenge of long-term development of HTS technology for electric power. The HTS program contains three program elements: The Superconductivity Partnership Initiative (SPI), The Second Generation Wire Initiative, and Strategic Research.

The Superconductivity Partnership Initiative (SPI)

Budget: FY99-$14.5M, FY00-$14.0M, FY01-$14.0M

Description, Objectives, and Performers. The SPI competitively solicits aggressive industry-led projects to design and operate pre-commercial HTS electric power equipment. SPI projects include transformers, motors, cables, current limiters, flywheel energy storage, generators, and magnetic separation systems. A unique SPI feature is that each project must be carried out by a vertically integrated team, typically including an electric utility, a system manufacturer and a superconducting wire supplier, and National Laboratories. This vertical integration has proven to be a powerful way to quickly develop mature end user systems while leveraging resources.

The SPI program promotes cost-shared development by manufacturers of equipment design technologies necessary to take commercial advantage of advances in HTS wire technology. By the end of the program, it is expected that SPI teams will have built and operated refined HTS versions of all of the major power equipment technologies that could represent a significant benefit for the electric utility infrastructure.

A total of 9 SPI projects either are or will soon be under way. Performance teams include 17 manufacturers, 6 utilities, 2 utility research associations, 5 National Laboratories, and a State research organization. Projects cover the entire program range including a 15kV current limiter, a 5000 Hp motor, 2 power transformers and 2 cables, as well as a magnetic separator and a flywheel energy storage system.

R&D Challenges. SPI teams must resolve a number of key technical challenges including:

- Conductor availability, performance, configuration, and cost.
- Electrical and thermal insulation performance and durability.
- Interface between the ambient environment (room temperature, atmospheric pressure) and the cryogenic temperature, high-pressure environment.
- Cooling system research, design, reliability, and performance.

R&D Activities. *Cable projects:* Activities are underway to determine the optimum configuration for wrapping the HTS tapes to assure the lowest possible alternating current (ac) losses. Such losses can add substantially to the heat load of the cryogenic system required to keep the cable cold. In addition, two candidate dielectric systems are being evaluated by different teams. One system, based on room temperature, extruded dielectric material, takes advantage of the large base of conventional cable experience, while another, based on a novel cryogenic temperature dielectric, offers potential for reduced ac losses.

The characterization and measurement of ac losses is complex for cables and the SPI cable teams are developing two alternative methods for these measurements. Either a transport or a calorimetric method is used and the teams have made good progress toward developing a detailed understanding of the ac loss phenomenon.

Low cost, reliable cryogenic systems to keep the cable cold are of crucial importance to the success of HTS cable technology and both teams are also evaluating options for increasing the cable length between cooling stations.

Terminations and splices are a special topic of research in the cable SPI projects. Most failures in today's conventional cables occur in either the terminations or the splices. Electrical, thermal, and mechanical stresses on materials must be balanced.

Transformer projects: Research activities in the transformer SPI projects include the development of appropriate conductor geometries, dielectrics, and the cooling system. Investigation of low-loss conductor and winding configurations are essential as ac losses, like thermal losses, must be carried away by the cryogenic refrigeration system. The core design and core cooling systems are active areas of research.

HTS motor project: The SPI motor team is focusing on innovative fluid transfer coupling technology for entry and exit of cryogen at the motor/refrigerator interface. They are also developing the wire and motor coil technology necessary for cost-effective, 3-Tesla operation at temperatures near 30°K. Another active area of research is the concept of cryocooling in a rotating reference frame. Sophisticated high power test beds have also been developed for full scale characterization of HTS motor performance.

Accomplishments. World record performances were achieved by SPI teams. The 200-horsepower motor exceeded the design goal by 50 percent during tests in 1997, and the world's first superconducting current limiter met its technical goals during testing at a utility substation in FY 1998. The next version will feature the world's largest HTS coil and operate long-term on a utility grid, a first for the SPI program. The world's largest HTS transformer commenced testing in FY 1998, and the world's longest HTS cable completed its tests successfully.

The Second Generation Wire Initiative

Budget: FY99-$8.0M, FY00-$8.0M, FY01-$8.0M

Description, Objectives, and Performers. The Second Generation Wire Initiative is exploiting 1996 research breakthroughs at Los Alamos and Oak Ridge National Laboratories that promise unprecedented current-carrying capacity in high-temperature superconducting wires. These breakthroughs, which made headlines worldwide, will allow long wire lengths to behave as a single crystal, thus eliminating internal barriers to current flow that may limit use of wires now being manufactured. The interest in second generation wires for energy applications is enormous. A total of nine high-performance project teams involving six national labs and nine industrial partners are at work to further develop the wire technology.

R&D Challenges. Moderate lengths (1 to 10 meters) of coated conductors are needed for use in coils and device prototypes during FY 1999-2000. The performance goals for such moderate length wires are: critical current (I_c)= 50 amps and engineering current density (J_e) =20,000 amps per sq. centimeter. R&D challenges include scale-up of promising short sample results to produce substrates, verification of superconductor film growth by a number of industrially scalable techniques, demonstration of adequate texture and epitaxy over length, and development of simpler, and more robust buffer layer systems.

R&D Activities. *Substrate development:* This project investigates two methods of making buffered, textured metallic substrates, ion-beam assisted deposition ("IBAD"), and rolling-assisted, biaxially-textured substrates ("RABiTS"), both developed by National Laboratories. An industrial partner is developing electron-beam evaporation for depositing the superconducting layer upon either of two substrates. Concerns are process conditions for buffer layer deposition, adequate texture in the rolled nickel metal foil, and thickness of the superconducting layer while maintaining acceptable levels of critical current density.

Buffer layer development: A team led by an industrial partner is developing a non-vacuum buffer layer technology for deformation textured metal substrates. Such a structure could offer cost and performance advantages over conventional vacuum deposition of these layers. The work

includes measurement of buffer layer texture, deposition of buffers and superconductor, and electrical characterization.

Alternative superconductors: A team of National Laboratories and industrial partners have also been working together to scale up yttrium-based (YBCO) coated conductors. Tasks include nonmagnetic deformation textured substrate development, substrate preparation, buffer layer development, IBAD sample testing, investigation of strain tolerance, statistical analysis of defects, environmental stability, microstructural studies, and measurements of critical current and critical current density. Near-term goals are a critical current density of 1 MA/cm^2 at 77°K on a nonmagnetic, deformation textured substrate 1 meter long. The team has the ultimate goal of demonstrating the commercial feasibility of the coated conductor technology.

Accomplishments. Initial FY 1998 scale-up goals were met for wire processing breakthroughs. The first 2-cm lengths of coated conductor were produced in FY 1998 using an *ex-situ* deposition process.

Strategic Research

Budget: FY99-$9.6M, FY99-$9.4M, FY00-$10.0M

Description, Objectives, and Performers. The Strategic Research R&D area focuses on developing underlying knowledge needed for the success of industry-led projects. The Second Generation Wire Initiative evolved from five years of strategic research that achieved world record performance in short wire samples. In addition, research and analysis will be conducted on issues associated with integration of superconducting systems into an increasingly competitive and restructured industry framework. Strategic Research performers include four DOE National Laboratories, two Department of Commerce labs, sevenuniversities, and two industrial partners.

R&D Challenges. Strategic research challenges include development of powder-in-tube wire that meets cost and performance needs of pre-commercial prototype developers, novel processing to increase pinning and connectivity to raise field and temperature operating windows for the HTS wire. Coils must be fashioned from the first lengths of second-generation wire, and the properties of these coils must be measured to provide input to system developers. An understanding of HTS material phase assemblage is critical to developing cost-effective HTS wire processes.

R&D Activities. Strategic research activities include bismuth/oxide (BSCCO) wire development research by two teams. The research includes development of novel means to produce high critical current density HTS tapes, including the new “coated BSCCO” approach that already has demonstrated over 40,000 A/cm^2 in short samples. The group studies the effects of processing conditions on the critical current and microstructure of the resultant wires.

Efforts to scale up the short sample BSCCO results to long lengths are conducted under several CRADAs. This research enables U.S. industry to use the National Laboratories’ special facilities and staff resources to solve key technical issues of filament uniformity, grain growth (bridging) between filaments, ac conductor losses, and others.

Research is also conducted by the laboratories and several universities to exploit the higher critical temperatures of the thallium and mercury compounds. National Laboratories and universities, for example, are working to deposit and characterize thallium HTS on RABiTS. Results of the order 0.5 MA/cm^2 have been obtained on short samples.

Phase diagram research enables the National Laboratories and industry to understand the physical and chemical properties of HTS compounds. This research is cost-shared with the Department of Commerce. In another cost-shared effort, the mechanical properties of the new laboratory-developed coated conductors are being examined, with plans underway to measure the private industry materials, as well, starting with the BSCCO tapes.

Strategic research also includes the fabrication and testing of small research magnets using the BSCCO compound (now) and the coated conductors when lengths of material become available. The understanding of normal zone propagation and quench characteristics of the new coated conductor in coil form will be needed if these wires are to be useful in electrical devices.

University research explores the physics of deposition of buffer layers and superconductor by electron beam evaporation, including the development of rate-monitoring apparatus, the nature of current flow through grain boundaries, and novel, high rate deposition of buffer layers.

Accomplishments. In FY 1998, the industry-led Wire Development Group achieved a record critical current density in BSCCO powder-in-tube wires of 71,500 A/cm^2. The average critical current in HTS wire made in FY 1998 for cables exceeds 100 amperes per tape in liquid nitrogen, a new record for commercially available wire.

Program participants have won five R&D 100 awards in the last 4 years, and have set most of the world's records for superconducting motors, transmission cables, and transformers.

Natural Gas Infrastructure

Budget: FY99-$1.0M, FY00-$1.0M, FY01-$13.2M

Background

The expansion of the North American gas markets to meet a 30 Tcf market by 2015 will require that new sources of supply be characterized, developed, and connected to new and existing gas system infrastructures. The gas industry and its suppliers face significant technology, market, and regulatory challenges to reach the 30 Tcf market. Regulatory constraints in the expansion of transportation and distribution pipeline systems and storage facilities could impede industry progress, harm the economy, and weaken the environment. Government funding of "public benefit" R&D will become more critical as private firms lose incentives for long-term, public service R&D. Technology constraints could lead to increased fugitive emission methane leaks from the aging gas transmission and distribution system. Market constraints could lead to higher gas prices for consumers and power generation sectors. The integrity of the gas delivery and storage infrastructures will be important in maintaining system throughput and in meeting future gas demands.

The natural gas delivery and storage system provides a vital link between production and end use. Natural gas supplies are transported through a nationwide pipeline network to move large volumes of gas from producing wells to consumers. Gas storage serves as the primary means of managing fluctuations in supply and demand. Gas from storage can supply up to 30 percent of daily gas demand in winter and summer months for heating and power. Storage enables greater delivery system efficiency by allowing more level production and transmission flows throughout the year. Without this leveling effect, the amount of transmission pipeline would need to be increased by 50 percent to connect the producing regions to the marketplace. Government funding of "public benefit" R&D will become more critical as R&D funding by private firms and the Gas Research Institute (GRI) declines.

The Natural Gas Infrastructure program includes the Gas Storage Technology program initiated in 1993 and two new programs for FY 2001--Enhancing Infrastructure Reliability and International Infrastructure Integrity. These two new program support DOE's activities and goals to enhance the reliability of existing and new pipeline infrastructure and to remediate greenhouse gas emissions in the gas industry. Significant methane emission reduction opportunities exist in Russia and other countries through the accelerated international deployment of advanced methane emission detection and repair technology for oil and gas pipelines.

Linkage to CNES Goals and Objectives

The program supports the following CNES goal and objective:

- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability. (oil and gas transportation and storage)

Program Description

DOE is working with GRI and industry to ensure that the gas delivery and storage system continues to provide a reliable, cost-effective supply of natural gas well into the next century.

Gas Storage Technology

Budget: FY99-$1.0M, FY00-$1.0M, FY01-$2.2M

Description, Objectives, and Performers. This program includes cooperative efforts with industry to help ensure the safe, reliable, and cost-effective supply of natural gas, and will enhance gas storage system deliverability, reservoir management, and operational flexibility. Through its Gas Storage Program, DOE supports the development of advanced technologies and methods to enhance deliverability, increase efficiency, and reduce the costs of operation and maintenance. Program drivers include:

- Federal Energy Regulatory Commission (FERC) regulatory changes increased system deliverability requirements.

- Projected increased gas demand in the South Atlantic and New England Regions and gas production shifting towards the western producing basin create a critical need for delivery and storage system expansion.

- The aging delivery and storage system infrastructure requires re-engineering for increased operational flexibility.

- Human health and safety concerns due to aging pipeline system and distribution system

- Increased constraints on the infrastructure operation systems due to environmental regulations and gas and electric deregulation

- Funding for long-term public benefit storage and infrastructure technology R&D is decreasing

R&D Challenges. Depleted oil and gas reservoirs are used for interim storage of natural gas primarily to meet the large increase in natural gas demand during the winter and for peaking services for power generation. Each reservoir has characteristics that determine the limits of injection and withdrawal rates and total storage capacities that can be achieved. Improved methodologies and technologies must be developed through rigorous R&D to prevent the loss of deliverability from these fields and to better remediate lost deliverability when it occurs. Natural gas storage is a critical segment of the Nation's overall energy system, and innovative gas storage methods are required to meet the projected increase in gas demand, especially in the power generation sector and in areas where conventional underground storage-depleted oil and gas reservoirs are unavailable (South Atlantic and New England Regions).

R&D Activities. DOE, in collaboration with industry, is conducting storage research in the following areas:

- Advanced storage technologies that will meet the specific storage needs of new and growing industrial and power generation markets, specifically the short-term or hourly requirements of the power generation sector. To provide science and engineering solutions for the development of gas storage facilities in regions without conventional storage options, and to ensure gas system infrastructure reliability, deliverability, and operational flexibility.

- Novel and advanced fracture simulation technologies and improved remediation treatments that will increase storage reservoir deliverability and help to offset the reported 5.2 percent annual loss in deliverability.

- Improved real-time storage measurement technologies and gas flow metering (e.g. ultrasonic meters, direct energy meters) and energy measurement technologies that will provide real time, automated monitoring of pipeline gas flow and energy content, increasing system deliverability and optimizing gas sales to customers and to reduce uncertainties in storage inventories attributable to storage metering biases.

- Re-engineering underground gas storage reservoirs to increase operational flexibility, extend the useful life of underground storage reservoirs using horizontal wells, and lower costs for storage.

Development of advanced technologies that meet industry needs would result in a more efficient natural gas storage system and benefit both industry and consumers. The gas storage industry would benefit from improved storage efficiency through increased deliverability, decreased deliverability revitalization costs, and increased operating efficiency. Local distribution companies would gain from improved system reliability and flexibility. Industrial and power generation end users would benefit from advanced storage concepts, and residential customers would benefit from lower costs for service.

Accomplishments. Program accomplishments include:

- Northern Indiana Public Service Company (NIPSCO) partnered with DOE and GRI to demonstrate the use of geological modeling and seismic survey techniques to optimize the development and operation of gas storage fields. Based on the results of this integrated study, NIPSCO drilled a horizontal well at the Royal Center field in Indiana. Initial flow tests indicate that the well will significantly enhance deliverability from the field and allow the utilization of gas from an area of the storage field that was not accessible from the existing vertical wells.

- Universal Well Services, located in Wooster, Ohio, pumped the first ever CO_2/sand fracture stimulations in a gas storage field to determine the applicability of a totally nondamaging fracturing fluid. The deliverability from two underground storage wells at the Galbraith field in Pennsylvania, operated by National Fuel Gas Supply Company, increased by 600 percent

Enhancing Pipeline System Reliability FY99-$0.0M, FY00-$0.0M, FY-$5.0M

Description, Objectives, and Performers. This is a new program for FY2001. The program includes cooperative efforts with industry to help ensure pipeline system reliability. The existing pipeline infrastructure is limited and there is increasing concern about restricted deliverability of the pipeline system and the high cost associated with system expansion, maintenance, and enhancements to serve growing gas demand. Better methods are needed to monitor, protect, maintain, and repair existing pipelines to ensure the integrity of the gas delivery system. Through its Natural Gas Infrastructure Program, DOE supports the development of advanced technologies and methods to enhance deliverability, increase efficiency, and reduce the costs of operation and maintenance. Program drivers include:

Federal Energy Regulatory Commission (FERC) regulatory changes increased system deliverability requirements.

- Projected increased gas demand in the South Atlantic and New England Regions and gas production shifting towards the western producing basin create a critical need for delivery and storage system expansion.

- The aging delivery and storage system infrastructure requires re-engineering for increased operational flexibility to maintain system throughput and meet growing gas demand.

- Human health and safety concerns due to aging pipeline system and distribution system

- Increased constraints on the infrastructure operation systems due to environmental regulations and gas and electric deregulation

- Funding for long-term public benefit infrastructure technology R&D is decreasing industry and energy service providers

R&D Challenges. There is a need to minimize threats to pipelines from mechanical damage by construction equipment and weather related landslides, flooding and washouts to ensure the reliability of the gas transmission and distribution network and increase the operational efficiency of the pipeline system. Current technologies have very limited success in locating underground facilities and detecting and characterizing mechanical damage, especially for those pipelines which cannot accommodate in-line inspection tools.

R&D Activities. DOE, in collaboration with industry, will initiate pipeline infrastructure research research in the following areas:

- Natural Gas Transmission System: including: design and engineering studies for program development work in real-time controls, meters, and sensors that are capable of monitoring pipeline integrity and are capable of managing delivery of gas to customers; development of advanced models, engineering tools, and pipeline and data visualization and communication technologies to lower barriers to distributed power generation and increase the efficiency of the pipeline system; gas system reliability analysis and distributed resource system integrated modeling; and modeling high deliverability gas storage system to serve the power generation marketplace

- Natural Gas Distribution System: Research directed to ensure the reliability and optimization of the distribution network, including development of longer life, high-strength, non-corrosive pipeline materials and research on obstacle detection systems for horizontal boring applications for laying distribution pipelines.

- Leak Detection: Development of pipeline leak and intrusion detection system using optical visualization methods. Development of a portable, hand-held and aircraft mounted, real-time natural gas visualization remote sensing technology to detect fugitive emissions during leak surveys in natural gas distribution systems and gas transmissions systems.

International Infrastructure Program

FY99-$0.0M, FY00-$0.0M, FY-$6.0M

Description, Objectives, and Performers. This is a new program for FY2001. This program is initiated in response to the June 1999 President's Committee of Advisors on Science and Technology report entitled *"Powerful Partnerships-the Federal Role in International Cooperation on Energy Innovation"*.

R&D Challenges. A natural gas leak visualization device is needed that is sufficiently compact and electrically efficient to allow operation in a hand-held format, as well as a remote leak visualization system with sufficient standoff range to operate from a low altitude aircraft. This will require development of a laser source that has sufficient power to accommodate the standoff range and two dimensional area coverage required, and optical receiver hardware capable of the required gas detection sensitivity.

R&D Activities. DOE, in collaboration and partnership with other Federal Agencies, industry, and host country government will initiate international pipeline infrastructure research oriented toward gas leak detection. Activities will include development of: a pipeline leak and intrusion detection system using optical methods; a portable, natural gas video imaging system that has application as a aircraft survey device for natural gas pipelines; improved corrosion-inhibition treatment alternatives in gas gathering and gas transmission lines; and pipeline inspection sensors with internal leak sealing capabilities.

Secure Energy Infrastructures

Budget: FY99-$0.0M, FY00-$2.1M, FY01-$13.0M

Background

The nation's energy infrastructure, which is composed of industries that produce and distribute electric power, oil, and natural gas, is susceptible to threats from natural, accidental, and intentional sources. The threats are directed at both physical and cyber assets of the energy sector. Recent trends toward increasing complexity and interconnectedness of the energy sector serve to increase the potential for significant disruptions to the energy grid and the other critical national infrastructures that the grid supports (i.e., information and communications, banking and finances, transportation, water, emergency services, and government services).

In order to effectively carry out DOE's role as the lead federal agency for the energy infrastructure under Presidential Decision Directive 63, this program is being undertaken to assure the continuity and viability of the nation's critical energy infrastructures and the elimination of any significant vulnerability of that sector to physical and cyber disruptions. This will involve leveraging and developing essential energy infrastructure protection, mitigation, response, and recovery methodologies, analytic tools, and technologies. It will also involve collaboration between DOE and the major stakeholders including private sector owners of energy infrastructure elements, other federal agencies involved in critical infrastructure protection, and state and local governments. The national laboratories, academia, and private research organizations will participate in developing and implementing the research program.

Linkages to CNES Goals and Objectives

The Secure Energy Infrastructures Program supports the following CNES goals and objectives:

- CNES Goal II, Objective 2 – Ensure energy system reliability, flexibility, and emergency response capability.

- CNES Goal III, Objective 2 – Develop technologies that expand long-term energy options.

Focused on the thrust areas of Analysis and Risk Management and Protection and Mitigation Technologies, the Secure Energy Infrastructures Program will result in real-time control mechanisms, integrated multi-sensor and warning systems, and risk management and consequence analysis tools that will help the national energy sector address the physical and cyber threats to, and vulnerabilities of, the energy infrastructures. Infrastructure interdependence methodologies, architectures, analytic tools, and technologies will also be developed that will improve the capability to assess the technical, economic, and national security implications of energy technology and policy decision designed to ensure the reliability and security of the nation's interdependent energy grid.

Program Description

The Secure Energy Infrastructure program will collaborate with industry, academia, and other federal agencies to conduct research that will enhance the protection of the nation's energy infrastructure from disruptions, the mitigation of potential disruptions that do take place, the response to potential disruptions, and the restoration the energy infrastructure to normal operation following a disruption. The program develops methodologies, architectures, analytic tools, and technologies in two program areas: Analysis and Risk Management and Protection and Mitigation Technologies.

Analysis and Risk Management

Budget: FY99-$0.0M, FY00-$2.1M, FY01-$10.3

Description, Objectives and Performers. To adequately determine the susceptibility of the energy infrastructure to disruption, critical assets (both physical and cyber) need to be identified, vulnerability assessments of those assets need to be conducted, and critical consequence analyses to determine the impacts (on public health and safety, on national security, and on economic well-being) of the loss of those assets need to be carried out. To date, there has been no systematic, comprehensive effort to cover all these issues for the energy infrastructure. Some individual energy companies have carried out analyses of their own assets. However, it is not a widespread industry practice to carry out regular, comprehensive, and detailed analyses of physical and cyber asset security. Further, there has been no attempt to systematically evaluate the security of the energy infrastructure on a regional or national scale. This is becoming increasingly important with the greater degree of interconnectedness, both physical and cyber, of the energy system. With the increasing interconnectedness of the energy system, it is no longer

possible for an individual company to address all the critical assets that its own system depends on.

The objective of this program element is to develop a better understanding of the nature and extent of the energy infrastructure's vulnerability to disruption and of the consequences of disruptions. The performers include private sector owners of energy infrastructure elements, other federal agencies involved in critical infrastructure protection, state and local governments, the national laboratories, academia, and private research organizations

R&D Challenges. The challenges to understanding energy infrastructure vulnerabilities and risks include:

- Lack of an effective methodology for processing and analyzing threat information.
- Rapidly changing vulnerabilities of the energy infrastructure, particularly in the cyber area.
- Increasing interdependence of energy infrastructure and other infrastructures.
- Increasing system interconnectedness and complexity of the energy system.

R&D Activities. The following R&D activities are designed to address the challenges.

Infrastructure Interdependencies: Develop, demonstrate, and deliver analytic capabilities and supporting knowledge bases that will significantly improve understanding of, and the ability to comprehensively study, the interdependent nature of the U.S. energy infrastructures. This will involve: (1) enhancing existing and developing new analytical tools that treat infrastructure interdependencies explicitly; (2) enhancing early alert screening tools that provide infrastructure stress indicators; (3) coordinating with other Federal agencies to link to models and simulations of other critical infrastructures; (4) enhancing existing and developing new policy and impact analysis tools; and (5) developing an integrated architecture for analyzing the technical, economic, and national security implications of energy technology and policy decisions.

Vulnerability Assessments: Expand upon previous infrastructure assurance efforts (in the electric power and, to a lesser extent, natural gas infrastructures) to work with utilities to identify and evaluate the threats to and vulnerabilities of the natural gas and oil infrastructures. This includes both cyber (information) and physical infrastructure components. One assessment of the natural gas infrastructure and three assessments of the oil infrastructure would be conducted at various utilities. A summary of lessons learned and recommended practices for the energy industry would be developed.

Scale and Complexity Analysis: Characterize the large, complex, non-linear energy infrastructures, focusing on stability, countermeasures, complexity reduction, uncertainty effects, and personnel behavior.

Critical Consequence Analysis and Tool Development: Develop the data, methodologies, and tools to evaluate the public health and safety, national security, and economic consequences of disruptions to energy infrastructures and the processes to assist in restoration and reconstitution.

Risk Management Tools: Develop tools to assist decision makers in planning and implementing protection and mitigation strategies and predictive risk management tools allowing for real-time, accurate interpretation of system monitoring information.

Evaluating Policy Effects and Institutional Barriers: Evaluate the cause-and-effect relationships between specific public policies, institutional barriers, and energy infrastructure vulnerabilities.

Accomplishments. This is a new program and is just starting.

Protection and Mitigation Technologies

Budget: FY99-$0.0M, FY00-$0.0M, FY01-$2.7M

Description, Objectives and Performers. Response and recovery procedures and technology are not adequate for dealing with the rapid changes in threats and with the changes in the structure of the energy system. This is especially true when dealing with deliberate threats (as opposed to natural and accidental threats) and is particularly true with regard to cyber assets. Technology and procedures that can detect emergency conditions before they become critical (e.g., sensors), that can be deployed quickly to reduce the impact of an emergency (e.g., rapid repair technology), and that can expedite restoration (e.g., information sharing among companies and emergency responders) are needed. The response and recovery technology and procedures used for physical damage are, in general, much better developed than those used for cyber damage. The objective of this activity is to develop energy system protection and mitigation technologies that are suitable for use in the rapidly changing, restructured energy markets.

The performers in this program element are in the national laboratory system, academia, and private research organizations. The work will leverage research in other parts of DOE by adding the security considerations to the development of related technologies.

R&D Challenges. The R&D challenges include the following:

- Technologies that can process large quantities of energy system information in real-time and can analyze the information to provide system operators with the ability to detect and react quickly to potentially destabilizing conditions

- Sensors that can respond in real-time and that can detect emergency conditions before they become critical

R&D Activities. The following R&D activities are designed to address the challenges.

Development of Real-Time Control Mechanisms in the Energy Infrastructure: Identify the vulnerabilities of real-time control systems and develop technologies that protect against unauthorized control of, or intrusion into the system.

Integrated Multi-Sensor and Warning Technologies for the Energy Industry: Develop an integrated, corroborative system of overlapping technologies, including sensors, designed to warn of attacks and impending failures at critical points in the energy system. The focus would be on tamper detection and failure warning technologies such as acoustic instrumentation, electronics signals, biological and chemical toxin sensors, video imaging, satellite oversight, remote methane detection (hand-held and airborne), expert system data interpretation, and standards development. Advanced technology approaches and cost regulation will be the focus of the R&D.

Geomagnetic Interference Warning Systems: Develop a methodology that would enable electric power system operators to establish emergency operating procedures for electric power systems under the influence of intense geomagnetic disturbance. This will provide a cost-effective approach to reduce power system vulnerability to predictive increases in sunspot activity in the next few years.

Accomplishments. This is a new program that is just being started.

Summary Budget Table (000$)

Enhancing Energy System Reliability Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Transmission Reliability	**3,019**	**2,455**	**8,000**
Real Time System Control	1,169	855	3,000
Distributed Resource Integration	900	800	2,000
Reliability and Markets	950	800	3,000
Distributed Power	**1,200**	**3,500**	**3,000**
Strategic Research	200	500	700
System integration	732	2,700	2,000
Regulatory and Institutional Issues	300	300	300
Energy Storage Systems	**4,445**	**3,429**	**5,000**
Integration	2,170	1,640	2,500
Components	1,384	1,000	1,600
Analysis	891	789	900
Superconductivity in Power Systems	**32,100**	**31,408**	**32,000**
The Superconductivity Partnership Initiative	14,500	14,000	14,000
The Second Generation Wire Initiative	8,000	8,000	8,000
Strategic Research	9,600	9,408	10,000
Natural Gas Infrastructure	**975**	**1,000**	**13,200**
Gas Storage Technology	975	1,000	2,200
Enhancing Pipeline System Reliability	0	0	5,000
International Infrastructure Integrity	0	0	6,000
Secure Energy Infrastructures	**0**	**2,100**	**13,000**
Analysis and Risk Management	0	2,100	10,300
Protection and Mitigation Technologies	0	0	2,700
Total	**41,739**	**43,892**	**74,200**