EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20502

February 20, 2003

President George W. Bush
The White House
Washington, D.C. 20502

Dear Mr. President:

We are pleased to transmit to you a copy of the report, "Improving Efficiency in the Nation's Electrical System," prepared by your Council of Advisors on Science and Technology (PCAST).

Upon your appointment of the PCAST membership in December 2001, PCAST formed a Panel on Energy Efficiency. Steven G. Papermaster, Chairman of Powershift Ventures, chairs this Panel. The accompanying letter from Mr. Papermaster summarizes the observations and recommendations contained in the report.

In brief, the report focuses on the Nation's electrical generating, transmission, distribution, and management systems and makes recommendations for increasing the efficiency of each portion of the system. The PCAST understands that energy has been a high priority for you and your Administration, and the National Energy Policy charges PCAST with making recommendations on improving energy efficiency. Accordingly, the report addresses the electrical system as a critical part of the Nation's energy enterprise, and one that can undergo substantial improvements in efficiency.

The recommended means of increasing the efficiency of electricity production are compatible with sound environmental practices, as they would lower emissions per megawatt produced. PCAST's recommendations also support and amplify many of the paths already being followed by the Department of Energy and the Administration.

Please let us know if you have any questions concerning the enclosed report.

Sincerely,

John Marburger

John H. Marburger, III
Co-Chair

E. Floyd Kvamme

E. Floyd Kvamme
Co-Chair

Enclosure

EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20502

February 18, 2003

The Honorable John H. Marburger, III
Director, Office of Science and Technology Policy
The Executive Office of the President
Washington, D.C. 20502

Mr. E. Floyd Kvamme
Co-Chair
President's Council of Advisors on Science and Technology (PCAST)
Washington, D.C. 20502

Dear Dr. Marburger and Mr. Kvamme:

I am pleased to transmit to you the final report, "Improving Efficiency in the Nation's Electrical System," prepared by the PCAST Panel on Energy Efficiency, which has the endorsement of the full PCAST. This report has been produced in response to a recommendation in the National Energy Policy, and contains recommendations for increasing the efficiency of electrical generation, transmission, distribution, and management in the U.S.

The National Energy Policy identified a number of needs for improving the Nation's supply, security, and use of energy. One of the Nation's key energy needs is improved efficiency, and the PCAST Panel on Energy Efficiency has identified our electrical system as having great potential for significant improvements in efficiency. This panel held hearings with a range of private and public sector organizations to gain insight into potential issues, and consulted a number of electrical experts around the country.

Based on these activities, the PCAST panel developed a report of its findings and recommendations. A copy of the panel's report is enclosed, and a summary of its conclusions follows.

Summary of recommendations

The PCAST Energy Efficiency Panel has identified the Nation's electrical generation, transmission, and distribution system to have significant potential for major improvements in energy efficiency. We have identified the four following aspects of the system to be most amenable to technical progress and solutions:

1. ***It is necessary to continue to use the Nation's secure and economically attractive resources of coal to generate electricity. However, major improvements can be gained in the efficiency of coal-fired electrical power plants that will save energy and reduce emissions. We recommend:***

- That the President direct the Department of Energy to develop possible strategies and incentives for repowering aging coal-powered power plants as a means of improving their efficiency and reducing emissions from these critical baseload electrical generating plants.

- That the President place greater priority on the Department of Energy's Vision 21 Coal Technology Program with the goal of integrating carbon sequestration technologies into the Clean Coal Initiative.

- That the President's Clean Coal Technology Initiative budget be increased further to accelerate research on the following components of clean coal technology to reduce cost and also accelerate the implementation of these technologies with the goal of increasing the average efficiency of the U.S. fleet of electric power plants by 5% before 2020:
  - Coal gasification process and coal gasification technologies
  - Gasification-combined-cycle technology for use in existing pulverized coal plants
  - Repowering technology for aging coal-fired plants
  - Tunable burners for coal gasification and natural gas combined cycle plants
  - High-performance turbines
  - Gasification-combined cycle/fuel cell hybrid technologies

2. ***The Nation must proceed with the development of the 21st Century electricity grid. As the Nation's electrical transmission and distribution system is reinvented and expanded in response to changing needs and growing demand, we have an opportunity to incorporate highly efficient superconducting technology into the generation, transmission, and end-use phases of the electrical system. We recommend:***

   - That the President direct DOE to include superconducting technologies in the implementation of its National Transmission Grid Study. DOE-funded research on superconductivity should be increased with a continuing focus on technologies that will reduce the cost of superconductive wire, transformers, generators, and motors, together with supporting technologies such as high-performance cryogenics.

3. ***A large number of distributed electrical generating devices are becoming available to residential, commercial, and industrial electricity customers. The incorporation of extensive distributed generation into the Nation's electrical generation portfolio is highly desirable, but poses many technical problems. We recommend:***

   - That DOE lead the development of an open architecture and standardized protocols for distributed generation, and that DOE be funded to establish a large-scale demonstration test bed for distributed generation technologies. Distributed generation devices, combined with storage technologies and secure communication and control systems, should be thoroughly tested in a test bed situation and DOE should work with FERC to provide an implementation strategy for generation devices, storage, and control systems as part of their distributed generation strategy.

4. ***In addition to making the devices in our electrical system more efficient, we should also strive to use our electric supply more effectively by using technology to help manage demand. We recommend:***

    - That DOE and FERC produce a coordinated implementation plan for demand-side management of electricity that is based on uniform technology, communication protocols, and business practices.

Our recommendations address these issues in the enclosed report. Many of the recommendations contained in this report will be necessarily studied and implemented by the Department of Energy.

The members of PCAST would like to express appreciation to the President for his interest in this important topic and for allowing us this opportunity to present our findings.

Sincerely,

Steven G. Papermaster
Chair, PCAST Panel on Energy Efficiency

Enclosure

PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY

Report on Energy Efficiency

Findings and Recommendations

The President's Council of Advisors on Science and Technology

Findings and Recommendations on Energy Efficiency

SUMMARY

In this report, the President's Council of Advisors on Science and Technology (PCAST) identifies the Nation's electrical generation, transmission, and distribution system to be a potential target for major improvements in energy efficiency.[1] In particular, the four following aspects of the system are identified as the most amenable to technical progress and solutions:

1. ***It is necessary to continue to use the Nation's secure and economically attractive resources of coal to generate electricity. However, major improvements can be gained in the efficiency of coal-fired electrical power plants that will save energy and reduce emissions. PCAST recommends:***

    - That the President direct the Department of Energy to develop a strategy and incentives for repowering existing coal-powered power plants as a means of improving their efficiency and reducing emissions from these critical baseload electrical generating plants.

    - That the President place greater priority on the Department of Energy's Vision 21 Coal Technology Program with the goal of integrating carbon sequestration technologies into the Clean Coal Initiative.

    - That the President's Clean Coal Technology Initiative budget be increased further to accelerate research on the following components of clean coal technology to reduce cost and also accelerate the implementation of these technologies with the goal of increasing the average efficiency of the U.S. fleet of electric power plants by 5% before 2020:
        - Coal gasification process and coal gasification technologies
        - Combined-cycle gas technology for use in existing pulverized coal plants
        - Repowering technology for aging coal-fired plants
        - Tunable burners for coal gasification and natural gas combined cycle plants
        - High-performance turbines
        - Gasification-combined cycle/fuel cell hybrid technologies

[1] PCAST recognizes that very significant opportunities for saving energy exist in the building, industry, and transport sectors, but they are not examined in this study.

2. ***The Nation must proceed with the development of the 21st Century electricity grid. As the Nation's electrical transmission and distribution system is reinvented and expanded in response to changing needs and growing demand, an opportunity exits to incorporate highly efficient superconducting technology into the generation, transmission, and end-use phases of the electrical system. PCAST recommends:***

    - That the President direct DOE to include implementation of superconducting technologies in the implementation of its National Transmission Grid Study. DOE-funded research on superconductivity should be increased with a continuing focus on technologies that will reduce the cost of superconductive wire, transformers, generators, and motors, together with supporting technologies such as high-performance cryogenics.

3. ***A large number of distributed electrical generating devices are becoming available to residential, commercial, and industrial electricity customers. The incorporation of extensive distributed generation into the Nation's electrical generation portfolio is highly desirable, but poses many technical problems. PCAST recommends:***

    - That DOE lead the development of an open architecture and standardized protocols for distributed generation, and that DOE be funded to establish a large-scale demonstration test bed for distributed generation technologies. Distributed generation devices, combined with storage technologies and secure communication and control systems, should be thoroughly tested in a test bed situation and DOE should work with FERC to provide an implementation strategy for generation devices, storage, and control systems as part of their distributed generation strategy.

4. ***In addition to making the devices in our electrical system more efficient, the Nation should also strive to use its electric supply more effectively by using technology to help manage demand. PCAST recommends:***

    - That DOE and FERC produce a coordinated implementation plan for demand-side management of electricity that is based on uniform technology, communications protocols, and business practices.[2]

[2] Although the efficiency of end-use electrical equipment is not itself a focus of this report, the management of demand is important in whatever form that demand takes.

The President's Council of Advisors on Science and Technology

Findings and Recommendations on Energy Efficiency

I. INTRODUCTION

A stable, reliable, and secure energy supply is critical to our country's economic well-being, environmental quality, and national security. Although energy production and sales accounts for only a few percent of U.S. GDP, the health and growth of the U.S. economy depends on the availability of clean, abundant, and affordable energy supplies. It is part of our national responsibility to use energy as efficiently as possible.

In May, 2001, the National Energy Policy was published by the National Energy Policy Development Group under the leadership of Vice President Richard B. Cheney. That document describes in detail the critical energy needs that face the U.S. and provides a series of 105 recommendations for actions by the Federal government to address energy needs for the country, including supply issues, conservation and efficiency, environmental aspects of energy production and consumption, renewable energy, energy infrastructure, and international energy issues. In the subsequent year, actions in response to most of those recommendations have been started and many have been completed. The National Energy Policy has provided both the impetus and direction for a number of important energy measures.

In addition, a number of energy studies have been conducted and published in recent years that address many specific issues and current needs. In fact, the President's Committee of Advisors on Science and Technology published a report in 1997 entitled "Report To The President On Federal Energy Research And Development For The Challenges Of The Twenty-First Century" and another in 1999, entitled "Powerful Partnerships: The Federal Role In International Cooperation on Energy Innovation." The Department of Energy has published a large number of reports and analyses on a variety of energy issues, including "Scenarios for a Clean Energy Future", commissioned by the DOE Office of Energy Efficiency and Renewable Energy and prepared by the Interlaboratory Working Group on Energy-Efficient and Clean Energy Technologies. More recently, the DOE published an assessment of the national electrical grid, which summarizes most of the major problems and possible solutions for a troubled electrical system. These reports, along with an enormous volume of ongoing technical work in the Department of Energy, the Environmental Protection Agency, Department of Defense, and many other industrial, university, and government laboratories provides a rich climate in which to re-examine some key energy issues.

Congress has also made energy a priority, and new energy legislation has been initiated in both houses of Congress. Both the House and Senate have passed versions of a "comprehensive energy bill." These bills differ considerably in their provisions, and ongoing conference debate (summer, 2002) may produce an energy bill for vote in both chambers during the autumn, 2002. Both the House bill (H.R. 4, 570 pages) and the Senate bill (S. 1766, amended to 972 pages) contain a number of important provisions regarding energy efficiency.

Serving as a backdrop for these Federal energy activities have been a series of energy-related traumas in the state and business sectors. California experienced an acute shortage of electricity in the summer of 2000, bringing into question the process of restructuring of the electricity markets. In the final analysis, the California model was a poor model for restructuring, for a variety of reasons, but the result has been some loss of confidence in the incremental restructuring process that has been ongoing across the country.

The President's Council of Advisors on Science and Technology has been asked to make recommendations about energy efficiency. The first recommendation in Chapter 4 of the National Energy Policy states, "The NEPD Group recommends that the President direct the Office of Science and Technology Policy and the President's Council of Advisors on Science and Technology to review and make recommendations on using the nation's energy resources more efficiently." This document is the PCAST response to the NEP recommendation. This report presents recommendations from PCAST to the President on energy efficiency issues that are necessarily and most appropriately addressed by the President. This report is not intended to be a comprehensive treatment of all energy or energy efficiency issues. Rather, it identifies a handful of critical issues related to energy efficiency that may materially benefit from leadership from the President.

II. CHARACTERISTICS OF THE EXISTING ENERGY SYSTEM

In many ways, the U.S. energy production, processing, and transportation processes are marvels of modern technology. No nation in the history of the planet has been so productive, and that productivity is directly related to the universal availability of affordable energy supplies. Although there are problems to solve and issues to address, many parts of the U.S. energy sector are not broken and should not be "fixed." The fundamental motivation of PCAST is to help ensure that energy is available to meet the demands of a strong U.S. economy by helping to increase the efficient use of energy supplies.

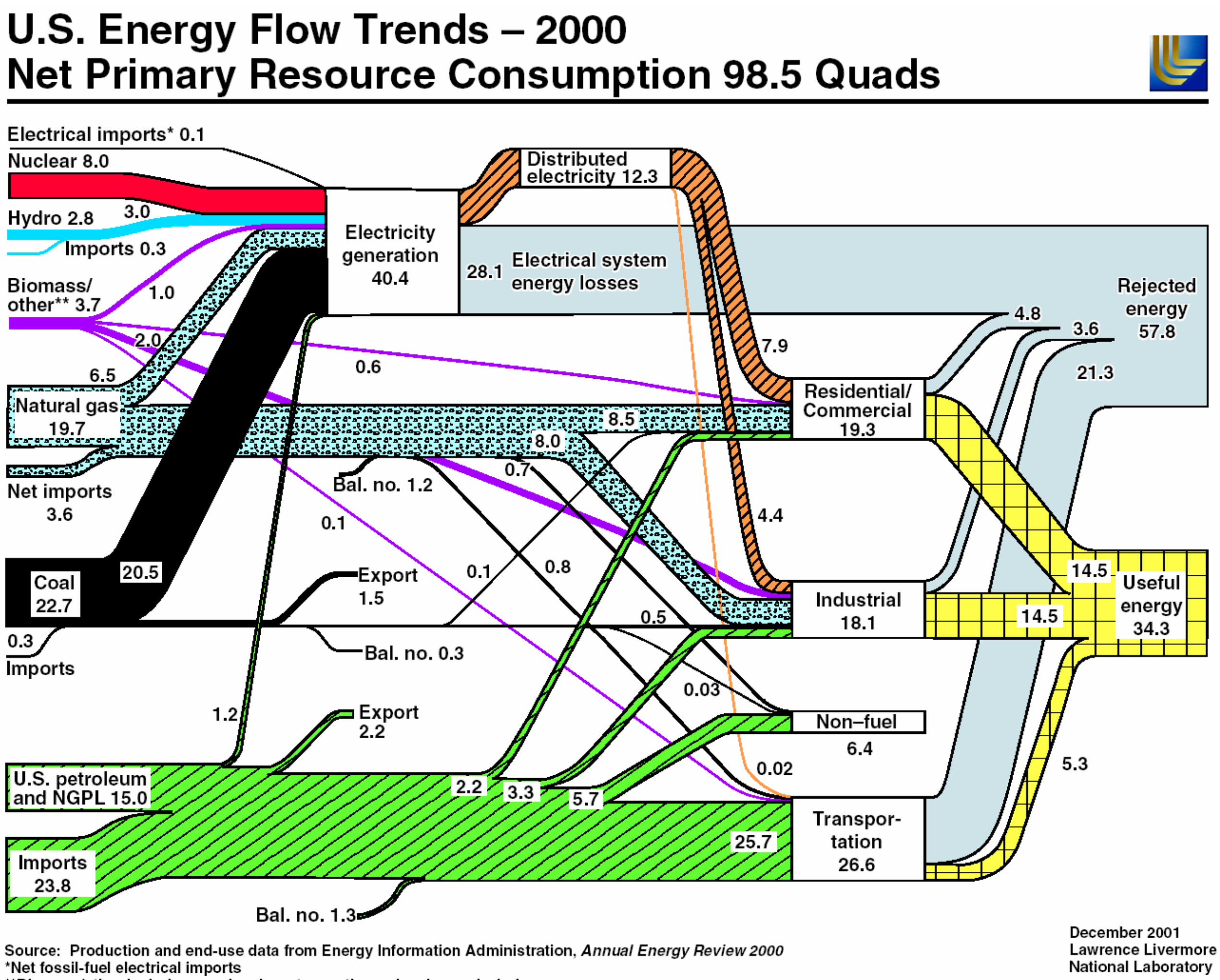
Despite the fact that the U.S. energy system has provided abundant energy for unprecedented economic growth over the last twenty years, important systemic efficiency problems must be addressed soon before the constraints of our energy system begin to affect the U.S. economy. Where are these areas of most serious inefficiency? Where can the Nation make rapid progress in improving efficiency? How can improvements in efficiency help make the Nation's energy supplies more secure? How are efficiency measures related to other energy issues such as infrastructure and security?

Several aspects of the U.S. energy sector are inefficient and are amenable to the application of evolving technology to make them more efficient (Figure 1). The U.S.

transportation system is one of the most inefficient sectors in the U.S. energy economy. The efficiency of the U.S. transportation system could be improved in many ways using many different strategies. In fact, the Freedom Car Program in the Department of Energy addresses automotive efficiency and the dependence of our transportation system on petroleum. In addition, several smart growth programs address the cultural and societal aspects of transportation efficiency, and are well underway in many parts of the country. Likewise, many of our commercial buildings and industrial processes are less efficient than they should be. The energy efficiency of housing could be improved. Energy efficiency of electrical appliances and industrial electrical devices could be, and is being, addressed by the Department of Energy, the Environmental Protection Agency, and other local, state, and Federal programs. In fact, the Department of Energy continues to provide leadership in identifying and addressing inefficiencies in energy production, transportation, and use.

In this report, PCAST focuses on the efficiency of the electrical generation, transmission, and distribution system. Each year, the U.S. uses approximately 40% of its energy to generate electricity. That process is only about 30% efficient. The report addresses the potential efficiency gains in coal-fired power plants that account for 55% of our electrical generation, the potential efficiency gains in the electrical transmission and distribution system, the potential efficiency, power quality, and security gains possible through the increased development and implementation of distributed energy technologies, and the potential for energy savings through improved management of energy demand.

Figure 1. Energy flow diagram for 2000 U.S. net primary energy consumption.



III. IMPROVING THE EFFICIENCY OF ELECTRICAL POWER PLANTS

In calendar year 2000, the U.S. consumed 40 quadrillion Btus (quads) of energy for generating electricity out of a total U.S. energy consumption of 99 quads. Those 40 quads produced 12 quads of electricity (3,606 billion kilowatthours), an overall efficiency of 30%.

Electric power is generated in over 10,000 power plants nationwide, but approximately 1100 power plants, fueled by coal, account for 55% of the electricity generated. These traditional coal-fired steam plants provide the majority of the U.S. electrical baseload capacity. With an average generating capacity of 270 MW, these coal-fired steam plants average about 33% efficiency (efficiency is defined here as electrical energy produced divided by primary energy consumed). This level of efficiency is typical of steam plants, regardless of fuel. In fact, traditional single-cycle steam plants fired by natural gas also exhibit about 33% efficiency.

In contrast, combined-cycle generating plants use the combustion gases to drive gas turbines and also use the waste heat coming out of the gas turbine to heat water to drive steam turbines, thus exploiting more of the energy consumed and making them more efficient. Combined-cycle electrical generating plants fueled by natural gas currently reach efficiencies as high as 50%, and advanced turbines currently in design may push efficiency past 60%. This higher efficiency, combined with scalability and a relatively low capital cost of construction makes natural gas combined-cycle plants the configuration of choice for most newly constructed electric plants. In fact, the Department of Energy has estimated that 90% of the next generation of power plants will be gas-fired generators, and the use of these highly efficient generators may reduce natural gas demand by more than 1 trillion cubic feet per year by the year 2020, compared to gas demand without the recommended efficiency improvements in coal plants. It is important to note that coal plants and nuclear plants continue to constitute most of U.S. baseload capacity, whereas the newly constructed gas plants are used primarily for intermediate capacity generation.

Greater reliance on natural gas (currently only 18% of electrical generation), and moving away from coal may seem desirable at first because gas has inherently lower emissions of SO_x and carbon dioxide per unit of heat, and may be installed at relatively low cost. But switching from coal to natural gas generation is not a simple decision or process. Currently, 55% of U.S. electricity is generated using domestically-produced coal as the primary fuel. Domestic electricity demand is expected to grow by about 2% annually over the next 20 years, so more than a thousand new power plants will be needed by the year 2020 to meet growing demand and offset plant retirements. During this expansion, the U.S. cannot afford to turn completely away from coal. Not only would it require more natural gas than we could currently supply, but switching from coal would unwisely abandon enormous U.S. coal resources at a time when there appears to be a great opportunity to develop and implement coal technology in a cleaner and more efficient way.

The President's Clean Coal Power Initiative addresses several critical coal issues, motivated primarily by limiting emissions of SO_x and NO_x, and mercury. But the President's Clean Coal Power Initiative is being built on the back of an existing program of clean coal technology, and the historic and current developments in coal power technology provide an opportunity to significantly increase the efficiency of coal-fired plants.

At the core of new coal technology is the use of a gasification process that converts coal to a combustible gas that can subsequently be fed into a combined-cycle generator similar to the natural gas-fired combined-cycle plants. This integrated gasification-combined-cycle (IGCC) technology boosts the efficiency of the coal-fired plants and also provides an opportunity to remove pollutants from the gas stream prior to combustion, thus making the plants cleaner as well. Some gasification combined cycle plants are already achieving 40 to 42% efficiencies, compared to the 33 to 35% efficiencies of conventional coal combustion plants. If additional technology is applied to these plants, they may exceed the 50% efficiency mark. Gasification combined cycle plants built as part of DOE's Clean Coal Technology Program near Tampa, Florida, and West Terre Haute, Indiana, achieve efficiencies of around 50% and are the cleanest, most efficient coal plants in the world.

Additional efficiency improvements may also be achieved at existing and new power plants. Computerized controls, improved burner designs, better gas cleaning systems, higher performance turbines and complementary fuel cells can all be used to enhance the production of electricity from coal. Worldwide, over 1500 megawatts of IGCC plants are fueled by coal today, and another 2200 megawatts are in design. Even at this early state, the combined economic and environmental benefits of using integrated gasification combined-cycle technology are estimated to be several billion dollars through 2020.

Incremental improvements in generating efficiency of coal-fired power plants would translate into huge energy savings. For example, improving the total U.S. electrical generating efficiency from 30% to 40% would save 5.5 quads of energy per year. That amount of energy is roughly equivalent to 25% of total U.S. coal consumption, 25% of U.S. natural gas consumption, or over half of U.S. nuclear power generation. Although that would be an ambitious goal, we believe that an efficiency improvement of at least 5% (from 30% to 35%) may easily be gained by 2020 simply by addressing technologies that could be used today in existing coal-fired power plants.

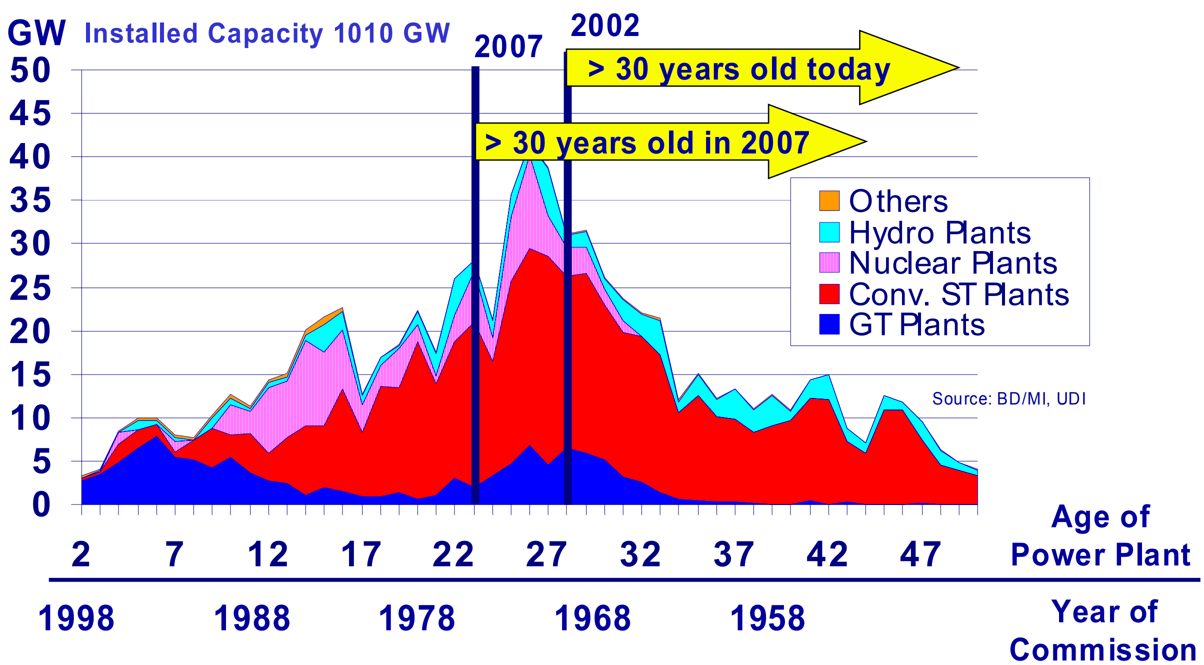
Repowering existing coal-fired power plants

Even if few new coal-fired power plants are constructed, the Nation could still reap significant energy and cost savings while reducing emissions from power plants by repowering older coal-fired plants with new technology. Repowering incorporates new power generating technology into an existing plant, while using much of the existing power plant facility, and typically increases plant capacity. This approach leverages the intrinsic value of existing sites, which are already permitted and have established infrastructure such as electrical transmission lines and fuel access. A relatively simple repowering option is to integrate a gas turbine with an existing boiler, using the exhaust to either heat feedwater or replace the primary air. Such approaches can increase capacity by 25 to 30 percent and improve plant efficiency by 5 to 13 percent. More sophisticated repowering options with greater pay-off in efficiency and capacity increases include Pressurized Fluidized Bed Combustion, Gasification Combined Cycle, Advanced Turbines, and Indirectly Fired High Performance Power Systems, and integration of artificial intelligence controls.

How much energy could be saved through gains in efficiency by repowering existing coal-fired plants with new technology? Power plants are traditionally renovated after about 30 years of production. These renovations may take the form of a retrofit, which would increase the capacity of the power plant using traditional technology, or the renovation may include a more extensive repowering process, in which higher efficiency, cleaner coal technologies are installed in the existing plant. If we examine only coal-fired power plants that will reach their thirtieth birthday in the next five years (between 2002 and 2007), at least 100 gigawatts of coal-fired generating capacity will be considered for retrofit or repowering (Figure 2).

Doing the Math: At an average generating capacity of 270 megawatts per plant, 100 gigawatts would represent over 350 coal-fired plants. A capacity of 100 gigawatts operating under a load factor of 71% (average for coal plants) would generate 622 billion kilowatthours of electricity per year and would require 6.36 quadrillion Btu of primary energy at 33% efficiency. If those 350 power plants due for renovation would be upgraded so that their generating efficiency is improved from 33% to 43% with no other changes, an additional 188 billion kilowatthours would be generated each year without burning additional coal. For comparison, the total generation of electricity by hydroelectric dams in the U.S. in 2000 amounted to 273 billion kilowatthours. Stated conversely, generating the same 622 billion kilowatthours of electricity in a 43% efficient coal-fired plant would require 4.88 quadrillion Btu of primary energy. That amount of energy is roughly equivalent to 75 million tons of coal not burned.

Figure 2: Age and year of commission of U.S. coal power plants. The red portion represents conventional steam plants.



Aside from the saving of energy which translates directly into lower costs, the reduction of coal consumption by improving the efficiency of U.S. coal-fired power plants would significantly reduce total emissions of SO_x, NO_x, mercury, and CO_2. In fact, improving efficiency of coal-fired electric power plants may be a very smart strategy for reducing emissions.

PCAST recommends:

- The President direct the Department of Energy to develop a strategy and incentives for repowering existing coal-powered power plants as a means of improving their efficiency and reducing emissions.
- The President increase funding for the Department of Energy Vision 21 Coal Technology Program with the goal of integrating carbon sequestration technologies into the Clean Coal Initiative.
- The President's Clean Coal Technology Initiative budget be increased further to accelerate research on the following components of clean coal technology to reduce cost and facilitate implementation with the goal of increasing the average efficiency of the U.S. fleet of electric power plants by 5% before 2020:
    - Coal gasification process and coal gasification hardware
    - Combined-cycle gas technology for use in existing pulverized coal plants
    - Repowering technology for aging coal-fired plants
    - Tunable burners for coal gasification and natural gas combined cycle plants
    - High-performance turbines
    - Gasification-combined cycle/fuel cell hybrid technologies

IV. IMPROVING EFFICIENCY OF ELECTRICAL TRANSMISSION

The U.S. electricity grid is composed of 150,000 miles of interconnected high-voltage power lines that connect over 10,000 electrical generating plants, through a system of substations, transformers and lower voltage lines, to industrial, commercial, and residential electricity customers. The U.S. electricity grid has been called the largest, most complex machine ever built. Unfortunately, the electricity grid is showing its age and is about to undergo a rather dramatic and necessary transformation in its technology, control, and business management. Ongoing efforts by the Federal Energy Regulatory Commission (FERC) promise to reinvent the Nation's transmission system by establishing regional transmission organizations (RTOs) that will more optimally allocate grid use and resources. As this transformation proceeds, it is essential that whenever transmission and distribution infrastructure is upgraded or replaced, it is done with efficiency, power quality, reliability, and security as primary National goals. By improving the capacity and streamlining command/control issues, these actions will minimize the loss of electricity during transmission.

The electricity grid, as it has evolved, has grown up as a number of local or regional transmission and distribution systems designed to move locally generated power to local customers. The local grids were connected together as they grew, but the resulting patchwork grid system was not designed with large-scale regional transmission efficiency in mind. As a result, we are left with a grid that suffers from inadequate capacity, poor command and control technology and mechanism, and poor efficiency. As the grid evolves over the next several years, it will be possible and desirable to address the capacity and command/control issues as well as incorporating more efficient transmission hardware into the system. These three grid characteristics are closely interrelated and should be addressed simultaneously.

Electrical supply location is changing as new generators are constructed in response to growing and shifting U.S. population and demand centers, and the distribution of electrical demand is shifting as industry, commerce, and housing develop in new areas of the country. Traditionally, the loss of electricity through transmission and distribution is estimated to be around 8%. However, as the electricity grid has become more massive and more complicated, some now estimate that the line loss may be as great as 10%. Several parts of the grid are reaching (and have recently exceeded) their transmission capacity under growing demand and must be modernized and expanded with new transmission capacity with improved performance characteristics.

A number of transmission technologies exist or are in development that should be incorporated into the grid as it is renovated over the next several years:

- High-voltage DC (HVDC) transmission lines are already in use and provide effective long-distance transmission of electricity; they also facilitate connections between AC transmission grids. Their use could be expanded.
- HVDC lines are especially effective if used with flexible AC transmission systems (FACTS), which improve flow control on the grid. When used with wide area measurement systems, FACTS can improve the efficiency of the grid through better monitoring and control.
- Supervisory control and data acquisition (SCADA) systems must be incorporated into any improved grid, along with the necessary understanding of how the system can be managed, to produce a "smart grid." Otherwise, new hardware will contribute little benefit to the grid for lack of management control.

In addition to existing technologies and processes, several new technologies are nearly ready for incorporation into the grid. One of the most promising emerging technologies is high-temperature superconductive (HTS) devices. [The term "high-temperature" is a relative term, since superconductivity was first observed in materials at liquid helium temperatures at –259ºC. Temperatures required for true superconductivity in newer materials are still very low, but they are considered high temperatures relative to early superconductive materials and may be achieved with liquid nitrogen, which is exists below -196.2ºC, is widely available, and is relatively inexpensive.]

At very low temperatures, certain materials exhibit virtually no resistance to an electrical current, and thus are called superconductive. Superconductivity permits devices to carry large amounts of electrical current that can be applied to electric power devices such as motors and generators. Superconductive cable may be used for electrical transmission with almost no resistive line loss, thus greatly improving the efficiency of the transmission process. Superconducting wire can carry as much as 100 times the amount of electricity of ordinary copper or aluminum wires of the same size. For an electrical system such as a motor, superconductivity may improve capacity, compared to conventional equipment of the same physical size, by a factor of 2 or more. Depending on size, motors today have efficiencies in the neighborhood of 95% and generators 98-99%; HTS equipment typically cuts these remaining losses in half. Cryogenic devices now include cables, transformers, current limiters, switches, generators, and energy storage devices.

The enormous advantage of high-temperature superconductive devices is that they can be cooled by liquid nitrogen (-196.2ºC), which is abundant and relatively inexpensive to produce. The anticipated range for HTS operating temperature (depending on the application) is up to 77 K (-196.2ºC). Improvements to critical current, operating temperature, and magnetic field tolerance, as well as improvements in cryogenic refrigeration technologies, will result in cost-effective HTS wire, the goal being $0.01/ampere-meter.

The development and incorporation of superconductive cables, transformers, and generators will have the greatest impact on the efficiency of the electricity generation, transmission, and distribution system. Superconductive devices share one very important characteristic: they are almost always significantly lighter and more compact than a conventional device with equivalent capacity. Much of the research and development investments in high-temperature superconductivity will help to advance the adoption and economic competitiveness of all of these devices:

- **Motors**- HTS motors: 50% smaller, 50% less losses compared to today's motors. Large motors convert 30 percent of all U.S. electrical energy generated, and 70% of these motors are well suited to utilize HTS technology. The primary applications of these devices will be large motors (greater than 1000 hp) used for pump, fan and compressor drives for utility and industrial markets.
- **Transformers**-oil-free HTS transformers: weigh ~45% less and reduce losses by 30% over conventional units.
- **Power Surge Protection** - HTS fault current controllers redirect the excess energy into HTS coils where it is safely absorbed without interrupting normal power supply.

Installation of superconducting cables benefit from underground conduits or trenches. The expense of underground installation and the necessity for circulating liquid nitrogen coolant makes superconductive cable a less attractive choice for long-distance above-ground transmission of electricity. However, the much higher conductivity of superconducting cables means that conventional underground transmission and distribution cables in urban areas can be replaced by HTS cables that carry two to five times as much electricity within the same space. Thus, superconducting cables are attractive for upgrading old cables in cities and towns where new trenches or underground installation might cost several million dollars per mile. In addition, where new cables must be installed in urban areas, superconductive cables provide very high capacity with a relatively small required right-of-way. The use of superconductive cables over longer distances may become possible depending on advances in cooling technologies and superconducting materials.

Research on superconductive devices is ongoing at six national laboratories, working in partnership with industry. The main emphasis is on the development of HTS wire that exhibits the necessary requirements for use in transmission and distribution applications. For example, the main requirement for commercial electric power applications is that the wires be flexible and strong, and that they are able to carry large currents over long distances in a magnetic field. In addition, the HTS wire must be fabricated at reasonable cost. Presently, a meter of HTS wire able to carry 1000 amperes costs $200. Traditional (copper) wire having equivalent capacity costs approximately $25 per meter. This HTS wire cost is predicted to reach $50 per meter as performance improves and volume production improves economics. Meanwhile, "second generation" HTS wire (now being actively researched worldwide) is predicted to eventually cost $10 per meter – significantly less than copper on this basis. As cost drops, the superconducting cable market is expected to reach almost $30 billion per year by 2020. If HTS cable were installed in each appropriate segment of the present electricity grid, it is estimated that the amount of energy saved would be roughly equivalent to the output of 40 medium-sized power plants.

Barriers remain, however, before HTS technology can become truly competitive in the marketplace. Current density, the amount of electricity that can be transmitted through a wire of a specific diameter, must be improved and manufacturing costs lowered. Research must be continued to develop even better conductors. Cryogenic refrigeration technologies must also become more economical in order to provide the coolant required for the superconductivity.

Diagnostics, monitoring, and understanding of the failure mechanisms of the new superconducting technologies (cables, motors, generators, and transformers) allows the identification of equipment that is at risk so that action can be taken in advance of failure. Federal research support in this area would promote acceptance of superconducting equipment and assure the industry that reliability will not be compromised when these new technologies gain widespread use.

A prototype HTS transmission segment has powered three factories in Georgia (25 MW) for over two years without reliability problems. A higher capacity (500 MW) segment is planned for operation in 2006 to serve residential and business customers in Long Island, NY. A prototype 10 MW transformer has been built and will be installed for 2003 testing at a Wisconsin substation. In addition, a 100 MW generator is under development and is expected to be tested in 2005. These highly efficient, superconducting technologies should become part of the U.S. electricity grid as it is expanded and upgraded over the next few years.

PCAST recommends:

- That the President direct DOE to include implementation of superconducting technologies in the implementation of its National Transmission Grid Study. DOE-funded research on superconductivity should be increased and focused on technologies that will reduce the cost of superconductive wire, transformers, and motors.

V. IMPROVING DISTRIBUTED ENERGY TECHNOLOGIES

The role of distributed generation in the U.S. electricity system

Another emerging group of technologies that should be become part of the U.S. electrical portfolio is distributed generation technology. The historic configuration of centralized power generators connected to local customers via radial grids is becoming less practical in a restructured national electrical market. New electrical generation technologies that are efficient, scalable, and stable are becoming economically competitive for local electrical needs. Natural gas turbines and microturbines, fuel cells, renewable sources such as wind and solar, though not necessarily economic now, will likely emerge as competitive sources of electric power for industry, commercial installations, and homes in the near future. These distributed generating technologies have several advantages: they are close to the consumer (obviating the need for long-distance transmission), they may provide extraordinarily stable electric power (a requirement for growing digital demand), and they can be less vulnerable to wide-scale blackouts. In addition, the electricity that is generated in excess of local demand could be fed to the grid as a supplement to central baseload power plants, if the technology and the market structure allow it.

Distributed generation (DG) refers to a group of relatively small power-generating devices that can be combined with energy management and storage systems to provide electricity for a home, a commercial facility, or a larger customer, whether or not those technologies are connected to an electricity grid. Distributed generation devices may range from a small electricity generator to provide backup power at an electricity consumer's site to a more complex system, highly integrated with the electricity grid and consisting of electricity generation, energy storage, and power management systems. DG systems range in size and capacity from a few kilowatts up to 50 MW. DG devices comprise a suite of technologies located at or near the location where the energy is used. DG devices provide opportunities for greater local control of electricity delivery and consumption. They also enable more efficient utilization of waste heat in combined heat and power (CHP) applications — boosting efficiency and lowering emissions. Appropriate CHP systems can provide electricity, hot water, heat for industrial processes, space heating and cooling, refrigeration, and humidity control to improve indoor air quality and comfort.

Distributed generation technologies can be used to meet baseload power, peaking power, backup power, remote power, power quality, as well as cooling and heating needs. Customers usually own the small-scale, on-site power generators, but they may be owned and operated by a third party. If the distributed generator doesn't provide 100% of the customer's energy needs at all times, it can be used in conjunction with a distributed energy storage device or a connection to the local grid for backup power (provided that the local market permits it). Distributed generation may support and strengthen the central-station model of electricity generation, transmission, and distribution. Distributed generation technologies have already begun to make an impact on the electrical generation capacity of the U.S.

Preferred or promising distributed generation technologies (borrowed table)

DER Technologies	Commercially Available	Emerging Technology
Microturbines	x	x
Combustion Turbines	x	
Reciprocating Engines	x	
Stirling Engines		x
Fuel Cells	x	x
Energy Storage / UPS Systems	x	x
Photovoltaic Systems	x	
Wind Systems	x	
Hybrid Systems	x	x

The Role of Energy Storage in Distributed Generation

One way to increase the efficiency of distributed electrical generation is to provide some storage mechanism for electricity generated by renewable or inexpensive means. Advanced energy storage systems will be integrated with distributed energy resources and renewables to provide optimum market value to the producer and user. Enhanced energy storage can provide multiple benefits to both the power industry and to its customers:

- Improved power quality and reliable delivery of electricity for customers as a result of addressing the $150 billion estimated annual cost due to power quality problems
- Improved stability and reliability of transmission and distribution systems
- Increased use of existing equipment, deferring or eliminating costly upgrades
- Improved market value of distributed generation sources
- Distributed generation storage combined with power electronic controllers and distributed power resources help ensure reliable delivery of electric services in a restructured market place.
- Reduced short outages and voltage sags to provide the required level of power quality.
- Increased reliability for the entire grid and flexibility for the end-user when coupled with advanced power electronics.

Advanced energy storage systems also will increase the attractiveness and value of renewable energy. Renewable resources such as solar and wind are not available for dispatch all the time, which is one of their major drawbacks. Storing energy from the renewable generator allows dispatch to follow load curves or to be held in reserve. For example, a large storage system attached to a wind energy resource could store energy when the wind blows and then dispatch that energy into the higher priced market as needed. In remote systems, storage allows photovoltaic-generated electricity to be used at night.

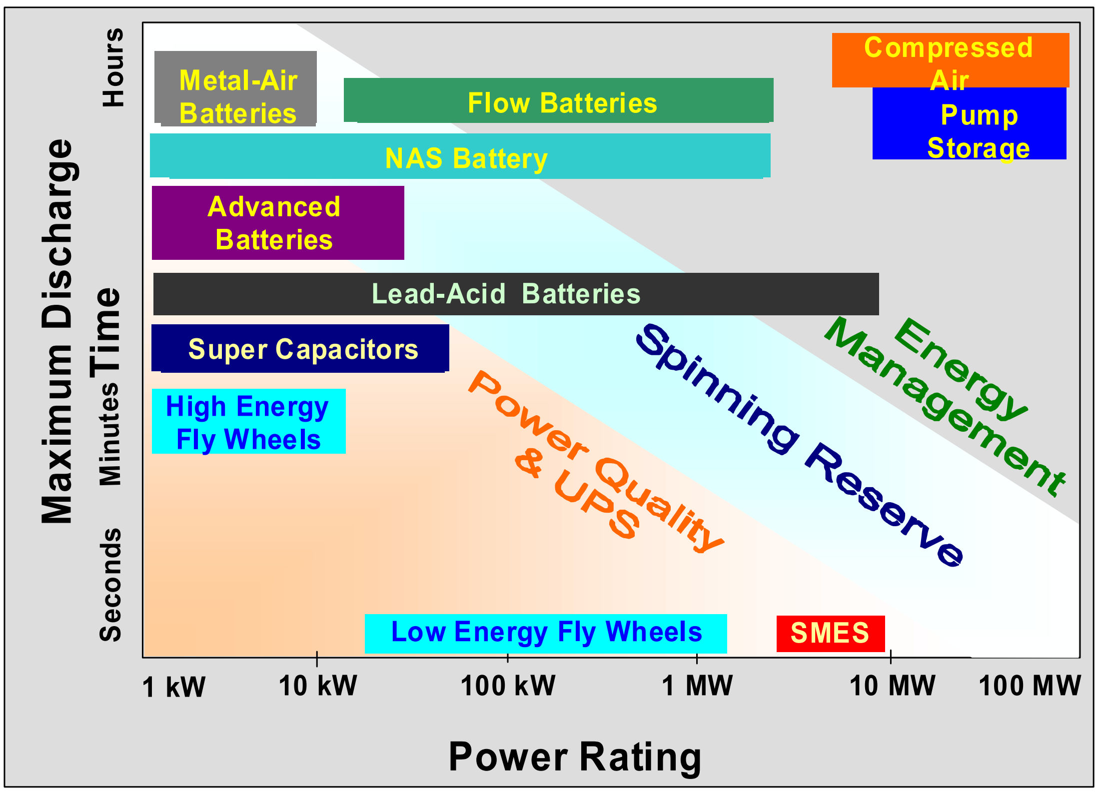
Existing or potential energy storage technologies and associated components include:

- batteries (both conventional and advanced) (store energy chemically)

- flywheels (store energy mechanically)
- compressed air storage (stores energy as a retrievable gas)
- high-energy-density capacitors (stores energy electronically)
- superconducting magnetic energy storage (SMES) (stores energy magnetically)

Each of these technologies has different potential for addressing both electrical storage and electrical quality needs over a range of power output and at different time scales (see Figure 3) and different geographic scales. Historically, the major drawback for electrical storage has been price, and therefore the greatest need is that cheaper storage be developed for application at all scales.

Figure 3. Power rating and maximum discharge time for different electrical storage technologies.



Communications and control systems for distributed generation

Distributed generation technologies, and the communications and control systems that are needed for their proper implementation, face both great opportunities and substantial technical challenges. A critical challenge lies in the need for a more unified vision of distributed energy systems. Two alternatives have emerged that are distinct, yet intertwined. The first alternative views distributed energy systems as complementing the baseload generating capabilities of utilities on an as-needed basis. The second views them as primarily customer solutions for addressing onsite energy needs for clean, reliable power and thermal energy (for those distributed devices that also generate heat). Integration of these two visions could assist in the effort to determine the proper role of distributed energy systems in the nation's energy system and to build consensus as to the types of communications and control systems that will be needed. A key aspect is the need to demonstrate the "value proposition" for distributed energy to suppliers, users, and public policy makers. In other words, what advantages does distributed generation provide over existing electrical supplies? A key aspect is the need for greater standardization of communications and other protocols for the interface of distributed energy systems with other aspects of the energy system. A national "plug & play" protocol could offer users easier operations and maintenance requirements, more reliable interconnection with utility systems, and less hassle in siting and permitting. Such communications protocols could enable real-time costs of power to be translated into price signals that flow through the entire power system, thus assisting in the creation of more readily identifiable revenue streams for distributed energy systems to capture.

The field of communications and controls for distributed energy systems is new and evolving rapidly. There is a large pool of existing technologies that can be used to address anticipated needs. Better functional specifications and workflow definitions are needed so that manufacturers, service providers, users, and others can have a better idea of how to make the best use of the existing suite of communications and controls technologies. Demonstration and field tests of DG systems – in both geographically concentrated and dispersed areas – are needed to help define better the functional specifications and the full range of communications and control system needs. The biggest technical unknowns involve scale-up issues for large scale deployment, which is what is implied by DOE's goals for distributed energy resources over the next ten years. To the extent possible, the architecture of the system for deploying communications and controls under a large scale deployment scenario should be as open as possible to promote "plug & play" and interoperability to the fullest extent possible. This will make it easier for customers to choose equipment from various manufacturers to suit their particular needs, and for them to have that equipment operate properly and reliably and with the least amount of technical problems.

Federal research and development efforts are needed to:

- support large scale demonstrations of distributed generation equipment, grid connection, and overall system control
- assist in defining the architecture and functional requirements for communications and controls systems
- assist in developing standard approaches to enable users to optimize their investments in energy equipment and services and in fostering a national "plug & play" environment
- strengthen ongoing research and development efforts through better technical coordination among government agencies and R&D projects cost-shared with industry, universities, and the national laboratories

The communication and control systems architecture could rely on existing communications networks (including existing products for aggregating current distributed energy devices) and involves multiple layers of controls, distributed intelligence, and the ability to respond, in real-time, to changes in market signals and power system conditions. This system architecture needs to exchange physical and financial information and include verifiable accounting procedures for market transactions. The aim is to solve large-scale optimization problems with real-time information, control, and tamper-aware security, privacy, and trust. Key architectural design considerations include achieving a proper balance between the need for open protocols, easy access for remote dispatching and diagnostics, and " plug & play" equipment; and the need for effective security of customer facilities and protection of customer privacy and personal/business information.

Secure communications for control systems, using open protocols that meet real-time operating requirements, are also needed. Development of national standardized and secure communications protocols for distributed energy systems remains an important step. While much can be accomplished using current communications protocols along existing networks (i.e., telephone lines, wireless systems, and the Internet), more needs to be done; interfaces between utility communications systems at the distribution and transmission system levels also need to be developed.

Power Quality and Reliability Issues in Distributed Generation

Power quality is an important concern for today's power grid and the loads that it serves. Computer equipment in particular is sensitive to power quality problems, and the ubiquity of computers in today's manufacturing environment means that high quality power quality is becoming important to a wide number of commercial and industrial firms, as well as to the average homeowner.

The most severe power quality problem is a large voltage surge caused by a lightning strike or blackout. Other power quality problems include a variety of voltage fluctuations caused by variations in electrical load (e.g., big motors being switched on or off), frequency variations that cause changes in the voltage and its waveform, and impulse events (sometimes called glitches, spikes, or transients) that produce very brief, but very strong variations in voltage.

Many digital applications demand "nine nines" of power quality, which means that the power must be far more stable than generally available from the current grid. Distributed generation technology will provide a good solution to power quality needs, and improved power quality will justify some of the capital costs for installation of distributed generation by some users. DG devices such as fuel cells may provide power that is currently more expensive than grid power, but is of such high quality that it could replace power conditioning hardware and uninterruptible power supplies in digital facilities.

On the other hand, the ability of distributed generation devices to automatically connect to and disconnect from the grid in response to demand or price signals potentially presents a new source of grid power fluctuation. Therefore, distributed generation devices that are connected to the grid must take into account the effect on the grid as well as the inherent power quality of the device itself. Distributed generation devices, combined with storage technologies and communication and control systems, should be thoroughly modeled and tested in a test bed situation.

PCAST recommends:

- That DOE lead the development of an open architecture and standardized protocols for distributed generation, and should be funded to establish a large-scale demonstration test bed for distributed generation technologies. Distributed generation devices, combined with storage technologies and secure communication and control systems, should be thoroughly tested in a test bed situation and DOE should work with FERC to provide an implementation strategy for generation devices, storage, and control systems as part of their distributed generation strategy.

VI. IMPROVING EFFICIENCY THROUGH THE TECHNOLOGY OF DEMAND-SIDE MANAGEMENT

Demand-side management (DSM) allows customers to respond to changes in the price of electric power as demand changes during the day by reducing non-critical power consumption. Real-time consumption monitoring and real-time pricing are technically feasible and would permit enormous savings of energy and “peak shaving” by allowing consumers (especially commercial and industrial customers) to respond instantly to price signals. Demand-side management is already used in scattered markets, but varies widely in availability and application. Although demand-side management does not necessarily improve the efficiency of individual generating or transmitting equipment, DSM does allow more effective use of existing equipment collectively and reduces the need for additional generating and transmission capacity by reducing the maximum load on the system.

The instrumentation and communication needed for demand-side management exist but have not been widely installed for this purpose. In order for customers and utilities to engage in real-time transactions, both the customer and the power provider need real-time pricing information so that the customer knows when to turn off non-essential equipment. That information would be transmitted to the customer via the internet or by telemetry. Simultaneously, the customer must have real-time metering at their site to monitor their own power consumption. This technology exists, but most distribution entities do not currently have the capability to conduct real-time monitoring or pricing. Utility DSM programs offer a variety of measures that can reduce energy consumption and consumer energy expenses. Electricity DSM strategies have the goal of optimizing end-use pricing and minimizing end-use demand to avoid or postpone the construction of new generating plants and transmission lines.

Load Reduction technologies are implemented to reduce total energy use. Load Leveling technologies are used to smooth out the peaks and dips in energy demand — by reducing consumption at peak times ("peak shaving"), increasing it during off-peak times ("valley filling"), or shifting the load from peak to off-peak periods — to maximize use of efficient baseload generation and reduce the need for spinning reserves. Load control technologies include energy management control systems (EMCSs), which can be used to switch electrical equipment on or off for load leveling purposes. Some EMCSs enable direct off-site control (by the utility) of user equipment. Typically applied to heating, cooling, ventilation, and lighting loads, EMCSs can also be used to invoke on-site generators, thereby reducing peak demand for grid electricity.

Energy storage devices located on the customer's side of the meter can be used to shift the timing of energy consumption.

Net Metering

Demand-side management may involve only the consumption of electricity provided over the grid, or it may also include the use of on-site distributed generation equipment. For those consumers who have their own electricity generating units, net metering allows for the flow of electricity both to and from the customer through a single, bi-directional meter. This arrangement is more advantageous to the customer than the two-meter arrangements that are more typically used for qualifying facilities authorized under PURPA. Under the most common two-meter arrangement, referred to as net purchase and sale, any electricity produced by a consumer that is not immediately used by the customer flows to the utility through the second meter. This excess generation flowing through the second meter is purchased by the utility at the utility's avoided cost, while the customer purchases any electricity off of the grid at the retail rate. There is usually a significant difference in the retail rate and the avoided cost. A typical retail rate might be as high as 8.5¢/kWh, while the avoided cost rate may be 2.5¢/kWh. This buy-back arrangement is not always in the best interests of the electrical distribution companies, especially if it is mandatory, and therefore net metering is experiencing resistance in some markets.

Time-of-Use Metering and Smart Meters

Time-of-use (TOU) metering refers to a metering arrangement where customers pay differential electric rates based on the time of day that they are consuming electricity. Whereas the flat rate for residences may be (for example) 8.5¢/kWh, the time-of-use your rate for peak energy use may be 14¢/kWh and 3¢/kWh for off-peak. The question is how to make time-of-use measurements while net metering. TOU metering requires an electronic pulse meter which is fundamentally different from standard spinning electro-mechanical meters, and these TOU meters typically do not record energy flows in both directions. There are two options for those who want to take advantage of both net metering and TOU metering. The first is to install a special electronic meter or smart meter that can measure energy flows in both directions and keep track of when those flows take place. While prices are decreasing, these meters can cost up to $300, and this would normally be an expense borne by the customer (assuming the utility allows you to have TOU metering with net metering). The other option – which was incorporated by New York state as part of its net metering rules – is to install a second meter (in addition to the TOU meter) that only measures net flows to the utility. This second meter, under the New York rules, is not a TOU meter, so the generation recorded on that second meter is allocated to the different rates based on expected distributed generation output. The simplest approach, which has been adopted in a few states, is to simply not allow net metering customers to operate under a time-of-use rate.

Electric utilities continually evaluate demand-side programs and create, modify or eliminate them as required to meet generation and transmission system needs, revenue needs, and customer needs. Demand-side programs, which were used to shave off 4.3 percent of peak demand during 2000 and reduce consumption by 0.4 percent, are declining in use by utilities. Any demand-side management arrangement must consider the investments that the utility companies have made in providing reliable power to customers 24 hours per day, 7 days per week, and their need to generate a profit. Both net metering and time-of-use metering must consider the needs and desires of the customer and the electrical provider. It is clear that there is great potential for further demand reduction through the application of existing technologies in today's markets.

PCAST recommends:

- That DOE and FERC produce a coordinated implementation plan for demand-side management of electricity that is based on uniform technology, secure communications protocols, and business practices.

REFERENCES:

U.S. Department of Energy, Office of Fossil Energy, Report DOE/FE-0400, *Market-based Advanced Coal Power Systems*, Final Report, May 1999, Washington, DC.

General Accounting Office, Report GAO-02-709, *Air Pollution: Emissions from Older Electricity Generating Units*, June 2002.

U.S. Department of Energy, *Clean Coal Technology, The Investment Pays Off:* A Report By The Assistant Secretary For Fossil Energy, November 1999.

U.S. Department of Energy, Office of Fossil Energy, *Vision 21 Program Plan: Clean Energy Plants for the 21st Century*, Federal Energy Technology Center, 1999.

U.S. Department of Energy, Office of Fossil Energy, *Vision 21 Technology Roadmap*, Federal Energy Technology Center, 1999.

California Energy Commission, PUB. NO. 400-02-005f, *Enhanced Automation: Technical Options Guidebook*, May, 2002.

Federal Energy Regulatory Commission, Office of Markets, Tariffs and Rates, *Demand Responsiveness in Electricity Markets*, January 15, 2001.

U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Consortium for Electric Reliability Technology Solutions: *Grid of the Future, Interconnection and Controls for Reliable, Large Scale Integration of Distributed Energy Resources*, Prepared for the Transmission Reliability Program, Office of Power Technologies, August 30, 1999.

U.S. Department of Energy, *National Transmission Grid Study*, May 2002.

U.S. Department of Energy, National Renewable Energy Laboratory, *Institutional Plan 2001 – 2005*.