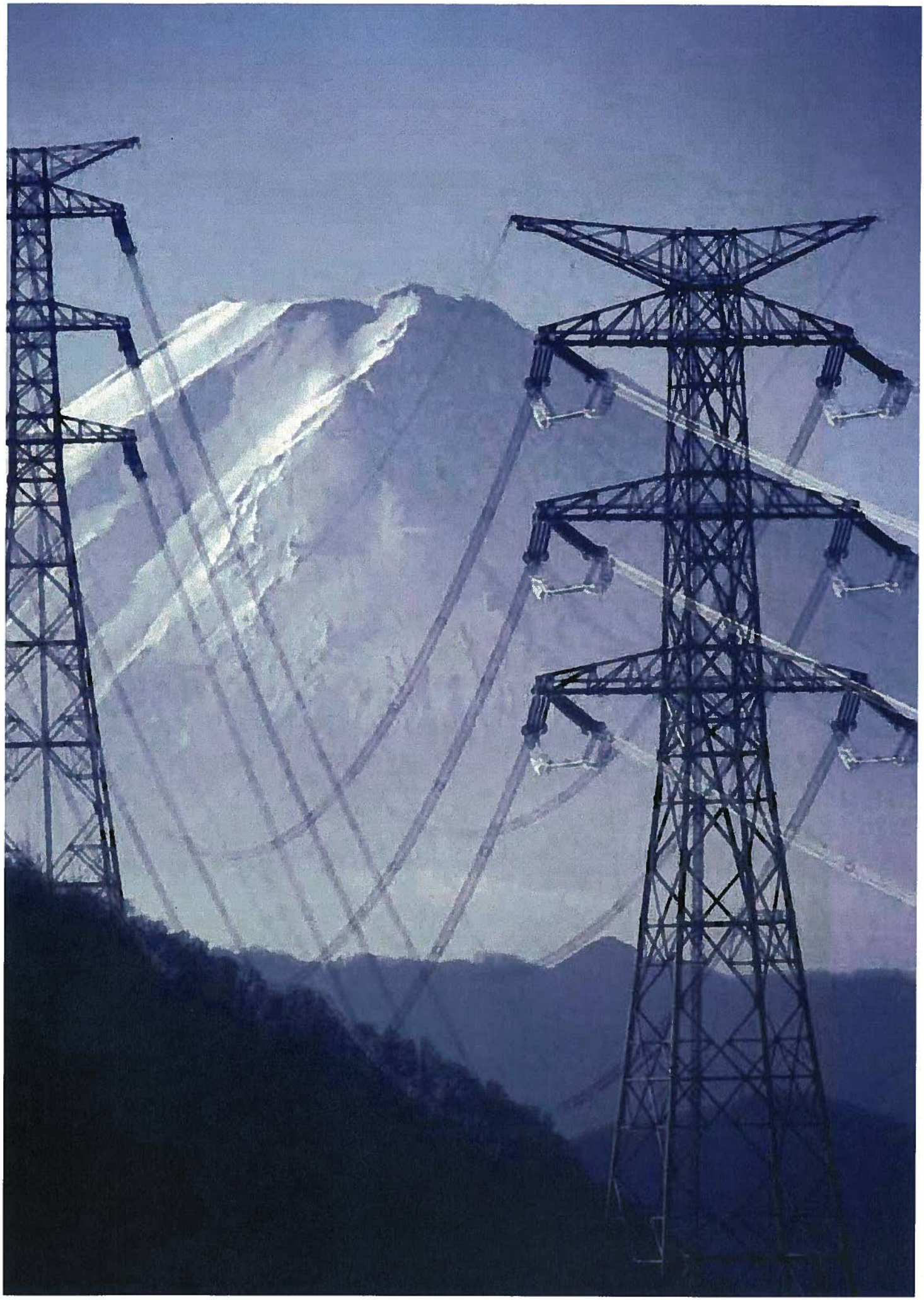
EFFICIENT ELECTRICAL ENERGY TRANSMISSION AND DISTRIBUTION

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

NMED-SAHU
EXHIBIT 4



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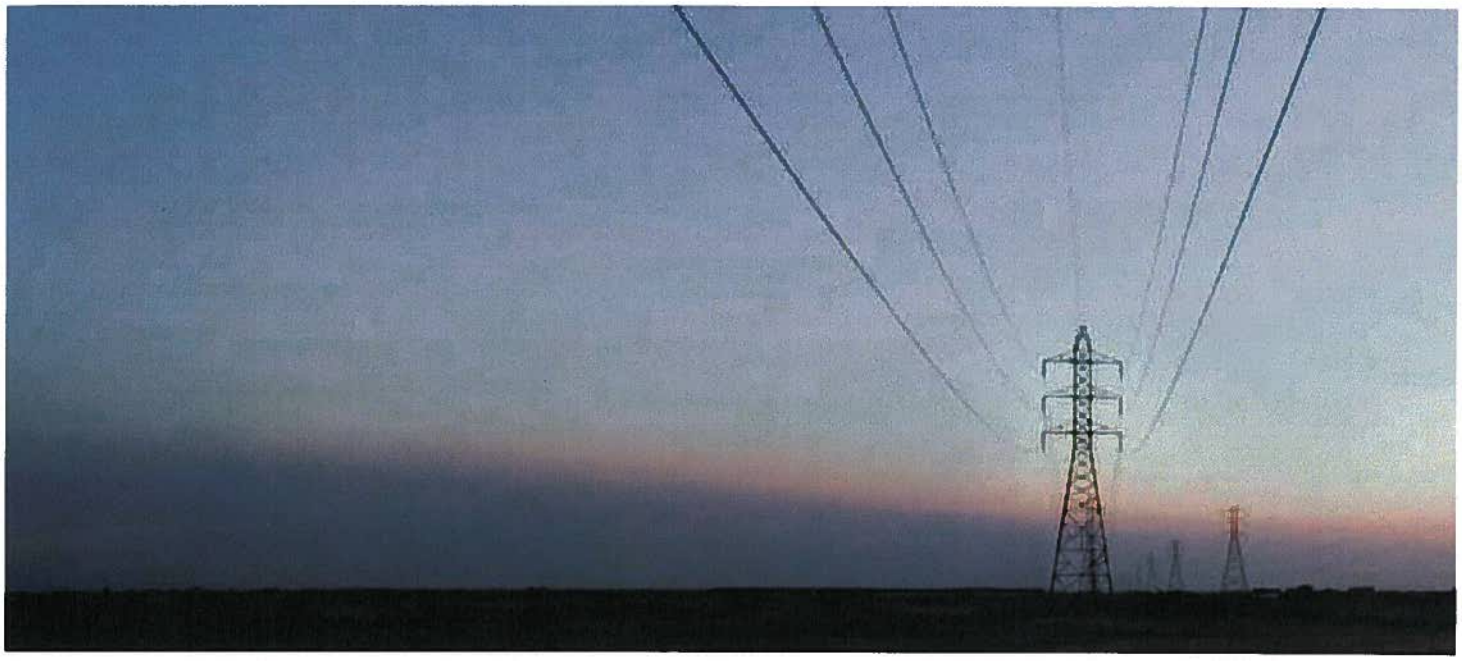


EFFICIENT ELECTRICAL ENERGY TRANSMISSION AND DISTRIBUTION

Growing populations and industrializing countries create huge needs for electrical energy. Unfortunately, electricity is not always used in the same place that it is produced, meaning long-distance transmission lines and distribution systems are necessary. But transmitting electricity over distance and via networks involves energy loss.

So, with growing demand comes the need to minimize this loss to achieve two main goals: reduce resource consumption while delivering more power to users. Reducing consumption can be done in at least two ways: deliver electrical energy more efficiently and change consumer habits.

Transmission and distribution of electrical energy require cables and power transformers, which create three types of energy loss:

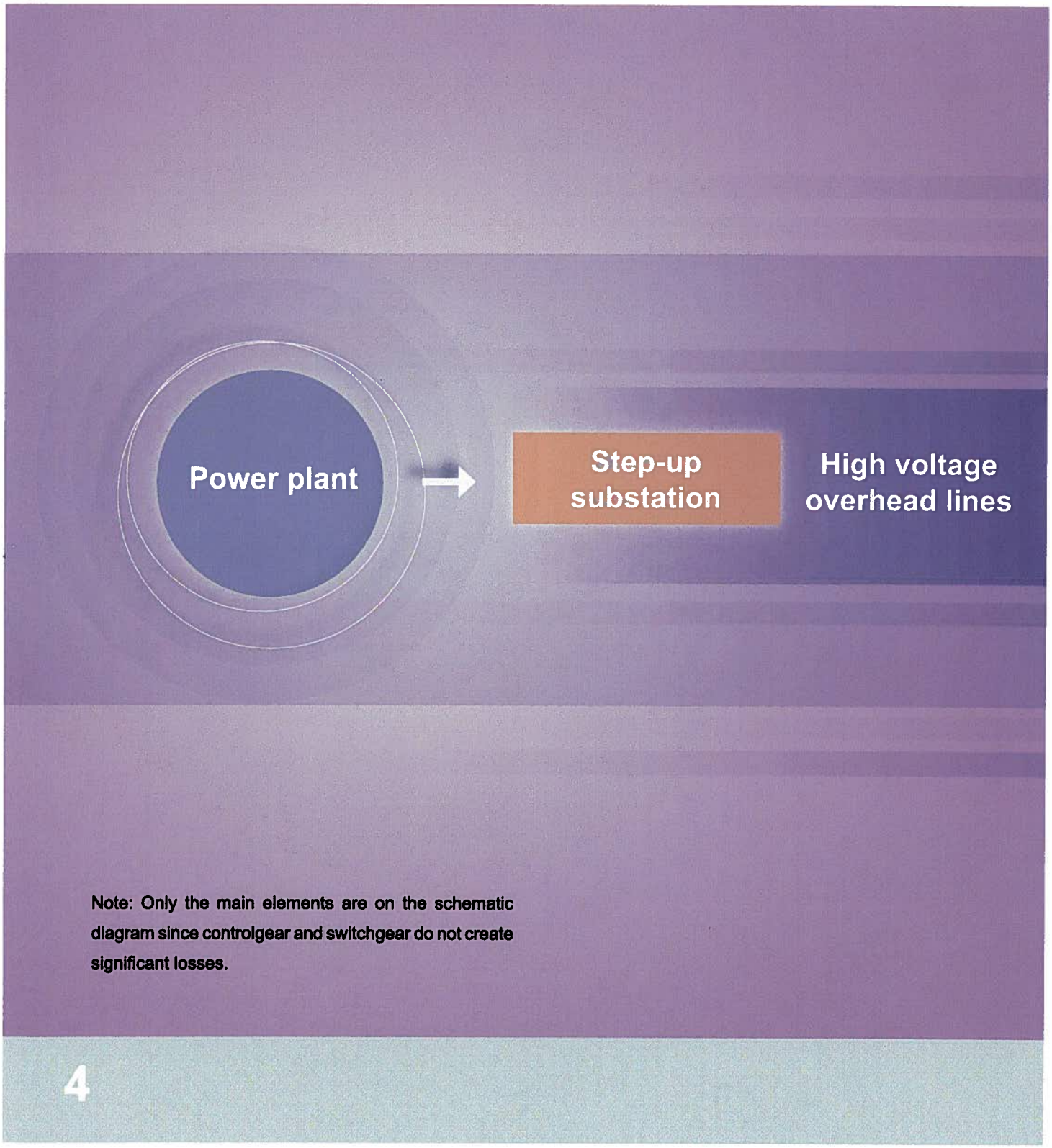
- the Joule effect, where energy is lost as heat in the conductor (a copper wire, for example);
- magnetic losses, where energy dissipates into a magnetic field;
- the dielectric effect, where energy is absorbed in the insulating material.

The Joule effect in transmission cables accounts for losses of about 2.5 % while the losses in transformers range between 1 % and 2 % (depending on the type and ratings of the transformer). So, saving just 1 % on the electrical energy produced by a power plant of 1 000 megawatts means transmitting 10 MW more to consumers, which is far from negligible: with the same energy we can supply 1 000 - 2 000 more homes.

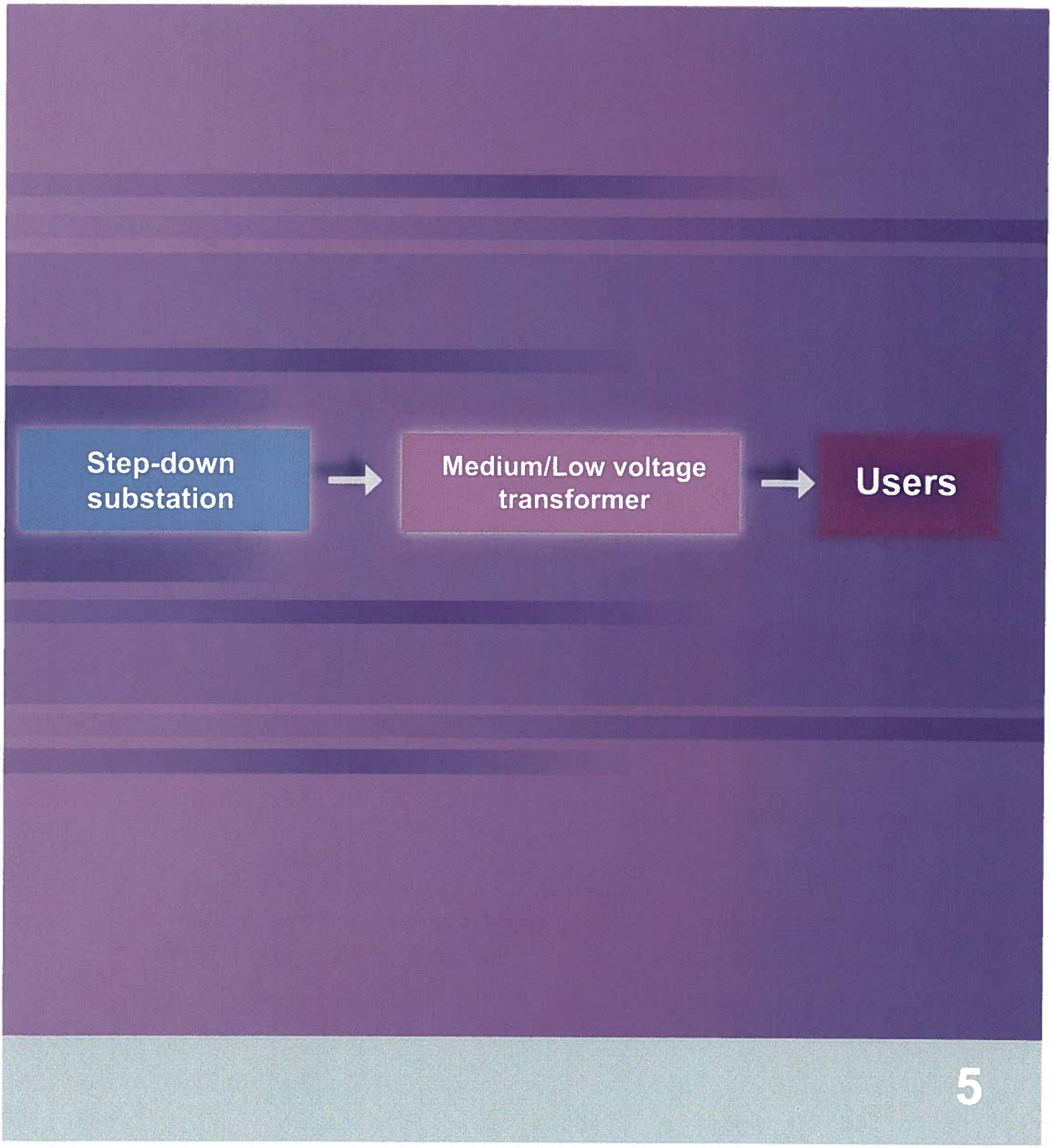
Changing consumer habits involves awareness-raising programmes, often undertaken by governments or activist groups. Simple things, such as turning off lights in unoccupied rooms, or switching off the television at night (not just putting it into standby mode), or setting tasks such as laundry for non-peak hours are but a few examples among the myriad of possibilities.

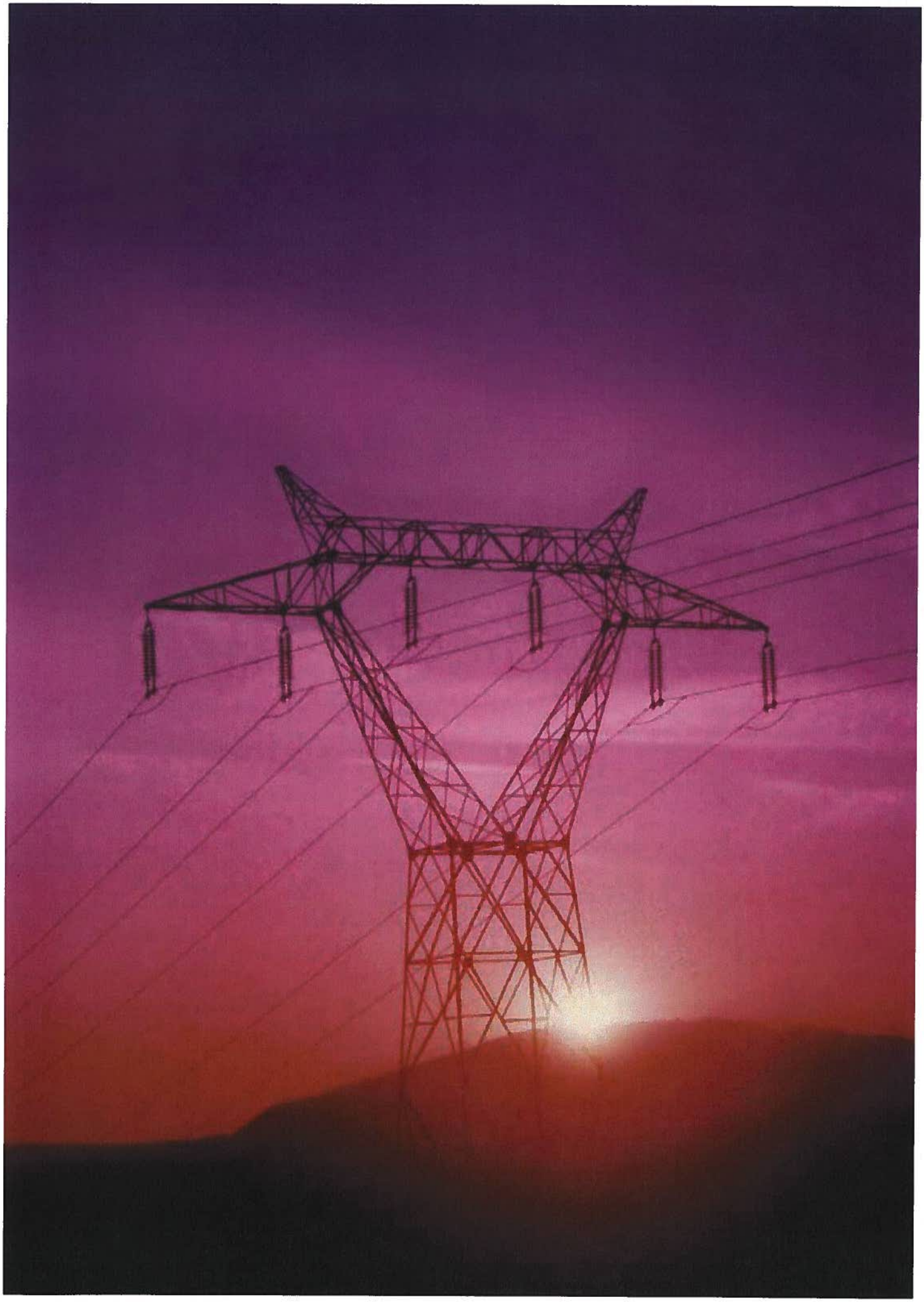
On the energy production side, building more efficient transmission and distribution systems is another way to go about it. High efficiency transformers, superconducting transformers and high temperature superconductors are new technologies which promise much in terms of electrical energy efficiency and at the same time, new techniques are being studied. These include direct current and ultra high voltage transmission in both alternating current and direct current modes.

OUTLINE OF AN ELECTRICAL TRANSMISSION/DISTRIBUTION SYSTEM



Note: Only the main elements are on the schematic diagram since controlgear and switchgear do not create significant losses.


Step-down substation
Medium/Low voltage transformer
Users



ELECTRICAL LOSSES AND OVERALL EFFICIENCY

A power plant produces electrical energy in medium (20 000 V) or low (1 000 V) voltage which is then elevated to high voltage (up to 400 kV) by a step-up substation. Electrical power is then transmitted across long distances by high-tension power lines, and the higher the voltage, the more power can be transmitted. A step-down substation converts the high voltage back down to medium voltage and electrical power can then be transported by medium voltage lines to feed medium and low voltage transformers using overhead lines or underground cables. Most of the users are fed in low voltage, but bigger ones, such as factories, commercial buildings, hospitals and so forth, can be directly fed in medium voltage.

The length of cables between a power plant and a step-up substation is short since they are usually installed in the same place, so the energy losses there are quite low. The situation is not the same between the step-down substation and users where kilometres of medium and low voltage cables must be erected or buried to reach them.

Energy losses essentially come about in transformers and cables. The efficiency of large power transformers in step-up and step-down substations is quite high and may reach 99 %, but this depends mostly on the real power delivered, compared with the maximum power it could in principle deliver. A transformer operating at power close to the assigned value has the best efficiency. Medium and low voltage transformers are of different types and their efficiency may range between 90 % and 98 %, again depending on the power delivered.

For cables it's the contrary. Those carrying high current sustain more heating and therefore endure more energy loss because of the Joule effect, which is an increase in heat resulting from current flowing through a conductor. Essentially, electrical current passing through a conductor raises its temperature and this heat bleeds away as lost energy. This raises design considerations for overhead lines for long distance transmission cables and underground ones which deliver energy from the step-down substation to the user.

Electricity supply companies generally try to limit energy losses in overhead lines to about 2.5 %. So, between the power plant and the step-down substation the total losses range between 3 % and 5 %. Between the step-down substation and users the losses can be about the same or even greater. Therefore the overall losses between the power plant and users can easily be between 8 % and 15 %, which suggests that there is still some room to improve efficiency in the transmission/distribution system and hence reduce CO_2 emissions.

RELEVANT IEC TECHNICAL COMMITTEES

IEC Technical Committees work in a variety of associated fields, with the list including:

- TC 7 Overhead electrical conductors
- TC 8 System aspects for electrical energy supply
- TC 10 Fluids for electrotechnical applications
- TC 11 Overhead lines
- TC 13 Electrical energy measurement, tariff and load-control
- TC 14 Power transformers
- TC 17 Switchgear and controlgear
- TC 20 Electric cables
- SC 22F Power electronics for electrical transmission and distribution systems
- TC 42 High-voltage testing techniques
- TC 55 Winding wires
- TC 68 Magnetic alloys and steels
- TC 90 Superconductivity
- TC 112 Evaluation and qualification of electrical insulating materials and systems

In addition, TC 113, *Nanotechnology standardization for electrical and electronic products and systems*, involves the IEC in a very promising area that could see important breakthroughs across a broad range of technological fields, including insulation and conductivity.

IEC STANDARDS AVAILABLE

Although the following list is not exhaustive, it does give a good idea of the broad range of subjects the IEC addresses when dealing with efficiency for electricity transmission and distribution:

- **IEC 60076** series for liquid immersed or dry power transformers covering ratings, test methods, measuring methods for losses, loading guides, and so forth.
- **IEC 61378** series on converter transformers.
- **IEC 61803**, Determination of power losses in HV direct current converter stations.
- **IEC 60183**, Guide to the selection of high-voltage cables.
- **IEC 60287** series for calculating the current rating and losses for electric cables.
- **IEC 60885** series on electrical test methods for electric cables.
- **IEC 61788** series on superconductivity.
- **IEC 60028**, International standard of resistance for copper
- **IEC 61039**, General classification of insulating liquids
- **IEC 61181**, Mineral oil-filled electrical equipment - Application of dissolved gas analysis (DGA) to factory tests on electrical equipment
- **IEC 61620**, Insulating liquids - Determination of the dielectric dissipation factor by measurement of the conductance and capacitance - Test method
- **IEC 60826**, Design criteria of overhead transmission lines
- **IEC 62052** series on general requirements, tests and test conditions for electricity metering equipment (AC)

- **IEC 62056** series on electricity metering - data exchange for meter reading, tariff and load control
- **IEC 62271** series on high-voltage switchgear and controlgear
- **IEC 60060** series on high-voltage test techniques
- **IEC 60317** series on specifications for particular types of winding wires
- **IEC 60404** series on magnetic materials
- **IEC 60505**, Evaluation and qualification of electrical insulation systems
- **IEC 60243** series on test methods for electrical strength of insulating materials

TECHNOLOGIES WITH POTENTIAL

High efficiency transformers, superconducting transformers and high temperature superconductors are technologies that promise much in terms of electrical energy efficiency.

High efficiency transformers

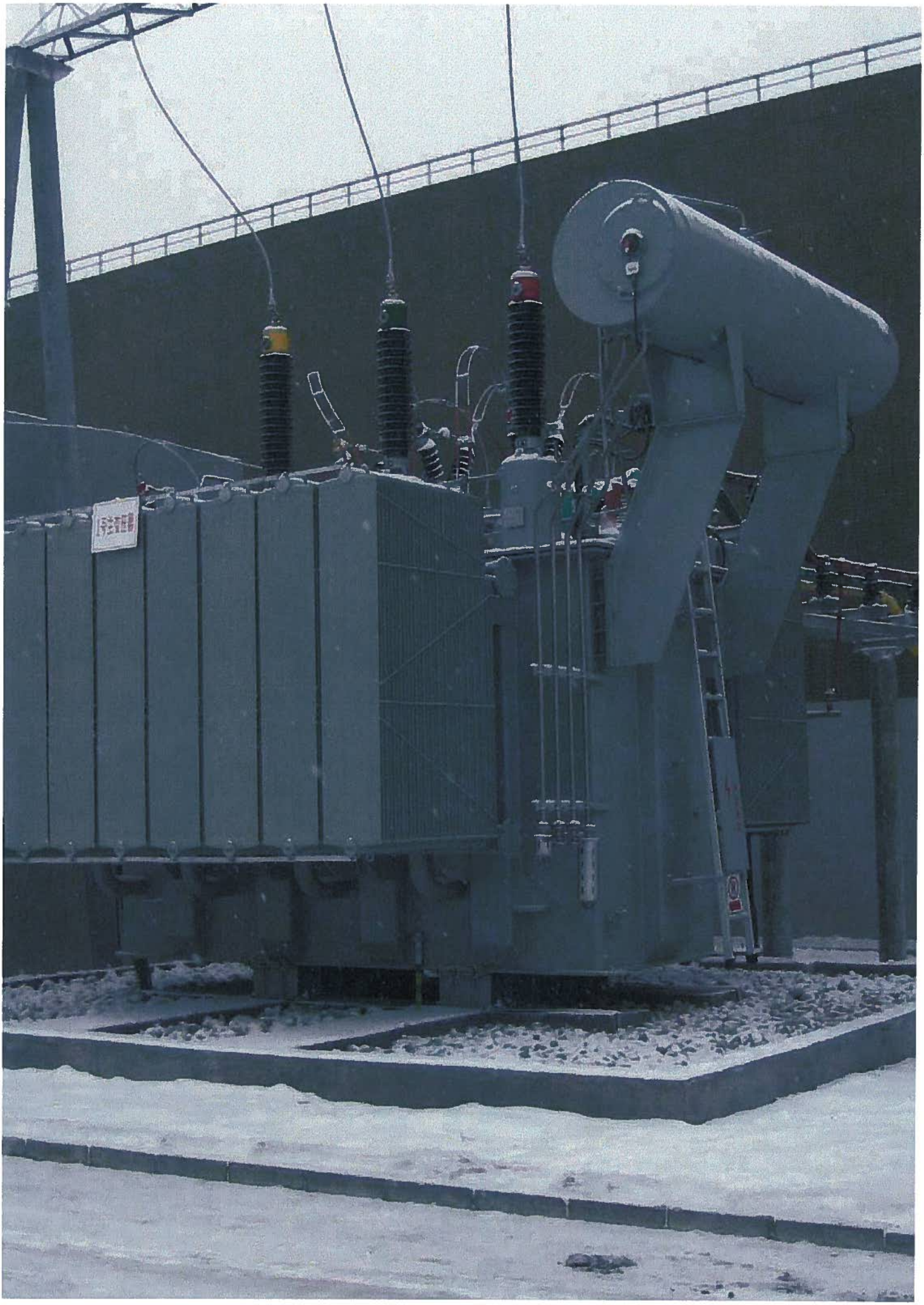
According to the Leonardo ENERGY website, which is the global community for sustainable energy professionals: "The worldwide electricity savings' potential of switching to high efficiency transformers is estimated to be 200 TWh. This savings potential is not only technically advantageous, but also brings economic and environmental benefits. Taking the full life cycle cost into account, selecting high efficiency transformers is often an economically sound investment decision despite their higher purchase price."

High efficiency transformers have been around for decades. But because their prices are greater than for ordinary transformers, buyers should estimate the energy savings which can be made during the life cycle of a transformer and then choose the most appropriate one. These transformers differ from ordinary ones in that they use high quality magnetic material and selected insulating substances and are designed in such a way that they can be cooled down better.

Regulators may also require using certain kinds of transformers within the context of the Kyoto Protocol.

Superconductivity

Most conductors have some degree of resistance which prevents electricity from flowing effortlessly. Superconductors are materials that have no resistance to the flow of electricity and mostly this occurs at extremely cold temperatures. The first occurrence, in 1911, was in a material which became superconducting at 4 degrees Kelvin (-269° Celsius / -452° Fahrenheit). By the 1950s with the discovery of new materials this had risen to 17.5° K and in the 1980s to 92° K, which is warmer than



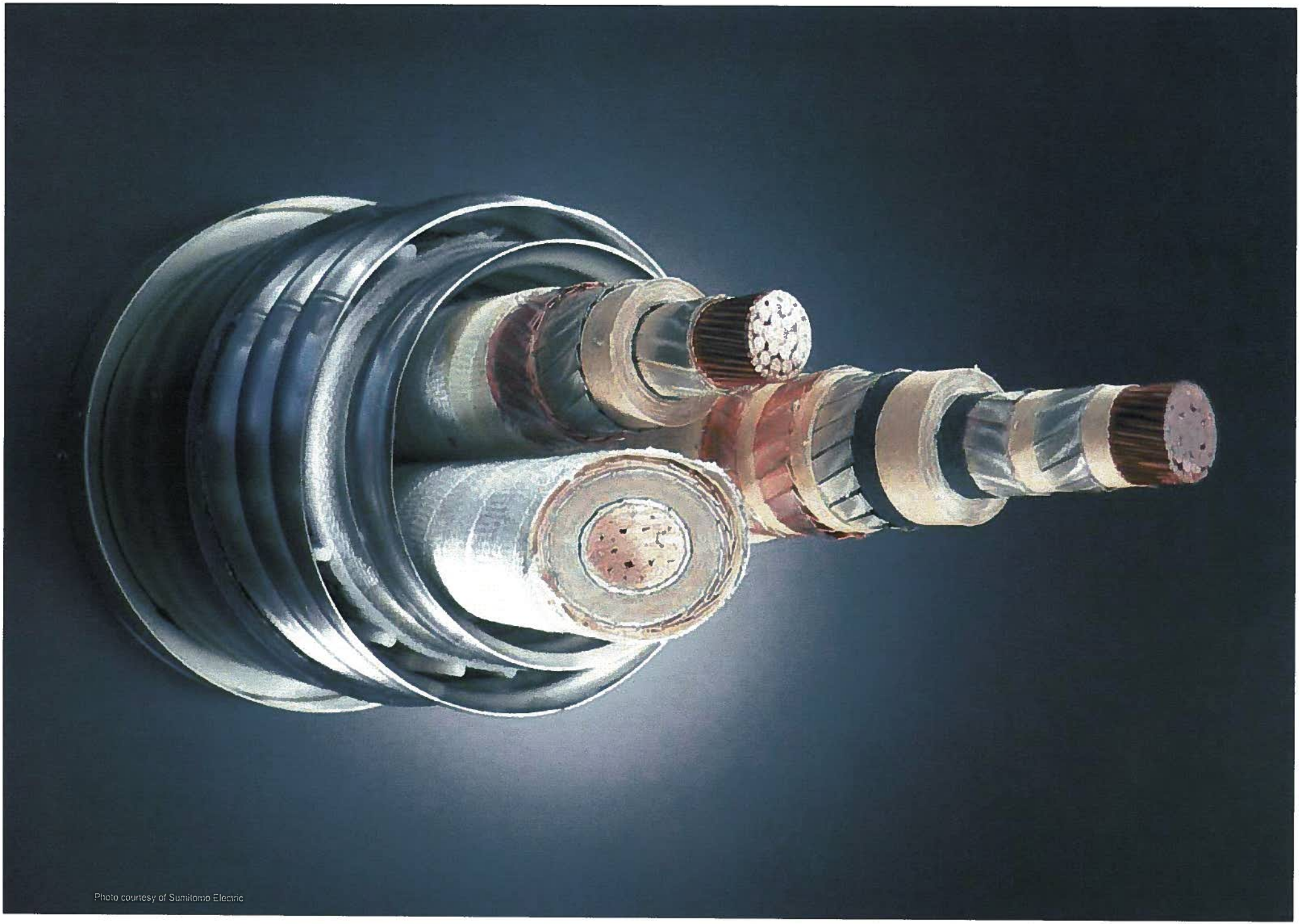


Photo courtesy of Sumitomo Electric

liquid nitrogen – a commonly available coolant. Today, superconductivity is happening at 138° K, but that's still -135° C (or -211° F). Despite the apparent coldness, this is known as high temperature superconducting, or HTS, and it holds a lot of potential for being energy efficient in the future.

Superconducting transformers

When a transformer is under a loaded condition, Joule heating of the copper coil adds considerably to the amount of lost energy. Although today's utility power transformers lose less than 1 % of their total rating in wasted energy, any energy saved within this 1 % represents tremendous potential savings over the expected lifetime of the transformer as they can be in service for decades.

We are all used to seeing copper and aluminium electrical wires and cables, which conduct electricity at ambient temperatures but lose energy due to the Joule effect. With superconductors, losses due to the Joule effect become essentially zero, thereby creating the potential for dramatic reduction in overall losses. Even with the added cost of making them cold enough for superconducting, transformers in the 10 MW and higher range are projected to be substantially more efficient and less expensive than their conventional counterparts.

High temperature superconducting cables

Superconducting cables offer the advantage of lower loss, lighter weight, and more compact dimensions, as compared to conventional cables. In addition to better energy efficiency of the utility grid, this can lead to easier and faster installation of the cable system, fewer linking parts, and reduced use of land. The high performance of superconducting materials leads to reduced materials use and lighter and more compact cable technology. In this way, energy and cost are saved in the whole chain of manufacturing, transport, installation, use and end-of-life disposal.

In the shorter term, these HTS cables offer energy efficiency, cheaper installation, and lower system cost. The long-term perspectives include low-loss backbone structures that transmit electric power over long distances. The driving factors for such backbone structures are:

- uninhibited exchange of electricity in interconnected networks;
- solar energy potential in North Africa;
- green energy (hydroelectric and wind) in northern Europe.

HTS cable backbones, which do not yet exist, would be designed as DC systems with power ratings in multiples of gigawatts. They can be created as "virtual backbones" joining and reinforcing existing networks, or as actual lines traversing continents.

HTS backbones will be an alternative or complement to gas and oil pipelines, oil tankers and overland transport of hydrogen or other energy types. The determining factors for them, apart from cost, are political stability within the connected regions, ownership and tariff structures.

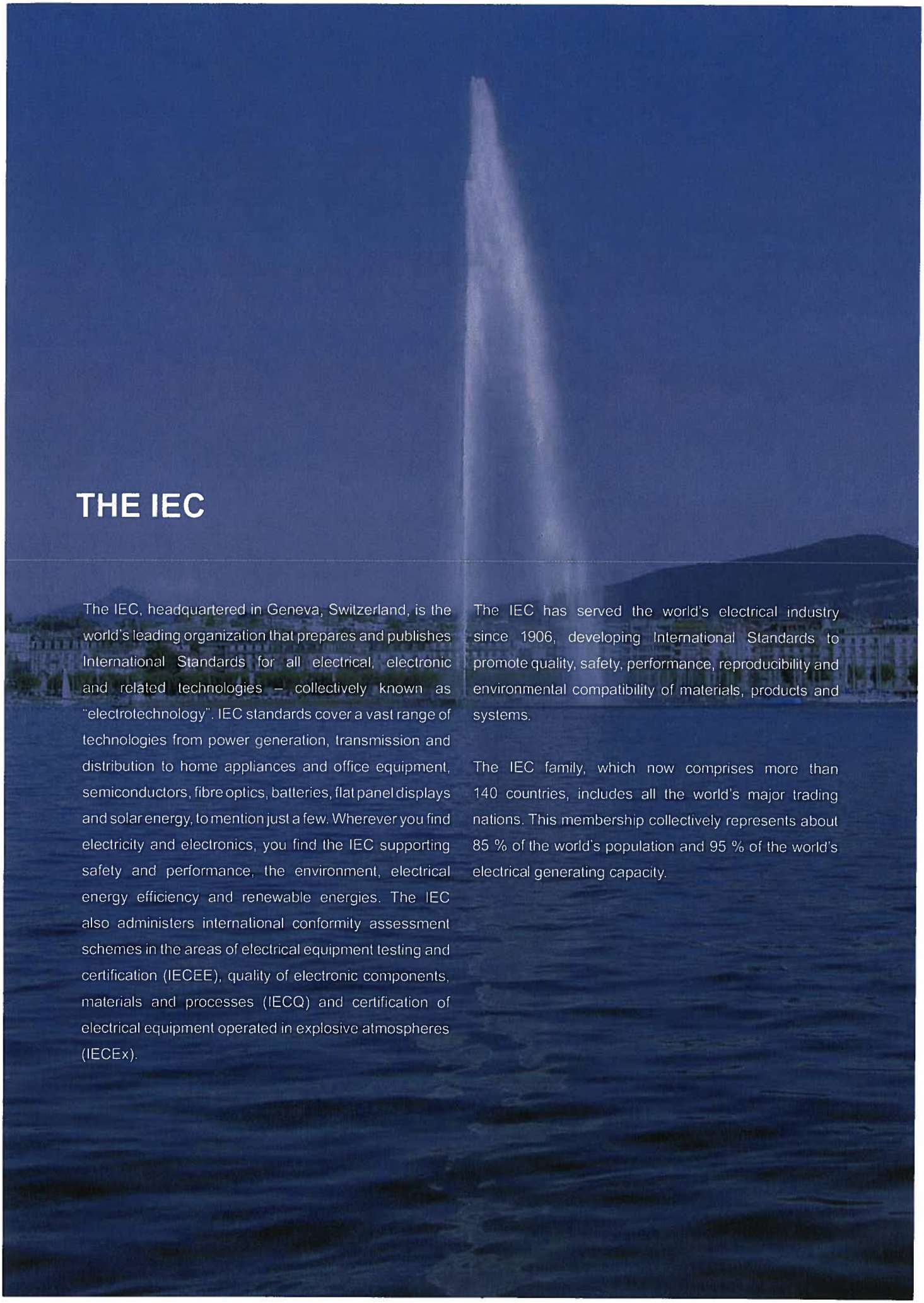
The IEC committees where these technologies are being considered are TC 14, *Power transformers*, TC 20, *Electric cables*, and TC 90, *Superconductivity*.

Other transmission techniques are also being studied, such as direct current and ultra high voltage in both alternating current and direct current modes.

CONCLUSION

The IEC has been developing standards that deal with electrical efficiency since its creation in 1906. As an example, at a meeting held in Paris in 1932, IEC Advisory Committee No. 2 (as the TCs were then known), which at that time covered the entire field of electrical machinery, decided to set up a permanent subcommittee to consider the issue of "efficiency and losses". Technical Committee 2, Rotating machinery, and TC 14, Power transformers, today continue that work by delivering the highest quality International Standards involving the best means of producing and providing electrical energy efficiently.

Overall, IEC work addresses a vast array of technologies. Standardizing the transmission and distribution of electricity is one of the fields where the IEC can really make a difference to the future of the world in its quest for greater energy efficiency.



THE IEC

The IEC, headquartered in Geneva, Switzerland, is the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies – collectively known as "electrotechnology". IEC standards cover a vast range of technologies from power generation, transmission and distribution to home appliances and office equipment, semiconductors, fibre optics, batteries, flat panel displays and solar energy, to mention just a few. Wherever you find electricity and electronics, you find the IEC supporting safety and performance, the environment, electrical energy efficiency and renewable energies. The IEC also administers international conformity assessment schemes in the areas of electrical equipment testing and certification (IECEE), quality of electronic components, materials and processes (IECQ) and certification of electrical equipment operated in explosive atmospheres (IECEx).

The IEC has served the world's electrical industry since 1906, developing International Standards to promote quality, safety, performance, reproducibility and environmental compatibility of materials, products and systems.

The IEC family, which now comprises more than 140 countries, includes all the world's major trading nations. This membership collectively represents about 85 % of the world's population and 95 % of the world's electrical generating capacity.

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

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

AUGUST 2006

U.S. Department of Energy

NMED-SAHU
EXHIBIT 5

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APPENDIX A. TECHNOLOGY CROSSWALK A-1

APPENDIX B. ENERGY POLICY ACT OF 2005 TITLE IX, SUBTITLE B B-1

1.0 INTRODUCTION

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

1.1 Energy Policy Act of 2005

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

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

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

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

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

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

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

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

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

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

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

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

1.2 Administration Guidance

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

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

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

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

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

1.3 Stakeholder Consultations

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

- Utilities

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

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

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

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

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

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

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

1.4 Federal Role

With the advent of more openly competitive markets for electric power, particularly at the wholesale level, utilities have the incentive to seek locally-optimized solutions which may not lead to the safety, security, and reliability needed regionally or nationally. Through

collaborative research and development, DOE can facilitate the adoption of advanced technologies, tools, and techniques that address both local and national needs.

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

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

1.5 Potential Benefits

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

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

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

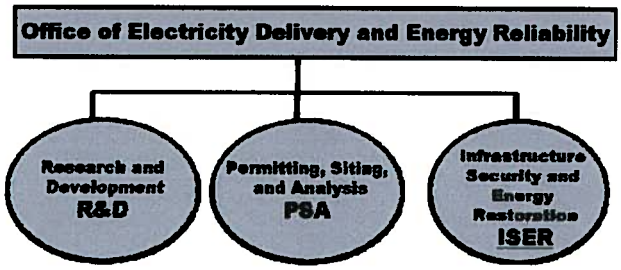
- Strengthen grid stability and reduce the frequency and duration of operational disturbances
- Increase efficiency of the electric delivery system through reduced energy losses
- Reduce peak demands and electricity price volatility

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

2.0 PROGRAM MANAGEMENT

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

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



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

2.1 OE Mission and DOE Goals

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

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

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

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

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

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

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

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

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

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

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

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

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

2.3 R&D Priorities

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

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

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

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

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

2.4 R&D Partnerships

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

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

University centers and national laboratories will also continue to play a critical role. In fact, EPACT Section 925 (f) calls for the "...use of a geographically distributed center, consisting of institutions of higher education and national Laboratories..." to be involved in

research, development, demonstration, modeling and analysis, and technology transfer activities outlined in this plan. OE currently works with several universities and national laboratories in conducting research, development, demonstration, analysis, and technology transfer activities.

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

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

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

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

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

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

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

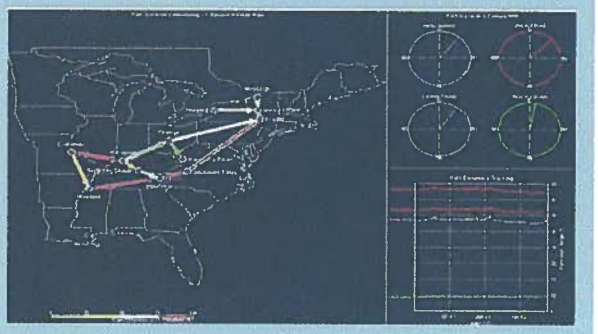
- Technology transfer and education

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

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

Phasor Measurement Projects

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



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

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

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

- connectivity with the internet

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

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

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

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

3.2 Long-Term Goal

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

3.3 Key Technical Challenges

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

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

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

3.4 Fiscal Year 2007 Baseline Activities

Activities in the Fiscal Year 2007 budget request include:

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

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

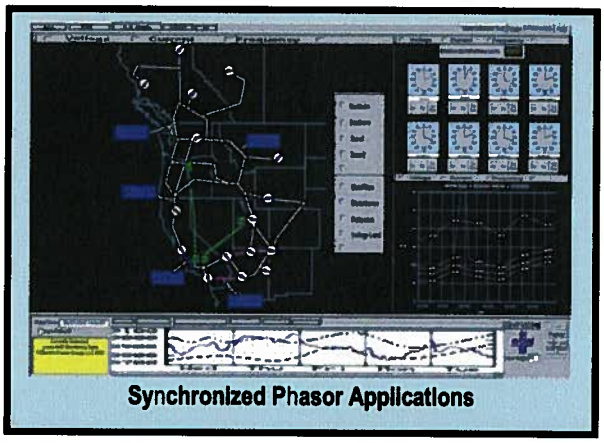
The technology development activities for improving electric transmission and distribution planning and operations include:

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

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

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

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


Synchronized Phasor Applications

The technical objective for the activities under system monitoring is to develop by 2014 a family of specific tools and techniques for grid operators to strengthen state estimation capabilities and improve analysis of system dynamics. There will be an annual internal assessment, validated every other year by independent peer review, toward the development of specific tools and techniques. One activity will be the development of a tool for dynamic security by 2009 that will enable real-time assessment of voltage levels. Subsequent activities will involve the development of grid stability alarm systems by 2010 that will enable analysis of characteristic power oscillations; and development of a

contingency evaluation tool by 2011 that will enable analysis of the ability of the system to withstand contingencies. If these activities are successfully implemented, this effort will culminate in the development of a set of system protection and control tools for automatic system reconfiguration by 2014 that will enable reactive power control, interruptible load management, and adaptive islanding. In the long run, it may become possible to merge this set of tools into a single suite of solutions based on real-time, large-scale, transient simulations.

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

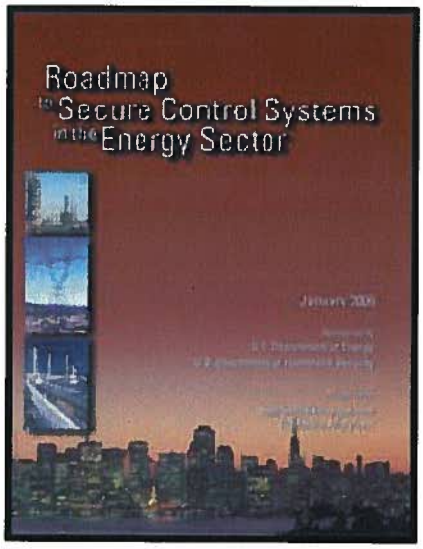
Control Room Displays

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

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

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

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



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

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

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

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

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

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

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

3.6 Linkages to Other Programs and Activities

The successful development and deployment of advanced electric generation systems (e.g., fossil, nuclear, and renewable) will require electric transmission systems for access to markets, particularly when these generation facilities are located far from load centers. One of the lessons from the August 14, 2003, regional blackout involved the operational difficulties encountered in accomplishing orderly and error-free shutdown and restart of the nuclear power plants that were taken off line when the grid went down. More effective and

secure grid planning and operations technologies is an essential "enabler" of generation capacity expansions and the delivery of electricity from suppliers to consumers. Coordination on grid-related issues and activities will be accomplished with DOE's programs in fossil, nuclear, and renewable electricity generation.

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

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

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

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

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

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

4.0 High Temperature Superconductivity

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

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

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

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

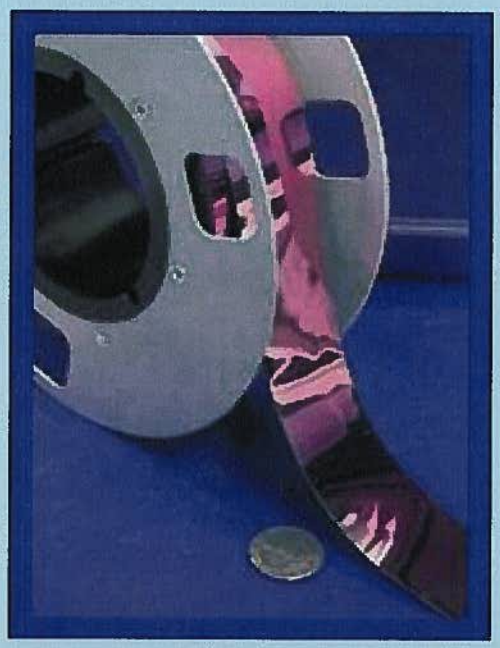
- Development of high temperature superconductors to enhance the reliability, operational flexibility, or power carrying capability of electric transmission or distribution systems; or increase the efficiency of electric energy generation, transmission, distribution, or storage systems
- Establishment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

4.1 Situational Analysis and Current Status of High Temperature Superconductivity

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

2nd Generation Superconducting Wire

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



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

centimeter of copper wire at or below the price-performance of copper ($/kiloamp-meters) in power grid applications.

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

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

4.2 Long-Term Goal

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

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

4.3 Key Technical Challenges

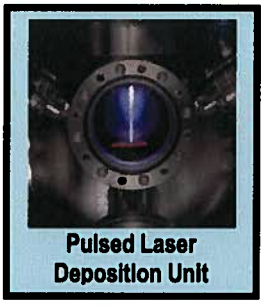
Achieving this long-term goal for HTS power applications requires 1) solving the difficult problem of manufacturing electrical wires from HTS materials – that require special processing before realizing their ability to carry large currents, and 2) designing super-efficient electrical systems that use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

Fault Current Limiter

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

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

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

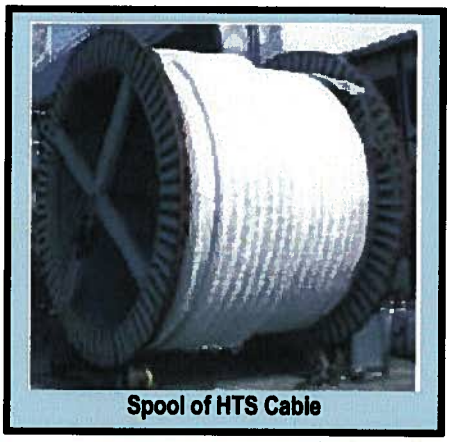

Pulsed Laser Deposition Unit

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

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

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

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


Spool of HTS Cable

4.4 Fiscal Year 2007 Baseline Activities

Activities in the Fiscal Year 2007 budget request include:

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

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

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

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

The technology development activities for high temperature superconductivity include:

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

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

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

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

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

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

Three-in-one HTS Cable System

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

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

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

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

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

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

HTS Refrigeration Subsystem

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

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

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

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

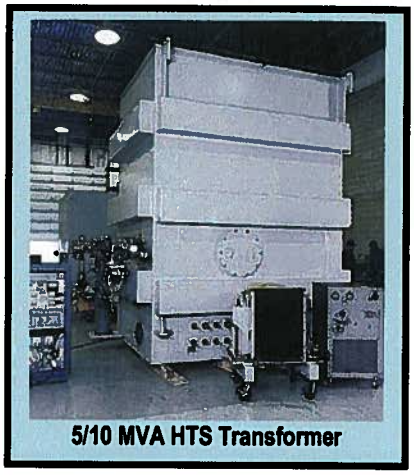
The technical objective for this activity is to develop by 2012 modeling and simulation tools that can benchmark how HTS components function in the grid. There will be an annual internal assessment, validated every other year by independent peer review, of the accuracy of the tools and their ability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

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

HTS Motor

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

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


5/10 MVA HTS Transformer

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

4.6 Linkages to Other Programs and Activities

DOE's Superconductivity Program facilitates the integration of industry, national laboratories, other agencies, and universities into a coherent, aggressive program of concurrently developed HTS technology development and system design and demonstration. The program works closely with electric utilities in order to realize the

potential benefits. The HTS program has a long history of successful industry participation and collaborative efforts. Private industry is involved in the planning, review, and research aspects of the program in order to develop as many HTS applications as possible. The program greatly leverages funding in order to accelerate the development of HTS electric power equipment.

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

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

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

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

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

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

5.0 DISTRIBUTED SYSTEMS INTEGRATION

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

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

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

5.1 Situation Analysis and Current Status of Distributed Systems Integration Technologies

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

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

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

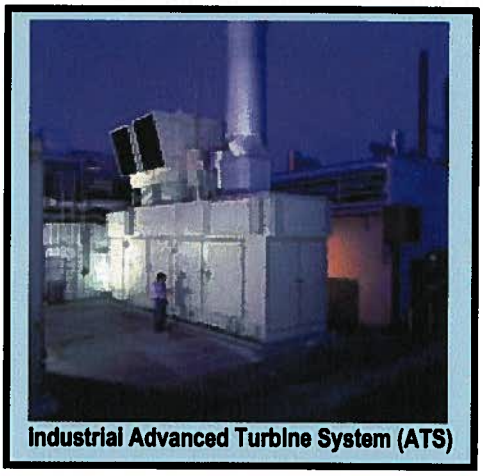
large combined heat and power units serving the pulp and paper and petrochemical industries.

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

Integrated Energy System

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

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



Industrial Advanced Turbine System (ATS)

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

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

5.2 Long-Term Goal

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

5.3 Key Technical Challenges

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

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

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

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

5.4 Fiscal Year 2007 Baseline Activities

Activities in the Fiscal Year 2007 budget request include:

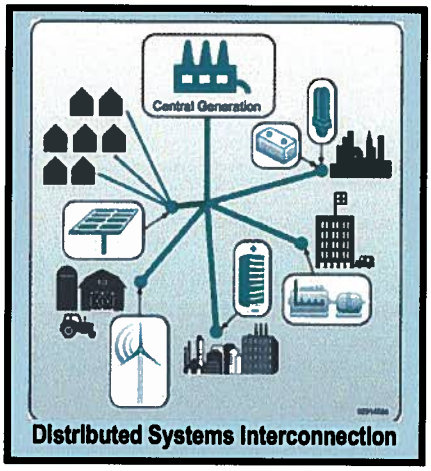
- Completion of research projects that have successfully improved the energy efficiency, costs, and environmental performance of a portfolio of distributed generation devices, including turbines, microturbines, and reciprocating engines
- Completion of advanced integrated energy system and combined heat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

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

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

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

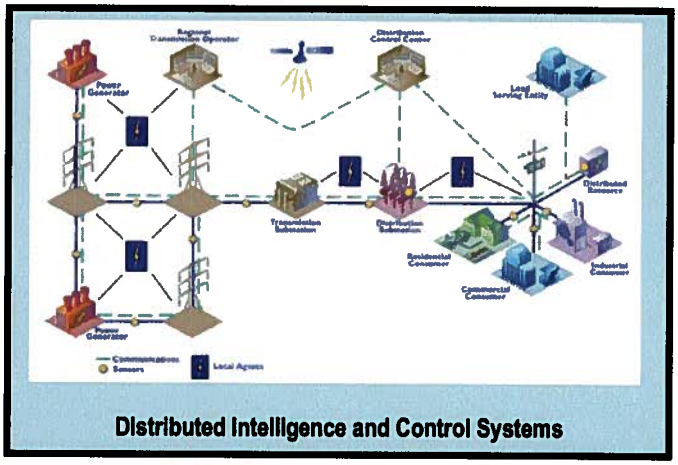
Distributed systems integration projects will be one of the key activities for addressing technology readiness and market acceptance issues for distributed systems and providing quantitative data on costs, benefits, business models, utility system impacts, and consumer impacts. The integrated demonstration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



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

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

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

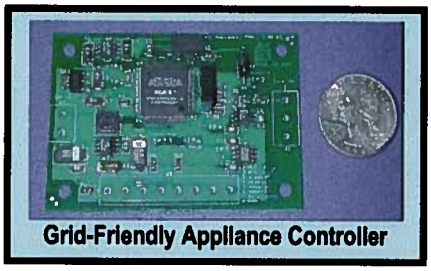

Distributed Intelligence and Control Systems

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

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

and performance within the context of specific operational strategies; and development of components, platforms, and prototypes to support a wider array of potential applications.

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


Grid-Friendly Appliance Controller

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

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

The technical objective for the activities under enabling technologies for load monitoring and load management is to develop by 2012 data acquisition and two-way communication systems with greater functionality for successfully empowering load management by both the utilities and consumers to serve their respective needs. There will be an annual internal assessment, validated every other year by independent peer review, of the costs of load

monitoring and load management systems that are competitive with today's systems. The initial activity will be an assessment of baseline costs. Subsequent activities will assess the yearly progression toward the achievement of reduction in cost.

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

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

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

Lithium Ion Battery Storage System

experience to verify technical performance and validate their ability to address "real-world" utility problems. Further progress is needed on flywheel systems to develop more durable and reliable systems and verify safety and performance.

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

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

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

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

5.6 Linkages to Other Programs and Activities

Development and demonstration of distributed system integration involve technologies, tools, and techniques that seamlessly integrate distributed energy and demand response into grid planning and operations. Coordination of activities will be needed with the research, development, and demonstration program activities, including those of: DOE's Office of Energy Efficiency and Renewable Energy that address residential and commercial buildings, industrial facilities and manufacturing plants, and transportation systems; state agencies such as the California Energy Commission and the New York State Energy Research and Development Authority; and utility research and development entities such as the Electric Power Research Institute. Organizations that represent utility companies

(e.g., the Edison Electric Institute, National Rural Electric Cooperative Association, and the American Public Power Association) and state agencies (e.g., National Association of Regulatory Utility Commissioners, National Council of State Legislatures, and National Association of State Energy Officials) will be important stakeholders in program activities, as will utility companies, national laboratories, trade groups (e.g., U.S. Combined Heat and Power Association and the GridWise Alliance), equipment manufacturers, and universities.

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

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

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

6.0 Power Electronics and Enabling Materials

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

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

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

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

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

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

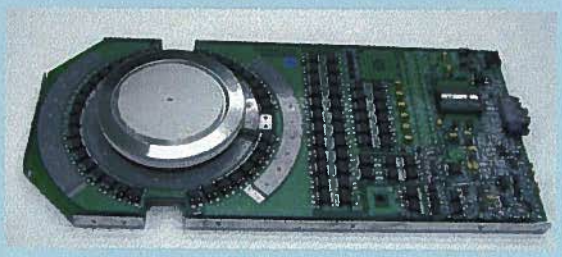
Substantial investment (public and private) in power electronics for transportation systems, consumer products, and industrial and military applications has occurred and continues today. Much less investment, however, has gone into power electronics for utility-scale applications. While size and weight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

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

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

High Power Converter

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

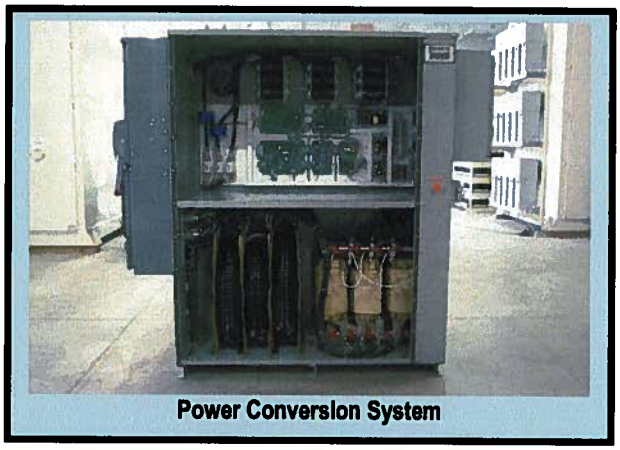


One of the most basic power system devices is the switch. A top priority technology need is the development of power electronics switches with the capability for high voltages, high currents, low losses, and high speeds, with little or no cooling requirements, and a favorable cost-to-value relationship. New approaches and materials (silicon carbide or diamond) that are not used today in power electronics are needed to achieve these aims. Working in the

high-voltage, high-current domain requires research in the fundamental properties of advanced materials. Industry is interested in working with Government to explore new materials that "go beyond silicon." Diamonds and silicon-carbide are promising materials for use in power electronics.

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

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


Power Conversion System

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

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

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

Advanced Flywheel Storage System

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

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

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

6.2 Long-Term Goal

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

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

6.3 Key Technical Challenges

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

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

6.4 Fiscal Year 2007 Baseline Activities

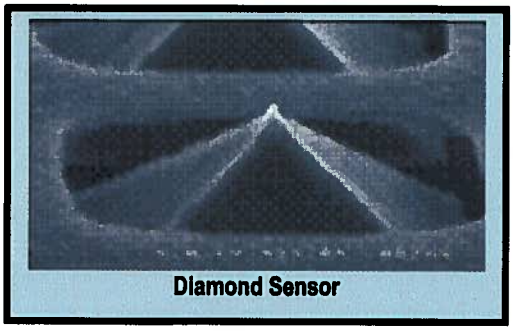
Activities in the Fiscal Year 2007 budget request include:

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

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

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

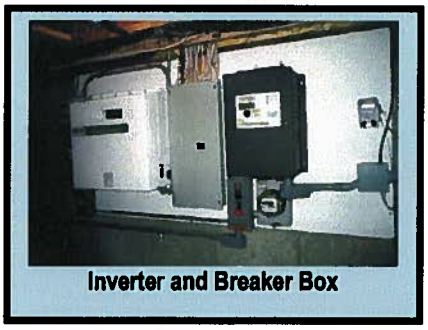
- **New materials** for higher voltage, current, frequency, and temperature


Diamond Sensor

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

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

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


Inverter and Breaker Box

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

The technical objective for the activities under new power electronics devices will be to have by 2012 advanced designs for cost-competitive switches that have substantially faster response times than conventional mechanical breakers. There will be an annual internal

assessment, validated every other year by independent peer review, of the response time. The baseline response time for mechanical breakers is 66 to 100 milli-seconds. The initial activity will involve development of electronic switches by 2010 that have response times of 5 milli-seconds, and 4 milli-seconds by 2012. If these milestones are successfully achieved, this activity could culminate in 1 milli-second response times by 2025.

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

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

6.6 Linkages to Other Programs and Activities

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

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

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

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

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

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

7.0 HIGH VOLTAGE TRANSMISSION

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

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

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

7.1 Situation Analysis and Current Status of High Voltage Technologies

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

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

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

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

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

7.2 Long-Term Goal

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

7.3 Key Technical Challenges

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

7.4 Fiscal Year 2007 Baseline Activities

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

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

The technology development activities for high voltage transmission lines include:

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

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

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

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

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

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

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

7.6 Linkages to Other Programs and Activities

Successful development, verification, and validation of power flow optimization through high voltage transmission involves new technologies, tools, and techniques and should be

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

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

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

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

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

8.0 High Power Density Industry Applications

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

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

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

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

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

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

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

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

At a time when thermal issues are actually disrupting product development plans, a number of innovative technologies are emerging at research labs and new business start-ups around the world that have potential to solve the problem of device and package-level cooling and thermal management. Whether for cell phones, laptops, servers, high-brightness LEDs, laser diodes, radio frequency components, micro-electric mechanical

systems, power semiconductors, or other similar applications, these new materials and technologies for active and passive cooling promise integral and cost-effective thermal management solutions.

8.2 Long-Term Goal

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

8.3 Key Technical Challenges

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

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

8.4 Fiscal Year 2007 Baseline Activities

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

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

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

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

Enhancing **performance of cooling technologies** is a key activity for integrating more energy efficient capabilities to reduce the electric demand of the facility. Fans and pumps are some of the largest users of energy in a data center and, as a result, it is critical that these and other technologies are carefully designed. The use of variable speed drives to allow for energy-efficient part-load operation should also be investigated. The electrical

consumption of the electronics inside server hardware is growing and activities should be centered on developing novel methodologies for reducing this load. Activities include integrating devices such as advanced chillers and desiccants and adjustable speed drives to optimize power consumption; and developing new server rack configurations that will increase rack cooling effectiveness and ultimately reduce electricity costs.

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

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

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

8.6 Linkages to Other Programs and Activities

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

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

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

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

9.0 MANAGING FOR RESULTS

The President's Management Agenda[9] says:

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

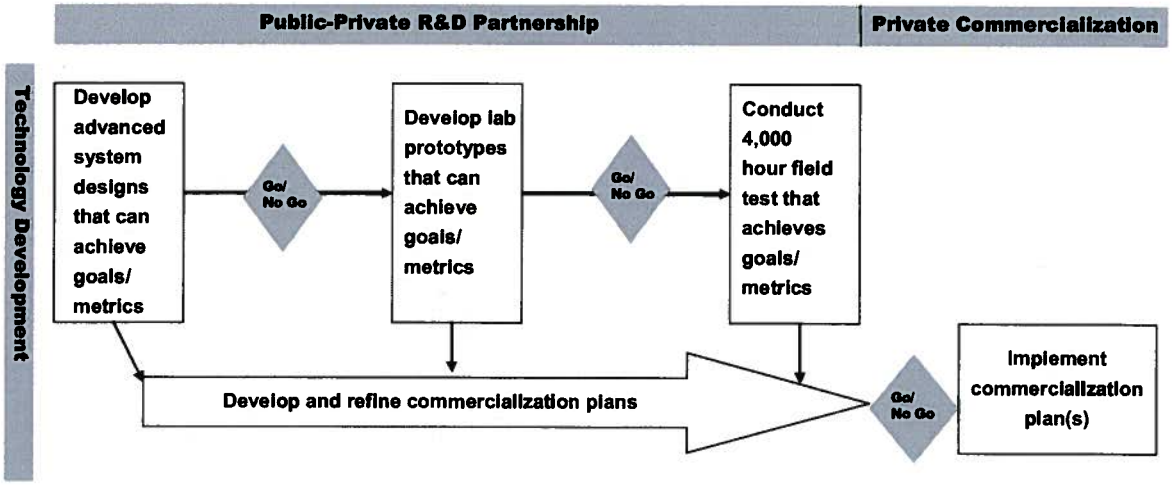
In pursuit of this goal, OE uses several techniques for managing its research, development, demonstration, and technology transfer activities. The activities outlined in this plan will include the following management practices:

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

9.1 Decision Making Processes and Analysis

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

Stage-Gate Decision Process



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

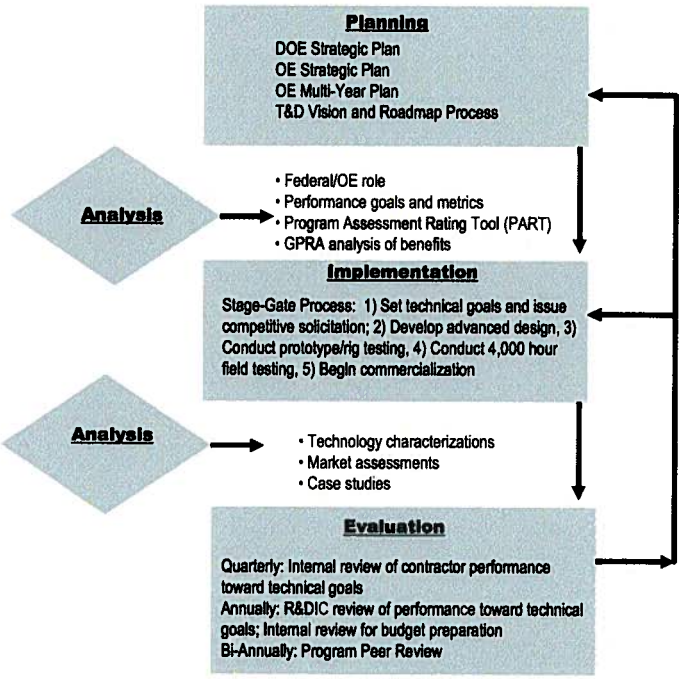
go" decision steps and down selections, build in corporate commitment to commercialization, and include systematic monitoring and evaluation of technical progress at each step of the way.

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

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

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

Role of Analysis in Planning, Implementation, and Evaluation



Decision making is based on analysis and the diagram to the right describes how analysis is integrated into program planning, implementation, and evaluation. One type of analysis is data development. These efforts are used build better baseline information about the current status of electric transmission and distribution system and the potential opportunities for "next generation" technologies to have an impact. Market assessments are used to evaluate potential

technology applications and commercialization strategies. Technology characterizations are used to develop baseline information on the costs and performance of today's technologies and to determine technology performance criteria for solicitations in the design and development of "next generation" systems. Benefits analysis provides information on the impacts of technology investments including reliability, system efficiency, and security.

9.2 Public-Private Partnerships

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

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

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

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

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

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

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

9.3 Peer Review

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

Recent peer reviews include:

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

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

9.4 Program Assessment

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

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

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

9.5 Portfolio Analysis

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

The analysis includes evaluation of different portfolio strategies. These strategies include alternative approaches to the Federal role: technology leader, technology explorer, and

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

APPENDIX A. TECHNOLOGY CROSSWALK

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

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

Subtitle B--Distributed Energy and Electric Energy Systems

SEC. 921. DISTRIBUTED ENERGY AND ELECTRIC ENERGY SYSTEMS.

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

(b) Authorization of Appropriations-

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

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

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

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

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

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

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

SEC. 922. HIGH POWER DENSITY INDUSTRY PROGRAM.

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

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

SEC. 923. MICRO-COGENERATION ENERGY TECHNOLOGY.

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

(b) Uses- The consortia shall explore--

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

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

SEC. 924. DISTRIBUTED ENERGY TECHNOLOGY DEMONSTRATION PROGRAMS.

(a) Coordinating Consortia Program- The Secretary may provide financial assistance to coordinating consortia of interdisciplinary participants for demonstrations designed to accelerate the use of distributed energy technologies (such as fuel cells, microturbines, reciprocating engines, thermally activated technologies, and combined heat and power systems) in high-energy intensive commercial applications.

(b) Small-Scale Portable Power Program-

(1) IN GENERAL- The Secretary shall--

(A) establish a research, development, and demonstration program to develop working models of small scale portable power devices; and

(B) to the fullest extent practicable, identify and utilize the resources of universities that have shown expertise with respect to advanced portable power devices for either civilian or military use.

(2) ORGANIZATION- The universities identified and utilized under paragraph (1)(B) are authorized to establish an organization to promote small scale portable power devices.

(3) DEFINITION- For purposes of this subsection, the term `small scale portable power device' means a field-deployable portable mechanical or electromechanical device that can be used for applications such as communications, computation, mobility enhancement, weapons systems, optical devices, cooling, sensors, medical devices, and active biological agent detection systems.

SEC. 925. ELECTRIC TRANSMISSION AND DISTRIBUTION PROGRAMS.

(a) Program- The Secretary shall establish a comprehensive research, development, and demonstration program to ensure the reliability, efficiency, and environmental integrity of electrical transmission and distribution systems, which shall include--

(1) advanced energy delivery technologies, energy storage technologies, materials, and systems, giving priority to new transmission technologies, including composite conductor materials and other technologies that enhance reliability, operational flexibility, or power-carrying capability;

(2) advanced grid reliability and efficiency technology development;

(3) technologies contributing to significant load reductions;

(4) advanced metering, load management, and control technologies;

(5) technologies to enhance existing grid components;

(6) the development and use of high-temperature superconductors to--

(A) enhance the reliability, operational flexibility, or power-carrying capability of electric transmission or distribution systems; or

(B) increase the efficiency of electric energy generation, transmission, distribution, or storage systems;

(7) integration of power systems, including systems to deliver high-quality electric power, electric power reliability, and combined heat and power;

(8) supply of electricity to the power grid by small scale, distributed and residential-based power generators;

(9) the development and use of advanced grid design, operation, and planning tools;
(10) any other infrastructure technologies, as appropriate; and
(11) technology transfer and education.

(b) Program Plan-

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

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

(A) utilities;
(B) energy service providers;
(C) manufacturers;
(D) institutions of higher education;
(E) other appropriate State and local agencies;
(F) environmental organizations;
(G) professional and technical societies; and
(H) any other persons the Secretary considers appropriate.

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

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

(1) describing the progress made under this section; and
(2) identifying any additional resources needed to continue the development and commercial application of transmission and distribution of infrastructure technologies.

(e) Power Delivery Research Initiative-

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

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

(A) to establish world-class facilities to develop high temperature superconductivity power applications in partnership with manufacturers and utilities;
(B) to provide technical leadership for establishing reliability for high temperature superconductivity power applications, including suitable modeling and analysis;
(C) to facilitate the commercial transition toward direct current power transmission, storage, and use for high power systems using high temperature superconductivity; and
(D) to facilitate the integration of very low impedance high temperature superconducting wires and cables in existing electric networks to improve system performance, power flow control, and reliability.

(3) INCLUSIONS- The Initiative shall include--

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

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

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

(i) demonstrate those technologies;

(ii) prepare the technologies for commercial introduction; and

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

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

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

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

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

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

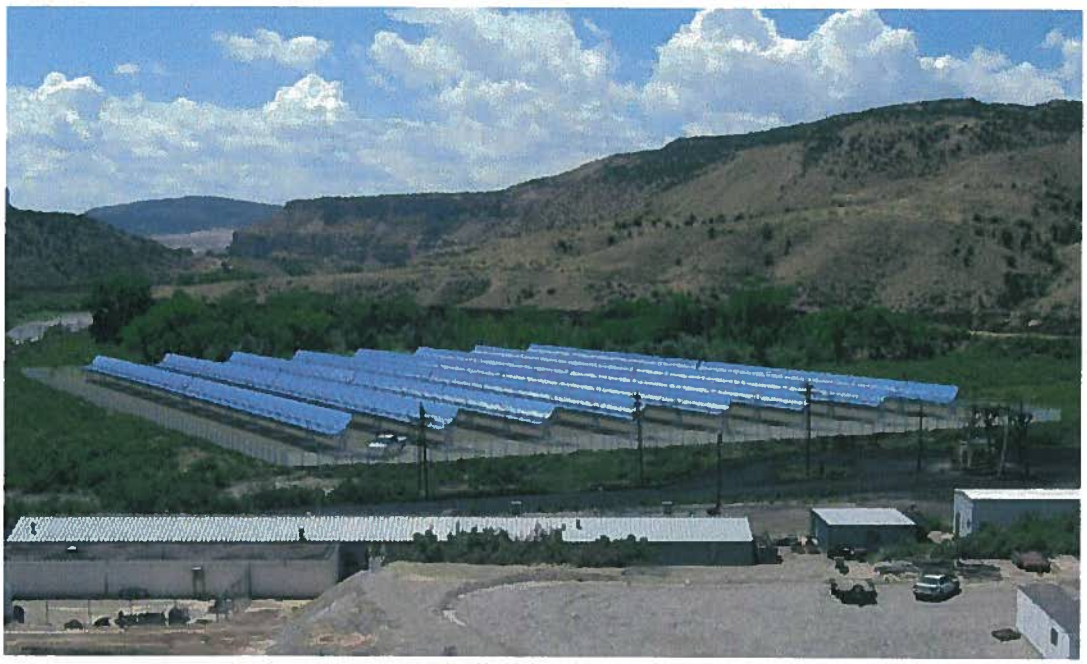
(B) to provide technical leadership in engineering and economic analysis for the reliability and efficiency of power systems planning and operations in the presence of competitive markets for electricity;

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

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

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

World's First Hybrid Coal-Solar Power Plant Goes Online in Colorado
Posted By Cameron Scott On July 12, 2010 (1:30 pm) In Air quality, Solar Power, global warming, green technology



Here's a case of strange bedfellows: the world's first hybrid coal-solar power plant is now up and running outside Palisade, Colorado. A joint project between the utilities giant Xcel Energy and Abengoa Solar, the unit of Xcel's Cameo plant is intended to show that solar power can reduce the environmental impact of coal-fired power plants.

NMED-SAHU
EXHIBIT 6

The plant uses parabolic trough solar collectors to heat the water that goes into the coal-fired turbine, which will reduce the amount of coal used at the facility by **2 to 3 percent**. For a cost of $4.5 million, the hybrid plant will produce the equivalent of just one of 49 megawatts from solar power.

It hardly sounds like a bargain to this blogger, but it's part of the coal industry's aggressive efforts to keep its irons in the fire as pressure mounts for cleaner energy alternatives. Indeed, several utilities have joined with the Electric Power Research Institute to study the hybrid coal-solar combination in North Carolina and New Mexico, and a solar-natural gas plant is already under construction in the Sunshine State.

Abengoa has pioneered the parabolic trough solar collector, in which glass mirrors which concentrate the sun's energy into a series of tubes filled with a heat transfer fluid — in this case, mineral oil. When the oil reaches 300°C, it is fed to an exchanger where the heat is transferred to water, bringing it nearly to boiling before it enters the boiler where a coal fire will convert it to steam, driving the turbine that generates electricity.

+ Xcel Energy

+ Abengoa Solar

Via Physorg

Article taken from Inhabitat - Green Design Will Save the World - http://inhabitat.com
URL to article: http://inhabitat.com/2010/07/12/worlds-first-hybrid-coal-solar-power-plant-goes-online-in-colorado/

Markron Technologies LLC

Integrating Solar Energy With Coal Plants

Solar Energy Integration With Coal-Fired Power Plants in New Mexico

April 16, 2010

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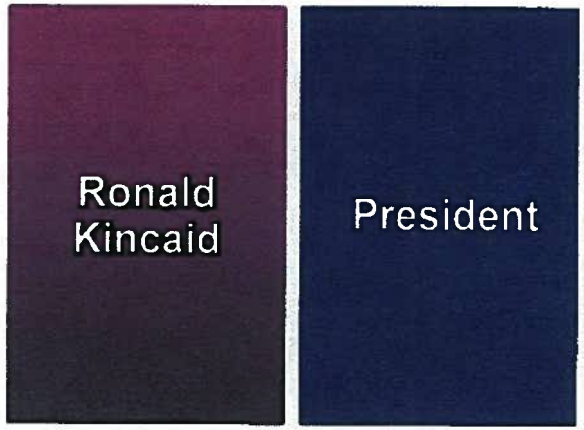
About Markron

Markron Technologies was established in 2002 and has more than 50 years of technological and business experience in the power and utilities industries.



- Mr. Kincaid is a co-founder and principal of Markron and is responsible for the business management of the Company. He has more than 25 years of experience in the energy and electric utility industries. He is an expert in utility and power economics. Mr. Kincaid was responsible for obtaining Markron's initial operating capital and project funding.
- MBA and BA in Economics from UC Irvine

- Mr. Skowronski is a co-founder and principal of Markron. He has been involved in power generation and alternate/renewable technologies for more than 30 years. He is an expert in power cycle concepts and has seven registered patents. Mr. Skowronski was a Consulting Engineer for Southern California Edison (1 of 12 out of over 700 engineers) and served as director for SCE's 10 MW Solar II demonstration project. He is the lead inventor for Markron's *Solar/FW* integration process.
- BS in Mechanical Engineering; Registered P.E.

About Markron

Our focus is to integrate large scale solar thermal energy with existing coal-fired power plants producing both a renewable energy benefit and a reduction in the host plant's coal use and coal related emissions by as much as 10% during peak solar hours.

- Leading player specializing in solar/coal integration applications
  started in 2003/2004.
- Patented process with additional patents pending
- Four projects licensed to Goldman Sachs (via Cogentrix)
  → San Juan Cogentrix has the right to do this; has secured land next to plant.
- U.S. solar integration market exceeds 5000 MW in solar potential

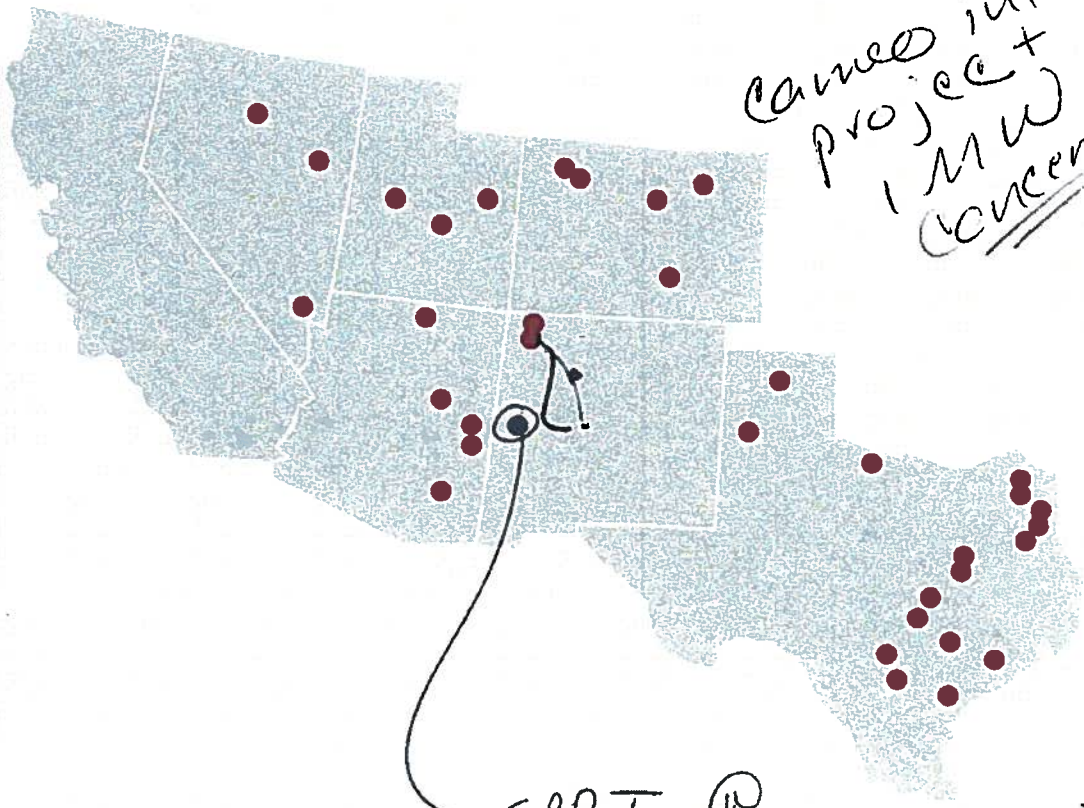
50 MW potential for preheat

- believes they have the most efficient process
- turbine study on turbines 3+4 by GE. signal digit cost for installation considering the PTC, but not the ~~cost of no~~ savings of not using coal on the AFTC.

The Solar/Coal Integration Market

Over 2,000 MW of the lowest cost solar thermal energy could be developed through integrating with coal plants in the Southwest and Texas.

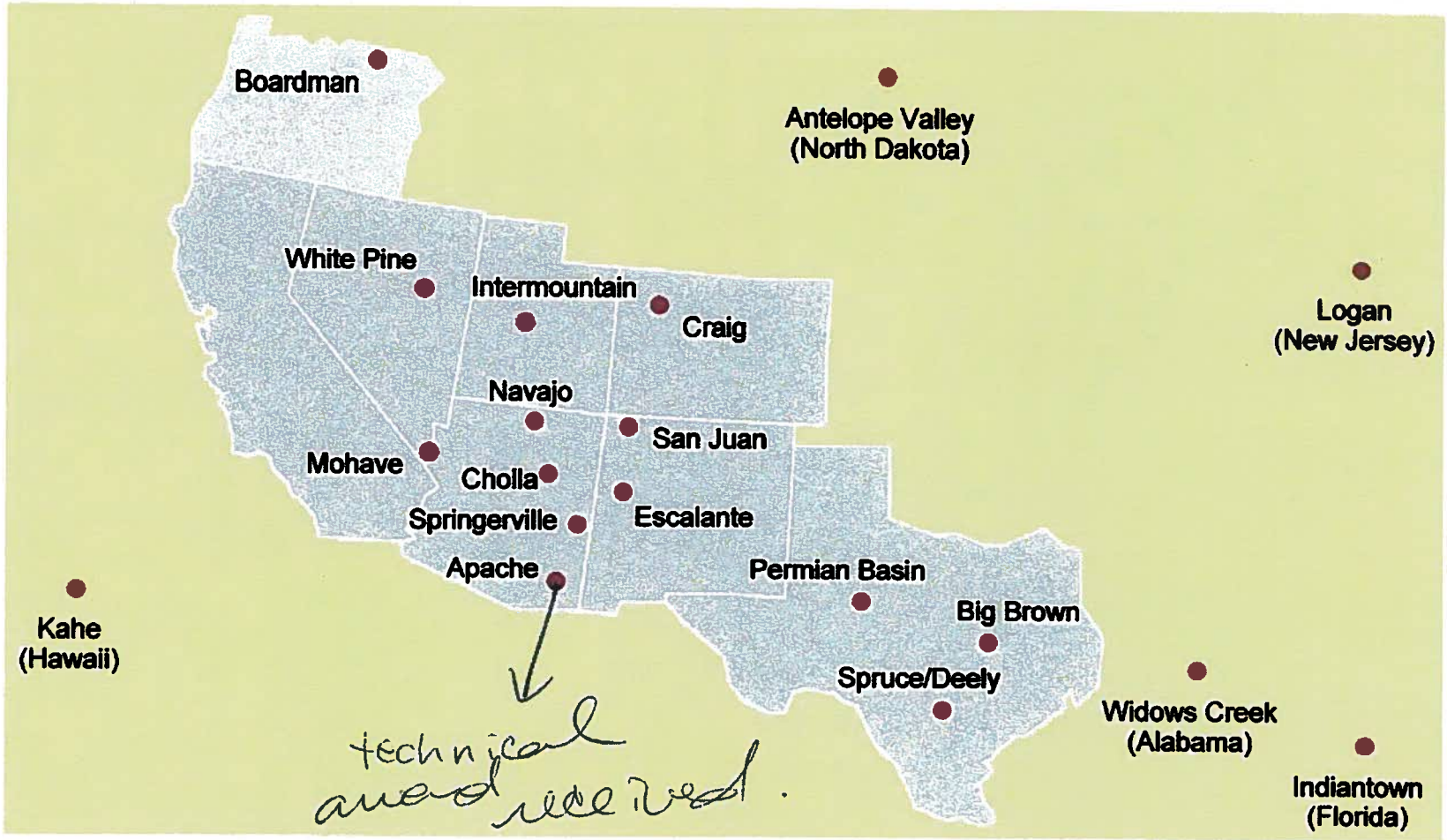
- **40,000 MW of coal plants exist in the Southwest and Texas with >2,000 MW of additional projects coming online within the next 5 years.**
- **Integrated solar potential ~ 2,000 MW - project investment totaling $6 billion.**



cameo integrat project w/ 1 MW concentrat

EPRI @ PEG s.a different process, no commercial decision made yet.

Markron has already modeled more than 20 fossil fuel-fired power plants for potential utility clients across the United States.



Integrated Solar and CO2 Reduction Potential for Existing Coal Plants in New Mexico

Martron Technologies LLC

April 16, 2010

New Mexico Solar Integration Potential Summary

New Mexico's coal plants could yield over 350 MW of integrated solar energy and reduce annual coal usage and CO2 emissions by about 375,000 tons and 700,000 tons, respectfully.

Four Corners (2,040 MW)

Solar Potential ~ *200 MW, 350,000 MWH/Yr*
Coal Reduction Potential ~ *210,000 Tons/Yr*
CO2 Reduction Potential ~ *400,000 Tons/Yr*

— proposing to integrate the 2 1g units w/ solar.

San Juan (1,800 MW)

Solar Potential ~ *125 MW, 210,000 MWH/Yr*
Coal Reduction Potential ~ *130,000 Tons/Yr*
CO2 Reduction Potential ~ *250,000 Tons/Yr*

2½% potential.

As much as 10% of ~~solar~~ output

need 4-5 acre per megawatt,

Escalante (235 MW)

Solar Potential ~ *35 MW, 60,000 MWH/Yr*
Coal Reduction Potential ~ *35,000 Tons/Yr*
CO2 Reduction Potential ~ *68,000 Tons/Yr*

Status of Integrated Solar Development in New Mexico

Four Corners

- Preliminary Economic Analysis
- Land Availability Study
- Support from Environmental Groups (GCT, SC, WRA)

San Juan

- Licensed to Cogentrix
- Preliminary Technical Feasibility and Turbine Study (Units 3 & 4)
- Initial Land Secured
- Ongoing Discussions with PNM et al.

Escalante

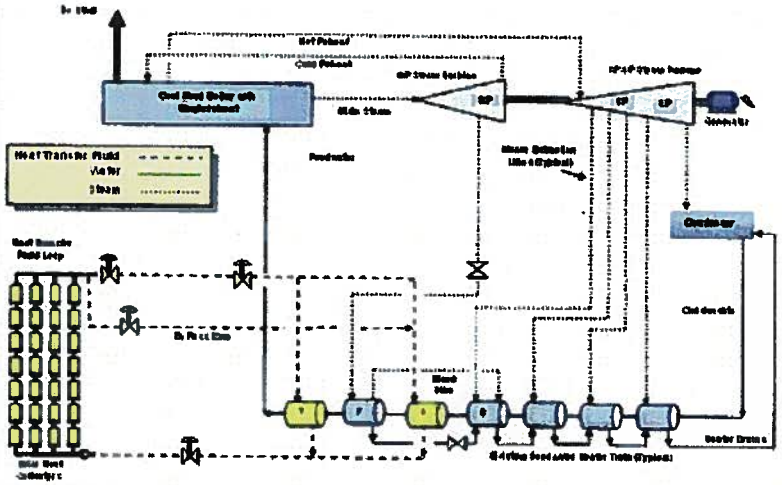
- Preliminary Technical Feasibility
- Definite Land Availability
- Ongoing Discussions with Plant and Tri-State Management

Process Description

and

Solar Background Information

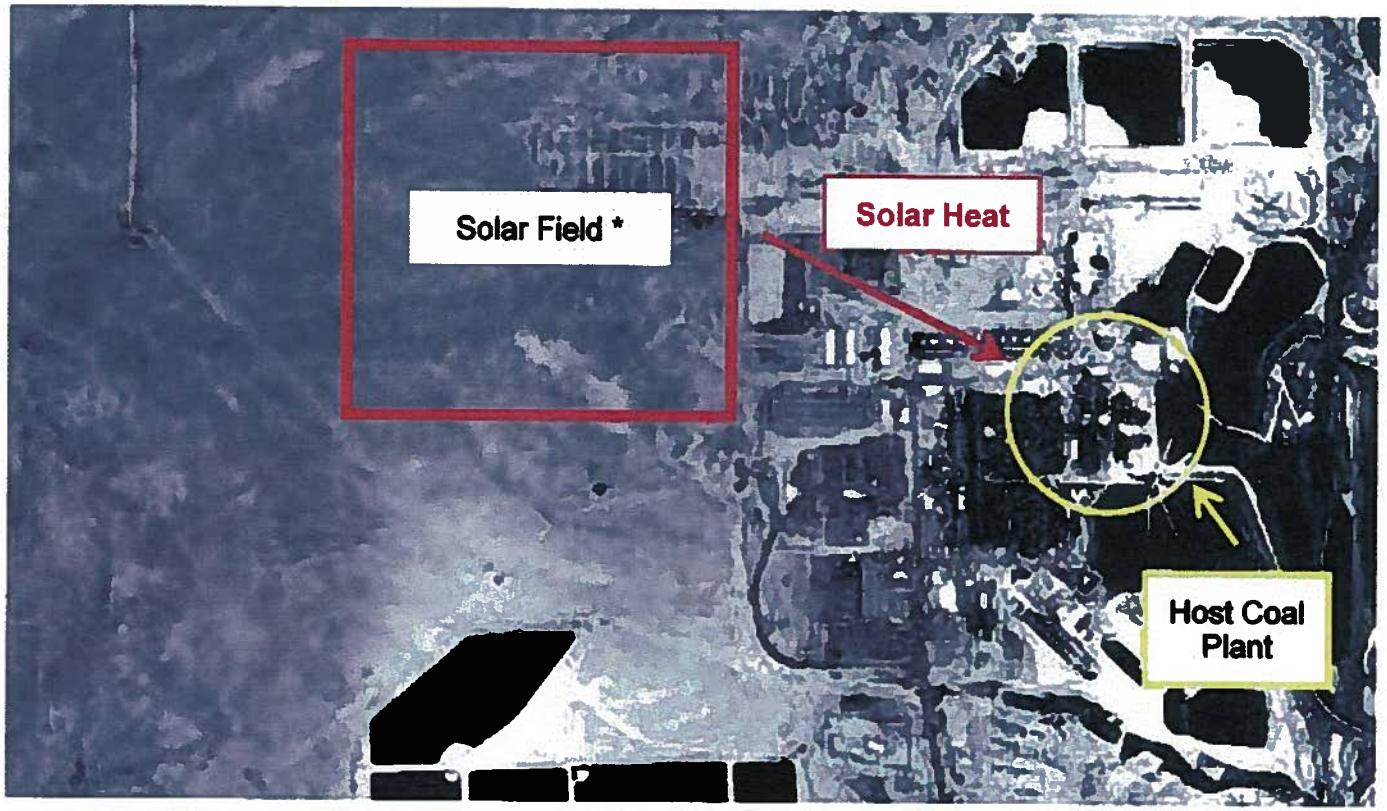
The Solar Technology and Solar Integration Process*



*U.S. Patent #7,640,746
Additional patents pending.

Process Summary

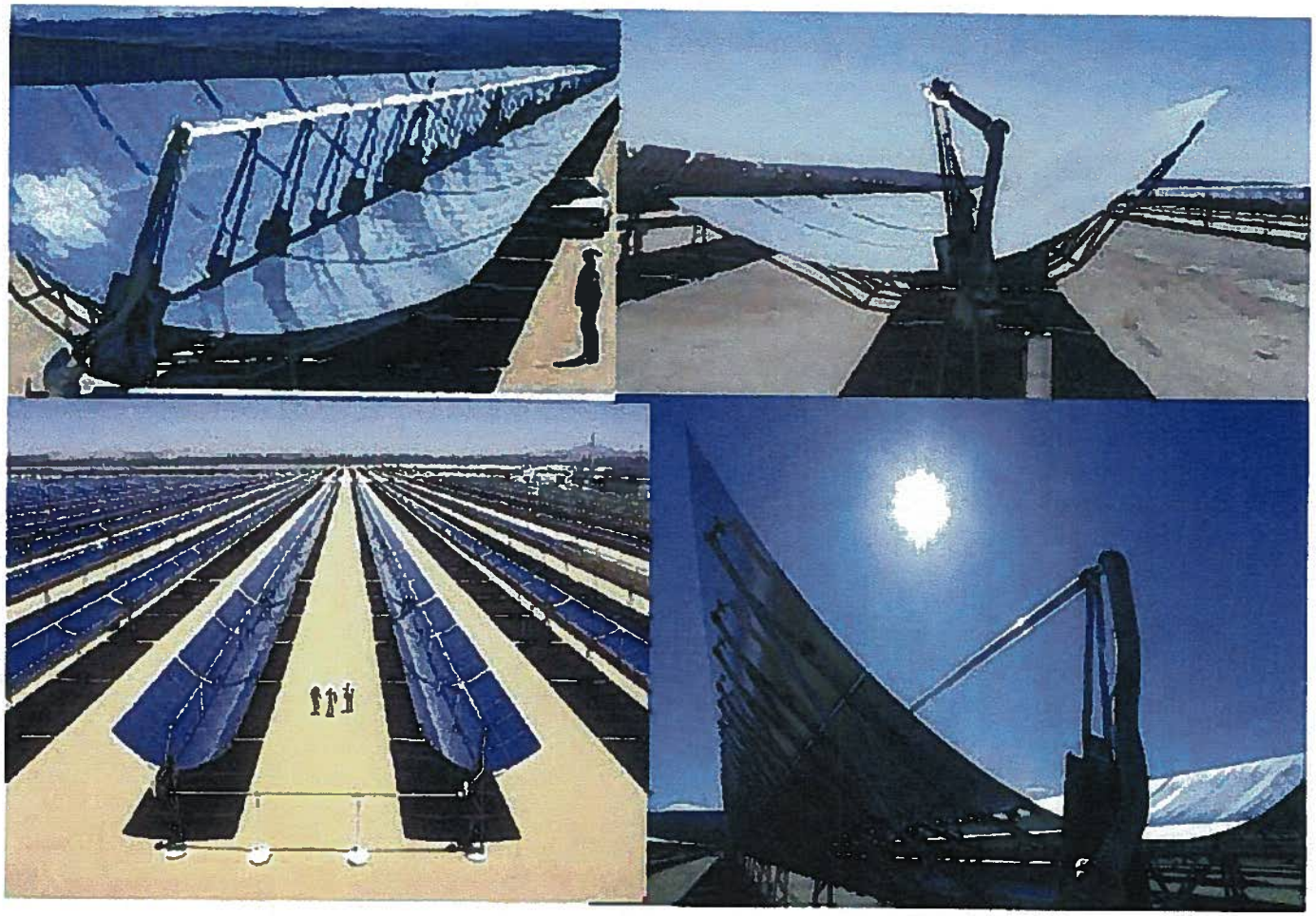
The solar field will capture the sun's heat energy and then transfer it to the coal plant where it will be used to preheat the water going into its steam boiler. This process will effect the production of solar electricity via displaced steam extraction flows. On peak sunny days as much as 10% of the host plant's net output would be from solar energy. No emissions will be produced from the solar field and significant CO2 and other coal related emissions will be abated.



* Solar field location is representative only. Actual location is subject to final land acquisition.

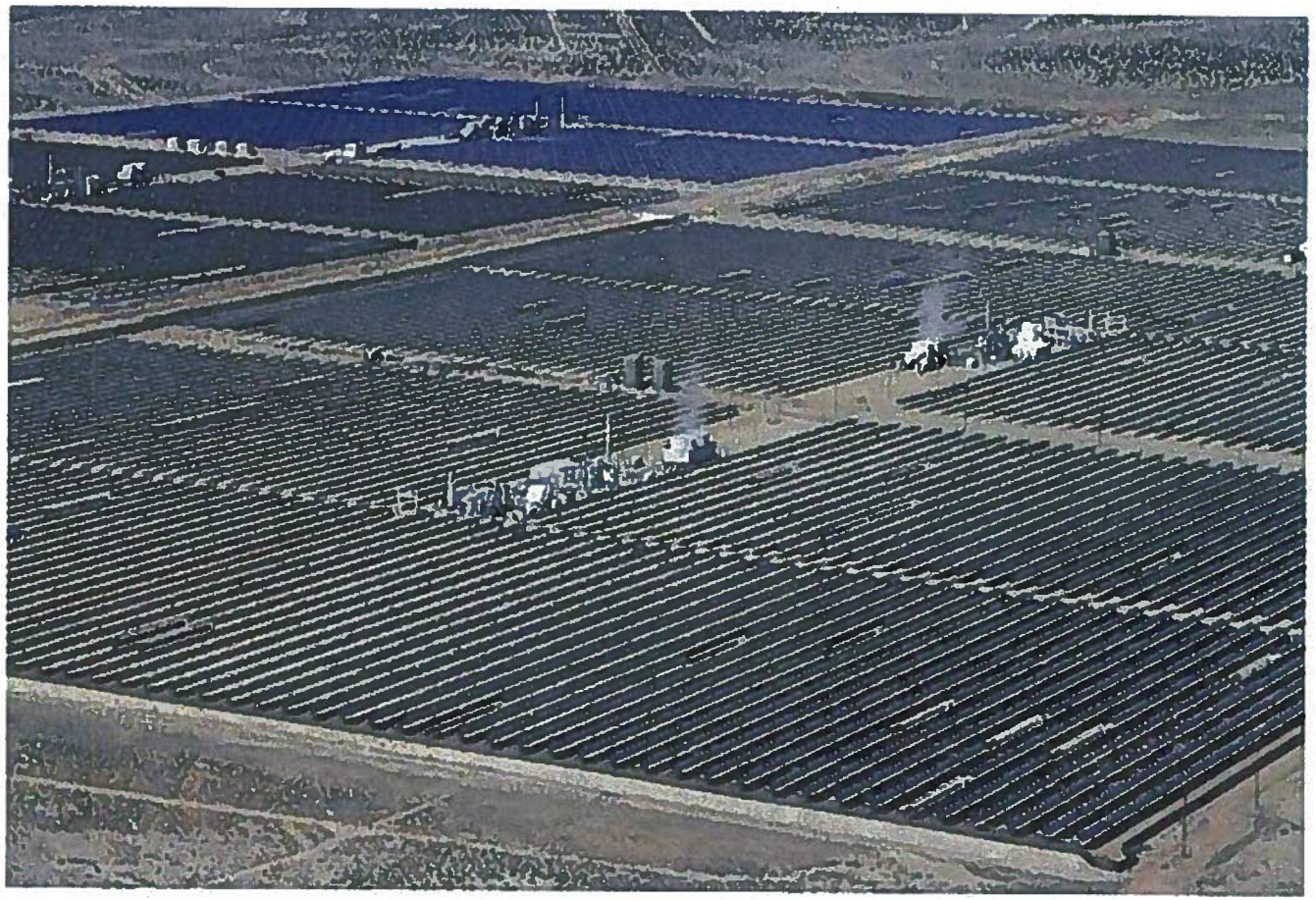
Solar Information - Technology Selection

The projects would utilize proven solar thermal trough technology which has been in use at the SEGS plants in California for 20 years.



Solar Information - SEGS Aerial View

The Solar Electric Generating Station (SEGS) facility located at Kramer Junction, CA currently produces 150 MW of solar thermal electrical generation.



Solar Information - Deployed Systems

California's Mojave Desert hosts the world's largest complex of solar parabolic trough systems comprising 354 MW of electrical generation. FPL Energy recently acquired 100% interest in SEGS III – IX.

Name	Size (MW)	Oper. Date	Location
SEGS I	13.8	1985	Daggett
SEGS II	30	1986	Daggett
SEGS III	30	1987	Kramer Junction
SEGS IV	30	1987	Kramer Junction
SEGS V	30	1988	Kramer Junction
SEGS VI	30	1989	Kramer Junction
SEGS VII	30	1989	Kramer Junction
SEGS VIII	80	1990	Harper Lake
SEGS IX	80	1991	Harper Lake

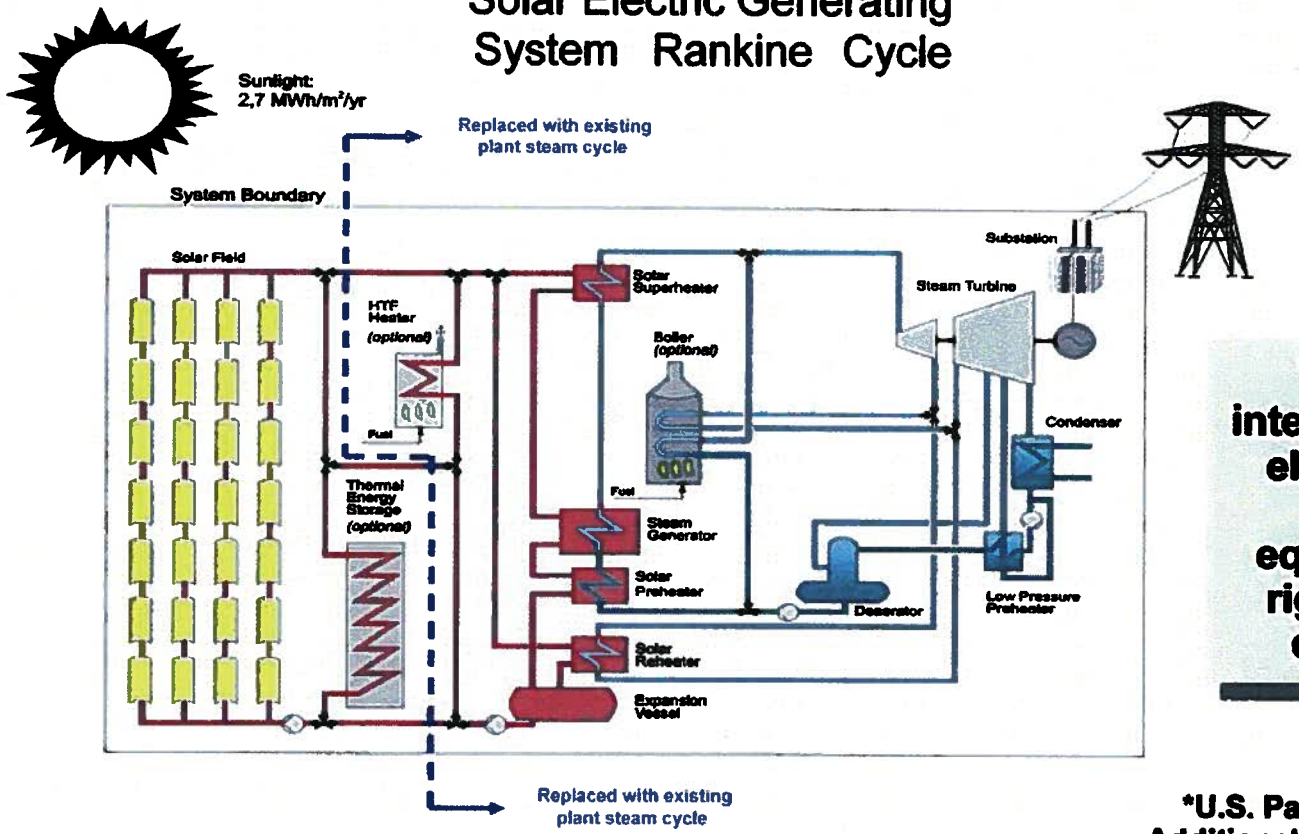
Solar Information - Nevada Solar One

The 64 MW Nevada Solar One project is the most recent and first solar thermal project to come online since SEGS. It is located southeast of Las Vegas, Nevada.

Business Focus - Solar Thermal Integration Strategy (*Solar/FW*)

Markron's integration process* leverages the infrastructure of existing coal plants to reduce solar energy costs by up to 40% with minimal intrusion to power operations.

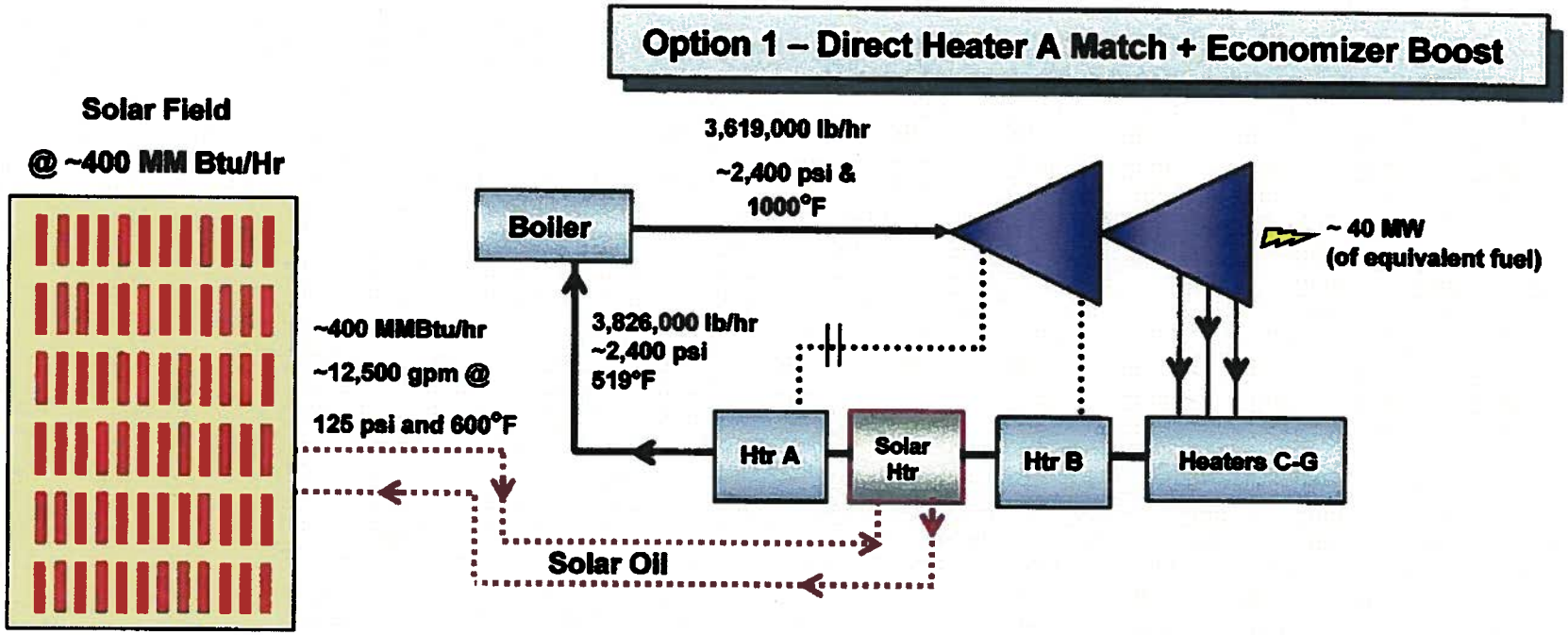
Solar Electric Generating System Rankine Cycle



The Markron integration process eliminates all or most of the equipment to the right of the blue dashed lines.

***U.S. Patent #7,640,746**
Additional patents pending.

Solar/FW Integration Flow Diagram for Typical 500 MW Coal Plant



Solar Input Scenario	Oil Pressure at Heater	Oil Temp	Oil Flow (Lbs/hr)	Enthalpy To Heater A (MMBTU/hr)	Enthalpy To Economizer (MMBTU/hr)	Incremental /Displaced MW [1]	Incremental /Displaced MWH/yr [1]	Coal Displaced (Tons/Yr) [2]	CO2 Displaced (Tons/Yr) [2]
Heater A & Economizer	100 psi	600 F	4.5 x 10^6	250	150	40	75,000	40,000	90,000

[1] All steam extraction flows will auto adjust (self-regulate) proportional to solar heat input.
[2] Based on equivalent net solar HR of 9,500 BTU/kWh (no boiler losses, HHV losses or auxiliary loads); no attemperation benefits are assumed with this analysis.

U.S. Patent #7,640,746
Additional patents pending.

Mantron Technologies LLC

April 16, 2010

Solar Integration Process Explanation (Typical ~500 MW Unit)

Markron's *Solar/FW* Integration Process* is simple and non-intrusive and can replace the host unit's lost capacity and energy due to CO_2 capture.

It can be used in two basic methods of implementation depending on the client's needs and value propositions:

Coal Displacement (refer to previous slide)

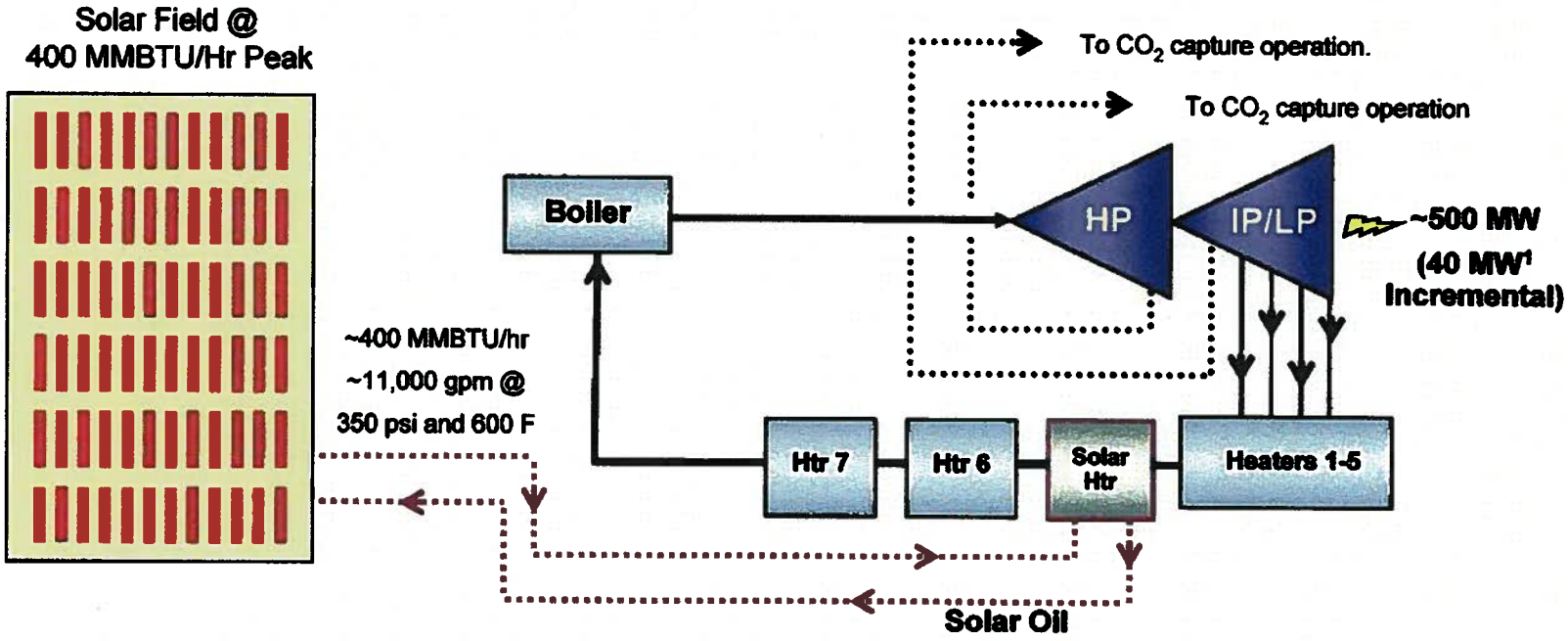
- Extraction steam (Heater A) that is displaced by solar energy is allowed to expand in turbine to reduce coal consumption (~40 MW peak displacement)

CO2 Scrubbing (refer to next slide)

- Extraction steam (Heater 6 & 7) that is displaced by solar energy is used for CO_2 scrubbing reducing the amount of low pressure turbine steam normally used
- Heater No. 6 extraction steam typically provides higher enthalpic steam to scrubbing process than the low pressure steam that is normally used (throttling may be required)
- Solar integration would allow Heater No. 6 & 7 to provide ~350,000 lbs/hr of extraction steam to scrubbing process at an average enthalpy of ~1,360 BTU/lb resulting in ~40 MW's of incremental peak solar capacity to system (assuming low pressure section provides ~60% of total turbine output)
- Solar heat can also restore feedwater temperature degradation resulting from reduced low pressure extraction flows that would otherwise cause additional coal burning. Solar heat can also be added to boost economizer temperature resulting in lower unit heat rate

*U.S. Patent #7,640,746
Additional patents pending.

Solar Integration Flow Diagram for CO_2 Process Enhancement (Markron's *Solar/FW* Process* w/ Solar Heater Upstream of Heater 6)



Solar Input Scenario	Oil Pressure at Heater	Oil Flow (Lbs/hr)	Enthalpy to Heater 6&7 (MMBTU/hr)	Enthalpy to Economizer[2] (MMBTU/hr)	Feedwater Design Makeup Enthalpy	Solar Capacity[3] (MW)	Solar Energy Generated[3] (MWH/Yr)
Heater 6&7 & Economizer	350 psi	4,400,000	~330	~70	??	~40	TBD

[1] Assumes 20% derate from CO2 abatement. MW output estimate requires computer boiler analysis verification and OEM turbine study.

[2] Feedwater temperature to economizer increased by 25F; verification needed by computer boiler analysis.

[3] Solar calculations have no boiler losses, HHV losses or auxiliary loads counted against unit performance. Also assumes no outages.

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April 16, 2010

*U.S. Patent #7,640,746
Additional patents pending.

Solar Integration Advantages

The integration of utility scale solar thermal energy with retrofit and new power plants provides significant benefits not attainable with greenfield solar projects.

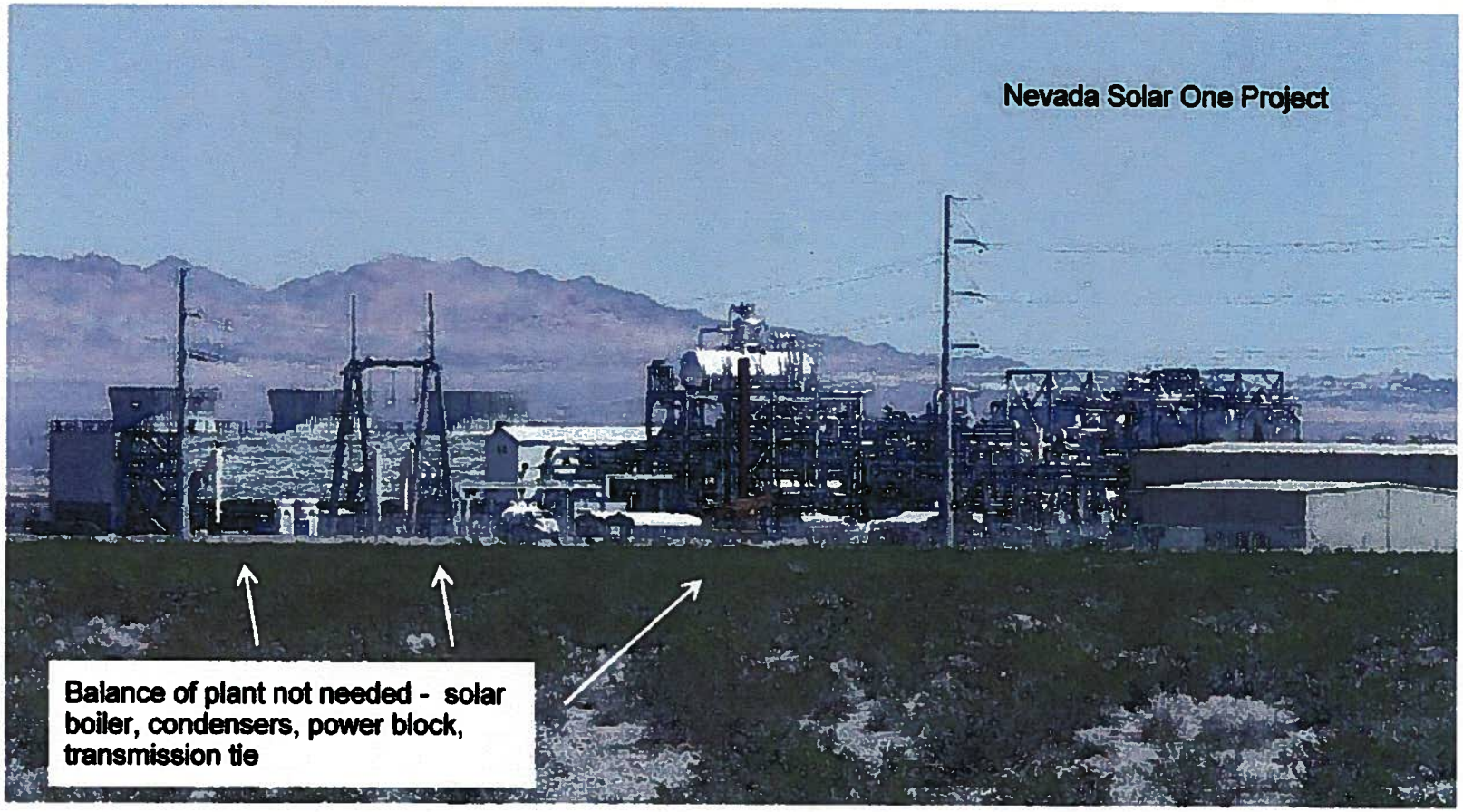
- 40% reduction in solar capital costs compared to standalone
- Produces host plant fuel savings
- Reduced permitting requirements
- Minimizes total cost to ratepayer/customer

Solar Integration Advantage - Capital Cost Reduction

The *Solar/FW* integration process will require only the mirror collectors and remove the steam production, generation and transmission equipment.

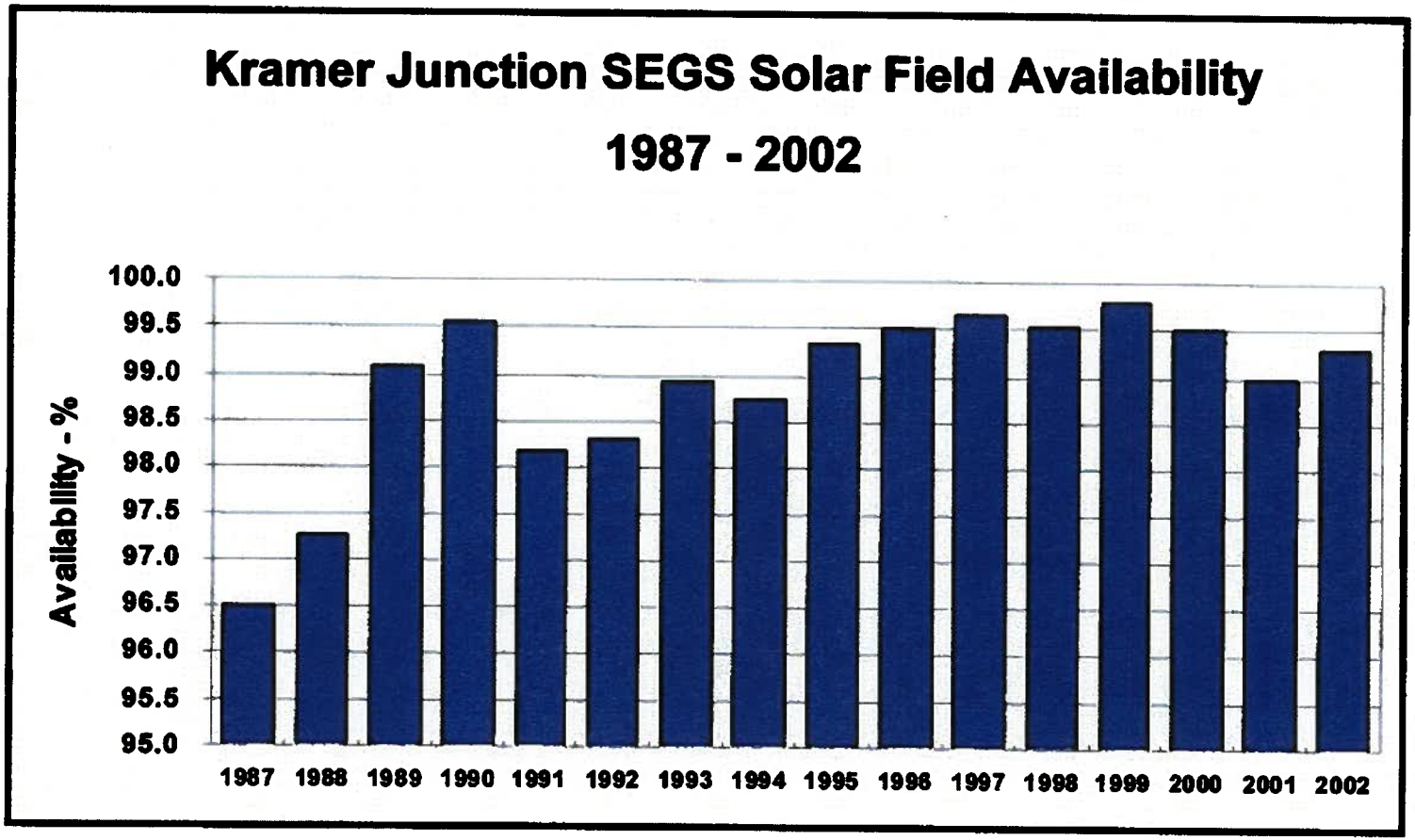
Solar Integration Advantage - Capital Cost Reduction

The elimination of the balance of plant not needed for Markron's *Solar/FW* integration process can reduce the solar thermal project cost by up to 40%.



Solar Information - Availability/Reliability Data

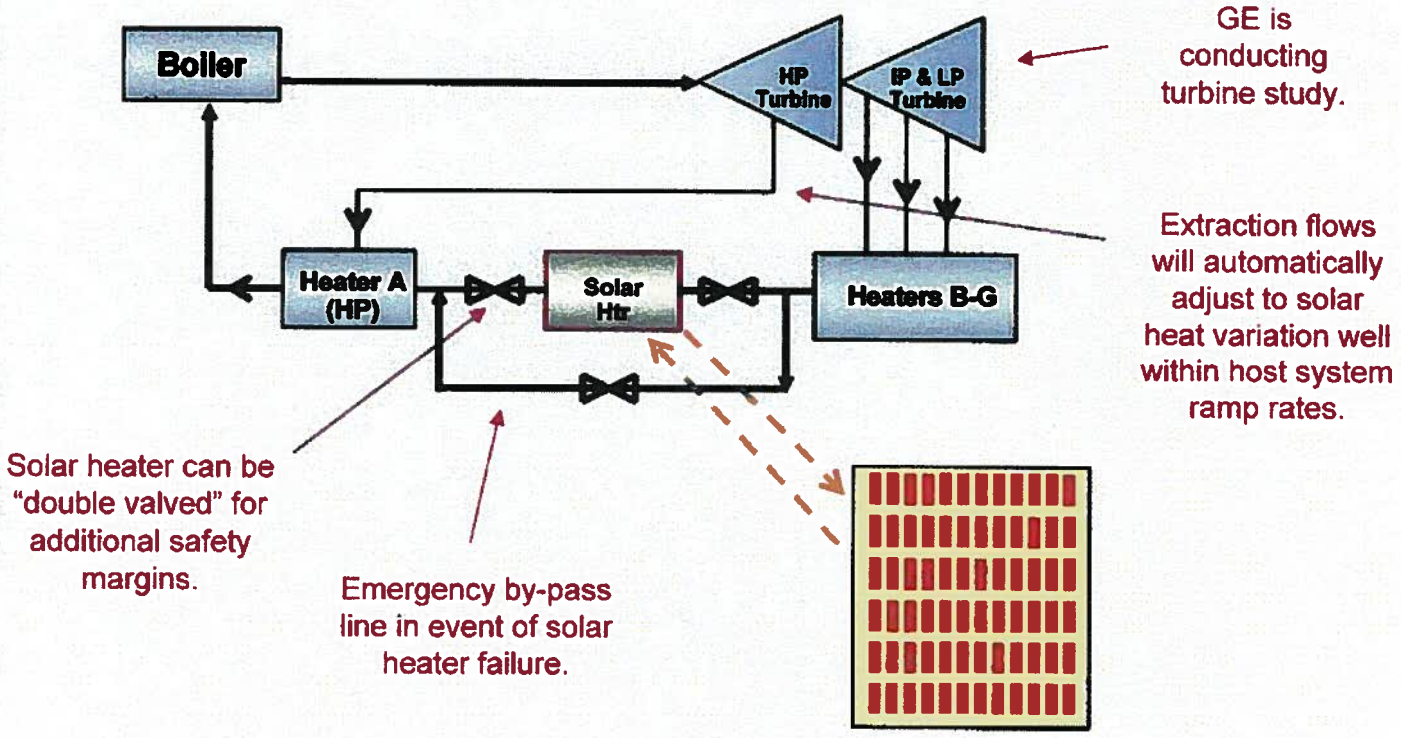
The SEGS plants have performed exceptionally well with a solar field availability factor consistently greater than 99% over the last several years of operation.



Process Risk And Benefits

Minimization of Host Plant Integration Risk

The *Solar/FW* integration method poses virtually no technical risk to the host plant and the Project's developer will incur all solar field and delivery related development activities, costs, and operating risks.



Technical Concerns Have Been Identified, Evaluated and Addressed and/or Compensated

- Redistribution of Heat in Boiler
  - *Analysis confirms favorable boiler heat absorption conducive to lower heat rate*
  - *Increased feedwater temperature to economizer also benefits boiler absorption rates*
- Thermal Cycling of Feedwater Heaters and Extraction Steam Piping
  - *"Mini" Extraction Flows maintain heater and piping temperatures to preclude cycling*
- Turbine Flows and Thrust loading
  - *Flow and thrust loads to be maintained within turbine tolerances*
- Contamination of Feedwater Due to Oil Leak
  - *Shell side oil flow is order of magnitude lower pressure than feedwater*
  - *Any leakage is from high pressure feedwater to low pressure oil*
  - *Hydraulic actuated double bypass can be incorporated*
- Boiler and System Impact due to Vagaries of Added Solar Heat
  - *Extraction flows and system operating parameters automatically compensate for loss (even permanent and catastrophic loss) of solar heated oil (minimum ramp rates)*
- Commercially Available Technology
  - *Solar Trough Technology has over 175 plant "operating years" at SEGS with outstanding solar collector field availability (>99%)*
  - *Feedwater heating since turn of the century in Rankine power cycles*
  - *Process is minimally intrusive to existing plant operation*
  - *Host plant runs in normal operating mode if solar feed-in is unavailable*

Cost of CO_2 Removal

- ~$.03/kWh direct cost w/o sequestration
- Does not include replacement power costs

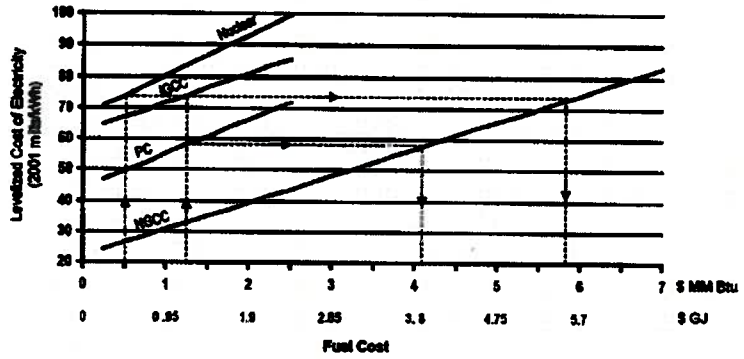


Figure 1. Levelized Electricity Cost Versus Fuel Cost Without CO_2 Removal

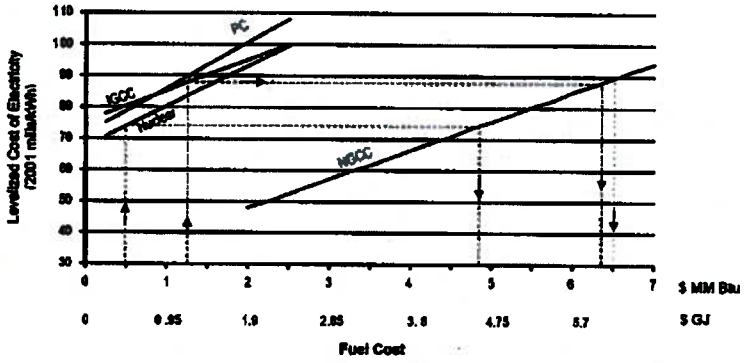


Figure 2. Electricity Cost Versus Fuel Cost With CO_2 Removal

Bechtel Study "Incremental Cost of CO2 Reduction in Power Plants" by Ram Narula, et al (ASME Turbo Expo, June 2005)

Markron Process Replaces Lost MW's due to CO_2 Scrubbing

Current emphasis on CO_2 removal is through solubility reduction with multi stage cascade flash process

- Energy intensive (half of low pressure steam diverted to CO_2 stripping process)
- ~25% capacity reduction at host plant
- Process appears quickest to commercialization

Markron's Solar Integration process replaces much of host plant's lost peak daytime capacity at a cost equal to or less than system incremental cost

- Up to 2/3 of capacity/energy lost during peaking times can be replaced by solar energy
- Solar heat converted at ~9,000 BTU/kWh; priced competitive to today's natural gas fired energy costs (~9.5 cents – 12.5 cents/kWh)*

"Cap and Trade" will require coal plants to reduce CO_2 on a decremental basis

- Economic strategy suggests that instead of cleaning "slip streams" at many plants, economy of scale dictates total stack CO_2 cleaning at selected plants to compensate for fleet averages

* Depending on solar region.

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April 16, 2010

Key Support Assistance Needed in New Mexico

- Continued Availability of Solar Production Tax Credit and Liquidity
- Assistance in Working With Navajo Nation and Tribes for Land Rights
- Property Tax Mitigation
- State Governmental Push of GHG and Renewable Energy Initiatives

Solar Integration Wrap-Up

The Markron Solar Process Provides Utilities All of the Following:

- Lowest Cost Solar Energy Available
- Assists Utilities in Meeting RPS goals
- Assists Utilities in Reducing CO_2 or recapturing lost MW's due to CO_2 abatement
- Can De-Couple for Standalone Operation

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Power Plant Optimization Industry Experience

2005 Update

1011794

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EXHIBIT 8

Power Plant Optimization Industry Experience

2005 Update

1011794

Technical Update, December 2005

EPRI Project Manager

J. Stallings

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Principal Investigator
S. Tavoulareas

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This publication is a corporate document that should be cited in the literature in the following manner:

Power Plant Optimization Industry Experience: 2005 Update. EPRI, Palo Alto, CA: 2005. 1011794.

PRODUCT DESCRIPTION

This report reviews industry experience with optimization software. Since the early 1990s, power plant optimization software has been used extensively by U.S. electric utilities. More than 400 units (coal-, oil- and gas-fired) have used optimization software products. Of this number, approximately 280-300 are coal-fired boilers; 100 to 130 of these systems are still in operation, all of them in close-loop mode.

Results & Findings

This study briefly surveys commercially available optimization software, provides an overall assessment of the extent optimization is currently used in the U.S. utility industry, summarizes the experience of U.S. electric utilities, and details the lessons learned, focusing on what makes a project successful.

Challenges & Objective(s)

The report's goal is to document the present status of power plant optimization and the lessons learned from the utility industry regarding the viability of optimization projects. The report also identifies reasons previously installed units are no longer in use, lists performance improvements that can be achieved by optimization, suggests ways utilities and vendors can work together successfully, and identifies typical costs for optimization projects.

Applications, Values & Use

Information in this report will assist utilities in successfully implementing optimization projects, from identifying components that can benefit most from optimization to establishing long-term working relationships with vendors.

EPRI Perspective

In September 1998, EPRI published the Proceedings from the Second Workshop on Power Plant Optimization (TR-111316), followed by the Power Plant Optimization Guidelines (TR-110718) in December 1998. In December 1999, the beta version of the Total Plant Cost Optimization Guidelines (EPRI AP-114702) was released. This tool to assist utilities in assessing the benefits of optimization has not yet been released as a final report.

The term "optimization," as it is used in this report, needs clarification for a number of reasons. In the past, most of the emphasis on EPRI-initiated work has been on combustion optimization using software based on neural networks. Combustion optimization was a key area due to the importance of optimizing the tradeoffs among NOx emissions, unburned carbon, and boiler efficiency. Recently, utilities also have become interested in optimizing other areas, such as flue gas desulfurization (FGD), selective catalytic reduction (SCR), and sootblowing. For this reason, the term "optimization" is used in this report to mean on-line multi-variable and multi-objective optimization of a single unit independent of the optimization technique used. Not included in the report are applications used off-line or intended to optimize maintenance activities.

Approach

The project team contacted U.S. utilities that have installed optimization software. Since the list of optimization users was long and many on the list preferred to keep their names and experience

confidential, the team relied on a sample of responses. The estimate of optimization systems in operation (100-130) was based on contacts with 15 utilities that have installed optimizers in multiple plants (representing a total of approximately 100 units). Information from these contacts was used to develop an estimate of the general experience in the industry. Rather than describe specific projects, the team focused directly on lessons learned and used examples from contact sites to illustrate those lessons.

Keywords
Fossil-fired power plants
Optimization
Heat rate
Performance
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- Pegasus Technologies: Peter Reck and Carolynn Hohenstein
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ABSTRACT

This report gives an overview of commercially available optimization software, assesses the extent optimization is currently used in the U.S. utility industry, summarizes the industry's experience, and details the lessons learned with an emphasis on what makes a project successful. The document's goal is to describe the status of power plant optimization and the lessons learned in terms of the feasibility of optimization projects. Project information came directly from contacts with U.S. utilities that have installed optimization software. The team's estimate of optimization systems currently in operation on coal-fired boilers (100-130 out of a total of 280-300 installed) was based on contacts with 15 utilities that have installed optimizers in multiple plants (representing a total of approximately 100 units). The team used contact information to develop an estimate of the industry's general experience with optimization software, focusing directly on lessons learned rather than specific projects. For this report, "optimization" refers to on-line multi-variable and multi-objective optimization of a single unit independent of the optimization technique used.

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1
EXECUTIVE SUMMARY

Since the early 1990s, multi-variable and multi-objective power plant optimization has been used extensively by U.S. electric utilities. A number of key factors contributed to this development: 1) the Clean Air Act Amendment of 1990 required NOx emissions reductions, but also provided flexibility on how this reduction would be achieved; 2) deregulation in the U.S. utility industry put pressure to reduce operating costs, providing an additional incentive to increase plant efficiency; and 3) neural-network-based software reached maturity and became available as commercial products.

Reportedly, more than 400 units (coal-, oil- and gas-fired) have used such optimization software, of which approximately 280-300 are coal-fired boilers. However, it also is clear that while many of these units have used optimization software for some time (after they have been installed and calibrated successfully), they are not using them any more. This is the result of many factors, including the fact that a number of optimization products are not available in the market anymore because they have been acquired by competitors.

Under these circumstances, EPRI member utilities are interested in learning more about the present status of power plant optimization. Most important are the lessons learned from the utility industry regarding the viability of optimization projects and the factors that contribute to a successful project. This study is in response to this need and attempts to provide

- a brief overview of commercially available optimization software,
- an overall assessment of the extent to which optimization is used in the U.S. utility industry, and
- lessons learned that contribute to implementing successful optimization projects.

Key Findings

- Presently, there are 100 to 130 coal-fired units in the United States that are using optimization software, all of them in closed-loop mode. This represents 35-45% of the units that have installed optimization systems; the remaining are not using them any more for a variety of reasons, including
  - o Ultramax had approximately 65 installations that are not operational because they were never set-up in closed-loop mode and stopped being used as soon as the company ceased to exist;
  - o operating objectives have changed since the optimization system was installed; incentives to reduce NOx emissions through combustion optimization is not the highest priority as units have been retrofitted with post-combustion NOx controls;
  - o changes in hardware (especially installation of selective catalytic reduction, or SCR, units but also replacement of economizers and air preheaters) or significant changes in coal

quality require recalibration of the optimization system, which was perceived to be costly;

- o perceptions of plant operators and performance engineers that optimization systems may have adverse effects on their job security; also, their perception that costs outweigh benefits; and
- o older power plants without digital control systems and adequate instrumentation and remote control capabilities installed optimization software, but realized that the systems were not effective.

The estimate of optimization systems in operation (100-130) is based on contacts with 15 utilities that have installed optimizers in multiple plants (representing a total of approximately 100 units). This number does not cover all plants with optimizers, but was used to develop an estimate of the general experience in the industry and was considered adequate for the purposes of this report.

- Recent experience confirms earlier estimates about performance improvements that can be achieved by optimization. NOx emissions can be reduced by 5-35% depending on the number of control variables available, the operating range of each variable, and whether the unit was tuned. Heat rate in base-loaded units was improved by up to 1.0 percentage point and in load-following and cycling units up to 2.0 percentage points. Units that are not recently tuned and units with many control variables and a wide operating range for each variable should achieve performance improvements at the high end of the above range.
- Reports from two cyclone units are consistent with the performance improvement of other types of boilers. Cyclones are singled out because they have inherently less operating flexibility. However, the addition of overfire air ports and instrumentation for each cyclone provides adequate flexibility to achieve reasonable performance improvement.
- Realignment of optimization vendors is continuing with power plant controls vendors becoming more active. The key optimization suppliers in the market are Emerson, Invensys, NeuCo, Pegasus, and URS. The power plant controls vendors (Emerson and Invensys) represent one-third (1/3) of the total optimization installations in operation with the remaining two-thirds (2/3) supplied by the traditional neural-network-based optimization suppliers (NeuCo, Pegasus, and URS).
- All suppliers are capable of implementing successful optimization projects, but attention should be paid to the specific experts that suppliers are committing to each project. Utilities should request resumes, interview prospective vendor experts (if possible), and ask for assurances that they will be available to support the project as needed.
- Optimization vendors are making significant efforts to expand optimization to other components and objectives such as sootblowing, post-combustion controls (SCR and selective non-catalytic reduction, or SNCR), flue gas desulfurization, on-line heat rate, maintenance optimization, and overall economics. However, it is not clear how successful these integrations will be both in terms of technical feasibility and cost-effectiveness. Integration of post-combustion NOx controls seems to be the most promising and problem-free. The others are yet to be demonstrated convincingly.

The industry experience is full of examples of what makes a successful optimization project and what contributes to an unsuccessful one. These are the key lessons learned:

- Corporate commitment is essential.
- Plant staff buy-in early in the project is important; there are negative perceptions related to optimization system cost-effectiveness and impacts on plant staff job security that need to be dispelled early on.
- A plant champion is needed at the plant and, preferably, at headquarters, too.
- The implementation team should bring together the following disciplines: 1) power plant engineering (plant design and operation); 2) instrumentation and controls; and 3) optimization techniques. Whether such expertise is in the utility organization or the optimization supplier is not important; what is important is to make sure that these experts are available to support the project when needed.
- Utilities should sign a maintenance contract with optimization suppliers to provide technical support on an as-needed basis and to provide software upgrades.
- Providing remote access to optimization suppliers has significantly improved the effectiveness of optimization systems. With cyber-terrorism and safeguarding proprietary data being major concerns for U.S. utilities, such access is not as simple as it used to be. Corporate guidelines and industry requirements need to be followed in providing such access. However, it is essential and needs to be arranged in the early stages of projects, certainly before contracts with optimization suppliers are signed.
- Optimization suppliers claim that optimization systems could be in closed-loop mode within three to four months from the project kick-off meeting. Experience shows that utilities should plan for a minimum of five to six months.
- Typical costs of optimization projects:
    - Optimization supplier contract: $400,000 for the first unit and $300,000 for subsequent units at the same plant. However, there is significant pressure and prices could decline by 30-40% from these levels.
    - Optimization supplier maintenance/technical support agreement: $20,000 – 40,000 per year.
    - In-house costs:
        - Three to four man-months during optimization installation and calibration.
        - Ten to twenty percent of a performance engineer's time after the optimization system is operating in closed-loop mode. Higher levels of support would be needed if significant hardware or coal quality changes require recalibration of the optimization software.

2
INTRODUCTION

Power plant optimization has developed into a technical area of interest for electric utilities. In the early 1990s, a number of software packages were introduced such as Ultramax, Pegasus' NeuSight, Pavilion's Process Insights, GNOCIS, and NeuCo's ProcessLink. These packages raised utilities' interest in multi-variable and multi-objective optimization. The timing was good because it coincided with the need for NOx emission reductions (required by the Clean Air Act Amendments of 1990), as well as competitive pressures (through deregulation of the utility industry) to improve plant efficiency.

Since then, approximately 280-300 coal-fired units in the United States have been reported to implement optimization. However, it is not clear how many of these units are still using optimization, how it is used, and how satisfied the utilities are. Consolidation of optimization vendors makes the situation even more complicated because some of them do not exist anymore as separate companies and their products are not marketed and supported.

Responding to the need of its members, EPRI supported a review of industry experience with optimization software, which is documented in this report. More specifically, the objectives of this report are to

- provide a brief overview of commercially available software,
- assess the approximate number of installations that continue to use optimization, and, more importantly,
- focus on the experience of U.S. electric utilities with optimization software and the lessons learned from successful projects.

To clarify both the extent to which optimization software continues to be used and to draw lessons learned from that use, the project team contacted key utilities and power plants that have implemented optimization software. With regard to lessons learned, initially the plan was to identify four to five projects and describe them in detail, hoping that this would highlight the lessons learned. However, as more utilities were contacted, it became clear that there were a number of reasons to switch from describing specific projects to stating directly the lessons learned and use examples from various sites to illustrate them. The reasons for this change in presentation are as follows:

- Most utilities were not willing to be quoted in a report; however, they were willing to share details (especially with regard to project schedule and costs) provided that their names would be kept confidential and the information would be included in the report as general experiences and conclusions not tied to specific companies and facilities.
- EPRI's objective is not to make any company look bad (whether utility or optimization supplier); the goal is to present the lessons learned so future projects can benefit from what works and from what does not.

- The lessons learned covered many more projects than just four or five.

This report is divided into four sections. In addition to Sections 1 (Executive Summary) and 2 (Introduction), Section 3 provides a brief description of commercially available optimization products, including Emerson, GNOCIS, Invensys, NeuCo, and Pegasus. The information collected on industry experience and lessons learned is presented in Section 4. In this section, we state each conclusion and then provide further clarification, including examples from utilities and power plants that had relevant experience.

Definitions and Terminology

The term *"optimization,"* as it is used in this report, needs to be clarified for a number of reasons. In the past, EPRI-initiated work on combustion optimization has primarily focused on using neural-net-based software. (Of course, this was not exclusive, as illustrated by Ultramax, which is not based on neural networks). Combustion optimization also was a key area due to an industry emphasis on optimizing NOx emissions, unburned carbon, and boiler efficiency. However, utilities have recently become interested in optimizing components such as flue gas desulfurization (FGD), SCRs, and sootblowing. For this reason, the term "optimization" will be used in this report to mean on-line multi-variable and multi-objective optimization of a single unit independent of optimization technique used.

A few limitations placed on this definition to keep the effort focused include the following:

- Methods that are applied off-line are not included. This does not mean that these methods are not important; they have been documented in numerous EPRI reports and studies and there is no substantial new information to provide.
- Optimization of maintenance activities is not included in this report. Performance optimization obviously has long-term impacts on unit reliability and maintenance requirements; however, integration of such activities has substantially increased the complexity of the optimization problem, and there are not many initiatives to report at this time.

Relevant EPRI Products:

- *Power Plant Optimization Guidelines* (TR-110718)
- *Total Plant Cost Optimization Guidelines* (Beta Testing Version; TR1001130)
- *Proceedings, Second Annual EPRI Workshop on Power Plant Optimization* (TR-111316)

3
DEVELOPMENTS ASSOCIATED WITH COMMERCIALLY AVAILABLE POWER PLANT OPTIMIZATION PRODUCTS

There have been a number of important commercial developments during the last two to three years:

- Consolidation of optimization suppliers: A number of optimization suppliers do not exist any more. The early leader in optimization software, Ultramax, was acquired by Pegasus Technologies, Inc. Pegasus also acquired the rights to the technology of Pavilion, which withdrew from the utility market.
- Power plant controls suppliers are becoming more active in optimization: Organizations such as Emerson and Invensys started offering optimization software for both specific components and unit-level optimization.
- Some optimization suppliers are becoming less active: In particular, URS (offering GNOCIS) and General Electric-Praxis (offering PECOS) have not introduced any new projects during the last couple of years.

Many other companies are continuing to be or are becoming active in plant optimization through performance monitoring (for example, Alstom, Black & Veatch, and General Physics) and parametric testing and off-line optimization (for example, Lehigh University, which signed a marketing alliance with METSO Automation). However, the project team decided that these products were not the focus of this report. Instead, we focused on software products for on-line multi-variable and multi-objective optimization that have at least one installation in a U.S. utility power plant. As a result, this section includes information on Emerson, GNOCIS, Invensys, NeuCo, and Pegasus.

This section provides a brief summary for each product. Detailed information on these products can be obtained from the vendors' web sites (which are provided in this report), as well as earlier EPRI publications, such as TR-111316 (Proceedings: Second Annual EPRI Workshop on Power Plant Optimization).

3.1 Emerson

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Description

Emerson offers a number of optimizer and advisory modules as part of their SmartProcess Software Suite:

- Combustion Optimizer
    - Low NOx Optimizer
    - Opacity Optimizer
- Cyclone Boiler Optimizer
- Economic Optimizer
- Fleet Emissions Optimizer
- Steam Temperature Optimizer
- Sootblower Optimizer
- Global Performance Advisor

Emerson also is developing optimization modules for SCR and FGDs.

These modules use empirical correlations, neural networks, and fuzzy logic or a combination of these techniques depending on the optimization objective. For example, the Combustion and Economic Optimizers use neural networks and are designed to allow for multi-objective optimization.

These modules are integrated in a closed-loop manner and provide optimal bias signals or revise the set-points in the control system.

The SmartProcess Software Suite has sensor validation capabilities through the following modules: PCS ACM, SmartSignal eCM, and Sensor Replacement.

Industry installations and experience

Emerson reports 108 installations worldwide employing some of these optimization modules. Seventy-five of these installations are coal-fired power plants (a few blend fuels). Most of these installations optimize NOx emissions and boiler efficiency.

Key installations of Emerson Optimizers include

- Ameren's Coffeen #2 (a cyclone unit) in 2004 and Newton #1 and 2 in 2002/03
- Constellation Power's Crane #1 and 2 (cyclone units) in 2002/03
- Duke Power's Allen #2 and 3 (T-fired units) in 2002/03
- Dynegy's Hennepin #2 (T-fired unit) in 2004
- Electric Energy's Joppa #1, 2, 3, 4, 5, and 6 in 2001/02
- We Energies' Oak Creek #7 and 8 in 2004, Presque Isle #3-6 in 2001, and Valley Power 1-4 in 1999-2000
- Xcel Energy's Sherburne County 1-3 in 2002 and Pawnee in 2001

Optimizers also were installed at some gas-fired boilers, including Entergy's Nine Mile Point, Xcel's Nichols, and Florida Power & Light's Martin County stations.

References

1. *Power Engineering Magazine,* "Neural network technology optimizes cyclone boilers at Constellation Energy's C.P.Crane station", October 2004 issue, page 73.

3.2 GNOCIS Plus

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Description

GNOCIS is a multi-variable optimization system designed for application at power plants. A detail description of GNOCIS is provided in EPRI report TR-111316, among others publications.

The original version of GNOCIS used Pavilion optimization technology. GNOCIS Plus, which replaced GNOCIS, uses core optimization technology developed by PowerGen Ltd of UK (presently E.ON UK).

Industry installations and experience

GNOCIS Plus was installed in approximately twenty power plants of the Southern Company power system, as well as TVA's Kingston #9. However, in the last two years, there are no new projects announced, and reportedly only one plant (Lansing Smith of Gulf Power) is actually using the software.

Both URS and E.ON UK[1] are active in power plant performance optimization and are likely to continue being involved, potentially with new products or services:

- URS is developing sootblowing optimization software (jointly with Synengco) that is being tested at TVA's Widow's Creek and Bull Run plants.
- E.ON UK is active in power plant optimization in Europe and offers PROATES, a plant performance monitoring and thermodynamic analysis tool.

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Description

Invensys, parent company of Foxboro and Simsci-Esscor, offers the ConnoisseurTM APC platform, which includes multi-variable model predictive control/optimization, dynamic neural network modeling, fuzzy logic, expert systems, and on-line model adaptation. The core of the system is dynamic multi-variable, model predictive constraint control (MVC) with on-line optimization. The product is integrated directly with the base control system of the plant and is designed for continuous closed-loop applications.

Key features of Connoisseur:

- built-in data acquisition and trend graphing;
- data historian and archiving facilities for a specified amount of process data;
- sensor validation;
- neural-network-based nonlinear optimizer for modeling and controlling NOx, CO, and other nonlinear responses;
- feed-forward variables for dynamic response to external changes;
- steam temperature and throttle pressure control;
- proprietary Burner Zone Module "provides virtual sensors for each burner" (estimates burner stoichiometry based on distributed control system, or DCS, data and design data);
- smart sootblowing system;
- mill optimization;
- dynamic control capability;
- on-line model learning throughout the load range; and
- off-line data analysis capabilities.

Connoisseur software runs on the Windows platform and supports up to nine (9) simultaneous users with one (1) user able to make changes.

Invensys projects that approximately three months are needed from contract award to a fully operational system in a closed-loop mode in one unit.

Industry installations and experience

Invensys has 15 installations of optimization systems, ten coal-fired and five oil/gas-fired. All installations focus on optimization of NOx emissions and combustion efficiency. Some of them, in addition, optimize steam temperatures and opacity. Also, there are six sites that use Invensys' sootblowing optimization.

Key U.S. power plants with Connoisseur are

- Entergy's Independence #1 and 2, each 800-MW coal-fired (2004);
- Dayton Power & Light's Stuart #1, 2, 3 and 4, each 600-MW coal-fired (2004);
- South Mississippi Electric Power Association's Morrow #1 & 2 (coal);
- NRG Energy's Huntley #67 and 68, each unit 200-MW firing coal (2001); and
- LCRA's Fayette station (coal-fired) and Sim Gideon #1, 2 and 3 gas-fired boilers (total 650 MW).

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3. Power Engineering Magazine, "Process optimizing offers performance boost without major capital improvements", February 2003 issue, page 17.

3.4 NeuCo's ProcessLink

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Description

NeuCo's ProcessLinkTM is a neural-network-based optimization system designed for fossil-fuel-fired power plants. Capabilities include

- Data validation and error-checking
- On-line, automatic retraining of the model
- Data historian
- Option to obtain data from another software or input to a dedicated ProcessLink database
- Sensitivity profiles

In addition to ProcessLink, which is considered the base platform (essential software), NeuCo offers optimizers that focus on specific equipment or objectives:

- CombustionOpt
- SCR-Opt
- SNCR-Opt
- Soot-Opt
- FGD-Opt
- MaintenanceOpt
- PerformanceOpt (unit performance optimization)
- ProfitOpt (optimization among multiple units, too)

ProcessLink runs on standard personal computers.

According to NeuCo, ProcessLink can be operational in closed-loop configuration in about four months from contract signing. More information on project schedule and training requirements are provided in the vendor's web site.

Industry installations and experience

According to NeuCo, there are more than 100 installations with the ProcessLink software. Power plants that are known to have installed ProcessLink include

- Canal Electric's Canal Generating #2, a 565-MW oil- and gas-fired (Babcock & Wilcox once-through subcritical) boiler;
- Arizona Public Services' Four Corners #3, a 250-MW Foster Wheeler boiler;
- Santee Cooper's Winyah units #2, 3 and 4 (each 180-MW Riley turbo boilers);
- Cajun Electric's Big Cajun II # 1 and 2 (each 600-MW Riley turbo boilers);
- LG&E's Roanoke Valley energy facility (two coal-fired units: #1 180-MW and #2 50-MW);
- AES' Harding Street #7, a 429-MW tangentially-fired boiler burning Illinois Basin coal;
- CMS' D. Karn #2, a 265-MW wall-fired boiler;
- Colorado Springs Utilities' Martin Drake #6 and 7;
- Portland's Boardman, a 585-MW unit burning Powder River Basin (PRB) and Utah coals;
- Deseret's Bonanza plant;
- Reliant's
    - Cheswick, a 570-MW T-fired boiler; and
    - New Castle with three operating units, two 103-MW units and one 142-MW unit.

NeuCo also has received $8.4 million co-funding from the US Department of Energy (DOE) to install ProcessLink at Dynegy's Baldwin station. The total project cost is $18.6 million and is expected to develop and demonstrate a host of capabilities including optimization of

- sootblowing,
- SCR,
- overall unit thermal performance, and
- plant-wide production costs.

Industry Partnerships

NeuCo is working closely with Black & Veatch (B&V) to interface PerformanceOpt with B&V's OPM (On-line Performance Monitoring) software.

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4. Smith, S., et al, "Combustion optimization case studies & emerging applications", presented at the Combined Power Plant Air Pollutant Control Mega Symposium, May 19, 2003.
5. Spinney, P, et al, "Colorado Springs Utilities expands combustion optimization system to incorporate advanced instrumentation" presented at the Power-Gen 2002, Orlando, FL.

3.5 Pegasus

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Description

Pegasus' optimization products are part of the DeltaE3TM product line, a tool kit of programs that includes

- DeltaE3 Combustion Optimizer
- DeltaE3 FGD Optimizer
- DeltaE3 SCR Optimizer
- DeltaE3 ESP Optimizer
- DeltaE3 Coal Blending
- DeltaE3 Visual Analysis
- DeltaE3 Performance Index
- DeltaE3 CIA (Carbon In Ash) Predictor
- DeltaE3 Sootblow Optimizer

DeltaE3 evolved from the previous generation of software, including NeuSIGHT (developed by Pegasus), Power PerfecterTM (developed by Pavilion and acquired by Pegasus), and others. The application includes neural-network-based software designed for multi-variable optimization of power plant performance and is customized to fit the specific needs of each power plant or application. Capabilities include the following:

- data validation and substitution;
- pattern recognition;
- on-line self-tuning;
- PERFIndex, a real-time boiler performance index that can be used as an indicator of the impacts of controllable losses on unit performance; and
- linkage to an Intelligence Sootblowing system offered by Pegasus.

Other recent improved features include

- multi-variable predictive controller;
- operation in the Windows platform, as well as in UNIX, the original platform;

- enhancement of the user interface; earlier versions of NeuSIGHT required changes in two different models that were maintained (for example, adjustment in constraints of variables). The new version allows users to make the changes only once.

DeltaE3 is operating system platform-neutral; NeuSIGHT used to run on UNIX requiring a Sun Workstation, but DeltaE3 can run on Windows, too.

Pegasus' typical installation takes about 5-½ months from contract award to full commissioning. More information on project schedule, as well as system design specifications, training requirements, and operator guide, are provided in the vendor's web site.

Acquisitions of optimization technologies

Pegasus has purchased the rights to Pavilion power plant optimization software as they apply to single-unit licenses and incorporated this technology into DeltaE[2]. Some projects that had Pavilion technology at the time of the acquisition upgraded the software to Pegasus; others kept the Pavilion software, which is maintained either by utility staff or by third parties.

Pegasus also acquired Ultramax Corp. with its sequential process optimization software. Since the acquisition, there have been no new projects using Ultramax technology and, reportedly, all plants that had it installed have stopped using it. Pegasus developed a product for industrial boilers that is based on the Ultramax technology.

Industry Partnerships

Pegasus has entered into a partnership with Alstom Environmental Control Systems to develop a range of "environmental control products" focusing on optimizing SCR and FGD systems in addition to boiler performance. Reportedly, they are in the process of developing SCR and FGD optimization modules. Alstom is authorized to license and resell Pegasus products.

A reseller agreement also has been signed with ABB's Industrial ITTM Solutions.

As of October 2004 , Pegasus entered into an alliance agreement with Ready Engineering Corp. to market and license worldwide Ready's intelligent fuel management system for coal-fired power plants.

Industry installations and experience

Pegasus has about 70 installations in U.S. power plants with more plants overseas as well as installed industrial (mainly chemical process) applications. Most of these applications are closed-loop.

Key installations and utilities that are implementing Pegasus products in the United States include the following:

- Ameren was one of the first utilities to install optimization software at its Labadie station, all four units (each 575-620-MW); after Labadie, Ameren installed the application at Meramec #1 and 2 (2004), Rush Island #1 and 2 (2004), and Sioux #1 and 2 (2005).

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[2] *Power Engineering Magazine*, Oct. 2004, pg. 22.

- Cinergy purchased Pegasus software to be installed throughout its power generation system. Although the software has been installed on virtually all of the units larger than 160 MW, a number of them have been turned off by the operators for many of the reasons discussed in this report.
- Carolina Power & Light's Asheville #1 installed the software on a 210-MW wall-fired boiler.
- MidAmerican tried the software successfully first at Council Bluffs #3 in 2002 and Neal 4, then installed it at Neal #1, 2 and 3, Louisa #1, and Riverside #5.
- TXU first tried the software at Big Brown #1 in 2002; then in 2003-04, they implemented it at Big Brown #2, Martin Lake #1, 2, and 3, Monticello #1, 2 and 3, and Sandow #4.
- Georgia Power installed the software at Scherer #1, 2, and 3 (2004-05), with an option to install it on unit #4.

In October 2004, Pegasus was selected by DOE to receive $6.1 million to "demonstrate the capability of sophisticated control processes and advanced sensor technologies to optimize mercury speciation and control from existing lignite and Power River Basin subbituminous coal". This project (valued at a total of $12.2 million) will be implemented jointly with Texas GenCo.

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4

THE EXPERIENCE OF U.S. UTILITIES USING POWER PLANT OPTIMIZATION

This section includes two main parts: 1) a description of the industry's overall experience , especially how many power plants have used optimization and what results they have achieved; and 2) lessons learned from this industry experience.

4.1 General experience of the utility industry

During the last 10 years, optimization software has been installed in approximately 280-300 coal-fired units; 100 to 130 of these systems are still in operation, all of them in close-loop mode.

Developing a definite estimate about the number of plants using optimization software is very difficult and time-consuming; also, many utilities and optimization vendors are not willing to share such information. However, this study's objective is not to count every single project but rather to get an accurate overall picture of what is happening in the industry.

The estimate of optimization systems in operation (100-130) is based on contacts with 15 utilities that have installed optimizers in multiple plants (representing a total of approximately 100 units). This number does not cover all plants with optimizers, but was used to develop an estimate of the general experience in the industry and is considered adequate for the purposes of this report. More specifically, the estimate for the plants using optimization was developed considering a number of different developments:

- ULTRAMAX had approximately 65 installations, none currently operating. In addition to the fact that Ultramax Corp. does not exist any more, Ultramax software was not configured to operate in closed-loop mode and, as such, it stopped operating as soon as plant engineers stopped using it.
- GNOCIS had approximately 20 installations with only one still operating.
- Some Pavilion installations continue to operate while others do not (Pavilion technology was acquired by Pegasus). Based on a sample of users contacted by phone, it is estimated that 50% of the software is still in use. However, these installations either need to upgrade to more advanced versions of the commercially available software or stop operating soon. Availability of maintenance and technical support is a key issue facing these installations. Some plants have obtained technical support from Pegasus, others (for example, Reliant's Conemaugh and Keystone) from third parties, and a few are maintaining the software themselves.
- Thirty to fifty percent of plants that have installed NeuCO and Pegasus software are not using the products any more for a variety of reasons (see below). In many cases, lack of use is not necessarily due to dissatisfaction with the optimization software.

- Emerson reports 108 installations of optimization software, but many of them involve optimization of steam temperatures alone; only 24 coal-fired installations were identified with multi-variable and multi-objective optimization.

In addition to cases where optimization suppliers were acquired or stopped operating (for example, Pavilion and Ultramax), other important considerations have contributed to the decision to stop using an optimization system that had been installed, calibrated, and successfully operated. Key factors contributing to shutting down such optimization systems include the following:

- *The initial motivation for the optimization project no longer exists.* This has been the case with many of the early projects (in the mid-1990s). The Clean Air Act Amendments (CAAA) of 1990 provided incentives for early compliance and flexibility to implement optimization to avoid installation of low-NOx burners or overfire air. However, subsequent regulations required installation of low-NOx burners and (in many cases) SCR systems, which reduced the need for NOx reduction through optimization.
- *Change of hardware required recalibration of the optimization system.* This is closely related to the previous factor and involves mostly installation of NOx controls (for example, low-NOx burners, overfire air, SCR, and SNCR). Also, there were cases in which the economizer or the air heater was replaced or the coal quality changed significantly. Theoretically, such changes do not eliminate the need for optimization. In fact, they provide an additional incentive for optimization. For example, in the case of SCR, an optimum operating point can be sought that reduces the ammonia costs while satisfying NOx emission requirements. However, some utilities found it more practical to shut down their optimization systems. Their main reason was that recalibration of the optimization system, while feasible in many cases, was not simple (certainly not as simple as changing a few parameters by the plant performance engineer, which some software suppliers claimed). Recalibration requires the support and involvement of the optimization supplier, which means additional expenses. So, the perception of some utilities was that the effort exceeded the expected benefit. Getting approval at a time of tight budgets to pay the optimization vendor to assist in recalibration also was perceived as too expensive or too difficult .
- *Operators and performance engineers perceived that the benefits from the optimization system did not outweigh the costs.* While the cost-benefit relationship is very site-specific, most optimization projects that have been evaluated thoroughly have concluded that optimization is very cost-effective, with payback periods less than three to four years and often less than one year. Nevertheless, there is often a perception that benefits do not justify costs, and a decision is made to shut down the optimization system. Examples of such perceptions (in most cases, without proof) were
    - optimization increases furnace slagging and backpass fouling;
    - optimization cannot handle frequently varying coal quality (this was stated by two utilities using lignite);
    - too many variables outside the control of the optimization system (for example, changes in coal quality or condenser backpressure) constrain its ability to achieve significant performance improvement;

- operators did not understand the need for and did not like the frequent operating changes required by the optimization system, especially during software calibration;
- a smart operator can do as well as the optimization system; and
- the job security factor: the optimization system will replace the operator and/or the performance engineer.

- *As soon as the plant champion was transferred out of the power plant, the optimization system was shut down.* This was the case in a number of power plants that successfully completed installation, calibration, and operation of the optimization system.
- *Some older units without DCS and adequate instrumentation installed the software, but it was proven ineffective.* Lack of a digital control system (DCS), lack of adequate instrumentation, and a limited number of control variables (for example, lack of remote capabilities to adjust air registers) were some of the reasons stated for shutting down optimization systems. This experience was recounted by a number of utilities (for example, MidAmerican and Cinergy) that were planning to install optimizers in all units, but stopped short of installing them in old units with inadequate instrumentation and controls.

Many utilities have either a system-wide license or have decided to optimize most of their units.

A number of utilities have obtained system-wide licensing:

- Ameren installed Pegasus at all four units of its Labadie station (each 575-620-MW), Meramec #1 and 2 (2004), Rush Island #1 and 2 (2004), and Sioux #1 and 2 (2005).
- Cinergy (Pegasus) at Cayuga #1 and 2, Gallagher #2 (2002), and remaining plants later on.
- MidAmerican (Pegasus) at Council Bluffs #3 and Neal 4; MidAmerican also plans to optimize Neal #1, 2 and 3, Louisa #1, and Riverside #5.
- TXU (Pegasus) at Big Brown #1 in 2002; in 2003-04, TXU implemented Pegasus at Big Brown #2, Martin Lake #1, 2, and 3, Monticello #1, 2 and 3, and Sandow #4.
- We Energies (Emerson) at Valley Power #1-4 in 1999-2000, Presque Isle #3-6 in 2001, and Oak Creek #7 and 8 in 2004.

Dynegy is the utility that has used the most commercially available optimizers, including Ultramax (in four plants), Pegasus (at Hennepin #1), Emerson (at Hennepin #2), and NeuCO (at Baldwin and Wood River[3]). Dynegy also is planning to install more optimizers at Havana #6 in 2006, Danskammer #3 in 2006, Danskammer #4 in 2007, and Roseton #1 and 2 later on. Dynegy's approach is to evaluate the available optimizers on a plant-by-plant basis.

Optimization proves effective in reducing NOx (5-35%) and heat rate (up to 1.0 percentage point for base-loaded units and higher for load-following or cycling units).

Recent experience confirms earlier reports (for example, EPRI's TR-110718) that NOx reduction in the 5-35% range can be achieved with optimization software. Of course, most well-tuned boilers tend to fall in the lower end of the range (5-20%) depending on the number of control

[3] Both planned projects; not operational yet.

variables available and the operating range for each variable; the higher the number of variables and the wider the operating range, the higher the probability for a higher NOx reduction.

NOx reductions above 25% often resulted from the fact that the unit was not well tuned. In these cases, significant NOx reduction could have been achieved by tuning and using knowledge of NOx formation in boilers before optimization was implemented (for more details, see EPRI TR-110718 and TR-105109[4]).

Heat rate improvement up to 0.5% at full load and higher (up to 1.5-2.0%) at lower loads has been reported. However, these are approximate estimates because it is difficult to monitor heat rate on-line. There also are numerous external (uncontrollable) parameters that may affect heat rate more than controllable parameters that are available to the control system and the optimizer.

Cyclone boilers

Specifically for cyclone boilers starting to implement optimization systems, a concern was expressed by some utilities regarding potential adverse impacts and the likelihood of achieving significant NOx emission reductions and performance improvements. There are a number of cyclone units that have already used optimization software. Two pertinent plants are

- Constellation Power's Crane station #1 and 2 and
- Ameren's Coffeen #2.

Both of these plants have installed Emerson's optimizer. Crane reports[5] NOx reduction in the 17-44% range with an average of 25% over the load range, which is consistent with the experience of other types of boilers.

Utilities in the early stages of deploying optimization in cyclone boilers are

- MidAmerican at Neil #1 (Pegasus),
- Ameren at Sioux #1 and 2 (Pegasus), and
- Dynegy's Baldwin (NeuCo).

The difference between cyclones and other types of boilers is that cyclones have a narrow window of operating conditions and less flexibility (lower number of control variables) to change their operating conditions. The addition of overfire air ports increases operating flexibility and the number of control variables and makes it more suitable for optimization. To optimize cyclone boilers effectively, each cyclone must be monitored and controlled. In most cases, this requires new instrumentation.

The industry is making a significant effort to expand optimization (beyond combustion and boiler performance) and link it to other modules, but the experience is not conclusive yet.

The first expansion of the optimization system is the extension from combustion or boiler performance optimization to include post-combustion NOx controls (SNCR and SCR) and FGDs. Nearly all optimization suppliers are developing such models, but it is not clear yet how valuable integrating these components with boiler optimization will be. For post-combustion

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[4] TR-105109, *NOx emissions testing and optimization for coal-fired utility boilers.*
[5] *Power Engineering*, October 2004, page 72.

NOx control, there is a clear incentive to reduce ammonia costs and optimize catalyst life, both of which can be affected by combustion optimization. However, it is not clear whether integrating a module, such as FGD, offers an added benefit.

Another component considered for integration is sootblowing optimization. Many such systems have been developed recently and optimization vendors are active in trying to integrate them into their product offerings or at least be able to interface with them. So far, we know of no experience of a combustion or boiler optimization system fully integrated with a sootblowing system.

Also, there were plans to integrate on-line heat rate monitors with optimization software. Portland General Electric's Boardman plant was planning to integrate Exergetic Systems' Calculational Engine with NeuCo's optimizer, and Constellation Power's Brandon Shores was planning to link the Calculational Engine with the Pegasus optimizer. Both utilities have abandoned their plans for such integration after encountering a number of problems. No details have been made available regarding specific issues; whether the problems were related to the approach followed at the specific site or were more fundamental to these types of systems could not be determined by this study. The author believes that it is the former; with appropriate configuration and interfacing of these two systems, they should be able to interface without serious problems.

Some vendors claim full integration among many of the above modules, as well as coal blending and maintenance optimization. However, smooth integration and operation has not yet been proven.

Realignment of optimization suppliers continues with more active participation of power plant controls suppliers

With the GNOCIS team becoming less active in the last two years, the leading suppliers of optimization systems are Emerson, Invensys, NeuCo, and Pegasus. The latter two have, from the beginning, developed and applied neural-network-based optimization systems. Emerson and Invensys are traditional power plant controls vendors who expanded their product line to optimization.

There are some differences in the approaches these two groups take, which utilities should take note of:

- Controls vendors are more inclined to offer many "topical" optimization modules and put less emphasis on global multi-objective optimization, which has been the trademark of neural network optimization systems.
- Neural network optimization suppliers have (or more accurately, are developing) a broader array of optimization modules and are expanding the technology envelope to include optimization modules such as SCR, FGD, electrostatic precipitation (ESP), and maintenance, as well as links to enterprise-level software.
- Controls vendors use all techniques available (including neural networks, artificial intelligence, and empirical correlations) on an as-needed basis instead of relying almost exclusively on neural networks.
- Controls vendors also have optimized systems outside the boiler, most notably steam temperature optimization, which has not been the focus of neural network vendors.

- Controls vendors seem to be exerting downward pressure on optimization system costs, including both the system's initial price and maintenance agreements. Most likely, this trend is related to the fact that the incremental cost of offering an optimization system should be lower from those companies that may already have offered a controls system and are already on site providing maintenance support to the utility.

This is not an endorsement of either group; every application has unique characteristics and requirements that may be more suitable for one or the other approach. Also, pricing varies significantly from project to project, making it necessary for utilities to consider all suppliers and evaluate them based on what they are offering for their specific project.

4.2 Lessons learned

All vendors of power plant software are capable of implementing a successful optimization project. Specific individuals involved in the project team could make a difference in a project's success.

Every single supplier of optimization software has demonstrated that it is capable of having a successful project. What has made the difference between successful and unsuccessful projects has been the specific expertise of the individuals involved in the project. While optimization software is capable of handling the optimization task, very often it is up to specific individuals to effectively communicate the project's objectives and operating constraints and, in general, use their knowledge in power engineering, controls, and optimization to achieve the project's objectives. A number of utilities have concluded that it is important to review carefully the resumes of all project participants and (ideally) interview them before selecting an optimization vendor.

For optimization projects to succeed, a corporate commitment to improve plant performance is needed.

There are a number of good examples of successful optimization projects that more than anything else reflect the corporate commitment to performance. This commitment is reflected in the allocation of an appropriate budget, availability of staff both at headquarters and in the plant, installation and calibration of instrumentation, use of modern control systems, and the right emphasis and incentives to performance improvement. Examples of such commitment include the following:

- Ameren Corp. considers plant performance enhancement a capability that gives them a competitive advantage and, as such, they try to build and keep this capability within the organization. For this reason, Ameren's performance engineers are very knowledgeable in power engineering and combustion and are very involved in installing and maintaining optimization systems. Also, they monitor developments in the industry and are prepared to invest in new technologies. However, their "focus is not technology, but achieving results." Recognizing that they may not have all the power engineering expertise, they have a close working relationship with a large architect engineering (AE) company to which they provide on-line access for performance monitoring and seek advice on an as-needed basis. Ameren recognizes that instrumentation is very important and is prepared to add what is needed to make optimization successful. Examples include feedwater heater monitors and on-line condenser air leakage monitors. A "report card system" ensures that all instrumentation and control (I&C) related issues are addressed on a frequent basis (monthly meetings). Each

plant has a performance improvement champion supported by the engineering staff from headquarters. As a result, Ameren has some of the most successful optimization projects, including the four units at Labadie that have had Pegasus optimization software for more than four years and have received national recognition.

- Portland General Electric is another company committed to performance enhancement. While its approach is different from Ameren, it has invested heavily on monitoring and heat rate enhancement and achieved significant improvements at its Boardman station, even though optimization software eventually did not play an important role there. As documented in EPRI report TR-1004749[6], the company invested heavily in
    - new instrumentation, including temperature and pressure measurements in feedwater heaters, turbine cross-over piping, steam turbine inlets, feedwater pump and boiler feed booster pump, additional O2 probes in the stack to account for flow stratification, moisture monitors at the stack, and orifices in steam lines;
    - extensive parametric testing and analysis to determine heat losses and significant heat rate improvement by reducing air in-leakage and eliminating water/steam leaks;
    - installation of an on-line heat rate monitor (from Exergetic Systems); and
    - installation of an optimization system (from NeuCo).

  New instrumentation, parametric testing, and analyses were part of Portland's on-line heat rate optimization that used Exergetic Systems' Calculational Engine™.

In most cases, optimization projects are easily justified by cost-benefit analysis, but very often utility management is reluctant to approve such projects. Having corporate support and commitment is essential for making decisions to implement optimization projects.

Get plant buy-in before starting to implement an optimization project.

There are many optimization projects that have been implemented successfully, but as soon as the project team left the site, plant staff did not continue using them. These were cases where utility headquarters conceived of the optimization project and proceeded to implement it without an effort to get plant staff buy-in. Project success depends almost exclusively on whether plant staff has been convinced of optimization's value.

Plant staff has its own concerns and perceptions that need to be addressed early on; staff needs to be convinced why the project is valuable and how it is going to enhance employees' abilities to better do their job. As mentioned earlier, there are frequent misconceptions that need to be addressed:

- *"The optimization system will replace the operator and/or the performance engineer:"* Obviously, this is not true, but plant operators deserve an explanation on how optimization will allow them to do their job better; they need to be convinced that optimization is giving them the flexibility to change performance objectives, analyze alternative operating conditions, improve set points and, in general, reduce plant operating costs. It should be clear that it is beyond the capabilities of the human mind to monitor a high number of

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[6] On-line Heat Rate Monitor Assessment/Results of the Demonstration and Application of Exergetic Systems' Calculational Engine, Dec. 2004.

parameters and conflicting objectives, and optimization is just another tool to allow us to analyze a complex situation. The plant operator and performance engineer are needed, nevertheless, and the optimization system will not replace them!

- *"Optimization costs outweigh benefits:"* Site-specific evaluations have shown conclusively that this is not the case for most plants. However, plant staff (including plant manager, operators, and performance engineers) needs to be convinced of the value of optimization by credible and detailed analysis.
- *"Optimization increases furnace slagging and backpass fouling:"* This is not a necessary outcome of optimization. If the formulation of the optimization problem is not done appropriately, increased slagging and/or fouling are possible outcomes. However, many optimization projects have demonstrated that not only can such adverse impacts be avoided, but persistent slagging and/or fouling can be eliminated or reduced through optimization.
- *"Optimization cannot handle frequently varying coal quality:"* Similar to slagging and fouling, variability in coal quality can be handled adequately. Of course, a sudden and substantial change in coal quality would require that the optimization system be recalibrated for the new coal.
- *"A smart operator can do as well as the optimization system:"* As mentioned earlier, this is true when the number of parameters (control variables) is limited and there is a single objective (for example, reduce NOx emission or improve boiler efficiency). However, with many parameters being monitored and the need to optimize multiple and often conflicting objectives, it is nearly impossible for a plant operator to achieve optimum results without a well-designed optimization system. For example, the objective may be to balance NOx reduction with heat rate improvement, unburned carbon, and economics related to consumption of ammonia (in the SCR/SNCR) and sorbent (in the FGD). It is impossible for an operator to keep track of so many parameters and objectives and to identify the optimum solution.
- *"Operators do not understand the need for and did not like the frequent operating changes required by the optimization system, especially during software calibration:"* This is, indeed, an issue that is encountered in many plants. In fact, the more knowledgeable the plant engineer is on power engineering design and operation, the more difficult it is to accept the need to frequently change operating conditions so the optimization system can "learn" the plant's performance characteristics. Training should address this issue and provide engineers with a good understanding of how the optimization system is learning the plant's characteristics.

One approach utilities may consider is to have a demonstration project in one of its plants during which engineers and operators from other plants have a chance to participate and learn before the system is implemented in their plant. Such projects also may provide an opportunity to create "a team of champions" who can be assigned to the other plants to assist in implementing optimization projects.

Make sure there is a "plant champion."

A plant champion is not necessarily a promoter of optimization, but rather somebody who is able and willing to use the optimization system and can assist others in using it as the need arises. The plant champion has been trained to modify the settings of the optimization system, use it to

analyze specific operating conditions, troubleshoot it, and, in general, use it to improve plant performance. Most often, the plant champion is a performance engineer.

Having a champion at the plant was singled out as the key element that contributed to the success of optimization projects. Examples:

- Ameren's Labadie consistently achieved excellent results by having one electrical and two mechanical engineers dedicated to providing performance improvement support, part of which was for optimization.
- Similarly, Dynegy's Hennepin plant was equipped with Pegasus on Unit #1 and Emerson software on Unit #2; originally there were two engineers on site and one at headquarters who provided optimization support.
- There are numerous cases where a successful project was terminated as soon as the plant champion moved out of the plant. For example, application of GNOCIS software was completed successfully at TVA's Kingston Unit #9. However, after the optimization champion moved to another plant, optimization was not used and plans to apply it to the plant's remaining units were changed. The same outcome occurred at three Dynegy plants that implemented Ultramax optimization.

The implementation team of an optimization project needs to bring together expertise in 1) power plant engineering (knowledge of power plant design and operation), 2) instrumentation and controls, and 3) optimization techniques.

Knowledge in all three areas (power plant engineering, I&C, and optimization) is essential for the success of an optimization project. It is not important whether an expert is part of the utility staff or the optimization vendor as long as the expert is available and committed to support the project when needed. There are many examples in which a vendor who had just completed a very successful project failed in a new project simply because the people with the right expertise were not available.

Often, some of the expertise, especially in power engineering and I&C, resides with the utility, either at headquarters or the plant or both. It is important to make sure that such experts are available to support the project.

The level of expertise available in-house varies significantly from utility to utility, and frequently the need arises for certain experts to be provided by the optimization vendor. In the 1990s, when optimization software first came on the market, many vendors had adequate expertise in optimization techniques and software engineering, but very limited expertise in power engineering and I&C. Since then, most of them have recognized the need for such expertise and have hired the right people.

However, optimization vendors have gone through phases when they did not have adequate expertise in power engineering and I&C. This lack of expertise was due to staff turnover or varying volumes of business, which forced them to lay off experts. There were other times when too many projects were being implemented at the same time, and the few experts they had in these technical areas (power engineering and I&C) were not available to support all projects.

Many utilities recommended (and we concur) that

- *you should request resumes of all the people provided by the optimization vendor;*
- *if possible, you should ask to interview these vendor experts; and*
- *you should ask for assurances (in writing) that the experts will be available and committed to your project.*

Furthermore, it is ideal to keep the implementation team together for multiple projects (in more than one unit and power plant) of the same utility. For example, TXU noted that they were very fortunate to have the same team implement optimizations at six different power plants. The fact that all these units were tangentially-fired boilers (similar design) helped, too.

Long-term maintenance and technical support by the optimization vendor is a must.

A long-term technical support agreement with optimization suppliers is highly recommended. The strategy of some utilities is to build expertise in-house in the use, modification, and maintenance of the system. Even in these cases, optimization vendors could be helpful (for example, when significant changes in the equipment or the operating conditions require recalibration of the optimization system). Also, the utility should have access to software upgrades that improve its usefulness and add capabilities. The long-term maintenance-technical support agreement can be designed to fit the needs of each utility and power plant.

Following are two examples covering the spectrum of support provided by optimization suppliers:

The minimum support case: Ameren has a maintenance support agreement with the optimization supplier (Pegasus for most of its plants), but the support provided is minimal. Ameren staff is using the optimization system and has become familiar with most adjustments that need to be made as part of routine operation and minor software maintenance. The optimization supplier is called to address only major changes and problems (on demand only, since no electronic access has been provided).

The maximum support case: The Roanoke Valley Energy facility (part of Louisville Gas & Electric) is a small utility and has a technical support agreement with NeuCo, which monitors the optimization system remotely and makes all required changes. Sometimes NeuCo makes changes based on what it sees in the optimization system and sometimes in response to requests from plant staff.

Maintenance support agreements are not fixed price, and significant differences have been observed from supplier to supplier. Utilities also have been able to negotiate agreements at very reasonable costs, depending on how the overall project has progressed (for example, whether the utility is satisfied with the overall performance, and whether the vendor was able to meet guarantees).

Remote access by the optimization vendor is a must.

Most utilities started implementing projects without giving remote access to the optimization vendor. Soon, they realized the value of providing such access, which has become a standard feature in most projects. As soon as remote access was arranged, there was usually significant improvement, especially in the reliability of the optimization software and the results achieved.

There are two types of remote access:

- Full access
- Access on demand

In the first case (full access), which is the most common and most effective, the optimization vendor can log into the plant optimization system anytime and make changes. Of course, changes are made after consultation with plant staff or based on an agreed-upon protocol. In the second case (access on demand), the optimization vendor has to call utility staff to obtain access.

With cyber-terrorism being a major concern for utilities, remote access may not be as simple as it used to be. First of all, there are communication standards that are being developed and used industry-wide. For example, software should be compliant with the Electric Utility Cyber Security Guidelines (NERC 1300/CIP 002-009). Utilities and optimization vendors should be aware that these standards are revised periodically.

Each utility has established guidelines that need to be followed to provide access to third parties (including passwords and security clearance procedures). These guidelines need to be made available to optimization vendors during bidding or negotiations, certainly before the contract is finalized and project implementation starts.

In some cases, optimization vendors may provide remote client software, which facilitates remote access for tuning and monitoring. Also, the preferred communication method—VPN (Virtual Private Networking), modem, or access through DMZ servers—needs to be specified.

Schedule: Allow for a minimum of five to six months from kick-off meeting to closed-loop operation.

Optimization vendor estimates of the time from kick-off meeting to closed-loop operation of the optimization software range from three to six months. Utility experience has proven that it is more realistic to plan for five to six months. Certainly, there have been projects that were implemented in four months, but there also are others that required more than 12 months. In some cases, extended schedules resulted from difficulties calibrating the optimization system. In other cases, delays were not related to the optimization system, but to plant issues. Such issues included lack of critical instrumentation, plant staff decisions to wait until significant hardware or operating changes were made to the plant, and longer-than-expected delivery of computer hardware or instrumentation. There were two cases where schedules were delayed more than 12 months because the optimization system did not meet guarantees, and plant staff decided to wait until hardware changes were completed before attempting to recalibrate the optimization system.

The project start date also is a factor that may affect the schedule. Minimum duration should be expected when the optimization project starts in early spring or early fall, and there are no outages planned for units that will be optimized. In this case, the units have more flexibility in terms of operation (system dispatch requirements are less demanding during spring and fall) and are least likely to be affected by adverse weather conditions.

A typical project schedule is outlined below:

	Weeks from kick-off meeting
• Contract award and kick-off meeting	0
• Workplan, functional design, and test plan review	6
• Hardware acquisition and integration for plant data acquisition	8
• Problem formulation, optimizer on-line and model development	12
• Data acquisition, model calibration, and testing	22
• Closed-loop integration	24
• Acceptance testing and training	25

Acceptance testing could take as little as one day or up to one month. The schedule above assumes that acceptance testing is one week.

Different optimization vendors have different requirements in terms of

- use of historical data,
- need for parametric testing, and
- model development (off-line or automatically).

Such activities may stretch or reduce the project's duration .

Optimization of multiple, identical units at the same plant could be done in a shorter schedule. After the first unit at the plant is optimized, the next unit could take 30-40% less time. While optimization of many units in parallel is feasible, it is not recommended. However, after the first unit is optimized, parallel optimization of the remaining units is less likely to encounter problems.

Typical costs for an optimization project

The costs of optimization projects should include the following:

- Out-of-pocket costs for software acquisition and installation
- Out-of-pocket cost of annual maintenance
- Internal costs for
    - Software acquisition and installation
    - Software maintenance and use

Out-of-pocket costs for software acquisition and installation

The average out-of-pocket cost for recently implemented optimization projects (based on at least 10 power plants that reported costs, as well as estimates provided by optimization vendors) is $400,000 for the first unit and $300,000 for the next unit at the same plant. However, the most recent projects show clear downward pressure on prices with suppliers willing to reduce prices by 30-50% below the $400,000 level. This downward trend is expected to continue, but it is not

easy to predict whether prices will stabilize at a certain level or continue their downward spiral. A price in the range of $200,000-300,000 for the first unit seems possible within the next few years.

The above estimates include computer hardware (which should not cost more than $5,000), but do not include instrumentation that may be needed to enhance the effectiveness of the optimization system.

Out-of-pocket cost of annual maintenance

Annual maintenance costs are negotiable and range from zero to about $50,000 per year. No cost (zero) has occurred when the optimization supplier has installed a new controls system at the same site. Zero cost also has resulted when the supplier did not meet optimization project guarantees and offered maintenance free of charge for a couple years. For planning purposes, maintenance support agreements should be calculated in the $20-40,000 range per year.

Internal costs

These costs are usually overlooked; also, they are more difficult to estimate. Software acquisition, installation, and calibration are a project's most labor-intensive tasks. Assuming six months for installation, calibration, and closed-loop integration, it is estimated that three man-months of a performance engineer are needed, including training. This is approximately 50% of one engineer during this period of time. If more engineers are involved, the estimated level of effort may reach four man-months.

During software use (after calibration is completed and optimization is operating in closed-loop mode), an engineer responsible for the optimization system should monitor it periodically, adjust objectives, maintain it as needed, communicate with the optimization vendor, and use it to analyze plant performance.

Ten to twenty percent of an engineer's time is needed for an optimization system once it has been integrated to operate in closed-loop mode. Utilities interviewed suggested that 10% of an engineer's time is a minimum and 15-25% is most desirable. For example, one assigned plant engineer indicated that he spends 5% of his time with the optimization system, but according to him this is clearly inadequate.

Export Control Restrictions

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