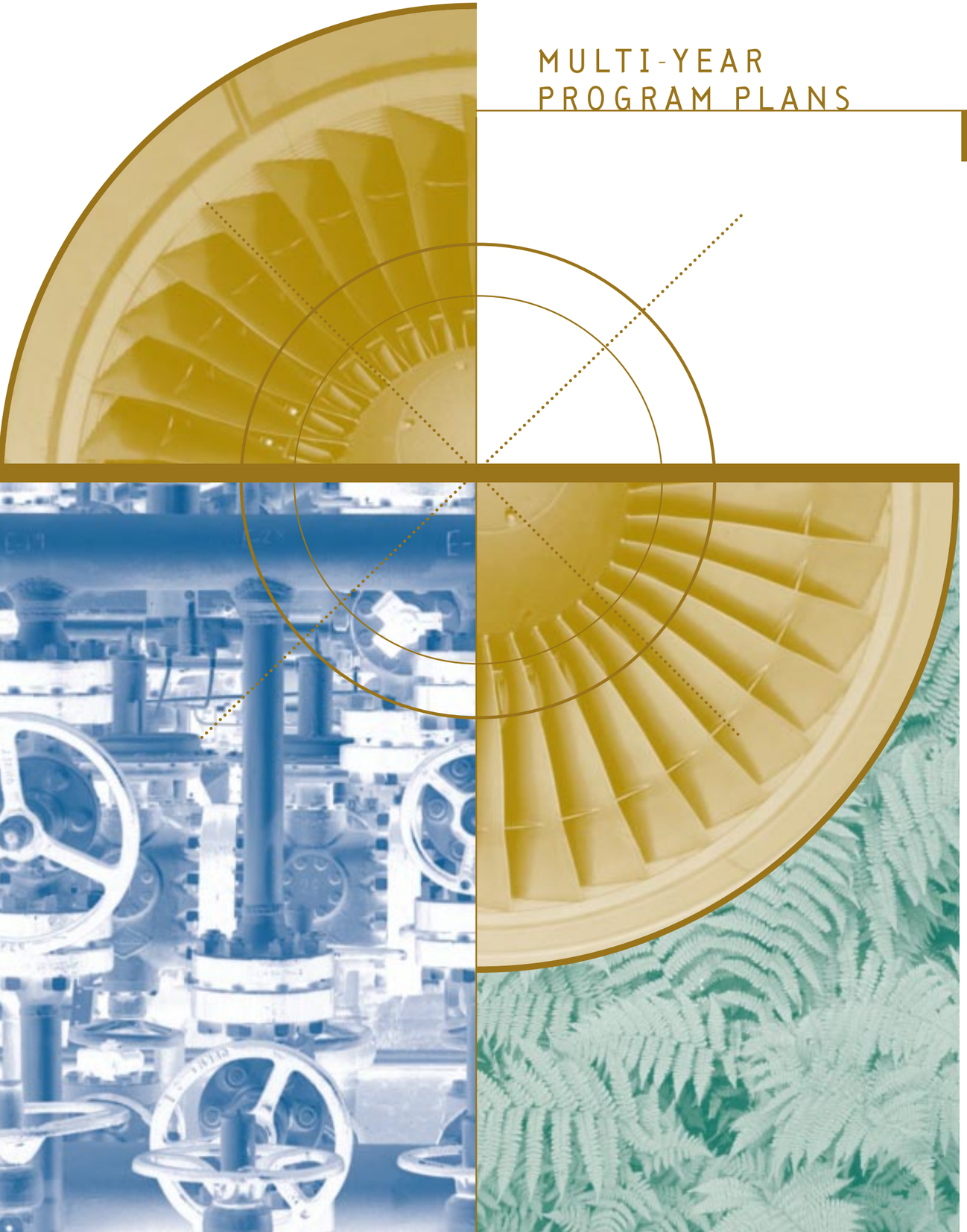

MULTI-YEAR PROGRAM PLANS

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TECHNOLOGIES FOR EXISTING PLANTS

COST-EFFECTIVE SOLUTIONS FOR TODAY'S FLEET

cost-effective

solutions

DOE IS DEVELOPING TECHNOLOGIES TO HELP EXISTING POWERPLANTS MEET ENVIRONMENTAL STANDARDS, INCREASE EFFICIENCY, AND IMPROVE OVERALL PERFORMANCE.

PROGRAM AREAS

Advanced Environmental-Compliance Technologies

- Advanced Control Systems
- Ambient Air Quality Monitoring
- Air Toxics
- Combustion By-Products Utilization

Improved Plant Efficiencies and Performance

- Repowering
- Advanced Computer-Based Controls

INTRODUCTION

ENVIRONMENTAL CONCERNS ARE THE DRIVING FORCE

The environmental drivers influencing the operation of existing coal-fired powerplants over the next decade are being defined today. Key environmental regulations have been proposed or promulgated over the past year establishing a basis for new technology needed to comply with them:

- Revised National Ambient Air Quality Standards (NAAQS) for fine particulate matter and ozone.
- Instructions to revise State Implementation Plans to address ozone concerns in the eastern U.S.
- Petitions by northeastern States for the Environmental Protection Agency (EPA) to require upwind States to reduce emissions of nitrogen oxides (NO_X) from powerplants.
- Requirements for States to address regional haze.
- Proposals to regulate mercury emissions from powerplants.

The cost to comply with these regulations is expected to be several billion dollars per year; the research challenge is to find improved technologies that dramatically reduce these costs and fill technology gaps.

STRATEGIES AND TIMING

It is imperative that needed technologies be developed through cost-shared collaboration between government and industry quickly enough to allow for demonstration and deployment prior to regulatory deadlines. Some of these regulations are already promulgated and their requirements must be met soon. For example, instructions to revise State Implementation Plans to address ozone concerns in the eastern U.S. will lead to State requirements for most eastern U.S. coal-fired powerplants to significantly reduce NO_X emissions (to 0.15 pound per million Btu) by 2003. Utilities are already ordering hardware for compliance. On the other hand, western U.S. powerplants are not subject to these regulations, but may need similar reductions to meet future regional haze or fine particulate matter ($PM_{2.5}$) standards in the 2007 to 2015 time frame. Because most of these regulations on the horizon are not yet finalized, and because the timing of implementation of the regulations has not yet been clearly articulated, judgment must be used in estimating the effectiveness and timing of needed technologies. Objectives being pursued in this program element are:

- Develop and demonstrate extremely low NO_X burner technologies (augmented by advanced computer-based controls) intended to provide the lowest-cost option for use on dry-bottom boilers, by October 2000.
- Further refine high-efficiency NO_X reduction technologies, such as selective catalytic reduction (SCR), to reduce compliance costs for wet-bottom boilers, by October 2000.
- Develop and demonstrate technologies to address mercury emissions by 2004.
- Develop a database in partnership with other public- and private-sector organizations on the sources and receptors of ambient fine particulate matter in support of NAAQS attainment/non-attainment determinations and State implementation strategies.
- Develop and transfer to industry the technology base for the cost-effective and environmentally acceptable utilization of coal-combustion by-products.

BENEFITS TO THE NATION

Environmental and economic security. Advanced technologies for improved plant performance and environmental compliance will yield benefits to human health as well as to the environment, and will result in cheaper, more efficient electric power.

Essential reductions in emissions. Specific benefits to the U.S. by 2010 will include reduction of emissions of SO_2, NO_X, and primary particulate matter from coal-based power systems to levels determined necessary to address human health and environmental concerns. Such concerns include ozone, $PM_{2.5}$, visibility impairment, acidification, and eutrophication.

Energy security. Electric power from indigenous coal resources will continue to be an integral component of the Nation's overall energy mix, thereby ensuring that the U.S. maintains a position of energy independence and security.

Continued value of investments. The existing infrastructure at older fossil-energy powerplants will be maintained using repowering and cofiring technologies.

Lower-cost electricity. Improvements in the efficiency and environmental and operating performance of existing powerplants will result in a lower cost of electricity. In fact, the U.S. could save up to $7 billion per year because of lower-cost environmental-control technologies to meet new standards.

- Develop and transfer to industry operational, performance, and cost information on advanced repowering, cofiring, and advanced computer-based control systems.

ACHIEVEMENTS TO DATE AND IN THE FUTURE

The U.S. electric utility industry has made major strides in reducing emissions of SO_2, NO_X, and particulates since passage of the 1970 Clean Air Act and its subsequent amendments. Emissions of SO_2 have been reduced from 1980 levels of 10.9 million to 5.3 million tons. NO_X emission rates from utility boilers are 40% below 1990 levels, from an average of 0.65 lb/mm Btu to an average of 0.39 lb/mm Btu. Particulate emissions from the utility sector have decreased by nearly one-third since 1988.

DOE-industry partnerships developing technologies needed for existing plants are expected to accomplish these goals:

- Postcombustion NO_X control technology that is capable of meeting NO_X emission standards for ozone mitigation at a cost 25% to 50% less than stand-alone SCR will be available by 2003.
- Postcombustion control technology that is capable of increasing the overall collection efficiency of primary fine particulates to 99.9%, especially for small particles in the 0.1 to 1.0 micron range, will be developed and demonstrated by 2005.
- Technologies that increase the utilization of high-volume coal-combustion by-products (fly ash and scrubber sludge) as well as create high-value uses of solid materials generated from advanced coal combustion systems will be available by 2000. Effective use of the solid by-products from coal combustion will be considered to be a "common business practice."

Coal combustion by-products are proving useful for such applications as the construction of this cattle lot.

TECHNOLOGIES FOR EXISTING PLANTS

- A suite of mercury-control technologies that remove all forms of mercury from coal-combustion flue gas will be developed and demonstrated by 2005.
- Technologies for repowering steam powerplants will be viewed as a preferred way to utilize existing powerplant assets by 2010.

ADVANCED ENVIRONMENTAL-COMPLIANCE TECHNOLOGIES

ADVANCED CONTROL SYSTEMS

The Advanced Environmental Control Systems subprogram focuses on the development of cost-effective environmental control technologies and systems that are able to meet current and future restrictions on the emissions of SO_X, NO_X, and particulate matter (PM) from the electric utility sector. It provides the scientific underpinning necessary to identify control technology needs and research priorities and to foster informed decision making. This part of the Coal and Power Systems Program helps to ensure that our indigenous coal resources are utilized in an environmentally sound manner, so that they can continue to be an integral component of the Nation's overall energy mix.

Areas of focus are:

- Developing postcombustion control technology—such as SCR, SNCR, and advanced reburning—capable of achieving significant NO_X reductions in response to environmental issues such as ozone transport, ambient fine particulates, acid rain, and eutrophication.
- Determining the formation, transport, and chemical composition of ambient fine particulate matter in order to better understand the relationship between anthropogenic emissions of SO_X, NO_X, and PM and ambient air quality.
- Improving the collection efficiency of particulate-control technology, especially fine particles in the submicron-size range, including both retrofits to conventional emissions-control hardware, such as electrostatic precipitators (ESPs), and the development of advanced systems.

Projects in Advanced Environmental Control Systems involve DOE-industry collaborations. Working with American Electric Power, several other utilities, and the Electric Power Research Institute (EPRI), DOE is field-testing an SNCR NO_X-control system on a 640-megawatt (MW) coal-fired unit located at the Cardinal power station in Ohio. This is a first-of-a-kind demonstration of this technology on an electric-utility boiler of this size. Utilities are considering SNCR systems to meet the emission reductions that will be required under the proposed NO_X emission regulations to address summertime ozone.

AMBIENT AIR QUALITY MONITORING

In response to the $PM_{2.5}$ National Ambient Air Quality Standards, DOE is also collaborating with EPA, EPRI, and the utility industry in the operation of several ambient monitoring sites to collect information critical to understanding the impact of coal-based power systems on air quality.

In DOE's Upper Ohio River Valley Project, an air sampler in Greene County, Pennsylvania, verifies that $PM_{2.5}$ standards are met and collects representative samples for detailed information on the chemical composition of fine particulate matter in outdoor air.

In the Upper Ohio River Valley Project, four monitoring sites will be located in the tri-state area around Pittsburgh, Pennsylvania. These sites will offer a comparison of ambient $PM_{2.5}$ in rural and urban settings, providing an understanding of local and regional pollutant transport issues. DOE is also participating in ambient $PM_{2.5}$ monitoring and characterization studies with the Tennessee Valley Authority in Great Smoky Mountain National Park and with Southern Company Services in the Atlanta, Georgia, area.

AIR TOXICS

Air toxics research promotes the development of postcombustion control options for mercury, particularly vapor-phase mercury. The emphasis is on augmenting the effectiveness of existing control technologies to enable capture of all chemical forms of mercury. The control approaches being investigated include sorbent injection upstream of a particulate-control device, such as an ESP or baghouse, enhanced removal across a lime- or limestone-based wet scrubber, and novel, stand-alone technology.

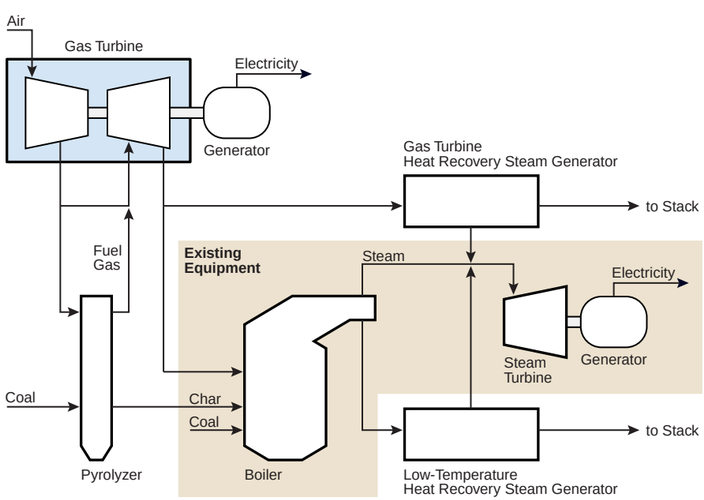
For example, the Advanced Emissions-Control Development Project is focused on evaluating and developing cost-effective strategies for controlling mercury from electric-utility boilers and making maximum use of existing emissions-control systems such as wet scrubbers, ESPs, and fabric filters. Under the Carbon-Based Sorbent Injection for Mercury Control Project, jointly funded by DOE and EPRI, Public Service Company of Colorado is evaluating the mercury-capture effectiveness of various carbon-based sorbents.

COMBUSTION BY-PRODUCTS UTILIZATION

Combustion by-products utilization focuses on developing new technologies and improving existing technologies for environmentally beneficial utilization of coal-combustion by-products from power systems. The emphasis is on by-products whose supply has traditionally far outpaced utilization capacity (flue-gas desulfurization [FGD] sludge and high-carbon fly ash) and the by-products from advanced power systems developed under DOE's Clean Coal Technology Program.

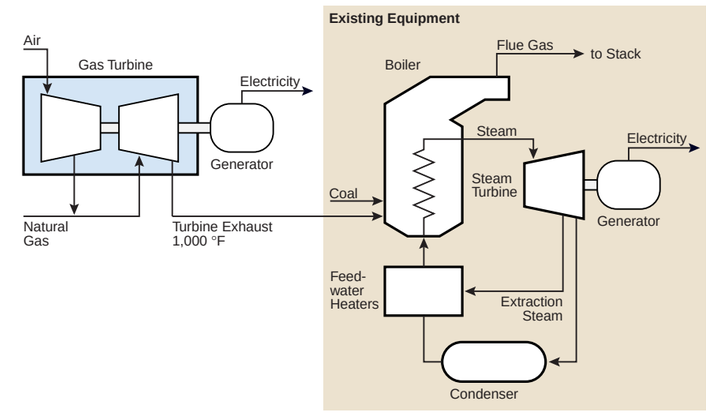
This issue is addressed through outreach activities that include facilitating technology transfer of data from DOE-sponsored coal combustion by-product (CCB) utilization projects to State regulators and CCB users. Field-scale demonstrations are under way that use large volumes of FGD material and fly ash to reduce surface subsidence and acid mine drainage and produce aggregate for transportation and other construction materials. The subprogram also includes product development for fly ash that contains large amounts of carbon.

REPOWERING



Repowering with a high-efficiency clean coal power system leads to an increase in net power capacity and net relative plant efficiency.

HOT WINDBOX REPOWERING



The hot windbox repowering approach, where hot turbine exhaust replaces the air entering the boiler, increases generating capacity up to 25%, and increases efficiency by as much as 15%.

DOE is implementing a CCB consortium managed by West Virginia University to form partnerships with the utility industry, other Federal and State agencies, universities, and special-interest groups to enhance the use of CCBs. The consortium will leverage Federal funds to initiate research projects, from feasibility studies through demonstration field tests, that have the potential to increase the options available to coal producers and users for disposition of CCBs.

IMPROVED PLANT EFFICIENCIES AND PERFORMANCE

Improving the efficiency and performance of the existing fleet of over 300 gigawatts of coal-fired powerplants with new equipment and technology could be one of the most cost-effective means of transforming older, underperforming plants into cleaner, lower-cost producers of electricity.

REPOWERING

The in-place fleet of fossil electric-generating plants continues to wear and age, with many units reaching 40 and 50 years of service. The U.S. power industry is being restructured and deregulated into a competitive market, with electricity being sold as a bulk commodity. Demand is for the lowest cost of electricity. Many existing plants will reach a point where they are worn out, are too inefficient to compete, face significant costs to upgrade emission controls, or must contend with any combination of these factors. Options include extensive refurbishment to extend the life of these units, retirement of aging units, replacing them with new capacity, or repowering them. Repowering uses existing equipment in the plant while integrating new technology, such as gas turbines, to allow the plant to produce more electricity than the original design.

The cost of new generating capacity, combined with the difficulty in obtaining permits and developing new plant sites, makes repowering an attractive option. Repowering existing coal-fired steam-generating units can boost generating capacity, improve efficiency, and reduce CO_2, SO_2, NO_X, and particulate emissions—all at competitive costs. The additional capacity and the typically low production cost of a highly efficient, coal-fired, advanced power system translates into high-capacity factors and a steady revenue stream. By comparison, life extension provides no major improvements in generating capacity or production cost.

One common option is hot windbox repowering. In this approach, hot exhaust from a gas turbine replaces the air entering an existing boiler, eliminating the need for forced-draft fans, increasing generating capacity up to 25%, and increasing efficiency by as much as 15%. Generally suitable for newer units larger than 300 MW, hot windbox repowering can be a low-cost option.

AN ENVIRONMENTAL SUCCESS STORY: LOW-NO_X BURNERS

A quarter of the coal-fired capacity in the U.S. today uses low-NO_X burners developed through DOE investment, significantly reducing emissions of one of the chief pollutants responsible for smog and ozone buildup.

A portfolio of cost-effective NO_X-control technologies suitable for the full range of existing boilers is now available. Three major new low-NO_X burners are now widely marketed, and sales of these will reach $4 billion in the next couple of years. Gas reburning has also been successfully demonstrated on a number of different boilers, reducing NO_X by over 65%. This process breaks down NO_X into environmentally benign gases by using natural gas or finely ground micronized coal to reburn the residues of coal-firing. The Generic NO_X Control Intelligent System is the latest innovation to lead the way to the zero-NO_X plants of the future.

The costs of reducing NO_X emissions by retrofitting powerplants are now up to 90% lower than they would have been without the Federal government's research investment.

Feedwater heating is another low-cost repowering option. In this approach, heat from the exhaust of a gas turbine is used to heat feedwater for the existing boiler. The benefits are a capacity increase of up to 30% and an efficiency improvement of 5% to 10%.

Repowering is made even more attractive because a suite of flexible advanced power system technologies developed through DOE sponsorship are available, allowing an optimum repowering strategy to be developed for site-specific situations. By repowering with clean, efficient power systems, such as a pressurized fluidized-bed combustor, integrated gasification combined cycle, or high-performance power system, net power capacity increases from 20% to 175% and net relative plant efficiency increases of over 30% can be achieved.

ADVANCED COMPUTER-BASED CONTROLS

Improving the way that existing plants are operated is an effective way to improve their environmental performance, reduce cost, and increase efficiency.

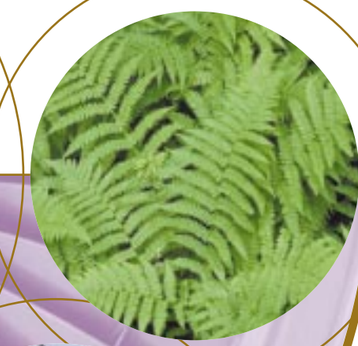
Modern control systems have significantly improved the operating performance—in terms of both cost and environmental performance—of coal-fired powerplants. However, the complexity of the optimization problem has limited the benefits achieved by conventional systems. This complexity can be overcome by embedding artificial intelligence or other advanced computer-based approaches in a powerplant's digital control system.

One of these artificial intelligence systems—the Generic NO_X Control Intelligent System (GNOCIS™)—was demonstrated at Georgia Power Company's Plant Hammond Unit 4 (a 550-MW opposed wall-fired unit), where it is fully operational and has achieved an efficiency improvement of 0.5%, a 3% reduction in the unburned carbon content of the unit's fly ash, and a 15% reduction in NO_X emissions at full load. This performance would allow a typical eastern U.S. powerplant rated at 1,000 MW to reduce its coal consumption by up to 25,000 tons per year. GNOCIS™, developed jointly by DOE, EPRI, PowerGen, Radian International, Southern Company, and the U.K. Department of Trade and Industry, is designed to operate on units burning gas, oil, or coal and is available for all combustion firing geometries. To date, 20 coal-fired plants have installed GNOCIS™. Adding these plants to the 15 powerplants that are in preliminary stages of applying this system of advanced computer-based controls suggests that by 2000 there will be 20,000 MW of power-generating capacity garnering the benefits of GNOCIS™.

NEAR- AND MID-TERM DEVELOPMENT AND DEMONSTRATION

POWER AND FUELS PRODUCTION FOR THE FUTURE

ultra-clean



ADVANCED COAL AND POWER SYSTEMS WILL ENABLE CLEANER, MORE EFFICIENT USE OF DOMESTIC FOSSIL ENERGY RESOURCES FOR GENERATING LOW-COST ELECTRICITY AND PRODUCING LIQUID AND SOLID FUELS, AND CHEMICALS.

ultra-efficient

PROGRAM AREAS

Clean Coal Technology Demonstrations

- Advanced Electric Power Generation
- Environmental Control Devices
- Coal Processing for Clean Fuels
- Industrial Applications

Power Systems

- Advanced Turbine Systems (ATS)
- Low-Emissions Boiler System (LEBS)
- High-Performance Power Systems (HIPPS)
- Fluidized-Bed Combustion (FBC)
- Integrated Gasification Combined Cycle (IGCC)

Fuels

- Transportation Fuels
- Solid Fuels and Feedstocks

INTRODUCTION

RESPONDING TO NEW MARKETPLACE REALITIES

DOE programs developing coal and power systems are responding to dramatic changes occurring in the energy marketplace. Energy industry deregulation could create intense cost-reduction pressures on power producers; DOE programs are geared to provide these producers with cost-competitive solutions to environmental challenges. At the same time, gas, electric, and oil companies are merging into larger business entities that are investing less in research. Therefore, DOE programs must leverage limited private-sector research dollars more effectively than ever. Deregulation is also creating new markets for energy products, like Vision 21 plant concepts that will use gas, coal, and biomass fuels to generate a mix of products that include electricity, liquid fuels, and chemicals, with virtually zero environmental impact.

STRATEGIES FOR SUCCESS

Specific strategies for the near- and mid-term development and demonstration program are to:

- Conclude commercial-scale demonstration projects in the Clean Coal Technology (CCT) Demonstration Program by 2005.
- Perform technology readiness and full-scale testing for two alternative natural-gas utility-scale Advanced Turbine System (ATS) concepts by 2002.
- Demonstrate proof-of-concept for a low-emission boiler system (LEBS), advanced pulverized-coal-fired powerplant by 2003.
- Develop high-performance power system (HIPPS) designs for large commercial plants, prototype plants, and repowering applications.
- Remove technological limitations on hot-gas filtration to achieve the full performance potential of fluidized-bed combustion (FBC) plant designs by 2002.
- Extend the superior environmental performance of integrated gasification combined-cycle (IGCC) systems beyond electric power generation to production of market-based energy and chemical products.
- Reduce the cost of producing coal-derived transportation fuels from $30 to $21 per barrel.
- Enable coproduction of power, liquid fuels, and premium carbon products from coal and fuels containing biomass or solid waste.

These strategies are yielding measurable benefits to the U.S. economy and environment. As the CCT program is being completed, for example, it is making readily available to industry a compendium of operational, technical, environmental, and economic performance data and experience on advanced, highly efficient fossil power technologies. The results will demonstrate to developers and users that these advanced power technologies provide benefits that far outweigh the risks often associated with new technology investments.

The U.S. will also realize economic benefits from exporting clean energy technologies resulting from DOE programs. International opportunities for advanced fossil energy technology exports are enormous. It is estimated that the annual worldwide demand for energy will reach 542 quadrillion Btu by 2015, 1.6 times the current level. Coal is expected to account for about 25% of this demand. The total worldwide market for new powerplants will be approximately $2 trillion between 2000 and 2030. The U.S. has the potential of capturing a large portion of this market—more than $480 billion in revenues, supporting 600,000 U.S. jobs over three decades.

Programs to produce liquid fuels from coal could also yield substantial economic and energy security benefits. Increasing production of liquid fuels by 1 million barrels per day using liquefaction technologies would reduce our Nation's balance of payments by $130 billion between 2015 and 2030.

A domestic industry based on converting coal into 2 million barrels per day of liquid fuels would provide, by 2030, more than 660,000 high-paying jobs in coal mining, manufacturing, and management, as well as jobs in indirect supporting labor, and would attract as much as $100 billion in new investments. Further, coal-derived fuels could "cap" imported oil prices. A $1 savings in the price per barrel of oil could yield a $6-billion-per-year benefit to our economy.

Coal-derived liquid transportation fuels provide significant environmental benefits. Fuels such as Fischer-Tropsch diesel or dimethyl-ether-derived diesel could enable the design of modified diesel engines with improved efficiencies and up to 47% reduction in emissions.

CLEAN COAL TECHNOLOGY DEMONSTRATION PROGRAM

The Clean Coal Technology Demonstration Program was implemented through a series of five nationwide competitive solicitations conducted over a 10-year period. The first solicitation selected technologies to balance the goals of expanding coal use and minimizing environmental impact. The next two solicitations favored technologies to mitigate potential impacts of acid rain from existing coal-fired powerplants. The fourth and fifth solicitations addressed post-2000 energy supply-and-demand issues: the capping of sulfur dioxide (SO_2) emissions in the Clean Air Act Amendments of 1990, the increased need for electric power, and the need to alleviate concerns over global climate change.

Now that more than half of the resulting projects have been completed, the value of the program is clear.

PERFORMANCE OF NEAR- AND MID-TERM COAL AND POWER TECHNOLOGIES

		Cost Performance			Environmental Performance			
Program Area	**Target Year**	**COE** [Note 1]	**Capital** [Note 2]	**Efficiency** [Note 3]	**SO_X** [Note 4]	**NO_X** [Note 4]	**CO_2** [Note 5]	**Particulate** [Note 6]
ATS (gas)	2002	10% lower	10% lower	60% (LHV)		<10 ppm	67% less	
LEBS	2002	10% lower	lower	45%	0.1	0.1	23% less	0.01
HIPPS	2008	20% lower	10% lower	55%	0.06	0.06	36% less	0.003
FBC	2008	$0.045	$950	52%	0.06	0.06	33% less	0.003
IGCC	2008	$0.045	$1000	52%	0.06	0.06	33% less	0.01

Notes
1—Cost of electricity (COE) in $ per kilowatt-hour. Lower refers to comparison with today's technology.
2—Capital cost in $ per kilowatt. Lower refers to comparison with today's technology.
3—Efficiency based on higher heating value unless noted otherwise.
4—Values as pounds-per-million Btu unless noted otherwise.
5—Reduction of CO_2 emitted compared to a 35% efficient coal plant.
6—Particulates as pounds-per-million Btu unless noted otherwise.

BENEFITS TO THE NATION

Economic security. A major benefit of near- and mid-term power technologies is low-cost electricity for citizens and industries. Because electricity expense is a major factor in the cost of providing products and services, sustaining a low-electricity production cost is critical for U.S. industry's competitiveness in the world market. Energy technology provides the foundation for competitive alternatives needed to meet varying marketplace situations.

Reduced balance-of-trade deficit. Because U.S. industry is de-emphasizing longer-term research as part of short-term survival strategies, federally sponsored technology development is critical to sustaining U.S. industry's competitiveness in the world marketplace. Energy technologies being developed address rapidly expanding global-market demands and are, therefore, central to U.S. responsiveness to export opportunities that translate into high-paying U.S. jobs.

Energy security. Providing technologies that use our abundant indigenous resources as a significant component of our Nation's fuel mix is critical to maintaining energy independence and security.

Environmental acceptability. These technologies offer the means to produce energy from abundant, low-cost fossil fuels without detriment to the environment.

Lower carbon dioxide emissions. Because of high-efficiency energy conversion, these advanced technologies will greatly reduce the release of carbon dioxide into the atmosphere as they replace less efficient technologies.

Results are benefiting existing plants as well as next-generation systems. Today, for example, NO_X reduction technologies demonstrated through CCT projects are being retrofitted to over 25% of the Nation's coal-fired capacity. These technologies can achieve not only existing regulated emissions levels, but also those proposed by the Environmental Protection Agency (EPA) for 2000. The program has also demonstrated several advanced technologies that have significantly improved the economic and environmental performance of SO_2 controls.

Furthermore, CCT technologies are being used to transform low-rank and noncompliance coals to useful, environmentally superior coal-based fuels for use by domestic utility and industrial coal users, and are being considered for major projects abroad. In addition, coal-based industrial processes are gaining significant environmental and economic benefit from the demonstration of these advanced technologies.

New power generation systems validated through the program include circulating fluidized-bed technology, pressurized fluidized-bed combustion (PFBC), and integrated gasification combined-cycle systems. These systems are now in or near commercial-scale operations that demonstrate their strong potential as electric power generation and coproduction plants of the next century.

The Clean Coal Technology Demonstration Program reached a significant milestone in 1997 with the completion of 21 of 39 active projects. Several demonstrated technologies, including fluidized-bed and gasification technology, are now being successfully commercialized.

CCT PROJECTS

Number of Projects	Market Segment	Number Completed
11	Advanced Electric Power Generation	2
19	Environmental Control Devices	15
5	Coal Processing for Clean Fuels	2
4	Industrial Applications	2

ADVANCED ELECTRIC POWER GENERATION

Approximately 56%, or about $3.2 billion, of total available government CCT funds has been earmarked for advanced electric power generation systems, to enhance their efficiency, environmental performance, and reliability. Over 900 megawatts (MW) of new capacity and over 800 MW of repowered capacity are represented by 11 advanced electric power generation projects. Projects include four IGCC systems, five PFBC or circulating fluidized-bed combustion (CFBC) systems, and two advanced combustion/heat-engine systems. These projects will provide environmentally sound, more efficient, and less costly electric power generation, while providing a demonstrated technology base necessary to meet new capacity requirements in the 21st century.

ENVIRONMENTAL CONTROL DEVICES

Valued at more than $700 million, 19 environmental-control projects include seven NO_X emissions-control systems installed on over 1,700 MW of utility-generating capacity, five SO_2 emissions-control systems installed on about 770 MW, and seven combined SO_2/NO_X emissions-control systems installed on about 700 MW of capacity. The operating experience of most of these environmental-control devices was documented by the end of 1997.

COAL PROCESSING FOR CLEAN FUELS

Five projects that create clean fuels by coal-processing, valued at nearly $520 million, represent a diversified portfolio of technologies. Three of them involve the production of high-energy-density solid compliance fuels for utility or industrial boilers; one also produces a liquid for use as a chemical feedstock. One project is demonstrating a new methanol production process. Another has developed an expert computer software system that enables a utility to predict the operating performance of coals not previously burned in its boiler.

INDUSTRIAL APPLICATIONS

Four projects with industrial applications have a combined value of nearly $1.3 billion. They include the substitution of coal for 40% of the coke used in iron making, integration of a direct iron-making process with the production of electricity, reduction of cement kiln emissions and solid-waste generation, and demonstration of an efficient, industrial-scale combustor.

FIVE POWERPLANT AWARDS PRESENTED TO CCT PROJECTS BY *POWER MAGAZINE*

- Tidd PFBC Demonstration Project (The Ohio Power Company)—1991
- Advanced Flue Gas Desulfurization Demonstration Project (Pure Air on the Lake, L.P.)—1993
- Demonstration of Innovative Applications of Technology for the CT-121 FGD Process (Southern Company Services, Inc.)—1994
- Wabash River Coal Gasification Repowering Project (CINergy Corp/PSI Energy Inc.)—1996
- Tampa Electric Integrated Gasification Combined-Cycle Project (Tampa Electric Company)—1997

POWER SYSTEMS IN THE MID-TERM

- By 2002, technology readiness and validation testing will be performed for two competing natural gas utility-scale advanced turbine system generation concepts.
- By 2003, proof-of-concept will be demonstrated for a LEBS advanced pulverized-coal-fired powerplant.
- By 2002, technological limitations on hot-gas filtration will be solved to achieve the full performance potential of FBC plant designs.
- By 2010, DOE will run a pioneer coproduction IGCC plant and, by 2015, a full-scale plant will deliver market-based energy and chemical products that cost less than those from any other sources.

POWER SYSTEMS

A key strategic goal of the Office of Fossil Energy is to develop progressively higher-efficiency power systems. In the long term, these systems are to produce near-zero levels of pollutants while simultaneously reducing electricity costs by 10% to 20%. Several advanced systems are near completion:

The ***Advanced Turbine Systems (ATS)*** program is close to commercializing a prototype utility gas turbine with remarkable improvements in efficiency and environmental performance. Over the next two years, testing will be completed for full-scale components and subsystems, as will manufacturing capability for the first test engines. Site preparation will begin for critical full-speed engine tests scheduled for the final phase of this program.

The ***Low-Emissions Boiler System (LEBS)*** is in its final phase. An 80-MW proof-of-concept facility, scheduled to be on-line in 2001, will reduce SO_2 and NO_X to less than one-sixth the levels required under New Source Performance Standards (NSPS). Incorporating supercritical boiler technology, the design will boost thermal efficiencies to 42% compared with today's 33% to 35%. More than 73% of the final phase's $127 million costs will be provided by the private sector and State government.

High-Performance Power Systems (HIPPS) are based on the indirectly fired combined cycle, a cycle that is particularly attractive because of its very high thermal efficiency and capability to handle a wide range of fuels, including "opportunity" fuels (such as petroleum coke or sawdust) and "wastes." Efficiencies of 47% to 50% can be achieved with gas turbines available today. With turbines expected to be available when HIPPS is deployed in about a decade, efficiencies of 55% will be possible.

The third IGCC plant to become operational in the United States, the 100-MW Sierra Pacific Piñon Pine project near Reno, Nevada, demonstrates a KRW air-blown gasifier with in-bed sulfur capture, advanced hot-gas cleanup, and General Electric power generation. With an anticipated efficiency of over 43%, the plant will deliver more efficient, less costly, and cleaner electricity.

Pressurized Fluidized-Bed Combustion (PFBC) technology moves coal combustion to a new plateau of performance with efficiencies for initial systems approaching 45%, and SO_2 and NO_X removals at levels one-fifth that required under the NSPS. Improvements could raise efficiencies to more than 55% and emission levels to one-tenth the NSPS limits.

Integrated Gasification Combined Cycle (IGCC) is a key system in the Vision 21 plant concept. The goal is to improve efficiencies, costs, and environmental performance for power, fuels, and chemical production.

ADVANCED TURBINE SYSTEMS

The DOE Office of Fossil Energy (FE) and the Office of Energy Efficiency and Renewable Energy (EE) share responsibility with industrial partners for developing advanced turbine systems. FE supports the utility-scale system development, industry/university consortium, materials research for advanced alloys, ATS applications for coal fuels, and the Federal Energy Technology Center (FETC) in-house R&D. EE supports the industrial-scale system development, materials research on thermal barrier coatings, ceramic retrofit engine development, and ATS applications for biomass fuels.

Program benefits include (1) commercialization of utility-scale ATS concepts as the cleanest, most efficient combined-cycle powerplant available by 2002; (2) reduced cost of electricity to consumers, thereby preserving competitiveness of U.S. industry in world markets; (3) sustained U.S. global technology leadership; and (4) major reductions in NO_X and CO_2 emissions.

UTILITY-SCALE ATS PERFORMANCE
60% (LHV) system efficiency
<10 ppm NO_X emissions
10% reduction in cost of electricity
Reliability, availability, and maintainability of current combined-cycle products

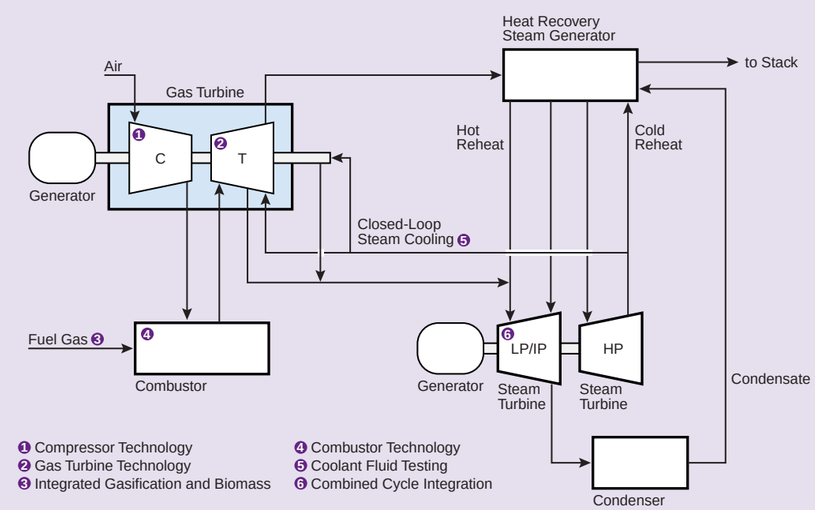
Utility-scale ATS

Utility-scale ATS concepts are being developed by General Electric Company and Westinghouse Electric Corporation.* Both will complete evaluation of their combustion, heat transfer, and aerodynamic design concepts under actual operating conditions by December 2000.

** Westinghouse Electric Corporation was purchased by Siemens on August 20, 1998, and was renamed Siemens Westinghouse Power Corporation.*

UTILITY ADVANCED GAS TURBINE SYSTEMS

Outstanding environmental performance and improved economics in both natural-gas-fired and coal-fired applications are promised by advanced turbine systems. In the near term, natural gas will play an increasing role in electric generation. Natural-gas units are more efficient and less capital-intensive, have lower non-fuel costs, are more rapidly constructed, and remain economical in small sizes. However, in the mid-term, advanced coal systems will replace or reduce natural-gas feed as gas systems become relatively more expensive than coal.



General Electric Company. General Electric is conducting compressor tests for the 7H ATS system. The compressor is the first stage of the turbine and increases the pressure of large volumes of air needed for combustion of natural gas or other fuels. High-temperature tests have verified effective cooling of hot turbine components by steam to achieve ATS turbine temperatures.

Casting of the largest advanced single-crystal turbine components in the world was also completed, a critical step toward commercializing the ATS gas turbine. Single-crystal materials, much stronger than the polycrystalline materials now used to produce blades, are better able to resist conditions present in the ATS. Technology development for the H program has already yielded many side benefits to U.S. industry. Turbine component development, which deals with manufacturing turbine blades, has improved with the use of advanced processes for casting complex, single-crystal metallurgical turbine parts.

Westinghouse Electric Corporation. Westinghouse has introduced the 501G ATS gas turbine, featuring an aerodynamic design incorporating the latest computer models and turbine-component design. Use of a computer model has resulted in reduced turbine component thickness and increased efficiency without increased manufacturing costs.

The piloted-ring combustor is a lean, premixed, multistage design that produces ultra-low pollutant emissions while maintaining stable turbine operation.

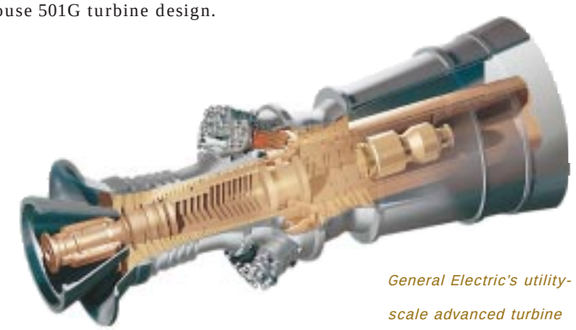
To solve efficiency losses caused by leakage around the ATS internal parts, Westinghouse has developed brush and abradable coating seals for the stationary sections of the turbine. These seals have already been incorporated into the Westinghouse 501G turbine design.

Other ATS program developments transferred to the 501G design are new thermal barrier coatings that permit higher turbine blade temperature.

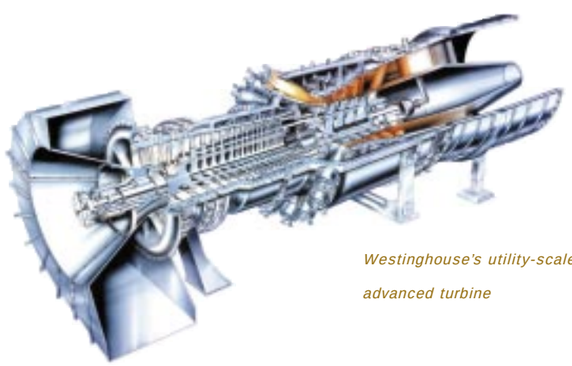
Technology base research and development

Critical technology barrier issues for ATS include development of advanced materials, low-emissions combustion, advanced turbine cooling, and advanced component design methods.

CONCEPTS	
General Electric	Developing two systems: a 9H (50 Hz) system, and a 7H (60 Hz) system
Westinghouse	Developing and testing 501G air-cooled engine as the precursor to an ATS design



General Electric's utility-scale advanced turbine



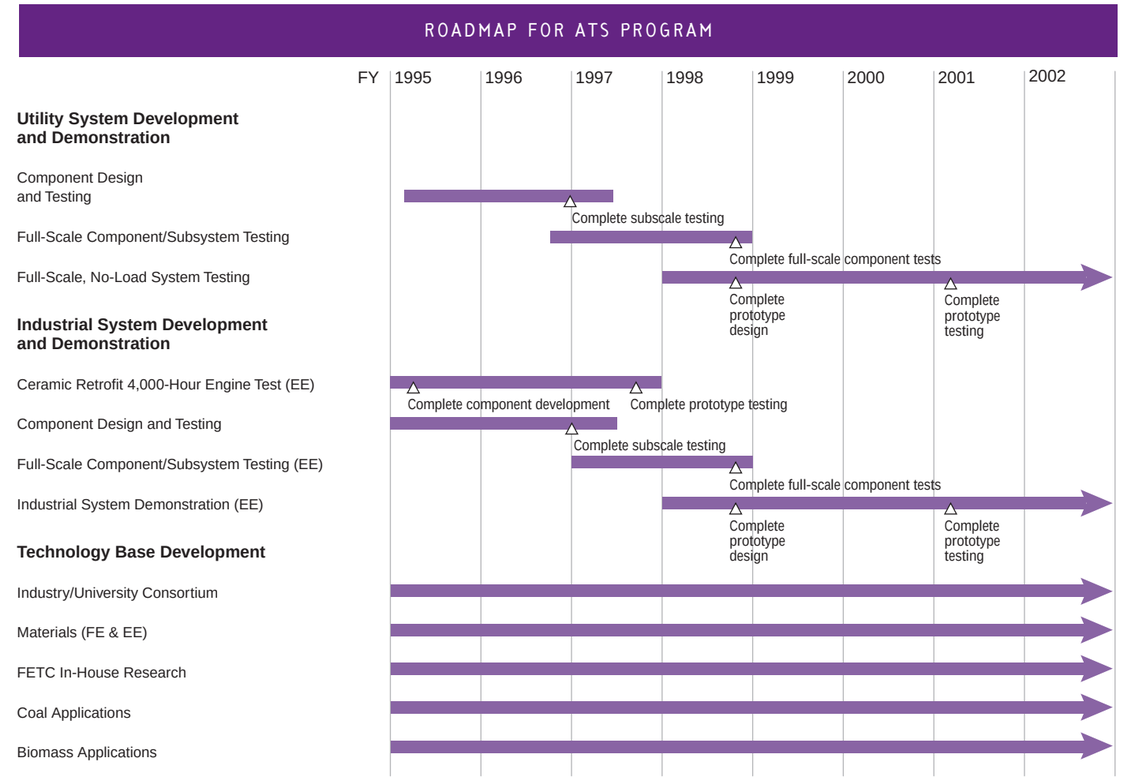
Westinghouse's utility-scale advanced turbine

Materials development. Projects include (1) single-crystal complex-cored airfoil technology to attain higher turbine inlet temperatures and (2) dependable thermal barrier coatings to enable increased turbine inlet temperatures while maintaining airfoil substrate temperatures at levels that meet ATS life goals. Emphasis is being placed on cost-effective casting of single-crystal components.

In-house R&D. FETC's combustion group, collaborating with university investigators, conducts laboratory tests to evaluate novel concepts for low-emissions-combustor modeling, mixing sensor development, heat-transfer sensor development, noise measurements in combustors, and combustor dynamics and control.

Industry/university consortium. DOE supports applied research for 95 U.S. universities, including workshops and student internships at industry facilities. Under the direction of the South Carolina Energy and Research Development Center, contracted universities perform applied research specific to the needs of major ATS developers in combustion, aerodynamics, materials, and heat transfer.

INDUSTRY/UNIVERSITY CONSORTIUM SUCCESSES	
University of California at Berkeley	Probe for in-situ measurements of fuel/air ratio
Syracuse University	Computer code to optimize turbine design
Georgia Institute of Technology	Process for producing thermal barrier coatings Control strategy for eliminating combustion instability



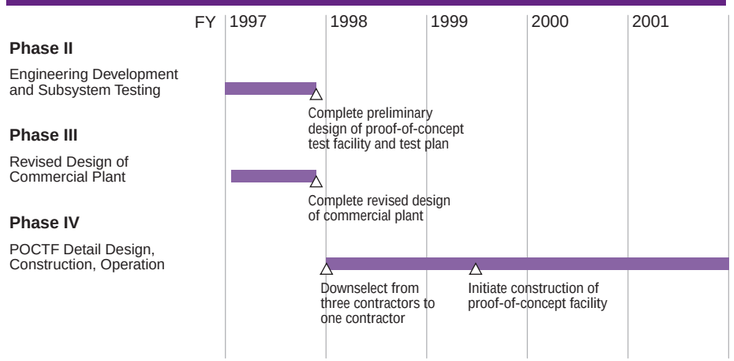
EE: Office of Energy Efficiency and Renewable Energy
FE: Office of Fossil Energy

To date, the consortium has conducted 51 projects that include combustion to improve fuel utilization and minimize environmental effects, heat transfer and aerodynamics to upgrade turbine blade life and performance, and materials to extend life and withstand higher operating temperatures for more efficient systems.

Humid air turbine (HAT) combustion testing. FETC and its industrial partner, United Technology Research Center, are identifying combustor configurations to efficiently burn high-moisture, high-pressure gas/air mixtures, resulting in low emissions for systems where injected moisture can boost both power and efficiency.

Computer models are being developed to aid in the design of combustion systems that operate with humidified air. In-house testing of new combustor components is under way. Test data will be compared to computer models for design of full-scale engine combustors.

ROADMAP FOR LEBS PROGRAM

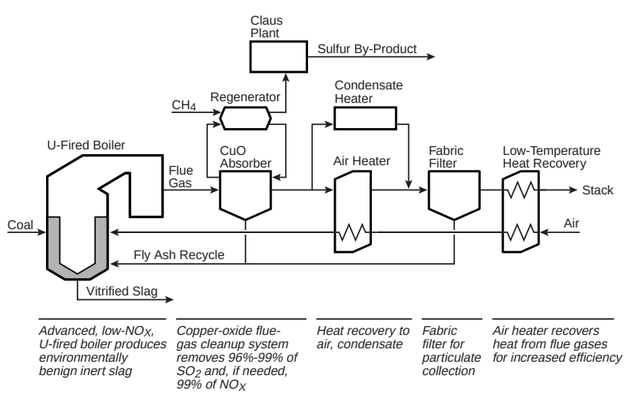


LOW-EMISSIONS BOILER SYSTEM

The low-emissions boiler system (LEBS) is a highly advanced pulverized-coal-fired powerplant being developed under an industry-DOE/Fossil Energy partnership. Its innovative design integrates components to maximize benefits achieved from advances in low-NO_X combustion, flue gas cleanup, and power-cycle technology at the lowest possible cost.

LEBS can be adapted to specific user requirements, such as limits on fuel availability, local regulations, and site conditions. It is positioned for ready acceptance by the electric power industry at home and overseas.

LOW-EMISSIONS BOILER SYSTEM



LEBS performance offers dramatic improvements over conventional coal-fired powerplants. Higher thermal efficiency will cut CO_2 emissions by 15% to 20% over today's new plants. Emissions of acid gases (SO_2 and NO_X) will be one-sixth or lower and particulate matter emissions one-third of current NSPS limits. Significantly, this is to be achieved along with a reduction in the cost of electricity.

After nearly five years of systems analysis, engineering development, and testing, three cost-shared industry teams delivered 400-MW commercial plant designs and proposed proof-of-concept approaches. In September 1997, the team led by DB Riley was chosen to construct an 80-MW LEBS plant at Elkhart, Illinois, adjacent to the Turris Coal Company mine, which produces Illinois #5 high-sulfur coal. The plant will use a low-NO_X, U-fired furnace developed under the LEBS program. A 10-MW test module for the moving-bed copper-oxide flue-gas cleanup process will also be built and operated.

Nearly all coal ash is converted by the U-fired furnace into a glass-like slag by-product that can be used in the construction industry. The volume of slag is only one-third that of the fly ash produced in a conventional coal boiler, significantly reducing solid-waste-handling requirements.

LEBS PERFORMANCE

Efficiency	42% to 45%
NO_X emissions	0.1 lb/10^6 Btu
SO_2 emissions	0.1 lb/10^6 Btu
Particulate emissions	0.01 lb/10^6 Btu

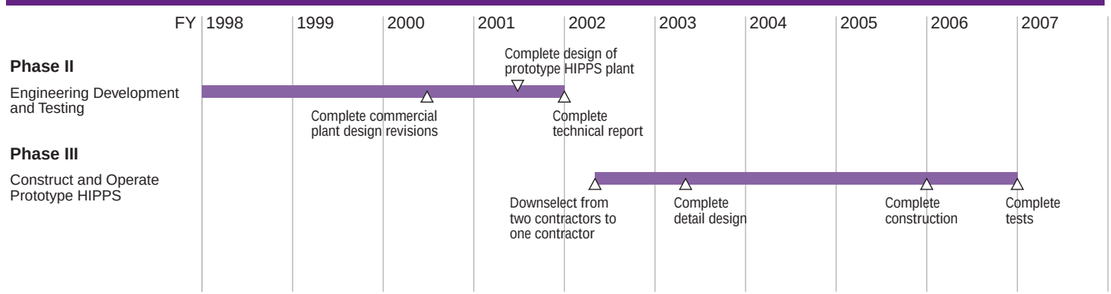
The furnace will use staged combustion and a concept called "reburning" to reduce NO_X pollutants. Flue gas leaving the boiler can be further cleaned of NO_X and SO_2 in the copper-oxide process. Ammonium sulfate fertilizer will be produced from the by-product streams.

HIGH-PERFORMANCE POWER SYSTEMS

The key to developing an indirectly fired cycle is learning how to transfer heat from combustion to the turbine air in a high-temperature air furnace (HITAF). This requires both innovative engineering and advanced materials. To realize high system efficiency, the HITAF must operate at higher temperatures than conventional coal-fired steam boilers.

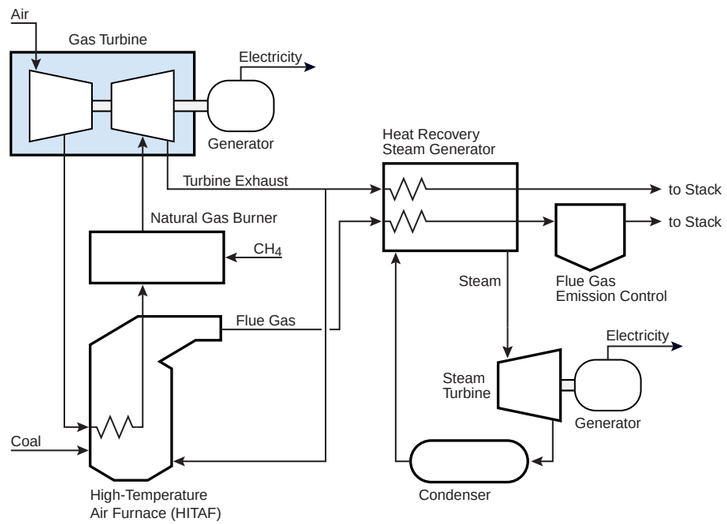
Two industry teams, led by Foster Wheeler Development Corporation and United Technologies Research Center, have been developing different versions of HIPPS. When fully developed, both versions are to be capable of achieving efficiencies of 55%. Less advanced configurations of HIPPS technology, available now, can be used to repower existing coal-fired plants to increase both their power output and efficiency.

ROADMAP FOR HIPPS PROGRAM



HIGH-PERFORMANCE POWER SYSTEM

In the HIPPS indirectly fired cycle, air is heated in a coal-fired, high-temperature air furnace (HITAF) to a temperature approaching the gas turbine inlet temperature. Natural gas or a clean-coal-derived fuel can be used to reach inlet temperature. This hot air is expanded in the turbine, producing over half the system's power output. Heat recovered from turbine exhaust and from the HITAF flue gas is used to raise steam for the steam turbine, to create more power. HIPPS will achieve an efficiency of 55% and has drawn potential as a key combustion-based technology module for Vision 21.



FLUIDIZED-BED COMBUSTION

Advanced fluidized-bed combustion (FBC) technology offers a viable power generation option for the post-2000 time frame. Commercial FBC units operate at competitive efficiencies, cost less than today's units, and have NO_X and SO_2 emissions below levels mandated by Federal standards.

FBC comprises three technology variations: atmospheric FBC, first-generation pressurized FBC or PFBC, and second-generation PFBC. Second-generation PFBC systems include a carbonizer reactor and topping combustor to increase efficiency levels.

Researchers in seven FBC subprograms are demonstrating advanced features of FBC and providing R&D to lower capital and production costs. Thrusts include simplification of FBC systems and components, incorporation of alternative feed and withdrawal systems, and incorporation of advanced subsystems and steam cycles.

Results from system studies will guide future R&D. Optimum turbine-compressor configuration and operation of first-generation PFBC are being studied. Optimum configurations of second-generation PFBC for Vision 21 concept plants with fuel cells and CO_2 sequestration options will be developed. Gas turbine studies will be performed on gas compositions and heat capacities specific to PFBC, which can lead to higher allowable turbine blade temperatures.

Advanced FBC systems demonstration

Two CCT projects are providing valuable information: one at Lakeland, Florida, demonstrating commercial-scale advanced pressurized FBC technology by 2002; and the other at Jacksonville, Florida, demonstrating circulating atmospheric FBC by 2000.

Topping combustor/turbine

Developing and demonstrating a topping combustor with suitable fuel flexibility, flame stability, and NO_X-emissions characteristics is critical to commercializing second-generation PFBC systems. Tests of a multi-annular swirl burner (MASB) have demonstrated good flame stability and NO_X performance. Systems testing of the MASB was performed at the Wilsonville Power Systems Development Facility (PSDF) during 1998, and integration of the MASB into ATS designs will occur after the turn of the century.

Combustion by-products utilization

FBC economics improve as combustion by-products are reduced or high-value uses are found. The goal is to reduce solid by-products from FBC systems without compromising sulfur capture or producing in-bed sintering. Variability of limestone will be assessed as a factor in the volume of solid by-products, and a limestone utilization model will be developed to optimize sulfur capture and minimize the volume of solid by-products.

Net operating costs and landfill requirements will be reduced by expanding markets for FBC by-products. FBC ash will be characterized for conventional applications, such as agriculture, mine remediation, and structural fill, and high-value uses of solid by-products from FBC systems will be developed.

Hot-gas filtration

Filter element durability, filter-ash bridging, and system costs are critical development issues being addressed. The challenge of producing candle-filter elements able to operate for more than three years is being met by enhancing monolithic filter elements made of various materials, such as clay-bonded silicon-carbide, porous-sintered metal, and alumina-mullite oxide.

A number of composite-type ceramic and iron aluminide-type filter elements are also undergoing development.

Filter cost can be reduced by 25% through optimized design of the system; filter vessel cost is about 75% of the total system cost.

Solids transfer

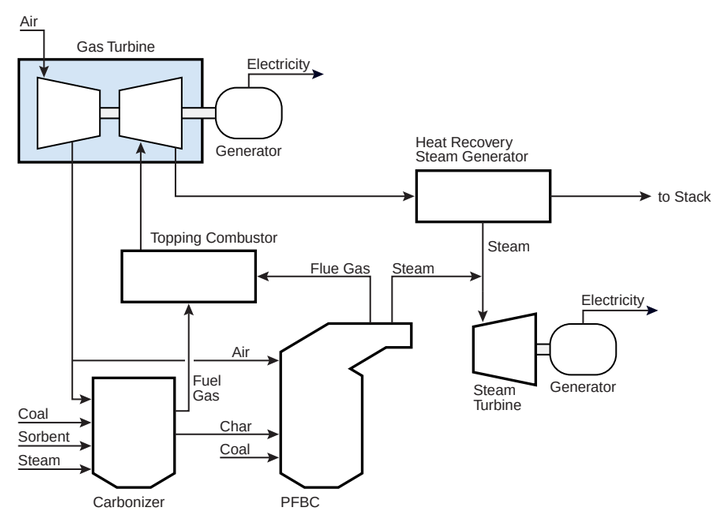
Cost reduction and reliability improvement can be achieved by improved handling of hot-solids material—feed and withdrawal, flow control, and fines removal. A feasibility study of a rotary high-pressure dry-solids feeder will evaluate the system's potential for reducing capital and operating costs.

An advanced system for simpler and more reliable transfer of hot char from the carbonizer to the fluid-bed combustor will be tested for its ability to decrease materials flow and handling-related downtime by at least 50%.

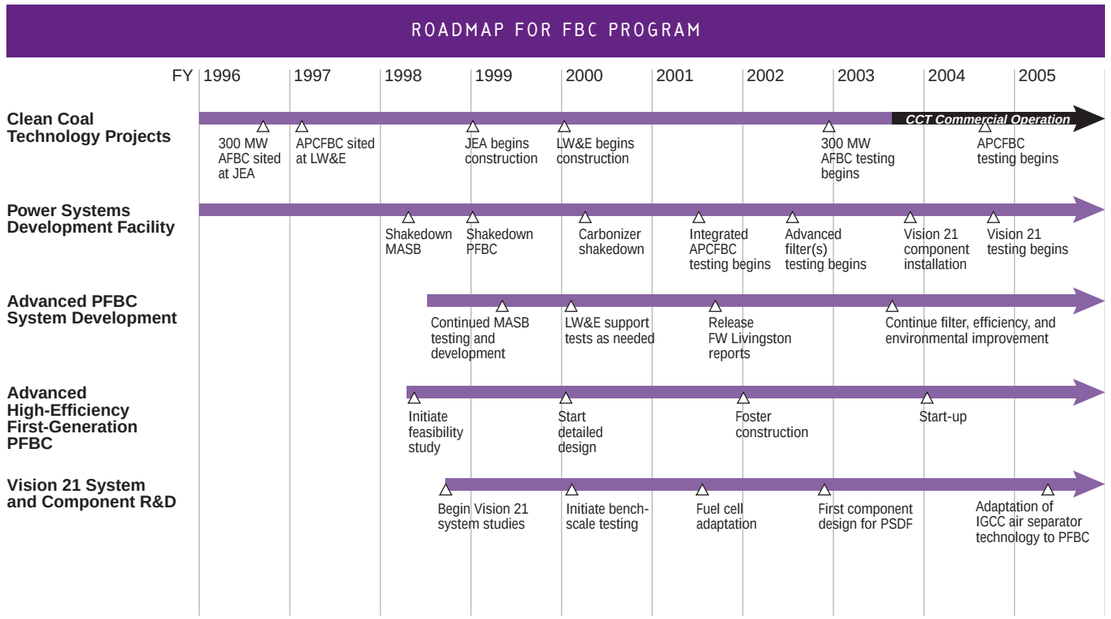
Sulfur/alkali removal

Alkali in hot-gas streams can limit gas turbine life and reliability. The severity of the alkali problem must be determined. Gas turbine tolerance to alkali, the amount of alkali released, the effect of filter-cake characteristics, and the ability to control alkali will be assessed. Also, experiments to determine sulfur removal and trace-contaminant levels in the gas stream during integrated demonstration will be conducted.

SECOND-GENERATION PFBC SYSTEM

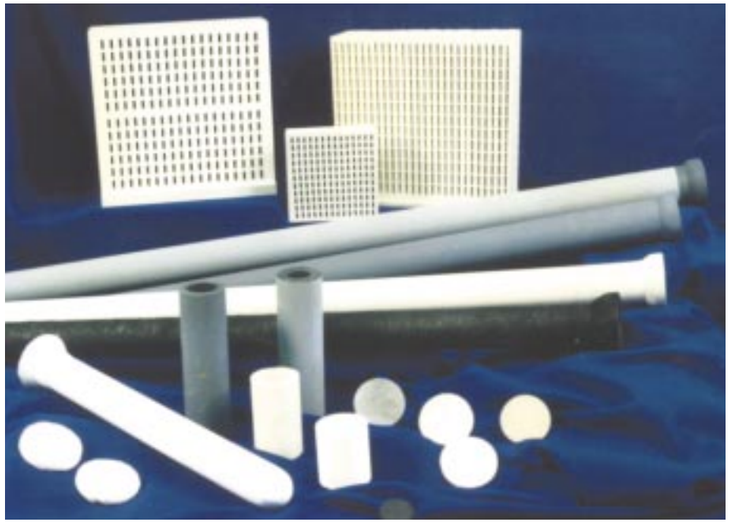


In a second-generation PFBC system, the feed is partially gasified in a pressurized fluidized-bed carbonizer. The carbonizer produces a low-Btu gas and a char. The char is burned in a PFBC. Both gases are cleaned by hot-gas filtration, and the pyrolyzer gas is burned in a topping combustor to heat the PFBC flue gas. The hot gas drives a gas turbine to generate power. The flue gas generates steam in a heat recovery steam generator, which is used to generate additional power. At the Wilsonville Power Systems Development Facility (PSDF), a highly advanced second-generation PFBC now demonstrates high efficiency at pilot scale.



Cofiring of biomass and industrial by-products

Existing fluidized beds are suitable for cofiring, but, to date, only 8 of the 100 units in the U.S. cofire material. Cofiring of biomass and industrial by-products could evolve into a standard practice as a near-term means to reduce CO_2 emissions. R&D data on heavy metals are needed so that environmental approval and permits for cofiring projects are not any more difficult to obtain than for single-fuel solid-combustion units.



Filter element durability, as it translates into useful performance life, is a critical factor for reducing FBC operating costs. Long-term studies of various types of hot-gas filters are being performed to study durability and performance.

IGCC MARKETS

- Domestic and international baseload power
- Domestic repowering
- Refinery cogeneration
- Pulp and paper
- Steel and aluminum
- Coproduction of fuels and chemicals

INTEGRATED GASIFICATION COMBINED-CYCLE SYSTEMS

The integrated gasification combined-cycle (IGCC) process provides industry with low-cost, highly efficient options for meeting a wide spectrum of market applications.

IGCC is one of the most efficient and environmentally friendly of today's commercial and advanced coal technologies. Gasification technology can process all carbonaceous feedstocks, including coal, petroleum coke, residual oil, biomass, and municipal and hazardous wastes, and is the only advanced power-generation technology capable of coproducing a wide variety of commodity and premium products to meet future market requirements.

IGCC technology is applicable to both domestic and international baseload and repowering applications. Industrial markets also include the production of environmentally superior transportation fuels, premium chemicals, and commodity products. IGCC systems are also very effective in converting hazardous industrial wastes into valuable, benign products.

Coal gasification processes must compete economically with natural-gas combined cycle technologies. Therefore, capital cost must be reduced, and reliability and capacity utilization must be improved. The use of natural-gas combined cycle today could be beneficial for IGCC tomorrow, because as natural gas prices rise, gasification units can be readily installed to replace natural gas.

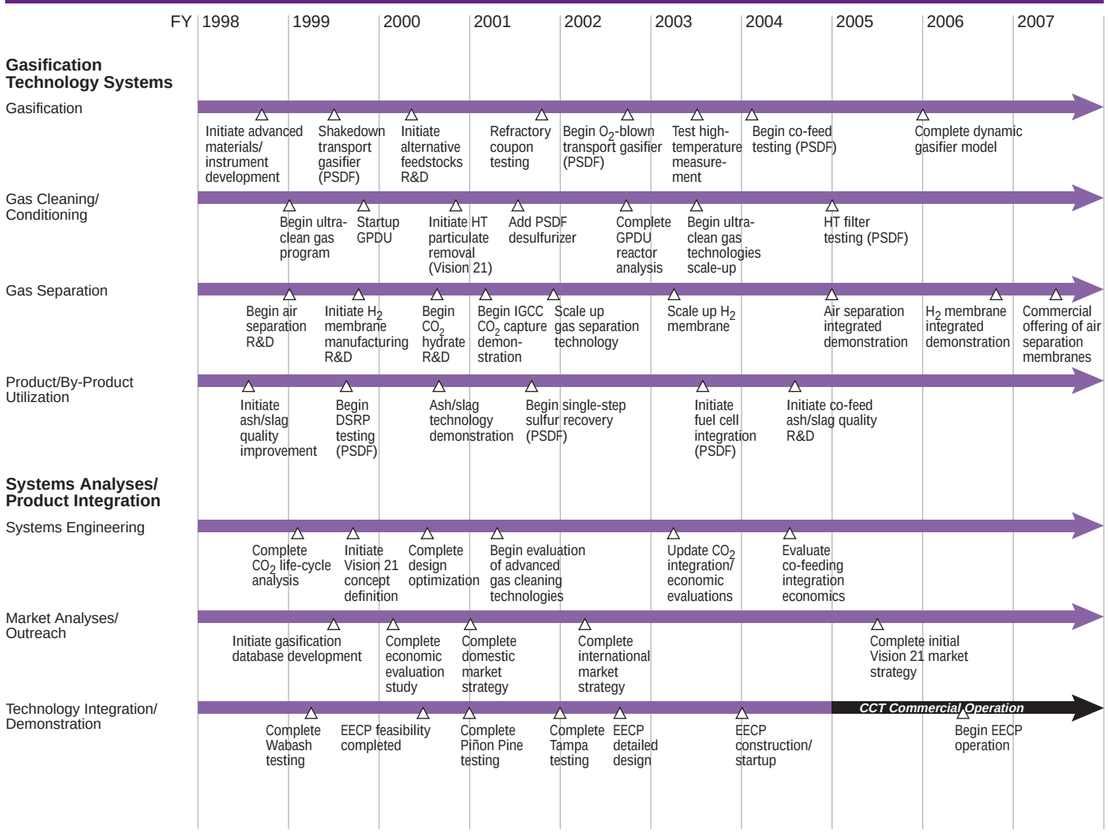
Gasification systems technology

The IGCC program strategy emphasizes capital and operating and maintenance (O&M) cost reductions, increased efficiencies, feedstock and product flexibility, and near-zero emissions of pollutants and carbon dioxide to meet future energy market demands and break the barriers to global commercial acceptance of gasification-based technologies. To achieve these goals, the strategy focuses on research and development of gasification system technologies, the conduct of engineering analyses, and the integration of advanced technologies from other programs, where appropriate.

Gasification. Advanced gasification technologies, such as the transport gasifier, are being developed through a coordinated program. Researchers are also developing fluid dynamic data and advanced computational fluid dynamic models to support the development of these advanced gasifiers. Investigations are being conducted to develop improved refractory materials and advanced instrumentation to enhance gasifier performance, reliability, and control.

The Power Systems Development Facility provides a critical bridge between research- and commercial-scale demonstrations of IGCC technology.

ROADMAP FOR IGCC PROGRAM



Alternative feedstocks such as petroleum coke, biomass, and municipal waste in conjunction with coal are being evaluated as feedstocks for power and coproduction applications in existing and advanced gasifiers.

Gas cleaning/conditioning. Research in this area is intended not only to reduce capital and O&M costs and increase the efficiency of IGCC systems, but also to meet more stringent gas quality requirements for cogeneration and coproduction applications. These new technologies are needed to ensure the supply of ultra-clean gas for fuel cell integration, to enable the catalytic conversion of synthesis gas to fuels and chemicals, and to enable advanced processes to effectively separate carbon dioxide. Advanced sorbents are being explored and novel technologies are being developed to achieve near-zero emissions of particulates, sulfur and nitrogen oxides, and hazardous air pollutants, and to minimize consumables and waste products. A wide range of process conditions are being considered in order to meet specific downstream processing requirements.

Gas separation. Advanced gas separation technologies are being developed that have potential for reducing capital and operating costs, improving plant efficiency, and concentrating and capturing carbon dioxide. New air separation technologies that use mixed-conducting ceramic membranes and that have potential for significant cost reductions and efficiency improvements are being developed.

Researchers are also investigating novel hydrogen separation technologies that are capable of operating at high temperatures and pressures for use in conjunction with fuel cells to improve overall IGCC plant efficiency. Tolerance to chemical and particulate contaminants, the ability to conduct reactions of carbon monoxide with water (the water-gas shift reaction) for the production of additional hydrogen, and the ability to concentrate CO_2 are critical issues that must be addressed to meet the goals of Vision 21. Other novel concepts for concentrating CO_2 from various IGCC process streams are being investigated.

Product/by-product utilization. This area focuses on developing technologies that can improve the utilization of process and waste streams to generate value-added marketable products and to minimize waste disposal costs. Technologies that improve the quality and marketability of gasifier slag and ash are being developed to enhance IGCC plant revenues and minimize waste disposal costs. These technologies will be particularly important when co-feeding coal with alternative feedstocks such as municipal waste and biomass. Processes are also being developed for the direct production of elemental sulfur from the waste streams produced by the gas cleanup technologies. In addition, work will also focus on the integration of fuel cell and fuel cell/turbine hybrid systems.

Systems analysis/product integration

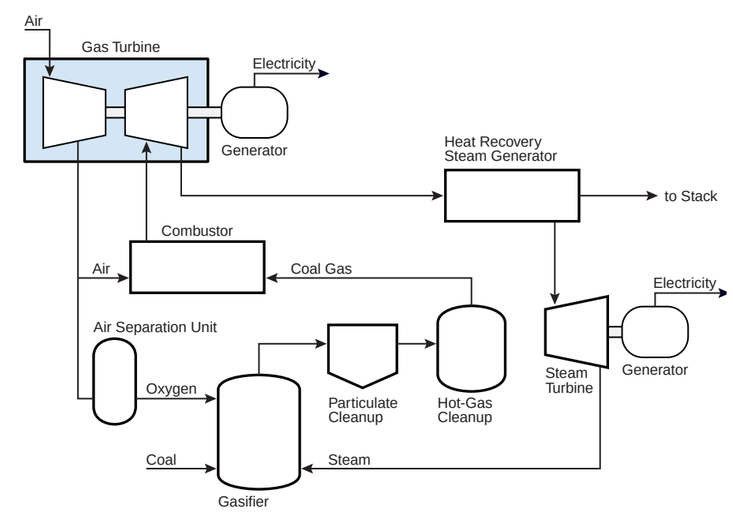
Economic analyses, process performance assessments, and market studies are planned to provide sound engineering and economic guidance for future R&D initiatives and to support commercialization activities, both domestically and internationally.

Systems engineering. An IGCC optimization study is being performed for baseload power applications, the cogeneration of power, steam, and hydrogen, and the coproduction of power, fuels, and chemicals. Through the use of advanced engineering design concepts for heat integration, equipment sizing, and construction, and the use of market-based costs, this study will provide the lowest-cost, highest-efficiency IGCC systems. This study, together with other engineering analyses, will be used to identify future R&D efforts to further reduce material cost, consumables, and total plant cost. In addition, these studies will be used to increase plant efficiency and profitability and to reduce emissions through integration of advanced gasification system, power generation, and synthesis gas conversion technologies.

The IGCC program, together with the Fuels program, is embarking on a cost-shared feasibility study of an advanced coproduction plant, called the Early Entrance Coproduction Plant (EECP).

IGCC systems are ideally suited to deliver a suite of energy products to meet future market requirements. IGCC systems use a gasifier to convert carbon-based feedstocks into synthesis gas (a mixture of carbon monoxide and hydrogen). The gases are cleaned of particulates, sulfur, and other contaminants before being combusted in a high-efficiency combined-cycle gas and steam turbine system to produce electricity, or are catalytically converted to high-value transportation fuels or chemicals. In addition, hydrogen and steam can be produced.

INTEGRATED GASIFICATION COMBINED-CYCLE SYSTEM



DEMONSTRATED SUCCESS FOR IGCC

Through cost-shared efforts by the Department of Energy and industry partners, the promise of gasification has been demonstrated in three coal-based IGCC plants that now provide reliable commercial service and a proving ground for IGCC technology.

A unique combination of gasification, gas cleanup, and advanced turbine technologies, IGCC systems offer an attractive approach for providing clean, affordable electricity as well as other valuable products. IGCC plants operated by the Sierra Pacific Power Company, Tampa Electric Company, and PSI Energy, Inc., now serve electricity customers with low-cost, environmentally friendly power. In the future, as a key integral unit in Vision 21 plants, IGCC units like these will supply synthesis gas, steam, transportation fuels, chemicals, and hydrogen, in addition to power.

By converting carbonaceous feedstocks such as coal and biomass to high-value and commodity products as well as to baseload power, IGCC can meet diverse national and international energy market needs. Coproduction of energy products maximizes returns on investment in these facilities while minimizing waste and environmental impact.

Thanks to investments in energy R&D by the Federal government and industry partners, U.S.-based companies are well-positioned to apply IGCC systems at home and to capture a healthy share of what promises to be a multi-billion-dollar export market for clean power-generation technologies.

It is intended that the results of this program and supporting R&D will lead to the construction and operation of a first-of-a-kind Vision 21 plant.

Market analysis/outreach. A detailed analysis of the market potential of IGCC technologies in conventional and niche market applications, both domestically and internationally, is being conducted. Using the results of this study, a commercialization strategy will be formulated for use in the next decade. This, together with a technology database currently undergoing development, will provide important information to both the public and private sectors for future decision making.

Technology integration/demonstration. Two key components of the IGCC program are the Power Systems Development Facility (PSDF) in Wilsonville, Alabama, and the Gas Processing Development Unit (GPDU) in Morgantown, West Virginia. These two facilities provide the critical link between R&D and commercial-scale demonstrations. Through cost-sharing industrial partnerships, these facilities will provide the means for performing integrated system and component testing at a scale of operation relevant to industry.

The four CCT IGCC demonstration projects, Tampa Electric, Wabash River, Piñon Pine, and Clean Energy, are also key elements of the IGCC program. These projects are currently confirming process scale-up, evaluating process performance, and providing data on reliability, availability, and maintenance. DOE will maintain an active role in these projects by providing technical assistance and supporting R&D to enhance their success.

The Tampa Electric IGCC system, built as a greenfield site, is one of the cleanest and most efficient coal-fired powerplants in the world.

FUELS

Coal and natural gas are versatile fuels and feedstocks. Improved solid fuels and economically competitive transportation fuels from gas and coal are expected near-term products of DOE programs. A key emphasis in transportation-fuels development is the production of high-quality, clean-burning diesel fuels from both natural gas and coal. The solid fuels and feedstocks program examines the environmental and economic benefits of blending biomass and waste feedstocks with coal, develops tailored feedstocks for making premium carbon products, and provides the means to remove trace contaminants from coal.

Through Vision 21, advanced technologies for coproducing power and fuels will enable our Nation to use its plentiful fossil resources to fulfill a broader range of energy and chemical feedstock needs while reducing impacts to the environment.

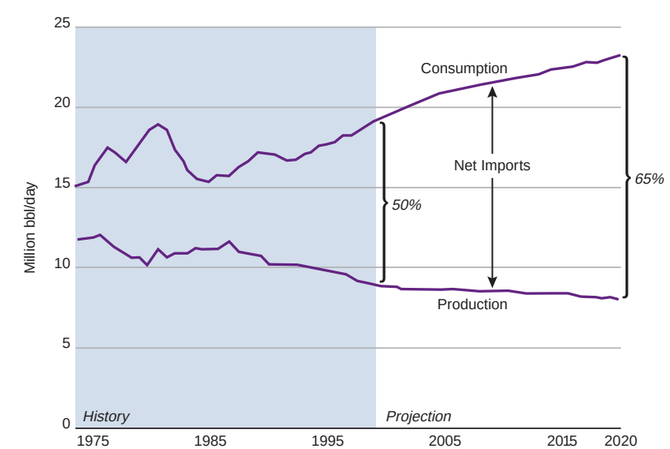
TRANSPORTATION FUELS

The Energy Information Administration (EIA) predicts that, by 2020, U.S. petroleum imports, already representing over 50% of consumption, will rise to 65% and increase our negative balance of payments. Total worldwide oil demand will double, creating a very competitive market for imports from sources that are likely to be politically unstable. From an environmental perspective, vehicles currently account for a large portion of urban air pollution, including carbon monoxide, nitrogen oxides, volatile organic compounds, and particulates. The transportation sector also contributes about one-third of U.S. greenhouse gas emissions. Further limits on emissions are likely and will be difficult to meet with conventional fuels.

The coal liquefaction technology program response to these environmental, energy security, and economic challenges is to provide the technical basis for a clean fuels industry capable of producing transportation fuels and chemicals from coal and other carbonaceous, non-petroleum domestic resources. Specifically, research is focused on developing clean fuels that (1) are environmentally superior to those derived from conventional petroleum-based fuels; (2) can satisfy the liquid fuel requirements of our Nation's transportation infrastructure; and (3) will help engine and vehicle manufacturers achieve higher performance with significantly lower emissions in both conventional and advanced systems.

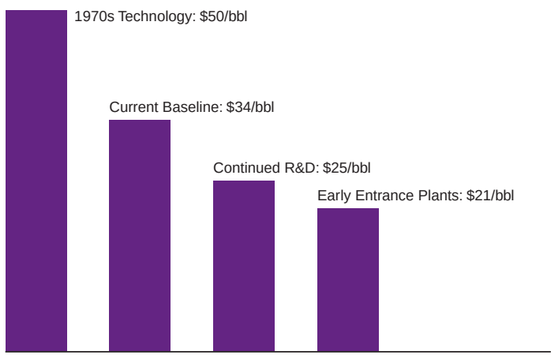
Many years of public investment in coal liquefaction and power systems RD&D have resulted in major advances, including reduced costs and mitigation of environmental impacts. Continued investments can provide the U.S. with technology options critical to our future energy security and economic strength.

EIA—PROJECTED U.S. CRUDE OIL PRODUCTION AND CONSUMPTION



Coal-derived transportation fuels can be an important element in the overall strategy to decrease our Nation's reliance on foreign oil. Currently, the United States uses 18 million barrels per day (bbl/day) of crude, over 50% of which is imported. Rising oil imports will worsen the balance of trade. Last year, the U.S. paid over $60 billion for imported oil; this amount could more than double (in constant dollars) by 2020.

COAL-DERIVED FUEL COSTS



Preliminary economic analyses indicate that liquid fuels can be coproduced at a cost equivalent to crude oil at $21 per barrel. These low costs can be achieved because of savings associated with integrating Early Entrance Coproduction Plants with existing petroleum refining facilities and using coal combined with low-cost feedstocks, such as petroleum coke and wastes.

Coal-derived liquid transportation fuels could also provide significant environmental benefits. Diesel fuels such as Fischer-Tropsch and high-cetane liquid oxygenates would enable the design of modified engines with improved efficiencies and up to 50% lower total emissions than conventional fuels.

To meet these research objectives and establish the foundation for a U.S. coal conversion industry by 2010, the program has developed strong partnerships with industry, academia, National Laboratories, and other government organizations to reduce the technical and environmental risks associated with commercial deployment. An example is the Early Entrance Coproduction Plant initiative, part of Vision 21, that is scheduled for implementation in FY 1999 as a joint effort with the IGCC program. Preliminary studies show that integrating technologies such as coal-based power and fuel production at one facility can offer economic and environmental benefits when compared with stand-alone plants. Teams will be pursuing industry-government cost-shared research and engineering studies that will be directed toward privately funded design, construction, and operation by 2007 of a first-of-a-kind commercial facility that coproduces multiple products—some combination of power, fuels, and chemicals.

Technologies are being developed in a time frame consistent with FE's mid-term Early Entrance Coproduction Plant strategy. Through cost-shared partnerships, program resources will be leveraged to provide the Nation with the capability to produce significant quantities of coal-derived transportation fuels, chemicals, and carbon products after 2010.

Technology status and direction

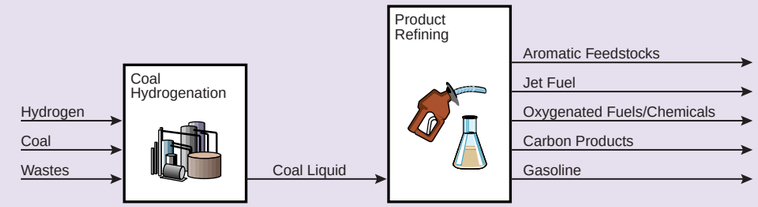
With current technology, the cost of producing direct liquids in stand-alone plants would be about $30 per barrel. The cost can be reduced to the $21-per-barrel target by coprocessing coal with low-cost feedstocks. Research has shown that these liquids can then be upgraded, at lower cost than crude oil, using conventional petroleum refining technologies to produce high-octane gasoline, jet fuels, and valuable chemicals. These fuels have much lower levels of pollutant-producing sulfur and nitrogen than those of typical petroleum crude.

R&D will pursue process improvements in the direct hydrogenation of coal—alone and in combination with petroleum residuals and waste material—including the development of more efficient reactors, more active and robust slurry catalysts, and methods that produce hydrogen more economically and reduce its consumption during liquefaction. Multiple feeds will be studied to reduce the production of greenhouse gases. Early commercial entry of direct liquefaction technology would most likely involve coprocessing heavy residual oil at a refinery.

Novel three-phase slurry reactor technology is also being developed to cost-effectively produce premium fuels, an excellent diesel-fuel blending component, or high-value chemicals using syngas produced from natural gas or coal.

DIRECT LIQUEFACTION

In a direct route from coal to transportation liquids, coal's large, complex structure is broken down and converted into distillate crude. During this process, hydrogen is added to the coal, raising the hydrogen-to-carbon ratio to a level comparable with that of petroleum crude.



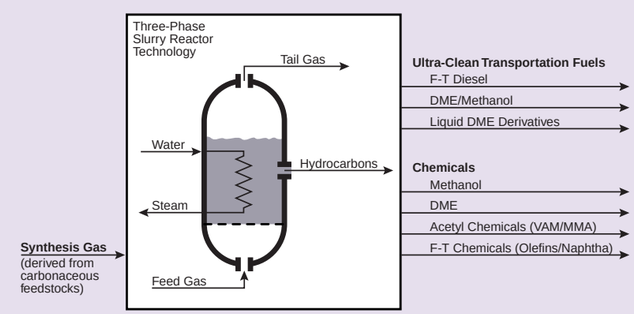
Because of its interest in the production of high-quality diesel fuel through the Fischer-Tropsch indirect liquefaction process, DOE's Office of Transportation Technologies is an important partner with the Office of Fossil Energy in developing fuels and transportation systems.

Early Entrance Coproduction Plant activities

To facilitate an industry-led effort to demonstrate advanced liquefaction technologies, the government will cost-share feasibility studies, R&D, and preliminary designs of first-of-a-kind commercial Early Entrance Coproduction Plants. These activities will help industry teams to refine their strategies, reduce technical risks, and define economic and environmental requirements. This information will enable the teams to pursue private-sector financing for detailed design, construction, and operation of their plants. One likely strategy would be to coproduce electricity, transportation fuels, and chemicals by integrating IGCC with indirect liquefaction. Feedstocks could include petroleum coke, wastes, and biomass in addition to coal.

ADVANCED SYNTHESIS GAS CONVERSION TO TRANSPORTATION FUELS AND CHEMICALS

Coal can also be converted to liquid form by an indirect route. Clean synthesis gas (hydrogen and carbon monoxide) is produced by gasifying coal with steam and oxygen. The synthesis gas is then reacted over catalysts to form premium refinery feedstock.



Systems engineering and analyses

Engineering and economic analyses are needed to define and prioritize future R&D initiatives and to support commercialization activities, both domestic and international. A major emphasis is on performing life-cycle environmental analyses on CO_2 emissions that arise from mining, transport, handling, conversion, and product utilization.

Proof-of-concept testing

Proof-of-concept (POC) evaluations to produce Fischer-Tropsch and other premium, high-performance fuels will provide optimum processing strategies and sufficient quantities of materials for engine and vehicle tests. All coal-fuels R&D, which culminates in POC activities and fuel testing, is focused, and will continue to focus, on developing fuels that assist the transportation sector in meeting its future emissions requirements. To this end, partnerships have been created with other Federal organizations and their stakeholders to facilitate commercial deployment of these advanced, alternative fuels.

Novel R&D in coal liquefaction

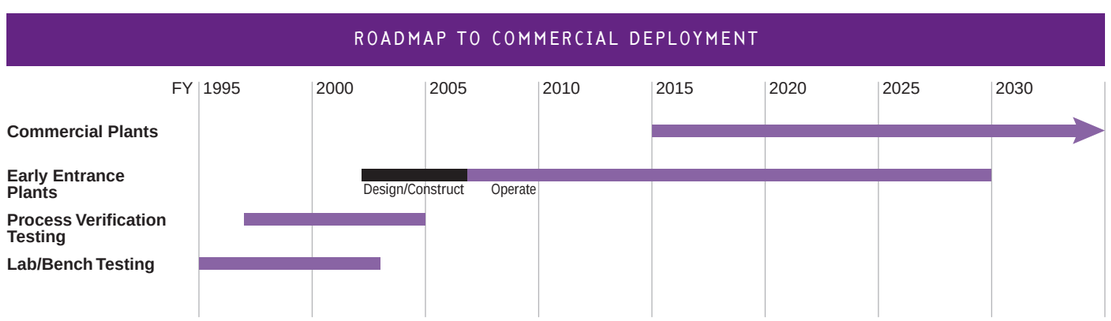
Computational chemistry techniques will be used to more efficiently develop kinetic models of coal conversion processes, which will in turn greatly reduce the laboratory R&D needed to effect process improvements. In addition, R&D will examine innovative hydrogen production technologies that have the potential to provide for both sequestration of CO_2 and significant reductions in manufacturing costs.

SOLID FUELS AND FEEDSTOCKS

The Solid Fuels and Feedstocks (SFF) Program is developing and commercializing advanced technologies for processing carbon-based solid materials that will (1) maintain U.S. industrial competitiveness, (2) contribute to efficient power production, and (3) promote environmental quality. A number of significant successes have already been achieved by the program. For example, the Microcel® flotation column developed with DOE support has had significant commercial success in coal and minerals applications, with over 50 units in use worldwide. Other successes include development of the Micro-Mag® heavy-medium cycloning process for coal cleaning and the GranuFlow® process for improved coal fines handling.

Based on the results of two successful workshops held to acquire stakeholder input, the Solid Fuels and Feedstocks Program is focused on activities to develop advanced technologies for the production of environmental solid fuels and tailored carbon feedstocks. The "Environmental Solid Fuels" activity is developing advanced technologies to enable the efficient use of coal, biomass, and waste fuels, while addressing existing and future environmental regulations and concerns associated with hazardous air pollutants, greenhouse gas emissions, and waste disposal/land reclamation issues. It includes the preparation and utilization of coal/biomass/waste composite fuels to permit a greater percentage of renewables to be utilized in new and existing power production systems to reduce CO_2 emissions by 10% or more. New approaches are also being developed to improve the recovery and handling of fine coal from existing production and waste coal ponds and piles.

The "Tailored Carbon Feedstocks" activity is concentrated on advanced technologies for the development of premium carbon products from coal and the preparation of specially designed (tailored) feedstocks for the production of advanced transportation fuels and chemicals from coal, biomass, and waste feeds.



Solid Fuels and Feedstocks Program key activities will result in new technology for: (1) precombustion control of potentially hazardous air pollutant emissions from coal by 2005; (2) converting one billion tons of impounded coal to clean fuel and the avoidance of the formation of new coal waste ponds by 2005; (3) facilitating 8 gigawatts of coal/biomass cofiring by 2010; and (4) producing cost-effective premium carbon materials from coal by 2015.

Environmental Solid Fuels

Research in this area is developing innovative methods for recovering useable fuels from materials that otherwise would be discarded at coal cleaning plants or utility power stations. Projects address the estimated 2 to 3 billion tons of coal fines that lie in waste impoundments at coal mines and washing plants around the country, the approximately 30 million tons of coal that is currently being wasted into ponds each year by active mining operations, and the millions of tons of unburned carbon found in powerplant fly ash landfills. Technologies are also being developed that combine coal and biomass or municipal solid waste into clean-burning fuels. A method for removing mercury from coal before it is burned, preventing the mercury from being released to form a hazardous air pollutant, is also being developed.

Other research in this area that will result in the more efficient use of solid fuels includes proof-of-concept (POC)-scale testing of a selective agglomeration process that uses a new mixing device (tubular processor); pilot-scale testing of an electrostatic separation process for dry, fine-size coal; and POC-scale testing of an advanced flotation control system. Industrial-scale testing of two advanced technologies will also be conducted—one for the production of carbonized slurry fuels for power production from coal, biomass, and waste and the other for the precombustion removal of contaminants from pulverized coal at utility powerplants. Work will also continue on the development of a national coal quality database on trace elements and cooperation with a broad-based, utility-sector consortium for coal utilization research.

Tailored Carbon Feedstocks

Premium carbon feedstocks and products are being developed by an industry-led, cost-shared consortium that will develop, demonstrate, and commercialize technologies for nonfuel uses of coal, such as:

- High-value premium carbon and graphite products
- High-strength, lightweight materials for improving fuel efficiency/reducing weight of vehicles
- Advanced feedstocks to reduce hazardous air pollutants, such as mercury
- Improved rechargeable batteries
- Fuel cell applications
- Chemically tailored carbon molecular sieves
- Adsorbents for water and air pollution control
- Specialty chemicals and coke
- Materials for heat-resistant applications

The Solid Fuels and Feedstocks Program uses engineering, market, and economic evaluations to understand how energy efficiency is improved and greenhouse and other gas emissions are reduced by new technology options for the production of metallurgical and foundry coke.

The Solid Fuels and Feedstocks Program investigates making premium carbon products from coal, such as high-quality graphite electrodes. (Courtesy of the Carbide/Graphite Group, Inc., Pittsburgh, PA.)

DISTRIBUTED GENERATION

OPTIONS FOR TOMORROW'S ENERGY MIX

reliable

flexible

DISTRIBUTED GENERATION SYSTEMS OFFER POWER PRODUCERS EASE OF SITING, MODULAR CONSTRUCTION OPTIONS, ENVIRONMENTAL BENEFITS, AND HIGH EFFICIENCY.

PROGRAM AREAS

- Fuel Cells
- Advanced Gas Engines
- Combined Heat and Power

INTRODUCTION

BOTH BASELOAD AND DISTRIBUTED GENERATION ARE NEEDED

As the U.S. moves to competitive utility markets, decisions on alternate power generation technologies will be based in large part on system costs and capital outlays. Distributed generation has many advantages to offer the energy industry. Distributed generation could augment the traditional central station grid system in relatively remote locations where upgrading the existing transmission grid would be more costly than installing a distributed generation system; and at sites requiring 100% availability (such as hospitals and industrial or commercial facilities where cogeneration loads can help make distributed generation economical). A report prepared by the Gas Research Institute estimates that gas-fueled distributed generation capacity could be as high as 6,000 megawatts (MW) per year for baseload fuel cells in 2010.

Distributed generation systems will be used largely in markets not served by centralized power. Some requirements for distributed generation systems to achieve their full market potential include:

- ***Low cost.*** In the U.S., technology selection will be based in large part on cost. Fuel cells and advanced heat engines are being designed to offer cost-effective energy solutions.
- ***Very high reliability***. Distributed generation systems must be robust because they will be used and maintained by companies that are not as experienced as powerplant operators and engineers in central power station facilities. Fuel cell systems have already performed reliably for long periods of time without complex or time-consuming repairs.
- ***Flexible size configurations.*** Availability in a variety of sizes from kilowatts (kW) to tens of megawatts is a key attribute of distributed generation technologies.
- ***Modular construction.*** The modularity of distributed generation technologies increases their flexibility to meet changes in demand as efficiently as possible.
- ***Environmental acceptability.*** Since many distributed generation systems may be located in communities near demand centers or in remote, environmentally pristine areas, their environmental performance must be extremely high.
- ***Rapid startup.*** Some distributed generation technology can meet peaking, intermediate load, and load following needs.
- ***Power quality.*** Distributed generation offers many ancillary benefits including voltage control, reactive power control, and regulatory control.

BENEFITS TO THE NATION

Industrial and commercial growth. Growth of U.S. industry will be supported by maintaining distributed generation technical rights and ownership, and by forming engineering and manufacturing infrastructures for distributed generation technologies within the U.S. Domestically manufactured goods can then be sold to world markets.

Reduced electricity costs. Distributed generation systems will result in reduced costs for electrical and heating/cooling systems expansion, as they do away with the need to transport electricity or heat and allow expansion of existing facilities in small increments.

Increased reliability. Power quality and reliability will be increased because distributed generation systems are not subject to transmission line and network voltage fluctuations, and because they are installed near end-use markets.

STRATEGIES FOR SUCCESS

The Distributed Generation Program is based on extensive participation with the private sector and other government agencies (such as DOE's Office of Energy Efficiency and Renewable Energy) for the development of fuel cells and advanced heat engines for stationary applications. Cogeneration and district heating are important elements of the program.

The program implements RD&D that promotes timely demonstration of fuel cell systems, focusing first on resolving technical issues, including cost reduction and packaging. Particular emphasis is placed on conducting the appropriate basic research and technology transfer to assist in commercialization.

Having established a consortium of U.S. engine manufacturers, engine users, and research institutions to evaluate developmental needs for an advanced gas engine, DOE is determining its role in cooperative research programs required to address public needs.

FUTURE ACHIEVEMENTS FOR DISTRIBUTED GENERATION

Measurable goals for DOE and industry partnerships are to:

- Yield commercial offerings of fuel cell powerplants in the 200-kW to 3-MW range.
- Lower fuel cell powerplant costs to under $1,500 per kW by 2003.
- Achieve fuel cell electrical conversion efficiencies of between 50% and 60%.
- By 2010, commercialize U.S.-manufactured advanced gas engines with 20% higher brake efficiency, 75% lower NO_X emissions, and lower cost compared to current engine technology.
- Demonstrate distributed generation technologies, such as advanced fuel cells and heat engines, in cogeneration and district heating/cooling applications with overall system efficiency reaching 85%.

FUEL CELLS

Fuel cells generate electricity and heat using an electrochemical process superior to that of a battery. A fuel cell continuously produces power as long as a fuel, such as natural gas, and an oxidant (air) are supplied. Present systems can exceed 50% electrical efficiency, based on the fuel's lower heating value. Next-generation systems are expected to achieve over 70% and, eventually, greater than 80% efficiencies.

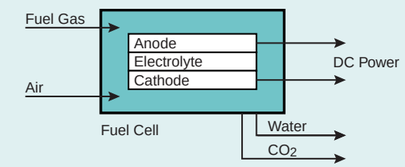
The Fuel Cell Program is being driven, in part, by the emergence of distributed generation approaches and deregulation of the electric power industry. Fuel cells offer greater customer choice; greater siting flexibility; the capability to use "opportunity fuels," such as gas produced in landfills; reduction of capital investment and risk; a highly efficient, reliable, and environmentally benign source of electricity; and elimination of transmission and distribution problems.

Maintaining U.S. leadership in the technology race is crucial in capturing world fuel cell markets. It is important to maintain the current technological edge in significant technologies and U.S. ownership and intellectual property rights in critical areas. This is being accomplished through the establishment of engineering and manufacturing infrastructures in the United States for new fuel cell industries.

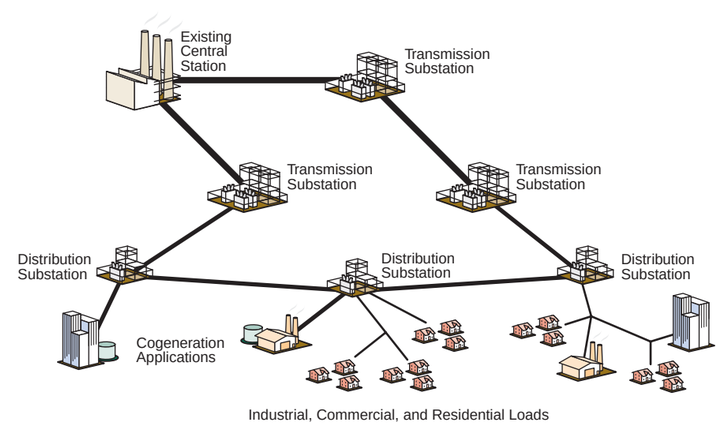
The Fuel Cells Program focuses on the development of highly efficient, environmentally benign, high-temperature fuel cell power generation technologies, such as molten carbonate fuel cells (MCFCs) and solid oxide fuel cells (SOFCs). It includes the integration of components for proof-of-concept testing, customer tests of subscale integrated systems, and eventual commercial demonstration of full-scale systems.

FUEL CELL DIAGRAM

A basic fuel cell consists of two electrodes, an anode, where the fuel is introduced, and a cathode, separated by an electrolyte. It produces DC power that is easily converted to common AC power by an inverter, and hot water for use in buildings or industrial processes. Fuel cell types are characterized by their electrolyte and corresponding operating temperature. For example, MCFCs use a mixture of carbonate salts as the electrolyte, which is a liquid at the fuel cell operating temperature of about 650°C. In contrast, SOFCs use a ceramic electrolyte that remains solid at their 1,000°C operating temperature.



DISTRIBUTED POWER GENERATION

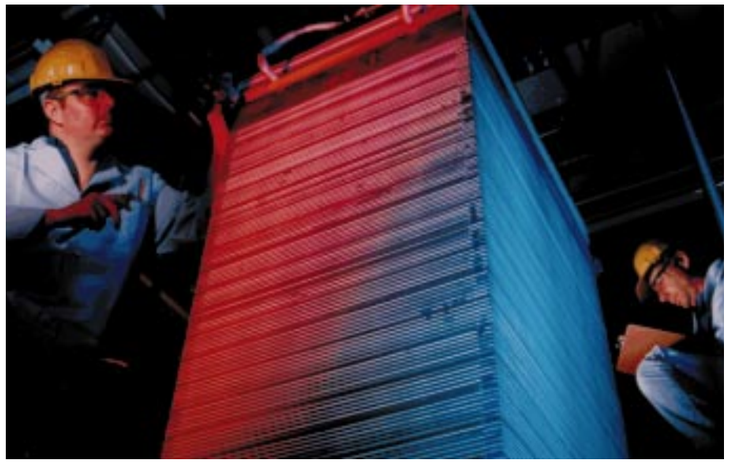


Distributed generation will offer utilities the opportunity to match the electricity demand of individual customers by providing reliable on-site generation. In this example, electricity is being produced at distributed generation substations located near electricity users. These distributed sources of electric power may, but are not required to, be connected to the central electrical transmission lines.

DISTRIBUTED GENERATION

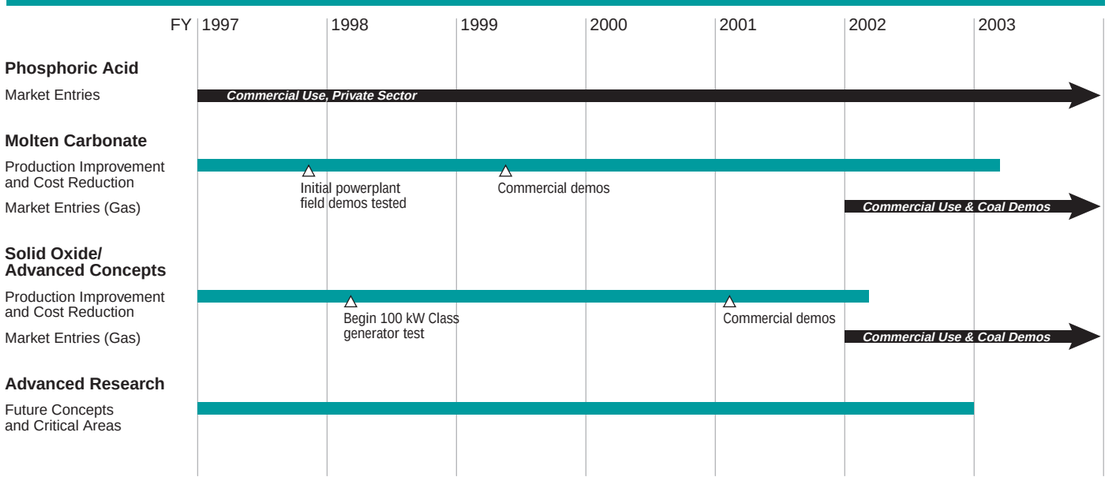
FUEL CELL PROGRAM ACCOMPLISHMENTS

- Over 160 phosphoric acid fuel cell (PAFC) units manufactured and operating worldwide.
- 250 kW and 2 MW molten carbonate fuel cell (MCFC) product development tests completed. 300 kW to 1 MW demonstration planned.
- 100 kW solid oxide fuel cell (SOFC) demonstration being conducted. Additional 100 kW to 1 MW demonstrations planned.
- Fuel cells and fuel cell/turbine hybrids are enabling technologies for Vision 21 concepts.

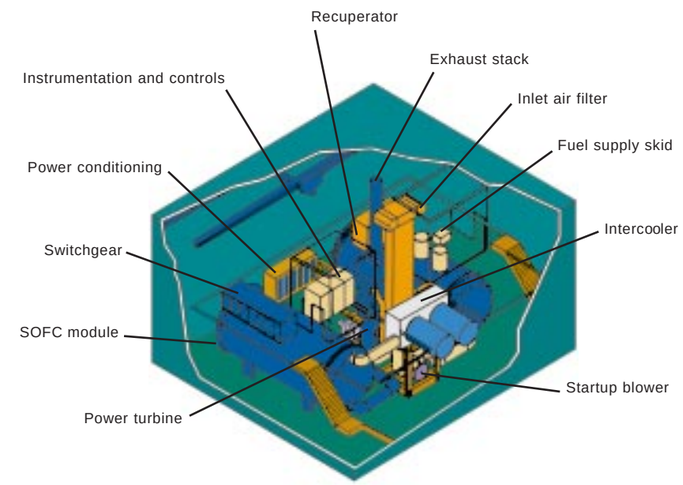


To produce a usable quantity of electric power, individual cells are assembled into a "stack" of electrically interconnected repeating components. This MCFC stack developed by Energy Research Corporation is made up of around 300 cells, with an area of 8 square feet. A fuel cell powerplant consists of one or more stacks integrated into a power section, which is then linked to a fuel processor and a power conditioner to convert the power from direct current (DC) to alternating current (AC).

ROADMAP FOR FUEL CELLS PROGRAM



SOLID OXIDE FUEL CELL POWERPLANT LAYOUT



FUEL CELL REBATE PROGRAM

With fuel cells, as with most other products, increased manufacturing volume lowers cost, increasing market penetration. To help increase market penetration, the Fuel Cell Rebate Program (also called the Climate Change Fuel Cell Program) was begun in 1996 using funds provided by the Department of Defense (DOD), Office of Deputy Under Secretary of Defense for Environmental Security.

Rebates are given to organizations installing a fuel cell manufactured in the U.S., with priority given to powerplants placed on DOD installations.

Rebate program status:

- In 1996, 33 grants of $1,000/kW (or a maximum of one-third of project costs) were awarded, resulting in sales of 42 fuel cell powerplants (200 kW) representing a crosscut of market potential.
- In 1997, 53 grants were awarded.
- In 1998, an additional $5 million was provided for awards to be announced in 1999.

ADVANCED GAS ENGINES

As the need for distributed power generation emerges, continued global market growth is projected for gas-reciprocating engines and industrial-scale gas turbines. Advanced industrial-scale turbines are being developed under the Advanced Turbine Systems (ATS) Program.

Projected growth in natural gas use will increase the Nation's need for efficient and clean gas-reciprocating engines. Orders for natural-gas-reciprocating engines were 38% higher in 1996 than in 1995. Assuming this market growth trend continues, improving the efficiency and reducing the cost of these engines will have significant environmental and consumer benefits.

Environmental constraints continue to become more stringent as policies to reduce greenhouse gas emissions and as regulations for non-attainment areas become more restrictive. Development of advanced gas-reciprocating engines would provide cost-effective products to enable engine users to comply with possible new climate change and air emissions standards.

U.S. manufacturers today are at a disadvantage with respect to foreign manufacturers. Foreign products are more efficient, less polluting, and cheaper. Developing advanced gas-reciprocating engines would provide U.S. manufacturers with a competitive edge in the global engine market.

DOE is organizing workshops and meetings to evaluate the need for a cooperative research program to develop advanced gas engines.

COMBINED HEAT AND POWER

Cogeneration is the simultaneous production of heat or cool air and electrical power in a single process or from a single piece of equipment. The heating or cooling produced can then be used in industrial processes or district-heating systems that distribute steam, temperature-controlled water, or air to multiple sites or buildings. Currently, district heating or cooling is provided by cogenerating plants or facilities designed specifically for this service.

By the end of the next decade, environmental requirements for all power systems may create significant opportunities for cogeneration and district heating. Electricity generators could reduce emissions while achieving the greatest return on investment and the highest efficiencies (about 85% higher heating value) by using high-tech cogeneration and district-heating systems. Capital costs associated with cogeneration and district-heating systems continue to be the main impediment to their use. All DOE advanced fossil-power systems can be adapted to cogeneration and district-heating operations.

Fuel cells, advanced gas turbine systems, and integrated gasification combined-cycle systems will have less impact on the environment if coupled with cogeneration applications.

These benefits are being demonstrated by the Fuel Cell Program in a small 100-kW district-heating program in the Netherlands, and at the Miramar Naval Air Station in Southern California. The Fluidized-Bed Combustion (FBC) Program has also worked with Alaskan Native groups to investigate the adaptation of coal-fired FBC cogeneration and district heating in remote villages.

Developing cost-effective cogeneration and district-heating technologies is closely allied with DOE's efforts to improve the overall efficiency and environmental performance of fossil-based power generation, both conventional pulverized-coal and advanced systems.

ECONOMICAL, RELIABLE, AND CLEAN ON-SITE POWER GENERATION

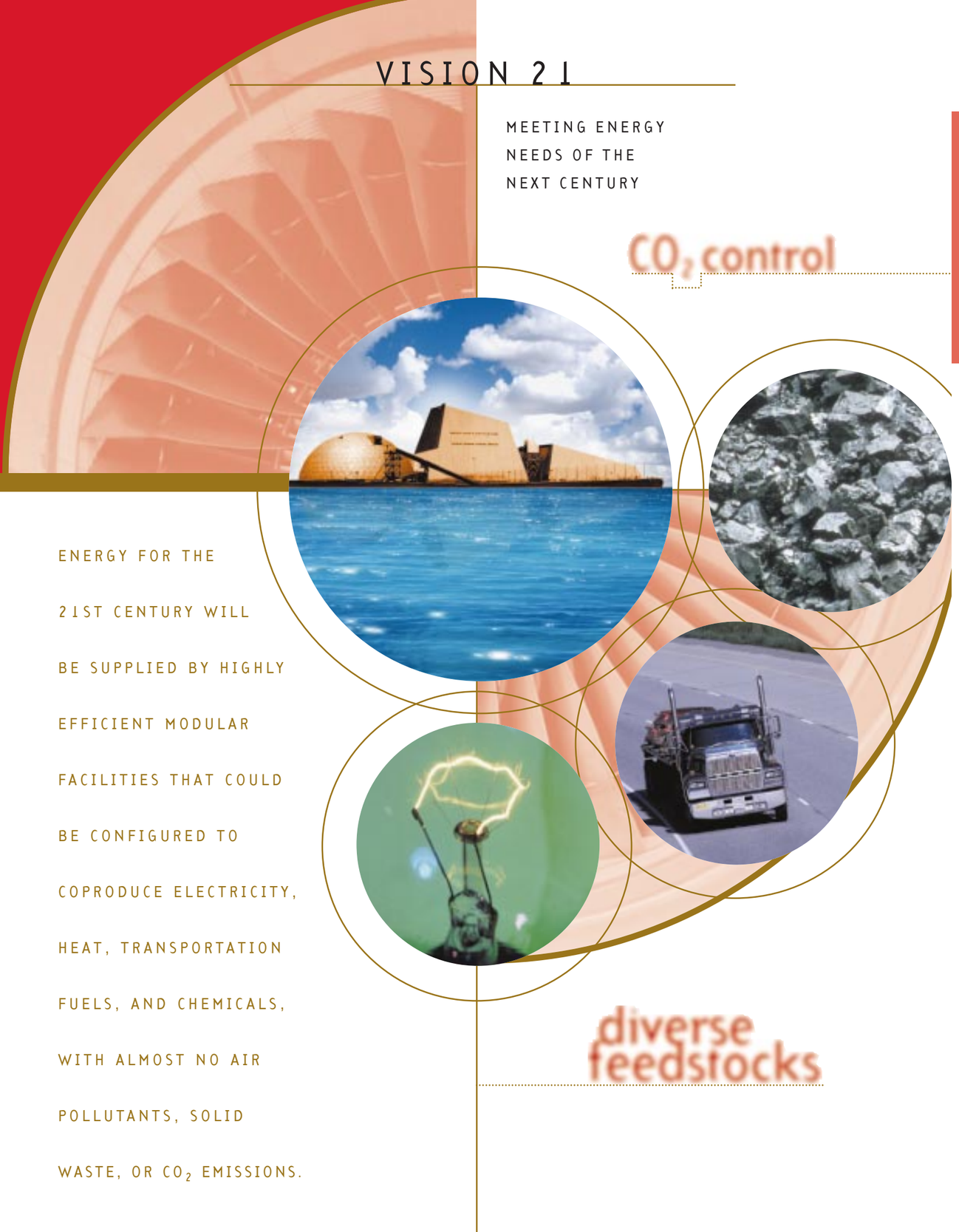
A compact phosphoric acid fuel cell has been supplying reliable electric power to a hotel in Spokane, Washington, for over a year, demonstrating the high efficiency and ease of installation of fuel cell power generation. This 200-kW ONSI unit was the first commercial fuel cell installation in the northwestern United States. Over 160 units have been manufactured so far, and the technology is speeding through the initial stages of commercialization. Worldwide deployment of the phosphoric acid fuel cell (PAFC) is expected within the next five years, as the need for high-efficiency power technologies with low emission rates increases. Concerns about potential climate change from CO_2 emissions will boost sales of fuel cells, as they can reduce CO_2 emissions by as much as 60% over those of today's coal plants.

The power generation system of choice in distributed generation scenarios, the PAFC is currently being sold with standard warranties. It is particularly well-suited for use in hospitals, hotels, and computer center, where its quiet, self-contained operation can be installed in modules to match individual customer demand. DOE-sponsored R&D led to the fuel cell's launch on the market, and DOE is now helping to implement its commercialization through the phosphoric acid fuel cell program and supporting research to lower its capital costs.

As in Spokane, where the PAFC supplies a flexible source of supplemental power to baseload electricity, Fuel cells are an ideal component of a diversified portfolio for U.S. power suppliers.

VISION 21

MEETING ENERGY NEEDS OF THE NEXT CENTURY



ENERGY FOR THE 21ST CENTURY WILL BE SUPPLIED BY HIGHLY EFFICIENT MODULAR FACILITIES THAT COULD BE CONFIGURED TO COPRODUCE ELECTRICITY, HEAT, TRANSPORTATION FUELS, AND CHEMICALS, WITH ALMOST NO AIR POLLUTANTS, SOLID WASTE, OR CO_2 EMISSIONS.

PROGRAM AREAS

* Enabling Technologies
* Supporting Technologies
* Systems/Market Analyses
* Vision 21 Plant Design

INTRODUCTION

WHY VISION 21 IS A NECESSITY

Vision 21 is a new approach to 21st-century energy production from fossil fuels. It will integrate advanced concepts for high-efficiency power generation and pollution control into a new class of fuel-flexible facilities capable of producing electric power, process heat, and high-value fuels and chemicals with virtually no emissions of air pollutants. These plants will be designed using a variety of configurations to meet differing market needs.

This concept is a vision of the way electricity needs to be generated in the 21st century in order to meet environmental requirements and keep energy costs affordable and consistent with robust economic growth. An aggressive industry cost-shared Vision 21 Program would:

- ***Remove environmental barriers to fossil fuel use.*** The technological innovations produced by the Vision 21 Program would allow use of a balanced mix of fossil fuels for our electricity and transportation fuels needs. Environmental barriers, including smog- and acid-rain-forming pollutants, would be effectively removed. Concerns over global climate change would be mitigated by carbon dioxide emission reductions as great as 50% resulting from thermal efficiency improvements. Net CO_2 emissions could be reduced to zero, if needed, through sequestration.
- ***Assure the availability of affordable transportation fuels.*** Vision 21 assures the U.S. of the availability of liquid transportation fuels that are cost-competitive with equivalent petroleum products. Our national security is increased because reliance on imported oil is reduced. Our international balance of trade is improved because oil imports can be reduced and also because the availability of alternative sources of transportation fuels tends to stabilize oil prices.
- ***Continue U.S. leadership role in clean energy technology***. By a recently published account, world trade in environmental controls has surpassed trade in armaments. Vision 21 would create the U.S. technology and know-how to promote the export of fossil energy technology, equipment, and services. U.S. fossil energy/environmental industries would expand and new industries would be created, providing local, regional, and national benefits.

BENEFITS TO THE NATION

High standard of living. Clean production of low-cost electricity and transportation fuels from coal will maintain or raise living standards for future generations.

Energy security. The availability of a clean, efficient fleet of powerplants for the 21st century will offer the U.S. the security of knowing that it can use its largest domestic resource to produce most of its energy needs. Fuel flexibility increases security by allowing the use of biomass and opportunity fuels.

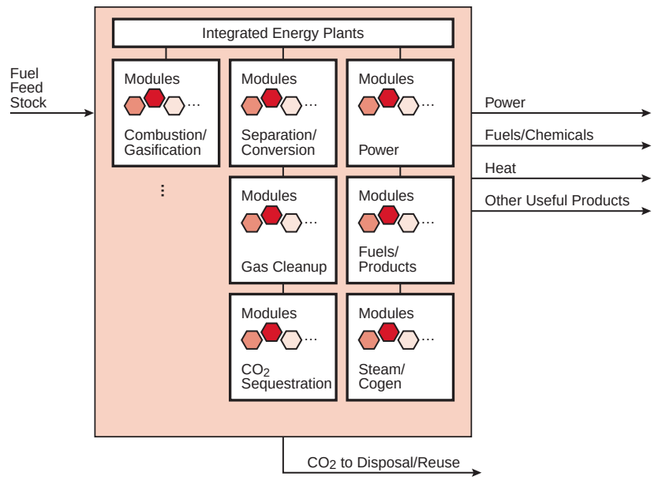
Economic security. The ultra-efficient use of resources in Vision 21 plants will support the continued strength of the U.S. economy, which is dependent on the availability of low-cost energy. Coproduction of high-value commodities will boost the economy further.

Competitive market position. Technologies developed under the Vision 21 Program will ensure that the U.S. will continue to lead the field in ultra-high-efficiency energy technologies with near-zero emissions.

Lower-cost electricity. Vision 21 plants will produce 10% to 20% cheaper electricity due to increased efficiency, the use of a variety of low-cost feedstocks, and the coproduction of high-value fuels and chemicals.

Consumer choices. Vision 21 technology will offer people in the U.S. the opportunity to choose the energy products best suited to their regional markets, economies, and geographies.

VISION 21 CONCEPT TECHNOLOGY MODULES



Discrete technology modules offer Vision 21 plant designers maximum flexibility in their choice of products, feedstocks, and environmental controls. Planners can select modules according to the feedstock supply and product demands of an individual region.

The rapidly changing domestic and international situation (i.e., climate change, oil security, environmental regulation, electric utility restructuring, aging U.S. energy infrastructure, global trade competition and privatization, and declining R&D budgets) requires that more be done. Vision 21 combines electricity- and fuel-producing subsystems in a way that seeks to maximize thermal efficiency, minimize emissions of traditional pollutants, and minimize cost, and yet is readily compatible with carbon dioxide sequestration.

LINKAGE TO OTHER STRATEGIC PROGRAMS

Vision 21 is seen as a long-range, cost-shared, industry-driven R&D program designed to produce public benefits from the present to 2030 and beyond.

Partnerships and linkages are being created with industry, universities, private and public R&D laboratories, and Federal and State agencies. The Vision 21 Program includes enabling technologies, supporting technologies, systems integration and market analyses, and Vision 21 plant design. The product of a Vision 21 Program would be the design basis for commercial-scale Vision 21 plants.

Significant near-term benefits may be realized by the Nation as Vision 21 follows its technology roadmap toward its ultimate goal. For example, high-efficiency fuel cell/turbine cycles using natural gas would be developed for the distributed-power-generation market. Technology improvements that produce fuels or chemicals from coal and other solid hydrocarbon feedstock would be available for other applications besides Vision 21. The Vision 21 Program is also related to the Carbon Sequestration Research Program, focusing on cost-effective, high-efficiency technologies in configurations well-suited to CO_2 sequestration; and the Office of Fossil Energy (FE) Materials R&D Program is an essential partner in the development of the new materials required to pursue these new technologies.

ENABLING TECHNOLOGIES

Enabling technologies allow the Vision 21 modules to meet efficiency, environmental-performance, and cost targets. Some needed enabling technologies are described below.

OXYGEN-SEPARATION TECHNOLOGIES

Oxygen is a key ingredient in many Vision 21 modules. It is required for combustion, gasification, and effective concepts for limiting CO_2 production. Using pure oxygen rather than air allows CO_2 to be more easily concentrated for sequestration because the large quantities of nitrogen found in air are no longer present. Successful technology options need low-cost air-separation technologies capable of making high-purity oxygen.

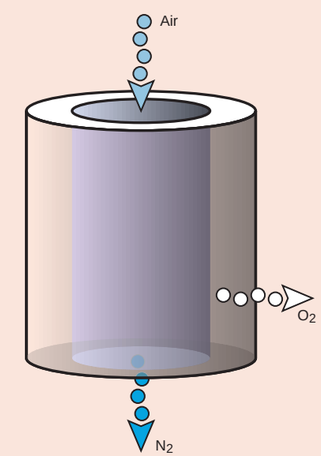
A novel class of dense ceramic materials called ion transport membranes (ITMs) have the potential to meet this need.

A recent study quantified the impact of advanced membrane technology on integrated gasification combined-cycle (IGCC) technology. The initial results showed a 31% decrease in the cost of oxygen, a decrease in total capital investment of $114 per kilowatt, a 2.9% increase in thermal efficiency, a 6.5% decrease in the cost of electricity, and a 500-fold decrease in SO_2 emissions.

Although these benefits are substantial, formidable obstacles must be overcome to develop this technology. These challenges are being addressed in a three-phase program spanning about seven years. The first phase addresses high-risk materials development, membrane fabrication, membrane performance, and engineering issues related to process integration. Subsequent phases will focus on scale-up of the membranes and fabrication techniques, evaluation of full-scale modules, process integration, and validation of process engineering and economic models.

ION TRANSPORT MEMBRANE

New low-cost air-separation technologies are an essential factor in realizing Vision 21. Producing high-purity streams of oxygen will reduce capital costs and increase efficiency, and separating hydrogen for sale will increase profitability significantly. Pure oxygen is also required by technologies that concentrate CO_2 for sequestration. DOE-sponsored R&D has identified a novel class of dense ceramic materials called ion transport membranes, which use mixed-conducting ionic ceramics to conduct both oxygen ions and electrons through the membrane wall. No external electric circuit is required to move electrons through the membrane, so the process produces virtually pure oxygen at far less cost than alternatives.



HYDROGEN-SEPARATION TECHNOLOGIES

One solution to global climate change is to develop a hydrogen economy based on renewable energy resources such as biomass or the photovoltaic splitting of water. In such an economy, the transportation sector would use hydrogen as a fuel, and electricity would be produced using hydrogen in high-efficiency fuel cells. In this scenario, there would be no net CO_2 emissions, a result that would stabilize or decrease the concentration of CO_2 in the atmosphere.

An alternative path to a hydrogen economy could use carbonaceous fuels as a source of hydrogen, with the sequestration of CO_2. However, no commercial technologies exist today that can accomplish the separation of hydrogen from other gases (for example, N_2, CO_2, CO) at high temperatures and pressures. Ceramic membranes could accomplish the desired separation economically. The first approach being pursued is to concentrate on fabricating membranes (molecular sieves) that have sufficiently small pores to permit only the passage of hydrogen molecules through the membrane wall at high temperatures and pressures.

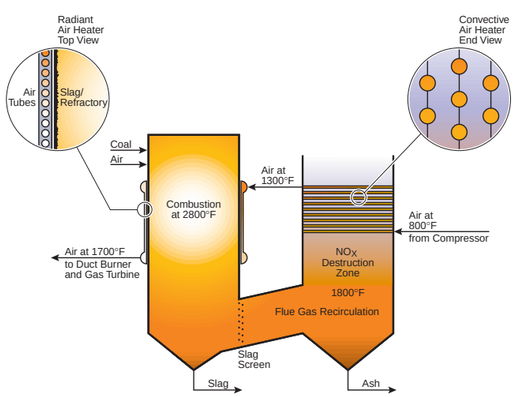
A second approach centers on the development of dense ceramic membranes that conduct hydrogen as protons (proton transfer membranes) through the membrane wall in much the same way as an ion transfer membrane (ITM). Both approaches focus R&D efforts on the water-gas shift reaction to produce hydrogen.

HIGH-TEMPERATURE HEAT EXCHANGERS

One way to increase efficiency in a powerplant is to operate at higher temperatures. The efficiency of a steam turbine (Rankine cycle) increases with the temperature of the steam entering the turbine, and the efficiency of a gas turbine (Brayton cycle) increases with the temperature of gases at the turbine inlet. High-temperature heat exchangers are key to achieving these higher temperatures.

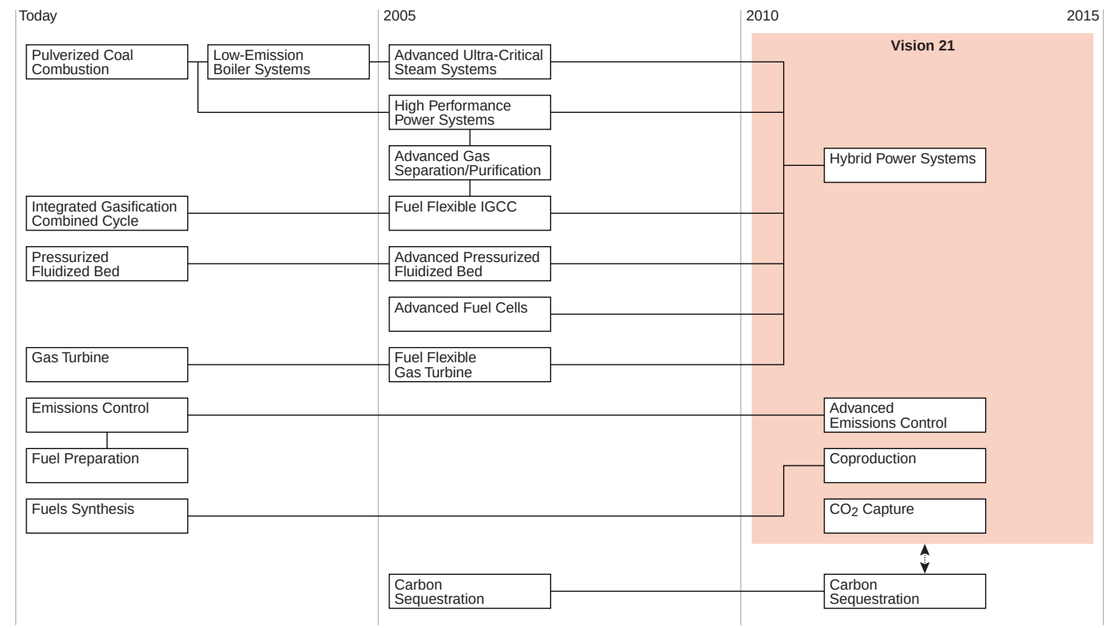
The materials available today limit the maximum temperatures in steam turbine plants to about 1,050°F to 1,100°F. For more efficient plants, high-efficiency heat exchangers are needed to superheat and reheat steam to temperatures of 1,300°F or higher. The Advanced Materials Program is meeting this need by developing advanced alloys that have both high-temperature strength and corrosion resistance for use in heat exchangers. When these improved alloys are available, conventional powerplants with efficiencies of 45% to 50% will become possible and Vision 21 plants with 60% efficiency will be achievable.

HIGH-TEMPERATURE AIR FURNACE



A team led by United Technologies Research Center is developing a high-temperature air furnace (HITAF) for heating turbine air in high-performance power systems, a type of indirectly fired cycle. The HITAF uses advanced materials and a highly innovative design that prevents hot heat exchanger tubes from contacting corrosive coal-combustion products. Such design concepts and approaches will be needed in Vision 21 plants.

ROADMAP FOR VISION 21 PROGRAM



FUEL-FLEXIBLE GASIFICATION

The Vision 21 concept depends on the ability to use the fuels, including waste materials, that are available at lowest cost in the area where the plant is located. This capability is being created by the development of advanced gasification technology to process a variety of feedstocks.

Investigations are focusing on:

- Defining the availability and cost of alternative feedstocks and identifying obstacles to achieving technical success.
- Evaluating alternative feedstocks in existing gasification facilities such as Clean Coal Technology projects and in developmental units.
- Developing novel gasification concepts that can lower costs and improve efficiency, feedstock flexibility, and modularity. Such technologies may include catalytic gasification, the use of novel ceramic membrane approaches, and the use of CO_2 instead of steam as the diluent for oxygen feed to the gasifier in systems that capture CO_2 for sequestration.

ADVANCED HOT-GAS CLEANUP

Key to achieving Vision 21 goals of high efficiencies, near-zero emissions, and low cost, is the cleaning and conditioning of gasification and combustion-product gases. Product gases must be cleaned of all particulate matter, all sulfur- and nitrogen-containing compounds, and all traces of other hazardous compounds that may affect downstream operations or be emitted into the atmosphere.

A ROADMAP OF VISION 21 TECHNOLOGY

Vision 21 provides a technology roadmap for progressively cleaner and more efficient energy production. The roadmap brings together enabling technologies, such as advanced, low-cost hydrogen and oxygen separation and advanced gas cleaning, that are needed to realize performance targets of efficiency and cost. It integrates and builds on advanced technologies now in the R&D and demonstration phase, such as those in the Clean Coal Technology Program.

Additional process improvements will be achieved through such supporting technologies as advanced materials and components, improved catalysts, environmental-control technologies, sensors and controls, and virtual demonstrations. Careful cost and market analyses will be pursued concurrently with technology development to ensure that resultant technologies achieve market acceptance.

Gases must be cleaned at temperatures and pressures close to gasifier/combustor operating conditions and those of downstream operations. Research activities are focusing on:

- Developing high-efficiency, high-temperature particulate filters that operate in either an oxidizing or a reducing environment.
- Investigating new classes of catalysts or sorbents capable of decomposing and/or removing chemical contaminants at high temperatures.

ADVANCED COMBUSTION SYSTEMS

Highly efficient, clean advanced combustion systems are being developed for Vision 21. These systems focus on the indirectly fired cycle because this cycle is inherently fuel flexible and highly efficient. A key characteristic of the indirectly fired cycle is that combustion products do not contact the turbine, thereby avoiding potentially serious corrosion problems that may arise from the use of sulfur- and ash-containing fuels and expanding the types of fuel that can be used.

FUEL CELL HYBRIDS

The Vision 21 concept is expanding the possibilities for advanced power generation systems to work together to achieve efficiencies that could not be attained in a single system. When a fuel cell and advanced gas turbine are integrated in a Vision 21 concept, the efficiency of the system is expected to exceed 70%. Many types of fuel cell hybrids are being studied to understand their potential.

FUEL-FLEXIBLE TURBINES

By 2002, advanced materials, combustion systems, and cooling techniques developed under the Advanced Turbine Systems (ATS) Program will provide the cleanest, most efficient natural gas turbine combined-cycle powerplant on the commercial market.

Vision 21 demands that these achievements be extended to other fuels, including fuel gas produced from coal and hydrogen. This goal is being pursued through the development of advanced-cycle configurations with increased pressure ratios, advanced alloys and ceramic materials, and combustion technology that could advance gas turbines to higher levels of performance at reduced cost.

COPRODUCTION

Coproduction integrates IGCC power production and indirect liquefaction to produce both electricity and fuels or chemicals in a single plant. Both IGCC and indirect liquefaction are now practiced commercially, but not together. One driver that could make coproduction in a Vision 21 facility attractive is CO_2 management.

The basic IGCC process gasifies carbonaceous feed at high temperatures to produce synthesis gas—a mixture of carbon monoxide and hydrogen. The gas is then cleaned of contaminants and fed to a gas turbine/generator and steam-bottoming cycle. In the coproduction mode, a portion of the synthesis gas is directed to a reactor that catalytically converts the gas into premium diesel fuels, gasoline, or chemicals.

The novelty of coproduction in a Vision 21 facility is integration of a highly efficient power cycle with fuel production in a way that facilitates the capture and sequestration of substantially all CO_2 produced.

SUPPORTING TECHNOLOGIES

Integral to the Vision 21 concept of clean and cost-effective use of fossil fuels is directed research on materials, components, controls, sensors, computer modeling, and other supporting technologies that cut across existing product lines and provide support to achieve program goals. These technologies are also applicable to other FE and DOE research and technology development programs. Much of this work is jointly defined and co-sponsored by a diverse group of industrial partners.

MATERIALS AND COMPONENTS

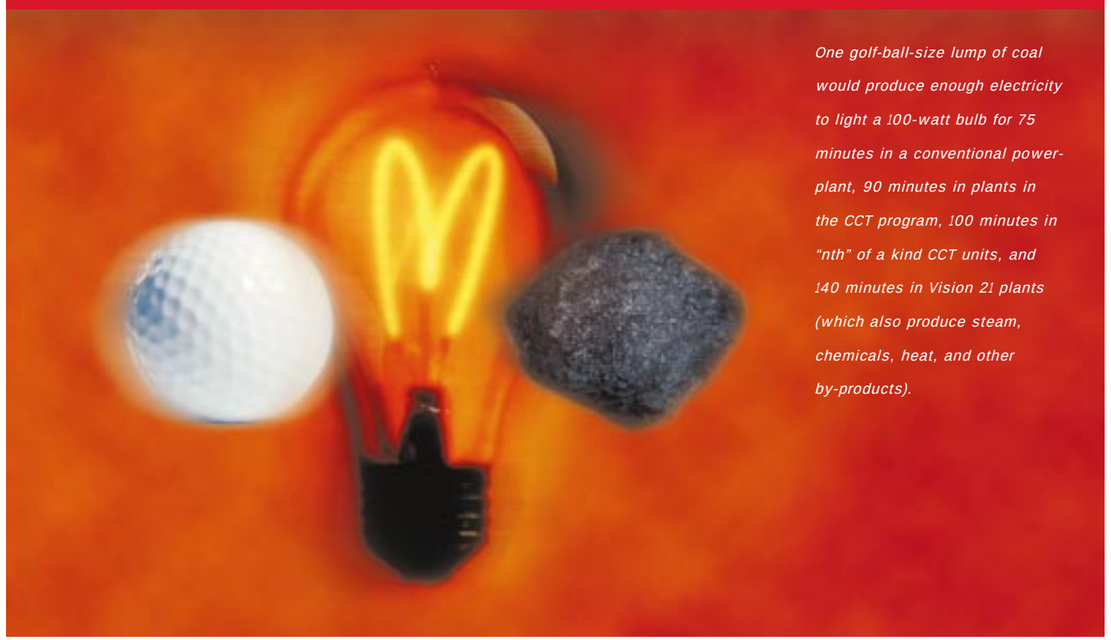
New materials and components are being developed to address the special needs of Vision 21. The ceramic materials required for novel membrane applications and special alloys for high-temperature heat exchangers are examples of products of this activity that are critical to the timely deployment of Vision 21 plants.

VIRTUAL DEMONSTRATIONS

Virtual demonstrations—the use of computer models and simulations to develop, test, and evaluate the design of new concepts—are critical to speed progress and reduce the cost of making Vision 21 plants a reality. Virtual demonstrations are already being used in other industries, e.g., aircraft design and manufacturing, as a cost-effective tool to reduce scale-up, construction, and operational risks. The ability to visually "walk" through a three-dimensional rendition of a new design for a plant and simulate its operation in different situations would be invaluable for identifying opportunities, steering supporting research, and confirming the performance of the design.

The Vision 21 concept provides maximum flexibility with respect to products, feedstocks, and environmental controls. Individual modules could be linked together in many different combinations to create Vision 21 plants. The only way to demonstrate all of these combinations is by using virtual demonstrations. In addition, virtual demonstrations could be used in a predictive fashion to prioritize combinations of modules for a Vision 21 plant for a specific site, based on feedstock availability, population density, environmental goals, and markets for coproducts.

POWERPLANT EFFICIENCY MATTERS



One golf-ball-size lump of coal would produce enough electricity to light a 100-watt bulb for 75 minutes in a conventional powerplant, 90 minutes in plants in the CCT program, 100 minutes in "nth" of a kind CCT units, and 140 minutes in Vision 21 plants (which also produce steam, chemicals, heat, and other by-products).

ADVANCED CONTROLS AND SENSOR SYSTEMS

With the advent of advanced power-generation and fuel-conversion technologies such as those proposed for Vision 21, a new generation of advanced controls and sensors must be developed. The new controls and sensors will be compact, modular, inexpensive, and easy to maintain. They will maximize the operational efficiency of advanced fossil-fueled processes while reducing emissions.

MODULARIZATION

Most large industrial and utility fossil fuel plants are designed on a site-by-site basis. Vision 21 plants will be built from modules available in several fixed-size ranges.

Modular design and construction would maximize shop fabrication, minimize expensive field construction, and maintain flexibility in the design and deployment of Vision 21 plants.

SYSTEMS/MARKET ANALYSES

Systems analysis is a critical part of the Vision 21 Program and serves to guide all activities. The key role of systems analysis is to develop Vision 21 system configurations that meet program objectives, and to define performance targets for individual subsystems and supporting technology needs.

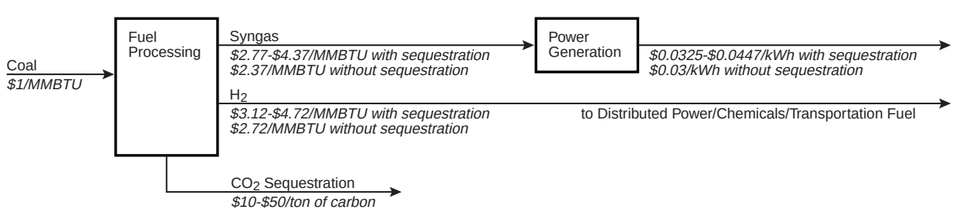
Market analyses will be concurrently performed to determine the acceptability of the most promising systems in both national and international markets. The results of market and system analyses will be used to ensure that Vision 21 closely meets market requirements.

VISION 21 PLANT DESIGN

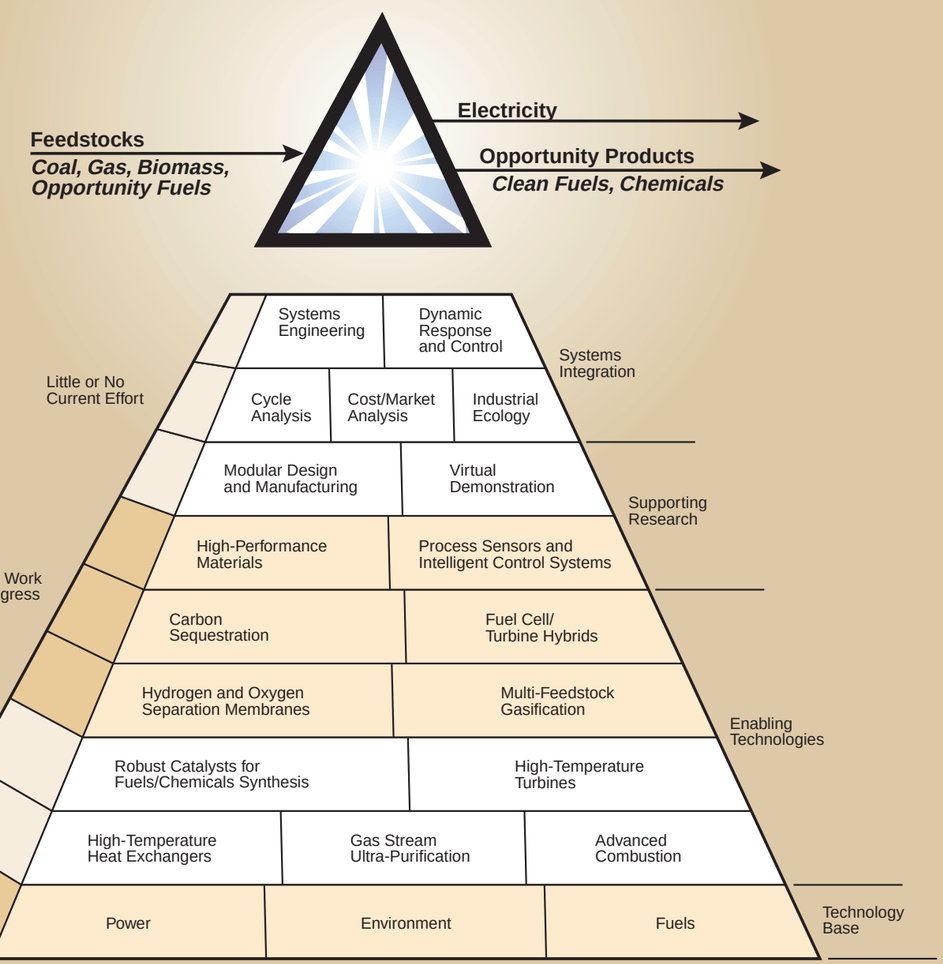
The Vision 21 Program will produce engineering-level designs for prototype (small commercial) and large commercial plants. The major products of the program are:

- ***Component/subsystem designs.*** The development of enabling technologies provides the building blocks for integration into Vision 21 systems.
- ***Prototype plant designs.*** Designs of prototype plants of varying complexity will be produced. The plants will utilize a range of feedstocks and produce various products.
- ***Commercial plant designs.*** The best of the prototype plants will serve as the basis for designs of large, commercial plants of varying complexity and product slates.

A VISION 21 CONCEPT



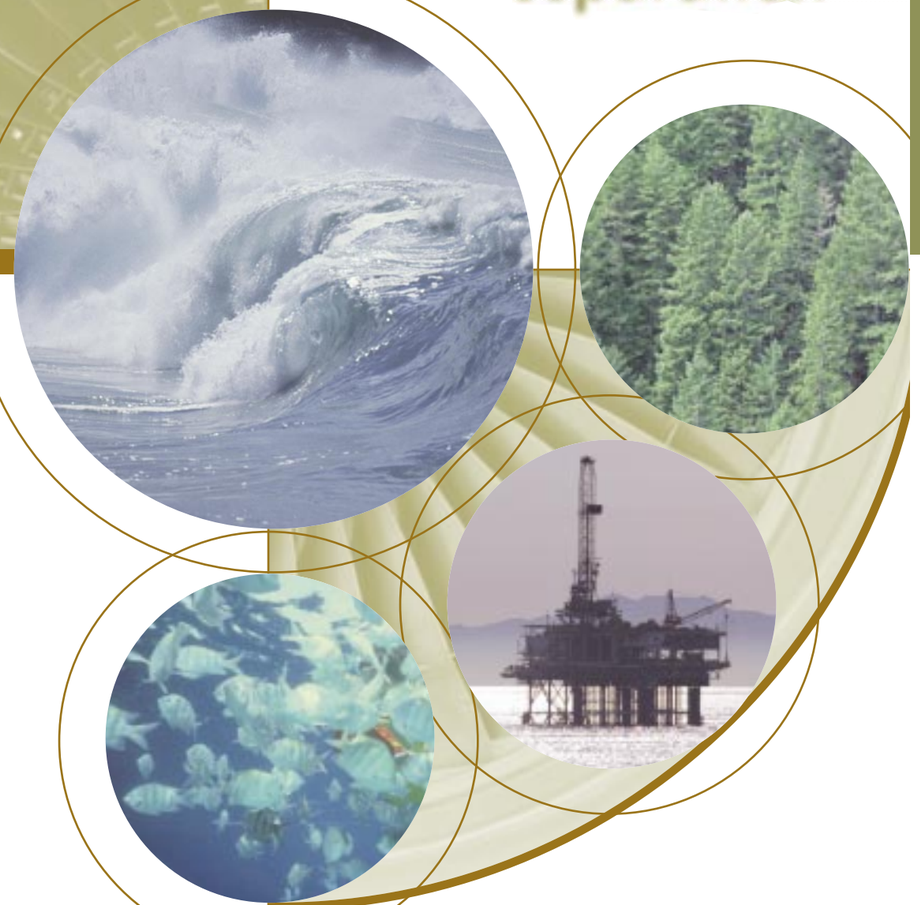
VISION 21



CARBON SEQUESTRATION RESEARCH

PURSUING MID- AND LONG-TERM SOLUTIONS

separation



control

CONCERNS ABOUT GLOBAL CLIMATE CHANGE DRIVE THE NEED TO DEVELOP LEADING-EDGE TECHNOLOGIES FOR COST-EFFECTIVE CARBON SEQUESTRATION AND REUSE.

PROGRAM AREAS

- System Studies and Assessments
- Enhanced Natural Sinks/ Offsets
- Capture and Separations Technology
- Geologic/Ocean Storage
- Chemical and Biological Fixation/Reuse

INTRODUCTION

NEW AND IMPROVED TECHNOLOGIES AT THE CORE OF DOE'S APPROACH

No single issue is as complex, or holds as many implications for the world's inhabitants, as global climate change. One of the primary environmental concerns of the 21st century, response to climate change could dictate fundamental changes in the ways in which we generate and use energy. Such measures as increasing energy efficiency, forest management options, and renewable energy applications are potentially important methods for reducing global greenhouse gas emissions in the short to medium term.

For the longer term, when much larger reductions may be sought, it is clear that additional technologies, including carbon sequestration, could be essential. The importance of carbon sequestration research has been underscored by the President's Committee of Advisors on Science and Technology (PCAST) report, *Federal Energy Research and Development for the Challenges of the Twenty-First Century*, November 1997. The PCAST report recommends increasing the U.S. Department of Energy's (DOE's) R&D for carbon sequestration. Specifically, the report recommends: "A much larger science-based CO_2 sequestration program should be developed.... The aim should be to provide a science-based assessment of the prospects and costs of CO_2 sequestration. This is very high-risk, long-term R&D that will not be undertaken by industry alone without strong incentives or regulations, although industry experience and capabilities will be very useful."

The Greenhouse Gas Sequestration portfolio concentrates on innovative sequestration concepts for longer-term solutions. It includes sequestration technologies for integration with Vision 21 plants at an energy facility site and approaches to remove carbon dioxide from the atmosphere by the enhancement of natural sinks to create greenhouse gas reduction credits.

The program addresses novel and advanced concepts for:

- Cost-effective CO_2 capture and separation processes
- Geologic storage options, including those that recycle carbon back to its source in natural formations
- Enhancement of natural processes in terrestrial and ocean sinks to complement point-source sequestration that is directly associated with energy production
- Chemical or biological fixation or reuse

A recent study by the Massachusetts Institute of Technology evaluated and prioritized research needs for the capture, use, and storage of CO_2 from fossil-fuel-fired powerplants (Herzog, Drake, Adams—*CO_2 Capture, Reuse, and Storage Technologies for Mitigating Global Climate Change*, January 1997). Based upon current assessments, the potential for sequestration is quite high but largely unexamined. In the United States, very little research and development has been done on promising options that might address these pathways.

BENEFITS TO THE NATION

Energy security. Effective carbon sequestration and reuse technologies will enable the U.S. to depend upon its vast and inexpensive domestic resources of coal, which now provide 55% of all electricity produced, and still satisfy environmental concerns.

Growth of U.S. industry. Development of a portfolio of innovative, cost-effective sequestration technologies will keep energy prices low and thus help the U.S. to remain a world economic leader.

Market competitiveness. Development of sequestration technologies will also enable the U.S. to compete in, and likely lead, a new global market for an entirely novel class of technologies.

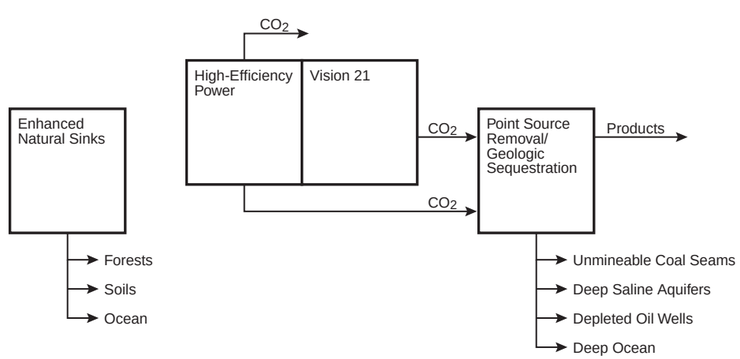
STRATEGIES FOR SUCCESS

The overall goal of the program is to develop a set of sequestration options with potential to offset all new growth in greenhouse gas emissions beginning in the year 2015, and to verify the environmental acceptability, technical feasibility, and cost-effectiveness of a sequestration capacity sufficient for wide-scale implementation starting in 2015.

During the 2005 to 2015 time period, a suite of cost-effective options with increasingly large carbon sequestration capacity will be made available. The program will seek to develop even lower-cost options by 2020, capable of sequestering carbon at a cost of $10/ton. The strategy for achieving this goal is to build upon ongoing scientific, technical, and environmental research using domestic and international cost-shared collaborations with industry, universities, and other governments (e.g., the International Energy Agency [IEA] Greenhouse Gas R&D Programme, the Climate Technology Initiative of the Framework Convention on Climate Change [Working Group 3], and other agreements). In addition, the Offices of Fossil Energy and Energy Research (ER) have established a formal working group to coordinate carbon-management science and sequestration technology research. DOE's program has also received considerable input from industry, government, and academic stakeholders via expert workshops held during the summer of 1998.

DOE's CO_2 sequestration portfolio aims to remove CO_2 efficiently from fossil fuel production and use and to store it for geologic time. Higher-efficiency powerplants will emit less CO_2; cost-effective Vision 21 plants will emit no net CO_2. Point-source sequestration and distributed sequestration, including enhancement of natural processes, will reduce CO_2 emissions and atmospheric concentrations.

COMBINED PORTFOLIO BENEFITS



Further workshops on specific areas of sequestration research, such as geologic sequestration, are being conducted during FY 1999.

The challenge for the future is to expand the current collaborative industry-university-government R&D partnerships that result in cost-effective, innovative technologies to complement and enhance natural sequestration processes.

The program emphasizes competitive, cost-shared solicitations to create partnerships. The first of these competitive solicitations, issued in FY 1998, selected 12 innovative novel concepts for the control of atmospheric emissions of CO_2, methane (CH_4), and nitrous oxide (N_2O). Sequestration-related topics are included in the Department's Small Business Innovation Research, University Coal Research, and Small Business Technology Transfer Program solicitations.

SYSTEM STUDIES AND ASSESSMENTS

A wide variety of activities are used to identify and assess promising novel and advanced concepts for sequestration technologies and the evolving technologies necessary to support them. Activities include system studies; exploratory research; technical, economic, and environmental assessments; full fuel-cycle analyses; expert workshops; and outreach activities to seek promising new ideas and to communicate findings and results to industry, academia, and the public.

ENHANCED NATURAL SINKS/OFFSETS

The annual exchange of CO_2 between the atmosphere and the combined ocean and terrestrial biosphere is extremely large compared to total annual anthropogenic emissions. This suggests that small increases in the net absorption of CO_2 in the global carbon cycle could have a significant effect on changes in atmospheric greenhouse gas concentration.

Dissolved CO_2 in the oceans is removed by the growth of phytoplankton, with plant decay products settling to the deep ocean or ocean bed. When carbon is thus removed, it is ultimately replaced by CO_2 drawn from the atmosphere. Numerous concepts have been proposed for enhancing oceanic uptake of atmospheric CO_2.

A TIMELINE TO ACCOMPLISH THE GOAL

FY 1998. Feasibility investigations of 12 novel concepts for greenhouse gas sequestration were initiated. International collaborative research in ocean sequestration activity is under way with Japan and Norway. An industry-government partnership addressing sequestration in deep, unmineable coal seams was initiated in collaboration with the IEA Greenhouse Gas R&D Programme. A comprehensive update of the assessment of research needs for CO_2 sequestration was completed.

FY 1999. Comprehensive CO_2 sequestration research roadmapping is being completed. The second phase of novel concepts investigations—to obtain the required engineering and economic data to proceed to proof-of-concept—is scheduled to begin.

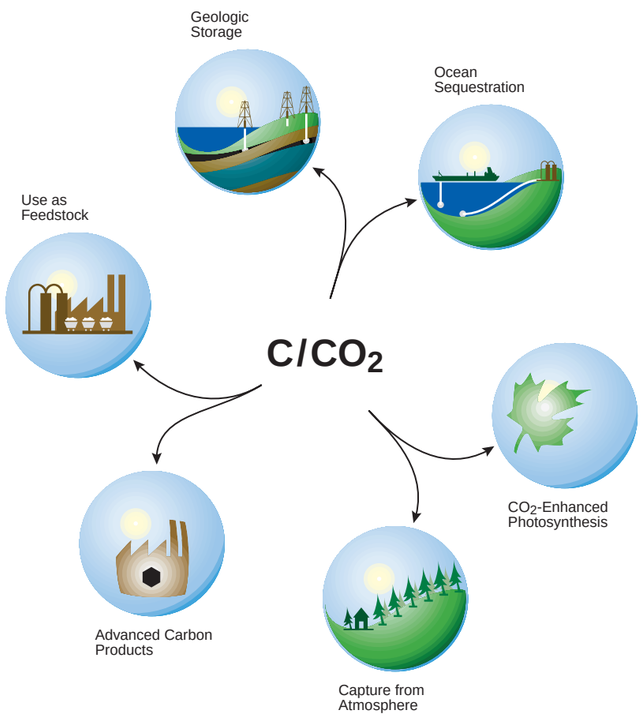
By 2010. In partnership with industry and international partners, DOE will establish the viability of a large capacity of sequestration approaches suitable for deployment by industry in the longer-term (post-2015) time frame.

An important component of terrestrial uptake of CO_2 is tree and plant growth. Trees can remove carbon from the atmosphere and sequester it in forests and forest products, whereas deforestation reduces the amount of carbon sequestered. Through improved forest-management technologies, substantial increases can be made in carbon sequestration by (1) halting deforestation, (2) expanding forests and reforesting areas, and (3) increasing the stocks of carbon in existing forests.

A recent study by the IEA Greenhouse Gas R&D Programme has confirmed that there are potentially large, cost-effective, forest sequestration opportunities. However, to achieve potential benefits, barriers to the application of advanced forest-management technologies must be overcome.

Carbon sequestration in soils is also a key part of the carbon cycle. In this area, research is needed to develop practical and economic technology approaches to increasing soil organic matter and to inexpensively monitor changes in it.

CARBON SEQUESTRATION



CAPTURE AND SEPARATIONS TECHNOLOGY

Sequestration from large point sources requires cost-effective capture of carbon, whether it is CO_2 or C, and its separation from other constituents not destined for sequestration. Capture and separation technology is available but is costly and inefficient.

The focus of this program area is the development of innovative concepts to address improvements in the technical and economic performance of existing technologies.

Carbon sequestration is the separation and capture of CO_2 for either geologic storage, enhancement of natural sinks, or chemical and biological fixation/reuse. It includes disposal either as CO_2 or as some other form of carbon. More than just storage, it includes both existing and new commercial uses of CO_2, CO, and C.

GEOLOGIC/OCEAN STORAGE

Another set of promising concepts for reducing CO_2 concentrations pertain to its storage in geologic formations. It is believed that CO_2 could be cost-effectively sequestered in these formations.

Options for geologic storage of CO_2 include sequestration in depleted or depleting oil or gas wells, coal seams, or deep underground saline formations. Statoil of Norway is currently sequestering CO_2 in a deep saline reservoir under the North Sea, the first practical project of this method of sequestering CO_2. Critical research questions center on understanding the effects of CO_2 on the chemical and physical properties of storage sites, environmental impacts, total potential storage capacity, and the economics of various candidate sites.

Similar carbon storage has already taken place for over a decade at more than 70 enhanced oil recovery sites around the world, where CO_2 injection is used to augment traditional oil recovery technologies.

Research is being conducted to answer the most critical technical questions about the feasibility of and capacity for ocean storage of CO_2 captured from combustion processes.

CHEMICAL AND BIOLOGICAL FIXATION/REUSE

Advanced chemical and biological sequestration is aimed at permanent, stable sequestration and at recycling carbon to create new fuels, chemical feedstocks, and other products. Research is being conducted to develop novel concepts to convert CO_2 , CO, or C into environmentally benign, economically useful products. The major advantage of these technologies is that they produce economically valuable products for the global economy while meeting a global environmental goal. All concepts for these technologies are at an early research stage. Better understanding of the basic processes and new chemistry and bioprocessing approaches is needed before practical, achievable technology performance or cost levels can be estimated.

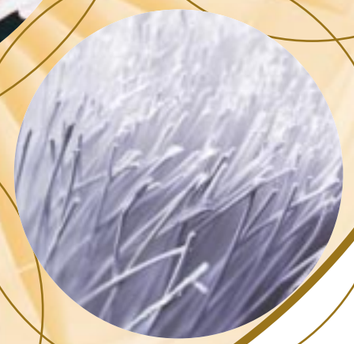
CHEMICAL AND BIOLOGICAL PATHWAYS FOR CARBON SEQUESTRATION

- Conversion of CO to new carbon-based products
- Chemical sequestration as a carbonate mineral
- Direct conversion of CO_2 into methanol or other products
- Decarbonization of fossil fuels with the capture of excess carbon
- Microalgae sequestration
- Biomimetic fixation of carbon

ADVANCED RESEARCH

THE FOUNDATION FOR INNOVATIVE SYSTEMS

materials



processes
innovation

FORGING THE PATH FROM BASIC RESEARCH TO REALIZATION OF THE VISION 21 CONCEPT. ADVANCED RESEARCH CONCENTRATES ON TECHNOLOGIES AND PROCESSES THAT ENABLE INNOVATIVE SYSTEMS.

PROGRAM AREAS

- Materials and Advanced Metallurgical Research
- Bioprocessing
- Coal Utilization Science
- University Coal Research
- Historically Black Colleges and Universities/Other Minority Institutions
- Small Business Innovation Research
- Advanced Clean Fuels Research

INTRODUCTION

The major goal of the Advanced Research Program is to develop, by 2015, a series of advanced materials, subsystem technologies, and breakthrough process concepts that are essential to the success of Vision 21.

MATERIALS AND ADVANCED METALLURGICAL RESEARCH

Program activities focus on developing a technology base in advanced materials synthesis, processing, life-cycle analysis, and performance characterization. The program funds exploratory research on new materials that could improve the performance or reduce the cost of existing fossil fuel technologies, and the development of materials for new systems. Partnering and cost-sharing with industry are central elements.

Research is currently being conducted by the Advanced Research and Technology Development Materials Program at Oak Ridge National Laboratory, the Advanced Metallurgical Research Program at Albany, Oregon, as well as materials-related activities at the Federal Energy Technology Center (FETC).

BIOPROCESSING

Primarily fundamental research, this program area includes research into the chemistry, biochemistry, microbiology, and engineering of bioprocessing technologies and focuses on the biological production and processing of fossil fuels, wastes, and biomass.

COAL UTILIZATION SCIENCE

The Coal Utilization Science (CUS) Program supports research to develop technologies for clean, efficient power generation from coal and other fossil fuels. Emphasis is placed on producing fundamental information by performing experimental research and theoretical investigations on processes and mechanisms that form technological barriers. Novel processes that address environmental issues as well as power generation are included.

AN ADVANCED RESEARCH SUCCESS STORY: NEW CERAMICS

A lightweight ceramic hot-gas filter material developed by the Advanced Research Program is now widely used to remove hot-gas particulates in fossil-fueled power generation and industrial systems, vastly improving their efficiency and productivity.

Developed as part of an industry-DOE cost-shared collaboration, the filter material is now sold commercially, with a potential international market of $7 billion over the next 10 years. The U.S. market alone is forecast to reach $200 million annually by the end of the century.

UNIVERSITY COAL RESEARCH

Grants are provided by the University Coal Research (UCR) Program to U.S. universities in order to support fundamental research and develop improved fossil energy technologies. Novel and innovative approaches are sought to solve national and global environmental and energy-related issues. This research sustains U.S. global preeminence in the areas of fossil fuel science and engineering by supporting fossil energy research at our Nation's universities. The result is a developing and expanding knowledge base in disciplines relevant to fossil fuels.

HISTORICALLY BLACK COLLEGES AND UNIVERSITIES/OTHER MINORITY INSTITUTIONS

The Historically Black Colleges and Universities/Other Minority Institutions (HBCU/OMI) Program was established to provide a mechanism for cooperative research between historically black institutions and other minority institutions with U.S. industries and Federal agencies. This program strives to support the education of scientists and engineers and sponsors research in support of the Office of Fossil Energy's (FE's) product lines. The HBCU/OMI program has emphasized improving the environmental compatibilities of advanced coal, oil, gas, and environmental technology concepts.

SMALL BUSINESS INNOVATION RESEARCH/ SMALL BUSINESS TECHNOLOGY TRANSFER

FE's Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) programs make competitive grants to small businesses for fossil-related technology research projects that interest small businesses while advancing the mission of FE. Research supports FE goals of obtaining clean fuels and energy from fossil sources.

ADVANCED CLEAN FUELS RESEARCH

Coal-derived substitutes for traditional petroleum products have the potential to provide the secure supply of transportation fuels that is critical to all sectors of our economy. Development of a synthetic fuels industry will positively affect our balance of payments and create high-paying jobs, while addressing the projected decline in petroleum production and the concomitant increase in demand after 2015. In addition, these fuels will be more environmentally friendly than any petroleum-based products, while using our vast domestic coal resources to provide a level of energy security not seen for decades.

This cutting-edge research program provides the basis for new technologies by serving as a bridge between basic and applied fuels research. The program is exploring novel concepts for the production of new fuels from coal and mixtures of coal and other resources. Research is done in concert with industry, academia, and other government agencies and laboratories at the national and State levels.

AN ADVANCED RESEARCH SUCCESS STORY: SUPER 9 CHROME ALLOY

Today Super 9 Chrome, an extremely strong steel alloy, is the worldwide industry standard for safer and more reliable coal-fired powerplants. Developed by the U.S. Department of Energy (DOE) advanced materials program, the new alloy is now used for superheater tubes, pipes, and forgings, allowing an increase in powerplant operating steam temperature from 1,005°F to 1,075°F.

The higher operating temperatures have allowed powerplants to boost efficiencies and to save on fuel costs. The greater reliability afforded by Super 9 Chrome parts and the improved stability of equipment incorporating the new alloy have also served to reduce maintenance charges, thereby improving the economic performance of the powerplant fleet overall.

BENEFITS TO THE NATION

High-efficiency power. Development of advanced materials will enable the production of advanced, high-efficiency power systems that better utilize fossil fuel resources.

Domestic liquid fuels. Production of non-petroleum-based liquid fuels with low environmental impact will give the U.S. an alternative source of transportation fuel.

Energy security. Maintenance of coal as the primary source of energy for electricity production will provide Americans with a dependable domestic source of power.

Economic security. Reductions in energy costs resulting from advanced technologies will ensure continued economic well-being for U.S. citizens.

Environmental acceptability. Advanced materials and processes are critical to meeting both tighter emissions standards and future restrictions on greenhouse gases. Reduction of emissions will improve human health and the environment.

INTERNATIONAL

PARTNERSHIPS IN EMERGING GLOBAL MARKETS

global environment

economic growth

WORKING TO ENSURE A CONTINUING AND GROWING WORLD MARKET FOR U.S. TECHNOLOGIES, DOE'S INTERNATIONAL PROGRAM HELPS PROMOTE ADVANCED POWER GENERATION SYSTEMS ABROAD.

PROGRAM AREAS

- Brazil
- India
- Ukraine
- Poland
- Middle East

INTRODUCTION

TACKLING GLOBAL ENERGY ISSUES OF THE 21ST CENTURY

Worldwide, the demand for power is increasing exponentially. The global market for electric power systems has been estimated at $2,279 billion (1993 dollars) between 1995 and 2010, and over half this investment will be for coal-fired units. At the same time, the energy sectors of many countries are undergoing major transformations. Increasingly stringent environmental regulations, growing international concerns over global climate change, and increased competition among fuels drive the need for advanced power technologies that deliver electricity efficiently, cleanly, and economically.

These trends offer great opportunities for clean coal technologies and advanced power generation systems, the wide-scale adoption of which would protect local, regional, and global environments and support the Administration's environmental goals.

STRATEGIES FOR SUCCESS

The International Program in the U.S. Department of Energy's (DOE's) Office of Coal and Power Systems has four major strategies:

- ***Provide leadership in international organizations.*** Office of Fossil Energy (FE) staff have leadership roles in several international organizations: the International Energy Agency, Latin America Energy Organization, Asia Pacific Economic Cooperation's Regional Energy Cooperation Working Group, United Nations Economic Commission for Europe Clean Coal Technology Initiative, and the World Energy Council.
- ***Maximize export opportunities.*** The U.S. is the world leader in the development of clean fossil-power technologies. The International Program works to ensure that U.S. companies get a share of the global market for clean power systems, thereby securing jobs, driving economic growth for the U.S., and contributing to global environmental protection.
- ***Establish effective partnerships.*** Partnerships play an important role in overcoming barriers facing U.S. companies pursuing export opportunities. Such barriers include trade, finance, inadequate understanding of U.S. clean power systems, and unfair competitive trade practices. Through its partnerships, the program facilitates business solutions to remove these barriers.
- ***Facilitate electricity transactions across international borders.*** The International Program ensures reliability and open-access transmission through border systems. The Office authorizes exports of electricity, collects and analyzes information on international electricity trade, conducts country-specific studies on electric power systems and the construction of international transmission lines, and provides electric power regulatory assistance.

ONGOING ACHIEVEMENTS

Through membership in international organizations, FE staff in the International Program influence policies to help support U.S. foreign policy and energy, environmental, economic, and national security objectives. Such policies can enhance opportunities for U.S. firms to expand into international markets. International agreements are executed with counterparts in key foreign countries that support FE's RD&D objectives, and foreign partners are supported in an advisory capacity as they pursue private power reforms.

To ensure that U.S. companies get a share of the global market for clean fossil power systems, bilateral efforts are ongoing in seven regions: Africa, Eastern Europe, the Pacific Rim, Russia and the Newly Independent States, South Asia and Near East, Western Europe, and Western Hemisphere. In each region, countries are assisted with adapting their power sectors to meet local demands and environmental pressures. This assistance facilitates dialogue between financial institutions and U.S. companies.

BRAZIL

The International Program, through FE's Office of Coal and Power Import and Export (ImEx), has sponsored several conferences and workshops to promote technology advances in Brazil's coal mining and power generation sectors. In addition, it has sponsored trade missions for industry and government where Brazilian participants have benefited by face-to-face discussions of common areas of interest with U.S. business entities. Projections indicate that coal-fired electricity generation in Brazil could increase substantially and require billions of dollars of investment by 2015. The United States is Brazil's largest trading partner and DOE's efforts in the energy field help maintain this position.

INDIA

Since 1982, the Federal Energy Technology Center (FETC) has managed six coal-related projects in India for the U.S. Agency for International Development (USAID). The total value of these projects, including contributions from the various Indian partners, is about $80 million, with about $15 million of the total brought to FETC for direct implementation.

Two of these projects have been completed recently: (1) Program for Acceleration of Commercial Energy Research (PACER), which was funded at $356,000, and (2) U.S.-Asian Environmental Partnership's (USAEP's) Indo-U.S. Coal Preparation and Beneficiation Project, which was funded at $382,000. The PACER project included engineering and economic analyses by FETC to support development of commercial coal washeries in India. This project has helped open the Indian coal preparation market, which has been valued at over $4 billion, to U.S. companies and technologies.

The second project supported deployment of an advanced coal-cleaning circuit, based on U.S. technology supported by DOE, at the first commercial non-coking-coal washery in India. The objective of this project is to demonstrate production of coal with less than 30% ash in the 2.5-million-ton-per-year commercial washery. Two U.S. firms, Spectrum Technologies and CLI, have taken equity positions in the commercial washery, and CLI, a U.S. coal preparation design company, has been awarded a $12-million engineer, procure, and construct contract and a $4-million-per-year operation and maintenance contract.

The Greenhouse Gas Pollution Prevention Project, initiated in 1995, is funded by USAID and the Indian government at a total of about $30 million. The Efficient Coal Conversion component of this project seeks to improve the efficiency and environmental performance of existing Indian coal-fired powerplants, while the Advanced Biomass Cogeneration component seeks to promote year-round cogeneration in Indian sugar mills with power export to the grid while using only biomass fuels.

MAJOR EVENTS TO COME

- Additional efficiency demonstration testing at several State Electricity Boards' coal-fired powerplants to increase awareness of greenhouse gas reduction opportunities and other benefits.
- Selection of three or four additional Advanced Biomass Cogeneration demonstration projects for funding.
- Additional training on the merits and operating characteristics of Advanced Biomass Cogeneration powerplants at Indian sugar mills.
- Monitoring, to world standards, of the Advanced Biomass Cogeneration demonstration projects when they become operational, to develop a database on Indian conditions.
- Assessment of advanced DOE technologies (e.g., fuel cells, pressurized fluidized-bed combustion) and recommendations to USAID-India to provide cost-shared pre-feasibility study funding.
- Continued championing of three integrated gasification combined-cycle (IGCC) projects that are under various stages of development in India with USAID and the World Bank/International Finance Corporation.
- Support of a coal-gasification-based plant, possibly with coproduction of chemicals and power.

BENEFITS TO THE NATION

A stronger economy. Increased international technology sales will improve the U.S. economy and increase the number of high-skill jobs for Americans.

Market competitiveness. The program improves the U.S. technological advantage and U.S. competitiveness in the international market.

Energy security. By promoting strategic international collaboration and supporting high-efficiency use of fuel resources, the FE International Program increases U.S. energy security.

Environmental security. A priority of the program is to mitigate the global environmental impact of increased fossil fuel usage by overcoming the obstacles to using clean fossil power systems.

Expanded markets. Facilitating both new market entries and expansion in existing markets, the program develops international markets for U.S. energy-related technologies, services, and energy resources.

Through a recently completed agreement with USAID-India, FETC supported demonstration of a U.S. advanced coal cleaning technology at the commercial Bilaspur Coal Washery in Madhya Pradesh. This 2.5-million-ton/yr washery is being built through a joint venture among Spectrum Technologies of New York, CLI Corporation of Pennsylvania, and Bombay Suburban Electricity Supply of India. Additional site-specific cost-benefit studies have been conducted to support establishment of other coal beneficiation plants in India with U.S. partners.

CUMULATIVE WORLDWIDE ELECTRIC POWER INVESTMENTS BY REGION (1995-2010)
(IN BILLIONS OF DOLLARS, 1993)

Investment Type	North America	Latin America	Western Europe	China	OECD Pacific Rim	East Asia	South Asia	Central and East Europe	Newly Indep, States	Middle East	Africa	World Total
Generation												
Solid Fuel	94	22	102	222	51	100	71	19	24	2	27	734
Natural Gas	32	23	89	1	14	41	13	10	33	27	15	298
Oil	1	8	1	0	0	1	1	7	2	2	6	29
Nuclear	6	3	8	18	39	21	6	3	26	0	0	129
Hydro/Renewal	17	52	15	67	5	6	48	5	13	3	5	235
Subtotal	**149**	**108**	**215**	**308**	**108**	**169**	**139**	**44**	**98**	**34**	**54**	**1,426**
Other												
Transmission	14	42	20	31	10	28	23	3	14	4	12	200
Distribution	54	36	78	84	39	61	60	11	30	10	19	480
General	14	17	20	43	10	17	21	6	14	5	7	173
Subtotal	82	94	118	159	59	105	103	19	58	18	38	854
Total	**231**	**202**	**333**	**467**	**167**	**275**	**242**	**63**	**156**	**52**	**91**	**2,279**
Annual Average	**15**	**13**	**22**	**31**	**11**	**18**	**16**	**4**	**10**	**3**	**6**	**152**

Source: Resource Dynamics Corp. estimates based on EIA's 1995 World Energy Outlook, Capacity Constraints Scenario, base case.

- Continued technical assistance for Advanced Biomass Cogeneration activities, including an anticipated interest in bagasse gasification for power or liquid fuel production.
- Technical assistance and training to foster "climate-friendly" policies and combat "climate change in cities" in India, two new USAID-India initiatives.

FE has also supported creation of a bilateral Coal Advisory Group, composed of coal and coal technology associations and academics, to advise the Indo-U.S. Bilateral Consultations on issues relevant to the coal industry. This group has the charter to identify topics of interest and propose joint efforts to address those issues. Principal topics of interest include fly ash utilization, coal cleaning, and powerplant efficiency improvements. Secondary issues include coal mine fires and coal-bed methane collection and utilization.

UKRAINE

In 1994, a U.S.-Ukraine Clean Coal Technology Task Force was established to develop a cost-effective approach to upgrading an anthracite-burning powerplant in Eastern Ukraine, Lugansk GRES. Members of the Task Force were drawn from the FE Office, FETC, the Ukrainian Ministry of Energy, and the Ukrainian Academy of Sciences.

The plant uses eight 200-megawatt (MW) slagging pulverized-coal combustors that were installed in the 1960s. While the units have been heroically maintained by plant staff with few resources, the equipment is well beyond its design life and is worn out. The boilers have been derated to 145 MW. In addition, coal quality has deteriorated since the units were put on line. They were designed for use with a low-grade anthracite having an ash content in the range of 18% to 20%. They have operated recently with coal that contains 30% to 37% ash. About 30% of the calorific feed to the boilers must be supplied by oil or gas to compensate for the poor coal and deteriorated boiler equipment.

Several approaches were used in devising a plan for upgrading Lugansk GRES. An engineering services company evaluated the plant and designed several alternative approaches for rehabilitating the existing boilers, including one that would increase power output above the nameplate capacity to 230 MW. In addition, they described how twin 60-MW circulating fluidized-bed (CFB) boilers could be installed in existing space to use low-quality coal without support fuel.

A shipment of 160 tonnes of Ukrainian anthracite was sent to the U.S. to test schemes for improving its quality by washing and for use in a large-scale test burn in a 2.5 MWt CFB boiler at Babcock & Wilcox Company's R&D Center in Alliance, Ohio. Tests with washed and unwashed coal in a pulverized-coal combustor at FETC confirmed the benefits of using cleaned coal for improving boiler performance and reducing the need for support fuel. The CFB test showed that coal could be combusted acceptably with no support fuel.

Economic and financial analyses of several approaches to refurbishing existing boilers and installing new CFB boilers were prepared, and several supporting studies by U.S.-Ukrainian teams evaluated coal and coal-waste sourcing, and the coal-cleaning plants available to Lugansk GRES. The option of shutting down Lugansk GRES and bringing in power from other areas was evaluated and found to be uneconomic.

DOE has conducted a cooperative project with the government of Ukraine and with funding from USAID to strengthen the country's thermal power sector. The project at Lugansk GRES developed a cost-effective approach to upgrading an anthracite-burning powerplant. The incentive was first to aid Ukraine in providing alternative sources of power to the nuclear station at Chernobyl, and second to help Ukraine reduce the amount of imported oil and gas it needs for cofiring with poor-quality anthracite at Lugansk GRES, easing its balance-of-payments problem with Russia.

A NEW ENERGY AND ENVIRONMENTAL TECHNOLOGY CENTER IN BEIJING

China will by 2015 replace the U.S. as holder of the dubious honor of being the largest emitter of greenhouse gases during energy conversion. Coal today provides 75% of China's energy needs and is projected to continue supplying at least 60% through 2050.

As a move both to help reduce global CO_2 emissions and to enhance the adoption of U.S. environmentally superior technologies in China, the U.S.-China Energy and Environmental Technology Center in Beijing was instituted in November 1997. Backed by joint DOE and Environmental Protection Agency funding, it demonstrates a long-term relationship, building on trust, mutual benefits, and goodwill.

Activities are jointly implemented by the U.S. and Chinese governments and conducted by a bi-national team. A Web database already contains more than 1,000 U.S. firms with energy and environmental technology and equipment that can serve the Chinese market. The Center is now conducting joint expert studies on coal liquefaction, IGCC for retrofit and repowering, coal preparation, and superfine coal applications, with plans to investigate applications for fuel cells. One recent agreement negotiated by the Center is between HTI, a New Jersey company, and China's Central Coal Research Institute to conduct a feasibility study on direct liquefaction, an area in which U.S. technology competes with Japanese and German suppliers.

In supporting the new center in China, DOE's International Program is advancing national goals of energy and environmental security and increasing opportunities for clean coal technologies in the global marketplace.

POLAND

In 1989, President Bush pledged that the U.S. government and U.S. companies would help the government and people of Poland to reduce severe air pollution in and around the Polish city of Krakow, the former capital. Krakow's monuments and other historic structures were being ravaged by pollution from uncontrolled coal burning.

Since then, DOE FETC has headed the Krakow Clean Fossil Fuels and Energy Efficiency Program, designed to upgrade boiler houses that provide industrial, commercial, and residential heat, as well as small stoves that fire raw coal for home heating and cooking. This usage, combined with low stack heights at district-heating and industrial plants, has caused substantial sulfur dioxide (SO_2), nitrogen oxides (NO_X), and particulates pollution.

The Krakow program, valued at $20 million, originally considered five different approaches to pollution reduction:

- Conservation and extension of central-station district heating
- Replacement of coal- and coke-fired boilers with natural-gas-fired boilers
- Replacement of coal-fired home-heating stoves with electric heating appliances
- Reduction of emissions from boilers using coal and coke
- Reduction of emissions from coal-fired stoves in private homes

Eight U.S. organizations are participating through cost-shared cooperative agreements that introduce clean coal technologies and upgraded equipment to the Polish marketplace. The U.S. government contribution is, at most, 50%. In some cases, funding comes from third parties or Polish partners.

Almost all of the companies have secured local Polish partners and formed joint ventures, which are expected to lead to the establishment of permanent businesses after the cooperative agreements are completed.

Technologies that are being pursued include boiler-modification and modernization equipment, novel separators that remove particulate matter, use of cleaned and graded coal for stoker boilers, district-heating extension, district-heating controls, briquettes for home stoves, a micronized-coal-combustion system, and automated boiler-combustion controls.

Financially, the program has been highly successful. To date, $11 million spent on cooperative agreements has leveraged $12 million from U.S. participants and their Polish counterparts.

In addition, the program has helped to establish three permanent joint ventures and one licensing agreement, to realign the Eastern European operations of a major U.S. firm, and to expand two Polish manufacturing sites. Coal-fired operations have been upgraded and environmental performance has been greatly improved. For example, because updated controls were installed on five boilers, fuel consumption in one boiler house decreased by 25%. Thirty-seven core separators, which have high efficiencies in capturing particulates, have been installed, and 16 more are in the process of being installed across Poland and elsewhere in Central Europe. A local district-heating system has been modernized and expanded, resulting in 41 MW of coal-fired boilers being retired and coal consumption being reduced by more than 1,300 metric tons per year.

INTERNATIONAL PROGRAM

Emissions have declined substantially. Particulate matter has been reduced by 3,924 metric tons per year, SO_2 by 884 metric tons per year, NO_X by 183 metric tons per year, and carbon monoxide by 1,330 metric tons per year.

MIDDLE EAST

Several coal and power systems projects are planned and under way in the Middle East. In Egypt, assistance is being provided to Cairo University and the Ministry of Power in their efforts to prepare a proposal to the U.S.–Egypt Science and Technology Joint Fund. The proposal will look at possible alternative solutions to a lack of adequate power. Egypt identifies two problem areas, which they refer to as areas of "chaotic growth" and "touristic villages," that are not adequately served by the electricity grid. One possible solution that is being proposed by the University of Cairo is the use of U.S.-developed fuel cells, which can provide high-efficiency power generation with no environmental problems.

In Israel, a proposal has been submitted to the U.S.-Israel Science and Technology Commission, administered by the Department of Commerce, to investigate the efficacy of cofiring coal with municipal and industrial waste. This approach has the potential advantage of both providing additional power and eliminating an environmental problem, because the waste is currently being landfilled at high cost in areas of high alternative-use value.

Additionally, Israel has expressed interest in IGCC for the gasification of refinery residuals and for coal gasification backup to new natural-gas-fired powerplants being built on the Mediterranean coast. The new powerplants would derive their fuel from a natural gas pipeline from Egypt, and the IGCC would provide security backup to any potential disruption of service. Discussions have been initiated between Texaco and Destec in the U.S., the Israel Electric Corporation, and Israel Refineries, Ltd. An IGCC market study is under way and a trade mission to the U.S. is being scheduled.

Eight U.S. companies have had opportunities to market their environmental technologies and establish businesses in Poland thanks to the DOE-led Krakow Clean Fossil Fuels and Energy Efficiency Program. The program also gathered fundamental information on pollutant emissions and reduction strategies for small-scale Polish boilers and home stoves, making this information available to organizations in the U.S., Poland, and Central Europe. Building upon their successes in Krakow, some U.S. businesses have already made additional sales worth several millions of dollars in Poland, Central Europe, and Russia.

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JANUARY 1999
PRINTED ON RECYCLED PAPER