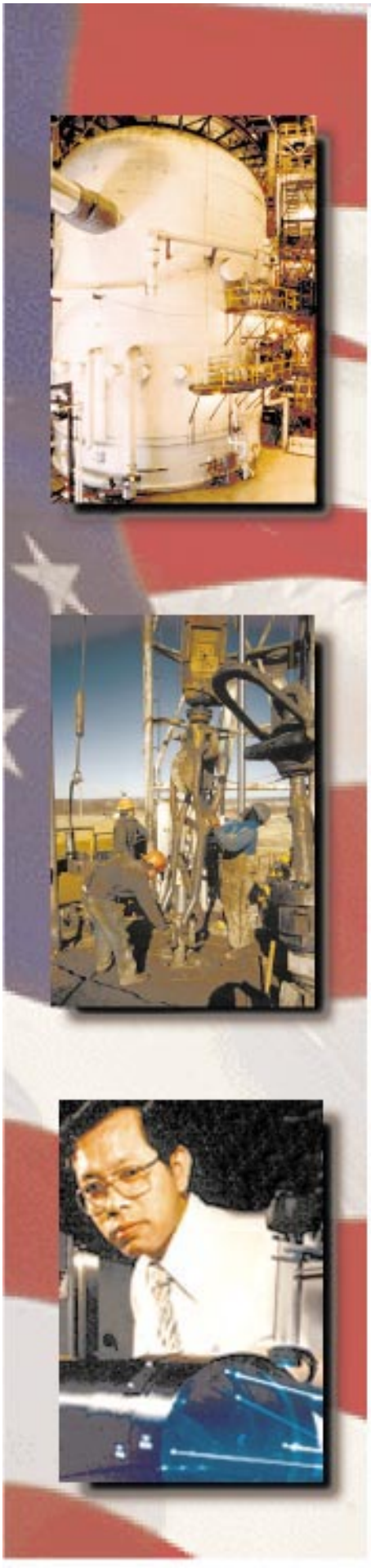
INVESTMENTS IN FOSSIL ENERGY TECHNOLOGY

How the Government's
Fossil Energy R&D Program
Has Made a Difference



Office of Fossil Energy
U.S. Department of Energy

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Introduction

America has the technological capacity to change its energy future. There is no reason, for example, why our nation must continue following a path of rising oil imports when billions of barrels of crude oil remain in domestic oil fields.

There is no reason why we cannot continue to use our abundant supplies of high-value, low-cost coal when we have the scientific know-how to remove virtually all of its pollutants and reduce greenhouse gas emissions.

There is no reason why we cannot turn increasingly to clean-burning natural gas and tap the huge supplies we know exist within our borders.

We remain a nation rich in the fuels that have powered economic growth. Today 85 percent of the energy we use to heat our homes and businesses, generate our electricity, and fuel our vehicles comes from coal, petroleum and natural gas.

As we move toward a new century, the contributions of these fuels will grow. By 2015, the United States is likely to require nearly 20 percent more energy than it uses today, and fossil fuels are projected to supply almost 88 percent of the energy Americans will consume.

We have the scientific know-how to continue using our fossil fuel wealth without fear of environmental damage or skyrocketing costs. The key is technology - developing cutting edge concepts that are beyond the private sector's current capabilities.

Some of the most important innovations in America's energy industry are the results of investments in the Federal government's fossil energy research and development programs. Today, our air and water are cleaner, our economy is stronger, and our industries are more competitive in the global market because these programs have produced results.

This booklet summarizes many of these achievements. It is not a comprehensive list by any means. Still, it provides solid evidence that the taxpayers' investment in government fossil energy research has paid real and measurable dividends.

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Secretary Peña

Why Government R&D?

"Research and development is critical if the U.S. is to maintain its technological edge. The question is: how should our national research and development investment be shared between the public and private sectors?

U. S. private sector spending for energy research and development is down more than 30 percent since the early 1980s. One reason is that recent changes in domestic energy markets, particularly deregulation of the natural gas industry and the move toward greater competition in the electric power industry, have encouraged general corporate cost-cutting but discouraged research and development, especially if the payoff is beyond one to three years. At the same time, the makeup of the U.S. oil industry is shifting from large, multi-national producers to smaller companies (who drill 85 percent of all new wells) with limited research and development capability and access to advanced technologies. In addition, expectations of continued low oil prices may be discouraging private research and development that could lower the cost of new sources of fuels.

When the result will clearly benefit the public at large - for example through cleaner air, more affordable energy, or greater energy security - government involvement is justified and can make the significant difference. This is especially true when the R&D is beyond the private sector's economic capability or interest. Some R&D has no current "market driver." Some R&D may be vital in the 21st century, but holds no economic incentive today for the private sector. For example, few companies can today justify an aggressive research program aimed at preventing the generation of the greenhouse gas carbon dioxide, much less investing in a means of capturing and disposing of it. There is no immediate "bottom line" payoff. If the public benefits are important - but research is too fundamental to offer commercial potential, or the advanced technologies pose too great a technical risk or are outside the time frame that would justify industry's investment on its own - then federal support is justified, and sometimes critical to secure public goals and benefits."

Federico Peña, Secretary of Energy
to the Subcommittee on the Interior and Related
Agencies, Senate Committee on Appropriations

Natural Gas and Petroleum Exploration & Production

The United States taught the world how to locate and drill for hydrocarbons. For many U.S. companies, technological innovation has meant the difference between keeping domestic oil and gas fields producing or shutting them down.

Since 1985, for example, advances in drilling, reservoir imaging and production technologies have allowed U.S. natural gas producers to increase production by 14 percent despite a 50 percent decline in wellhead gas prices. Today only 9000 wells are required to find and produce what 14,250 wells found and produced a decade ago.

Improved technologies have kept many smaller oil and gas producers in business. The Uinta Basin in southern Utah is undergoing a resurgence of drilling by independent companies because a government co-sponsored field test showed how a field about to be abandoned could be revitalized. Horizontal drilling has boosted oil production in the Austin Chalk region of Texas and because of a government-industry-university project, it is likely to do the same for independent oil companies in Michigan.

Today in the United States, independent companies - not the majors - produce more than 40 percent of the nation's domestic oil and 60 percent of our natural gas. The following are some of the technological innovations developed in the Department of Energy R&D program that have made a difference to these companies and, for many, will continue to spell the difference between success and failure in the future:

One of the most important advances in drilling technology took place in 1986 when Department of Energy research produced a breakthrough bonding technique that made polycrystalline diamond drill bits commercially practicable.

Drilling with Diamonds

One of the most important advances in drilling technology took place in 1986 when Department of Energy research produced a breakthrough bonding technique that made polycrystalline diamond drill bits commercially practicable.

Previously diamond cutting bits failed after prolonged periods of drilling because the cutting assembly would break away from the bit. "Our engineers tried for two decades to stick diamonds on drill bits, but they could never crack the code," said a vice president for an oil field service company. "The DOE scientists figured out how to do it."

At its Elk Hills Naval Petroleum Reserve in California, the Department of Energy used a diamond drill bit similar to this to achieve a record-setting 1,058 hours of drilling operations without having to remove the bit. Diamond bits generally are run between 230 and 260 hours without a trip.

Sandia National Laboratories, working to solve problems for both geothermal and oil/gas drilling, applied a diffusion bonding technology, an outgrowth of defense research. The technique interlocks the molecules of the diamond cutters and the bit stud, creating a permanent bond. Department scientists also developed a computer code for optimizing cutter facings and drill bit design and contributed the use of one-of-a-kind drill bit testing facilities to manufacturers.

Within one year of the Department's successful demonstration of the prototype drill bit, dozens of U.S. companies were applying the technology to manufacture the world's first commercial polycrystalline diamond compact bits. A new world record was set by the bit: 20,000 feet of drilling without a bit change. For time-critical drilling, into hard rock or deeper formations or in offshore operations, the drill bit can save as much as $1 million per well. Today, U.S. companies sell more than 4,000 of these diamond bits each year. The polycrystalline drill bit now accounts for one-third of the worldwide drill bit market, and sales are well above $200 million per year.

Detecting Hydrocarbons by Sending Sound Waves Between Wells

Called "crosswell seismic imaging," the technique minimizes much of the subsurface interference by lowering the soundwave generator and receiver into the boreholes....The results are resolutions beyond what the industry imagined possible just five or six years ago.

Traditionally, companies have searched for natural gas and oil by sending sound waves from the surface deep into underground formations and measuring their reflectance. Because the seismic signals pass through thousands of feet of rock during their round trip, they become diffused and less effective. A new technique, developed in DOE's national laboratories and now being offered commercially, overcomes many of these limitations. It could represent the next major advancement in geologic imaging technology.

Called "crosswell seismic imaging," the technique minimizes much of the subsurface interference by lowering the soundwave generator and receiver into the boreholes. Sound waves travel directly from wellbore to wellbore over much shorter distances and at higher frequencies. The results are resolutions beyond what the industry imagined possible just five or six years ago. Where traditional techniques can "see" geologic objects 50 feet across, the crosswell technique can see objects 5 feet across, revealing much greater detail in the images of underground rock formations and increasing the potential for finding natural gas and oil deposits.

Sandia National Laboratories and OYO Geospace Corp. have developed seismic receivers rugged enough to be lowered nearly 3 miles underground. The receivers are now on the market. Los Alamos National Laboratory is developing a new seismic source that would use explosives to generate sound waves deep in a wellbore. Both laboratories are working with private companies to develop a hydraulically-powered vibrator tool as a downhole source of sound waves.

To link the seismic system of tomorrow, several firms are working with national laboratories to develop a fiber optics data communications system that can transmit enormous amounts of data to the surface much faster than conventional logging cable. For areas where wells don't already exist, a national laboratory-industry team is developing miniature seismic sensors that can be inserted into"micro-holes" less than an inch in diameter. "Micro-holes" may be a very inexpensive way to probe a formation to learn its oil or gas potential before drilling more expensive wells.

A New Way of Thinking in Utah's Green River Formation

Throughout its production history, the Green River Formation in the Uinta Basin has baffled oil producers. Its complex geology, laced with hundreds of discontinuous oil-bearing zones, its waxy oil, and its lack of sufficient reservoir pressures made traditional oil field production technology ineffective. Or so producers thought.

A DOE-cosponsored oil recovery field demonstration project proved conventional wisdom wrong. The initial project began in 1992 when Lomax/Inland Resources of Denver, CO, with cost-sharing from DOE, began a high-risk waterflooding project near Roosevelt, UT. Injecting water under pressure to force more crude oil through a reservoir is used in hundreds of thousands of oil fields throughout most of the United States. But operators in the Uinta Basin were skeptical. Many had been unable to maintain economical production, and as the flow of oil slowed, several had shut down operations, even though only 5 percent or less of the Basin's oil had been produced.

The Lomax field test, however, showed that a properly conducted waterflood would work in the Uinta Basin. The key was technology that could locate previously undetected natural fractures in the reservoir. Often these fractures would

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divert waterfloods away from production wells. Knowing how the fractures were oriented allowed new wells to be properly placed. A magnetic resonance imaging logging tool helped locate oil-bearing zones in sections of the reservoir previously thought to be barren. Sophisticated computer models tied the fracture and magnetic resonance imaging data together and gave operators a production strategy to boost oil flow. Production increased from 45 to 330 barrels per day.

The success of the initial field test created a resurgence of drilling in the region. Neighboring companies initiated 11 new waterfloods involving more than 300 wells. These wells are expected to produce 31 million barrels of additional oil. Because the operations are taking place on federal lands, the direct return to the U.S. Treasury in royalty revenues will likely exceed $160 million, more than enough to offset DOE's entire investment in all its jointly-sponsored projects in its oil recovery field demonstration program.

A DOE co-sponsored field project has brought new life to the Crystal Field...The new well was completed successfully and began producing 100 barrels of oil per day - 20 times better than the best conventional well in the field.

Moreover, since these 11 projects cover only 13 percent of the area, widespread application of waterfloods could double or triple the region's producible reserves and increase federal revenues to $500 million, a huge payoff from reservoirs that once were almost abandoned.

Using Horizontal Drilling to Give a Michigan Oil Field New Life

As much as 85 percent of the oil known to exist in the Dundee Formation in the Michigan Basin has been bypassed. Early production techniques in the 137 fields were poor, and so today, Michigan's leading oil-producing formation was at risk of being abandoned, leaving millions of barrels of oil behind. A prime example of a "worn out" field is Crystal Field, a once prolific producer which had been reduced to a handful of wells, the best of which produced only 5 barrels per day.

A DOE co-sponsored field project, however, has brought new life to the Crystal Field. Horizontal drilling is one of the most promising technologies available for oil production. A team, led by Michigan Technological University, used new computer modeling and analysis methods to pinpoint the location for a horizontal well to drain more of the remaining oil than a vertical well could. The new well was completed

successfully and began producing 100 barrels of oil per day, 20 times better than the best conventional well in the field.

Estimated recoverable reserves for the new well alone are 200,000 barrels of oil. The success of the well has spawned a "miniboom" in drilling in the Dundee Formation. As a direct result of the project, 9 new horizontal wells have been permitted for drilling in Crystal Field, and 20 to 30 horizontal wells have been permitted in geologically similar fields in the Dundee Formation.

Further development in Crystal Field alone is expected to produce an additional 2 million barrels. If other abandoned Dundee fields are redeveloped in a similar manner, the additional oil production will probably be about 80 to 100 million barrels, worth about $210 million in tax revenues alone. This is oil from existing U.S. fields with proven production, not from riskier new fields in environmentally sensitive regions or those controlled by foreign nations.

"Seeing" Oil and Gas Through Old Well Casings

Evidence is mounting that large amounts of remaining natural gas and oil have been missed or bypassed by past drilling and production technologies. In some cases wells were unknowingly drilled through these deposits in search of more productive "pay zones." Once metal casing is inserted into the wells, it has been impossible to use electrical resistivity tools (one of the most common hydrocarbon detection techniques) to pinpoint missed deposits. The metal casing created too much interference, rendering conventional electrical resistivity logging devices ineffective - until now.

A DOE-sponsored research project with ParaMagnetic Logging, Inc., has given companies a way to "see" through the metal casing. The advanced tool, developed with joint funding from the Gas Research Institute, overcomes the interference problem. Companies are now able to go back into 30- and 40-year-old fields, some of which were never "logged," and use existing wells to pinpoint untapped hydrocarbons. By avoiding the expense of redrilling, this technique can lead to the economical production of oil and natural gas that might otherwise have been abandoned. The technology has now been licensed to two major oil service companies.

A DOE Fossil Energy-sponsored research project with ParaMagnetic Logging, Inc., has led to a way to "see" through [a well's metal casing... Using it, companies are now able to go back into 30- and 40-year-old fields, some of which were never "logged," and use existing wells to pinpoint untapped hydrocarbons.

Using Mud Pulses to Transmit Downhole Drilling Telemetry

One of the most important, time-saving innovations in today's drilling industry is "measurement-while-drilling" instrumentation. Before its invention, operators determined drill bit direction by ceasing drilling, removing hundreds or thousands of feet of drill pipe, and lowering an instrument into the well. Readings would be taken, the instrument retrieved, drill pipe would be lowered back into the hole, and drilling would recommence. A Department of Energy research project with Teleco, Inc., helped change that expensive, time-consuming process. It pioneered a wireless system could transmit the location of a drill bit by sending pressure pulses through the drilling mud from the bit to the surface.

Because of its performance and safety advantages, mudpulse telemetry has gained wide acceptance in the drilling industry.

Mudpulse telemetry offered several new benefits for the the drilling industry: (1) the capability to receive bit orientation data from the base of the borehole while drilling was underway, (2) real-time information on drill rates and equipment performance, (3) a way to evaluate, or log, a geologic formation almost instantaneously during drilling, (4) the ability to steer the drill bit, and (5) the means to receive advance warnings of impending well drilling hazards.

Mudpulse telemetry has gained wide acceptance in the drilling industry. By 1996 its commercial use was saving the natural gas and oil industry as much as $400 million per year in drilling costs, not including the benefits of reduced personnel injuries and greater environmental protection. The net present value of benefits from DOE's $2 million R&D investment in this technology in the 1970s now exceeds $4 billion (in constant 1996$).

Fracturing Gas/Oil Formations with "Reservoir Friendly" Carbon Dioxide and Sand

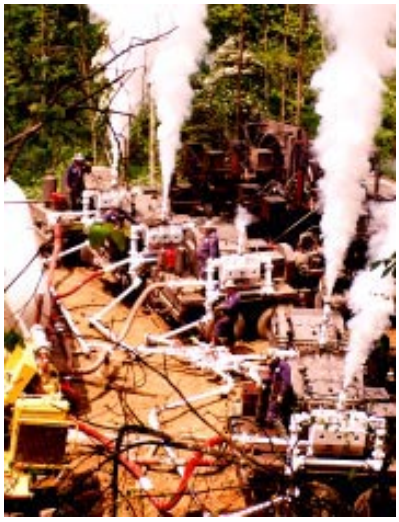
In the tightly-packed shale formations of Appalachia, natural gas producers often inject nitrogen under intense pressure to fracture the rock, creating pathways for gas to flow. Nitrogen by itself, however, isn't able to carry tiny sand particles, called proppants, that keep long fractures open after the nitrogen pressure is relieved. To keep the fractures from re-sealing, operators often resort to injecting water-based foam with the nitrogen to carry the sand grains into the

reservoir to prop open the cracks. But water causes clay in the shales to swell, and the formation can eventually plug, throttling the flow of hydrocarbons.

A relatively new technology, however, offers an alternative to conventional aqueous foam, but for more than a decade after it was first developed in Canada, few U.S. producers had sufficient confidence to try it. A series of Department of Energy-sponsored field tests in the 1990s changed that.

The technique is called CO_2-Sand Fracturing. It uses liquid carbon dioxide rather than aqueous foam. Liquid carbon dioxide is a reservoir-friendly substance. It provides enough force to create long, propped fractures, and the absence of water or oil-based fluids offers a near damage-free way to enhance oil and gas production.

Petroleum Consulting Services of Canton, OH, with support from DOE, used the technique to get four times the production rate of wells fractured with nitrogen foam. Although more expensive than conventional treatments, the increased production rates typically give paybacks in around five months. *Hart's Oil and Gas World* magazine was so impressed by the results of the DOE-sponsored tests that it gave the CO_2-Sand Frac technique its distinguished *"Best Technology in the Northeast"* award for 1994.



A CO_2-Sand fracturing operation produces four times the production rates of wells fractured with conventional foam.

The [DOE-sponsored] tests demonstrated that slant hole drilling is commercially viable in tight gas reservoirs since the added drilling expenses were more than offset by the resulting production.

Drilling "Sideways" for Natural Gas

High-angle or horizontal wells have restored new life to many aging oil reservoirs in Texas and elsewhere, but until DOE began an R&D project in western Colorado, the technique had not been tried by many westem natural gas producers. It was considered too risky, especially in low permeability (dense) gas reservoirs. In 1990, DOE funded CER Corporation to begin a field research project that led to a new level of confidence in the effectiveness of slant hole drilling in these reservoirs.

During five months of well testing, CER's test well (#1-SHCT) produced over 150 million cubic feet of natural gas including five weeks at a steady rate of 3 million cubic feet per day. A gas deliverability test predicted an "absolute open flow potential" of 19 million cubic feet per day. More importantly, the tests demonstrated that slant hole drilling is commercially viable in tight gas reservoirs since the added drilling expenses were more than offset by the resulting production.

The highly productive CER's #1-SHCT well was given the industry-sponsored *"Best New Well"* award at the 1993 "Best of the Rockies" competition. As a result of the DOE success, Barrett Resources, a Denver independent producer, and Meridian Oil Company, active in the Piceance Basin, have drilled their own horizontal wells in the Cozzette sand on acreage adjacent to the DOE slant hole test site.

Finding More Natural Gas in "Depleted" Fields

When is a natural gas field "depleted?" Not as soon as traditional production techniques would indicate, a DOE project has determined.

The study concluded that secondary gas recovery is likely to increase booked reserves of natural gas in southwest Texas by nearly 4 trillion cubic feet through the year 2000, resulting in cumulative gross production revenues that could approach $1.4 billion.

In 1988, DOE began a research project to determine if older gas fields still contained economically producible quantities of so-called "secondary" natural gas. The project discovered significant amounts of natural gas in three of the Gulf Coast's largest producing formations that conventional exploration and production techniques had missed. The information was conveyed to operators in the region which make up more than a quarter of the nation's gas producers. Using the technologies and methods applied in DOE's secondary gas recovery project, producers began finding and producing more natural gas from fields that otherwise would have been considered depleted.

To assess the benefits of the project, DOE commissioned the University of Texas, Bureau of Economic Geology, to compare reserves added per well completion in 1993-1994 to those added in 1990-1992, prior to the application of secondary gas recovery technologies. The study found that producers were finding and extracting a much larger amount of gas than before and well above the general trend elsewhere in Texas.

The study also concluded that secondary gas recovery is likely to increase booked reserves of natural gas in southwest Texas by nearly 4 trillion cubic feet through the year 2000, resulting in cumulative gross production revenues that could approach $1.4 billion.

Revitalizing Aging Reservoirs With CO_2-Miscible Flooding

One of the most used enhanced oil recovery techniques today in the United States is CO_2-miscible flooding. Carbon dioxide is injected into aging reservoirs to force out oil that conventional production techniques cannot recover. In large part, industry gained confidence in this technology through a series of field tests conducted by private oil producers with funding from the Department of Energy and its predecessors.

CO_2 miscible flooding is now an accepted industry practice principally in West Texas and eastern New Mexico and is being extended to oil fields in Wyoming and North Dakota, principally because the Federal Government shouldered some of the initial risk in the early demonstrations of its commercial viability.

Removing Wax Buildup from Old Oil Wells

About a third of all U.S. oil wells suffer a common problem: the slow buildup of paraffin in the wellbore that can clog the well and pumping machinery. A technique ca11ed "hot oiling," in which heated oil (or water) is pumped back into the well casing to melt the paraffin, works fine in some wells but is less effective in others and in some cases, can cause more harm than good.

Producers need a way to predict if hot oiling will be effective before going to the expense of installing the necessary equipment.

Now, because of a DOE program at Sandia National Laboratories, oil producers have such a method. A new software program, available to industry free of charge, predicts where paraffin will be a problem and whether hot oiling will be effective.

Paraffin buildup is particularly bothersome in stripper wells (that produce less than 10 barrels per day), but because of the Federal program, the small independent producer now has an affordable and effective way to counter the problem.

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An Automatic Casing Swab

Automatic Casing Swab

Many older U.S. reservoirs no longer have sufficient natural pressure to force gas or oil to the surface. An increasing number of these reservoirs also produce too slowly to justify the cost of installing conventional surface pumps. Yet large quantities of oil and natural gas remain in these marginal fields. With a $400,000 DOE grant, Sandia National Laboratories developed a low-cost way to keep these low-volume wells in production. The Automatic Casing Swab (ACS) is a device that seals off the lower portion of a well, allowing gas or oil to flow into the wellbore below the swab. When enough pressure builds up, the ACS unseats and gas or oil is released to the surface. As the flow slows and pressure in the upper portion of the well again builds up, the ACS reseats until sufficient oil or gas again accumulates below it. Sandia transferred the ACS technology to Belden & Blake Corporation, an oilfield equipment manufacturer. A subsidiary of Belden & Blake has applied ACS hardware to approximately 350 wells that are today producing more than 3.5 million cubic feet of natural gas per year that otherwise could not have been economically extracted.

[Lawrence Livermore] scientists applied their knowledge of fossil fuel pyrolysis to develop laboratory experiments that, in a matter of hours, could predict the course of chemical reactions that occur over millions of years.

Modeling the Forces of Nature

In 1987, Lawrence Livermore National Laboratory successfully modified chemical kinetic models originally developed for underground oil shale retorting to locate undiscovered pockets of crude oil. Laboratory scientists applied their knowledge of fossil fuel pyrolysis (decomposition by heat) to develop laboratory experiments that, in a matter of hours, could predict the course of chemical reactions that occur over millions of years. They took the knowledge gained in these experiments and created KINETICS, a computer code that can predict the creation and accumulation of oil and gas in geological formations containing petroleum source rocks.

Run on a personal computer and easily used by nonexperts, KINETICS was licensed for commercial distribution to Humble Instruments and Services Inc. Humble is now one of Houston's fastest growing businesses, due, in large part, to sales of KINETICS technologies. According to Humble President Dan Jarvie, "The benefits this technology provided were national and international sales meaning job creation and taxable income for our country."

In 1990, Lawrence Livermore National Laboratory signed a collaborative agreement with Platte River Associates to provide technical assistance to the company's basin modeling software development effort. Today, that program,*BasinMod* , is the best selling program of its type in the world. This 7-year, $3 million project has been crucial to the success of many small American oilfield service companies, companies that today have over $5 million in annual sales.

For its basin modeling efforts, Lawrence Livermore received the 1990 Federal Laboratory Consortium*Award for Excellence in Technology Transfer* .

Simulating How Oil Flows in a Reservoir

Using a computer to simulate how oil and other fluids might flow through a reservoir has been an enormous boon to the small, independent producer. With the advent of computerized simulation software, oil production was no longer as much of a "hit-or-miss" proposition. The only problem was that the best software typically ran on a mainframe computer, and its use was often too expensive for cash-strapped small producers.

Over 2,400 copies of BOAST PC software have been distributed by DOE. Several oil industry consulting firms have modified the program to their own specifications. Universities are using BOAST as a textbook for reservoir simulation instruction.

DOE's investment in oil field computer simulators, however, has changed that. In 1982, DOE's Office of Fossil Energy introduced BOAST, for Black Oil Applied Simulation Tool, originally as a mainframe application. In 1989, the Department released a new, more powerful version that could operate on a personal computer. Capable of assessing larger areas, more wells, and a greater number of solution options, BOAST II became an immediate success in the industry. Now BOAST III is available with new features that include 3-dimensional modeling.

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A second simulator, UTCHEM, has been developed specifically for chemical flooding. A third, MASTER, was developed to assist the natural gas industry in evaluating miscible and non-miscible gas enhanced oil recovery processes.

Studies indicate that use of these processes will generate a 3-billion barrel increase in potential domestic reserves. Widespread use of these simulators is not only producing more domestic oil and natural gas, but additional revenue for the government from federal taxes and revenues. By developing these computer simulation tools, DOE has calculated that the return to the taxpayer is over $1,000 for every $1 invested by the government.

Regulations Based on Solid Science

Now being applied in four other States, the DOE methodology is likely to lead to hundreds of millions of dollars in regulatory compliance costs while ensuring that drinking water supplies in and around oil- and gas-producing regions remain safe.

Domestic natural gas and oil producers face the challenge of producing from older reservoirs while complying with increasingly costly environmental regulations. For example, to comply with regulations drafted by the Environmental Protection Agency under the Safe Drinking Water Act, producers must conduct an Area of Review (AOR) of all disposal and injection wells including those grandfathered under current rules. Well-by-well reviews, however, may not be necessary if there is little risk of contaminating ground water.

To help regulators determine whether variances to the well-by-well reviews could be granted and still assure groundwater protection, DOE began working with the University of Missouri-Rolla to develop a methodology to validate AOR variance requests.The methodology was first tested in East Texas in August 1995.

Based on the reservoir pressure analysis generated by this methodology, the Texas Railroad Commission granted AOR variances to the East Texas Salt Water Disposal Company and other operators in the field. This variance saved operators in the field $86 million in compliance costs, allowing more dollars to be used for actual oil and gas production.

Now being applied in four other States, the DOE methodology is likely to lead to reduce regulatory compliance costs by hundreds of millions of dollars while ensuring that drinking water supplies in and around oil- and gas-producing regions remain safe.

Clean Electric Power Generation and Industrial Coal Technology

The U.S. electric power industry, for most of its history, has had only a limited number of technology choices for generating electricity and reducing emissions.

The pulverized coal boiler has historically been the most prominent means for burning coal to produce electricity. The conventional "wet scrubber" has been the traditional choice for cleaning sulfur dioxide from coal combustion flue gases for the last 15 years. Few technological options have existed for controlling smog-causing nitrogen oxides affordably. Significant reductions in carbon dioxide, a greenhouse gas, were beyond the capabilities of conventional technology.

In the last decade, this situation has changed dramatically because of the Federal investment in advanced electric power generating technologies, fueled by coal and by natural gas.

New power generating concepts, such as fluidized bed combustion, gasification-combined cycle, and fuel cells, are now moving toward the commercial threshold. Innovative technologies for reducing acid rain emissions that existed only on drawing boards 10 years ago are now available because of Federal/private R&D partnerships. For the 21st century, new coal concepts are advancing that reduce CO_2 through efficiency improvements. Some examples are:

Power Magazine has called the development of fluidized bed coal combustors "the commercial success story of the last decade in the power generation business." This success [is] perhaps the most significant advance in coal-fired boiler technology in more than half a century.

Fluidized Bed Coal Combustors - "The Commercial Success Story of the Last Decade"

Power magazine called the development of fluidized bed coal combustors "the commercial success story of the last decade in the power generation business." This success, perhaps the most significant advance in coal-fired boiler technology in more than half a century, was achieved largely through research, development and demonstration sponsored by the Department of Energy and its predecessors.

The Federal government, in cost-shared programs with the U.S. boiler industry, demonstrated the first industrial-scale atmospheric fluidized bed units, including one that is still operating nearly 18 years later on the campus of Georgetown

University. It showed how pulverized coal-fired boilers could be converted into cleaner, more efficient atmospheric fluidized bed units and how fluidized bed combustors could burn a variety of low-grade fuels ranging from Pennsylvania anthracite culm to the refuse of coal washing plants. Today, every major U.S. boiler manufacturer offers an atmospheric fluidized bed system in its product line. There are now more than 170 fluidized bed combustion boilers of varying capacity in operation.

Today, more than $6.2 billion in domestic sales and $2.8 billion in foreign sales have resulted from the U.S. public and private investment in circulating fluidized bed technology research, development and demonstration.

The technology has progressed into larger scale utility applications due, in large part, to Federal partnership programs with industry. The Colorado-Ute Electric Association project in Nucla, CO (now operated by Tri-State Generation and Transmission Association, Inc., of Denver) was one of the early demonstrations in the Clean Coal Technology Program and is responsible for significant design improvements and commercial confidence in this state-of-the-art, low-polluting combustion system. In November 1994, Tri-State Generation and Transmission began repaying the Federal investment in the project, having produced sufficient operating revenues to trigger the recoupment provision of the company's Clean Coal Technology project agreement.

The 70-megawatt Tidd Pressurized Fluidized Bed Combustor pioneered a new, cleaner way to burn coal in utility power plants.

Today, more than $6.2 billion in domestic sales and $2.8 billion in foreign sales have resulted from the U.S. public and private investment in circulating fluidized bed technology research, development and demonstration. These sales support 75,000 new job-years for the United States.

The next generation of fluidized bed technology - the pressurized fluidized bed system - is now approaching commercial readiness, again due to Federal partnership programs with industry. The advanced pressurized power system uses both gas and steam turbines to boost the amount of electricity that can be generated from coal. The results are lower-cost power and substantial reductions in carbon dioxide, a greenhouse gas, compared to a traditional coal power plant.

A project co-funded by DOE in the Clean Coal Technology Program, American Electric Power's Tidd Plant in Brilliant, OH - *Power* Magazine's *1991 Power Plant of the Year* - has been successfully completed after 11,500 hours of operations, producing data that will help establish the technical foundation for cleaner, more efficient coal-burning power plants in the 21st century.

Tomorrow's Scrubbers: Lower Cost and More Effective

The first utility in the United States to reduce emissions in compliance with new Clean Air Act standards for sulfur dioxide did so using advanced technology from the DOE Clean Coal Technology Program.

Northern Indiana Public Service Corp. installed the Pure Air scrubber, owned and operated by a joint venture involving Air Products and Chemicals Inc., at its Bailly Station near Gary, Indiana. Because of several design innovations, the Pure Air scrubber cost only half as much as earlier units. Also, instead of the waste sludge commonly produced by older scrubbers (which causes landfill problems), it produces a commercially marketable gypsum material. The Pure Air scrubber is eliminating 50,000 tons of SO_2 emissions each year, turning an air pollutant into enough wallboard to construct nearly 19,000 homes. The project earned *Power* magazine's 1993 *Power Plant of the Year* award.

Air Products and Chemicals is working with Florida Power and Light (FP&L) to obtain approval to replicate the scrubber on a 1600-MWe station (twin 800-MWe units). The units currently burn fuel oil and FP&L wants to switch to a low cost fuel known as Orimulsion. With the advanced scrubber, the company can burn Orimulsion and meet air quality standards. Burning the lower cost fuel could save utility ratepayers approximately $2.5 billion over the next 20 years.

Another flue gas scrubber to be commercialized under the Clean Coal Program is the CT-121 Flue Gas Desulfurization System. This system, demonstrated by Southern Company Services at a Georgia Power Station near Atlanta, proved that large vessels needed for scrubbers could be built out of low cost fiberglass and operate reliably over a wide range of conditions. The system consistently removed over 93 percent of the sulfur in the flue gas from high-sulfur coal combustion. The system also removed 99 percent of the particulate matter in the flue gas.

Southern Company Services, in association with Fluor and Chiyoda (the technology owner) is currently building at CT-121 scrubber at a tar sands oil extraction facility in Murray, Alberta Canada. Sized at the equivalent of a 350-MWe power system, the scrubber has an estimated value of $75 million with a U.S. employment impact of 260 job-years.

Equipped with the Pure Air advanced desulfurization unit, the Bailly Station on the shores of Lake Michigan is now removing more than 95 percent of the sulfur pollutants from its coal combustion flue gas.

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Reducing Smog with Low-NOx Burners

Technicians install an advanced low-NOx burner into a retrofitted boiler at Southern Company Services' Plant Hammond.

Today [utility power] plants have new ways to reduce [NOx] emissions at much lower costs - up to 10 times lower - than the technologies that would have been available without the Federal Government's research investment.

Nitrogen oxides are one of the chief pollutants responsible for smog and ozone buildup, particularly in urban areas. Nitrogen oxides, or NOx, are released from most combustion sources, including automobile engines and factories. Utility power plants are also a major emitter of NOx, but today these plants have new ways to reduce these emissions at much lower costs - up to 10 times lower - than the technologies that would have been available without the Federal Government's research investment.

The type of Low-NOx Burner know as Cell Burners, demonstrated by Babcock and Wilcox under the federal Clean Coal Technology Program were the first to be sold commercially. Both Babcock and Wilcox and Foster Wheeler are also marketing their wall-fired low-NOx burners following successful tests in the Clean Coal Technology Program. ABB Combustion Engineering is also marketing its Tangential-Fired LNCF-III and T-2000 Low-NOx burners, both products of the Clean Coal Technology Program. Nearly a quarter of coal-fired capacity in the United States has installed these low-polluting burners. Sales to date exceed $750 million and will approach $4 billion by 2000.

Another NOx control technology that has been commercialized is gas reburning - a technique in which natural gas is burned above the main coal-burning zone under conditions that break down NOx pollutants into environmentally-benign gases.

Under the Clean Coal Technology program, gas reburning was successfully demonstrated on three types of boilers. All three reduced NOx over 65 percent. Today the technology has been applied both to coal fired units and to boilers that fire other types of fuels. In February 1997, the Air and Waste Management Association announced that the technology was the winner of its *J. Deane Sensenbaugh Award* for a new commercially successful technology that meets or exceed mandated standards.

Reburn technology is now being carried a step further. Rather than using natural gas as the reburn fuel, finely ground micronized coal can be used. Eastman Kodak at its Kodak Park in Rochester N.Y. facility is the first to demonstrate this technology and intends to use this technology on at least two other units upon successful completion of the Clean Coal Technology demonstration.

High Value from "Low-Rank" Coals

The Clean Coal Technology Program has also led to new advances in producing high-value fuels from the nation's vast wealth of "low rank" coals, found predominantly in the West. The Rosebud SynCoal Project in Colstrip, Montana has demonstrated a way to upgrade low-quality subbituminous and lignite coals into a high heating-value, low sulfur fuel.

In December 1996, binding written agreements between Western SynCoal Company, Minnkota Power Cooperative, Square Butte Electric Cooperative, BNI Coal, Ltd and Center SynCoal Partnership were signed for the construction of a $32.8 million, 100 ton/hour (feed rate) scale up of the Rosebud SynCoal Partnership's Advanced Coal Conversion Process technology at Center, North Dakota. The Center SynCoal Project would be integrated into the existing Minnkota Milton R.Young lignite-fired power plant that houses a 250 MW unit and a 438 MW unit.

The Rosebud SynCoal Project in Montana has demonstrated a way to upgrade low-quality subbituminous and lignite coals into a high heating-value, low sulfur fuel.

Rosebud SynCoal Partnership has also signed a technology marketing agreement with Ube Industries, Ltd., of Tokyo, Japan. Under the agreement, Ube Industries has been granted a non-exclusive right to represent Rosebud in marketing and commercialization of the SynCoal technology outside the United States.

The "Coal Refinery" of Tomorrow

Raw coal can be a rich source of a valuable liquid and solid fuels and chemicals. Much like an oil refinery produces a slate of products by processing crude oil, future "coal refineries" could produce a variety of products from the nation's most abundant fossil fuel. The government cost-shared ENCOAL™ project near Gillette, WY, has demonstrated that such future plants are feasible.

By producing a multiple slate of value-added fuels and other products from coal, the ENCOAL™ plant near Gillette, WY, could be the forerunner of future coal "refineries."

ENCOAL™ has successfully demonstrated the Liquids-From-Coal, or LFC, process, which converts low-rank western coals into two products: Process Derived Fuel, a low-sulfur clean coal product with a higher heating value than the unprocessed coal; and Coal Derived Liquid, a low-sulfur hydrocarbon liquid that has similar properties to distillate fuel oil.

On October 22, 1996, ENCOAL™ Corporation announced that it was beginning the permitting process for a full-scale

Liquids From Coal (LFC) plant in Campbell County, Wyoming, a project 15 times larger than the demonstration project conducted as part of the Clean Coal Technology Program.

In another commercial area, TEK-KOL, which owns and licenses the LFC process, is discussing options to license full-scale plants overseas. TEK-KOL Development Center has tested and analyzed 10 domestic and 21 foreign coals to determine the most promising candidate coals for LFC processing. Based on these tests, letters of intent for engineering and economic assessments are in place with two Indonesian companies, and other international opportunities are being developed. ENCOAL™ also has attracted the attention of the Chinese government which signed an agreement to study the feasibility of a 5,000-ton-per-day "coal refinery" for the Shandong Province of China.

A DOE co-funded Clean Coal Technology project, however, has shown how steel companies can cut their need for coke by up to 40%.

Tomorrow's Blast Furnaces - Injecting Coal Directly to Lessen the Need for Coke

Coke is a necessary ingredient in traditional ironmaking processes, but the huge ovens needed to manufacture coke can emit large quantities of nitrogen oxide, sulfur dioxide and air toxic pollutants. A DOE co-funded Clean Coal Technology project, however, has shown how steel companies can cut their need for coke by up to 40%. The technology has caught the attention of the steel industry and the first commercial sales have occurred.

At its Burns Harbor site on Lake Michigan, the Bethlehem Steel Corporation is demonstrating the "coal injection" technology on high-capacity blast furnaces. The technology substitutes granulated coal for coke in the steel making process. The need for coke in the blast furnace is reduced by 40 percent. Sulfur pollutants from coal-burning are captured by limestone, and the gases leaving the furnace contain virtually no measurable SO_2 or NOx emissions.

This demonstration has shown the technology to be a cost-effective way to reduce coke usage and the attendant environmental damage of coke production. Based on its success, a new license for the technology has recently been sold to the United States Steel Company .

Summer Internship Leads to Commercial Coal Cleaning Technology

In 1980, a summer faculty appointee from Virginia Polytechnic Institute and State University began experimenting at DOE's Federal Energy Technology Center on the use of microbubbles to separate clean coal from its impurities. The initial results showed promise, and the professor subsequently won a federal University Coal Research grant to develop the technology.

Today, the summer experiment has become a commercial success story. The technology, microbubble coal cleaning, is now marketed under the name *Microcel*. *Microcel* fine coal cleaning technology can produce cleaner coals for electricity generation and can recover coal from refuse ponds which in the U.S. are estimated to contain more than 2 billion tons of fine coal. If *Microcel* reaches its full potential in the market of producing coal-water fuels from coal waste, it would create an estimated 29,400 jobs in the United States. Currently, the technology is being sold worldwide for use at coal preparation and minerals processing plants, with applications in the United States (in eight states), Korea, China and Australia. A major coal company in Australia, which selected Microcel over a competing domestic technology, has bought 16 *Microcel* columns for use at its largest mine. The technology is also being used in various non-coal mineral processing applications around the world.

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Applying Tomorrow's Technology To Today's Gas Turbines

The combined cycle power plant is the primary technology of choice for generating electricity today. At the heart of the combined cycle plant is the gas turbine. U.S. turbine manufacturers have dominated the market for gas turbines worldwide since its inception, but foreign technology has recently dominated technological advancements. A major technological leap is needed for U.S. manufacturers to regain their edge in this vital technology.

In 1992, DOE initiated a program, in cooperation with major turbine manufacturers and a university consortium, to develop a "quantum leap" gas turbine. This advanced gas turbine will include features vastly superior to any gas turbine developed to date. The research and development

effort has already yielded benefits. Some of the advanced features were deemed so successful that manufacturers have already incorporated them into current turbine models.

For example, the Westinghouse 501G introduced in late 1994, uses the advanced turbine design developed in the DOE program for its first 16 compressor stages. Employing state-of-the-art 3-dimensional computer-aided models, Westinghouse has been able to reduce airfoil thickness and increase the efficiency of each stage without increasing manufacturing costs.

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The 501G also incorporates the "piloted ring combustor," also developed in the DOE program. This combustor is a lean premixed multistage design that produces ultra low NOx emissions with excellent combustion stability. The DOE program has also produced new seals that prevent hot combustion gases moving through the turbine from leaking into the environment. These seals proved to be so successful that they were incorporated into the Westinghouse 501G design.

New thermal barrier coatings, also developed under the DOE program, have found their way into the Westinghouse 501G design. The new coatings provide longer life and improved abrasion resistance. Defects in these coatings were difficult to identify after manufacture and post installation service. Today, thermal wave imaging, a new inspection tool developed in the DOE program, can spot defects before they become a problem. Thermal wave imaging is now used in the factory and in field service for identifying defects in thermal barrier coatings in the Westinghouse 501F and 501G designs.

The Fuel Cell: A Revolutionary Way to Generate Electricity

The electric generating industry of the 21st century could look much different than today's industry - both in its make-up and in the technologies it uses to generate power.

For example, because of the Federal investment in the 1980s and early 1990s, a truly revolutionary approach, the fuel cell, is today becoming available for commercial power generation. Relying on electrochemistry rather than combustion, the fuel cell is attractive for both heavily polluted urban areas and remote applications. Not only does

it emit none of the smog-causing pollutants associated with conventional power plants, it is ideal as a distributed power source; that is, it can be sited close to the electricity user, for example, at electrical substations, or at shopping centers or apartment complexes, or in remote villages, minimizing the need for long-distance transmission lines.

The phosphoric acid fuel cell is the first technology to emerge from the joint public-private, cost-shared program. The U.S.-based firm ONSI Corporation, a subsidiary of International Fuel Cells Corporation, is now manufacturing a line of 200-kilowatt commercial, onsite cogeneration systems and has sold 120 units throughout the world, including 60 in the United States. Accumulated fleet operation is over one million hours at an average availability of 95 percent. One of the fuel cell power systems, operated by Southern California Gas at a Kaiser Permanente Hospital facility in Riverside CA, set a record for uninterrupted operation, generating electricity and heat continuously 24-hours-a-day for more than a year at more than 80 percent efficiency.

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In the 1990s, the Federal-private R&D program will produce advanced generations of fuel cell technology: the molten carbonate and solid oxide technologies. Both are higher-efficiency, lower-cost systems that will firmly establish the United States as the global leader in fuel cell technology. The first full-scale, prototype molten carbonate fuel cell power plants are now operating. One is generating power in Santa Clara, CA, the other at the Miramar Naval Air Station in San Diego, CA. Both are proving that these new, ultra-clean energy systems can operate in one of the nation's most environmentally stringent regions.

By the early part of the 21st century, annual sales of fuel cell technology could exceed $1 billion.

Gasification Power Plants - Drawing Board Concepts Become Commercial-Scale Realities

For more than 20 years, utility engineers have envisioned power plants that would substitute coal gasifiers for the traditional boilers. Coal gasification produces hot, high-pressure gases that can be cleaned of virtually all of their pollutant-forming impurities, then used to fuel a gas turbine/steam turbine combined cycle, one of the most efficient ways to extract electric power from fossil fuels. In the 1990s, the drawing board visions became reality.

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The Tampa Electric Company's pioneering gasification combined cycle facility is one of the cleanest and most efficient coal-fired power plants in the world.

More than 20 years of technology development culminated in 1995-97 when three first-of-a-kind commercial-scale integrated gasification combined cycle power plants began generating their first electric power in the DOE Clean Coal Technology Program. Capable of reducing sulfur emissions by more than 98 percent and lowering carbon dioxide emissions by 20 to 40 percent (through higher coal-to-electricity efficiencies), these facilities are pioneering a new era in clean power generation from coal.

Wabash River Coal Gasification Repowering Project. The first was the Wabash River Repowering Project in West Terra Haute, IN. Constructed at an existing power plant, the new technology substituted a Destec gasifier, gas cleanup system and GE gas turbine for a conventional coal boiler in one unit of the plant while using the plant's existing steam turbine. The project became operational in November 1995. In its first year of operation, the plant achieved more than 2,000 hours of operations on coal. In the second year, the plant has been setting monthly records for operation on coal and the production of syngas, including a record-setting continuous coal run of 500 hours from mid-December 1996 through mid-January 1997. The project received *Power* magazine's *Power Plant of the Year Award* for 1996.

Tampa Electric Integrated Gasification Combined Cycle Project. In October 1996, a second gasification combined cycle power plant began operating. The Polk Power Station is a "greenfield" plant built with all new components. Employing Texaco's entrained gasifier and a state-of-the-art GE gas turbine, the project became fully operational in October 1996. Since then, it has operated 90 percent of the time, one of the smoothest startups of any project in the Clean Coal Technology Program. Tampa Electric Co., DOE's project partner, restored 1,500 acres of an abandoned surface phosphate mine near Lakeland, FL, for the plant.

The Piñon Pine Power Project. In the spring of 1997, the third of this new fleet of advanced coal technology plants will move into test operations. The 100-megawatt Piñon Pine Power Project, being constructed by Sierra Pacific Power Company, will be the first in the United States to use advanced hot gas cleanup technology for the entire gasification output (the Tampa Electric project tests hot gas cleanup on a portion of the gas). It will also be the first to use GE's advanced MS 6001FA gas turbine generator. Construction is virtually complete, and the plant will be formally commissioned in April 1997.

Super 9 Chrome Alloy: Higher Strength Metal Boosts Power Plant Performance

All power generation engineers share at least one common aim: improve the efficiency of their boilers. During the 1980's, a new metal alloy developed in the Department of Energy advanced materials program gave engineers a way to increase efficiency. Today, *Super 9 Chrome* , a super-strong steel alloy, is the worldwide industry standard for safer and more reliable coal-fired power plants.

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The metal is used for superheater tubes, pipes, and forgings. With code approval of this new alloy, it became possible to increase a power plant's operating steam temperature from approximately 1005°F to 1075°F and, at the same time, extend the life of power plant equipment. The higher operating temperatures allowed power plants to boost efficiencies by three to five percent - a significant increase in power plant performance, cost savings, and environmental protection.

For example, a 500-MWe power plant operating at 38 percent efficiencies will burn nearly 111,000 tons of coal less each year than the same plant operating at 35 percent efficiency. That translates into a cost savings of $1.8 million per year in fuel costs and a reduction of carbon dioxide emissions by 280,000 tons per year. An Oak Ridge National Laboratory study has confirmed more than $200 million in sales resulting from the DOE investment in this advanced material.

Toughened Ceramics

Ceramics - glass-like materials capable of withstanding very high temperatures - can be toughened against fracture by adding whiskerlike fiber reinforcements that act like steel reinforcing bars in concrete.

Such strong, durable ceramics markedly improve the energy performance characteristics of equipment used in a wide variety of high-temperature applications, ranging from automobile, airplane and heavy-duty engines, to industrial applications, combined-cycle power plants, and oil refineries.

Although toughened ceramics are now widely used, the road to commercialization was filled with stumbling blocks. In the early stages of development, toughened ceramics suffered from brittleness, unreliable strength, and poor resistance to extreme changes in temperature. Despite these problems,

DOE recognized the promise of this technology and sponsored basic research, including computer modeling of toughening mechanisms and fundamental studies of the interface between ceramics and the toughening agents. As the Yergin Task Force on Strategic Energy Research and Development pointed out in its June 1995 report, "This research not only surmounted the technological obstacles that led to commercialization, but is among the most highly regarded scientific work done worldwide on ceramics over the past decade."

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Coupled with the basic research, the Department sponsored applied research on toughened ceramics. One major success was the development of a new ceramic compound by one of its national laboratories in the early 1980's - silicon carbide whisker-reinforced alumina - now used in a wide variety of industrial applications, including metalworking die inserts and fastcutting machine tools. The current estimate of worldwide sales of products made of this innovative ceramic by U.S. companies is more than $30 million per year.

The Department's ongoing support for R&D on ceramics continues to yield important technological advances. One of these is gelcasting, a precision complex-shape-forming process that yields a near-net-shaped part requiring minimum machining. Another is a lightweight ceramic hot-gas filter material, used to remove hot gas particulates in fossil energy power generation and industrial systems, thus improving the efficiency and productivity of the parent system. Developed as part of a cost-shared collaboration between the Department of Energy and industry, the filter material has been licensed for commercial production and is estimated to have a potential intemational market of $7 billion over the next 10 to 15 years, with the U.S. market alone forecasted to reach $200 million annually by the end of the century.

DOE Computer Code Now in Use by 42 of the World's 50 Largest Chemical Companies

Modeling an energy or chemical process on a computer is a much more affordable way to try different process configurations prior to building or modifying actual plant hardware. Today one of the standard process simulation models in use by industry is the product of a DOE-funded development effort. In the late 1970s DOE funded the initial code for the ASPEN model at the Massachusetts Institute of

Technology. Guided by an advisory committee made up of more than 50 industrial participants, ASPEN became one of the most flexible and powerful computer software programs for the chemical and energy industry. Developers of the model founded AspenTech in 1981 to commercialize the technology. AspenTech has since evolved into a fast growing, high-tech company with nearly $58 million in annual sales. The company now has more than 450 commercial customers for the process simulation model, including 42 of the 50 largest chemical companies in the world.

Neutralizing NOx with Neural Networks

Minimizing the formation of nitrogen oxides - or NOx - in a coal-fired boiler often requires rapid and precise adjustments to the firing conditions of scores of individual burners in a typical boiler. Digital control systems for power plants have been a major advance in "fine-tuning" these burners.

Now, because of a collaborative effort between DOE, Southern Company Services, the Electric Power Research Institute, and others, a neural network, a type of artificial intelligence software program, has been developed to greatly improve digital controls of the burners.

Called the Generic NOx Control Intelligent System (GNOCIS), the neural network models the combustion characteristics of a boiler and makes continuous adjustments to the firing conditions to lower NOx emissions while enhancing boiler efficiency. Testing of GNOCIS at Southern Company Service's Gaston station showed NOx reductions of 15 percent and combustion efficiency improvements near 0.5 percent. Because of the successful tests at Gaston and at the United Kingdom's Kingsnorth stations, GNOCIS will be installed at 21 U.S. sites this year.

Spinoffs- From Medicine To Metals Recycling

Spinoff applications for technologies can rarely be planned and are often the most difficult to track. Yet, spinoffs have been important success stories in the Fossil Energy program. Three of the most prominent are:

A Better, Safer Artificial Heart

Using laser imaging technology developed for coal slurries, a federal researcher analyzes simulated blood flow through an artificial heart.

The flow of blood through an artificial heart may seem far removed from the flow of coal slurries through a combustor nozzle, but researchers at the DOE Federal Energy Technology Center and the University of Pittsburgh Schools of Medicine and Engineering saw some beneficial similarities. They saw how a DOE-developed imaging device could help medical researchers understand how dangerous clots might form in and around an artificial heart pump.

Using laser imaging and other advanced equipment originally developed at the Center to study the microscopic flow of coal liquids, the medical researchers were able to improve the design of the artificial heart pump, and later an artificial lung device, to minimize areas where blood stagnation could promote clotting.

Researchers at the DOE Federal Energy Technology Center and the University of Pittsburgh Schools of Medicine and Engineering …saw how a DOE-developed imaging device could help medical researchers understand how dangerous clots might form in and around an artificial heart pump.

Industrial Coal Furnace Technology to be Used byAluminum Industry

A DOE Fossil Energy program to develop an industrial coal-fired process heater has led to a new, more cost-effective way to recycle aluminum potliner. DOE's industrial research partner, the Vortec Corp., licensed the furnace technology to a major aluminum producer which will install it in a commercial recycling facility. The technology will be used to melt spent aluminum potliner to prepare it for recycling. The technology also has a wide range of other applications, including vitrification of low-level radioactive waste and the production of glass fibers from such sources as boiler ash, sewage sludge ash, and glass wastes.

Making Fertilizer from Coal

One of the future concepts for converting coal into other fuel forms is to apply biological processes. Certain microbes "feed" on coal, producing liquids and other substances as "waste" products. Although as a source of fuels, the technique is well into the future, it has resulted in an important near-term spinoff. ArcTech, the company that worked with the Department to develop a biological coal conversion process, has now adapted the process to produce an organic, environmentally safe fertilizer made from coal.

Sold under the tradename *Actisol*™, the fertilizer is now available from lawn care and home improvement stores. It is also being sold worldwide, most notably in Saudi Arabia, where the need for organically rich soil supplements is particularly acute, and in South Korea.