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Getting Domestic Technology Transfer on Track

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GETTING DOMESTIC TECHNOLOGY
TRANSFER ON TRACK

An internship report in partial fulfillment
of the requirements for the degree of
Master of Science

By

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B.S., United States Air Force Academy, 1983

1992
Wright State University
I HEREBY RECOMMEND THAT THE INTERNSHIP REPORT PREPARED UNDER MY SUPERVISION BY Donovan O'Neil Robinson ENTITLED Getting Domestic Technology Transfer on Track BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT


The confluence of the recession and end of the Cold War has brought the issue of technology transfer to the forefront of national debate. Each of these significant events is challenging by itself but together they are greater than the sum of the parts. At the center of technology transfer debate is the U.S. laboratory system. A de-emphasis on defense related R&D coupled with a move toward commercial applications is the predominant policy choice to strengthen America's international competitiveness. This paper examines technology transfer from the Department of Energy to the private sector as reported in "Fossil Energy: From Laboratory to Marketplace." Although chiefly anecdotal and narrow in focus, the problems highlighted by the purported successful transfers are not sui generis to the fossil energy program.
I. INTRODUCTION

The issue of domestic technology transfer has sublimated to the top of our national policy agenda. As America turns its attention to solving its own problems, the introspection leaves many people apprehensive. The consensus is that for the first time in over two centuries the standard of living future generations will enjoy will be below our current level. To keep our standard of living rising our productivity must be undergoing the same dynamic. This means we need to be creating surpluses (trade and budget) not deficits. The heightened sense of alarm is palpable across the country. Answers are being sought in every aspect of our lives: education, drug policy, health care, trade, and tort reform to name a few. One area of intense focus is the transfer of government research to the private sector. Where the government is the final consumer of technology (i.e. defense procurement) the innovation process functions very well. However, cases where the technology must jump the gulf from the laboratory to the marketplace yields only marginal results.

According to the General Accounting Office, the U.S. government spends in excess of $60 billion annually (1989) on research and development in some 700 laboratory facilities. This network of labs consists of government-owned, government-operated (GOGO); government-owned, contractor-operated (GOCO); and contractor-owned, contractor-operated (COCO) labs. The ideas engendered in these national resources are fertile ground for new products and processes which could rebuild our international competitiveness. If the royalties collected form license of government technology is accepted as a measure of success, then domestic technology transfer is
woefully inadequate. Royalties were approximately $3 million in 1988 for a return on investment of .00005 percent. Royalties may be a much too narrow criteria for return on investment since it totally ignores the fiscal stimulus of government spending. Regardless of the yardstick, there are efficiencies to be gained by improving domestic technology transfer.

Efforts to improve this situation have mainly come in the form of legislative and directive action to create the institutional and policy framework required for technology transfer. The 1980s brought a flurry of policy actions: Stevenson-Wydler Technological Innovation Act (1980), University and Small Business Patent Procedures Act (1980), Small Business Innovative Research Act (1982), National Cooperative Research Act (1984), Federal Technology Transfer Act (1986), Executive Order 12591 (1987), and Omnibus Trade and Competitiveness Act (1988). (See Appendix for highlights.) Though these initiatives cannot be fully assessed in their brief history, preliminary indications show they are effective only at the margins and fundamental problems still need to be resolved. This paper examines technology transfer from the Department of Energy to the private sector as reported in "Fossil Energy: From Laboratory to Marketplace." Although my inquiry is chiefly anecdotal and narrow in focus, the problems highlighted by the purported successful transfers are not sui generis to the Fossil Energy program or the Department of Energy.

II. PROGRAM EVALUATION

"The Federal Government has had a substantial, broad-based energy R&D program since the 1973 oil embargo. From 1980 through 1990, the Government has invested
about $21 billion in energy technology R&D. This investment has had relatively little 
payoff, for a combination of reasons...."  "It was in the 1980s that many of the creative 
concepts and scientific curiosities of the 1960s and 1970s matured into engineering and 
commercial realities. New Technologies moved into the marketplace and redefined the 
'state-of-the-art' in fossil fuel processes and hardware." These statements from the 
Budget of the United States Government, Fiscal Year 1992 and "Fossil Energy-From 
Laboratory to Marketplace" respectively, represent the leitmotif of the Office of 
Management and Budget and the Department of Energy. It is under this umbrella of 
inter-agency conflict the DOE Fossil Energy R&D program evaluation developed. The 
problem or issues to be examined: How are priorities determined? How is success 
measured? What have some of the successes been? To begin to answer these questions 
several technology areas were arbitrarily chosen for a more careful examination. 
Specifically, the following research programs identified as "In the Marketplace" were 
reviewed: 

Fuel Cells

Phosphoric Acid Fuel Cell Power Plants

Enhanced Oil Recovery

CO₂ Miscible Flooding Technology for Oil Recovery 
Tailored Pulse Fracturing of Oil and Gas Wells 
Air Drilled Horizontal Wells 
Steam/Foam Flooding for Heavy Oil Recovery 
Anelastic Strain Recovery Method for Measuring Stress in Oil and Gas Reservoirs 
New Polymers for Enhanced Oil Recovery
Combustion Systems

Atmospheric Fluidized Bed Coal Combustion
Super 9 Chrome

As part of the verification process for the purported successes, telephone interviews were conducted with researchers, contractors, and industry representatives to gain a broader perspective on the research efforts and their results. Data on R&D contract funding was also gathered from DOE. Prior to the program evaluation the Fossil Energy office gathered information from Morgantown and Pittsburgh Energy Technology Centers and its project offices to produce the following synopsis of each commercial success. They are reproduced here for convenient comparison prior to the results of the telephone inquiries.

Atmospheric Fluidized Bed Coal Combustors

"Power Magazine" recently called the development of fluidized bed coal combustors "the commercial success story of the last decade in the power generating business." This success, bringing about the most significant advance in the coal-fired boiler in 60 years, was largely achieved through research and development sponsored by the Office of Fossil Energy and its predecessors.

Unlike the pulverized coal boilers first used in the 1920s, the fluidized bed boiler captures and removes sulfur from burning inherently in the combustion process. By controlling the flow of air that is injected upward from the bottom of the boiler, a mixture, or "bed," of burning coal and limestone takes on many characteristics of a boiling fluid, hence the term "fluidized bed." The tumbling action helps the limestone capture sulfur pollutants as they are released from the coal. The temperature of the bed is maintained in a range that enhances sulfur capture and significantly retards the formation of nitrogen oxide pollutants.

The fluidized bed technique has been used since the 1920s in various chemical and industrial processes. But it was not until the 1960s that the Office of Fossil Energy’s predecessors realized its potential for use with coal and began a program to develop the technology as a clean coal combustion energy process. Throughout the 1960s and 1970s, two 18 inch fluidized bed combustors built at DOE’s Morgantown Energy Technology Center were operated to support development of the technology.
By 1979, the Nation’s first industrial-scale atmospheric fluidized bed unit to be used in regular commercial service was installed at Georgetown University in Washington, DC, as a DOE-cofunded project. That unit was soon followed in the early 1980s by other DOE-sponsored installations, at the Great Lakes Naval Training Center near Chicago; at Shamokin, PA; at East Stroudsburg University in Pennsylvania; and at Wilkes-Barre, PA. Today, virtually every major U.S. boiler manufacturer offers an atmospheric fluidized bed boiler in its product line -- each a direct descendant of the pioneering units funded through the Fossil Energy R&D program. Foster-Wheeler, Combustion Engineering, Tampella Keeler, and Wormser Engineering have made commercial sales with and estimated value in excess of $700 million. DOE-sponsored fluidized bed research at Battelle Laboratory resulted in the development of a process that was licensed to Riley-Stoker, Foster-Wheeler, Struthers-Wells and Mitsui. Each firm, in turn, has made commercial boiler sales based on this Fossil Energy-developed concept.

More than 200 industrial-scale atmospheric fluidized bed combustors are now operating and producing energy in the U.S., burning a wide range of fuels from wood wastes to anthracite culm to high sulfur coal to petroleum coke. Several full-scale utility units are also underway.

ATMOSPHERIC FLUIDIZED BED COAL COMBUSTORS

Combustion Engineering researched Fluidized Bed Combustors (FBC) but dropped its efforts in 1955 based largely on economics. The energy crisis renewed industry interest and the Department of Energy released a Program Opportunity Notice which Combustion Engineering was awarded. As a result, a demonstration facility was constructed at Great Lakes Naval Training Center. In 1979 a German company named Lurgi was investigating other applications of similar technology it had developed for the aluminum industry. Lurgi approached the Electric Power Research Institute (EPRI), who went to Tennessee Valley Authority (TVA), and Combustion Engineering was tapped for a design study. Positive results led Combustion Engineering to pursue the technology. They developed Lurgi (circulating bed) type systems which were bought by Texas/New Mexico Power and TVA. The technology in these systems utilizes a portion of DOE derived technology. However, the plants today are very different from the Great Lakes
facility. Combustion Engineering offers both the Lurgi (circulating bed) and Great Lakes (bubbling bed) plants. Given a scenario where the utility company and its architecture and engineering firm have decided on a fluidized bed system, a determining factor between the two is the size of the plant. Economies of scale are realized with the Lurgi technology as plant size increases. The Great Lakes technology is only competitive for smaller plants. Combustion Engineering holds patents for components of both systems. From 1984, fluidized bed combustors have generated approximately a billion dollars in revenues; 90% from Lurgi technology.

Phosphoric Acid Fuel Cell Power Plants

Fuel cells have provided power for spacecraft, and since the mid-1970s, the Department of Energy has funded research to develop a terrestrial version of this advanced power technology. Similar to a continuously operating battery, the fuel cell is an electric power and heat generator that is both clean and quiet. Because of these unique qualities, a fuel cell can be cited in environmentally sensitive or populous areas. And it has the potential to be significantly more efficient than most other fossil fuel plants on the market. In cogeneration applications, efficiencies of fuel cell plants are expected to be in the range of 80 percent. Fuel cells can operate with a variety of fuels. During the 1980s DOE's research into components and systems, along with studies of electrochemical catalysts and corrosion resistant materials, culminated in the first demonstrations and commercial offerings of fuel cell technology. Phosphoric acid fuel cells -- named for the electrolyte used within the cell -- have been the first to cross the commercial threshold. In the early 1980s, the Office of Fossil Energy and the Gas Research Institute jointly funded tests of forty seven 40-kilowatt pre-commercial prototype power plants.

A decade later, International Fuel Cell Corp. (IFC) has received orders for more than fifty 200-kilowatt fuel cell power plants from gas and electric utilities in the U.S. and overseas. Delivery of the power plants will begin in 1991. The company is nearing completion of a $20 million phosphoric acid fuel cell stack manufacturing facility in Middletown, CT.

The stacks for an 11-megawatt power plant now operating near Tokyo were manufactured in the United States by IFC, as will those for a 1-megawatt power plant planned for Italy.
PHOSPHORIC ACID FUEL CELL POWER PLANTS

According to the CEO of International Fuel Cell Corporation, fuel cell research programs existed at General Electric, United Technologies Corporation (UTC), and Union Carbide during the 1950s. Applications were primarily for aerospace (manned space) and submarine technology. There was not any previous Government support for research and development before the space program fuel cell (alkaline systems) competition for manned space flight. The Government did not become involved in stationary fossil fuel power plant concepts until the energy shocks of the mid-1970s. UTC and several gas utilities developed a 1 megawatt and 40 kilowatt facility. The Government was approached after private sector investment of 150-175 million dollars and technical feasibility achieved. DOE funded the fuel cell element not the power plant concept. They supported operational feasibility research but did not pursue the developmental work needed to prove economic viability. The following systems represent approximately 300 patents:

-5 MW plant - pure sale to Japan (TEPCO), firm fixed price

-11 MW plant - IFC licensed technology to Toshiba

-200 KW plant - 62 orders

In each machine about 25-27 are essential; 10-15% of which are a result of DOE R&D investment. The 5 MW plant started as a joint UTC, EPRI, and Government program. Consolidated Edison was the host utility. The sale to the Japanese was accomplished after the program was judged a failure. Since 1984, when United Technologies and Toshiba signed an agreement creating IFC, Toshiba has invested approximately $100
million, $35 million from overseas customers (premium on paid facilities purchased), and Government support has been minimal. Ward’s Business Directory lists IFC’s 1990 sales as $50 million. Phosphoric acid fuel cell technology accounted for 35-40% of total sales.

"Super 9 Chrome"

For use in high temperature corrosive applications, stainless steels are relatively expensive, subject to stress corrosion cracking and use a strategically important material, chromium.

In 1980, DOE’s Fossil Energy program began studying a new 9% chromium-1% molybdenum alloy that had been largely developed by Oak Ridge National Laboratory (ORNL) and Combustion Engineering Inc. for the Breeder Reactor Program. The Fossil Energy program subsequently funded a cooperative effort with utilities to conduct metallurgical analyses and plant testings that confirmed the applicability of this new alloy to fossil fired processes. As a result, the material was included in the ASME Boiler and Pressure Code for use in fossil applications. Among its advantages are lower costs, higher allowable design stress and immunity from stress corrosion cracking. ORNL received the prestigious IR 100 Award for this development in 1982.

The alloy is now used commercially for higher performance and more durable and reliable fossil-fueled power plants. One company has sold the material for use in 66 fossil power plants around the world, and another has recently received its largest order ever to provide the material to a Korean power plant. Although most of the funding to develop the alloy was provided by DOE’s Office of Nuclear Energy, the highly leveraged Fossil Energy support was essential to commercializing the alloy for use in the fossil fuel power industry.

SUPER 9 CHROME

The idea to apply this alloy to fossil fuel combustion systems originated at Oak Ridge National Lab. Because the research was being conducted for a nuclear program, information on T91 was prohibited from public release. However, if its use in conventional plants could be established then it could be released to industry. The Fossil Energy office leveraged a multi-million dollar research effort with $200,000 for the purchase of the first commercial size heats. These were used for metallurgical testing for
ASME approval. A technology transfer conference held in Knoxville, TN, with U.S. companies only, resulted in a negative industry response. The technology was then offered internationally. The response of foreign companies (Japan and France) was much more favorable and they pursued the technology with their own funds. Today, foreign companies dominate the T91 market; producing the majority of the more than 4,000 tons already used throughout the world in large utility boilers and petrochemical units.

CO₂ Miscible Flooding Technology for Oil Recovery

Fifteen percent of all domestic enhanced recovery (about 100,000 barrels per day) is produced by injecting carbon dioxide into aging reservoirs to force out oil that conventional production techniques cannot recover. The gas mixes with some of the remaining oil in the reservoir and creates a miscible bank of fluid that pushes additional oil to production wells. In large part, industry gained confidence in carbon dioxide flooding technology through a series of eight field tests conducted in the 1970s and cofinanced by oil companies and the Department of Energy and its predecessors.

Because of the success of CO₂ enhanced oil recovery, CO₂ pipelines have been built throughout West Texas and eastern New Mexico, the principal region for successful CO₂ miscible flooding. With the completion of the LaBarge pipeline, CO₂ enhanced recovery has also been extended to oil fields in Wyoming, and could reach North Dakota.

CO₂ MISCELLE FLOODING TECHNOLOGY FOR OIL RECOVERY

In 1976 Pennzoil responded to a DOE Request for Proposal (RFP). Over the duration of the contract awarded, they delivered over 100 reports to Morgantown Energy Technology Center (METC). The pilot test conducted at Rock Creek Field, West Virginia, never developed into an economically viable enhanced oil recovery method. According to the program manager at METC, the Bureau of Mines started funding CO₂ research in 1973. Industry had already started lab work in the 1950s and the first field tests were conducted in the late 1960s. Of the seven field tests conducted, only the Week's Island field continues CO₂ flooding. CO₂ Miscible Flooding can reduce residual
oil from 25% to 3-4% in water flooded fields. Despite its technical success the cost of CO₂ makes its use economically prohibitive except in certain areas. The technology is currently confined to West Texas and eastern New Mexico.

Tailored Pulse Fracturing of Oil and Gas Wells

Oil or natural gas in a reservoir may be inaccessible because the tiny fractures that allow the hydrocarbons to move through the formation may not lie in the proper orientation needed to provide a pathway to producing wells.

To create this path, producers have developed techniques that use massive quantities of high pressure water and explosives to open manmade fractures in the rock. Unfortunately, in some rock formations, these techniques are not effective enough to create fractures with the proper orientation.

Through DOE's program to develop methods for producing gas from unconventional resources, a "tailored pulse fracturing" technique emerged that provided a more controllable, omni-directional fracturing pattern. With tailored pulse fracturing, precise quantities of solid rocket fuel-like propellants are ignited in the wellbore to create fractures in a more predictable pattern. Following DOE-sponsored development and field tests, the technology was commercialized by Petrotek Corp. of Ohio, Servo Dynamics Corp of California and Sunburst Recovery of Colorado.

To date, thousands of wells from Wyoming to Texas have been stimulated using this technology, mostly in the western United States.

TAILORED PULSE FRACTURING OF OIL AND GAS WELLS

The concept was developed in 1956 by Mr Henry Mohaupt. A patent was issued for the use of a rapid ignition propellant contained in a pressurized container for reservoir fracturing. In the mid-1980s DOE funded a parametric investigation of this technology at Sandia Labs. They were trying to determine the rate of pressure buildup in small diameter holes necessary for fractures with the required orientation. The result was a more accurate pressure-time profile of the fracturing process. Tailored Pulse Fracturing is the foremost method of extracting oil and gas. Servo Dynamics is being approached
by companies all over the world and currently has contracts with Shell, Mobil, Meridian, Oryx, and Texaco. This technology is representative of a range of EOR procedures whose use is determined by the reservoir characteristics and the particular problem to be solved. Tailored Pulse Fracturing increases oil production by 7-28 barrels/day.

**Air Drilled Horizontal Wells**

Horizontal wells -- boreholes that initially penetrate downward and then are turned to move horizontally through a hydrocarbon-bearing formation -- are among the most promising techniques to improve production from marginal oil and gas reservoirs. The horizontal path of the drill permits it to intersect more natural fractures and thereby open up a greater portion of the reservoir for drainage. In many Appalachian formations, however, water from the mud causes the underground rocks to swell, shutting off natural fractures and reducing production.

To overcome this problem, DOE has developed horizontal drilling techniques that use air to drive and cool the motor and to remove drilling debris.

Air motors based largely on the DOE technology are now being sold by Eastman-Christensen Corp. and Wilson Downhole Inc. These two firms account for most of the new holes being drilled in eastern gas formations. DOE is continuing efforts to increase the efficiency of air drilling horizontal wells.

**AIR DRILLED HORIZONTAL WELLS**

Eastman-Christensen was a subcontractor to several different companies involved in this research: SAIC, Gruy Federal, BDM, Columbia Natural Resources, Prime Energy, and Cabot Corporation. DOE was funding these prime contractors to conduct research for enhanced oil recovery in Devonian Shale. Eastman-Christensen, through their own research and development, experimented with down-hole motors for other applications. DOE sponsored a market study to prove that high angle drilling produced more oil and is a faster and relatively cheap drilling method. As a result, modified motors were developed which greatly contributed to air drilling technology. These new tools provided
through DOE market stimulation has quadrupled Eastman-Christensen’s business at its West Virginia operation. There are also spinoff applications to remedial cleanup of hazardous waste sites.

Steam/Foam Flooding for Heavy Oil Recovery

Many oils, particularly those in California fields, are too thick to move through the reservoir to reach producing wells. Steam is often injected into the reservoir to thin the oil and move it to a producing well. In many cases, however, the steam, which is lighter than the fluids, rises and overrides the oil saturated zone, leaving adjacent oil untouched.

With funding from the Office of Fossil Energy and private industrial sponsors, the Stanford University Petroleum Institute (SUPRI) developed a technique for injecting foam with the steam and using it to seal off areas of the reservoir where oil has previously been produced. This allows the steam to be redirected to oil-saturated zones. Additional oil recovery over the lifetime of wells treated in this manner can total as much as 10 to 15 percent.

The SUPRI process is now being used commercially by many of the larger heavy oil producers.

FOAM/STEAM FLOODING FOR HEAVY OIL RECOVERY

Foam technology research started in the late 1950s for gas applications. In 1976 Stanford University Petroleum Research Institute was founded to replace the Bureau of Mines’ Heavy Oil Lab. In the late 1970s interest was revived in the technology and a surfactant (petroleum sulfonate) that could withstand steam temperatures was investigated. The process was proven in field-tests and is currently used commercially by major heavy oil producers (Shell, Phillips, Mobil, Chevron). Steam/Foam Flooding is also used in Canada, Europe, and Venezuela. Alternatives are available but this is the most cost effective and efficient procedure.

According to Shell Oil, they are not using this technology. In the mid-1970s Shell began its own research efforts on steam enhance oil recovery agents. Field tests were
done at Kern River using their agents and the drive process. The process was subsequently patented. Although it worked technically and oil recovery predictive models were developed, in 1986 Shell Oil decided not to install the process in any major project. Oil price levels are too low to make it economically viable. The major expense of the process is the surfactant. Additional oil recovery is 10% over and above the steam process.

Anelastic Strain Recovery Method for Measuring Stress in Oil and Gas Reservoirs

Knowledge of in situ stress -- the geologic forces at play within an underground reservoir -- is critical in understanding an oil or gas reservoir's characteristics, particularly as the reservoir's pressure declines over its production life. To improve industry's ability to measure geologic stress at the depths of an oil or gas reservoir, Sandia National Laboratories developed a method called "anelastic strain recovery."

The technique consists of mounting highly accurate and sensitive clip-on displacement gauges on a sealed core sample of reservoir rock immediately after the core is retrieved from the borehole. The gauges record the "relaxation" of the core at the surface, revealing the magnitude of stress. And because the core has been oriented so that its relation to north is known, the direction of stress can also be determined.

From 1982 to 1987 a series of DOE-sponsored Sandia/industry cooperative experiments were conducted to evaluate the method in different geologic environments and apply the results to massive hydraulic fracturing in tight gas reservoirs and enhanced oil recovery projects. Amoco, Arco, British Petroleum, Exxon, Esso Canada, Phillips Petroleum and the Gas Research Institute participated in these tests.

This cost-effective, reliable method has been used commercially by Phillips in the North Sea to study how oil production is being influenced by compaction of geologic strata and subsidence of the seafloor. The technique is now being offered commercially by at least two service firms, Terra Tek and Halliburton, and is being used in the U.S. by such companies as Chevron, British Petroleum and Mobil.

In recognition of the importance of this technique to industry, the method's originator, L.W. Teufel, received the Federal Laboratory Consortiums' award for Excellence in Technology Transfer in 1988.
ANElastic Strain Recovery Method for Measuring Stress in Oil and Gas Reservoirs

The theoretical framework for ASR was written about as early as the mid-1960s. Researchers at Sandia Lab developed better gages with which to monitor core strain. Research was also done on theoretical and physical models of relaxation cracking. They were issued a patent (#4587739) dated May 1986. To transfer the technology, papers were presented at the Society of Petroleum Engineers; an industry conferences was held at Core Labs; and a series of developmental test were conducted with several oil companies where they provided access to reservoirs, logistics, and coring operations. These activities generated interest in the technology and started the innovation process. Once the technology was proven, oil producers and service companies developed their own systems for commercial applications.

Phillips Petroleum participated in the field tests of Anelastic Strain Recovery. They are currently using the DOE derived technology for in situ stress measurement. ASR is used to determine the compression characteristics of the reservoir rock and to improve hydraulic fracturing stimulation of the reservoir. Phillips primarily (95%) uses ASR in the North Sea Ekofisk field in conjunction with its European partners. Prior to ASR in situ stress could only be measured in the vertical direction. ASR measures three dimensions. Other technologies are available such as micro-fractures but ASR is the most cost effective and accurate.

Halliburton developed their own ASR system based on DOE technology which they offer as commercial service. ASR is viewed as leading-edge technology which requires special training and experience. In 1985 they began development of their current
ASR instrumentation. In 1990 they initiated another round of development to keep their competitive edge. ASR represents less than one percent of sales. It is basically offered as an ancillary service to hydraulic fracturing.

Terra Tek began its investigation of in situ stress measurement 15 years ago with Amoco. By the mid-1980s the research was progressing well and Terra Tek expended substantial resources to develop their own instrumentation. Terra Tek offers ASR commercially for a $30,000-50,000 fee. Advanced development research conducted by Sandia is viewed by Terra Tek as deleterious government intervention in the marketplace. They cannot compete with the Government’s below market price. The North Sea is the primary area for application of ASR and Sandia continues research efforts there. Terra Tek forecasts ASR to develop into only a $5-10 million dollar market.

New Polymers for Enhanced Oil Recovery

Waterflooding is a standard technique of increasing oil production. Water is pumped into an oil-bearing reservoir to flush out the remaining oil and move it to production wells. Various Chemicals, including polymers, can be used to increase the viscosity of the water and augment the efficiency of water-floods. Minerals that have dissolved in formation water, however, can create highly saline conditions that dilute the effect of the polymer additives.

Under the Fossil Energy program in the late 1980s, a new polymer was developed and patented by the University of Southern Mississippi. This polymer retains its viscosity in high-salinity reservoir environments, allowing greater use of waterflooding techniques and a greater sweep of oil from a reservoir. The polymer has been licensed for development by Oryx, a major independent oil company.

NEW POLYMERS FOR ENHANCED OIL RECOVERY

Sun Oil had a licensing agreement with the University of Southern Mississippi (USM) for the development of the polymer AMB. USM conducted research in the synthesis of AMB and its characteristics in brine. Prior to the separation of Oryx from
Sun Oil expended approximately a million dollars on developmental flow experiments in porous media and core flood experiments. Modification of AMB to increase its ability to propagate resulted in the loss of some of its desirable characteristics. AMB is still in the lab. Oryx is working with a chemical company to assess AMB and other polymers' commercial feasibility. The current economics of production, high cost of the polymer and the low price for oil, places polymer EOR low on the Oryx priority list.

III. ECONOMICS OF R&D

Before attempting to digest, analyze, and draw inferences from these comparisons, it is essential that some of the fundamental concepts and theories pertaining to research and development economics be illuminated. The economics of R&D encompasses market forces and the allocation of scarce resources, with the added element of uncertainty. Uncertainty plays a supernatural role because no one knows if or when the outcome of any research and development effort will bear fruit. Uncertainty is therefore an important attribute separating two important parts of the R&D process: invention and innovation.

The distinction in an economic sense between invention and the development process underlying innovation is best summarized in the difference between the two words "predictability" and "describability." Basic invention is truly unpredictable: even the most competent scientist cannot predict when or how it will come, let alone what the solution will resemble. On the other hand, he or she knows in appraising the detailed problems of development [innovation] that an answer will be obtained and can only not describe what the answer will be. (Scherer, p. 6)

Given this shroud of uncertainty, the firm's R&D decision reduces to maximizing the net gain from the stream of benefits for the cost of any R&D effort. Neither the costs nor the benefits are static values but rather are time dependent. The end game is to
optimize the expected value of the benefits to be gained from the expected costs within
a temporal constraint. This highlights one of the most widely accepted principles in the
economics of R&D. The question is how best to allocate resources (cost) to optimize my
expected benefit given the costs and benefits of any R&D project is a function of time.
In general, the less time you allocate to achieving a desired goal, the greater the cost will be. This time-cost trade-off is graphically represented in Figure 1.\footnote{This figure was reproduced from (Dorfman, p. 35) with slight modifications.} The convexity of this relationship can be attributed to several factors:

1. Concurrent tasking required for faster development time requires more tasks to be
pursued with incomplete knowledge. More tasks will yield wrong results and be a waste
of resources than would occur in series tasking. 2. Diminishing marginal returns to the
additional resources added to decrease development time. 3. Hedging activities within
a given task will also consume resources as "backup" activities are performed to meet
time constraints. (Dorfman, p. 36-7) The uncertainty inherent in this time-cost trade-off
leaves the expected stream of benefits as a deciding factor. If the stream of benefits are
deep then resources should be allocated to minimize R&D time. If they are shallow, the
cost should be minimized.

Another characteristic of the cost of R&D is its similarity to the Gaussian normal
curve. As you move through the stages of technical advance: basic research, applied
research, development, and commercial production, the R&D cost curve builds to a
maximum around the initiation of commercial production. This is the pattern evident in
Du Pont's investment in nylon production. Figure 2 shows the investment required for
commercial production of nylon technology significantly dwarfs the investment for research and development.\textsuperscript{2} If this pattern is the norm rather than the exception, then it has serious implications for domestic technology transfer which will be addressed later.

Although cost-time-benefit considerations are the primary focus of the individual firm, technological change does not happen in isolation. External considerations factor into the decision process such as market structure, rivalry, concentration, diversification, and firm size. The seminal theoretical issues of research and development economics is attributed to Joseph Schumpeter according to the literature reviewed. Schumpeter redefined and moved beyond the fiat price competition of classical economics. General equilibrium theory has the forces of supply and demand determine the price and quantity of goods bought and sold. Within a perfectly competitive market firms compete based on price. But how does a firm lower its price to sell more of its goods than its competitor? Schumpeter looks below the surface of price competition to see the internal mechanism of competition through innovation. Innovation produces new products, makes old products more cheaply, creates jobs, captures market share, and ultimately leads to economic growth. Since sustained economic growth is a desirable outcome, understanding the conditions that foster it is imperative. Kamien and Schwartz present four Schumpeterian hypotheses that form the basis of many corollary theories and which most of the empirical studies try to falsify. First, there is a positive relationship between

\textsuperscript{2} This figure was reproduced from (Scherer, p. 4). It shows DuPont's annual investment in nylon technology from 1928-1948. The relationship between the various phases of the innovation process and expenditure levels is paradigmatic.
monopoly power and innovation. Second, large firms innovate more than proportionately to small firms. Third, in the technology-push hypothesis, R&D with commercial potential is brought to management for innovation. Lastly, in the demand-pull hypothesis, management initiates innovation by asking the research staff to solve production or market driven problems. "The last two hypotheses are relevant to the first two in that they reflect possible influences on innovation that one must control for in a statistical test of the influence of market power or firm size on innovation." (Kamien and Schwartz, p. 47)

The difficulties in conducting empirical tests to directly corroborate these hypotheses are substantial. The studies cited by Kamien and Schwartz are all regression analyses assuming a linear, quadratic, or cubic relationship in the variables. Regression analysis is based on its own simplifying assumptions which create serious problems of interpretation. The results of any econometric study only shows high or low correlation of dependent and independent variables and in no way implies any cause and effect. Also, the variables under study: innovation, firm size, technological opportunity, economic opportunity, and monopoly power, have no readily accepted or available definition or measurement. The only recourse is the use of surrogates. Throughout these studies firm size was measured by total assets, total employment, or total sales; R&D activity by technical/scientific personnel to all employees ratios or fraction of annual budget devoted to R&D as inputs; patents or industry innovations as output; and market power by concentration ratios.
Addressing these hypotheses in reverse order brings us to the internecine conflict between technological and economic opportunity; better known as technology-push and demand-pull. Which is the driving force behind innovation? A few examples emphasize the salient points. Research in superconducting materials has gone on for years. Recent breakthroughs in high-temperature superconductors have brought visions of a future filled with magnetically levitated transportation systems. The increase in basic knowledge affords the opportunity for development and commercial application. On the other hand, pharmaceutical companies are researching cures for many human ailments. If they can find a remedy for any disease, the demand is ready and waiting. The difference in these two scenarios can be illustrated by examining one possible outcome to levitated transportation. If people continue to desire the autonomy of their own private transportation, then the cost of innovation will most likely exceed the stream of benefits realized. The link between economic and technological opportunity is uncertainty. In economic opportunity the technology is uncertain and the demand is uncertain in technological opportunity.

All in all, the evidence suggest that technological opportunity does influence the pace and direction of technical advance in a broad sense and especially in the long run.... Yet when one gets down to the level of specific inventions, it becomes apparent that it is economic opportunity that is essential. In fact, of course technological opportunity and economic opportunity are complementary influences on the course of invention.... Economic opportunity accelerates the exploitation of technological opportunity and in the long run there is feedback leading to new technological opportunities. (Kamien and Schwartz, p. 64)

Moving to the next hypothesis, we analyze the empirical evidence of the role firm size in technical advance. The small business is a phenomenon deeply rooted in the
American psyche. Whether its the "mom and pop" neighborhood grocery store or garage start-ups like Apple Computer, the small business is the epitome of American capitalism. The pro-small business attitude goes back to the latter part of the last century with the Sherman Anti-trust Act; formalizing the national faith in perfect competition. Small businesses are viewed as the driving force in our economy; responsible for a significant portion of employment and gross domestic product. However, with the rapid advance in technology, has the small firm become obsolete? Is the sphere of technical advance dominated by large firms with the resources (financial and technical) to capitalize on serendipity? Kamien and Schwartz reviewed the results of twenty regression studies focusing on the relationship between firm size and input to innovation; and five on firm size and innovation output. The results of both sets of studies support the same conclusion.

"[T]he conclusion about the effect of size on innovational effort tends to be supported and reflected in the evidence on size and innovational output. Beyond some magnitude, size does not appear to be especially conducive to either innovational effort or output in either this country or European countries. (Kamien and Schwartz, p. 84)

The evidence implies that increasing economies of scale in innovation occurs as firm size increases but at some point continued increases in firm size produces constant and eventually decreasing returns to scale. The specific transition points differ between industries.

The last hypothesis it the most difficult to assimilate into centuries of market idolatry. Perfectly competitive markets are the ideal on which our economic science and therefore economic policies are based. Perfect competition affords firms a normal profit
and maximizes consumer welfare. However, it is recognized theoretically that firms in a perfectly competitive market gain nothing from R&D. The responsibility then falls on external organizations such as the government. If perfect competition is not the media to promote R&D could the opposite end of the spectrum be conducive to R&D? That is the main Schumpeterian hypothesis based on the following arguments:

First, the costs of innovating are so great that only large firms can now become involved. Second, projects must now be carried out on a large enough scale so that successes and failures can in some sense balance out. Third, for innovation to be worthwhile, a firm must have sufficient control over the market to reap the rewards. (Mansfield, p. 557)

In one particular analysis of the economics of research and development, the conclusion reached is it may be optimal (second best alternative) for the government to finance R&D projects for a monopoly. The first choice being no monopoly R&D and the concomitant loss in consumer surplus. The conflicting dimensions in this argument is clear and the statistical evidence provides no clear consensus. "Little support for this hypothesis has been found. Instead a new hypothesis has emerged that a market structure intermediate between monopoly and perfect competition would promote the highest rate of inventive activity. (Kamien and Schwartz, p.104)

IV. ANALYSIS OF DATA

In analyzing the anecdotal data, no attempt will be made to substantiate the validity or veracity of one version of events or the other. Nothing much is to be gained by finger pointing and the reader is free to draw his or her own conclusions. With that said, there are more fundamental problems exemplified by these scenarios which need to be addressed.
The nexus of the phases of the research and development process is uncertainty. Within the private sector, firms commit resources and make management decisions about invention and innovation where the outcome is unknown. These are not blind leaps of faith but informed action with some probability of success. Within their purview, steps are taken to minimize risk. However, when a firm becomes involved in commercializing government technology they lose a certain amount of control and the uncertainties are multiplied.

United Technologies Corporation (UTC) had several research and development contracts with DOE for fuel cell technology. Subsequent to these efforts, UTC in conjunction with Toshiba decided to commercialize fuel cell technology into power plants. This joint venture, International Fuel Cell Corporation, is now in the business of fuel cell power plants. The decision to proceed with commercialization weighed the risks against the expected benefits. If this was the end of the story the technology transfer process could mark one in the success column and it would be a great example of how the system is supposed to work. Unfortunately, the situation deteriorates into a prime example of why government research remains in the laboratory. Fuel cell research continues at the DOE through other contracts with another firm. This government action leaves IFC with three options; all of which are bad. If they want to be a viable participant in this technology, they will have to continue their own research and development. They are therefore forced to compete against another company being funded by the deep pockets of the Government. The second alternative is to seek their own government program if they can marshall the political clout. This option has limited viability. The last option
is to cut their losses and eventually concede the fuel cell business. None of these scenarios were contemplated when decisions were being made by IFC but they are forced to deal with reality not expectations. This is not the only occurrence of this type of conflict within the handful of technologies investigated.

Terra Tek, an oil industry service company, is identified by DOE as a commercial user of their Anelastic Strain Recovery technology. Terra Tek's primary market for this service is the North Sea. Sandia Lab is pursuing further development work on ASR. The research provides services in the North Sea and Terra Tek cannot compete with the Government's below market price. As research, the Government does its stress measurements at minimal cost to the oil companies.

Circumstances such as these, just based on the probability of finding similar instances in a larger sample, abound within the realm of domestic technology transfer. Government action is zealously focused on not giving any particular firm an unfair advantage. However, minimal attention is given to the harm of government action. Rational decisions subject to the vicissitudes of government activities creates a more uncertain environment for the private sector, prohibitive to domestic technology transfer.

A clear example technology transfer gone awry is Super 9 Chrome. This steel alloy developed at Oak Ridge National Lab was offered to the U.S. steel industry through a technology transfer conference. The inquiries of the 120 attendees was, "Tell me where the market is and how many tons will I sell?" (Emison, p. 53) The response of the scientists was that they are neither economists nor promotional experts. At that point you have stalemate and the rest is history. The response of the steel industry is
understandable given the substantial costs usually required for plant and equipment in the production phase of the innovation process. The government’s attitude is that by conducting research for technology it is absorbing a major portion of the cost. If the cost profile in Figure 2 is the norm, then this view does not reflect reality. The policy assumes that by providing ten or twenty percent of the cost of innovation, industry will risk ninety or eighty percent on technology in the public domain.

Successful innovation generally involved greater attention to education of users, publicity, market forecasting, and selling. Most significantly, successful innovations was marked by an understanding of user needs. This understanding was needed by those in R&D performance as well as in marketing and general management. (Kamien and Schwartz, p. 62)

It seems that a little bit of effort by all parties concerned to address these issues would have this alloy a viable part of the American economy. Instead, when Dayton Power and Light refurbished their boiler units with 540 tons of T91 they bought it from overseas. (Emison, p. 53)

Urging the government to participated in activities normally reserved for the private sector may be too simple a rationalization of this particular chain of events. In a study testing the hypothesis of large firms being more conducive to innovation, the coal, petroleum, and steel industry were examined. The assumption was, ceteris paribus, a large firm should be responsible for a larger percentage of the significant innovations in its industry than its market share. Based on the crude data from before (1919 - 1938) and after (1939 - 1958) World War II, indications were that the hypothesis generally held in petroleum and coal but not the steel industry. (Mansfield, p. 561) What the actual results are is not as important as the fact that inter-industry differences exist. To treat each
industry generically when there are differences in characteristics related to the technology transfer process is a prescription for the poor results identified with Super 9 Chrome.

Several of the enhanced oil recovery technologies succinctly encompass the conflicting and complementary nature of technological and economic opportunity. CO₂ Miscible Flooding, Foam/Steam Flooding, and New Polymers for EOR are all technical successes. Despite the success, producers and users of these technologies (Oryx and Shell Oil) identify economic viability as the reason these technologies were shelved. Clearly economic opportunity is the final arbiter of successful technology transfer.

Similar issues are addressed in what is referred to as the "culture" problem at government labs. Patents and licensing activities in technology transfer are in conflict with the anxious researcher’s need to publish. Most labs produce information, with the possible exception of defense related R&D. Knowledge for its intrinsic not economic value. These EOR techniques are technologically advanced but the cost is too high in the current market. In the long run, the technological opportunity will be there.

V. CONCLUSIONS AND RECOMMENDATIONS

As indicated by the qualitative and anecdotal nature of the Fossil Energy report, there is not an established methodology for examining program results above the project level. Between FY 1981-90, Congress authorized DOE to spend $3.9 billion on the Fossil Energy program. Other than accounting for this expenditure in a bookkeeping sense, the results have gone unexamined for a decade. Some of the more basic techniques of measuring R&D effectiveness include: five-year goal attainment assessment, integrated output mapping, scientist productivity studies, return on investment, bibliometrics, and
R&D efficiency studies. These types of effectiveness measures would include citation rate per researcher and patent production rates. (Crow, p. 87)

The difficulty in evaluating government R&D is not determining the costs. "The real difficulty is that in most areas of government research and development there exists no actual or potential market to impute through the mechanism economic values reflecting the independent preferences of millions of private citizens." (Dorfman, p. 13) This problem requires a flanking rather than direct approach to benefit-cost analysis. The decision making criteria is to proceed with programs whose benefits exceed the costs. Two of the approaches to making this determination is the benefit-cost ratio (B/C) and net present value (NPV). A ratio greater-than one or a NPV greater-than zero is a positive result. The general form of these calculations in the R&D literature is

\[
C = \int_0^T c(t, T) e^{rt} dt
\]

\[
B = \int_r^H b(t, T) e^{rt} dt
\]

where,

r=discount rate
T=time variable
T=total R&D time
H=length of benefits
C=present value of costs
B=present value of benefits.
Determining these functions is very difficult and no attempt is made to give them more specificity. Despite the difficulties, the costs are much easier to determine empirically than the benefits. By using a proxy for the costs, a threshold can be determined for comparison purposes with attempts to specify the benefits. Although specific benefits and values cannot be determined, the aggregate magnitude offers some useful information.

Table 1 is a compilation of the cost data available from the Fossil Energy office for fiscal year (FY) 1981-90. The budget authority (BA) figures are the authorized spending levels. The portion of the BA expended specifically on R&D contracts is listed in the FE column. Using historical deflator data from the Office of Management and Budget, these figures were converted to constant 1990 dollars. Proximate costs by the budget authority of the Fossil Energy program between 1981-90 is $4.7 billion. Assuming the standard ten percent discount rate and a 30 year benefit stream, the minimum annual benefits required is $502 million. If the costs are reduced to only the research and development contracts issued during the same period, then the benefits required is $251 million per annum. These benefit streams may never be captured but improvements can be made.

To move beyond the .00005 percent return on investment, several actions must be taken. The current mechanism for domestic technology transfer is a labyrinth of steps with uncertain results. Whatever changes are made to the policy construct, they must mitigate the uncertainties for firms pursuing government technology. This may be

3 The budget authority and fossil energy research numbers were compiled by the Fossil Energy Office in DOE.
achieved by preventing the negative impact of government action or providing an avenue to correct problems. The government needs to leave uncertainty in the technology and

FOSSIL ENERGY FUNDING PROFILE
(Billions of Dollars)

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<th>FE</th>
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</tr>
</tbody>
</table>

Table 1

not in the technology transfer process. The process must also be flexible enough to accommodate inter-industry differences of market structure and firm size.

The current policy framework changes the priority of all government labs to technology transfer. This type of blanket action may be doing more harm than good. The shift in the culture of government labs, with their emphasis on publishing, will not be achieved by legislative action. Technology transfer requires a change in the Gestalt of the laboratory system. Change will continue to meet resistance until individual uncertainties about a shift to commercial application of R&D are resolved. The greatest uncertainty being the budget of those labs failing to achieve commercial goals. Research
indicates that there is resistance to reform due to a bias toward the status quo whenever individual losers and gainers from reform cannot be identified beforehand. (Fernandez and Rodrik, p. 1146) The response to policy initiatives is indifference bordering on obstruction. The precatory nature of the legislative vehicles leaves compliance at the whim of agency officials. This kind of impetus will not overcome status quo bias.

Another problem with co-opting the entire laboratory system into technology transfer is that not all labs are equally efficient at the tasks required. The efficiency gains will be offset by the less capable. In a study examining the environmental taxonomy of the U.S. laboratory system, focusing on public and market influence, nine different categories were identified. They ranged from the private technology lab with high market influence, to the public science lab with high public influence. The conclusions are significant and worth repeating at length.

The most general conclusion from this study is that the Environmental Input Taxonomy, when applied to a large sample of U.S. R&D laboratories, discriminates among those laboratories in a way that seems to facilitate the understanding of laboratory behavior and characteristics.... If the federal government wanted to direct its laboratory network (realizing that most of this network is operated under contract) toward increased market relevance as is proposed in numerous new Congressional policy outputs, it could dramatically affect the output character and structure of the R&D laboratory system.... While this may, indeed, be useful in many respects, any technology transfer effort must be evaluated from the perspective of opportunity costs. That is, what are the opportunities foregone as a result of this new focus and how does the new focus detract from the core mission - proving basic research and generic technology.... It might be wiser to consider the development of new laboratory structures that are Public Technology in their character to address the need for increased market relevance. (Bozeman and Crow, p. 46-7)

If the government is shifting its R&D focus to technology with commercial application, then an awareness of economic opportunity is essential to success. One way
to determine the existence of economic opportunity, without the government becoming a market participant, is through the insistence of industry cooperation in R&D funding. Requiring the commitment of industry dollars will decrease the chances of government R&D remaining in the lab. Correlation calculations from the National Comparative R&D Laboratory Project indicate industry funding is a major factor in technology transfer. Industry funding assumes an importance in technology transfer well beyond its relative size. (Rahm, Bozeman, and Crow, p. 974) The importance of this variable has not gone unnoticed by the Department of Energy. Over the past decade the government share of Fossil Energy R&D has dropped precipitously. In fiscal year 1981 the government share of R&D contracts for DOE and the Fossil Energy Office was approximately 96 percent. By 1991, DOE decreased its share to 90 percent while the Fossil Energy Office share plummeted to 75 percent. (See Appendix B)4

This narrowly focused and anecdotal examination of domestic technology transfer is only a beginning. The issues raised and recommendations made are by no means definitive. They do, however, represent the nuances that must be factored into any technology policy construct. The recent slate of legislative and directive actions paint technology transfer with a broad brush. Although the framework is established, institutional obstacles in the laboratory system and private sector must be addressed if this national resource is not to be wasted.

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4 This graph is a product of the Fossil Energy Office.
APPENDIX A

LEGISLATIVE AND DIRECTIVE ENVIRONMENT

Stevenson-Wydler Technology Innovation Act of 1990

Enacted Oct. 21, 1980. Established the Offices of Research and Technology Applications at each of the national labs, mandated technology transfer activities at the Department of Commerce and the National Science foundation, and established a precedent for allowing research performers to elect title to patents based on Federally-funded research (at the time limited to Centers for Industrial Technology formed under the Act).

The University and Small Business Patent Procedures Act

Enacted Dec. 12, 1980. Gave small businesses, universities, and non-profit research performers the automatic right to elect title to any invention arising form Federally-funded research. The Act also allows a contractor to withhold information regarding an invention from public disclosure for up to two years while the contractor decides whether or not to elect title to the invention.

National Cooperative Research Act of 1984

Enacted Oct. 11, 1984. This Act amended the anti trust law to allow companies within the same industry to cooperate on pre-competitive research (but no product design, production, or sales) through cooperative R&D ventures. The law does not give carte-blanche to such ventures, but it excludes them from the treble-damage antitrust penalties, and presumes the ventures to be innocent of any anti-competitive actions unless proven guilty. (Under most antitrust laws, any cooperative actions by competitors are presumed to be anti-competitive unless the prove themselves innocent). To receive these protections, the cooperative R&D venture must register with the Department of Justice and the Federal Trade Commission and must abide by the restrictions on allowed activities. Promotion of joint research is intended to enhance the diffusion of new technologies within an industry and allow companies to better leverage their research funds. Federal support and participation in such ventures would allow government funds and technology transfer to benefit an industry sector rather than a single company.

Federal Technology Transfer Act of 1986

Enacted Oct. 20, 1986. Amended the Stevenson-Wydler Act, creating the Federal Laboratory Consortium for Technology Transfer, creating authority for GOCO labs to enter in to "cooperative agreements" with industry, which differ from standard procurement-type contracts in that personnel can be exchanged, and the GOCO
can accept money from an industrial partner, and explicitly making technology transfer a responsibility of all lab researchers. In addition, it made provisions for the distribution of license royalties -- some goes to the Treasury and some is retained at the lab, to provide royalty payment to the inventors and to support independent R&D.

Executive Order 12591: Facilitating Access to Science and Technology

Issued on April 10, 1987. Provides the basic Administration statement of principles for implementation of the pervious Acts, particularly emphasizing the waiver of patent rights to contractors, involvement of researchers in the labs in technology transfer activities, the exchange of personnel between labs and industry, and lab participation in industry research consortia.

Omnibus Trade and Competitiveness Act of 1988

Enacted Aug. 23, 1988. This Act contains numerous provisions that amend the Stevenson-Wydler Act, reorganize and rename the National Bureau of Standards as the National Institutes of Standards and Technology (NIST), establish new technology transfer activities at NIST and at universities, and strengthen certain types of patent protection. The changes that reorganize NBS int NIST are all intended to make NIST a more active player in enhancing U.S. manufacturing competitiveness, with numerous extension activities. One of the initiatives will create within NIST a program to screen and refer to other agencies inventions submitted by individuals and small businesses. The Act creates an "Advanced Technology Program" within NIST, which allows NIST to enter into cooperative agreements with businesses (especially small businesses) for the purpose of technology transfer. It also allows NIST to provide "minority share" financial assistance (for a limited period of time) to industry cooperative R&D ventures, if such assistance is necessary to get the venture going. If NIST provides support to a cooperative R&D venture, the Government is entitled to a share of the royalty stream returning to the venture in proportion to the Government's contribution to project costs. The program is to avoid "providing undue advantage to specific companies." The Act authorizes the creation, at not-for-profit institutions, of "centers" for the transfer of advanced manufacturing technology to industry, especially to small and medium-size businesses. The Act also strengthens some protections for process patents, by providing significant penalties for the importation or sale of products made overseas by a process that infringes on a U.S. patent, even if there are no overseas patents.
APPENDIX C

EVALUATION DATA SHEET

Project Title: Air Drilled Horizontal Wells

POC: Brooks Javins Phone: (304) 292-3344

Organization: Eastman-Christensen

Procurement Mechanism: Contract

Prime Contractor: SAIC
Gruy Federal
BDM
Columbia Natural Resources
Prime Energy
Cabot Corporation

Subcontractors: Eastman-Christensen

In what phase of the R&D process did DOE initiate funding?

Proof of concept/advanced development

Did research contribute to basic knowledge or provide product/service potential?

Service

Were any patents issued?

No. Research resulted in modification of existing tools.

Are there any licensing agreements based on these patents?

No

Were spin-off companies created from lab or contractor?

No

Technology Transfer Measure:

Quadrupled business for West Virginia office.
Do you agree with the DOE characterization of the technology?

DOE stimulated the market for directional air drilled wells but did not develop the technology.
PRODUCER: Eastman-Christensen

Do you provide the technology?

Yes

No

Was the technology originated by DOE?

Are better alternative technologies available?

Are similar technologies offered?

Is this due to external market factors?

Which is used more extensively?

Is this due to a cost factor?

What is the impact on sales?

Can you quantify results in dollars?

Eastman-Christensen was a subcontractor to several different companies involved in this research: SAIC, Gruy Federal, BDM, Columbia Natural Resources, Prime Energy, and Cabot Corporation. DOE was funding research for enhanced oil recovery (EOR) in Devonian Shale. Eastman-Christensen, through their own research and development, experimented with down-hole motors for other applications. DOE sponsored a market study to prove that high angle drilling produced more oil and is a faster and relatively cheap drilling method. As a result, modified motors were developed which greatly contributed to air drilling technology. These new tools provided through DOE market stimulation has quadrupled Eastman-Christensen’s business at its West Virginia operation. There are also spinoff applications to remedial cleanup of hazardous waste sites.
EVALUATION DATA SHEET

Project Title: Anelastic Strain Recovery Method for Measuring Stress in Oil and Gas Reservoirs

POC: Rod Boade Phone: (918) 661-9510
Robert Kuhlman (405) 251-3744
Lawrence Teufel (505) 844-8680
Sid Green (801) 584-2400

Organization: Phillips Petroleum
Halliburton Services
Sandia National Lab
Terra Tek

Procurement Mechanism: DOE funded research at Sandia

In what phase of the R&D process did DOE initiate funding?

Research funded advanced development of the technology.

Did research contribute to basic knowledge or provide product/service potential?

Product and Service

Were any patents issued?

Yes, the Government holds the patent.

Are there any licensing agreements based on these patents?

No

Were spin-off companies created from lab or contractor?

No
Do you agree with the DOE characterization of the technology?

The theoretical framework for ASR was written about as early as the mid-1960's. Researchers at Sandia developed better gages with which to monitor core strain. Research was also done on theoretical and physical models of relaxation cracking. They were issued a patent (4587739) dated May 1986. Papers were presented at the Society of Petroleum Engineers; an industry conferences was held at Core Labs; and a series of developmental test were conducted with several oil companies where they provided access to reservoirs, logistics, and coring operations. These activities generated interest in the technology and started the transition process. Once the technology was proven, oil producers and service companies developed their own systems for commercial applications. (Teufel)
Phillips Petroleum participated in the field tests of Anelastic Strain Recovery (ASR). They are currently using the DOE derived technology for in situ stress measurement. ASR is used to determine the compression characteristics of the reservoir rock and to improve hydraulic fracturing stimulation of the reservoir. Phillips primarily (95%) uses ASR in the North Sea Ekofisk field in conjunction with its European partners. Prior to ASR, in situ stress could only be measured in the vertical direction. ASR measures three-dimensions. Other technologies are available such as micro-fractures but ASR is the most effective by cost and accuracy of measurements.
PRODUCERS: Halliburton Services, Terra Tek

Do you provide the technology?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Are better alternative technologies available?</td>
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<tr>
<td>Are similar technologies offered?</td>
<td>Is this due to external market factors?</td>
</tr>
<tr>
<td>Which is used more extensively?</td>
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<tr>
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<td>What is the impact on sales?</td>
<td></td>
</tr>
<tr>
<td>Can you quantify results in dollars?</td>
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</table>

Halliburton developed their own ASR system based on DOE technology which they offer as commercial service. ASR is viewed as leading-edge technology and requires special training and experience. In 1985 they began development of their current ASR instrumentation. In 1990 they initiated another round of development to keep their competitive edge. ASR represents less than one percent of sales. It is basically offered as an ancillary service to hydraulic fracturing.

Terra Tek began its investigation of in situ stress measurement 15 years ago with Amoco. By the mid-1980’s the research was progressing well and Terra Tek expended substantial resources to develop their own instrumentation. Terra Tek offers ASR commercially for a $30,000-50,000 dollar fee. The advanced development research conducted by Sandia is viewed by Terra Tek as deleterious government intervention in the marketplace. The North Sea is the primary area for application of ASR and Sandia continues research efforts there. Terra Tek forecasts ASR to develop into only a $5-10 million dollar market.
EVALUATION DATA SHEET

Project Title: CO₂ Miscible Flooding for Oil Recovery

POC: Paul King Phone: (304) 422-6565
Royal Watts (304) 291-4218

Organization: Pennzoil
METC

Procurement Mechanism: Contract

Prime Contractor: Columbia Gas Transmission Corp.
Gulf Oil
Guyan Oil Company
Pennzoil Company
Shell Oil
Louisiana State University
New Mexico Institute of Mining and Technology

Duration: Seven separate actions 06/03/76 through 09/30/93.

Dollar Value:

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</table>

Subcontractors: None identified.

In what phase of the R&D process did DOE initiate funding?

Advanced development/field tests
Did research contribute to basic knowledge or provide product/service potential?

Service

Were any patents issued?

No

Are there any licensing agreements based on these patents?

No

Were spin-off companies created from lab or contractor?

No

Do you agree with the DOE characterization of the technology?

All of the field tests were technical successes. Only one of the seven continues to use CO₂ flooding for EOR.
In 1976 Pennzoil responded to a DOE RFP. Over ten years they delivered over 100 reports to METC. Albert Youst and Royal Watts were program managers. The pilot test conducted at Rock Creek Field, West Virginia, never developed into an economically viable EOR method. According to Royal Watts, the Bureau of Mines started funding CO$_2$ research in 1973. Industry had already started lab work in the 1950’s and the first field tests were in the late 1960’s. Of the field tests conducted, only the Week’s Island field continue CO$_2$ flooding. CO$_2$ Miscible Flooding can reduce residual oil from 25% to 3-4% in water flooded fields. Despite its technical success the cost of CO$_2$ makes its use economically prohibitive except in certain areas. The technology is currently confined to West Texas and eastern New Mexico.
EVALUATION DATA SHEET

Project Title: Atmospheric Fluidized Bed Coal Combustor

POC: Carl Bozzuto Phone: (203) 285-5824

Title: Research Laboratory Director

Procurement Mechanism: Contract

Prime Contractor: Combustion Engineering

Duration: Ten separate actions 01/01/76 through 04/30/92

Dollar Value:

<table>
<thead>
<tr>
<th>BIN</th>
<th>FE PORTION ($)</th>
<th>DESCRIPTION</th>
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</thead>
<tbody>
<tr>
<td>AC01-76ET10134</td>
<td>48,777</td>
<td>CLEAN FUEL FROM COAL PROCESS</td>
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<tr>
<td>AC01-76ET10204</td>
<td>17,414,068</td>
<td>DEVELOPMENT OF COAL GASIFICATION PROCESS</td>
</tr>
<tr>
<td>AC02-80CH10047</td>
<td>2,320,529</td>
<td>INDUSTRIAL FUEL GAS UTILITY DEMONSTRATION PROJECT</td>
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<td>AC22-82PC50271</td>
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<td>COMBUSTION AND FUEL CHARACTERIZATION OF COAL-WATER MIXTURE</td>
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<td>AC22-86PC90275</td>
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</tr>
</tbody>
</table>
Subcontractors: None identified.

In what phase of the R&D process did DOE initiate funding?

Combustion Engineering responded to a DOE Program Opportunity Notice (PON) for large boiler systems. They were selected to build a demonstration project at Great Lakes.

Did research contribute to basic knowledge or provide product/service potential?

Product

Were any patents issued?

Patents are held on aspects of bubbling bed technology.

Are there any licensing agreements based on these patents?

Yes

Were spin-off companies created from lab or contractor?

No

Do you agree with the DOE characterization of the technology?

The technology is offered but demand is very low.
Do you provide the technology?

<table>
<thead>
<tr>
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<th>No</th>
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</thead>
<tbody>
<tr>
<td>Was the technology originated by DOE?</td>
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<tr>
<td>Are similar technologies offered?</td>
<td>Is this due to external market factors?</td>
</tr>
<tr>
<td>Which is used more extensively?</td>
<td></td>
</tr>
</tbody>
</table>

Is this due to a cost factor?

What is the impact on sales?

Can you quantify results in dollars?

Combustion Engineering researched Fluidized Bed Combustors (FBC) but dropped its efforts in 1955 based on economics. The energy crisis renewed industry interest and DOE released a PON which Combustion Engineering was awarded. As a result, a demonstration facility was constructed at Great Lakes Naval Training Center. In 1979 a German company (Lurgi) was looking at other applications of similar technology it had developed for the aluminum industry. They approached EPRI, who went to TVA, and Combustion Engineering was tapped for a design study. Positive results led Combustion Engineering to pursue the technology. Lurgi (circulating bed) type systems were bought by TX/NM Power and TVA. The technology in these systems utilizes a portion of DOE derived technology. However, the plants today are very different from the Great Lakes facility. Combustion Engineering offers both the Lurgi (circulating bed) and Great Lakes (bubbling bed) plants. In a scenario where the utility and its A&E firm have decided on a FBC system a determining factor between the two is the size of the plant. Economies of scale are realized with the Lurgi technology as plant size increases. The Great Lakes technology is only competitive for smaller plants. Combustion Engineering holds patents for components of both systems. From 1984 to the present FBC's have generated approximately a billion dollars in revenues; 90% from Lurgi technology.

POC: Walt Campbell  Phone: (908) 730-4563

Procurement Mechanism: Contract

Prime Contractor: Foster Wheeler

Duration: Nine separate actions 01/01/76 through 02/12/92
Dollar Value:

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<td>AC05-78OR05642</td>
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<td>R&amp;D SERVICES FOR ATMOSPHERIC FBC/COMPONENT TEST &amp; INTEGRATION UNIT</td>
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<tr>
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<tr>
<td>AC22-83PC60049</td>
<td>319,208</td>
<td>EVALUATING ROTATING DISC CONTRACTOR FOR DEASHING</td>
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<tr>
<td>AC22-83PC60049</td>
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<td>INTEGRATED SUPERFINE COAL COMBUSTION SYSTEM (ISCOS) FOR CONVERTING OIL-FIRED STEAM GENERATION TO COAL FIRING</td>
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<td>AC01-76ET10322</td>
<td>-103,747</td>
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<tr>
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<td>ENGINEERING TECHNICAL SUPPORT SERVICES</td>
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<tr>
<td>AC21-86MC21023</td>
<td>22,609,119</td>
<td>PRESSURIZED FBC--SECOND GENERATION SYSTEMS</td>
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</table>

Foster Wheeler supplied the boilers for the Georgetown University facility. The bubbling bed FBC technology commercially available is a combination of DOE funded R&D and their own research. Approximately 46 of these systems have been sold. They are no longer in demand and orders have decreased. Circulating bed boilers are replacing this technology. A 250 MW facility under development for the city of Tallahassee, Florida will be supplied circulating FBC’s by Foster Wheeler.
EVALUATION DATA SHEET

Project Title: Tailored Pulse Fracturing of Oil and Gas Wells

POC: Henry Mohaupt Phone: (805) 967-0196

Title: President, Servo Dynamics

Procurement Mechanism: Research funded at Sandia National Lab

Subcontractors: None identified.

In what phase of the R&D process did DOE initiate funding?

Advanced development/field tests.

Did research contribute to basic knowledge or provide product/service potential?

Service

Were any patents issued?

A patent on the technology was already issued to Mr Mohaupt when DOE became involved.

Are there any licensing agreements based on these patents?

No

Were spin-off companies created from lab or contractor?

No

Do you agree with the DOE characterization of the technology?

Yes, the technology is used extensively.
The concept was developed in 1956 by Mr Mohaupt. A patent was issued for the use of a rapid ignition propellant contained in a pressurized container for reservoir fracturing. In the mid-80's DOE funded a parametric investigation of this technology at Sandia Labs. They were trying to determine the rate of pressure buildup in small diameter holes necessary for fractures with the required orientation. Tailored Pulse Fracturing is the foremost of extracting oil and gas. Servo Dynamics is being approached by companies all over the world and currently have contracts with Shell, Mobil, Meridian, Oryx, and Texaco. This technology is representative of a range of EOR procedures whose use is determined by the particular problem to be solved. Tailored Pulse Fracturing increases oil production by 7-28 barrels/day.
EVALUATION DATA SHEET

Project Title: Phosphoric Acid Fuel Cell Power Plants

POC: Gregory Sandelli Phone: (203) 727-2348
     William Podolny (203) 727-2220

Title: Program Manager
       Chairman

Procurement Mechanism: Contract

Prime Contractor: International Fuel Cells Corp

Duration: Seven separate actions 09/27/79 through 03/17/94

Dollar Value:

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<td>AC21-88MC24221</td>
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Subcontractors:

None identified.

In what phase of the R&D process did DOE initiate funding?

DOE funded a significant program through the 70’s and 80’s with GRI and EPRI. DOE effort concentrated in technology development and demonstration; GRI in applications.

Did research contribute to basic knowledge or provide product/service potential?

Product

Were any patents issued?

Yes.

Are there any licensing agreements based on these patents?

Toshiba has licensed technology.

Were spin-off companies created from lab or contractor?

The charter of IFC dedicates the company solely to fuel cell commercialization. Subsidiary of United Technologies and Toshiba. IFC is the only company in the US licensed to provide fuel cell power plant technology commercially; includes warranties.

Do you agree with the DOE characterization of the technology?

Accurate statement. Orders for more than 60 200 kW power plants received.
PRODUCERS: IFC

Do you provide the technology?

Yes

Was the technology originated by DOE? Are better alternative technologies available?

Are similar technologies offered? Is this due to external market factors?

Which is used more extensively?

Is this due to a cost factor?
What is the impact on sales?
Can you quantify results in dollars?

No

The technology provided "definitely" incorporates the result of DOE funded research. Fuel cell technology originated in space program research for NASA. United Technologies United Technologies realized potential commercial applications and approached ERDA. Single technology being offered. Gas utilities are the driving force as owners and operators. Revenues for last year was $50 million. In general about 50% of revenues are generated through Government sources (NASA purchase of Orbiter fuel cells, DOD special applications, 10% DOE funding) and 50% are commercial revenues (demonstration power plants). DOE definition of commercial readiness/technical success is much too soon in the technology transfer process. By pulling out early, companies are forced to seek venture capital wherever it’s available to complete a substantial portion of the process. This leads to technology transfer not from government to industry, but US to foreign countries. Toshiba has a minority interest in IFC and Japanese are supporting commercial demonstration. (Sandelli)

Fuel cell research programs existed at GE, United Technologies, and Union Carbide. Applications were primarily for aerospace (manned space) and submarine technology. No previous Government support in research before space program fuel cell (alkaline systems) competition for manned space flight. Government did not become involved in stationary fossil fuel power plant concepts until the energy shocks of the mid-70’s. United Technologies and gas utilities developed a 1 MW and 40 kW facility. Government was approached after private sector investment of 150-175 million with technical feasibility achieved. DOE supported operational feasibility research but did not pursue economic viability. DOE funded the fuel cell element not the power plant concept.

5 MW plant - pure sale to Japan (TEPCO), firm fixed price
11 MW plant - IFC licensed technology to Toshiba
200 kW plant - 62 orders
The 5 MW plant started as a joint UTC, EPRI, and Government program. Consolidated Edison was the host utility. The sale to the Japanese was accomplished after the program was judged a failure. These machines represent approximately 300 patents. In each machine about 25-27 are essential; 10-15% of which are a result of DOE R&D investment. Since 1984, when United Technologies and Toshiba signed an agreement creating IFC, Toshiba has invested $100 million, $35 million from overseas customers, and government support has been minimal. According to Ward’s Business Directory IFC’s 1990 sales were $50 million. Phosphoric acid fuel cell technology accounted for 35-40% of total sales. The Government’s funding of Westinghouse fuel cell technology was raised as a concern. (Podolny)
EVALUATION DATA SHEET

Project Title: New Polymers for Enhanced Oil Recovery

POC: Dr. Charles McCormick Phone: (601) 266-4872
     Dr. Jim Davitt Phone: (214) 470-1344

Title: Principal Investigator
       Oryx Oil Company

Procurement Mechanism: Contract

Prime Contractor: University of Southern Mississippi

Duration: 09/17/85 through 01/17/89

Dollar Value:

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<tr>
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<td>ASSOCIATIVE POLYMERS FOR MOBILITY CONTROL IN EOR</td>
</tr>
</tbody>
</table>

Subcontractors: None identified.

In what phase of the R&D process did DOE initiate funding?

USM responded to a proposal request from DOE to do synthesis work for brine tolerant polymers.

Did research contribute to basic knowledge or provide product/service potential?

Product

Were any patents issued?


Are there any licensing agreements based on these patents?

Oryx has licensed the technology.
Were spin-off companies created from lab or contractor?

No

Do you agree with the DOE characterization of the technology?

USM licensed the technology to Oryx for development but they are not aware of its current status.
**PRODUCERS:** Oryx

Do you provide the technology?

<table>
<thead>
<tr>
<th>Yes</th>
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<tbody>
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<tr>
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<td></td>
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<tr>
<td>Can you quantify results in dollars?</td>
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</tbody>
</table>

Sun Oil had a licensing agreement with USM for the development of the polymer AMB. USM conducted research in the synthesis of AMB and its characterization in brine. Prior to the creation of Oryx, Sun Oil expended approximately a million dollars on developmental flow experiments in porous media and core flood experiments. Modification of AMB to increase its ability to propagate resulted in the loss of some of its desirable characteristics. AMB is still in the lab. Oryx is working with a chemical company to assess AMB and other polymers’ commercial feasibility. The current economics of production, high cost of polymer and low price for oil, places polymer EOR low on the Oryx priority list.
EVALUATION DATA SHEET

Project Title: Steam/Foam Flooding for Heavy Oil Recovery

POC: Louis Castanier Phone: (415) 723-2223
Lyle Henderson (713) 241-5260

Title: Director SUPRI
Shell Oil

Procurement Mechanism: Contracts and grants

Prime Contractor: Stanford University (SUPRI)

Duration: Six separate actions 09/29/80 through 02/22/93

Dollar Value:

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<td>AC03-81SF11564</td>
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<td>RESEARCH IN HEAVY OIL RECOVERY</td>
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<tr>
<td>AC21-85MC22042</td>
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<td>RESERVOIR CHARACTERIZATION FOR THE CO2 EOR PROCESS</td>
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<td>FG22-87BC14126</td>
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<td>OIL RECOVERY MECHANISMS IN HEAVY OIL RESERVOIRS</td>
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<tr>
<td>FG21-89MC26253</td>
<td>486,082</td>
<td>SCALE-UP OF MISCELLY FLOOD PROCESSES</td>
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<tr>
<td>FG22-90BC14600</td>
<td>1,490,000</td>
<td>OIL RECOVERY MECHANISMS IN HEAVY OIL</td>
</tr>
</tbody>
</table>

Subcontractors:

Field test of the technology was done under contract AC03-80F11445. Two subcontractors were competitively awarded to the Chemical Oil Recovery Company (CORCO) and Petro Lewis. CORCO conducted the field tests and Petro Lewis provided the field site.
In what phase of the R&D process did DOE initiate funding?

DOE funded proof-of-concept/demonstration.

Did research contribute to basic knowledge or provide product/service potential?

Primarily a service with spillover contributions to chemical companies.

Were any patents issued?

No

Were spin-off companies created from lab or contractor?

No

Do you agree with the DOE characterization of the technology?

Additional oil recovery of 10-15% is a reasonable average.

Foam technology research started in the late 1950s for gas applications. In 1976 SUPRI was founded to replace the Bureau of Mines' Heavy Oil Lab. In the late 1970s interest was revived in the technology and a surfactant (petroleum sulfonate) that could withstand steam temperatures were investigated. The process was proven in field-tests and is currently used commercially by major heavy oil producers (Shell, Phillips, Mobil, Chevron). Steam/foam Flooding is also used in Canada, Europe, and Venezuela. Alternatives are available but this is the most cost effective and efficient procedure. (Castanier)
Do you use the technology?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

Is it DOE’s technology?

<table>
<thead>
<tr>
<th>Are better alternative technologies available?</th>
</tr>
</thead>
</table>

How extensively is it used?

<table>
<thead>
<tr>
<th>Is this due to external market factors?</th>
</tr>
</thead>
</table>

Is this due to a cost factor?

How does it affect productivity?

How effective is it?

What is the impact on sales?

Can you quantify results in dollars?

Shell Oil is not using this technology. In the mid-1970s Shell began its own research efforts for a steam EOR agents. Field tests were done at Kern River using the drive process. The process was subsequently patented. Process worked technically and oil recovery predictive models were developed. Shell Oil decided in 1986 not to install the process in any major project. Oil price levels are too low to make it economically viable. The major expense of the process is the surfactant (petroleum sulfonate). Additional oil recovery is 10% over and above steam process. (Henderson)
EVALUATION DATA SHEET

Project Title: "Super 9 Chrome"

POC: Dominique Sanonico Phone: (203) 285-5824
Eugene Hoffman FTS 626-0735
Dr Vinod Sikka (615) 574-5112

Organization: Combustion Engineering
ORNL

Procurement Mechanism: Contract

Prime Contractor: Combustion Engineering Inc. (ORNL)

Duration: Ten separate actions 01/01/76 through 04/30/92

Dollar Value:

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<tr>
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<td>8,516,764</td>
<td>COMBUSTION AND FUEL CHARACTERIZATION OF COAL-WATER MIXTURE</td>
</tr>
</tbody>
</table>
Subcontractors: None identified.

In what phase of the R&D process did DOE initiate funding?

DOE supported initial program to develop a modified 9Cr-1Mo steel. Of the approximately $8 million dollars, roughly $200,000 was contributed by FE.

Did research contribute to basic knowledge or provide product/service potential?

Product

Were any patents issued?

No patents issued. Patent counsel determined technology was not patentable.

Were spin-off companies created from lab or contractor?

No

Do you agree with the DOE characterization of the technology?

Yes. DOE provided the lion share of the money, T91 evolved form DOE concept, and DOE achieved ASME approval. (Sanonico)
PRODUCERS: Vallourec Industries (France)

Do you provide the technology?

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The idea to apply this technology to fossil fuel combustion systems originated at ORNL. Because the research was for a nuclear program information on T91 was prohibited from public release. However, if its use in conventional plants could be established then it could be released. FE leveraged a multi-million dollar research effort with $200,000 for the purchase of the first commercial size heats. A technology transfer conference held in Knoxville, TN with U.S. companies only resulted in a negative industry response. The response of foreign companies (Japan and France) was much more favorable and they pursued the technology with their own funds. Today foreign companies such as Vallourec Industries dominate the T91 market.
BIBLIOGRAPHY


