OFFICE OF NATURAL GAS AND
PETROLEUM TECHNOLOGY

OIL AND GAS R&D PROGRAMS

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Securing the
U.S. Energy,
Environmental
and Economic
Future

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Department of Energy
Washington, DC 20585

To Our Readers:

The United States is dependent on oil and gas for approximately 65 percent of the energy it consumes. The Energy Information Administration 1997 *Annual Energy Outlook* projects increasing demand for oil and gas to 2015, and others forecast continuing dependence on these energy sources well into the next century. In recognition of these forecasts, the broad goal of the Department of Energy's Natural Gas and Petroleum Technology Program, located in the Office of Fossil Energy, is to ensure that reliable, competitively priced oil and gas supplies are available to support a strong U.S. economy while protecting the environment and providing energy security through the 21st century.

The Department is actively engaged in reevaluating and directing its oil and gas research and development (R&D) programs with the objective of clearly defining the Department's goals, including environmental, energy security, and economic benefits. At the same time, the Department recognizes that budgets are being tightened, and public and private implementation resources are being reduced. We are attempting to recognize and respond to stakeholder recommendations provided by: the National Petroleum Council studies, *RD&D Needs of the Oil and Gas Industry* and *Future Issues — A View of U.S. Oil and Natural Gas to 2020;* the Petroleum Technology Transfer Council report *Technology and Related Needs of U.S. Oil and Natural Gas Producers*; the report of the Yergin Task Force on Strategic Energy Research and Development; and relevant information from other sources.

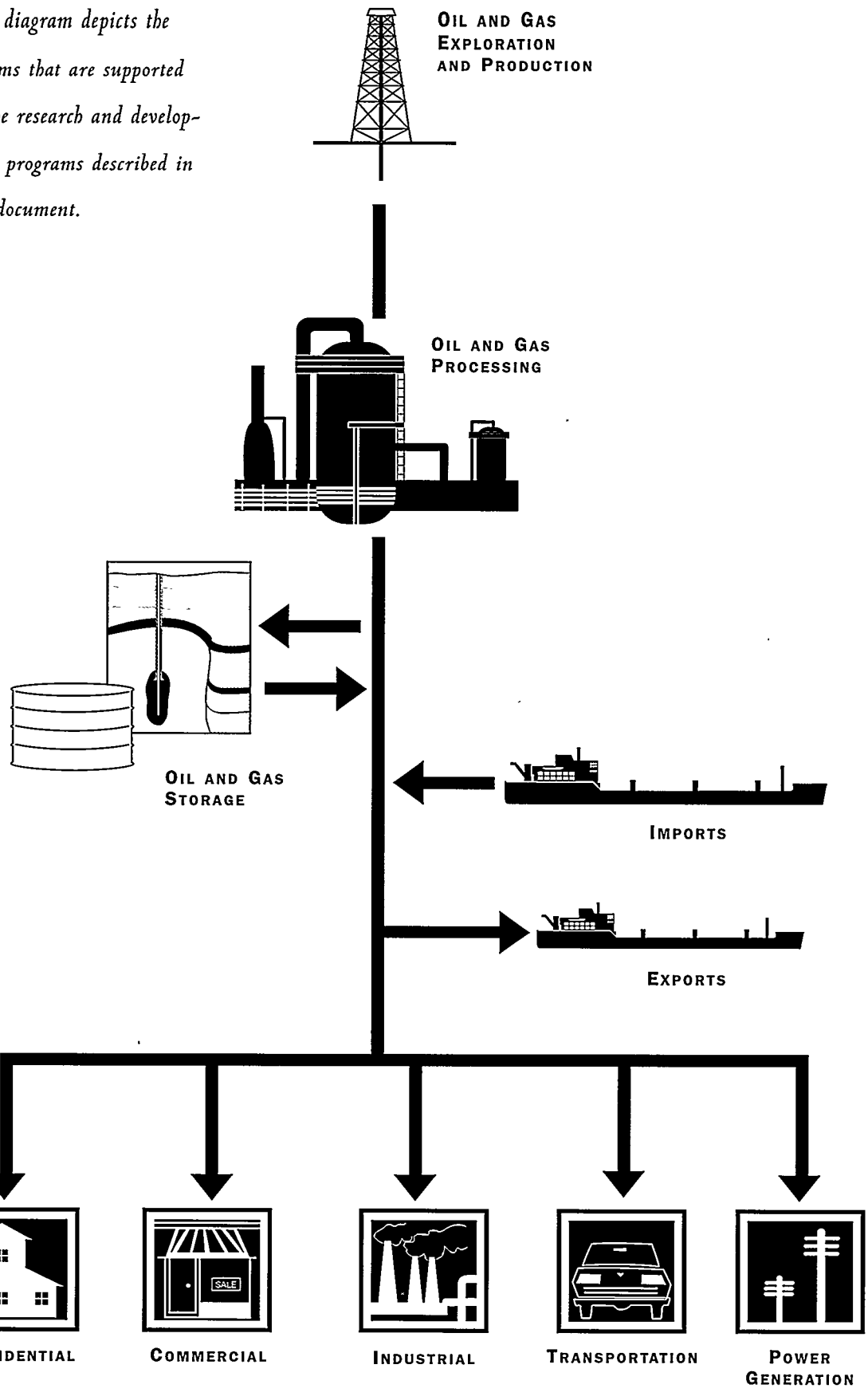
This document is intended to provide a user friendly, single source which describes the major components of the Office of Natural Gas and Petroleum Technology programs. Included are: (1) Long-Term Program Rationale; (2) eight technology program plans: Advanced Drilling, Completion & Stimulation Systems, Advanced Diagnostics and Imaging Systems, Reservoir Life Extension, Gas Storage, Gas Processing, Oil Processing, Oil and Gas Environmental Research and Analysis, and Oil and Gas Modeling and Analysis; and (3) Coordinated Strategic Plan for the Oil, Natural Gas, and Related Environmental Technology RD&D Programs.

We invite your comments or questions regarding this report or the programs described therein. A list of people to contact for information about the programs is provided on the inside back cover of this report.

Sandra L. Waisley

Sandra L. Waisley
Acting Deputy Assistant Secretary
for Natural Gas and
Petroleum Technology
Office of Fossil Energy

This diagram depicts the systems that are supported by the research and development programs described in this document.



Introduction

This publication describes the major components of the research and development programs of the Department of Energy's Office of Natural Gas and Petroleum Technology. These programs are commonly referred to collectively as the "Oil and Gas Program." This document provides customers with a single source of information describing the details of the individual technology program components.

This document reflects the results of a planning cycle that began in early 1996 with the development of a scenario analysis for the programs, followed by the development of the coordinated strategic plan.

The technology program plans, which are the most recent products of the planning cycle, expand on the program descriptions presented in the coordinated strategic plan, and represent an initial effort to coordinate the Oil and Gas Program exploration and production programs and budgets. Each technology program plan includes a "roadmap" that summarizes the progress of the program to the present and indicates its future direction. The roadmaps describe the program drivers, vision, mission, strategies, and measures of success.

Both the individual technology program plans and the strategic plan are dynamic and are intended to be updated regularly.

Overview: DOE's Oil and Natural Gas RD&D Programs

ISSUES & DRIVERS

National Issues and Drivers

A secure supply of reasonably priced energy is a prerequisite to U.S. strength in the global marketplace.

Oil and gas account for two-thirds of total U.S. energy consumption, and 97% of transportation fuels.

- **Consumption will continue to increase despite energy efficiency improvements.**

Growing energy demand will increase U.S. dependence on petroleum imports.

- **Imports currently account for 54% of crude oil supply, and are projected to climb to 68% in 2015.**
- **Imported crude is the largest factor in negative U.S. trade balance.**
- **Concentration of oil supplies in politically unstable regions poses a national security threat.**

Development of advanced oil and gas technologies is essential to efficiently maximize the production of domestic resources while preserving our environment.

- **Advanced technologies are required to slow the decrease in domestic exploration and production of oil and gas, to enable the processing and use of lower quality domestic crude, and to enhance the production and deliverability of natural gas.**

The U.S. is a mature oil-producing region; domestic production is more difficult and more costly than overseas production.

- **While an estimated two-thirds of all U.S. oil remains in the ground, much of it is located in deep, complex reservoirs or environmentally sensitive areas.**
- **High costs of operations and environmental compliance place U.S. producers at a competitive disadvantage with foreign producers.**

Global competition is causing the oil and gas industry to sharply curtail basic and applied RD&D.

- **Industry RD&D spending fell 22% from 1994 to 1996.**
- **Expenditures are shifting toward near-term product and technical services.**
- **The Federal government has also cut oil and gas RD&D funding (by 31% from 1995 to 1997).**

In turn, these advanced technologies are critical to sustaining high paying industry jobs and continued global leadership in technology.

- **The industry employs over 300,000 directly and supports as many as a million more throughout the economy.**
- **U.S. exports account for 40% of the world's petroleum equipment and services and thousands of jobs.**

ROLES

Federal Roles and Responsibilities

- **Ensuring reliable energy supplies at reasonable costs**
- **Providing strategic guidance for national energy policy**
- **Supporting efficient and sustainable use of domestic energy resources**
- **Protection of the environment and public safety**
- **Enhancing the value of Federal lands**
- **Enhancing global market opportunities for U.S. energy technologies**
- **Contributing to U.S. science and technology leadership**
- **Applying a unique national perspective to technology development that is independent of company-specific or State-specific interests.**

DOE's Roles in Oil and Gas RD&D

To support national goals:

- **Enhance the efficiency and environmental quality of domestic oil and natural gas exploration, recovery, processing, transport, and storage operations.**
- **Focus on high risk technology that private companies alone won't undertake.**
- **Provide scientific and technological information and analysis to assist policymakers in their decision making.**
- **Contribute to science based improvements in regulations to reduce uncertainties and costs while achieving optimal environmental protection.**

PROGRAMS

Oil and Gas Programs

Advanced Drilling, Completion & Stimulation Systems

- To increase recovery through wellbore improvement

Advanced Diagnostics and Imaging Systems

- To find and exploit new resources through resource- and reserve-base expansion

Reservoir Life Extension

- To extend the life of domestic energy resources and reduce well abandonments

Gas Storage

- To improve natural gas storage and retrieval for peak usage

Gas Processing

- To increase refinery efficiencies
- To reduce environmental emissions
- To bring remote gas to market

Oil Processing

- To improve refining efficiencies
- To advance technologies for refining lower quality crude

Oil and Gas Environmental Research and Analysis

- To minimize any potential environmental damage from oil and gas operations
- To improve understanding/industry cooperation in environmental compliance

Oil and Gas Modeling and Analysis

- To estimate potential economic recovery of domestic oil and gas over range of technologies, economic criteria, and legislative and regulatory environments

Benefits

Already realized:

- Gas production up 14% with 50% reduction in wellhead prices over the last decade, and with fewer well completions (1985 - 14,250 vs. 1994 - 9,000)
- Success rates of exploratory oil and gas wells up from 30 to 38% since the 1980s, with substantial cost reductions.

Potential by 2010:

- 3.7 billion barrels of additional oil reserves and 55.6 trillion cubic feet of gas
- $28.8 billion in Federal revenues and $41.7 billion in State revenues
- $16 billion savings in environmental costs (produced water, remediation, and air emissions control)
- 16 million tons of carbon dioxide reduced and 1,250 tons of ammonia; and a 2.5 percent reduction in coke

Partnership Approach

- R&D is conducted in partnership with universities, State and local governments, industry, and other stakeholders.
- DOE programs combine the R&D resources of government and industry, including the unique strengths of the National Laboratories.
- In cooperation with industry and other partners, DOE supports R&D of promising technologies in priority areas identified by the domestic oil and gas industry.
- Results are transferred through cooperative efforts of DOE and State and industry organizations, including the PTTC.

DOE's RD&D . . . an Essential Foundation for U.S. Economic Strength

DOE's RD&D catalyzes and supports domestic oil and gas production. In turn, this supports the reliability and affordability of energy supplies and the stability of energy markets, providing an essential foundation for U.S. economic strength in the global economy. By offsetting some increased oil imports, domestic production also enhances U.S. energy security and contributes positively to the U.S. balance of trade.

The Natural Gas and Petroleum Technology Program focuses on eight areas:

- Advanced Drilling, Completion & Stimulation Systems
- Advanced Diagnostics and Imaging Systems
- Reservoir Life Extension
- Gas Storage
- Gas Processing
- Oil Processing
- Oil and Gas Environmental Research and Analysis
- Oil and Gas Modeling and Analysis

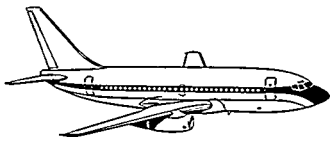
Natural Gas and Petroleum RD&D Program: Long-Term Rationale

The Natural Gas and Petroleum Technology Program (Oil and Gas Program) has one overriding goal: to ensure that competitively priced oil and gas supplies are available to support a strong U.S. economy. In pursuing energy security, DOE does not have a direct role in finding and producing hydrocarbons, but rather supports the development and transfer of technology to domestic operators and the service industry. DOE also provides scientific information and analysis to assist policymakers with decisions affecting domestic oil and gas resources.

The program's research, development, and deployment (RD&D) efforts focus on enhancing the efficiency and environmental quality of domestic oil and natural gas exploration, recovery, processing, transport, and storage operations. Improved technology and information are required to boost production of natural gas, a clean and abundant domestic fossil fuel that is an increasingly important component of our Nation's energy portfolio, and to extend the life of domestic oil reservoirs.

Even though remaining U.S. oil and gas reserves are substantial, they are becoming more difficult and expensive to discover and produce. Past technology has recovered only an estimated one-third of the oil in place, leaving two-thirds of the U.S. oil resource base — about 350 billion barrels — still in the ground. Yet high operating costs are resulting in the abandonment of more than 16,000 U.S. wells each year; and, with the rising costs of environmental compliance, U.S. oil and gas producers and processors can face competitive disadvantages relative to operators in other areas of the world. These competitive disadvantages contribute to the fact that many major companies are concentrating their new exploration, production, and processing investments overseas.

By reducing the costs of domestic oil and gas production, advanced technologies can help to maintain reliable domestic supplies of these vital fuels at competitive prices — a goal of strategic importance to our Nation.



In the United States, we depend on oil and gas for about 65 percent of all the energy we consume, and for 97 percent of energy in the transportation sector. Many forecasters predict that this high dependency will continue well into the next century.

Federal government role

Economical energy is a prerequisite to U.S. strength in the global marketplace, enabling our industries to compete effectively and generate export-related jobs. Domestic production of oil and gas helps to stabilize energy markets, and also slows our Nation's need for imports, which currently account for 54 percent of U.S. crude oil supply. According to projections by the Energy Information Administration (EIA), the share of imports could rise to 68 percent in 2015.

Because reliable domestic energy supplies are vital to our economy, the Department of Energy conducts a range of programs designed to enhance the efficiency and environmental quality of domestic oil and natural gas exploration, recovery, processing, transport, and storage operations. These R&D programs are conducted in partnership with universities, State and local governments, industry, and other stakeholders.

In cooperation with industry and other partners, DOE supports research and development of promising new technologies in areas identified as priorities by the domestic oil and gas industry. DOE programs combine the R&D resources of government and industry, including the unique strengths of the National Laboratories, which focus on technology developments where long-term payoffs are likely to prevent private companies from investing adequately on their own. By providing science based information and analysis for legislative and regulatory decision making, DOE programs contribute to policies that encourage increased domestic supplies of oil and gas.

The Federal government is responsible for ensuring that U.S. natural resources are used to the maximum benefit of the public. There are three bases for the Federal role: responsibility, unique capabilities that only the Federal government can provide, and consumer dependence on government, as described below.

The Federal government has a responsibility to:

- **Ensure efficient and sustainable use of domestic natural resources**
- **Enhance the value of Federal lands**
- **Conduct strategic energy R&D**
- **Implement legislative and regulatory requirements**

Therefore, the Federal government must develop technology to:

- **Increase cost effective recovery of domestic oil and gas**
- **Improve recovery from geologically complex, deeper reservoirs**
- **Develop long-term research projects**
- **Cost effectively meet environmental regulatory compliance standards**

Private industry depends on the Federal government to:

- **Serve as a catalyst for Federal, State, and industry partnerships**
- **Enhance global market opportunities for U.S. energy technologies**
- **Provide national energy policy and strategic guidance**
- **Contribute to domestic science and technology leadership**

Therefore, the Federal government must develop technology and methodologies to:

- **Provide incentives to increase oil and gas exploration, production, and processing**
- **Demonstrate promising, but still unproven, energy supply technologies**
- **Extend the life of domestic energy resources and reduce well abandonments**

Energy consumers depend on the Federal government for:

- **Reliable energy supplies at reasonable costs (energy security)**
- **Protection of the environment and public safety**
- **Efficient production of energy resources, especially on Federal lands**
- **Market stability**

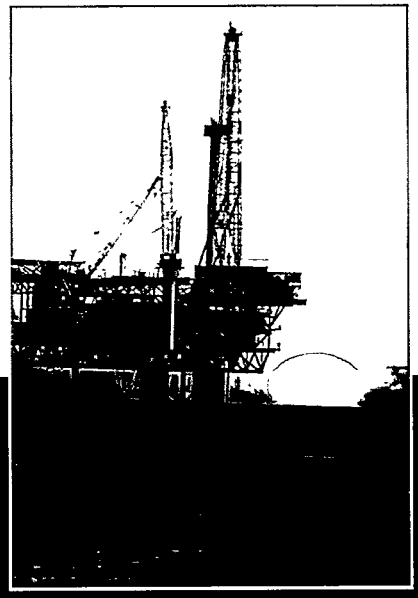
Therefore, the Federal government must develop technologies to:

- **Provide safe, stable, and affordable energy supplies**
- **Cost effectively move fuel supplies to consumer markets**
- **Support oil and gas exploration and production technologies in environmentally sensitive areas**
- **Ensure U.S. leadership in science and technology**

IMPACT OF TECHNOLOGY

Historical data demonstrate that technology advances are key to keeping energy prices low for consumers and to maintaining the profitability and long-term survival of the domestic oil and gas industry. Since the 1980s, because of 3-D seismic, advanced drilling systems, and fracturing technologies, our Nation has seen a 14 percent increase in its gas production, despite a 50 percent decline in wellhead prices. Higher gas production in 1994 was achieved with fewer than 9,000 well completions, as compared to 14,250 completions in 1985. Further, success rates of exploratory oil and gas wells have increased from 29 percent to 38 percent since the 1980s, while costs have substantially decreased.

In the future, technology advances can further the trend toward more cost effective recovery of domestic oil and gas, particularly from geologically complex, deeper reservoirs. Such advances will equip domestic producers to continue exploring for and recovering oil and gas from reservoirs that would otherwise be economically unviable. Other new technologies can enable processors to continue refining oil domestically while complying with environmental requirements, and can support pipeline companies in cost effectively moving fuel supplies to consumer markets.



The oil and gas industry employs over 300,000 people in the U.S., and its expenditures support as many as one million additional jobs. Oil and gas production activities contributed nearly $70 billion to the domestic economy in 1994. U.S. companies export about 40 percent of the world's petroleum equipment and services, achieving sales of $4.3 billion in 1995.

R&D CRISIS

The Energy Information Administration's 1997 forecast shows increased domestic gas production and a slight decrease in annual domestic oil production for the period 1997 to 2015. This forecast can be realized only if the assumed technology development and deployment increases are achieved.

Yet the Nation's historical dominance in developing and using oil and gas technologies may be lost as industry reduces its funding for long-term R&D activities. In the last three years alone, major oil and gas companies have reduced overall R&D spending by 22 percent. Today, of the approximately $1.5 billion invested annually for exploration and production R&D by these companies, only $450 million is allocated to basic and applied R&D. The remainder is spent for near-term product development and technical services, areas where major companies have focused efforts to solve today's operational problems. Longer-term research has been curtailed, reflecting the inability of the companies to capture economic benefits of such investments and their targeting of "next quarter" financials.

Furthermore, the 8,000 independent producers, which drill 85 percent of the wells and produce 66 percent of the gas and almost 50 percent of the oil in the lower-48 States, conduct no R&D of any type. The independents lack the capital to conduct R&D or to assume the risks of trying advanced, but unproven, technologies.

In total, the oil and gas industry appears to be following the Low Technological Progress Case as outlined in EIA's Annual Energy Outlook 1997 (AE097) projections. In comparison to the Reference Case, gas prices in 2015 are forecast to be 30 percent higher in this case and economically recoverable oil and gas resources in the lower-48 States are forecast to be 26 and 16 percent lower, respectively.

Compounding the crisis in private R&D investment, Federal government R&D has been declining significantly in the past two years. In the oil and gas supply and processing R&D area specifically, R&D spending was reduced by 31 percent in the period from 1995 to 1997.

DOE'S OIL AND GAS PROGRAMS

At $70 million, DOE's 1997 oil and gas R&D budget is about 16 percent the size of the $450 million invested annually by the oil and gas industry for basic and applied R&D. Although its programs represent a relatively small percentage of the total R&D, DOE brings a unique national perspective to technology development that is independent of company-specific or State-specific interests. The DOE programs pursue a balanced portfolio of technologies and reflect the shift of production sources through time.

The DOE program uses EIA technology assumptions, translating them into a portfolio of technology projects that will contribute to product volumes forecast by EIA models. For example, in partnership with industry, DOE is conducting R&D to develop technologies required for increasing gas production from more difficult formations. Increased production from these formations — including onshore deep gas reservoirs (greater than 15,000 feet), offshore Gulf of Mexico, and remote North Slope of Alaska — will be essential in satisfying the 30 percent increase in gas demand forecast for 2015. Gas supply from offshore Gulf wells will contribute significantly after 2005. Accordingly, industry and government will target R&D on technologies aimed at improving recovery efficiency and lowering costs from deeper and more complex reservoirs while increasing economic recovery from conventional reservoirs.

Areas of emphasis for the DOE oil and gas R&D program are:

- Resource- and reserve-base expansion to find and exploit new resources
- Recovery technologies to increase recovery from known oil and gas resources
- Reservoir characterization and modeling to define reservoirs and characterize their potential
- Drilling, completion, and stimulation to increase recovery through wellbore improvement
- Processing to reduce environmental emissions, to increase refinery efficiencies, and to bring remote gas to market
- Environmental technology to minimize any potential environmental damage through oil and gas operations and to improve general understanding and industry cooperation in environmental compliance
- Gas storage to improve natural gas storage and retrieval for peak usage

Each of these program areas is designed to reduce risks and costs, improve efficiencies, and protect the environment while contributing to the overall goal of maximizing production.

PAYOFFS FROM DOE'S INVESTMENT IN R&D PROGRAMS

Metrics that quantify the benefits of DOE's oil and gas R&D programs have been developed through modeling and analysis, and indicate that the impacts of these programs are substantial. For example, by 2010, potential benefits to our Nation include:

- 3.7 billion barrels of additional oil reserves and 55.6 trillion cubic feet (Tcf) of gas
- $20.8 billion in Federal revenues and $8.4 billion in State and local revenues
- $29.2 billion in public sector revenues
- Savings of $16 billion in environmental costs (produced water, remediation, and air emissions control)
- Pollution reduction of 16 million tons of carbon dioxide and 1,250 tons of ammonia; and 2.5 percent coke reduction

DOE's oil and gas R&D programs have already shown a significant return on the taxpayer's investment. For example, DOE has received favorable reactions from industry to the polycrystalline drill bit developed in the 1980s, and the Reservoir Class Demonstration Program implemented in the 1990s. Total DOE investment in the Class Program, which consists of three classes of reservoirs containing 32 projects and 102 participants, was $115 million, of which $1.8 million was used for the Inland Resources project. The return from the Inland Resources project alone will be $160 million in Federal royalties and taxes — larger than the entire cost of the Class Program. Because the project covers only 13 percent of the area, widespread application of demonstrated technology could double or triple the reserves in the area, resulting in about $500 million in Federal revenues.

DOE has also received favorable responses from industry to its coalbed methane reservoir R&D from the 1980s. This resource shifted from the nonconventional category to conventional by the 1990s. Reserves have doubled since 1990 to 10 Tcf. The combined DOE-Gas Research Institute investment totaled $100 million, but industry revenues are now $150 million per year. After six years, the Secondary Gas Recovery Program has also covered DOE's investment of $11 million. The actual value of this R&D, based on trends of production in 1993 and 1994, could reach hundreds of millions of dollars in revenues.

As an alternative to requiring an Area of Review (AOR) for each well, as required by current Safe Drinking Water Act regulations, DOE is working with the Underground Injection Practices Research Foundation and agencies in more than a dozen States to develop AOR variance systems for an entire region. This approach is expected to relieve the burden of regulatory compliance where appropriate, while maintaining environmental protection. As a result of the use of the AOR variance methodology in a single East Texas field, the Texas Railroad Commission approved a variance for the field, saving the industry an estimated $86 million. Program partners and performers are working with agencies in oil-producing States to develop similar AOR variance systems. DOE estimates that exemption from maximum AOR costs for pre-1982 wells in all States could save the industry $340 million; variances for newly drilled wells could save more than $200 million.

PROGRAM PLANS

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ADVANCED DRILLING, COMPLETION, AND STIMULATION TECHNIQUES CAN HELP UNLOCK DOMESTIC OIL AND GAS RESOURCES

Of the entire exploration and production effort, drilling is the moment of truth for oil and gas producers. Drilling tests the validity of geological, geophysical, engineering, and mechanical theories on the existence of new oil and gas reservoirs and demonstrates whether subsurface analyses have, in fact, succeeded in pinpointing productive pay zones. Sizable investments ride on the results.

Risks have always been inherent in drilling for oil and gas. Today, those risks are becoming increasingly high for producers in the U.S. Much of our remaining oil and gas is locked away in geologically complex formations that necessitate deeper drilling and penetration of harder rock, and the increasing application of such techniques as underbalanced directional drilling, slimhole drilling, and multilateral configurations. Drilling challenges often make investment in domestic exploration and production less attractive than investment in easier-to-produce overseas reservoirs.

How aggressively will companies invest in new oil and gas projects in the United States in the future? The answer may hinge largely on advanced technologies. Operators are currently focusing on a level of investment that results in higher net present value for the whole project, taking into consideration all aspects of well operations over its entire life cycle.

Working with industry partners, the Department of Energy is supporting the development of advanced drilling, completion, and stimulation technologies that will increase the overall profitability of exploration and production of our Nation's significant domestic resources, and thereby reduce our reliance on foreign sources of supply.

DRILLING

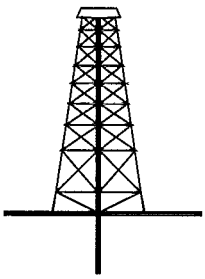
ENABLING COST EFFECTIVE DOMESTIC OIL AND GAS EXPLORATION AND PRODUCTION

COMPLETION

ADVANCED DRILLING, COMPLETION &

STIMULATION SYSTEMS

Advanced technologies enable access to our Nation's oil and gas resources while preserving the environment



In 1994, the $68 billion oil and gas industry drilled over 20,000 new oil and gas wells in the United States at a total cost of $9.7 billion. This drilling brought the total number of active wells in the Nation to almost 900,000.

DOE's Advanced Drilling, Completion & Stimulation Systems Program focuses on the development of sophisticated technologies and methodologies that can encourage investments in producing new oil and gas plays, and that can increase production from existing plays. Technology advances in this field have already succeeded in reducing costs per foot drilled in the U.S. by 8 percent over the last 10 years, and the potential for further improvements is significant. Future advances are most likely to result from addressing the full drilling system, not just individual components, with a focus on increasing the net present value of the entire investment.

Technologies under development can increase the value of the exploration and production effort in several ways. First, by increasing the rate of penetration or lengthening bit life, new methods enable producers to drill faster, farther, and longer, resulting in reduced rig time. Improved drilling and completion technologies also reduce formation damage, helping to maintain high well productivity. New stimulation technologies can be more effective than current methods in reviving well productivity after the well production rate declines to below economic levels. New methods also more effectively preserve the integrity of the wellbore over time. Finally, cost savings and increased environmental protection are also possible by reducing the volume of fluids needed in drilling and stimulation.

Improved environmental protection is an important benefit. Some advanced drilling, completion, and stimulation technologies promise to reduce drilling wastes. Others use a closed system approach that recycles and reuses materials that previously would have been treated as wastes. Other methods such as directional drilling can prevent the disturbance of wetlands and sensitive surface environments.

Another important environmental contribution is the smaller amount of acreage impacted, thanks to the greater longevity and productivity of existing wells when advanced technologies are used.

To accelerate the availability and application of innovative new technologies, DOE supports research, development, and testing efforts in cooperation with industry partners, including the Drilling Engineering Association, the Completion Engineering Association, the Gas Research Institute, and the National Advanced Drilling and Excavation Technologies program. Through a forum of the DOE Natural Gas and Oil Technology Partnership, DOE also collaborates on efforts to apply the unique capabilities of the National Laboratories for near-term improvements in drilling, completion, and stimulation.

Major focuses of DOE's program are aligned with the high priority research needs identified by the National Petroleum Council and the Petroleum Technology Transfer Council, such as drilling surface and subsurface instrumentation, hardware, software, and drilling fluids; advanced hydraulic fracturing technology to reduce damage or improve the productivity of the well; and completion hardware, perforation techniques, and cementing processes. The program is closely coordinated with activities of the Gas Research Institute, the research arm of the natural gas industry.

THE ROLE OF DOE

In partnership with industry, DOE plays a crucial role in catalyzing long-term research on the new drilling, completion, and stimulation technologies required to access our Nation's remaining oil and gas. Industry is reducing its funding for R&D that would advance such technologies, particularly as larger oil producers concentrate their investments in overseas production and shift their research toward technical service and support areas.

Many advanced technologies will ultimately be applied by smaller U.S. producers that lack the financial resources to invest in R&D. Developing and then transferring advanced technologies to independent oil and gas producers not only improves the Nation's energy security, but also enhances the value of Federal lands.

The United States currently leads the world in developing sophisticated drilling and completion technologies. As global petroleum reservoirs begin to pose the same problems to producers as domestic reservoirs do now, such advanced technologies will enjoy significant export opportunities. Our Nation's science and technology leadership in this field will both stimulate investment and promote export revenues.

POTENTIAL BENEFITS

By furthering the development of advanced technologies, the DOE Advanced Drilling, Completion & Stimulation Systems Program will by 2010 contribute the following economic improvements:

- **Reduced total drilling costs of 0.5 to 2 percent per year**
- **Reduced development drilling costs of 10 to 20 percent per year**
- **Reduced stimulation costs of 20 to 30 percent**
- **Reduced operating costs of 1 to 15 percent**

and the following technological improvements:

- **Reduced dry hole rates of 5 percent**
- **Increased reserves per well of 5 to 10 percent**
- **Reduced skin factor of 40 to 70 percent**

These economic and technical improvements will result in incremental increases in annual production of:

- **167 million barrels of oil and 260 billion cubic feet of natural gas in 2010**
- **Reserve additions of 195 billion barrels of oil and almost 6 trillion cubic feet of natural gas (cumulative from 1996 through 2010)**
- **Public sector revenues of over $7 billion (cumulative from 1996 through 2010)**

Accelerating the penetration rate of new technologies into the marketplace by two to five years and increasing the technology market saturation point by 5 percent are important program goals, essential to reducing dependence on foreign, often unstable, sources of oil and gas.

TRANSFERRING RESULTS NATIONWIDE

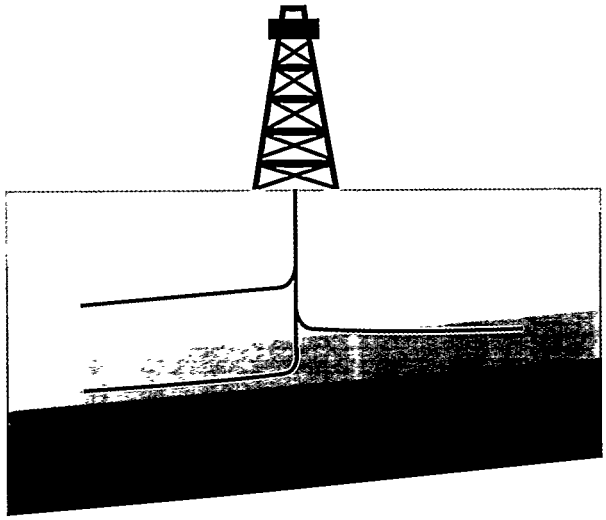
Whether a project is initiated at a single site or in multiple States, technology transfer is an integral part of the program approach. Once a project proves successful, the program focuses on transferring the results nationwide. Such technology transfer is part of the original design of every project, and before a project is even initiated, the methods used to transfer the technology to its target audience are already being developed. The transfer of technologies forms an ongoing element of every project so that lessons can be learned from failures as well as from successes.

INDUSTRY ISSUES

- DEVELOP ADVANCED REVOLUTIONARY DRILLING SYSTEMS
- DEVELOP HIGH RATE OF PENETRATION DRILLING SYSTEMS
- DEVELOP UNDERBALANCED DRILLING SYSTEMS
- IMPROVE EFFICIENCY OF DRILLING RIG SYSTEMS
- DEVELOP ADVANCED COMPLETION AND STIMULATION SYSTEMS TO IMPROVE WELL PRODUCTIVITY
- DEVELOP ADVANCED DRILLING FLUIDS
- REDUCE FORMATION DAMAGE
- DEVELOP TECHNOLOGIES TO PROVIDE ENVIRONMENTAL COMPLIANCE
- PROMOTE TECHNOLOGY TRANSFER

HORIZONTAL WELL

Multilateral technology takes the benefits of horizontal wells a step further by enabling a single well to reach multiple targets.



Advanced Drilling, Completion & Stimulation Systems Program

Drivers

- The economic viability of domestic oil and gas production is under intense pressure because of:
  - Shift in investment from mid- and long-term R&D by major oil companies
  - Decreasing cost effectiveness of current drilling technology in difficult reservoirs
  - Environmental regulations demanding smaller footprints and fully reclaimed sites
  - Loss of experienced staff due to major oil company downsizing

Vision

By 2010, industry use of a portfolio of advanced drilling, completion, and stimulation products will provide the technology needed to maintain adequate oil and gas supplies at competitive prices from deeper, harder to drill, fluid-sensitive, marginal, and difficult to access reservoirs. The portfolio of advanced drilling, completion, and stimulation technology will be matched to the geologic distribution of remaining oil and gas reserves and focus on providing higher value over the producing life of the reservoirs.

Mission

Assist industry in developing the tools and techniques needed to improve rate of return on investments in oil and gas exploration and production.

Strategies

- Assist petroleum industry in drilling R&D for near- and mid-term product development.
  - Use tool-hardened, near-bit sensor for real-time drilling and reservoir information in difficult drilling environments.
  - Commercialize steerable air percussion measurement-while-drilling (MWD) systems in priority basins.
  - Commercialize coiled-tubing and steerable air percussion drilling systems.
  - Develop and commercialize lightweight mud for underbalanced drilling.
- Develop with industry completion and stimulation technologies/methodologies that promise improved reservoir development economics.
  - Develop, test, and demonstrate high efficiency, nondamaging hydraulic fracture fluids and stimulation technologies for reservoirs to 25,000 feet.
- Encourage demonstrations of new technologies/methods that enhance project profitability.
  - Demonstrate slimhole coiled-tubing products for drilling and completion of wells.
  - Demonstrate integrated underbalanced motor MWD systems in priority basins.
  - Demonstrate cost effective domestic drilling rig retrofit components or system.

Measures of Success

By 2010, DOE and industry partnerships will yield:

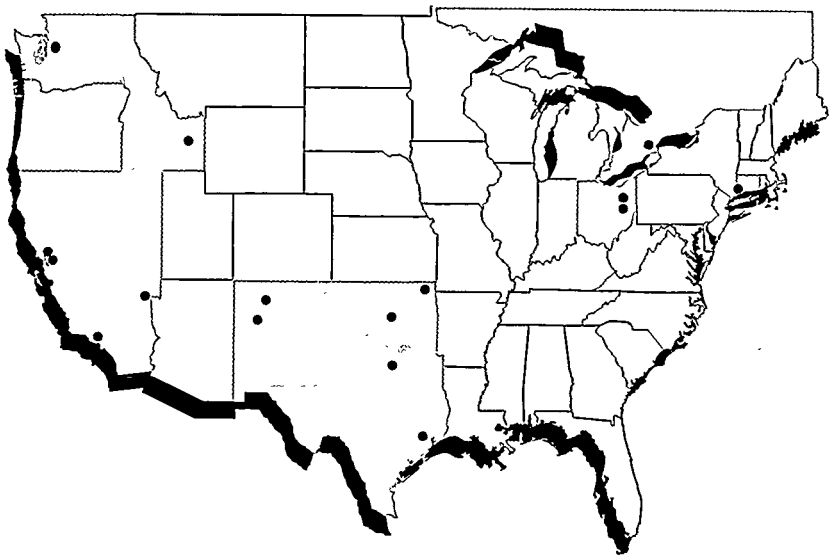
- Completion of advanced drilling concept feasibility demonstration project showing improvement in drilling efficiency
- Increased domestic use of underbalanced drilling technology
- Use of minimum-formation-damage stimulation technology for fractured U.S. wells
- Use of cost effective drilling rig component retrofit systems, resulting in reduction in drilling time to complete domestic gas wells in priority basins
- Routine use of microseismic based hydraulic fracture geometry mapping in target basins

RELATIONSHIP TO OTHER DOE PROGRAMS

Technologies developed through this program improve the efficiency of the entire oil and gas exploration and production effort, because decisions made during the drilling, completion, and stimulation phases affect the long-term productivity of the well. Furthermore, by minimizing fluids use and surface disruption, the program upholds the environmental goals of the Oil and Gas Program.

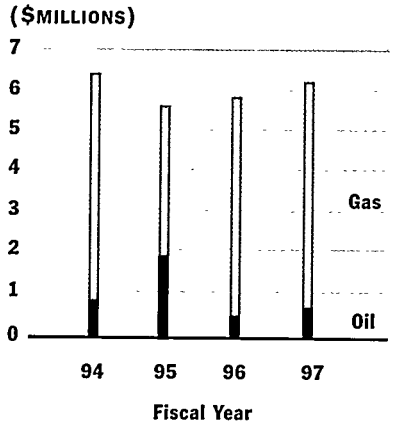
Advances achieved in diagnostics and imaging technologies are particularly valuable to improved drilling methods, enabling identification of potential well locations and reducing the risk of drilling a dry hole.

PROJECT SITES



Currently, 24 projects sponsored by DOE make important contributions to the drilling, completion, and stimulation industry. Project activities are conducted in the shaded oil and gas producing States and Ontario, Canada. Dots represent concentrations of projects.

ADVANCED DRILLING, COMPLETION & STIMULATION SYSTEMS PROGRAM BUDGET*



*Additional funding is included under the National Laboratory partnership.

PROGRAM AREAS

- DRILLING SYSTEMS
  - CONVENTIONAL DRILLING SYSTEM EFFICIENCY
  - UNDERBALANCED DRILLING SYSTEMS
  - NEW CONCEPTS IN DRILLING SYSTEMS
- ADVANCED COMPLETION AND STIMULATION SYSTEMS

THE FOLLOWING PAGES HIGHLIGHT PROGRAM ACTIVITIES IN EACH OF THESE AREAS.

Advanced Drilling Technologies

An appropriate role for the U.S. government is to serve as a catalyst to industry to develop the next generation of drilling systems.

—National Research Council (1994)

Drilling a well involves far more than making a hole. It entails the integration of complex technologies requiring individual decisions to cope with unexpected pressure regimes and rock formations. The resulting well is the sole conduit for the movement of fluid from reservoir to surface, a conduit that must last at least 50 years. The hole and the pipe that lines it must have long-term integrity, yet be flexible enough in design to allow for the application of future technologies. The drilling operation must confront and solve extremely difficult technical, safety, and control problems as it bores through layers of subsurface rock to access oil- or gas-bearing strata. Furthermore, drilling must be done in a way that protects the geologic formation, the ultimate productive capacity of the well, and the surface environment.

In partnership with industry, DOE develops tools and techniques that reduce the costs of drilling and support services. It also develops methods for reducing potential damage to the geologic formation, and for enhancing environmental protection. Drilling tools under development in DOE projects consist of nondamaging fluids and advanced hardware for high efficiency directional drilling, offering faster rock penetration rates and reduced costs. Higher efficiency rig equipment also promises increased profitability. Promising drilling technologies currently being developed and demonstrated include the following.

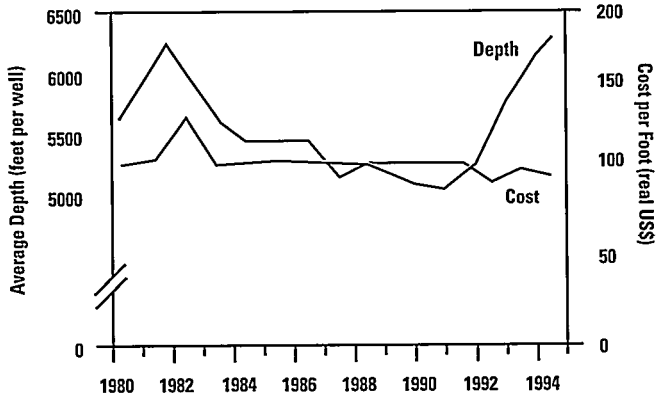
Steerable Air Percussion Drilling System

For hard rock applications, a steerable air percussion drilling system currently being developed by DOE and Smith International will increase drilling speed and accuracy. The drilling assembly will be independent of drill string rotation, and include auxiliary components such as stabilizers. Developers are also investigating wireless telemetry systems for steering the hammer, although wireless steering tools will be used initially to transmit the directional information. This effort is directed at an immediate market need, as no directionally controlled percussion drilling system is now available commercially.

Advanced Mud Hammer

Mud hammers offer a potentially cost effective alternative to motors in medium and hard rock formations. To increase drilling penetration rates in target formations, a prototype hammer has been developed, laboratory tested, and field tested. Following industry review, it is now being redesigned for more efficient application.

Drilling Costs and Average Well Depth



Source: CERA-Natural Gas Trends, 1996

In the past decade, natural gas producers have had to drill increasingly deep wells to reach productive zones. Advanced technologies have helped to offset the costs of deeper drilling by increasing drilling efficiency.

High pressure downhole pump for jet-assisted drilling

In partnership with FlowDrill and the Gas Research Institute, DOE is developing and demonstrating a high pressure downhole mud pump, designed to produce 30,000 pounds per square inch of fluid pressure to assist rock cutting (drill faster). The pump operates by extracting power from lower pressure mud flow to raise the pressure of a fraction of the total flow. Up to twice the rate of penetration is expected using jet-assisted bits.

Slimhole underbalanced measurement-while-drilling (MWD) system

A new slimhole electromagnetic MWD system now under development will be capable of operating with underbalanced drilling fluids such as nitrified mud, aerated mud, foam, air mist, air, nitrogen, or natural gas. Wireless MWD service to the underbalanced drilling market is currently limited to operation in wells of conventional size. This effort, carried out in conjunction with Geoscience Electronics Corporation and Sperry Sun Drilling Services, will meet the needs of all slimhole underbalanced drilling, including high angle and horizontal wells in low pressure, water sensitive gas formations. A prototype is now being field tested.

Near bit sensor

Accurate placement of horizontal and directional wells becomes increasingly critical as wells get longer. To drill effectively within a small window on the target horizon, exact measurements of directional data and formation parameters at the drill bit are essential. A newly designed near bit sensor, consisting of a gamma ray and inclinometer telemetry sub, can now acquire data from just behind the bit and transmit these data to a base MWD system. This is the first time a MWD system has been located directly behind the bit. Benefits include improved well control, more accurate wellbore placement, improved identification of formation boundaries in thin pays, increased penetration rates, and extension of downhole tool life. The new system will also increase well productivity, reduce drilling costs, improve drilling rates, and result in fewer drill string trips. Developed in partnership with Maurer Engineering, the near bit sensor is compatible with all manufacturers' equipment and can be used with electromagnetic or mud pulse telemetry.

Integrated underbalanced directional drilling system

To date, no service industry sector exists that can provide a complete underbalanced directional drilling system, required by operators when the pressure in the wellbore is less than hydrostatic pressure. Now, in the first effort of its kind, DOE and industry partner Sperry Sun Drilling Services are developing an integrated system to provide the petroleum industry with a commercial service. A fleet of newly designed motors combined with an electromagnetic MWD telemetry system will form the basis of the most advanced directional drilling system yet capable of operating with the complete family of underbalanced fluids. These "fluids" include air, natural gas, nitrogen, air mist, foam, aerated mud, nitrified mud, and other underbalanced mud. Specially designed motors will be matched to the underbalanced drilling fluid, extending operation and significantly reducing industry costs.

Positive displacement motors

In partnership with BDM-Oklahoma and Tulsa University, DOE is designing and developing an improved high performance positive displacement motor compatible with underbalanced coiled-tubing drilling systems. Prototype design and construction will follow in the next few years. A successful design will result in significant improvements in coiled-tubing efficiency and decreased formation damage, and allow increased oil and gas production.

Success Story

Since DOE pioneered measurement while drilling (MWD) in the 1970s, it has revolutionized drilling operations. The first system to transmit drill bit location by sending pressure pulses through drilling mud was developed by DOE and Teleco, Inc. Today, this mud pulse telemetry has become standard in the industry, saving hundreds of millions of dollars in time and labor.

Success Stories

Air motors based on DOE horizontal drilling technology are now being used for most new wells drilled in eastern gas formations. Horizontal drilling techniques using air in place of mud to drive and cool the downhole bit motor and remove drilling debris have vastly improved the efficiency of drilling in Appalachian reservoirs, where mud use causes formation swelling and fracture blockage.

✦✦✦

Since their introduction in the 1980s, polycrystalline diamond drill bits have yielded impressive savings for the drilling industry, reducing costs by as much as $1 million per well. Early generations of diamond bits failed because the cutting assembly broke away after prolonged periods of drilling. Through DOE-sponsored research, Sandia National Laboratories provided the solution, a diffusion technique that permanently bonds the cutters to the bit.

✦✦✦

Recent runs in a slanthole well produced over 150 million cubic feet (mmcf) of gas in five months, including five weeks at a rate of three mmcf per day. DOE and partner CER Corporation predict gas deliverability with an "absolute open flow potential" of 19 mmcf per day at the Colorado low permeability reservoir, proving the commercial viability of slant drilling.

In Alaska, advanced technologies developed by DOE in partnership with industry have resulted in significantly less impact on the environment by oil and gas drilling operations. The well footprint is one-quarter the size it was 20 years ago, and new waste management techniques have eliminated surface disposal entirely. New drilling fluids allow for a considerable reduction in produced water.

	1970s	1990s
Production pad	40 acres	10 acres
Well spacing	100 feet	10 feet
Lateral distance from surface location to bottomhole location	1½ miles	3 miles
Production pad and road materials	gravel (permanent)	ice (temporary)
Drilling waste	surface reserve pits	no waste
Number of wells needed in Prudhoe Bay	42	11

Source: *Oil & Gas Journal*, Aug. 28, 1995, p. 36

HIGH POWER SLIMHOLE DRILLING SYSTEM

A slimhole multi-lobe downhole drilling motor is expected to prove a much better match for the advanced capabilities of thermally stable polycrystalline diamond bits than technologies in current use. The high power motor is a four-fifths design, and is expected to deliver higher horsepower, torque, and speed. This combination of technologies, undertaken in cooperation with Maurer Engineering and Amoco, has the potential to reduce drilling costs where applicable by 60 to 75 percent.

CUTTINGS TRANSPORT

The ability of aerated fluids to clear cuttings away from a drilling bit is not yet fully understood. Working with an industry consortium and INTEVEP-Venezuela, DOE is focusing on laboratory investigation into the design of fluids capable of carrying cuttings to the surface when underbalanced drilling systems and aerated mud systems are in use.

ADVANCED UNDERBALANCED DRILLING FLUIDS

Lightweight muds for underbalanced drilling are attracting increasing attention. DOE and industry partner Maurer Engineering are now testing additives capable of reducing freshwater mud to the 6 to 8 pound per gallon level, in anticipation of their use in preventing or minimizing formation damage and lost circulation. Such fluids are also expected to increase penetration rates.

PC BASED FOAM DRILLING MODEL

A personal computer based foam drilling model has now been developed by DOE, Maurer Engineering, and Clearwater, Inc. to assist drilling engineers in designing and executing foam drilling operations in the field. On-site engineering of mechanical and electrical equipment requires system analysis in real time in order to ensure quality control during foam drilling operations. The new model answers an urgent industry need for assistance in foam drilling.

COILED-TUBING STRESS MODEL

In an effort to predict stresses on tubing under a variety of operating conditions, DOE, in partnership with Tulsa University and BDM-Oklahoma, is developing and refining a comprehensive mathematical model for the transfer of axial load along coiled tubing in an inclined or horizontal well. The model successfully allows drillers to operate at maximum speed and efficiency, while remaining in a "safe" envelope to prevent losses due to buckling.

ADVANCED DRILLING SYSTEM DEVELOPMENT

DOE recently solicited applications for development of advanced drilling systems that can reduce overall systems costs and increase rates of penetration, and that will allow economical development of remaining U.S. oil and gas resources. Advanced drilling equipment may evolve from existing systems or may require revolutionary advances in materials science and engineering. Innovative systems that combine two or more drilling technologies are being considered.

THE NADET PROGRAM

FOUR MAJOR INDUSTRIES DEPEND ON DRILLING AND EXCAVATION TECHNOLOGIES: MINING, ENERGY PRODUCTION, CONSTRUCTION, AND ENVIRONMENTAL PROTECTION. AS POPULATION GROWTH STIMULATES DEMAND FOR ENERGY AND HOUSING, AND GREATER ATTENTION IS FOCUSED ON ENVIRONMENTAL ISSUES, THESE INDUSTRIES URGENTLY REQUIRE LOWER COST, MORE EFFICIENT, BETTER PRODUCING DRILLING TECHNOLOGIES WITH MINIMIZED ADVERSE ENVIRONMENTAL IMPACT. YET DEVELOPING SUCH TECHNOLOGIES IS, IN MANY CASES, BEYOND THE BUDGETS OF THE SEPARATE INDUSTRIES.

THROUGH DOE'S NATIONAL ADVANCED DRILLING AND EXCAVATION TECHNOLOGIES (NADET) PROGRAM, VARIOUS PROGRAM OFFICES WITHIN THE DEPARTMENT ARE COORDINATING THEIR PROGRAMS IN CONCERT WITH INDUSTRY TO FOCUS ON DEVELOPMENT OF ADVANCED REVOLUTIONARY DRILLING SYSTEMS THAT WILL ASSIST INDUSTRY INTO THE 21ST CENTURY.

NADET PROVIDES FOR IMPROVED CROSS FERTILIZATION AMONG INDUSTRIES, AND EMPHASIZES TOTAL SYSTEM DEVELOPMENTS, COORDINATING SINGLE COMPONENT PROJECTS TO ACHIEVE REALISTIC SYSTEM GOALS. THE PROGRAM SEEKS TO CREATE A NEW GENERATION OF ADVANCED, ENVIRONMENTALLY SOUND TECHNOLOGIES BY THE YEAR 2010.

Advanced Completion and Stimulation Technologies

Once the well has been drilled and lined with pipe, the connection between the geological formation and the well must be established and assured. Completion includes installing suitable tubing or casing, cementing this casing, using rock section isolation devices, and perforating the casing to access the producing zones. DOE research and development projects develop better completion tools, such as nondamaging fluids and hardware for efficient zonal isolation in vertical and directional slimhole and conventional wellbores.

In some reservoirs, the geological conditions dictate that stimulation processes be applied to improve reservoir permeability or flow conductivity, facilitating production through the wellbore. DOE's R&D efforts focus on new or improved stimulation methods, including fracture propagation control and less damaging fracturing fluids.

Success Stories

Foam fracturing was originally introduced in the eastern United States by DOE in the late 1970s. Today, this technology is the stimulation technology of choice for low permeability, low pressure gas reservoirs in the United States.

✦✦✦

Thousands of wells from Wyoming to Texas have been stimulated using a DOE-developed technology, tailored pulse fracturing, contributing to an increase in gas production of some 50 billion cubic feet a year. Now commercialized by Petrotek, Servo Dynamics, and Sunburst Recovery, tailored pulse fracturing uses solid "rocket fuel" propellants that create a pressure pulse when ignited to form predictable fracture patterns.

FRACTURING FLUID CHARACTERIZATION

Hydraulic fracturing processes apply pressures as high as 20,000 pounds per square inch to a borehole, and use fluids such as water- or oil-based gels, acids, gases, and foams to create a vertical fracture that can increase hydrocarbon yield and accelerate the rate of recovery. But the chemistry of fracturing fluids is complex, and their physical properties are dependent on variations in shear, temperature, rock formation properties, and fluid additives. Fluid flow is further influenced by the different proppant particles included in a slurry to hold open the newly created fracture.

To study the changes and responses of fracturing fluids and the shape and extent of a hydraulic fracture as it propagates, DOE and the Gas Research Institute have been sponsoring a fracturing fluid characterization facility with industrial partners, including Halliburton Energy Services and MTS Systems Corporation. Located at Oklahoma University, the high pressure test cell provides a simulation setting in which state-of-the-art instrumentation can monitor fracture shape and measure the properties of fracturing fluids and proppant-laden slurries to determine changes during the process, as well as their responses to different pressures, temperatures, and rates. Current projects include baseline characterization of linear and borate crosslinked gels and slurries, and determination of the pressure loss associated with the flow of different fluids through perforations.

Precise information on fracture fluid performance leading to accurate design and control of cost effective hydraulic fracturing treatments can result in savings to industry of up to 30 percent in time and materials costs.

DOE has been a partner in this effort for five years now, with a 50 percent cost share of $6.8 million. The test cell is now available for commercial use.

Field Fracture Multi-Site Facility

To enhance hydraulic fracturing efficiency, DOE and the Gas Research Institute have joined forces in a field fracture multi-site facility that allows measurement of the physical extent of a fracture. A major step toward improving the predictability of hydraulic fracturing, the project is likely to lead to technology that will save operators significant capital and increase the Nation's recovery of natural gas from massive deposits in western tight sandstone reservoirs. Hydraulic fracturing is already a billion-dollar service business in the petroleum industry.

The field based DOE project, conducted in partnership with CER Corporation, uses seismic measurement and computerized data processing systems to analyze the geometry of fractures resulting from tests conducted in low permeability formations. Results will give industry producers much greater precision in designing fracturing treatments.

At the multi-well experiment site, seismic surveys and pressure/time measurements are being used to map the lengths and directions of hydraulically induced fractures, and seismic signals are relayed from the propagating fracture to a new seismic signal receiving well. Natural gas flow rates are also monitored to assess the effectiveness of stimulation and other well management techniques.

Carbon Dioxide/Sand Fracturing Stimulation

Carbon dioxide/sand fracturing technology was introduced into the United States by DOE, assisting the U.S. oil field service industry. The non-damaging technology, which uses a sand-laden liquid CO_2 slurry to extend fractures, has the potential to significantly outperform traditional stimulation approaches. Yet oil and gas producers were hesitant to try it until its success in the field was demonstrated.

To encourage industry evaluation of the technology, DOE and its partner Petroleum Consulting Services have been working with industry to apply CO_2/sand fracturing, along with other stimulation methods, to newly drilled wells of similar design and geological setting. So far, comparisons show much higher production from CO_2/sand fracturing. In fact, production improvements at the earliest U.S. wells stimulated by this process were so significant that DOE received the 1994 Hart's Oil and Gas World Award for introducing the "Best New Technology in the Northeast."

Oil field service sector involvement has been high. Universal Well Service pumped the first few stimulations, and in 1995 obtained an exclusive license from the initial developer, Canadian FracMaster, to provide commercial service in the United States.

Casing Damage Assessment

DOE is working with the Drilling Engineering Association to review casing damages worldwide. The project involves the identification of successful mitigation strategies, and geomechanical simulations of various casing and cementing configurations. It will aid in the development of operational diagnostic methods and of better well designs that prevent casing collapse due to fluid withdrawal.

Fracture Geometry Mapping

In a joint industry-Gas Research Institute project, the geometry of rock fractures is being mapped to advance engineers' understanding of how hydraulic fractures propagate, and to further outline the development of a commercial service. Even modest improvements in the ways fracture stimulation treatments are designed will result in significant savings. If, for instance, this mapping led to improvements in the fracture stimulation treatments applied throughout the gas field where the project is sited, it could easily result in savings exceeding $10 million.

ADVANCED DIAGNOSTICS AND IMAGING CAN REDUCE THE COSTS AND RISKS OF EXPLORATION AND PRODUCTION

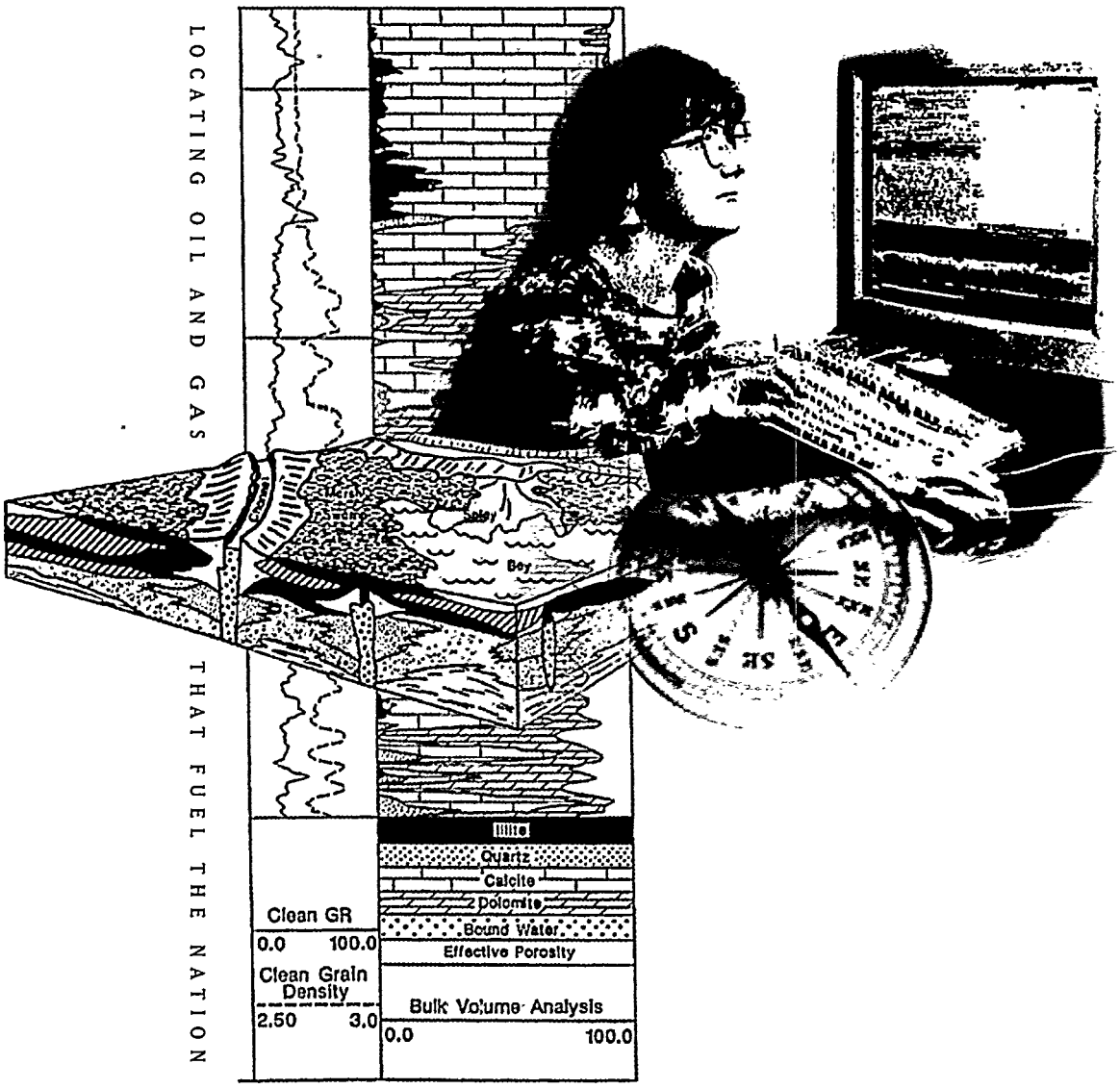
Advanced imaging is an increasingly powerful tool for discovery and insight in medicine, engineering, and many other fields. In the oil and gas industry, sophisticated diagnostics and imaging technologies can be key to cost effectively locating and producing our Nation's remaining reserves.

Although our Nation's largest, most easily identified reservoirs have been discovered, potentially substantial reserves still exist, both onshore and offshore, in geologically complex settings or in deeper and smaller compartmentalized reservoirs. With advanced diagnostics and imaging technology, the costs and risks of exploring for these reserves can be significantly reduced.

Advanced imaging and computer modeling technologies also hold great promise for more efficient production of the Nation's remaining discovered oil and gas, about half of which is economically unrecoverable using today's technologies. Using tomorrow's more powerful technologies, the industry will be better equipped to produce the Nation's remaining oil and gas reserves. As a result, our Nation may be able to slow the rate at which domestic oil and gas fields are abandoned in the future.

In partnership with the oil and gas industry, the Department of Energy is supporting research, development, and demonstration of advanced diagnostics and imaging techniques, combining the best public and private capabilities to accelerate the creation and implementation of promising, innovative approaches.

DIAGNOSTICS



LOCATING OIL AND GAS THAT FUEL THE NATION

IMAGING

ADVANCED DIAGNOSTICS

AND IMAGING SYSTEMS

New RD&D builds on our national leadership in cost effective oil and gas exploration and production technologies

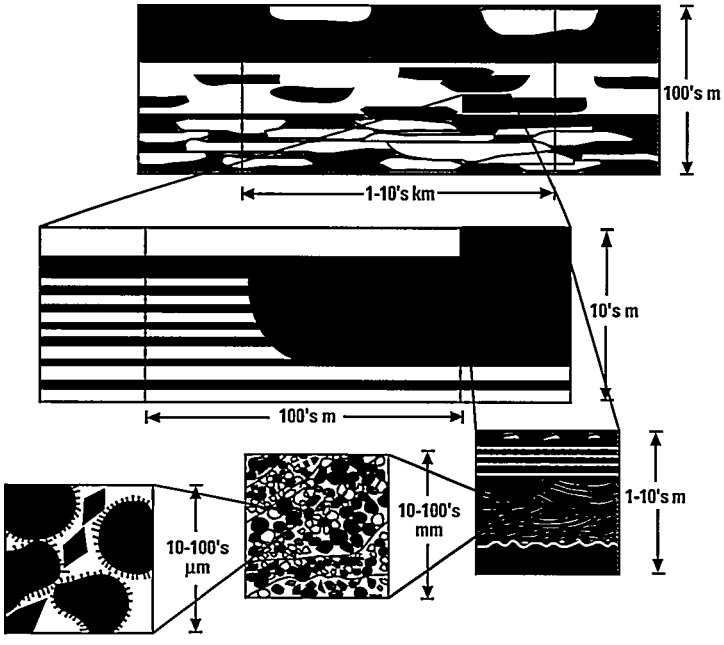
The Department of Energy's emphasis on diagnostic and imaging technology RD&D has greatly increased over the past 10 years in parallel with industry interest in putting new technologies to work. This growing interest is driven by the need to reduce risk and uncertainty in a low product price environment; the need for improved resolution to define smaller, more compartmentalized, and deeper reservoirs; and the understanding that reservoir heterogeneity impacts all recovery processes, an observation made in the late 1970s and early 1980s during enhanced oil recovery projects.

Diagnostics and imaging is an important component of the oil and gas industry. As one indication of the program's significance, the industry is expected to spend over $3 billion in 1997 on seismic acquisition, processing, and interpretation.

Sophisticated new reservoir imaging and drilling technologies have already helped the oil and gas industry increase the efficiency of exploration and production.

- **By 1994, exploratory well success rates had risen to 38 percent, up from 30 percent in the 1980s.**
- **Higher gas production was achieved in 1994 with fewer than 9,000 well completions, as compared with 14,250 well completions in 1985.**
- **Oil production in the Federal Offshore Gulf of Mexico increased by 125,000 barrels per day in 1995.**
- **In May 1996, total oil and gas footage drilled in the Gulf was almost 11 million feet, up 45 percent from May 1995.**
- **Industry and the Department of the Interior estimate that new discoveries in the Gulf of Mexico, an area with little exploration activity just a few years ago, may yield as much as 18 billion barrels of oil — more than Prudhoe Bay, Alaska. Technological innovations in subsalt imaging, reservoir characterization, and drilling technologies enhance the ability to discover such potential reserves.**

Levels of Reservoir Heterogeneity



Geologists better understand reservoir flow and barriers to flow by studying variations in rock porosity and permeability at microscopic, strata, and field scales.

In the future, newly developed imaging and modeling technologies can enable production from tight, inaccessible, and fractured reservoirs, which contain major portions of our Nation's future oil and gas resources. Such reservoirs include fractured shale, fractured tight gas reservoirs in the Rocky Mountain region, deeper parts of producing basins, and reservoirs in deep water or below salt in the Gulf of Mexico.

THE ROLE OF DOE

To enable continued access to valuable U.S. energy resources, DOE is committed to improving the cost effectiveness and efficiency of oil and gas exploration and production. The Advanced Diagnostics and Imaging Systems Program's specific role in this endeavor is threefold: to support the research, development, demonstration, and use of advanced imaging technologies in partnership with industry; to preserve and provide access to subsurface data; and to develop analytical tools to more accurately quantify oil and gas resources and reserves.

DOE's support of RD&D is essential to achieving continued improvements in diagnostics and imaging technologies and to realizing the enhanced oil and gas production these technologies promise. Intense cost pressures in the domestic energy market are limiting investments the industry can allocate to such long-term RD&D. The RD&D resources of smaller producers, which account for a significant portion of U.S. oil and gas production, are particularly limited. These operators require reservoir characterization and extraction technologies to maintain and increase production.

Without the impartial information and advanced technologies provided by DOE, including costly modeling software, much of the more complicated domestic production would not occur.

Industry has traditionally recognized State and Federal agencies as stewards of nonproprietary subsurface data. Today, important well data and other subsurface information are being lost as wells change hands during mergers and transfers. By finding ways to preserve subsurface data, the government ensures that this valuable information will be available to producers for identifying bypassed oil and gas and performing the reservoir characterization necessary for efficient secondary and tertiary project design. Data preservation requires a long-term commitment that many in industry believe only government can provide.

Accurate, unbiased estimates of domestic resources and reserves are needed to stimulate industry activity in untested formations and poorly explored basins.

Technology transfer is crucial to all aspects of the Advanced Diagnostics and Imaging Systems Program. Technology transfer ensures that results and information from research and new technologies and tools are communicated to industry users. The Petroleum Technology Transfer Council is a major player in providing industry with DOE technologies and guidance on how to use the technologies. In addition, DOE Internet services provide general technology information, as well as downloadable reports and computer modeling and simulation programs.

INDUSTRY ISSUES

- DEVELOP SEISMIC DEPTH IMAGING TECHNOLOGIES (E.G. SUBSALT)
- DEVELOP SEISMIC APPLICATIONS
- IMPROVE TECHNIQUES FOR DETECTION AND PREDICTION OF RESERVOIR COMPARTMENTS
- INCREASE ACCURACY OF RESERVOIR MODELING AND SIMULATION TECHNOLOGIES
- DEVELOP TECHNOLOGIES FOR CASED-HOLE AND PERMEABILITY LOGGING
- ENHANCE UNDERSTANDING OF FRACTURED OIL AND GAS RESERVOIRS
- PROMOTE PRESERVATION AND DISSEMINATION OF SUBSURFACE DATA
- ASSIST NATIVE AMERICAN TRIBES TO DEVELOP THEIR OIL AND GAS RESOURCES
- QUANTIFY RESOURCES AND RESERVOIRS
- INCREASE ACCURACY OF PRESENT AND FUTURE OIL AND GAS RESOURCE ESTIMATES

Meeting industry needs

The Advanced Diagnostics and Imaging Systems Program focuses RD&D on areas identified by industry as having significant potential benefits. Recent industry recommendations concerning DOE-funded RD&D in diagnostics and imaging technologies are summarized below.

In its fiscal year 1997 funding recommendation to DOE, the Gas Industry RD&D Advisory Board identified advanced diagnostics and imaging as one of many technology development programs recommended for government support. The group — a coalition of 36 oil and gas research and trade organizations — specifically emphasized the need for basic geological studies, reservoir modeling, and infield evaluation techniques for bypassed reservoir compartments.

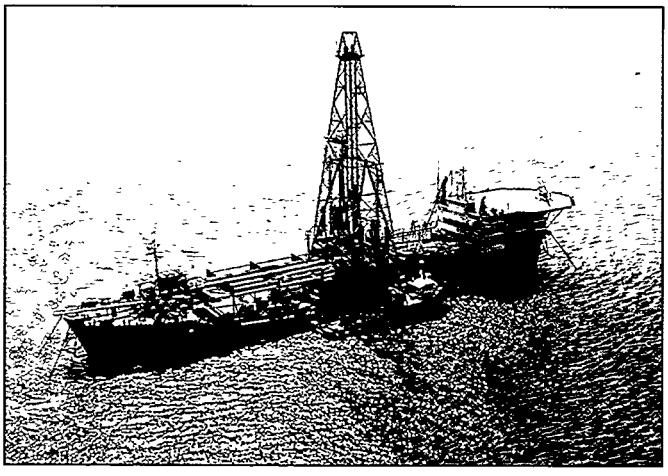
In *The Dynamics of Sedimentary Basins* (1996), the National Research Council recommended two research areas and a collaborative approach that are integral to the Advanced Diagnostics and Imaging Systems Program:

- Development of basin models to enhance understanding of diverse processes such as fluid flow along fractures that impact resources like petroleum
- Continuation of efforts to preserve, archive, and disseminate data on sedimentary basins
- More collaboration between industry, academia, and government researchers, linking diverse research disciplines

In another study, *Rock Fractures and Fluid Flow* (1996), the National Research Council recommended additional research to increase the understanding of fractured rocks, specifically the origin and development of fracture systems and the relationship between stress, fluid flow, chemical processes, and temperature. Development of improved fracture detection methods and numerical flow models was also recommended.

The National Petroleum Council (NPC) has also identified advanced diagnostics and imaging as a high priority. In its 1995 study *Research, Development and Demonstration Needs of the Oil and Gas Industry*, the NPC identified high resolution seismic depth imaging, through-casing logging, and simulation techniques as key technology needs.

Additional short-term RD&D technologies were also cited, including advanced seismic acquisition, computer based 3-D geologic modeling, development-scale seismic applications, and permeability logging.



Potential benefits

By playing an active part in technology development and use, data preservation and use, and the development of more accurate resource and reserve quantification tools, DOE expects that its RD&D will aid industry in achieving the following positive results by 2010:

- A reduction in the proportion of dry holes drilled, through an increase in the resolution of reservoir imaging technology and improvements in the capability to locate hydrocarbons
- An increase in production from fractured reservoirs through improved fracture imaging and prediction and fluid flow modeling, allowing wellbores to intersect and drain multiple fractures (necessary for ensuring economic production rates)
- An increase in U.S. exploration, especially in underexplored basins and Native American lands, through greater industry access to and use of geologic and geophysical basin-scale data
- An increase in the cost effectiveness of field development, infill drilling, and extraction processes by providing industry with modeling and simulation tools for improved process design or optimization

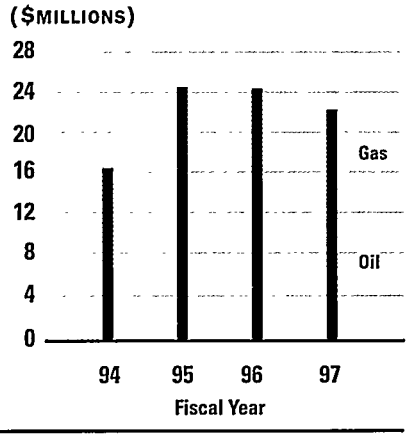
The Advanced Diagnostics and Imaging Systems Program expects by 2010 to contribute 100 million barrels per year of additional oil production and over 2 trillion cubic feet (Tcf) per year of additional gas production. By 2010, cumulative additions of 1.6 billion barrels in oil reserves and 37 Tcf of gas reserves will add $10 billion to public sector revenue.

RELATIONSHIP TO OTHER DOE PROGRAMS

Tools resulting from DOE's Advanced Diagnostics and Imaging Systems Program improve efficiency in oil and gas drilling and extraction and benefit natural gas storage practices. Information collected in developing natural gas reservoir atlases is incorporated into DOE's Gas Systems Analysis Model, a comprehensive system for estimating recovery and use of natural gas over a wide range of conditions. Diagnostics and imaging technologies also contribute to the environmental goals of the Oil and Gas Program by reducing the wastes associated with drilling and production and decreasing the number of drill sites.

In turn, DOE's research and field demonstrations of drilling, extraction, and natural gas storage technologies provide the data and the heightened understanding of reservoir architecture required for further improvements in diagnostics and imaging technologies. Field demonstrations, in particular, often stimulate advances in diagnostics and imaging as technologies are put to the test in full-scale applications.

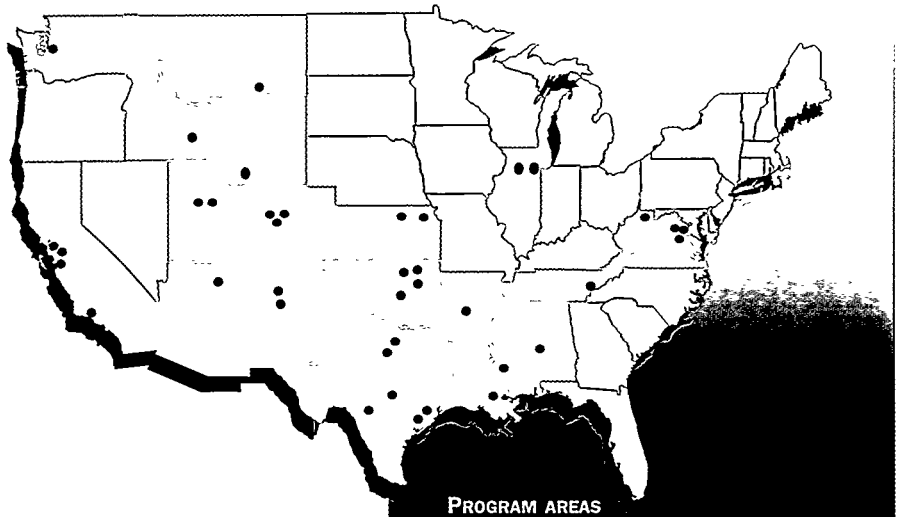
ADVANCED DIAGNOSTICS AND IMAGING SYSTEMS PROGRAM BUDGET*



* Budget includes all National Laboratory partnership activities, including work described in the Drilling, Completion & Stimulation and Reservoir Life Extension programs.

PROJECT SITES

This program conducts RD&D in 39 laboratories and field sites in 20 States. Participants include major and independent oil and gas production companies, universities, State agencies, Native American Tribes, research institutes, service and consulting companies, National Laboratories, and the Gas Research Institute.



PROGRAM AREAS

THE ADVANCED DIAGNOSTICS AND IMAGING SYSTEMS PROGRAM IS DIVIDED INTO SIX AREAS:

- OIL RESERVOIR MODELING AND SIMULATION
- OIL GEOSCIENTIFIC MEASUREMENT
- OIL RESERVOIR DESCRIPTION
- LOW PERMEABILITY GAS RESERVOIRS
- NATURAL GAS RESOURCES AND RESERVES ANALYSIS
- OIL EXPLORATION RESEARCH

EACH OF THESE AREAS IS SUMMARIZED ON THE FOLLOWING PAGES.

Advanced Diagnostics and Imaging Systems Program

Drivers

- U.S. remaining resources are in deeper, smaller, and more complex structures that require ongoing improvement of reservoir imaging capability for economic production.
- Recovery of the large volume of petroleum remaining after primary production requires improved reservoir imaging and modeling at pore-to-interwell scales.
- Significant resources of oil and gas in fractured reservoirs require specialized imaging and modeling technologies for economic production.
- Independent operators, who conduct an increasing share of U.S. exploration and production activities, require access to digitized subsurface geologic data and PC based modeling, simulation, and risk analysis tools.

Vision

By 2010, industry use of advanced imaging tools and diagnostic modeling will have maximized U.S. oil and gas production and assured world leadership in reservoir characterization technology; U.S. industry will have access to all applicable digital subsurface data and resources and reserves estimates; and production from fractured reservoirs will be economic for all major geographic regions.

Mission

Support the development and use of advanced technologies for reservoir characterization and risk based decision making; preserve and provide access to subsurface data; and develop analytical tools to perform the analyses required for accurately quantifying oil and gas resources and reserves.

Strategies

- Improve seismic and other geophysical acquisition, processing, and interpretation technologies to provide increased resolution and accuracy, with emphasis on single-well, crosswell, and novel surface methods.
- Increase understanding and measurement of rock and fluid properties, rock fluid interactions, and fluid flow, and develop techniques to measure reservoir properties that are not currently measurable.
- Increase accuracy and performance of geologic and reservoir modeling and simulation, especially fast, user friendly, PC based techniques.
- Develop and demonstrate techniques to predict, locate, and exploit reservoir fractures for improved production from low permeability reservoirs.
- Improve industry knowledge of and access to reservoir characterization technologies.
  - Develop methodologies for quantitative description and prediction of reservoir characteristics, including fractures and diagenesis.
  - Transfer reservoir characterization data, models, and tools to industry.
- Increase accuracy of present and future oil and gas resources and reserves estimates, and industry access to them.
  - Work with industry and State and Federal agencies to preserve irreplaceable subsurface geologic data.
  - Provide industry, government, and academic customers with accurate, unbiased, and timely current and predicted future estimates of U.S. natural gas resources and reserves.
- Assist Native American Tribes to stimulate environmentally safe exploration activity in currently underdrilled areas and in untested formations within older producing areas.
  - Update and increase the amount of publicly available information on regional geology, resource and recovery estimates, and hydrocarbon prospects on Tribal lands for use by explorationists.

Measures of Success

By 2010, DOE and industry partnerships will yield:

- Increased discoveries of new domestic oil and gas fields
- Increased reserve growth rate of existing fields
- Increased volume of "booked reserves" per new wells
- Increased use of advanced seismic imaging to define drilling locations
- Increased use of advanced logging and wellbore geophysics for field development
- Increased availability and use of subsurface geologic data

Oil Reservoir Modeling and Simulation

Researchers in this area focus on improving quantitative representation of reservoir properties and flow unit boundaries, and on increasing the speed and accuracy of geologic and engineering reservoir simulators.

Research on more advanced technologies for modeling and simulation is being conducted in Alabama, Maryland, Oklahoma, Texas, Utah, Virginia, and Washington.

Descriptions of several exemplary projects follow.

GEOSCIENCE RESEARCH — INTEGRATED GEOSCIENCE/ ENGINEERING METHODS OF OPTIMAL RESERVOIR UPSCALING

Research by BDM-Federal, in partnership with Union Pacific Resources, will focus on two main areas of advanced diagnostics and imaging: (1) the reservoir characterization and model construction of barrier island tidal facies; and (2) the determination and development of reservoir upscaling methods and methodology based on reservoir studies. The primary target of the work is the Almond Formation, which forms the reservoir in Patrick Draw Field and crops out in the adjacent Rock Springs Uplift, Sweetwater County, Wyoming.

Industry's application of the upscaling methods will reduce simulation costs by $500,000 per year.

RESERVOIR ARCHITECTURE MODELING: NONSTATIONARY MODELS FOR QUANTITATIVE GEOLOGICAL CHARACTERIZATION

The objective of this project by the University of Tulsa is to develop numerical models of reservoir fluid flow that will honor the multiscale and nonstationary characteristics of the spatial distribution of reservoir facies. The description of geological architecture is a crucial step in predicting the future production performance of a petroleum reservoir. This project will focus on the description of the geological facies that are generated as a result of sedimentation processes. The project will use a multidisciplinary approach, involving scientists in geology, petroleum engineering, and mathematics.

FRACTURED RESERVOIR CHARACTERIZATION AND MODELING

Seven research contracts were awarded for fractured reservoir characterization and modeling research in 1996. The two- to three-year projects will study the relationship of geologic stress and local fracture patterns to regional tectonic systems and develop techniques to use this information to predict petroleum recovery. Recipients are the University of Alabama; Golder Associates; Science Applications International Corporation; Southwest Research Institute; TerraTek; the University of Texas at Austin, Bureau of Economic Geology; and the University of Utah.

DOE projects that reserves in fractured reservoirs will increase by 32 million barrels within 11 years as a result of this research.

Success Story

Ongoing simulator development has led to the recent release of BOAST3, a new version of the Department of Energy's three-dimensional, three-phase "Black Oil Applied Simulation Tool." Over 2,000 copies of BOAST versions have been distributed, primarily to independent producers, for use in designing waterfloods and other improved recovery projects.

Oil Geoscientific Measurement

Geoscientific measurement is concerned with developing tools and analytical techniques to acquire and process subsurface data. Research to develop advanced measurement technologies is being conducted in California, New Mexico, Texas, and Virginia.

Descriptions of several exemplary projects follow.

Multifrequency crosshole electromagnetic (EM) technology, and oil field characterization and process monitoring using EM methods

Lawrence Livermore National Laboratory and its partners, Schlumberger, Mobil, Chevron, and the University of California at Berkeley, are developing tools for surface-to-borehole and cross-borehole EM technology for reservoir characterization and monitoring in-situ conductivity changes during enhanced oil recovery operations. Both hardware and software tools for high resolution multifrequency EM imaging are being developed.

Several companies have expressed an interest in commercializing the technology and in developing environmental applications. More accurate identification of subsurface contaminants and improved tracking of injectants can improve the cost effectiveness of remediation efforts.

Microseismic fracture mapping

Slimhole geophones that can be used in producing wells are being developed by Los Alamos National Laboratory and its partners, Schlumberger, Enserch Exploration, Ohio Kentucky Oil, Petro-Hunt, and Meridian. This technology will eliminate the high cost of pulling the production tubing ($40,000 – $200,000 per survey) and will allow reservoir fractures to be mapped at interwell distances by detecting and locating micro earthquakes induced by well stimulation and normal production activity. Greatly reduced survey costs and improved signal-to-noise character can be expected to result from commercial deployment of through-tubing seismic devices and may double the use of seismic fracture mapping.

National geoscience data repository system

A national data repository system could preserve seismic, core, and log data worth billions of dollars, and make this information accessible to independent operators and service companies.

A three-phase project is under way to implement a national network of existing regional data centers that will capture, preserve, and make available valuable geoscientific data currently in jeopardy of being lost or destroyed. Phase I determined that there is strong interest and need for a national system, and that there is an excellent match between the expected contributions of data companies and the interests of potential system users. Phase 2 addresses the specific organizational, operational, and business requirements for establishing the system. In Phase 3, private sector data will be transferred to existing repositories.

The project is being conducted by the American Geological Institute and its partners, Mobil, Conoco, Petrochemical Open Software Corporation, the University of Texas at Austin Bureau of Economic Geology, The Information Store, and PGS.

Natural Gas and Oil Technology Partnership

The Natural Gas and Oil Technology Partnership provides the petroleum industry with a mechanism to collaborate with DOE's National Laboratories on near-term R&D efforts to improve exploration and recovery of oil and gas. Through the Partnership, industry gains access to unique capabilities of the Laboratories in such areas as electronics, instrumentation, materials, computer hardware and software, engineering, systems analysis, physics, and expert systems.

The Natural Gas and Oil Technology Partnership consists of three independently run forums: Recovery Technology, Seismic Technology, and Drilling and Completion Technology.[1] An environmental forum will be added in the future. The Partnership stimulates, facilitates, and coordinates the development and rapid transfer of technology to industry. The program is industry driven and leveraged by matching contributions.

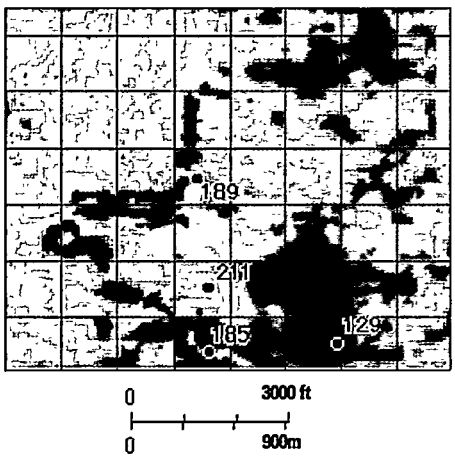
The Seismic Technology Forum comprises 26 companies (18 oil companies and 8 service companies) that annually review and prioritize proposals related to cutting edge geophysical methods for improved reservoir characterization. Projects identified as priorities by the forum include a multistation borehole seismic receiver, subsalt seismic imaging, advanced wellbore telemetry systems, three-component vibratory source, and microborehole seismic instrumentation. Several projects will contribute technologies for crosswell seismic imaging.

Success Story

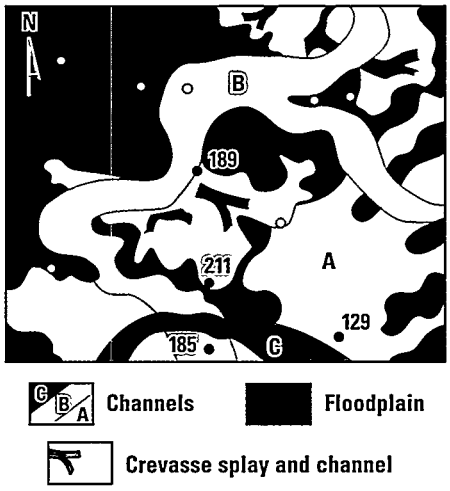
Two outcomes of the Natural Gas and Oil Technology Partnership are:

- An accelerometer based, multi-level receiver system for seismic monitoring of reservoirs and production processes
- A prototype system that reduces the time needed for crosswell imaging to one-fifth the time of conventional technology and provides a 10 percent cost savings when used for monitoring fracture treatments

Application of 3-D Seismic Imaging to Identify and Track Thin-Bed Reservoirs



Updated Reservoir Model Based on Engineering, Geologic, and 3-D Seismic Amplitude Horizons



Illustrated above are a horizontal seismic slice and a derived map interpretation of a channel system in the Stratton gas field, Texas.

[1]The Recovery Technology Forum is described in the Reservoir Life Extension Program plan, and the Drilling and Completion Forum is described in the Advanced Drilling, Completion & Stimulation Systems Program plan.

Oil Reservoir Description

As reservoir imaging and computer modeling become more powerful, industry will be better equipped to produce more of the Nation's remaining petroleum using exploratory and infill drilling, waterflooding, and cost efficient injection technologies.

Multidisciplinary reservoir studies using surface and subsurface data contribute to a better understanding of reservoir architecture and the ways post-depositional modifications impact flow boundaries. Research to improve the understanding of reservoir architecture and flow boundaries is being conducted in California, New Mexico, and Oklahoma.

Descriptions of three exemplary projects follow.

GEOMECHANICS FOR RESERVOIR MANAGEMENT

Geomechanical principles will be applied to reservoir management by project participants Sandia National Laboratories and its partners, Union Pacific Resources, Parker & Parsley, Shell, Chevron, and Amoco. The project will focus on:

- **Quantitative analysis of fracture systems in relation to lithology and regional tectonics**
- **Influence of in-situ stress on fracture conductivity**
- **Measurement of rock properties as a function of stress and stress history**
- **Numerical analysis**
- **Development of laboratory capability to simulate reservoir conditions and the response of reservoir rocks**

Three reservoir types will be studied: Austin Chalk, Spraberry, and poorly consolidated California and Gulf Coast sandstones.

DOE estimates that improved simulations of fractured reservoirs may lower development costs by 10 percent through improved well placements and production strategies, such as pore pressure maintenance.

GEOSCIENCE RESEARCH — CORRELATION OF PORE CHARACTERISTICS WITH MULTIPHASE RELATIVE PERMEABILITY AND CAPILLARY PRESSURE FUNCTIONS

This project, conducted by Mobil and BDM-Federal, will develop a systematic approach for estimating capillary pressure, permeability, and relative permeability from pore size distribution, coordination number, and pore structure. The project's first tasks are tests on water-wet and intermediate-wet rocks with different absolute permeabilities to examine relationships among rock pore size distribution, coordination number, pore structure, and oil/brine steady-state relative permeability.

Success Story

Seven multidisciplinary reservoir characterization projects, competitively selected in 1992, are nearing completion. Early results show that the technologies being studied are improving oil recovery:

- **$14 million in additional reserves have been identified in Hambert-Aristrocrat field, Weld County, Colorado (Colorado School of Mines).**
- **15 million barrels of additional recoverable reserves have been recognized in the Tensleep Sandstone (University of Wyoming).**
- **Geologically targeted infill wells, based on characterization of the South Cowden field, have reversed the steep production decline of this giant west Texas field (University of Texas at Austin, Bureau of Economic Geology).**

The five-year goal is to develop a relative permeability model relating fluid flow to pore structure, pore size distribution, and other parameters determinable from drill cuttings or core fragments. Accurate relative permeability data will enable reductions of field development costs by $3 million per year.

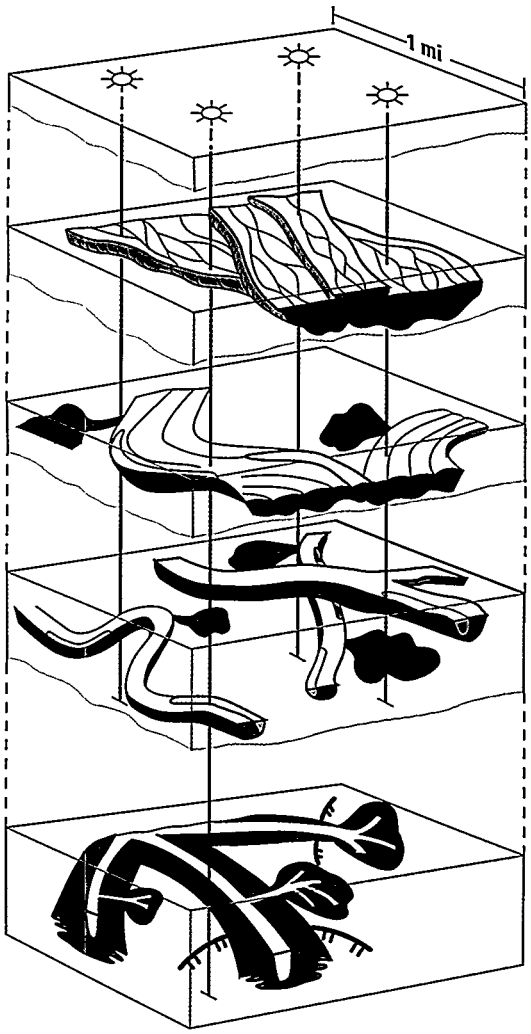
A comprehensive experimental and theoretical research program to better understand the basic mechanisms of oil recovery and recovery enhancement of fractured petroleum reservoirs is being conducted by Reservoir Engineering Research Institute, in partnership with Stanford University, Amoco, British Petroleum, Marathon, Mobil, Phillips, and Texaco.

Several important issues related to oil and gas displacement in fractured petroleum reservoirs have been resolved as a result of the work to date. Discussions of these issues and their solutions have been presented in 35 papers, mostly Society of Petroleum Engineers publications.

Reservoir Engineering Research Institute

The mechanisms of fluid transfer between matrix blocks and fractures and the interaction of matrix blocks for immiscible and miscible flow are not well understood. Consequently, complicated numerical models currently in use do not yield reliable results. A key element to recovery enhancement of fractured petroleum reservoirs and the use of models to simulate those reservoirs is an adequate knowledge of multiphase flow in fractured porous media. Therefore, the main objectives of this project are to develop a full understanding of the role of diffusive, capillary, gravity, and viscous forces in the flow of fluids in fractured porous media.

Detailed Stratigraphic and Structural Cross Sections



Strategically targeted wells optimize recovery from multi-compartment reservoirs. Reservoir compartments are determined from production history, detailed well-log cross sections, and 3-D seismic imaging.

Low Permeability Natural Gas Reservoirs

Success Story

Northern Indiana Public Service Company used vertical seismic profiling (VSP) technology developed by DOE's low permeability reservoirs program to help design a horizontal gas storage well to intersect fractures. Following successful completion of the well, an additional VSP survey will monitor fracture response to storage pressure changes.

The gas industry and DOE have joined forces on research to characterize the geology of the natural gas resources in the western U.S., and to develop and demonstrate cost effective development strategies for low permeability gas formations. The research is being conducted in California, Colorado, New Mexico, Texas, Virginia, West Virginia, Wyoming, and Washington, DC.

Descriptions of three exemplary projects follow.

Directional drilling at Greater Green River Basin

Union Pacific Resources will test and demonstrate the effectiveness of directional drilling in developing the Greater Green River Basin (GGRB) gas resource in Wyoming. The DOE-GGRB project is part of a DOE-GRI coordinated program. The DOE-industry project includes geologic and reservoir engineering studies to design the integrated geoscience/engineering reservoir scaling project in Sweetwater County, Wyoming, and a high visibility field production test and technology demonstration well. The test well consists of a vertical site characterization hole with optional high angle directional and horizontal production laterals. The well and its laterals are to be production tested to evaluate the effectiveness of directional drilling. The GRI program is focused on complementary field testing in "wells of opportunity" in the GGRB. The GRI and DOE activities are closely coordinated to ensure that knowledge gained in each program is adopted in the other.

Naturally fractured tight gas reservoir detection optimization: integrated methodology

The Advanced Resources International project in the Piceance Basin in Colorado integrates several geological and geophysical techniques that producers can use to predict where natural fractures exist. Techniques include:

- Remote imaging using aerial or satellite photographs for regional analysis
- Low cost, high resolution aeromagnetic surveys to locate structural or stratigraphic anomalies
- Mapping of deep "basement" formations and associated faults and fracture systems
- 3-D seismic applications to evaluate the aeromagnetic anomalies in detail and to locate wells
- A newly developed model of the geology of the Rocky Mountain basin area (called the Reactive Transport Model or RTM)

This integrated modeling methodology can help operators target potentially productive areas before drilling expensive exploratory wells. The new RTM basin model can be used to develop and analyze a variety of geologic data, such as basin tectonics, fluid migration, and hydrocarbon generation, which allow industry to focus on fractured reservoir targets that contain gas resources.

The project information presented at technical conferences and workshops provides independent gas producers with cost effective tools to develop new gas resources.

NATURALLY FRACTURED TIGHT GAS RESERVOIR DETECTION OPTIMIZATION USING SEISMIC DATA

In this Wyoming project, Coleman Research will collect detailed information about the structural geology of the field and develop a large database of fractures and related gas production history. The work will be done in three phases:

- **In Phase 1, researchers will test the quality of surface S(shear) wave reflection data and the extent to which these data can be obtained and interpreted. Next, researchers will develop the necessary correlations for subsequent interpretations of seismic anomalies to reservoir characteristics.**
- **In Phase 2, researchers will create 3-D maps of the structure and faults controlling the reservoir in the Madden Gas Field in Wyoming and determine the full temporal, spatial, and offset characteristics of the P(primary) wave reflected energy.**
- **In Phase 3, researchers will enhance methods of mapping natural fractures using unconverted S wave reflection, integrate the information with all three datasets, and determine the information content about fractures that can be extracted from reprocessing existing high quality 2-D P wave data.**

Project results will define the most economical geophysical methods to be used in locating fractures in low permeability reservoirs.

OIL FIELD DEMONSTRATION PROGRAM

THE RESERVOIR CLASS FIELD DEMONSTRATION PROGRAM IS AN INTENSIVE EFFORT TO INCREASE PRODUCTION FROM U.S. OIL FIELDS AND TO PREVENT THE PREMATURE LOSS OF ACCESS TO THESE FIELDS AND THE JOBS THAT GO WITH THEM. THE PROGRAM PROVIDES FEDERAL MATCHING FUNDS OF UP TO 50 PERCENT TO OIL FIELD OPERATORS WHO AGREE TO DEMONSTRATE A WIDE RANGE OF EXISTING OR NOVEL ADVANCED TECHNOLOGIES THAT CAN PROLONG THE ECONOMIC LIFE OF DOMESTIC FIELDS. MANY TECHNOLOGIES CURRENTLY AVAILABLE ARE UNDERUSED, DESPITE DWINDLING PRODUCTION LEVELS, AND MANY NEW ADVANCED PROCESSES ARE BECOMING AVAILABLE THAT CAN DRAMATICALLY IMPROVE THE ECONOMIC PRODUCIBILITY OF A RESERVOIR. FOR THESE REASONS, DEMONSTRATIONS ARE CRITICAL IN PROMOTING THE USE OF BOTH NEW AND EXISTING TECHNOLOGIES.

THE RESERVOIR CLASS FIELD DEMONSTRATION PROGRAM, ALTHOUGH PART OF THE RESERVOIR LIFE EXTENSION PROGRAM, HAS IMPORTANT IMPLICATIONS FOR THE ADVANCED DIAGNOSTICS AND IMAGING SYSTEMS PROGRAM. DIAGNOSTICS AND IMAGING TECHNIQUES TO BE DEMONSTRATED AND TRANSFERRED INCLUDE ADVANCED SEISMIC, ADVANCED WELL TESTING AND LOGGING TECHNIQUES, AND 3-D GEOLOGIC MODELING. MANY OF THE DEMONSTRATIONS ARE IN FIELDS WHERE THESE TECHNOLOGIES WERE NOT CONSIDERED TECHNICALLY OR ECONOMICALLY FEASIBLE. VALUABLE DATA GATHERED FROM THESE DEMONSTRATIONS CAN BE USED TO IMPROVE TECHNOLOGIES AND CREATE OPPORTUNITIES FOR FURTHER RESEARCH AND DEVELOPMENT.

Natural Gas Resources and Reserves Analysis

DOE conducts research necessary to provide industry, government, and academic customers with accurate, unbiased, timely, and focused estimates of current and predicted future U.S. natural gas resources and reserves. Research first characterizes the location, geology, gas availability, trapping mechanism, and specific reservoir geometry for natural gas reservoirs in any given area. Based on this characterization, specific products are developed that enable analyses of specified basins, as well as assessment of the natural gas resources and reserves for any given type of natural gas reservoir.

Resources and reserves products include:

- Tight gas basin studies within the framework of the DOE-U.S. Geological Survey Interagency Agreement, which provide a framework for DOE reservoir evaluation studies.
- Natural gas atlases, which are hard copy publications indicating locations of known or inferred natural gas reservoirs within the identified geological basin. Atlases include reservoir characteristics, reservoir volume, gas trapping mechanisms, and potential gas estimates.
- Natural gas databases containing data relevant to basin geology and the reservoirs within a basin, such as depth, geologic formation, and any associated deposits (e.g., oil, water). They also contain data on reservoir areal extent and reservoir thickness, porosity, and permeability.
- Reservoir models to mathematically simulate flows, predicting the development and production of a reservoir and, ultimately, its technical and economic producibility. Analyses can be based on current and potential future conditions.
- Estimating methodologies that can be generated for each type of reservoir identified, such as normal and tight gas reservoirs at shallow, average, and deep depths; geopressured formations; low quality gas reservoirs; other secondary type production reservoirs; and hydrates.

Success Story

Five of six planned natural gas atlases, cofunded by GRI, have been completed: Rocky Mountain, Midcontinent, Appalachian Basin, Texas, Central and Eastern Gulf Coast. The sixth, an atlas of Northern Gulf of Mexico oil and gas reservoirs, is in progress.

Improved imaging and modeling of the facies in these highly compartmentalized reservoirs can boost recovery efficiencies.

FLUVIAL DOMINATED DELTA FACIES RELATIONSHIPS

Oil Exploration Research

Oil exploration research is aimed at stimulating activity in currently underdrilled areas and in untested formations within older producing areas. Work focuses on updating and increasing the amount of publicly available information on regional geology and hydrocarbon prospects (basin analysis) for use by explorationists, and on improving techniques used in exploration and basin analysis. Basin analyses will also develop and refine resource and recovery estimates for high priority basins.

The program is developing and disseminating improved risk based decision management tools to improve confidence in economic analysis of exploration and production. The future activities will focus on assisting Native American Tribes to identify and develop their oil and gas reserves. Projects are conducted in Alabama, Arizona, California, Illinois, Kansas, Montana, and Oklahoma.

Descriptions of three exemplary projects follow.

Success Story

As a result of DOE's basin analysis, the Hopi Tribe is considering opening its reservation in northeast Arizona to oil and gas exploration activities.

Basin analysis of underexplored regions

DOE-funded exploration research primarily assists oil and gas producers and Native American Tribes that own hydrocarbon bearing lands. Because these groups have limited research capabilities, DOE-funded research identifies new targets that would otherwise go unidentified, and also stimulates oil and gas production in existing reservoirs. Regions to be analyzed include the Black Mesa Basin (northeastern Arizona), the Midcontinent Rift Zone, the Northern Rockies, and the Mississippian interior salt basin. Partners in the project are BDM-Federal, the University of Alabama, the Montana Bureau of Mines and Geology, the Hopi Tribe, and the Three Affiliated Tribes.

Software for risk based exploration and development decision making

This project, conducted by BDM-Federal, is developing risk analysis software for petroleum industry applications, targeting the needs of independent producers. Applying risk analysis technology to reduce uncertainty in exploration and development will involve such disciplines as geoscience, petroleum engineering, environmental science, business, mathematics, and computer science. This software will provide specific techniques for petroleum exploration risk analysis that are not found in commercially available general-purpose risk analysis and decision making software products.

Flow experimentation, modeling, and assessment of productivity and injectivity of horizontal wells

Partners in this project are Stanford University and industrial affiliates: AGIP, Amoco, Institute Français du Petrole, British Petroleum Company, Chevron, Minerals Management Service, Intevep, Marathon, Mobil, Norsk Hydro, Petrobras, Texaco, and Union Pacific. Stanford will conduct flow experiments and develop modeling and assessment techniques to improve quantitative tools for assessing horizontal well performance under a variety of reservoir conditions.

Project activities include modeling horizontal wells; analyzing the effect of heterogeneities on reservoir characterization; developing improved methods for calculating multiphase pressure drops; developing multi-well models; testing horizontal well models with field examples; and screening enhanced oil recovery applications for use in horizontal wells.

RESERVOIR LIFE EXTENSION TECHNOLOGIES EQUIP PRODUCERS TO RECOVER MORE OF OUR NATION'S OIL AND GAS RESERVES

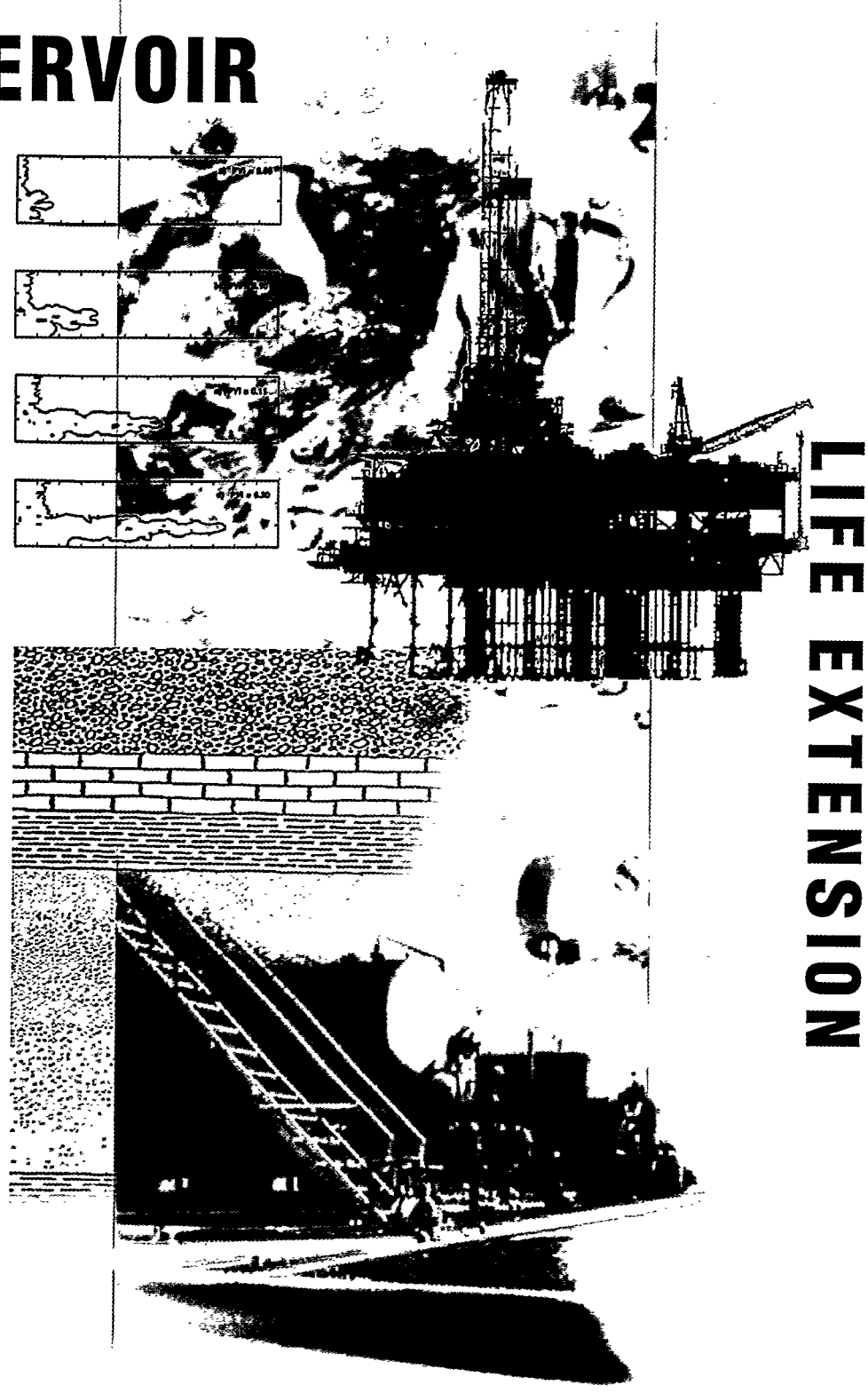
Nearly 140 years after the birth of the U.S. oil and gas industry, resources in the ground are still double the amount producers have extracted. Yet recovering these remaining resources poses technical and financial challenges.

Many oil fields are in danger of being abandoned even though they retain one-half to two-thirds of their original oil. The high capital cost of drilling wells, and the difficulty in restoring production leases, make it unlikely that abandoned fields will ever be reopened, even if future oil prices increase sharply. Premature abandonment, in effect, permanently cuts off access to valuable oil assets.

In many reservoirs producing natural gas, previously unrecognized gas producing zones can be brought into production, extending the life of these gas reservoirs.

The Department of Energy, in partnership with the U.S. oil and gas industry, supports the development of innovative and cost effective technologies that can extend the productive life of domestic reservoirs. By encouraging advances in oil and gas recovery technologies and facilitating their transfer to producers, DOE can help to slow the rate of premature abandonment of U.S. oil and gas wells, and to reduce our reliance on energy imports.

RESERVOIR



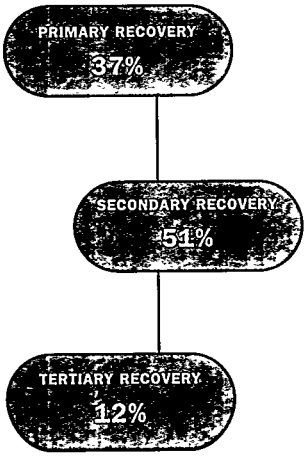
ENCOURAGING PRODUCTION OF REMAINING OIL AND GAS

LIFE EXTENSION

RESERVOIR LIFE

EXTENSION PROGRAM

New technologies can slow the premature abandonment of U.S. oil and gas wells



Current U.S. oil production is 6.4 million barrels of oil per day. Of this amount, 37 percent is produced by primary recovery. In mature oil fields, the contribution of primary recovery declines each year while the contribution of secondary and tertiary recovery increases over time.

The goal of DOE's Reservoir Life Extension Program is to slow the rate of abandonment of commercially marginal oil and gas reservoirs by accelerating the development and transfer to industry of innovative, cost effective technologies. These technologies, if widely applied by the Nation's oil and gas producers, are estimated by DOE to be capable of increasing the annual yield of tertiary oil up to 1.9 billion barrels and the annual yield of natural gas up to 6.0 trillion cubic feet by the year 2015.

Typically, only about one-third of the oil discovered can be produced economically. Production at most petroleum reservoirs includes three distinct elements: primary, secondary, and tertiary recovery. Tertiary oil recovery is also known as improved oil recovery (IOR) or enhanced oil recovery (EOR). Primary recovery refers to production when energy stored in the reservoir is sufficient to drive the oil through reservoir rock into a wellbore. As reservoir pressure declines along with oil production rates, much additional oil can still be recovered using secondary recovery techniques. One such technology, waterflooding, displaces the oil and drives it to the wellbores of the producing wells.

Oil displacement in the reservoir is incomplete, however, even with secondary recovery processes. Tertiary oil recovery technologies — such as thermal, gas-miscible, chemical, or microbial methods — can provide additional production. Such technologies could potentially recover about half of the 350 billion barrels of "discovered but unrecovered" oil in the U.S.

The problems associated with more complete gas recovery are somewhat different. Research conducted by the Texas Bureau of Economic Geology, on behalf of the Gas Research Institute and DOE, has demonstrated that current production practices fail to recover a large portion of the gas in place. Even after 50 years of commercial production, substantial infield reserve growth exists in bypassed, incompletely drained, and untapped reservoir compartments, not to mention deeper pool potential in many fields. The DOE natural gas recovery program focuses on a more complete characterization of complex, heterogeneous reservoirs to afford a more precise placement of new wells and recompletions in existing wells.

Even though improved oil recovery technologies have significant potential to extend reservoir life, and have been successfully demonstrated in the laboratory and in the field since as early as the 1960s, their historically high cost has limited their widespread application. In the last decade, however, dramatic improvements in analytical and assessment tools have led to a greater understanding of the geology of reservoirs and the physical and chemical processes governing flows in porous media. This understanding has led to the development of new technologies that have potential for reservoir life extension.

The Reservoir Life Extension Program supports research and development of promising technologies in areas identified as priorities by the domestic oil and gas industry. Some of this research taps the unique strengths of the National Laboratories, which focus on high risk technology developments, where long-term payoffs are likely to prevent private companies from investing adequately on their own.

The National Petroleum Council, in its 1995 report, *Research, Development and Demonstration Needs of the Oil and Gas Industry,* identified reservoir life extension among its highest priority areas. The report included well productivity, stimulation techniques, recompletion techniques, and reservoir management as key technology needs.

The 1995 report of the Secretary of Energy Advisory Board, *Task Force on Strategic Energy Research and Development,* recommended reservoir life extension technologies in secondary and tertiary oil recovery. These technologies included polymer-augmented waterfloods and polymer-gel profile modification; continuous steam injection and in-situ combustion techniques; continuous gas injection, cyclic, and water-alternating-gas injection; and micellar surfactant and alkaline surfactant polymer flooding.

THE ROLE OF DOE

Today there is an increasing need to transfer improved secondary and tertiary recovery technologies more effectively to domestic producers to slow the rate of premature oil well abandonment, extend the life of mature reservoirs, and avoid the permanent loss of significant oil and gas reserves.

A recent study by the National Petroleum Council found that by the end of 2004, nearly 175,000 marginal wells and the associated production could be lost through premature abandonment. In 1995 alone, industry reports that more than 17,000 oil wells and more than 3,500 gas wells were abandoned. In addition, 100 to 150 offshore platforms are removed each year from the Outer Continental Shelf, and more than 25 percent of the remaining platforms are more than 25 years old.

Many of these wells, oil and gas fields, and offshore platforms could yield additional oil and gas with current recovery technologies, if technology transfer were more efficient. Because it is not economically feasible to renew production at an abandoned well, the loss of an oil resource due to abandonment is permanent.

DOE's Reservoir Life Extension Program, conducted in partnership with industry, supports research, development, and selective demonstrations of promising technologies, and encourages their transfer to U.S. producers, particularly independent producers, who now account for about 40 percent of the oil and 66 percent of the gas production in the U.S.

INDUSTRY ISSUES

- SUPPORT RESEARCH AND POLICIES TO LIMIT THE DECLINE OF DOMESTIC OIL PRODUCTION AND TO INCREASE GAS PRODUCTION
- EXTEND THE LIFE OF OIL AND GAS RESERVOIRS WITH DISCOVERED BUT UNRECOVERED RESERVES
- REDUCE ABANDONMENT OF OIL AND GAS STRIPPER WELLS
- IMPLEMENT COST EFFECTIVE SECONDARY AND TERTIARY OIL AND GAS RECOVERY TECHNOLOGIES
- ACCESS PC-COMPATIBLE RESERVOIR SIMULATIONS SOFTWARE THROUGH THE INTERNET
- GAIN ACCESS TO TECHNOLOGY AND INFORMATION ABOUT RESERVOIR LIFE EXTENSION THROUGH PARTICIPATION IN TOPICAL SEMINARS AND WORKSHOPS

Reservoir Life Extension Program

Drivers

- The Nation's energy security is at risk, with steadily increasing demand for transportation fuels and steadily declining domestic oil production.
- Rates of abandonment of oil and gas wells (17,000 and 3,500 per year, respectively) and offshore platforms (100 to 150 per year) are unacceptably high.
- Independent oil and gas producers (over 7,000 companies) conduct an increasing share of U.S. production activities, and they have limited capital to buy R&D and do not have the means to assume the perceived risk to try advanced technologies used by majors.
- Recovery of additional large volume of oil and gas requires improved extraction processes, sophisticated extraction numerical models, and improved reservoir management approaches. The technical problems are so complex that only joint research involving producers, service companies, universities, and National Laboratories can produce acceptable results.

Vision

By 2010, improved and new technologies will be made available to industry, helping to stabilize domestic oil recovery at current rates. Improved and new technologies will be helping to locate and produce additional gas from poorly drained and untapped reservoir compartments. Abandonment rates of marginal oil and gas wells will have stopped increasing, stabilizing at current rates.

Mission

Assure reliable supply of oil and gas by assisting industry in developing the tools and techniques needed to improve the rate of return on investments in oil and gas production activities. Maximize oil and gas extraction through focused research on reservoir life extension technologies and technology transfer.

Strategies

- Conduct research to develop and demonstrate the tools and methodologies of known reservoir life extension processes.
  - Focus projects on mature oil and gas fields in danger of premature abandonment, and on opportunities to increase the recovery of oil and gas from Federal lands.
  - Revisit Class 1 program on fluvial dominated deltaic reservoirs.
- Expedite technology transfer to industry by conducting pilot and field-scale demonstrations of proven laboratory technologies, and by working with industry associations such as the Petroleum Technology Transfer Council (PTTC) to provide focused technology workshops, information resource centers, and computer based information.
- Support ongoing university research in critical reservoir life extension areas (e.g., extraction technologies and recovery process modeling).
- Develop the scientific basis for major technology breakthroughs that are applicable to oil and gas as well as to other industries.

Measures of Success

By 2010, DOE and industry partnerships will yield:

- Stabilization of the rate of oil and gas well abandonments at the current level of 17,000 and 3,500 abandonments per year, respectively
- Matching or exceeding of the historical record of the rate of enhanced oil recovery (761,000 barrels of oil per day in 1992) by the year 2000
- Arrested overall decline in oil production by the ~~year 2000~~ 2005
- Production of additional gas from mature reserves
- Increased use of program products by industry, particularly by independent oil and gas producers
- Increased participation of oil and gas producers in technology transfer seminars and topical workshops
- Establishment of a regional network of PTTC resource centers, with full support and, eventually, full funding by industry

POTENTIAL BENEFITS

Individual projects within the Reservoir Life Extension Program are selected for their potential application throughout the domestic oil and gas industry. Research dollars are focused on those oil and gas reservoirs threatened by premature abandonment. Also important in the selection process is the total number of sites that might benefit from any given technology without severe modification or customization. Geologic class was chosen as the mechanism for clustering oil reservoirs immediately available for technology application. This assumes that reservoirs in similar geologic classes experience the same technical barriers, and, as a result, technology successfully field tested for one reservoir in a geologic class should be suitable for another reservoir in a field of the same geologic class. Industry contribution to reservoir class field demonstration and secondary gas recovery projects, which are conducted at actual producing sites, is over 50 percent.

Technology transfer includes technical assistance to solve a specific problem; training in advanced equipment, techniques, and processes; use of costly or unique facilities; access to patents and software; exchange of personnel; and cooperative research. Regardless of its form, technology transfer is the guiding strategy for the Reservoir Life Extension Program.

RELATIONSHIP TO OTHER DOE PROGRAMS

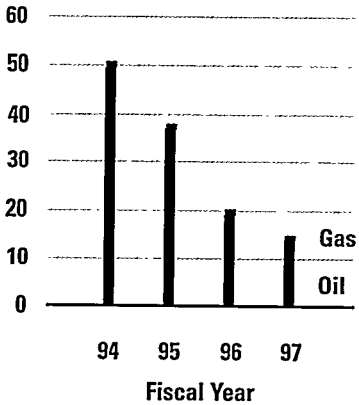
DOE's research in oil and gas extraction provides the data and heightened understanding of reservoir architecture required for gas storage technologies and for further improvement in diagnostics and imaging technologies. In particular, new advances in diagnostics, imaging, drilling, well completion, and reservoir simulation are often tested in pilot projects or in full-scale oil and gas recovery projects.

PROJECT SITES

Project activities are located in the shaded States; dots indicate concentrations of projects. A total of 90 projects are under way.

RESERVOIR LIFE EXTENSION PROGRAM BUDGET

($MILLIONS)



PROGRAM AREAS

RESERVOIR LIFE EXTENSION PROGRAM EFFORTS ARE ORGANIZED IN THE FOLLOWING FOUR AREAS:

- ENHANCED OIL RECOVERY RESEARCH AND DEVELOPMENT (SUPPORTING RESEARCH)
- RESERVOIR CLASS FIELD DEMONSTRATIONS
- SECONDARY GAS RECOVERY PROGRAM
- THE RECOVERY TECHNOLOGY FORUM OF THE NATURAL GAS AND OIL TECHNOLOGY PARTNERSHIP

THE DISCUSSION OF THE FOUR PROGRAM AREAS ON THE FOLLOWING PAGES HIGHLIGHTS SPECIFIC PROGRAM ACCOMPLISHMENTS AND SUGGESTS THE RANGE AND VARIETY OF PROGRAM ACTIVITIES.

Enhanced Oil Recovery Research and Development

DOE, in partnership with industry, focuses on research and development of four improved oil recovery methods: thermal, gas-miscible, chemical, and microbial. By organizing research in these four areas, DOE can focus its efforts on those wells most threatened by premature abandonment and the resulting loss of significant oil reserves. DOE directs most of its support, which includes financial contributions as well as personnel and unique facilities and expertise, to recovery technologies that have the highest potential for increased oil and gas production.

A total of 20 discrete research projects are now under way in the enhanced oil recovery (EOR) area of the Reservoir Life Extension Program. This area, more than the other program areas, is oriented to basic research, which is typically conducted by universities, National Laboratories, and the National Institute for Petroleum and Energy Research. The projects highlighted on these two pages are representative of the supporting research needed to build a solid technology foundation on which the other program areas can build.

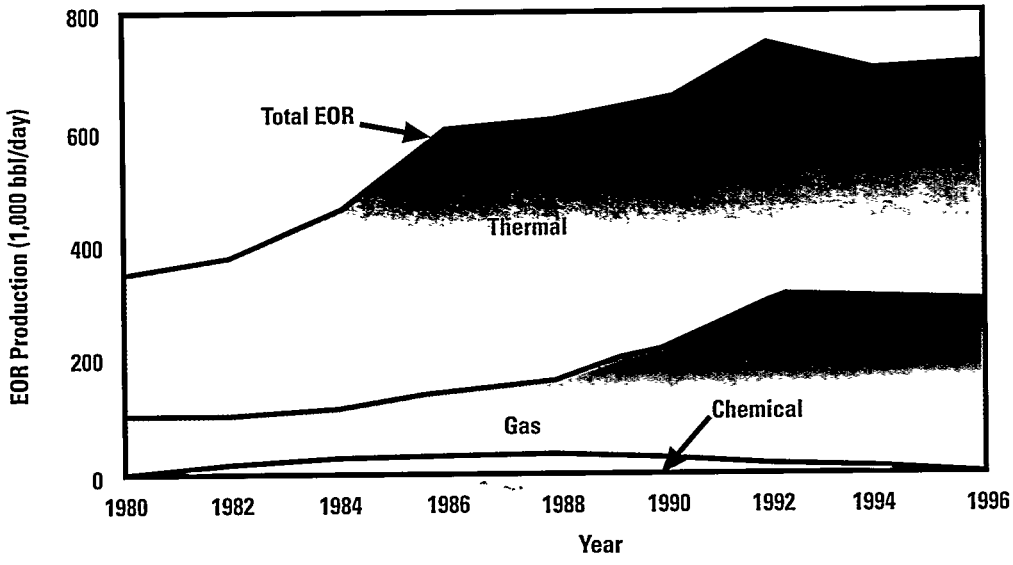
Fluid Diversion Using Polymer Gels

The New Mexico Institute of Mining and Technology, working with eight of the Nation's leading oil companies, developed a fluid diversion method in which chemical gels are used to plug depleted areas of the reservoir. Plugging diverts the waterflood toward oil-rich areas and reduces the total volume of water needed for the flood.

Six wells in Prudhoe Bay, Alaska, were treated with chemical gels, and, after treatment, the total yield of oil per day for the wells increased, while the total production of salt water decreased by 19,000 barrels per day.

U.S. Enhanced Oil Recovery by Major Recovery Technology

At present, EOR methods contribute 725,000 barrels per day to U.S. oil production. The specific contribution of gas-miscible projects using carbon dioxide is growing.



Field testing of microbial recovery

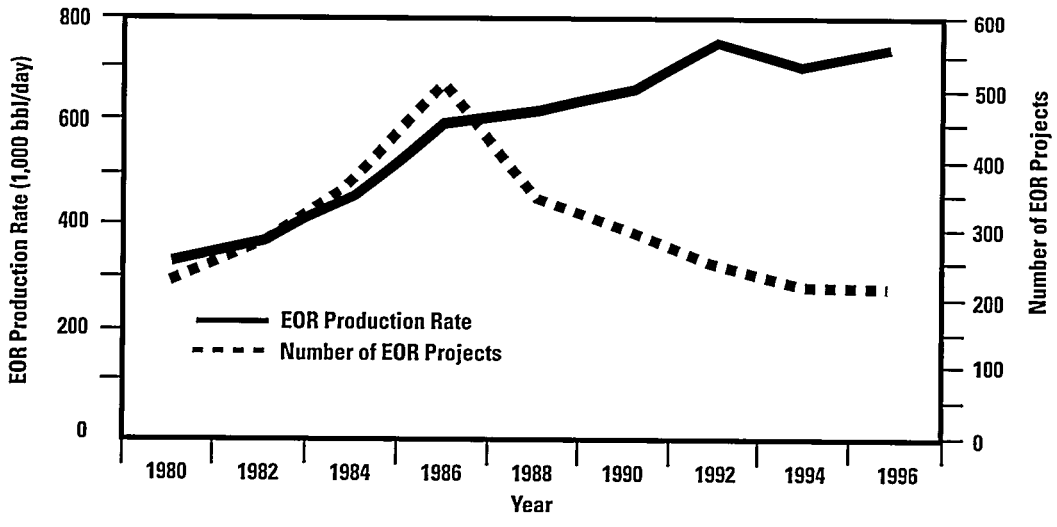
Laboratory research on the use of microbes in oil wells with low production was applied in two extensive field tests recently completed in Oklahoma. The tests demonstrated 13 and 20 percent improvements in the oil recovery rate. Based on these results, negotiations were completed for licensing the technology to a private company, and issuance of a license is awaited. The laboratory work has also led to the development of a permeability modification technology and a patent application in that area.

Supporting software, handbooks and manuals for independent producers

A total of 21 user friendly software packages, designed to help independent producers recover more oil from mature oil fields nearing abandonment, are available for downloading directly from the Internet without charge. All run on personal computers. Popular software packages include the so-called "simplified predictive models" for EOR technologies. By predicting the performance of steam flooding, in-situ combustion, polymer flooding, carbon dioxide flooding, and chemical flooding, this software provides a simple, inexpensive way to identify the technology most suitable or economic for a given oil property. The predictive models can be checked and downloaded from: http://www.bpo.gov./bpo-software.html

Enhanced Oil Production Rate and Number of Enhanced Oil Recovery Projects

Tertiary oil production in the U.S. continues to increase each year, though the number of EOR projects has declined. The increasing EOR production rate coming from fewer projects attests to the strength of the technology.



Reservoir Class Field Demonstrations

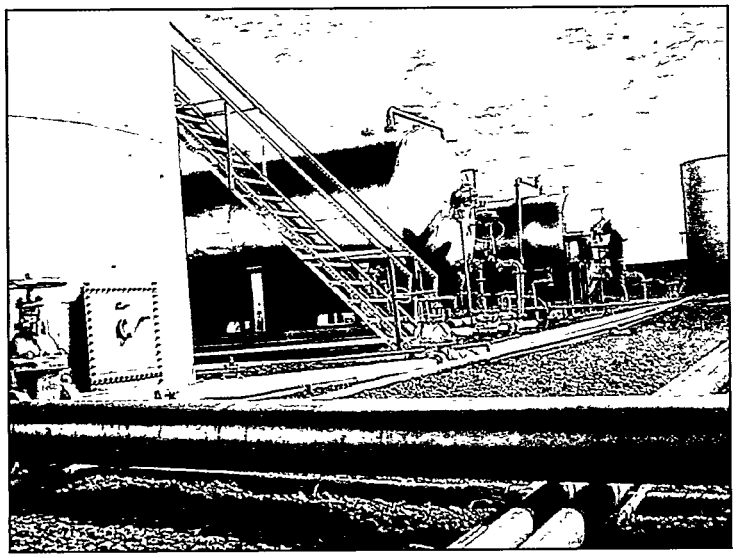
The trend toward abandonment of individual wells and fields must be turned around to prevent further loss of access to our Nation's precious oil reserves. To demonstrate that today's reservoir life extension technologies are a highly cost effective alternative to abandonment in many real life situations, DOE launched the Reservoir Class Field Demonstration Program. This area represents the opportunity for in-the-field application of many improved and new reservoir life extension technologies.

The technological premise of the Reservoir Class Program is that reservoirs with a common geologic origin often have common producibility problems. These problems should respond similarly to reservoir life extension technologies. As new or advanced technologies are ready to be demonstrated in the field, a group of producing oil wells, often spanning multiple States, are chosen as likely candidates for the demonstration. The wells are chosen because their reservoirs share similar geology, belonging to one of the three reservoir classes selected for demonstrations.

The Reservoir Class Program was identified as a high priority program in the late 1980s. The background and technical rationale are documented in the April 1990 issue of the DOE Oil Research Program Implementation Plan. Originally, 10 reservoir classes were identified for further testing, but only three could be completed with available funds. From the outset, effective technology transfer has been a critical component of the Reservoir Class Program. A revised strategy calls for revisiting the three classes and analysis of lessons learned.

A commitment on the part of all program partners to technology transfer has been a critical factor in the program's success to date. Oil producers (including both small independent companies and major producers), universities, State agencies, service companies, and consultants, in partnership with DOE, team up for development, application, and transfer efforts. Project results are also being fed into a national petroleum technology transfer network.

DOE selected the first group of projects for the Reservoir Class Program in 1992. Currently, 29 projects in the three reservoir classes described below are under way in 15 States: Alabama, California, Colorado, Illinois, Kansas, Louisiana, Michigan, Mississippi, Montana, New Mexico, North Dakota, Oklahoma, Texas, Utah, and Wyoming. A single reservoir can be the site of more than one field demonstration project.



Results from field demonstrations, such as this application of carbon dioxide flooding technology, can often be widely transferred.

Fluvial deltaic (Class I)

These reservoirs were formed in ancient river deltas and originally contained about 70 billion barrels of crude oil. Class I reservoirs now contain over 5 billion barrels of potentially recoverable oil; half of this oil is at risk of abandonment by 2010. In April 1992, 14 projects were selected representing nine States — Alabama, Colorado, Illinois, Kansas, Louisiana, Oklahoma, Texas, Utah, and Wyoming — and Offshore Gulf of Mexico. Three projects were terminated during start-up as a result of economic problems, and four projects were completed successfully in 1996. The final seven projects will be completed by 2000.

Shallow-shelf carbonates (Class II)

Formed in shallow ocean shelves, these reservoirs originally contained more than 68 billion barrels of crude oil. Most of the remaining 48 billion barrels are at risk of being abandoned. Advanced technologies have the potential to recover an additional 5 billion barrels. Nine projects, initiated in 1993, are now active in eight States: Kansas, Michigan, Montana, New Mexico, North Dakota, Oklahoma, Texas, and Utah.

Slope basin (Class III)

Created from sediment deposited in deep ocean slope and basin areas, these reservoirs are estimated to have originally contained nearly 60 billion barrels of light and heavy crude oil; most of the remaining 44 billion barrels are in danger of being abandoned unless more sophisticated techniques are widely deployed. Advanced technologies have the potential to recover an additional 5 billion barrels. Nine projects were awarded in three States: California (onshore and offshore, Outer Continental Shelf), New Mexico, and Texas.

Key enhanced oil recovery methods

Although enhanced oil recovery methods are generally placed in one of three categories — thermal, gas-miscible and -immiscible, or chemical recovery — new or improved technologies often combine elements from more than one category. Methods of the future — including such unconventional approaches as fieldwide development of strategically placed horizontal wells, gravity drainage enhancement, microbial EOR, and radio frequency heating — introduce whole new categories of EOR technologies. Each technology below is identified by its predominant recovery method.

Thermal recovery

Steam injection. Applicable for individual well stimulation or fieldwide flooding, steam injection and flooding are very effective for recovery of heavy, viscous crudes.

In-situ combustion. This process attempts to recover oil by heating it through the burning of a portion of in-place crude. Air or oxygen is injected to facilitate burning. The process is very complex, involving multiphase flow of flue gases, volatile hydrocarbons, steam, hot water, and oil, and its performance in general has been insufficient to make it economically attractive to producers.

Gas-miscible and -immiscible recovery

Miscible gas drive. In place of the costly hydrocarbon gases used in the past, miscible gas drives now inject such gases as carbon dioxide, nitrogen, or flue gas. Along with steam flooding, carbon dioxide flooding has proven to be among the most promising EOR methods for the U.S. because it takes advantage of plentiful, naturally occurring carbon dioxide.

Chemical recovery

Polymer flooding. In this enhanced waterflooding method, high molecular weight, water-soluble polymers are added to the injection water to improve its mobility ratio, reducing oil "bypassing" and raising yields. Permeability profile modification treatments with polymer solutions are becoming increasingly common.

Surfactant flooding. Also known as micellar-polymer flooding, low tension waterflooding, and micro-emulsion flooding, this method typically involves injection into the reservoir of a small slug of surfactant solution, followed by polymer-thickened water, then brine. Despite its very high displacement efficiency, micellar-polymer flooding is hampered by the high cost of chemicals and excessive chemical losses within the reservoir.

Natural Gas and Oil Technology Partnership

The Recovery Technology Forum, one of three forums organized through the Natural Gas and Oil Technology Partnership, was created specifically to tap the unique capabilities and knowledge of the National Laboratories, particularly the insights derived from DOE-funded research in weapons and energy. Operating since 1989, the Partnership involves nine multipurpose National Laboratories working jointly on about 50 projects with over 80 participants in industry, universities, and several States. The Recovery Technology Forum currently directs 12 selected, cost shared projects that aim to improve production from existing oil and gas wells by expediting the development and transfer of recovery technologies.

Improving the yield of marginal wells, making them economically sound for longer periods to discourage premature abandonment, does not always require application of the most sophisticated reservoir life extension technologies. Sucker rod failures, inability to measure oil properties in the field, paraffin build-up — any one of these problems can sway delicately balanced economic scales toward abandonment. By providing independent producers with immediate, cost effective, and realistic solutions to these and other problems, the Recovery Technology Forum is helping to "buy time" for producers and extend the life of marginal wells.

Recovery Technology Forum partnerships are characterized by industry-driven technology transfer, flexible cost sharing agreements, and short proposals and response times. Industry partners include independent and major oil and gas producers as well as service companies.

Success Stories

DOE's National Laboratories developed cutting edge expertise in advanced computing during the Cold War. Now, through the Natural Gas and Oil Technology Partnership, this expertise is helping to maintain the technology leadership of the U.S. petroleum industry. Parallel computing and Internet technologies, for instance, promise to revolutionize industry practices in oil discovery and recovery.

✦✦✦

Through the Natural Gas and Oil Technology Partnership, oil and gas data of public record are being made more accessible to hundreds of small, independent producers. Over 20 oil-producing States have asked to join the initial participants, Texas and California, in creating a standardized data interface that will be accessible via the Internet in the future.

ONE-DIMENSIONAL RESERVOIR SIMULATION

Researchers at the Department of Petroleum Engineering at Stanford University, funded by DOE and a consortium of oil companies, have developed a novel computational technique that greatly improves current state-of-the-art reservoir simulation technology. Basically, fluid flow in a reservoir is calculated in one dimension, but separately, along many "streamlines." This one-dimensional simulation technology is 1,000 times faster than conventional reservoir simulation and is more accurate as well (even for very complex production scenarios). Such speed-ups in the time needed to complete simulations will allow a much more extensive search for optimal production strategies.

APPLIED PRODUCTION TECHNOLOGY PROJECT

New wells and the booking of potential reserves receive a lot of attention, but if a new well is not carefully managed and if new technologies are not introduced at the site at appropriate times, then the total recovery potential for the well can be jeopardized.

The goal of the Applied Production Technology (APT) project is to target prompt application of low cost reservoir life extension technologies. Under the leadership of Sandia National Laboratories, the APT project addresses technology transfer for such specific areas as sucker rod failures, automatic casing swabs, field measurement of oil properties, and paraffin control. Through the APT project, small oil-patch businesses can receive technical assistance through Sandia's technology transfer organization.

Special attention to keeping the stripper phase of production economically viable as long as possible can significantly increase reserves. (Stripper wells are commercially marginal wells producing, by definition, less than 10 barrels per day.) In 1995, stripper well production accounted for 14 percent of U.S. production, or 946,000 barrels per day. Nearly 23,000 industry jobs and 27,000 collateral jobs depend directly on or are affected by production from the Nation's 434,000 stripper wells. The overall economic impact of stripper well production in 1995 was $8.5 billion. Implementation of the advances represented by APT projects can have a marked impact on preserving and enhancing this financial and energy resource.

Participants in the APT project include Albert Engineering, Belden & Blake, Flexbar, Petrolite, the University of Oklahoma, the Paraffin Control Working Group, and the Sucker Rod Working Group.

RECOVERY TECHNOLOGY FORUM PROJECTS

- ADVANCED TILMETER HYDRAULIC FRACTURE IMAGING
- APPLIED PRODUCTION TECHNOLOGY
- EXTENDING BOREHOLE ELECTROMAGNETIC IMAGING OF CASED WELLS
- FLUID INJECTION INTO TIGHT ROCKS
- FRACTURE MAPPING AND SLIMHOLE GEOPHONE ARRAY
- IMPROVED PREDICTION OF MULTIPHASE FLOW IN PETROLEUM RESERVOIRS
- MAPPING STEAM AND WATER FLOW IN DIATOMITE
- REDUCTION OF WELL FAILURES IN DIATOMITE
- OPTIMIZING RESERVOIR PRODUCTION
- SURFACTANT-ENHANCED DISPLACEMENT OF STIMULATION FLUIDS FROM HYDRAULIC FRACTURES
- ULTRASONIC REDUCTION OF FORMATION DAMAGE
- WIRELESS TELEMETRY TOOL

Secondary Gas Recovery Technologies

The Secondary Gas Recovery Program project brings together the technical expertise and research capabilities of DOE, the Gas Research Institute, the State of Texas, and various industry partners. The project has been operating for eight years and has been funded at $36 million. Of this, the Gas Research Institute has contributed $16.1 million. The project participants approach the Secondary Gas Recovery project with this philosophy: if more can be learned about the internal architecture of a mature, producing gas reservoir, then U.S. natural gas producers can target drilling efforts in an attempt to capture some of the estimated 25 percent of recoverable gas now unattainable through conventional methods. The principal components of the Secondary Gas Recovery project are reservoir analysis and targeted application of innovative drilling technologies in an attempt to increase recovery of secondary natural gas reserves.

Like the Reservoir Class Program, the Secondary Gas Recovery project also conducts field demonstrations at producing wells, a strategy that reduces risk to producers.

Secondary gas recovery demonstrations were initiated in South Texas and later shifted to the southern midcontinent and Permian Basins. It is anticipated that the demonstrations will shift again, this time to the Appalachian region. Demonstrations have been conducted at these Texas gas fields: Stratton, Lake Creek, McAllen Ranch, Agua Dulce, North McFaddin, Boonsville, and Lockridge-Waha.

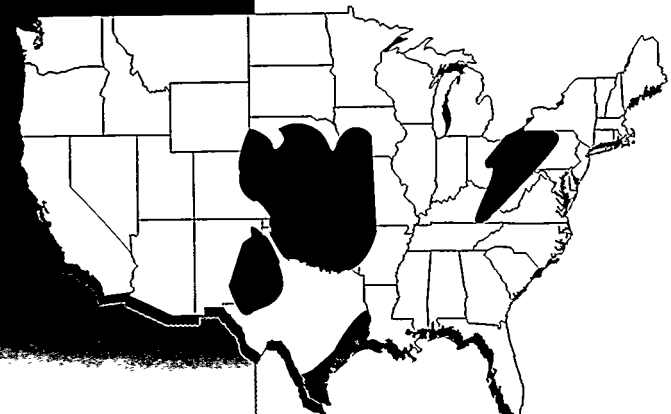
Field demonstrations of reservoir analysis and focused drilling have been completed or are under way at locations where gas reservoirs have been deposited in fluvial, fluvial deltaic, and carbonate environments. Though numerous other reservoir environments exist, these three promise to yield the greatest increases in production after application of new technologies. Each field study is conducted by a team of six to ten people representing expertise from core disciplines. Knowledge gained from each field study is promptly transferred to industry through an extensive and intensive technology transfer program component. Key industry beneficiaries include the thousands of small, independent oil and gas operators that now manage the majority of the Nation's onshore hydrocarbon-producing properties.

The magnitude of the work and the degree of industry cofunding determines the actual amount of public funding required for any one field demonstration. Industry partners provide additional cash or in-kind contributions. In every field demonstration, industry's dollar-value contribution significantly exceeds the combined DOE and Gas Research Institute funding.

Success Story

Lifting the geologic veil that has until now obscured gas pools in producing reservoirs in southwest Texas has had dramatic economic results. With the application of technologies developed through the Secondary Gas Recovery project, proved natural gas reserves are increased by about 4 trillion cubic feet in the Gulf Coast alone. Gross production revenues from secondary gas reserves are expected to approach $1.4 billion. Project results have tremendous potential to be replicated in other regions.

SECONDARY GAS RECOVERY PROGRAM TARGET AREAS



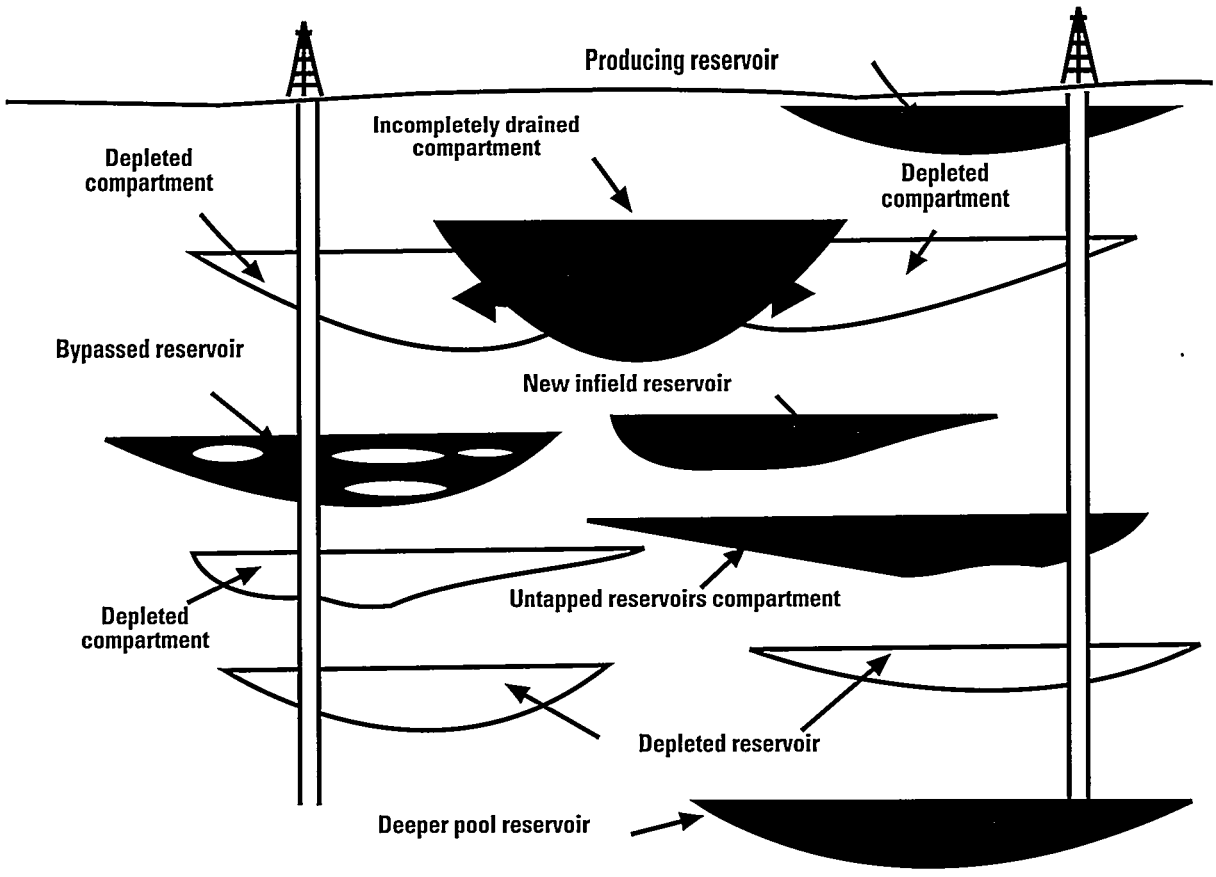
RESERVOIR "SNAPSHOTS" FOR FOCUSED DRILLING

Advanced exploration and production technologies such as crosswell seismic tomography provide a better "snapshot" of the internal architecture of producing gas reservoirs. Such technologies, coupled with already existing and newly acquired 3-D seismic, logging, and other data, help producers understand how gas reservoirs are compartmentalized. With this information, drilling efforts can be targeted to reach new production zones or bypassed compartments.

Correct reservoir analysis directs the type of drilling most appropriate for any one reservoir. When appropriate, new, smaller bore drills can be used, minimizing the surface area needed for drilling and reducing the impact on the environment. Analysis also allows producers to determine if wells can be drilled in one location and completed several miles away, again protecting the surface environment while allowing recovery of valuable oil and gas resources deep within the earth.

SECONDARY GAS RECOVERY PROJECT

Secondary gas recovery technologies can tap "hidden" pools of natural gas.



THE NATURAL GAS STORAGE SYSTEM PROVIDES A VITAL LINK BETWEEN PRODUCTION AND END USE

In February of 1996, temperatures in the northeast and midwest United States plunged below zero for several days, causing a surge in natural gas demand for residential and commercial heating. The gas industry's success in meeting this surge was due to the reliability of the gas delivery and storage system, which plays a critical role in ensuring adequate supply of gas during periods of heavy demand.

But will this system be able to continue to meet peaks in demand into the next century? At the same time that forecasters are predicting increased demand for clean burning, abundant natural gas, the gas industry faces unprecedented challenges. Extensive restructuring, driven primarily by Federal regulatory change, has transformed the heavily regulated industry of the past into an intensely competitive, market driven one. Deregulation has placed significant demands on the gas delivery and storage system, demands that will intensify with impending electric utility restructuring. The gas industry must also address the need for system expansion in response to increased demand in the east and the westward shift in gas supply, and plan for the increased maintenance required by the aging delivery and storage system infrastructure.

Advanced technologies will be a key factor in meeting the challenges facing the natural gas industry. These challenges require significant investment in R&D at a time when gas distribution companies are focusing their resources on operating profitably in a deregulated environment. The Department of Energy is working with industry to help ensure a safe, reliable, and cost effective supply of natural gas. Through its Gas Storage Program, DOE promotes the development of advanced technologies and methods to enhance and expand the delivery and storage system. These cooperative efforts will increase gas system deliverability, contributing to our Nation's energy security, economic competitiveness, and environmental goals.

ENHANCED

DELIVERABILITY

MEETING PEAK DEMAND FOR NATURAL GAS SUPPLY

GAS STORAGE PROGRAM

Gas storage is the primary means of managing fluctuations in supply and demand

The natural gas market is a $90 billion per year industry, with over $50 billion spent in 1995 for the purchase of natural gas, including imports and liquefied natural gas. Interstate pipeline capacity charges and local distribution company capacity tariffs exceed $32 billion.

Deregulation has prompted significant change in the natural gas industry, introducing market efficiencies that have saved consumers $90 billion over the last 10 years. A key aspect of deregulation, the unbundling of gas transportation from the supply function, has put new demands on the gas delivery and storage system.

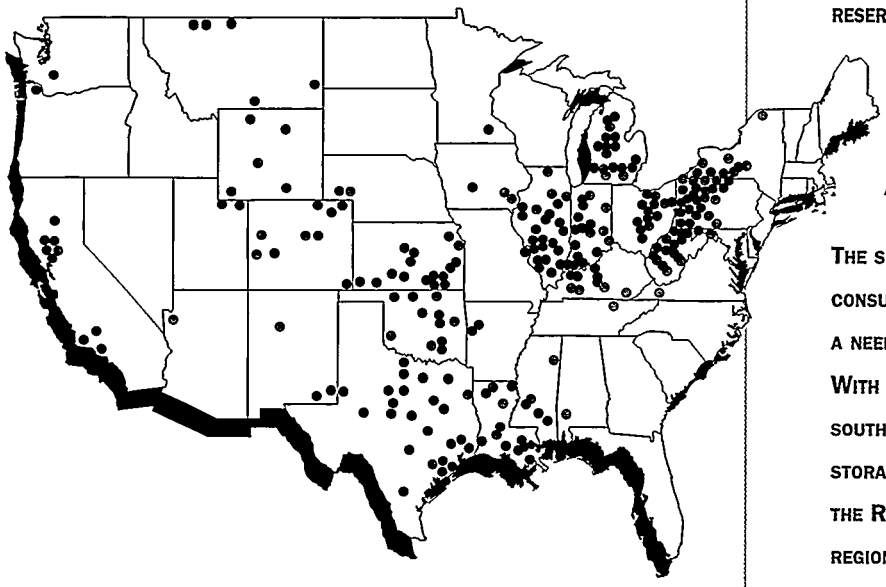
Gas storage is the primary means of managing fluctuations in supply and demand. To ensure that adequate supplies are available to meet customer requirements in winter, industry injects large amounts of gas into underground storage reservoirs from April through October. During these months gas demand declines as temperatures rise. During the heating season, industry supplements pipeline capacity from the producing regions with supplies from storage to meet demand. Gas from storage can supply up to 30 percent of daily gas demand in winter months.

Storage enables greater system efficiency by allowing more level production and transmission flows throughout the year. Because of this leveling effect, storage decreases the amount of transmission pipeline that must be constructed to connect the producing regions to the marketplace by 50 percent. End use customers gain from such system efficiency with reduced overall costs of service. Storage also allows continuous service even when production or pipeline transportation services are interrupted. In 1992, for example, storage enabled continuous service to customers despite the damage to gas production facilities caused by Hurricane Andrew.

Industry will need to expand the existing gas storage system to meet anticipated future demand for gas, which is forecast to increase by as much as 4 trillion cubic feet (Tcf) by 2010. This rising demand raises concerns about the system's ability to meet peak requirements in the future.

GAS STORAGE MUST ADDRESS SHIFTS IN SUPPLY AND CONSUMPTION

NATURAL GAS IS DISTRIBUTED TO VIRTUALLY EVERY REGION OF THE COUNTRY THROUGH AN EXTENSIVE SYSTEM MADE UP OF MORE THAN 1.3 MILLION MILES OF PIPELINE, METERS, COMPRESSOR STATIONS, AND APPROXIMATELY 375 STORAGE RESERVOIRS. THE GAS INDUSTRY CURRENTLY HAS THE CAPABILITY TO DELIVER APPROXIMATELY 3.5 TCF OF GAS FROM THESE STORAGE SITES, WHICH ARE HEAVILY CONCENTRATED IN AND NEAR MAJOR EASTERN AND MIDCONTINENT MARKETS.



THE SIGNIFICANT SHIFT IN NATURAL GAS SUPPLY AND CONSUMPTION PATTERNS EXPECTED BY 2010 WILL CREATE A NEED FOR NEW TRANSMISSION AND STORAGE FACILITIES. WITH THE ANTICIPATED DECLINE IN PRODUCTION FROM THE SOUTHWEST CENTRAL REGION, ADDITIONAL TRANSMISSION AND STORAGE CAPABILITY WILL BE REQUIRED TO MOVE GAS FROM THE ROCKY MOUNTAINS AND FROM CANADA TO NEIGHBORING REGIONS AND TO THE NORTHEAST AND CALIFORNIA.

THE ROLE OF DOE

DOE is working with industry to ensure that the gas delivery and storage system continues to provide a reliable, cost effective supply of natural gas well into the next century. Through its Gas Storage Program, DOE supports the development of advanced technologies and methods to enhance deliverability, increase efficiency, and reduce the costs of operation and maintenance.

The gas storage industry currently spends over $100 million annually for deliverability enhancement. Advanced revitalization technologies could reduce these maintenance costs by 20 percent. In sharp contrast, less than $3 million per year is spent on gas storage technology research and development ($1.6 million by the Gas Research Institute and $1 million by DOE). DOE and GRI projects focus on high priority technology needs as identified by industry.

In its *Fiscal Year 1997 Funding Recommendations to the U.S. Department of Energy for Natural Gas Research, Development, and Demonstration*, the Gas Industry RD&D Initiative Group highlighted transportation and storage needs as part of a broad program of technology developments recommended for government support. Specific storage needs cited include:

- Engineering techniques that can revitalize storage well deliverability
- Accurate, real time metering and measurement flow technology

The National Petroleum Council (NPC), in its 1995 study of *Research, Development, and Demonstration Needs of the Oil and Gas Industry*, ranked gas storage technologies for well deliverability restoration and reservoir management as high priority needs in both the short and long term.

DOE's Gas Storage Program activities also build on the findings and recommendations in the NPC report, *The Potential for Natural Gas in the United States* (1992); the Federal Energy Regulatory Commission/DOE study, *Natural Gas Deliverability Task Force Report* (1992); the *Domestic Natural Gas and Oil Initiative* (1993); and the *Task Force on Strategic Energy Research and Development* (1995).

Joint DOE-industry projects are selected for their potential application throughout the domestic gas industry. Current technology development efforts include:

- Novel and advanced fracture simulation technologies and improved remediation treatments that will increase storage reservoir deliverability and help to offset the reported 5.2 percent annual decline in deliverability
- The development of improved gas flow metering and energy measurement technologies that will provide real time, automated monitoring of pipeline gas flow and energy content, increasing system deliverability and optimizing gas sales to customers
- Advanced storage technologies that will meet the specific storage needs of new and growing industrial and power generation markets, specifically the short-term or hourly requirements of the power generation sector

Another way that DOE maximizes its R&D investments is through technology transfer. Technology transfer is a key component of all DOE projects and assures that R&D results are shared among industry and other stakeholders.

INDUSTRY ISSUES

- Develop novel and advanced fracture simulation technologies
- Develop improved gas flow metering and energy measurement technologies
- Develop advanced storage technologies to meet the needs of new and growing industrial and power generation markets
- Implement uniform production reporting model guidelines
- Reengineer underground gas storage reservoirs to increase operational flexibility
- Optimize deliverability of gas to consumers via low cost gas storage systems
- Improve methods and lower costs for storage system operation and maintenance
- Extend the useful life of underground storage reservoirs
- Gain a better understanding of reservoir damage mechanisms
- Develop liquefied natural gas peak shaving technology

Gas Storage Program

Drivers

- Regulatory changes increased system deliverability requirements.
- Increased demand and shifting sources of supply create a need for delivery and storage system expansion.
- The aging delivery and storage system infrastructure requires increased maintenance.

Vision

By 2010, industry use of advanced natural gas storage, transmission, and distribution technologies will have enhanced the operational flexibility and deliverability of our Nation's gas storage system, providing a cost effective, safe, and reliable supply of natural gas to meet demand in new and expanded market regions.

Mission

Advance technologies and methods to increase the efficiency and reliability of the natural gas gathering, transmission, storage, and distribution system.

Strategies

- Promote the development and use of advanced technologies necessary for efficient delivery and storage of natural gas.
  - Enhance gas storage field deliverability.
  - Demonstrate improved gas flow measurement technologies.
  - Demonstrate technologies to optimize storage field development strategies.
  - Develop accurate, real time reservoir information systems to optimize gas storage.
  - Enhance reservoir management and control of gas migration from storage fields.
  - Demonstrate advanced direct energy meters for delivery systems and gas storage facilities.
- Identify strategic market areas for new and growing natural gas use.
  - Determine projected natural gas demand.
  - Identify gas storage capacity and system deliverability requirements.
  - Advance storage concepts to increase gas supply at market centers.

Measures of Success

By 2010, DOE and industry partnerships will yield a more efficient natural gas market by improving gas storage service to consumers.

- Advanced storage well revitalization technologies are increasing deliverability from storage and reducing storage well revitalization and deliverability maintenance costs.
- Novel storage technologies are being used to meet the projected growth in gas demand.
- Ultrasonic meters are widely used at storage facilities because of their increased accuracy, lower installation costs, and reduced operating costs.
- Direct energy meters with real time flow measurement and energy content monitoring technology have increased pipeline capacity utilization and improved system reliability.

POTENTIAL BENEFITS

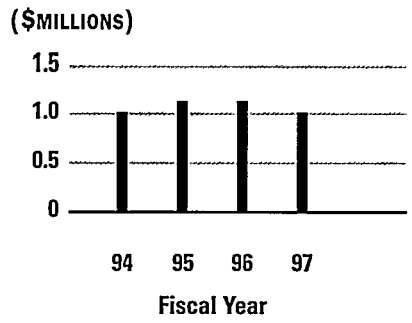
Development of advanced technologies that meet industry needs would result in a more efficient natural gas storage system and benefit both industry and consumers. The gas storage industry would benefit from improved storage efficiency through increased deliverability, decreased deliverability revitalization costs, and increased operating efficiency. Local distribution companies would gain from improved system reliability and flexibility. Industrial and power generation end users would benefit from advanced storage concepts, and residential customers would benefit from lower costs for service.

An enhanced gas storage system would also contribute to increased use of clean burning, abundant domestic natural gas resources, helping to meet our Nation's energy and environmental goals.

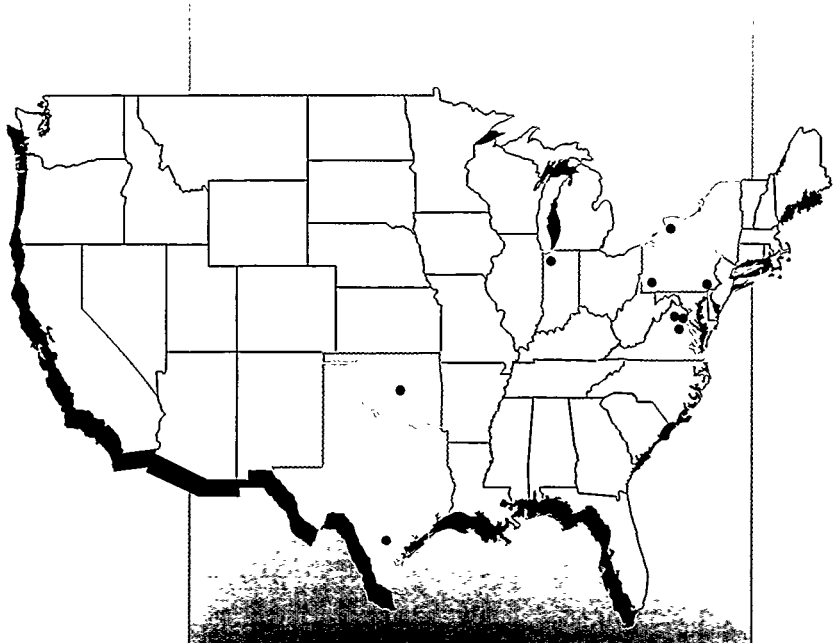
RELATIONSHIP TO OTHER DOE PROGRAMS

Once natural gas is produced, the gas delivery and storage system provides the link between wellhead and burner tip. DOE's Gas Storage Program focuses on the development of technologies and methods to enhance and expand this system. Many of the advances in other oil and gas program areas directly benefit the gas delivery and storage system, improving the development, deliverability, and maintenance of underground storage caverns.

GAS STORAGE PROGRAM BUDGET



PROJECT SITES



Project activities are under way at the sites indicated on this map.

PROGRAM AREAS

THE GAS STORAGE PROGRAM IS CURRENTLY FOCUSED ON A RANGE OF PROJECTS IDENTIFIED AS HIGH PRIORITY BY INDUSTRY. THE FOLLOWING PAGES HIGHLIGHT SOME SPECIFIC PROJECTS AND THEIR POTENTIAL RESULTS.

Gas Storage Technologies

DOE's Gas Storage Program is currently focused on a range of projects identified as high priority by industry. Some of the new storage technologies, such as ultrasonic metering, have potential for use in pipelines as well. Future projects may focus on technologies to improve transmission aspects of the storage system.

Success Stories

Northern Indiana Public Service Company (NIPSCO) partnered with DOE and GRI to demonstrate the use of geological modeling and seismic survey techniques to optimize the development and operation of gas storage fields. Based on the results of this integrated study, NIPSCO drilled a horizontal well at the Royal Center field in Indiana. Initial flow tests indicate that the well will significantly enhance deliverability from the field and allow the utilization of gas from an area of the storage field that was not accessible from the existing vertical wells.

✦✦✦

Universal Well Services, located in Wooster, Ohio, pumped the first ever CO_2/sand fracture stimulations in a gas storage field to determine the applicability of a totally nondamaging fracturing fluid. The deliverability from two underground storage wells at the Galbraith field in Pennsylvania, operated by National Fuel Gas Supply Company, increased by 600 percent.

✦✦✦

Well stimulation technology has improved deliverability from the HS-23 well in KN Energy's Huntsman Field in Nebraska by 16 million scfd. Two additional wells are scheduled for stimulation based on these results. KN Energy initially wanted to withdraw from the stimulation project due to a concern over damaging the reservoir seal and fracturing into an overlying water-bearing sand. DOE's contractor (Advanced Resources International) put together a test plan to gather data that provided a better estimate of whether the fracture height could be contained. Based on these data, KN Energy decided to proceed.

STORAGE WELL DELIVERABILITY IMPROVEMENT

This joint project focuses on a technology that reduces storage well maintenance costs and enhances deliverability. Project partner Advanced Resources International is demonstrating the use of fracture stimulation technology for revitalization of existing underground gas storage wells.

Many storage wells decline in deliverability after several years of production/injection cycling and require remediation to reestablish deliverability. The gas storage industry spends approximately $70 million annually trying to revitalize many existing wells, but current revitalization methods such as mechanical cleaning, blowing/washing, acidizing, and reperforating often provide only limited, temporary delivery restoration. Fracture stimulation technology shows high potential for long-term deliverability improvement at moderate cost. The first field test, conducted on three wells at the Galbraith Field in Jefferson County, Pennsylvania, increased deliverability from 8.7 million standard cubic feet per day (scfd) to 22.4 million scfd.

Not all storage wells will benefit from fracture stimulation technology, so DOE is working with the Gas Research Institute to determine damage mechanisms that reduce storage well performance. The goal is to enable operators to select the best remediation treatment for the type of damage affecting deliverability, leading to more cost effective treatments.

Anticipating new storage needs for power generation and other end users

The energy industry forecasts that the Nation's total power generation requirements will increase by one-fifth in the next decade, and that natural gas will supply as much as 40 percent of that increase. The Energy Information Administration forecasts that gas demand in the industrial market will increase 15 to 20 percent by the year 2000. The New England and South Atlantic regions have a combined projected growth of 1.5 Tcf of gas by 2010.

To service the projected increase in gas use in these markets, the gas industry must identify the market needs for new storage development and expansion of existing storage facilities in close proximity to existing and planned industrial and power generation facilities.

Project partner ICF Resources is conducting this analysis, studying gas use patterns for existing and planned facilities and establishing storage design criteria to meet expected demand. ICF will provide an assessment of the regional potential for capacity development by conventional methods and examine alternative methods of gas storage in areas where conventional methods would not work. The complete analysis will provide a blueprint for industry expansion in these new market areas.

DOE also issued a Program Research and Development Announcement in 1996 to conduct feasibility studies and develop conceptual designs for advanced storage concepts. These new or improved storage methods will provide storage in areas where conventional storage is not available or does not meet the requirements of end users.

Using ultrasonic meters to measure natural gas flow

Ultrasonic meters use high frequency sound pulses to obtain precise measurements of gas velocity. The Gas Research Institute (GRI) has been evaluating the use of ultrasonic meters for natural gas flow applications. DOE-supported research at GRI's Metering Research Facility at Southwest Research Institute will address issues involving gas storage field applications of ultrasonic meters, including:

- Bidirectional testing for undisturbed flow conditions over a range of gas pressures and temperatures
- Testing to evaluate thermowell effects on ultrasonic meter performance
- Low range testing, conducted at pressures below 200 psia, to check the accuracy and repeatability of ultrasonic meters down to about 0.2 percent of the rated flow capacity
- Compilation and evaluation of field performance data from industry trials

Ultrasonic metering technology offers significant cost savings for industry, including potential installation savings of 35 to 55 percent over typical orifice/turbine meter transmission measurement stations. Projected operating and maintenance cost savings range from $9,000 to $15,000, primarily due to fuel gas savings from pressure loss reduction.

This technology also represents a large economic opportunity for U.S. manufacturers of ultrasonic meters. The potential market for natural gas applications is estimated at $50 billion.

GAS PROCESSING TECHNOLOGIES CAN CONVERT UNMARKETABLE NATURAL GAS RESOURCES INTO VALUABLE GAS AND OIL PRODUCTS

In Alaska's far North Slope, there are vast natural gas resources that remain untapped because the gas is too remote from the marketplace for cost effective transport. Throughout many of our western States, there are gas reserves containing high levels of contaminants, which render these reserves economically unmarketable in most instances. Finding ways to utilize such unmarketable gas resources has become essential to sustaining a reliable domestic supply of gas and liquid fuels as our Nation's most accessible and economical supplies are depleted.

In partnership with the U.S. oil and gas industry, the Department of Energy seeks to advance technologies and processes that will enable the conversion of unmarketable gas resources into valuable oil and gas products needed by our Nation. For instance, gas-to-liquids technology could be used to convert remote natural gas into a liquid form suitable for easy transport and even direct use as an environmentally desirable transportation fuel. Similarly, gas reserves with high contaminant levels can be upgraded to market specifications using gas purification technologies. And advanced processes to collect and utilize the methane released during underground coal mining would harness this greenhouse gas and prevent it from being vented into the atmosphere.

All of these unmarketable gas resources have the potential to significantly increase our domestic energy supplies, and technology development is vital to tapping that potential. Through its Gas Processing Program, DOE works with industry and the Gas Research Institute to promote gas conversion and upgrading technologies that will enhance our Nation's energy security and reduce our dependence on oil imports. These efforts will also strengthen the economic competitiveness of the U.S. oil and gas industry and create export opportunities for advanced U.S. technologies.

MARKETABLE PRODUCTS

GAS PROCESSING PROGRAM

CONVERTING UNMARKETABLE NATURAL GAS RESOURCES INTO VALUABLE PRODUCTS

Technology development will enable use of unmarketable domestic gas resources

Current projections for producing Alaskan oil reserves show that in order to ensure operation of the Trans Alaska Pipeline, gas-to-liquids technology must be ready for deployment between 2009 and 2016. DOE and industry researchers are working together to ensure that advanced, cost effective conversion technology will be ready for U.S. commercialization within that time frame.

Over the past decade, DOE's Gas Processing Program has evolved in support of our national goal to expand the development and utilization of our abundant domestic natural gas resources. The use of natural gas offers environmental benefits over other conventional energy sources and helps to offset increasing oil imports.

Targeting unmarketable gas resources, joint government-industry R&D efforts focus on developing a technical base in gas upgrading and exploring processes to chemically convert gas to stable hydrocarbon liquids. The U.S. gas processing industry currently invests $10 million to $15 million annually in these efforts. DOE's Gas Processing Program has maintained a steady funding level of approximately $4 million annually.

Recent breakthroughs in gas-to-liquids conversion research indicate a potential 25 to 35 percent reduction in conversion costs, a key program goal. This fact, coupled with growing market opportunities for conversion technologies, has led to recent expansion of the program in order to build on the technology breakthroughs.

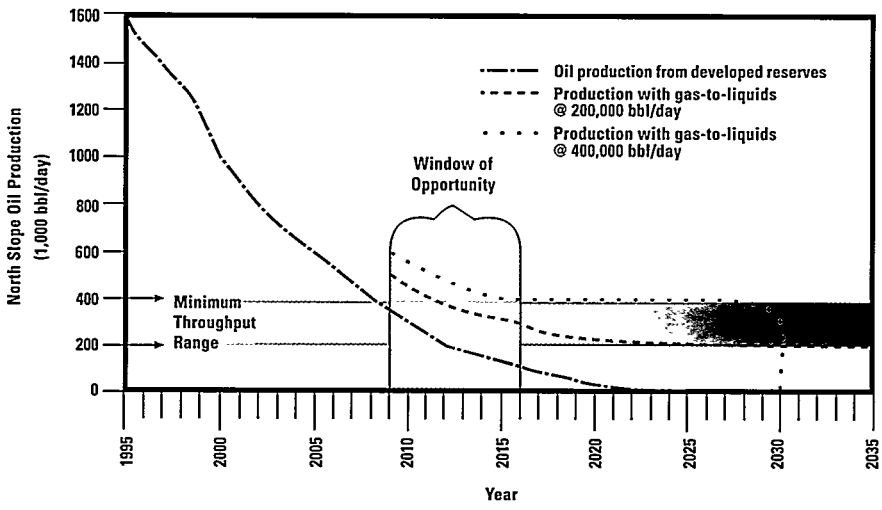
Tapping remote gas reserves

The vast natural gas reserves in Alaska's North Slope could be marketed if converted into a petroleum-like liquid that is more easily transported via pipeline and tanker to market. Similar gas-to-liquids (GTL) conversion processes can be accomplished on offshore platforms or barges in the Gulf of Mexico to facilitate oil and gas production from wells that do not have pipeline access.

Converted gas from Alaska's North Slope could be transported through the underutilized Trans Alaska Pipeline System, which carries crude oil from the Prudhoe Bay field on the North Slope to Valdez for tanker shipment to markets. Production from that field is declining at a rate of about 10 percent per year. Even with additional production from newer, more marginal fields, pipeline flow will eventually fall below the minimum volume needed for viable pipeline operation.

Use of this existing pipeline for transport of converted gas would not only reduce the cost of producing and marketing North Slope gas, it would also ensure that as much as 200,000 barrels per day of the last remaining North Slope crude oil will not be shut in due to insufficient pipeline utilization. Continued pipeline operation is vitally important to Alaska's economy, which depends heavily on the oil industry for jobs and revenue.

Window of Opportunity for Technology Deployment to Maintain Oil Pipeline Operation and Harness U.S. Energy Potential



The investment hurdles of present GTL technology, however, are formidable, and the gas conversion industry is in its infancy. Reducing capital requirements is a key goal of DOE's gas conversion research. A Shell Oil pioneer plant in Malaysia currently uses GTL technology to produce more than 15,000 barrels a day of high quality diesel fuel. This plant cost well over $500 million to build. In the Mideast nation of Qatar, Exxon plans to build a larger GTL plant to produce at least 50,000 barrels per day of similar liquids. The proposed plant is expected to cost over $1 billion to build. Building the same size plant in Alaska's North Slope could cost between $500 million and $1 billion more, primarily because of Alaska's harsher weather conditions.

In today's intensely competitive global business environment, many U.S. oil and gas companies have been forced to concentrate their investments overseas. DOE is working with industry to remove the technical and economic barriers to producing Alaska's North Slope gas reserves. Breakthrough technologies under development will improve the economics of large-scale GTL technology, making it economically viable and competitive with other oil and gas projects around the world.

Expanding Production of Low Quality Gas

Improving the economics of gas upgrading technologies is another priority for joint DOE-industry efforts. More cost effective gas purification technologies would allow greater volumes of low quality gas to be marketed.

Approximately one-third of our Nation's natural gas resource is low quality gas that does not meet market specifications for pipeline shipment. Typical specifications call for gas with no more than: 2 percent carbon dioxide; 4 percent total carbon dioxide, nitrogen, and other inert gases; and 4 parts per million of hydrogen sulfide gas. Some low quality gas can be blended with higher quality gas to meet market requirements. But much of our low quality gas must be upgraded through gas purification technologies that eliminate or substantially reduce inert and hazardous contaminants. Current technologies can be costly and, in some cases, cost prohibitive. In situations where the cost of upgrading would make producing the gas uneconomical, the gas is simply shut in. Advanced upgrading technologies under development will improve purification techniques while significantly lowering costs.

Utilizing Coal Mine Methane

Methane, a greenhouse gas considered at least 20 times more harmful to the atmosphere than carbon dioxide on a unit basis, is released naturally from coal and surrounding strata in the course of underground coal mining. Most of this methane is currently exhausted to the atmosphere through the mine's ventilation system.

Coal mine methane R&D efforts focus on the demonstration of available methods to economically collect and utilize this methane for pipeline sales, small-scale electric power generation, and other uses. The goal is to expand the number of mines that utilize emitted gas instead of passing it into the atmosphere.

The Role of DOE

Through its Gas Processing Program, DOE provides the science and technology leadership necessary to support industry efforts to develop economically viable advanced gas conversion and upgrading technologies. In its 1995 report, *Energy R&D: Shaping Our Nation's Future in a Competitive World*, the Secretary of Energy's Advisory Board included the need for gas processing technology advancements in its recommendations. Gas-to-liquids research was ranked highest in priority of all oil and gas technology activities.

To accelerate gas processing technology development, DOE facilitates cooperative partnerships that combine the scientific and technical resources of both industry and government to maximize results. Several of the technologies under development have proven successful at small scale and are ready for practical scale-up to engineering- and commercial-scale dimensions. If these technologies prove successful under large-scale operating conditions, DOE will serve as a catalyst for demonstration and deployment.

INDUSTRY ISSUES

- Improve the economics of large-scale gas-to-liquids technology
- Develop small-scale gas-to-liquids technology
- Replace imported methanol and other petroleum based feedstocks with inputs produced from our domestic natural gas reserves
- Develop economical organic and inorganic membranes to screen and separate natural gas components
- Develop cost effective gas-contaminant absorption and adsorption systems

Gas Processing Program

Drivers

- Our Nation's most accessible and economical supplies of oil and gas are being depleted.
- Utilization of unmarketable remote and low quality natural gas resources would help to sustain a reliable domestic supply of gas and oil fuels.
- Current technologies for gas-to-liquids conversion to easily transportable liquids and for low quality gas upgrading are costly, which limits or prevents their use.
- Technology development and demonstration are critical to deployment of improved, economically viable conversion and upgrading technologies
- Increasingly stringent environmental laws and regulations are intensifying the need for more advanced technologies to provide cost competitive clean burning fuels.

Vision

By 2010, the use of advanced natural gas conversion and low quality gas upgrading technologies will have maximized the value of all producible domestic gas resources, regardless of the location or original quality of these resources.

Mission

Assist industry in providing a diverse, secure domestic supply of natural gas as well as oil fuels by developing advanced gas technologies that convert unmarketable remote or otherwise low quality natural gas to valuable liquid and gas fuels and other products.

Strategies

- Develop and timely transfer to industry gas-to-liquids conversion technologies that offer significant cost reductions compared to today's marginally cost effective processes.
- Develop and transfer to industry cost effective technologies for upgrading low quality natural gas to pipeline quality and direct use, and for conversion to higher hydrocarbon liquid fuels.
  - Develop cost effective organic and inorganic membranes for separating low quality gas components.
  - Develop economical gas contaminant absorption and adsorption systems.
- Demonstrate technologies to cost effectively capture and productively use methane gas released during the underground coal mining process to reduce the escape of this gas into the atmosphere.

Measures of Success

By 2010, DOE and industry partnerships will yield:

- Improved technology for more efficient and lower cost removal of contaminants from natural gas
- Demonstration of advanced natural gas-to-liquids conversion technology that economically converts remote Alaska gas to pipeline-ready liquid fuels, ensuring minimum flow volumes necessary to keep the Trans Alaska Pipeline System open
- Development and demonstration of technology for improved nitrogen removal from natural gas
- Deployment of cost effective technologies for coal mine methane recovery and use that will double present coal mine methane utilization, despite little or no growth in underground coal mining
- Development of advanced gas-to-liquids technology to enable maximum cost effective deployment of clean burning diesel and other liquid transportation fuels from domestic onshore gas resources

POTENTIAL BENEFITS

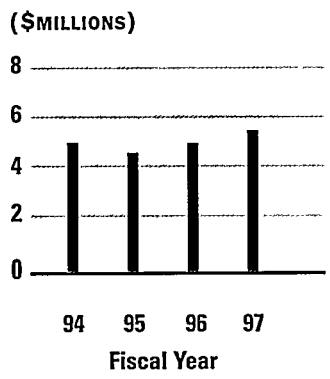
By advancing technologies to convert unmarketable gas resources into valuable products, cooperative efforts between DOE and industry could yield the following benefits by 2010:

- **Advanced techniques for nitrogen and hydrogen sulfide/carbon dioxide removal from low quality gas will have been developed and demonstrated sufficiently to have boosted cost competitive production capacity of U.S. gas resources by as much as 150 trillion cubic feet (Tcf). These techniques will expand domestic production potential by more than 1 Tcf per year.**
- **Our shortfall in domestic production of oil will be reduced by 200,000 to 500,000 barrels per day of high quality liquid transportation fuel made from Alaska's North Slope gas resources. Such gas-derived liquid will be transported through the Trans Alaska Pipeline System for domestic tanker delivery. This volume of light, gas-derived liquid will ensure that as much as another 200,000 barrels per day of North Slope crude oil will not be shut in because of insufficient pipeline utilization.**
- **Advanced gas-to-liquids conversion technology that yields ultraclean burning diesel fuels that meet the most stringent emissions requirements, at costs below those of comparable fuels made from crude oils, will be utilized. Other advanced gas-to-liquids technologies that produce petrochemicals and other liquid fuels from our domestic gas resources will replace imported methanol and petroleum based chemical feedstocks, reducing price and supply swings, and replacing foreign jobs with domestic jobs.**
- **Small-scale gas-to-liquids technology for both natural gas liquefaction and chemical conversion to higher hydrocarbon liquids will enable economic and environmentally sound production of remote offshore oil reservoirs with associated gas, and also onshore gas reservoirs without pipeline access.**
- **As much as 13 billion cubic feet of natural gas, currently vented to the atmosphere each year by underground coal mines, will be utilized through innovative gas recovery, upgrading, and power generating technologies.**

RELATIONSHIP TO OTHER DOE PROGRAMS

The Gas Processing Program has links to a number of areas in the overall DOE oil and gas technology effort, including gas production, storage, environmental, and oil processing and downstream operations. Program efforts are also interrelated with the indirect liquefaction component of the Coal and Power Systems Program and the global climate change action effort. The technology transfer mechanisms built into all DOE programs ensure that information and R&D results are shared among interrelated programs to achieve maximum benefits.

GAS PROCESSING PROGRAM BUDGET



PROGRAM AREAS

THE GAS PROCESSING PROGRAM CONSISTS OF THREE AREAS:

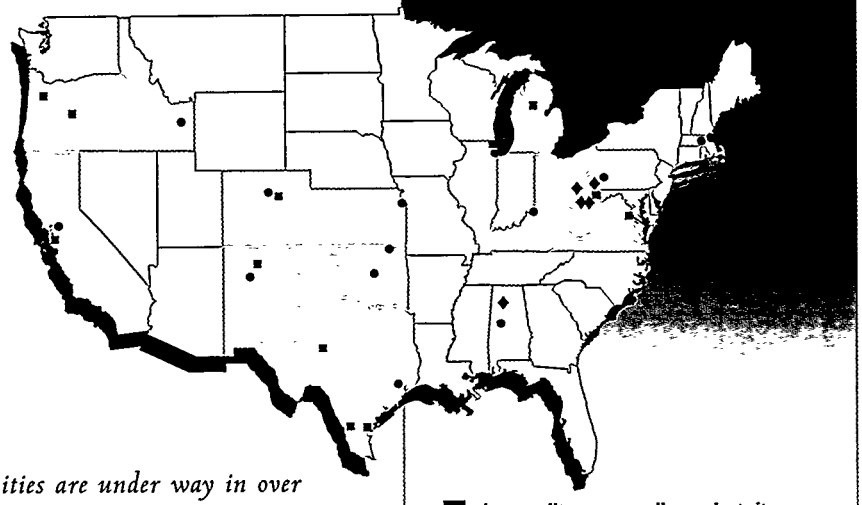
GAS-TO-LIQUIDS CONVERSION

LOW QUALITY GAS UPGRADING

COAL MINE METHANE COLLECTION AND UTILIZATION

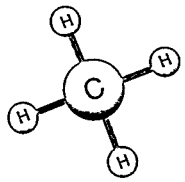
THE FOLLOWING PAGES HIGHLIGHT SOME SPECIFIC GAS PROCESSING PROGRAM PROJECTS AND THE RESULTS THESE PROJECTS HAVE PRODUCED.

PROJECT SITES



Project activities are under way in over 20 locations across the United States.

Gas-to-Liquids Conversion Technologies



The symmetrical nature of the methane molecule gives it great stability, making its conversion to different, selective compositions difficult.

Gas-to-liquids conversion technologies use chemical or physical means to convert natural gas to a liquid form suitable for ready transport or direct use. The conversion is accomplished in one of two ways:

- Compression and refrigeration, in which the gas is liquefied cryogenically and subsequently regasified for eventual use
- Chemical conversion, in which the gas molecules are chemically altered and combined to form a stable liquid that can be used directly as a transportation fuel or petrochemical feedstock or product

Program efforts to advance gas-to-liquids conversion technologies are focused on new approaches and processes to significantly reduce costs and accelerate deployment.

Economics of Alaska's North Slope Gas Options

A program strategy/assessment project conducted by DOE's Idaho National Engineering Laboratory, with technical assistance from oil industry consultants and DOE personnel, examined the economics of Alaska's North Slope gas options. The objective of the study was to determine if the application of gas-to-liquids technology could make an estimated 25 trillion cubic feet of known, producible North Slope gas economically marketable.

The study found that current state-of-the-art gas-to-liquids technology would be economically comparable to the large-scale liquefied natural gas manufacture and export plan presently proposed in Alaska.

This conclusion incorporates the savings to current oil-producing reservoirs that would result from extending the productive life of Alaska's oil pipeline, but conservatively ignores the benefits for new oil reservoirs. The study also found that near- and mid-term advancements in gas-to-liquids technology would lower the cost of this option by 25 percent or more, primarily through reduced capital costs and conversion efficiency gains.

The study provides State and industry leaders with credible scientific and technical information useful in considering the options and timing for future decision making.

Ceramic Membrane Reactor Systems for the Conversion of Natural Gas to Synthesis Gas

This engineering development project builds on the success of process exploration work conducted by Argonne National Laboratory and Amoco Corporation. Their exploratory work showed that existing Fischer-Tropsch chemical conversion costs might be reduced as much as 25 percent or more by using a special ceramic membrane capable of integrating oxygen separation from air and methane partial oxidation in a single step. This process would eliminate the need for expensive oxygen produced by cryogenic means to make the intermediate syngas product of carbon monoxide and hydrogen, which then can be readily converted to the desired hydrocarbons.

A competitive solicitation to develop and demonstrate this advanced process at pre-commercial scale was issued in 1996. Following selection of the best qualified industry bidder, project work is scheduled to begin in 1997. This DOE-Fossil Energy project is also supported by DOE's Office of Energy Efficiency and Renewable Energy.

PRODUCTION OF METHYL CHLORIDE VIA OXYHYDROCHLORINATION

A new engineering-scale development project, conducted by Dow-Corning at its Kentucky facilities with Gas Research Institute and DOE support, builds on earlier DOE-sponsored laboratory and bench-scale exploratory work in which hydrochloric acid and oxygen were successfully reacted with methane to form methyl chloride. This intermediate product can then be converted to a number of desirable products, including silicones, liquid transportation fuels, and other chemicals.

The use of oxyhydrochlorination reactions to produce methyl chloride from domestic gas resources has the potential to enable cost competitive methyl chloride production without the need for current methanol based technology. This process can help to reduce U.S. dependence on methanol imports for silicone and other gas-derived products. In addition, an advanced gas separation technology developed as a part of this process could be used throughout the chemical industry to reduce volatile organic compound emissions.

Awarded in 1996, this government-industry cost shared project features a repayment agreement: DOE's 37 percent funding share of the project costs will be repaid to the Federal treasury upon process commercialization.

THERMOACOUSTIC NATURAL GAS LIQUEFACTION

Another government-industry collaboration involves Los Alamos National Laboratory and Cryenco Inc., a small Colorado manufacturer specializing in cryogenic storage technology. Together, they are developing a process for small-scale liquefied natural gas (LNG) manufacture at remote offshore and onshore locations.

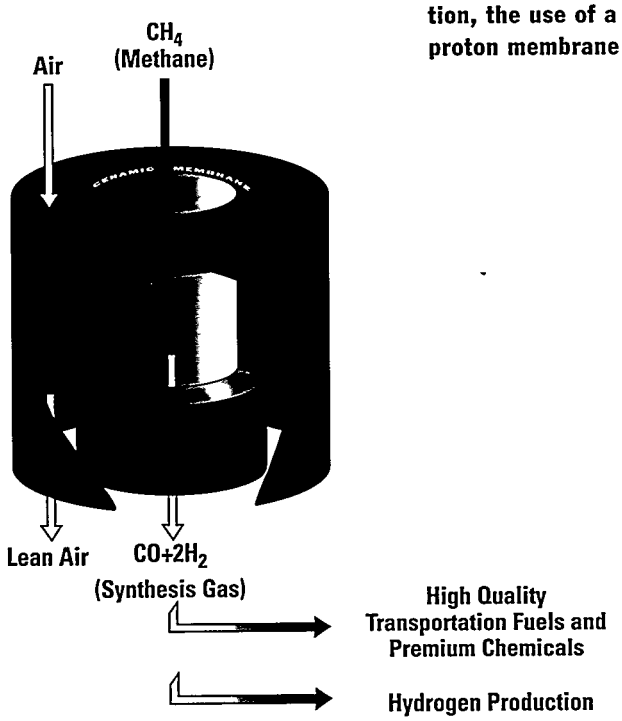
The process uses direct gas burning to generate sound waves to drive an orifice pulse tube refrigerator. This process is designed for small-scale LNG generation at wellhead or other locations, at one-half the cost of traditional refrigeration. The process does not require electricity and lends itself for use at remote offshore locations as well as onshore locations.

Prototypes for 10 barrel/day and 250 barrel/day of LNG capacity are planned. This project builds directly on exploratory work sponsored by DOE's Energy Research and Defense programs.

STEADY-STATE AND TRANSIENT CATALYTIC OXIDATION AND COUPLING OF METHANE

Direct chemical conversion of methane to a desirable liquid hydrocarbon has long been a DOE research goal, but conversion of the methane molecule to different, but very selective, compositions has proven difficult in the quantities required to approach economic feasibility. DOE-sponsored research at the University of California at Berkeley focuses on oxidative coupling, a method by which oxygen reacts over a catalyst with methane to form water and a methyl radical. The methyl radicals combine to form a higher alkane such as ethane, which then dehydrogenates easily to an olefin such as ethylene.

One of the stumbling blocks to this process is the rapid formation of carbon dioxide before the radicals link up, due to reaction thermodynamics. Berkeley researchers are exploring whether quick separation of the oxygen and radical streams as the reactions take place can achieve the objective of significantly raising single-pass yields of alkanes from the 25 percent levels achievable with today's best coupling technology. To accomplish this separation, the use of a surface catalyzed proton membrane is being tested.



CERAMIC MEMBRANE TECHNOLOGY

The partial pressure difference in oxygen that occurs between the air side and the methane side of the membrane when synthesis gas is formed facilitates oxygen ion transport through the membrane.

Low Quality Gas Upgrading Technologies

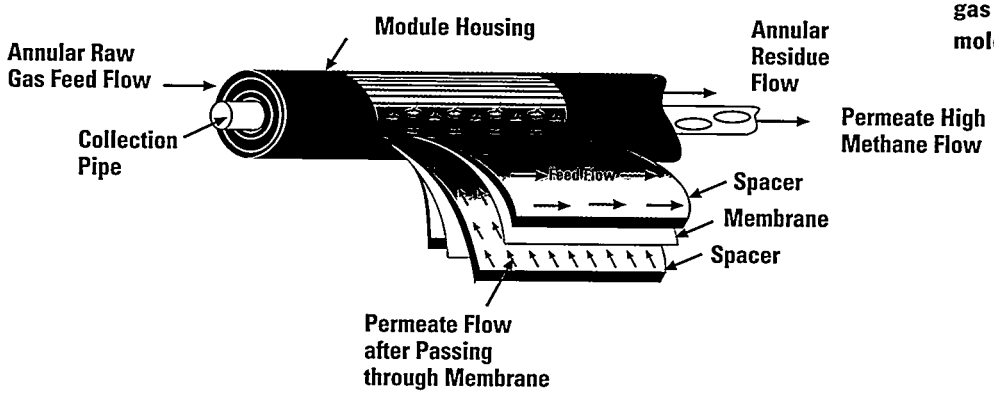
Efforts to advance gas purification technologies are focused on finding lower cost ways to remove sulfur, carbon dioxide, nitrogen, and other impurities from low quality gas. The gas purification technologies enable the upgraded gas to meet specifications for pipeline shipment to market.

Low quality gas upgrading program efforts target two technology areas. The first is the development of organic and inorganic membranes that screen and separate gas components. Membranes offer high component selectivity and overall gas throughput. The second area of technology development is gas-contaminant absorption and adsorption systems that have rapid regeneration capability.

Both areas of technology development have the potential to significantly reduce gas upgrading costs compared to current technologies.

Typical Spiral-Wound Gas Separation Membrane Module

In this model case, smaller methane molecules would pass from the raw feed flow through a selectively permeable membrane to a lower pressure collection pipe. Larger nitrogen molecules would not pass through the membrane, remaining as residue in what would become a high nitrogen waste stream.



Microbially Enhanced Redox Solution Reoxidation for Sweetening Sour Natural Gas

Researchers at Texas A&M University at Kingsville are looking at new ways to improve current technology for removal of hydrogen sulfide from gas. When found in moderate concentrations, hydrogen sulfide is often removed from gas through the absorption of the sulfide in an absorbent, followed by regeneration of the absorbent by partial oxidation of the sulfide to elemental sulfur and water. However, reoxidation of the absorbent can be slow and irregular.

With support from DOE and the Gas Research Institute, Texas A&M researchers are examining how families of microbes can enhance the reoxidation rates and what process conditions best facilitate reoxidation. Enhanced reoxidation rates would enable purification plants to operate continuously, which in turn would allow a reduction in plant size. Smaller purification plants would require less capital and operating costs.

Methane Separation from Nitrogen by Methane-Permeable Membranes

The removal of nitrogen from natural gas is an expensive operation, and these processing costs can jeopardize potential development of natural gas reserves in fields containing high nitrogen concentrations. Researchers at Membrane Technology & Research in Menlo Park, California, are looking at new semipermeable membranes that can selectively pass the slightly smaller methane molecules in natural gas and resist the larger nitrogen molecules.

Based on positive findings for two of the membranes examined, researchers will now focus on the development of spiral-wound membrane modules for laboratory testing and subsequent pilot process testing. Semipermeable membranes could potentially lower nitrogen removal costs by as much as 50 percent compared with current cryogenic processes.

HIGH EFFICIENCY GAS-LIQUID PACKING AND CONTACTORS FOR ACID GAS PROCESSING

Another DOE-sponsored project is focused on the development of more efficient and compact physical solvent systems for the upgrading of natural gas with high carbon dioxide and/or hydrogen sulfide content. Researchers at the Institute of Gas Technology are working with representatives from the Gas Research Institute, Shell Oil, Michigan Consolidated Gas, and others to develop the advanced system designs required to enable the separation processes to proceed using structured packing and/or rotating solvent-gas contactors in place of traditional large absorber towers with many sets of contactor trays.

The new designs would allow a five-fold or greater reduction in the size of gas upgrading plants. Such size reduction is particularly valuable for platform-scale upgrading in the Gulf of Mexico.

Success Story

The use of a new physical solvent, N formyl morpholine (NFM), has reduced the cost of purifying high CO_2 and H_2S (acid) raw gas by 30 to 50 percent. This upgrading process is accomplished with less hydrocarbon loss and lower cost equipment than previous processes.

Coal Mine Methane Recovery and Utilization Demonstrations

Five mines located in Alabama, Ohio, Pennsylvania, and West Virginia will demonstrate the feasibility of alternate ways to recover and utilize methane released during the underground coal mining process. The projects will demonstrate the productive use of low methane ventilation gas as well as gob gas of irregular methane content for pipeline sales, small-scale electric power generation, and other uses.

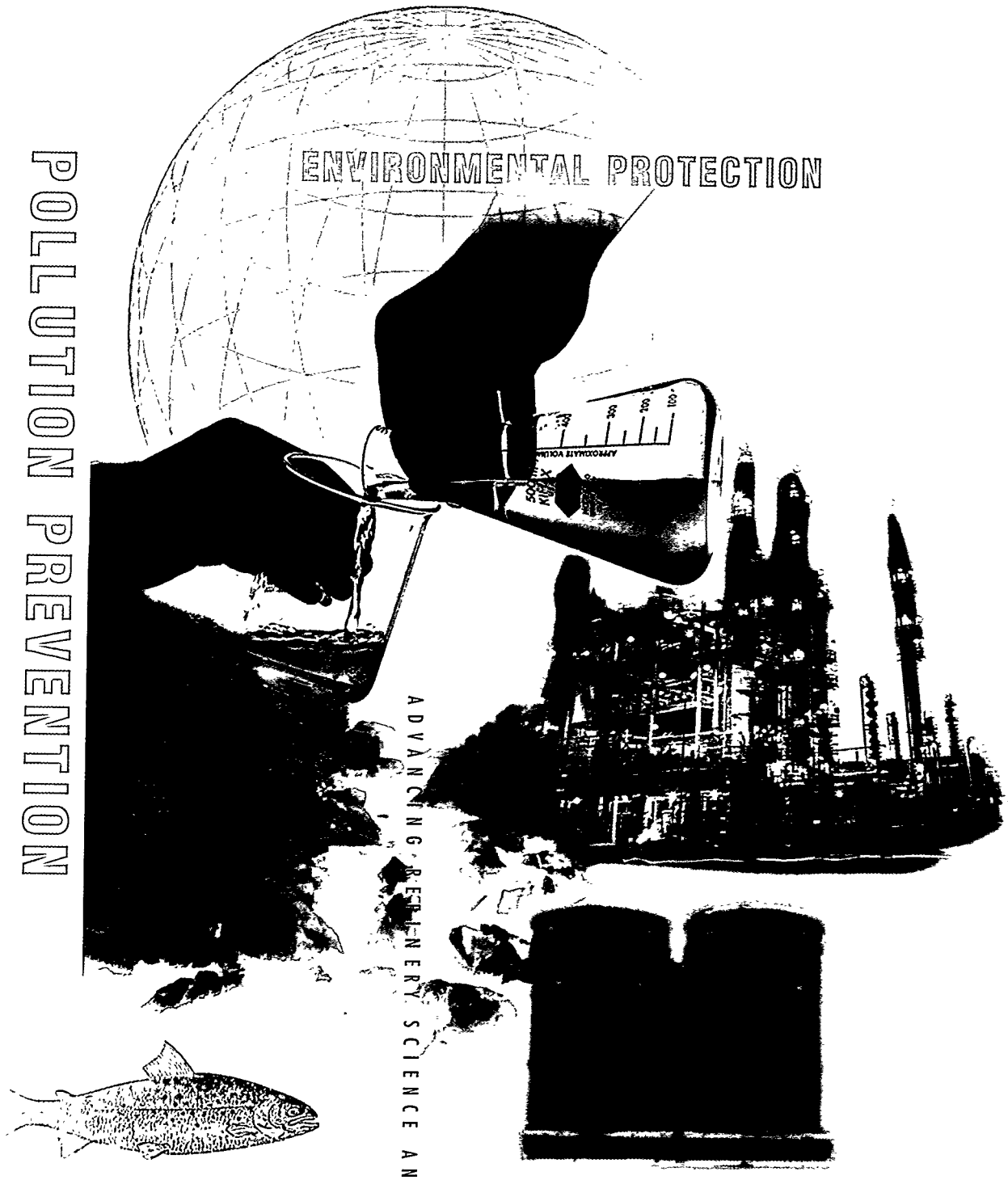
Design activities for each of the cost shared projects are under way. These demonstration projects reflect either new concepts for mine methane use or build on earlier utilization successes. For example, at an active coal mine in Harrison County, Ohio, DOE and industry partners have developed an electric power generating facility fueled by waste methane. The facility is currently generating 500 kW of electricity, about one-quarter of the mine's total power consumption. The new demonstration project will expand the power generating facility with the addition of a fuel cell.

ADVANCED CRUDE OIL PROCESSING TECHNOLOGIES ARE CRITICAL TO THE NATION AND TO THE REFINING INDUSTRY

The U.S. refining industry contributes significantly to our Nation's economy, producing refined products valued at over $110 billion per year and employing about 121,600. Further, our Nation's leadership in technology positions U.S. companies to export refining technologies and equipment to rapidly growing international markets. Such export opportunities could amount to many billions of dollars by 2010.

However, the need to allocate funds for complying with environmental regulations is now undercutting the ability of the refining industry to retain its leading edge in oil processing technology and to stay competitive in a world market. The industry currently spends an estimated 75 to 90 percent of its capital equipment budget to meet environmental regulations, especially the Clean Air Act Amendments of 1990. Between 1993 and 2000, the industry will spend an estimated $31 billion on capital equipment to meet regulations, severely limiting funds available to develop and demonstrate new technology and equipment. Additional expenditures are expected to meet the proposed standards for particulate matter (PM 2.5) and ozone.

New refinery technologies can equip the industry to prevent pollution and protect the environment more efficiently than is possible with today's costly retrofit approaches, to handle the challenges posed by lower quality domestic feedstocks, and to produce the more complex, high value product slates that the market now requires. DOE's Oil Processing Program, conducted by the Office of Fossil Energy, has important roles to play in the research and development of such technologies. Program personnel are working closely with the industry to gather the scientific information that is essential for sound regulatory decision making as well as to develop refining technologies that increase efficiency, decrease costs, and enhance environmental performance.



POLLUTION PREVENTION

ADVANCING REFINERY SCIENCE AND TECHNOLOGY

OIL PROCESSING PROGRAM

Refineries today face more formidable technological challenges than ever before

In the last decade, environmental regulations have had a far-reaching impact on both the processes and products of the U.S. refining industry. Refineries must comply with increasingly stringent emissions and discharge limits on their processes. At the same time, they must meet demands for lighter, high value finished products, such as gasoline, diesel fuel, jet fuel, and petrochemical feedstocks, whose composition and quality have changed markedly to meet environmental standards. The Clean Air Act Amendments of 1990 have required the production and use of reformulated gasoline, for example. This and other projected changes in the product slate will result in higher storage and transportation costs, added capital expenditures, and product exchange complications.

According to a recent study by the National Petroleum Council, between 1991 and 2010 environmental compliance costs are projected to exceed $150 billion, including $36 billion for capital equipment. Since 1994 alone, the refining industry has committed over $20 billion to capital equipment for improving environmental performance. Such equipment has absorbed between 75 and 90 percent of total capital expenditures.

Environmental regulations have resulted in the closing of a number of smaller, less efficient U.S. refineries that have been unable to afford the required capital expenditures, and these regulations make the construction of new refineries in the U.S. unlikely. While larger refining operations are expected to remain viable, recent studies suggest that another 10 percent of U.S. refineries may close, resulting in the loss of over one million barrels per day of capacity. With U.S. refineries already operating at near maximum utilization rates, such a loss in capacity exposes U.S. consumers to gasoline price spikes caused by interruption of operations at any one refinery.

The declining quality of crude oil feedstocks compounds the challenges facing U.S. refineries. Crude oil feedstocks, particularly those from domestic sources, are becoming heavier, with rising levels of sulfur, nitrogen, and heavy metals. Using present technology, the processing of heavy crudes yields unacceptably high levels of low value residual oils, coke by-products, and wastes. As the market for residual oils declines, more processing is necessary to create higher value products, producing even more coke. Disposal options for this polluting coke are becoming increasingly limited. While our Nation could export coke in the past, such exports are expected to decline as environmental regulations in foreign countries reduce the economic viability of reusing these products.

Advanced technologies can potentially yield refining processes that greatly reduce low value coke while cost effectively producing high value products. With such technologies, our Nation would be able to tap sources for large-scale production of heavy crude in California, Alaska's North Slope, the Gulf Coast, and parts of the Rocky Mountains. An increase in heavy crude production would help to slow the continuing decline in overall domestic oil production.

The utilization rate of U.S. refineries has gradually increased over the last decade to the point where refineries have no excess capacity to make up for emergencies or national disasters.

UTILIZATION RATE OF U.S. OIL REFINERIES

Year	Operable Capacity (1,000 bbl/day)	Input to Distillation (1,000 bbl/day)	Utilization Rate
1982	17,445	12,176	69.8%
1985	15,671	12,161	77.6%
1990	15,623	13,610	87.1%
1995	15,346	14,119	92.0%
1996 (est.)	15,336	14,286	93.2%

Note: These are latest estimates for 1996 as of January 27, 1997. *Oil & Gas Journal* final numbers not available.

Unfortunately, at this moment of unprecedented need for oil technology development, industry investments in R&D are declining. Intense global competition has forced the industry not only to reduce total R&D but to shift remaining investments away from long-term R&D toward more immediate services and applied technology for environmental compliance. As a result, few investment dollars are left for R&D on new processing technologies.

At this time, the U.S. oil refining industry continues to lead the world in technology. The industry has developed new refining technologies for preventing pollution and providing the more diverse product slate required for improved environmental performance. U.S. refineries still account for approximately 21 percent of worldwide crude processing capabilities, and the industry as a whole remains the most sophisticated. Nevertheless, the enormous costs the industry faces constrain its abilities to develop the technologies needed to remain competitive. A loss of U.S. technology leadership would also translate into an erosion of the current export strength of U.S. equipment manufacturers serving the refining industry.

THE ROLE OF DOE

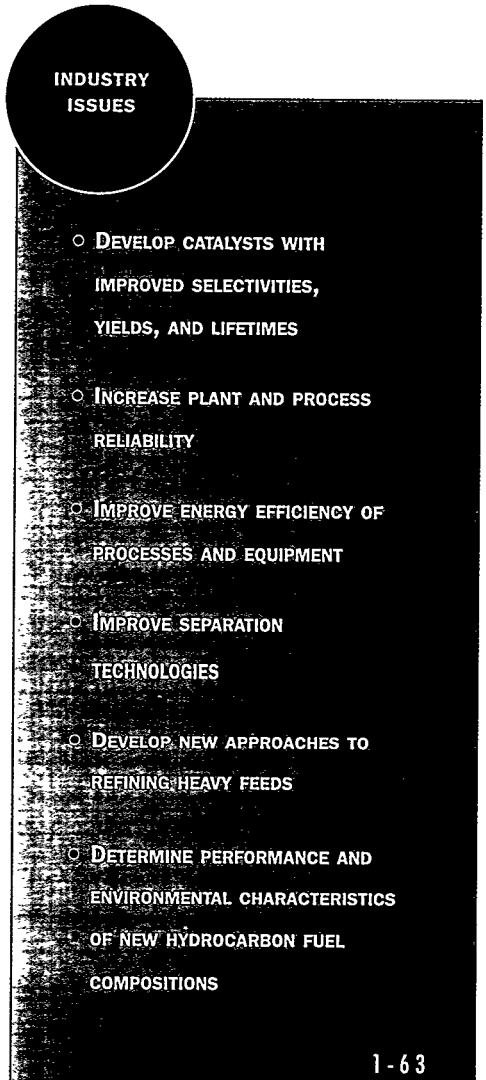
Though small, the DOE Oil Processing Program is a vital element of the total U.S. oil processing research effort. The research programs of the major oil companies tend to focus primarily on maintaining throughput and meeting existing environmental regulations, rather than on processing future feedstocks or reducing environmental impacts. DOE's Oil Processing Program will supply key basic science and information, particularly on long-range technologies and concepts.

Since the 1940s, DOE has conducted a world class thermodynamics and chemical analysis program for refinery processes. Its aim is to identify parameters necessary for efficient refining of crude oil. Today, as crude oil becomes heavier and contains more sulfur, nitrogen, and heavy metals, these types of data are needed more than ever.

Several shifts in focus over recent years are helping to ensure maximum returns for program investments. The program has:

- Increased emphasis on identifying the science and technology necessary for regulators to create and implement science based, risk based environmental regulations
- Increased emphasis on scientific data that can facilitate industry development of new technologies for minimizing waste products and risk to supply during the processing of heavy crude oils
- Implemented more vigorous outreach to ascertain industry needs before research is planned and implemented. Working with groups that have a broad industry coalition, such as the Petroleum Environmental Research Forum, the Western States Petroleum Association, the American Petroleum Institute, and the National Petroleum Refiners Association, is being emphasized

As a result, the program is now positioned to provide the science and technology base to assist the U.S. refinery industry in maintaining its technological edge and its environmental leadership, and in remaining competitive in the global marketplace.



Oil Processing Program

Drivers

- Crude oil supplied to refineries is becoming heavier with more sulfur, nitrogen, and heavy metals, while the market requires a product slate that is lighter, with less sulfur and nitrogen and more oxygenates.
- The market for the heavier residues of refined oil has been substantially reduced, thus requiring that the residue undergo further processing before it can be used.
- Environmental regulations, particularly the Clean Air Act Amendments of 1990, are forcing refineries to devote substantially more of their budgets to environmental compliance at the expense of their technology development efforts.
- Proposed environmental regulations (e.g. on particulate matter and ambient ozone concentrations) threaten to significantly increase compliance costs and accelerate the closing of domestic refineries.
- During the past decade, the number of refineries has decreased from 333 to 169, yet throughput has increased from about 14 million to nearly 15 million barrels per day. Thus the potential disruption to fuel supply caused by refinery upset or major accident is much more significant today than in the past.

Vision

By 2010, improved and new technologies that are efficient and environmentally beneficial will be made available to petroleum refiners, helping to enable them to process heavy crude oil cost effectively and remain competitively viable; and a streamlined regulatory framework based on sound science will be in place for domestic refineries.

Mission

Assist the refining industry in maintaining its viability by developing cost effective and environmentally acceptable heavy oil and residual upgrading processing technologies that will maximize the output of transportation fuels while minimizing output of low value products and waste streams.

Strategies

- Working with industry organizations and government regulators on joint projects, continuously generate and transfer to the refining industry new technologies and thermodynamic data that will lead to a streamlined regulatory framework and at the same time lower the environmental impact and waste fraction percentages in a barrel of crude and increase efficiencies.
  - Communicate with all clients so as to understand their needs and continuously plan activities to address those needs, consistent with national priorities.
  - Encourage the development of rational science- and risk-based regulations on refinery and downstream operations by providing sound science.
  - Help provide the technologies to prevent the formation of pollutants by process modifications and/or unit changes in the refineries and reduce risk to equipment malfunctions.
- Work with the industry and industry organizations to develop cost effective and environmentally acceptable domestic heavy oil and residual upgrading and processing technologies.

Measures of Success

By 2010, DOE-industry partnership will yield:

- Increased crude oil processing efficiencies for processing heavy crude oil; reduced air emissions; and reduced production of residual products
- Reduced dependence on imported oil (vs. Energy Information Administration base line) as a result of increased production of transportation fuels by domestic heavy oil refineries
- Reduction in the number of refinery closings predicted by the Environmental Protection Agency (EPA)
- Economic production of reformulated transportation fuels such as CARB-Phase 2 gasoline in quantities sufficient to satisfy consumer demand and prevent drastic price increases
- Downward trend in environmental compliance costs as a function of total operating costs for refineries
- Increased capital expenditures on technology development and decreased expenditures on pollution control equipment on the part of refineries

PROGRAM BENEFITS

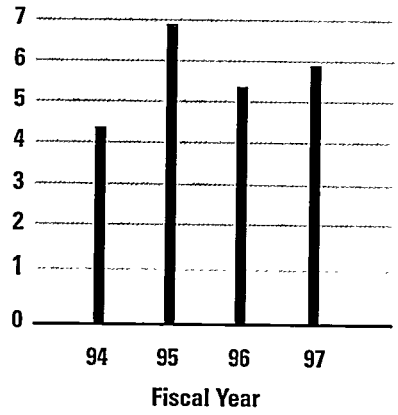
The ultimate impact of DOE's Oil Processing Program is the continued strength of our domestic refining industry. Measuring the value of the program is difficult since many of our efforts are in basic science and must be implemented by industry. However, meeting the program goals can be expected over the next 20 years to result in:

- **Decreased oil imports of approximately 50,000 bbl/day**
- **Reduced number of refinery closures by 10 percent below EPA estimates**
- **Approximately 500,000 bbl/day of additional U.S. refined products from heavy oil**
- **Reduced output of lower value products from 1.2 million bbl/day to less than 500,000 bbl/day**
- **Cost savings of over $130 million**
- **Reduced CO_2 emissions of over 20 million tons**
- **Over 20 million barrels of heavy oil reserves made economic to produce**

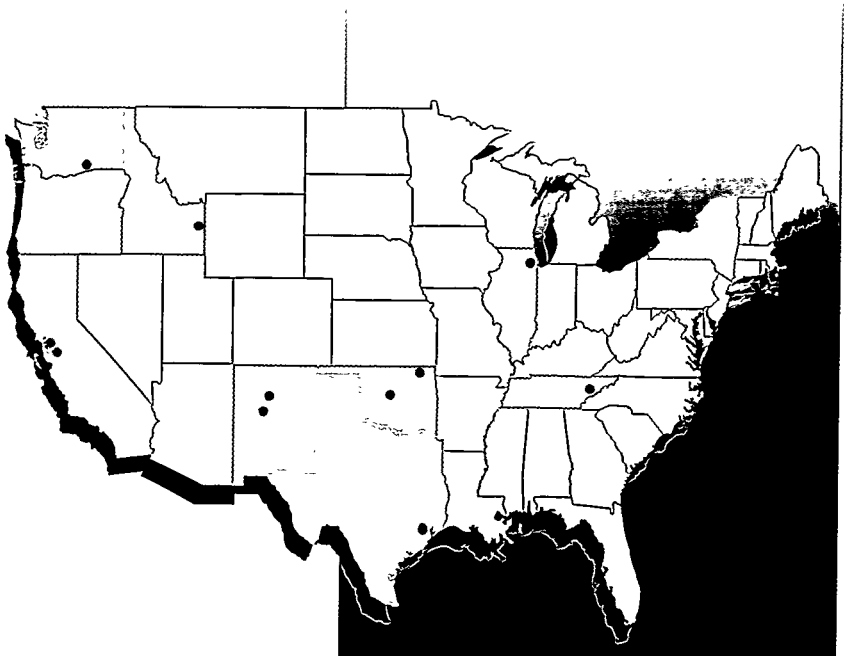
RELATIONSHIP TO OTHER DOE PROGRAMS

On such issues as tank evaporative emissions, spill remediation, and selenium and heavy metals in effluents, the Oil Processing Program conducts research that complements work being done in the Environmental Research and Analysis Program. The Oil Processing Program also shares areas of mutual interest with Fossil Energy's Coal Liquids Programs, including the development of thermodynamic data for the design of technologies to upgrade heavy oil and convert coal to liquid fuels. In addition, program activities are coordinated with the Petroleum Refining Industry of the Future strategy of DOE's Office of Energy Efficiency and Renewable Energy. The use of biotechnology to upgrade heavy oil is one area of shared research interest.

OIL PROCESSING PROGRAM BUDGET ($MILLIONS)



PROJECT SITES



The Oil Processing Program conducts 27 R&D projects in 9 States. Dots indicate the 12 project locations.

PROGRAM AREAS

DOE'S OIL PROCESSING PROGRAM FOCUSES ON TWO PRIMARY AREAS:

- **SCIENCE AND TECHNOLOGY LEADERSHIP IN THE U.S. REFINING INDUSTRY**
- **SOUND SCIENCE FOR ENVIRONMENTAL PROTECTION**

EACH OF THESE AREAS IS DESCRIBED IN THE FOLLOWING PAGES.

Science for Environmental Protection

DOE's Oil Processing Program serves the Nation's environmental objectives in a wide variety of ways. Specifically, it provides sound science for improved regulation and develops fundamental scientific data to facilitate the development of effective refining technologies for heavy crude. Efforts include the identification of the constituents of heavy crudes in order to prevent pollution formation during processing.

Representative projects are highlighted below.

Environmental Technology Initiative

To develop a framework of scientifically based regulations for the refining industry, the Environmental Protection Agency (EPA) has created the Common Sense Initiative. DOE's environmental efforts complement this initiative by applying unique capabilities for generating independent, high quality scientific data related to oil processing to the streamlining and improvement of existing regulations and laws. Working closely with industry and the EPA, DOE's Office of Fossil Energy is developing a prototype multimedia approach that integrates advanced knowledge of toxic chemical management with next-generation refinery design. The intent is to go beyond the retrofitting of technologies to existing refineries in order to comply with specific regulatory requirements. Retrofitting has commonly proven to be very costly in relation to the actual benefits realized. Instead, the new approach starts with a broader systems perspective that encompasses all aspects of refinery wastes and encourages the development of innovative technologies to achieve environmental goals.

Fate and transport of selenium in the North San Francisco Bay

In this project, DOE is assisting the San Francisco Bay Water Quality Board in determining whether low levels of selenium from local refineries pose a health hazard to aquatic life in the bay. The industry contends that the effluent does not pose a hazard, while the board has stated its belief that refineries must significantly reduce the concentration of selenium in the effluent discharged into the bay. The project is a multi-company, multi-agency effort to develop definitive data.

Determining the effects of the effluents on selenium concentrations is complicated by the preexistence of selenium in the bay's sediment, originating from a number of sources, some natural. The board is delaying new regulation until the data from the fate and effect study are available.

The larger objective of the project is to establish a fate and effect protocol based on scientific study for assessing the risk of refinery effluent to natural water systems. The output of this research will be crucial in determining the environmental impacts of the continued refining of crude oils with a high selenium content, such as those from Kern County, California.

Effects of Residual Hydrocarbons

In response to a request by the Petroleum Environmental Research Forum (PERF), DOE is sponsoring research to examine the effects on plants and animals of the low levels of residual hydrocarbons left after bioremediation. Specifically, the projects being conducted at Lawrence Berkeley Laboratory and Oak Ridge National Laboratory are to develop an understanding of biotransport of chemicals to support the need for reform of spill cleanup regulations. In a sense, the 35 oil processing companies that PERF comprises are looking to these projects to address the issue of "How clean is clean?"

Heavy Oil Storage Tank Emissions

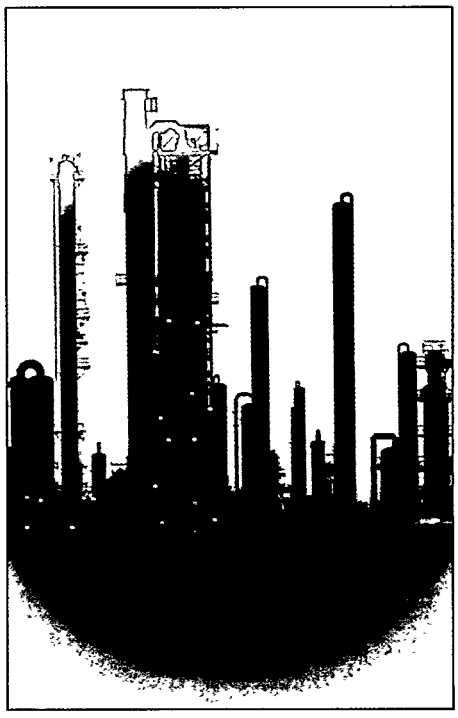
Researchers are concerned in this project with the measurement of emissions from heavy oil storage tanks. In complying with the Clean Air Act Amendments of 1990, which regulate emissions from heavy oil storage tanks, the California Air Resources Board had planned to use existing data on emissions from light oil storage tanks. But these data would probably overestimate actual emissions by a significant degree because heavy oil has less volatile components than light oil. Ongoing project data will enable the State to issue regulations that are based on the more specific and appropriate risks of vapor from heavy oil.

Study of Refinery Effluents and Treatment Alternatives

In this two-part project, DOE is collaborating with the Western States Petroleum Association. The first part of the project will determine background levels of heavy metals in Puget Sound, providing data for regulations establishing acceptable heavy metal concentrations in the effluent of five refineries. The data will provide a sound scientific basis for the regulations, reducing the uncertainty that might otherwise necessitate a high safety factor.

The second part of the project will evaluate and demonstrate low cost analytical techniques recently developed at Pacific Northwest Laboratory (PNL) for performing highly accurate analysis for ultralow concentrations. This will be followed by assessment of the potential for utilizing technology developed at PNL to minimize or utilize the waste from the biotreatment of refinery waste. One process to be investigated was originally developed for the reuse of biosludge in landfarms. While reuse of municipal biosludges in landfarms is common, refinery biosludges present different characteristics, liabilities, and economics. This study will report on potential applications and obstacles, and provide recommendations for overcoming problems.

In another process to be evaluated, acid is added to the biosludge stream from a wastewater treatment facility, heated, and placed in a hydrolysis reactor. This acid hydrolysis process reduces solids in the resulting stream by 50 to 90 percent. The remaining solids are much easier to filter and dewater, and the amounts of biosolids and water sent to a landfill or incinerator are greatly reduced. The project will provide data for conceptual design of the processing equipment.



Pollution Prevention

In the National Petroleum Council's 1995 study, ***Research, Development and Demonstration Needs of the Oil and Gas Industry***, the industry identified areas where research efforts are needed to develop the science and technology foundation required to help the U.S. refining industry. These recommendations were valuable in formulating DOE's Oil Processing Program. These areas include new approaches to refining heavy feeds, improvements in the energy efficiency of processes, the development of catalysts with improved selection and yields, improvements in plant and process reliability, and research in new separation technologies.

Examples of DOE science and technology designed to meet these industry needs include the following projects.

Property Measurements of Heavy Oil Components

The process engineering properties of the components of heavy oil will provide the basis for designing efficient process units and setting optimum process conditions for refining heavy crude. Data developed at National Institute for Petroleum and Energy Research (NIPER) for light oil components have allowed refineries to achieve current high efficiencies. The current studies on heavy oil components are expected to produce data that will allow the Nation's refineries to continue to operate at maximum efficiency while minimizing pollutants.

Predicting the Physical Properties of Hydrocarbons

The relationship between the molecular structure of hydrocarbons and their physical properties (boiling point, melting point, viscosity, and other thermodynamic parameters), though essential for efficient refining, is not well understood by chemists. A feasibility study now under way will develop and validate a method for computational prediction of boiling-point distributions for hydrocarbons with given molecular formulae.

Processing Heavy Crude Oil and Residue

Large refineries currently utilize coking as the principal method of upgrading heavy crude oils. Several research projects seek to aid small producers in California by converting low grade heavy oil and residual to higher grade material that can be used as a refinery feedstock. Technologies being investigated include aqueous pyrolysis, vacuum distillation followed by pyrolysis, and fluidized-bed conversion. Development work is directed at units that could be installed in the production site at lower capital costs. Considerable interest has been shown by smaller companies.

Disposal Approaches for Refining Process Water

This project is concerned with injection-well disposal of refining process water. The objective is to characterize the types of contaminants and their concentrations in refinery wastewater and compare them to those in wastewater from exploration and production operations that can be disposed of in Class II wells. Class II wells are easier to permit and less expensive to construct and maintain than Class I wells, which are presently required for refinery waste water disposal.

Advanced bioprocessing concepts

Advanced bioprocessing concepts could gain increasing importance in energy transformations and conservation, particularly in the context of the processing of fuels or energy-rich chemicals. Work conducted at several National Laboratories has shown that crude oils can be biochemically converted to lighter oils through removal of heteroatoms with simultaneous reduction in sulfur, trace metals, and nitrogen compounds. One current research project utilizes biocatalysts to implement a new concept of emulsion-phase contacting carried out in a bioreactor. This research is being conducted with multiple industrial partners to ensure that the technologies developed are quickly transferred to commercial application.

Research is also under way to develop cheaper and more complete biochemical methods for removing nickel and vanadium from heavy crude oil before it enters the refinery. This approach would reduce the costs of recovering metals from the refined product and disposing of them. It would also enhance processing of the crude.

Another project is developing benchmark costs that must be achieved by novel biochemical processes if they are to become commercially feasible. Analyses have been completed for sulfur reduction processes, and similar analyses are being carried out for nitrogen compounds and metals processes.

Another biochemical project targets remediation of soils whose quality has been reduced by petroleum hydrocarbons. Three alternative remediation approaches are being compared: (1) "no action," or simple weathering; (2) bioremediation, in which nutrients or surfactants are introduced into tainted soils; and (3) phyto-remediation, where plants growing in such soils remove, contain, or biodegrade pollutants. The project will extend the database on toxicity of petroleum products in different soils and determine which remediation approach achieves the lowest ecological risk for the least cost.

Ceramic membrane development

DOE researchers are exploring the use of ceramic membranes to separate high value hydrogen from low value refinery gases. (Hydrogen is a key, but expensive, reactant for upgrading of heavy petroleum.) The result will be an increased yield of light, high value products and a considerable reduction of low value coke produced. Refiners have long used organic membranes as a reliable and inexpensive way to recover hydrogen for use as a fuel. Inorganic membranes, however, promise far more economical recovery of the hydrogen for subsequent use in processing. These ceramic membranes are much more rugged, can be operated at higher pressures and temperatures, and can deliver very high separation factors and permeances. The project, which builds upon membrane technology used to separate nuclear isotopes, represents the first instance of declassified nuclear technology in this area being transferred for an industrial application.

Upgrading research

Two processes are being investigated to improve the quality of heavy crude before it enters the refinery. Argonne National Laboritory is investigating catalysts for their ability to upgrade heavy crude. Idaho National Engineering Laboratory is investigating the use of a submerged reactive plasma process to react natural gas with heavy crude to reduce the viscosity of the oil for improved transportability.

Success Stories

As the quality of crude oil available to U.S. refineries continues to decline, disposal of increasing amounts of high sulfur petroleum coke produced by these refineries is a growing problem. A DOE project to measure thermochemical and thermophysical properties of poly-cyclic hydroaromatic compounds will help refineries develop new processes to cope with the lower quality crudes. Based on a conservative assumption that overall crude processing efficiencies in U.S. refineries are raised by only 1 percent, savings of 500 million barrels of crude oil, $16 billion in reduced costs of transportation fuel conversion, and elimination of 255 million tons of CO_2 emissions will be achieved over the next 20 years.

✦✦✦

DOE-supported research at the Brookhaven and Oak Ridge National Laboratories is now being done to evaluate the technical and economic feasibility of processes for converting crude oils through biochemical treatment with selected catalysts. Particular attention is being paid to heavy crudes such as those found in California. Current results show that biochemical processing can decrease sulfur, nitrogen, and trace metals in oils; convert heavy ends to lighter hydrocarbons; and enable recycling of oil wastes. Sulfur removal alone can feasibly yield potential net savings of 65 cents per barrel of oil.

DOE AND INDUSTRY ARE USING THE BEST INFORMATION AND SCIENCE AVAILABLE TO FIND NEW WAYS TO ADDRESS OUR NATION'S ENVIRONMENTAL CONCERNS

Can the needs of a vital, growing U.S. economy be balanced with our Nation's commitment to a healthy environment? Nowhere is this question more pointed than in the domestic oil and gas industry.

To power our economy, the Nation depends on a mix of fuels, but oil and gas still account for more than 60 percent of all energy consumed in the U.S., and for over 95 percent of energy in the transportation sector. Fuel is not the only contribution of the oil and gas industry to the economy. The industry employs over 300,000 people directly, and its expenditures support as many as one million additional jobs throughout the economy. In total, oil and gas production activities contributed nearly $70 billion to domestic economic activity in 1994.

Yet the economic contributions of the domestic oil and gas industry are being endangered by rising environmental compliance costs. Higher costs could cause valuable domestic oil and gas resources to become uneconomical to produce, potentially raising imports and increasing the trade deficit. Gas supply could be constrained, preventing natural gas from filling its role as the environmentally preferred fuel.

The Department of Energy is working closely with industry to stem the rising costs of environmental protection, and to enable domestic oil and gas producers to operate more efficiently, contributing fuels, jobs, and economic value to the Nation. DOE and industry are using the best information and science available to find new ways to address our Nation's environmental concerns, and to demonstrate that the needs of a strong economy and a healthy environment can be fully compatible.

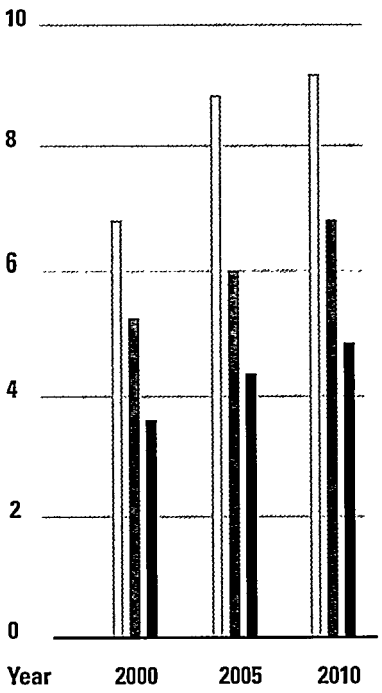
PROMOTING COOPERATIVE ENVIRONMENTAL AND REGULATORY PROBLEM SOLVING

ENVIRONMENTAL PROBLEM SOLVING

OIL AND GAS ENVIRONMENTAL RESEARCH AND ANALYSIS

Common sense regulatory development benefits the environment and the economy

Environmental Compliance Costs Are Likely to Rise (costs in $ billions)



In recent decades, environmental concerns led to numerous Federal and State regulations being imposed on oil and gas operations in the United States. While these regulations provided the framework for many environmental improvements by the industry, compliance has become costly and increasingly complex. Currently, the petroleum industry, including refining, spends as much on environmental protection as it spends searching for new domestic supplies of oil and natural gas — 9 cents for each gallon of gasoline Americans buy. That amounts to $10.6 billion a year, nearly twice the budget of the U.S. Environmental Protection Agency.

As in other industries, the oil and gas industry has become subject to overlapping, duplicative, and sometimes unnecessary or outdated regulatory requirements. Although these regulations were created with the best of intentions, the time has come to focus on implementing regulations with greater flexibility and efficiency, and achieving optimal levels of environmental protection at the lowest possible cost.

The higher cost of meeting environmental regulations places a substantial economic burden on industry. The burden is magnified by the economically marginal condition of a large percentage of domestic oil wells, and a growing share of domestic natural gas wells. Over two-thirds of domestic oil wells produce, on average, less than three barrels per day, making them highly sensitive to increasing costs.

Modest increases in cost can cause marginal wells to be plugged and abandoned, permanently cutting off access to oil and gas resources left in the ground. Premature abandonment of wells and forgone exploration and production threaten to increase our Nation's reliance on oil imports, and to reduce the supply of natural gas at a time when its use is being promoted as a partial solution to such environmental concerns as acid rain and global warming.

New Approaches to Addressing Environmental Concerns

There is growing recognition in government and industry of the need for more cost effective approaches to environmental protection. The National Petroleum Council, at the request of the Secretary of Energy, recently identified ways that government and industry could work together to meet this need. Among the Council's recommendations were development of a more flexible policy and regulatory framework; more efficient recovery technologies to reduce environmental impacts; cost effective, risk based regulations; and better science, dialogue, and education.

The American Petroleum Institute has underscored these concerns with a call for "common sense" regulatory development. Unlike approaches that mandate specific technologies or make it difficult to address cross-media impacts of pollutants, common sense approaches would give oil and gas producers more flexibility in determining how they can best meet standards, yielding the same environmental benefits at lower costs. Such approaches would also apply risk assessment more broadly, to determine whether the problems posing the greatest relative risks are being addressed, and to evaluate whether costs of proposed requirements are commensurate with associated risks.

DOE'S ROLE IN THE SOLUTION

Working with industry, DOE's Office of Fossil Energy is helping to ensure that environmental protection approaches make technical, environmental, and economic sense. DOE is well positioned between industry and regulators to champion balanced, cost effective approaches to environmental protection. DOE's environmental program pursues improvements to the regulatory process, supports development of new technologies, and exercises key responsibilities for energy policies that encourage efficient recovery and ensure adequate, secure energy supplies.

To support more informed regulatory decision making, DOE facilitates dialogue among Federal officials, State regulators, industry personnel, and other stakeholders. Through its program activities, DOE can provide assessments of costs or risks, lending an independent voice to the debate. DOE also characterizes problems and possible alternative solutions, catalyzing and contributing to the process of achieving common sense approaches.

Many times, more cost effective environmental approaches hinge on the development of new technologies. DOE supports such development, focusing on beneficial technology investments that could not be justified by a single company or small group of companies. Some of these technologies have longer term payoffs or high risks; others may have widely diffused benefits that a single company could not capture, but that will accrue to the Nation.

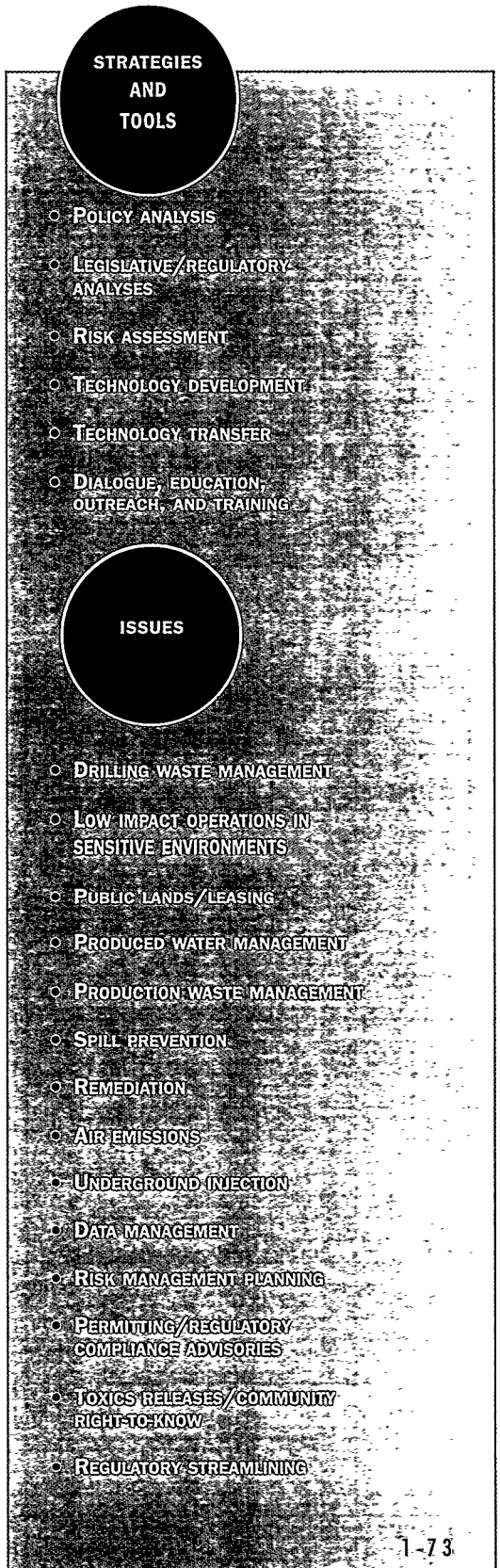
DOE brings unique capabilities to its role, including the scientific capabilities of its National Laboratories and modeling/analysis tools developed specifically to address energy policy questions. A fundamental commitment to outreach and technology transfer — putting information and new techniques into the hands of those who can use them — enables DOE's efforts to generate maximum benefits for the Nation.

A RESULTS-ORIENTED PROGRAM

By furthering risk based, streamlined regulations based on credible scientific information, and by developing lower cost compliance technologies, the program could ultimately:

- Decrease cumulative industry compliance costs through 2010 by as much as $16 billion
- Retain production of up to 60,000 barrels per day of oil that would otherwise be abandoned
- Increase gas production by 900 billion cubic feet per year
- Contribute over $8 billion to Federal and State treasuries by 2010
- Add as many as 11,000 jobs to the U.S. economy

DOE's Oil and Gas Environmental Research and Analysis Program addresses wide-ranging issues, using a diverse set of strategies and tools.



Oil and Gas Environmental Research and Analysis Program

Drivers

- Our Nation needs a reliable domestic supply of oil and natural gas.
- Protecting the environment is vital to national and global prosperity.
- Environmental regulations have raised the cost of exploration and production and have limited access to new resources.
- Future regulations will further increase costs.
- Rising costs of environmental compliance could accelerate the decline in U.S. oil production and limit the availability of natural gas. U.S. would lose jobs and tax revenues, and increased imports would raise trade deficits.

Mission

- Maximize the recovery of U.S. oil and gas resources by reducing the costs of effective environmental protection.

Goals

- Enable industry to reduce compliance costs and improve environmental performance.
- Expand the capabilities of State and Federal government to make more cost effective, risk based regulatory decisions — promoting sound science and common sense.
- Improve communication and technology transfer among industry, government, Tribes, and the public toward balancing national energy, economic, and environmental objectives.

Strategies

- Promote dialogue, education, collaboration, and innovative problem solving.
- Work with States and Federal agencies to streamline regulations.
- Develop credible scientific and technical information to serve as the basis for risk based regulation and compliance, including economic and energy impact analyses and tools for regulators to make risk based decisions.
- Develop new, lower cost environmental compliance technologies.
- Promote sound environmental practices through outreach and assistance to industry.
- Work cooperatively with States, Federal agencies, and industry to leverage efforts to accelerate progress toward reducing the costs of effective environmental protection.

Measures of Success

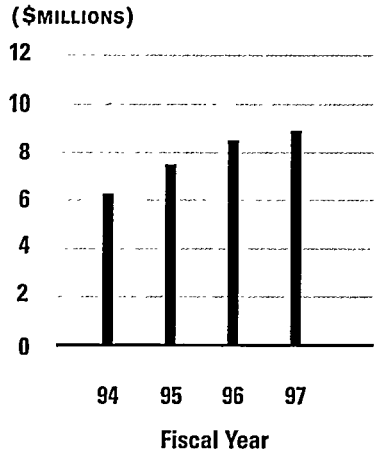
- Adoption and implementation of program products by industry, Tribes, States, and Federal agencies
- Reduction in environmental compliance costs, both for specific environmental technologies and for the industry as a whole
- Changes in State and Federal regulations and policies to reduce duplication and overlap, simplify compliance, and eliminate unnecessary requirements

TRANSFERRING RESULTS NATIONWIDE

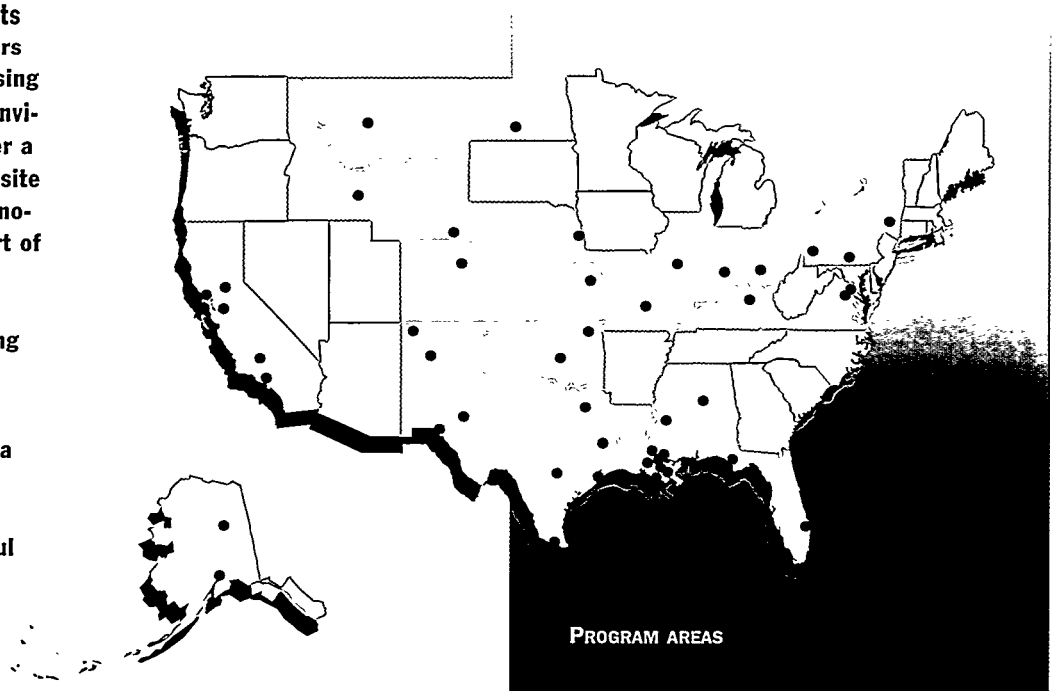
DOE is currently conducting over 60 environmental research and analysis projects. Some projects are national in scope and others are regional in nature, addressing specific technology needs or environmental constraints. Whether a project is initiated at a single site or in a handful of States, technology transfer is an integral part of the program approach. Once a project proves successful, the program focuses on transferring the results nationwide.

For example, a Risk Based Data Management System (RBDMS) originally developed for six States has proven so successful that 25 States have formed a users' group to help each other implement the system. The RBDMS is a PC based program that allows States to manage their underground injection data easily and use it to make risk based regulatory and operational decisions, such as where to assign inspectors for maximum effectiveness. The system enables States to generate reports quickly for the Environmental Protection Agency and the public.

OIL AND GAS ENVIRONMENTAL RESEARCH AND ANALYSIS PROGRAM BUDGET



PROJECT SITES



Over 60 environmental R&D projects are being conducted in the highlighted States.

PROGRAM AREAS

SIMPLY CHARACTERIZED, DOE'S OIL AND GAS ENVIRONMENTAL RESEARCH AND ANALYSIS PROGRAM FOCUSES ON FOUR ELEMENTS:

- FOSTERING UNDERSTANDING OF ENVIRONMENTAL AND ENERGY CHALLENGES
- REGULATORY STREAMLINING
- RISK BASED DECISION MAKING
- LOWER COST ENVIRONMENTAL COMPLIANCE TECHNOLOGIES

THE DISCUSSION OF THE FOUR PROGRAM ELEMENTS ON THE FOLLOWING PAGES HIGHLIGHTS SPECIFIC PROGRAM ACCOMPLISHMENTS AND SUGGESTS THE RANGE AND VARIETY OF PROGRAM ACTIVITIES.

Understanding of Environmental and Energy Challenges

A core component of all DOE Oil and Gas Environmental Research and Analysis Program activities is the collaborative process, the building of trust through sharing of ideas and information, and the hard work of creating consensus, identifying needs, and finding solutions.

Assessing Environmental Trends and Setting Priorities: Program Planning and Analysis

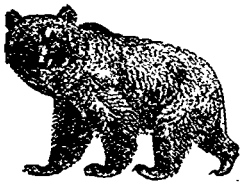
Program planning and analysis underpin the entire program. Environmental issues and technology constraints are characterized to help determine future program directions. Energy and economic impacts of potential legislative, regulatory, and policy initiatives are analyzed as input to government decision making and interagency coordination activities. DOE also conducts education and outreach activities addressing the industry and the program, and evaluates program benefits and possible alternative program directions.

DOE strives to ensure that its program is responsive to the needs of stakeholders. In evaluating potential projects and allocating resources within the program, DOE uses key criteria, such as potential compliance cost impact or savings; extent of oil and gas resources affected; environmental benefits; ability to positively influence key industry and government decisions; and geographic equity. To accelerate progress toward reducing the costs of effective environmental protection, DOE works cooperatively with States, other Federal agencies, and industry to identify high priority environmental issues and leverage efforts.

Increasing Public, Industry, and Government Understanding

DOE conducts some projects with the express purpose of increasing public, industry, and government understanding of the national situation with respect to energy and environmental issues. Three projects undertaken by DOE in collaboration with the Interstate Oil and Gas Compact Commission, an organization representing the governors of the 29 States that produce virtually all our Nation's oil and gas resources, are excellent examples:

- **A study of oil and gas exploration and production waste management in 17 States, conducted in 1993**
- **An annual report on the energy and economic importance of the Nation's marginal oil and gas wells**
- **Nationwide studies of idle and orphaned wells, including State and Federal strategies for reducing environmental risk and ensuring more efficient resource recovery, conducted in 1992 and 1996**



Under a memorandum of understanding with the Department of the Interior, DOE makes available its analytic capabilities to improve oil- and gas-leasing program decision making.

A FORUM FOR COOPERATIVE DECISION MAKING: THE GREEN RIVER BASIN ADVISORY COMMITTEE

DOE is an active participant in Federal advisory committees and interagency work groups that provide a national energy perspective and promote cost effective approaches to protect the environment. The Green River Basin Advisory Committee is a forum for discussion and cooperative decision making among oil and gas industry representatives, environmental organizations, hunting and fishing advocates, and local and State officials. Created by the Secretary of the Interior, the committee is developing recommendations to help the Bureau of Land Management make decisions that ensure timely development of oil and gas resources, as well as the protection of wildlife and environmental resources in the Greater Green River Basin area of Colorado and Wyoming.

The Department of the Interior believes that natural gas reserves in the Greater Green River Basin probably represent the most significant onshore natural gas source underlying Federal lands in the lower-48 States. The region provides a habitat for mule deer, moose, and elk, and the world's largest herd of pronghorn antelope. Additionally, a healthy small animal population supports a broad diversity of raptors.

DOE's contribution to this effort has included both participation on the committee and analysis to demonstrate the feasibility and benefits of such concepts as reducing royalty rates for companies that undertake environmental impact assessments, environmental mitigation, and monitoring beyond that required by law.

ANALYZING NEW COMPLIANCE METHODS: STUDY ON THE USE OF SALT CAVERNS FOR OIL FIELD WASTE DISPOSAL

A key program strategy is to increase the availability of more cost effective environmental compliance technologies, including environmentally sound waste management methods. DOE commissioned Argonne National Laboratory — in consultation with Sandia National Laboratories, the Texas Bureau of Economic Geology, the Solution Mining Research Institute, and the Ground Water Protection Council — to conduct a study on the potential use of salt caverns for disposal of nonhazardous oil field waste. Preliminary analysis suggests that salt caverns, which are currently used for storage of crude oil, natural gas, and hydrocarbon products, offer a lower risk alternative to landfill and surface pit disposal of oil field wastes.

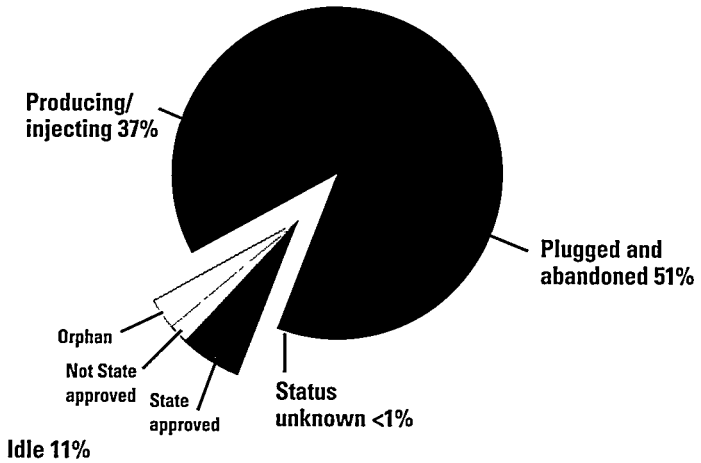
In response to demand for the practice, the regulatory structure to support cavern disposal is being developed. The Texas Railroad Commission has authorized six disposal caverns and is in the process of developing regulations for cavern disposal. Information from the DOE study will aid in the development of these new regulations. Ten other States with both oil production interests and suitable salt formations are following Texas' experience with interest.

ANALYZING PROPOSED LAWS AND REGULATIONS: USING MODELING SYSTEMS TO PROJECT ENERGY AND ECONOMIC IMPACTS

DOE's Office of Fossil Energy has unique capabilities, through its databases and modeling systems, to perform detailed engineering and economic analyses of potential legislative, regulatory, and policy initiatives, including proposed regulations under the Resource Conservation and Recovery Act, Clean Water Act, Safe Drinking Water Act, and mineral leasing statutes. This capability enables DOE to help States and other Federal agencies understand the potential oil and gas supply consequences of alternative regulatory scenarios and ultimately make more cost effective regulatory decisions.

States use innovative strategies to address idle and orphan wells — balancing environmental, economic, and energy concerns.

STATUS OF WELLS DRILLED IN THE U.S.



Regulatory Streamlining

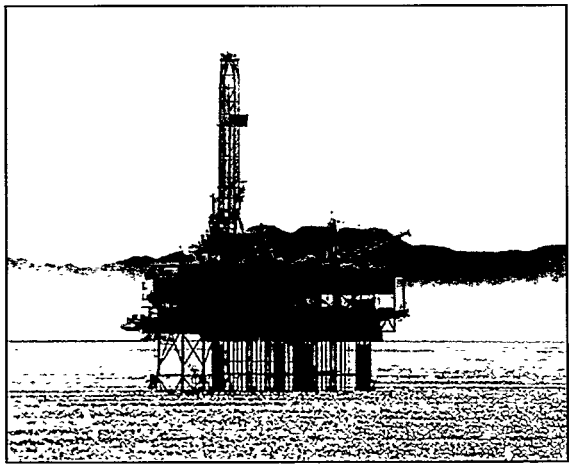
Cooperative streamlining efforts focus on simplifying regulation without compromising environmental protection, and on eliminating duplicative, unnecessary, or overlapping regulation. These activities support industry and government priorities of cutting red tape and achieving common sense regulation, as well as Congressional efforts to promote regulatory reform. DOE fosters interagency cooperation and facilitates dialogue and partnerships among industry, State and Federal agencies, Tribes, the public, and other affected parties. Regulatory streamlining is a win-win proposition: it reduces costs to oil and gas operators and to regulatory agencies, and promotes a healthy respect for the environment.

A key to more effective regulatory programs is ensuring that industry understands its compliance responsibilities. To improve environmental performance, DOE is working with States and industry on:

- **Modern, online permitting and environmental compliance advisory systems**
- **Environmental guidance manuals and compliance handbooks in Colorado, Kentucky, New Mexico, Texas, and Wyoming that bring all environmental requirements together in one place**
- **Guidance and workshops for small operators facing new requirements**

Simplifying compliance and improving environmental performance involves teamwork

DOE works collaboratively with States and other Federal agencies to enhance the efficiency and effectiveness of regulatory programs. DOE has been a longstanding supporter of Interstate Oil and Gas Compact Commission (IOGCC) efforts to improve State programs for regulating the management of oil and gas wastes. These efforts are funded by the Environmental Protection Agency and involve industry and environmental groups.



An alternative to traditional regulation: voluntary safety and environmental management planning

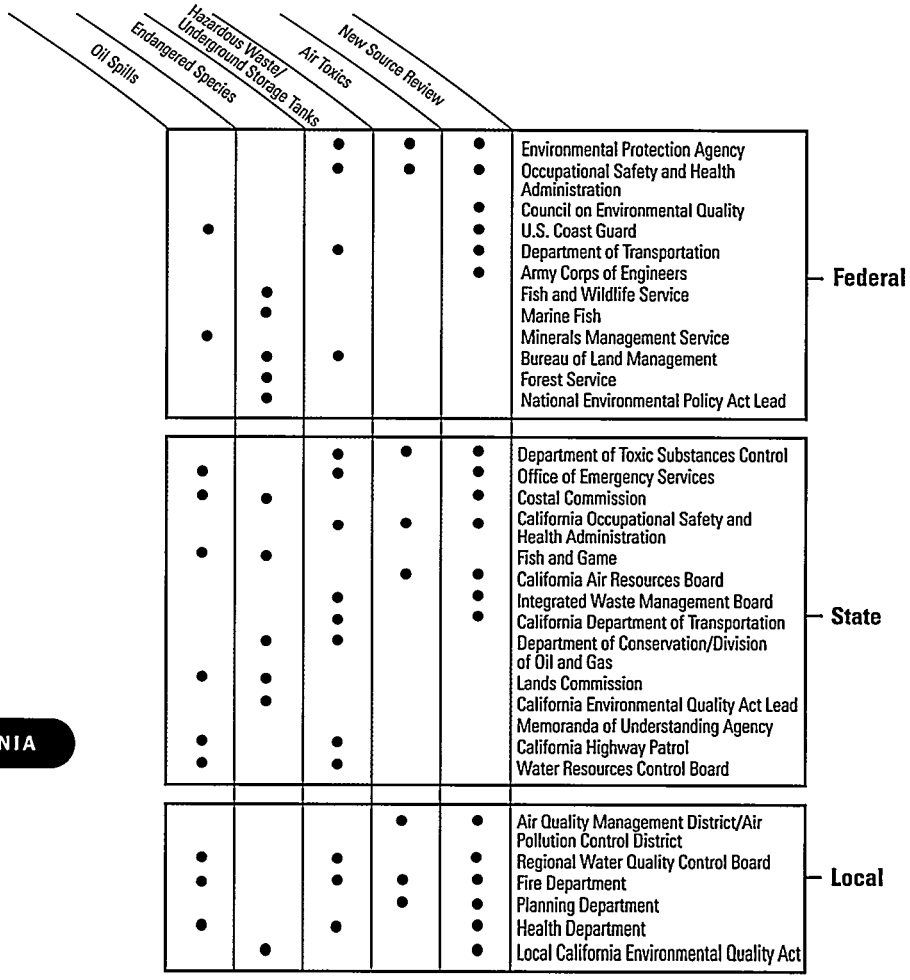
Demonstrating the feasibility of Safety and Environmental Management Planning (SEMP) as an alternative to traditional command-and-control regulation is the focus of a joint project involving the Department of the Interior, industry, and DOE. The American Petroleum Institute and the Offshore Operators Committee developed this innovative planning concept to improve worker safety and environmental protection on offshore platforms. Using SEMP, industry is responsible for identifying potential hazards in the design, construction, and operation of offshore platforms and for developing specific processes to improve safety and environmental protection. A DOE-funded project involving Taylor Energy will determine the cost and effort required by small to medium-sized operators, who may not have the extensive environmental and safety expertise of major oil companies, to implement SEMP. The project will serve as a model for other independent operators.

REMOVING BARRIERS TO NEW TECHNOLOGY DEPLOYMENT: USE OF SYNTHETIC DRILLING FLUIDS

In the early 1990s, synthetic drilling fluids were developed in response to prohibitions on discharge of conventional oil based fluids and increasing restrictions on discharge of mineral oil based fluids. Although these fluids may increase drilling efficiency and offer significant environmental and safety advantages, existing regulations are so narrowly constructed that they preclude use of this advanced technology. In 1994, DOE initiated a dialogue involving industry, the Environmental Protection Agency (EPA), and the Minerals Management Service to evaluate synthetic drilling fluids and to eliminate any unnecessary regulatory barriers to their use and discharge. Use of such fluids could save the industry over $50 million annually. As a result of these efforts, regulations promulgated by EPA in October 1996 should enable the use of this innovative waste minimization technology that may be crucial for deepwater drilling.

OTHER REGULATORY STREAMLINING PROJECTS INCLUDE:

- **A "Direct Dialogue" project to streamline oil and gas regulations in Indiana with citizen involvement as a model for other States.**
- **A dialogue group for Appalachian and Illinois Basin State regulators to share information on environmental problems, solutions, and regulatory innovations.**
- **Facilitating dialogue between States and the EPA on Community Right-to-Know and expansion of Toxics Release Inventory requirements for oil and gas exploration and production.**
- **Assisting the Bureau of Land Management with a National Performance Review of its onshore oil and gas regulatory program. At the end of 1995, more than 51,000 leases existed on Federal lands covering 37 million acres. About 19,000 of these leases are in producing status and contain more than 63,000 oil and gas wells. This effort included initiatives to simplify regulations for oil and gas operations on Federal lands, and incentives for increasing oil and gas production.**
- **Sponsoring the IOGCC's Public Lands Project, which focused on simplifying regulatory requirements in four western States — California, Colorado, New Mexico, and Wyoming — that contain large holdings of Federal land with oil and gas potential. Working together, representatives from government, industry, and environmental groups designed three common permit application and reporting forms to be used by the States and the Bureau of Land Management, and identified seven areas of regulatory responsibility that could be transferred from the Bureau to States as a way to reduce overlapping activities and requirements.**



ENVIRONMENTAL COMPLIANCE IN CALIFORNIA

Operators in California and other States are subject to potential regulatory overlap and duplication when multiple agencies have regulatory jurisdiction.

Risk Based Decision Making

DOE assesses environmental risks associated with oil and gas exploration and production and develops data and tools to support risk based regulatory, enforcement, and compliance decisions. As a source of credible scientific data to support risk based regulation, DOE has already been successful in influencing development of new regulations based on environmental risk, cost, and energy impacts, which have resulted in considerable savings for industry.

Eliminating unnecessary compliance costs: exemption from Area of Review requirements

To protect underground drinking water sources from contamination by subsurface injection, current Safe Drinking Water Act regulations require oil and gas producers to conduct a quarter-mile radius Area of Review (AOR) analysis of disposal and injection wells. Under certain conditions, however, AOR variances can be granted.

With support from DOE, the University of Missouri–Rolla developed a methodology that could be used by regulators to validate AOR variance requests. A pilot study of the variance methodology, sponsored by DOE and the American Petroleum Institute, was conducted in an East Texas oil field where the oil reservoir lies 3,000 feet below the base of the region's principal fresh water aquifer. The study demonstrated there is little risk of aquifer contamination from underground injection in that field and led the Texas Railroad Commission to approve an AOR variance. Industry cost savings related to this single AOR variance are estimated at $86 million. Cost savings for industry-wide AOR exemptions in low risk areas are projected to exceed $300 million. DOE is currently working with California, Kansas, and Oklahoma to implement this methodology.

Improved data management systems for States and industry

Through its Underground Injection Practices Research Foundation, the Ground Water Protection Council, with funding from DOE, has developed the Risk Based Data Management System (RBDMS) to help State oil and gas agencies and industry with risk based data management. RBDMS is the only comprehensive, fully relational PC based oil and gas regulatory data management system in the country.

Due to overwhelming acceptance by States and industry, the system — originally designed to manage oil and gas underground injection data — is being modified to also manage production data. In addition, some States are pursuing RBDMS modifications that will include data management for hazardous and industrial injection wells. Advanced data management techniques help States make better regulatory decisions and have gained widespread acceptance. In a related project, DOE has supported efforts of the Interstate Oil and Gas Compact Commission Data Standardization Committee to inventory State data management capabilities and identify data requirements for effective State regulation.

Scientific data for improved regulatory decisions: assessing impacts of discharges from Gulf of Mexico operations

As part of a four-year study, DOE has worked with Continental Shelf Associates and the Brookhaven and Lawrence Livermore National Laboratories to assess environmental and human health risks associated with produced water discharges from offshore and coastal oil and gas operations in the Gulf of Mexico. The project's goal is to increase scientific knowledge about:

- Characteristics of produced water and sand
- Environmental effects of organic materials, trace metals, and naturally occurring radioactive materials in water, sediment, and biota
- Impacts on commercially and recreationally important fish and shellfish species in coastal and offshore waters
- Seafood catch and consumption in the Gulf region
- The ability of wetlands and open bays to recover from prior oil and gas development activity
- The impact of existing and anticipated Federal and State offshore and coastal discharge regulations on energy supply and the economy

The project provided scientific data to enable industry to continue discharging produced water in open bays in coastal Texas and Louisiana through January 1997, and to continue discharging produced water on the Outer Continental Shelf.

Risk based regulations: California pipelines and heavy oil storage tanks

By legislative mandate, the California Fire Marshal was required to assess the fitness and safety of a category of crude oil pipelines, and to evaluate options that would encourage necessary replacements or upgrades. To maintain credibility with all interested parties, input to this issue was needed from a diverse group. DOE sponsored a project completed by BDM-Oklahoma, the California Fire Marshal, and a statewide steering committee to assemble a database of the pipelines and assess the risk. The final report, which includes recommendations for industry incentives, will be presented to the State legislature for use in future decisions on pipelines in California.

Current regulations require that oil storage tanks be fitted with costly scrubbers to prevent the emission of volatiles. These regulations were originally designed for tanks that store light oil, and may not be appropriate for the large number of tanks in California that store heavy oil, which contains less volatile material. DOE is funding the Lawrence Berkeley National Laboratory to lead a working group that includes the Western States Petroleum Association, the California Air Resources Board, the Environmental Protection Agency, and Air Quality Districts in two counties. This effort will lead to test methods for properly estimating the amount and type of reactive gases emitted from heavy oil tanks, and to potentially less stringent regulatory requirements based on scientific data.

Evaluation of the distribution and natural biodegradation of MTBE in ground water

Recent studies of contamination from leaking underground fuel tanks in California strongly suggest that natural bioremediation has effectively contained the vast majority of fuel hydrocarbon plumes, lessening potential adverse effects on ground water. MTBE (methyl tertiary-butyl ether) is a gasoline additive used to substantially reduce air emissions from automobiles. Several studies indicate that MTBE is not biodegraded as easily as other gasoline compounds, and is more mobile in the subsurface. DOE is sponsoring research at Lawrence Livermore National Laboratory to examine the movement and potential for natural biodegradation of MTBE. This research is critical to assessing remediation alternatives for MTBE-contaminated sites.

Lower Cost Environmental Compliance Technologies

Protection of wetlands and other sensitive environments is a focus of a number of DOE's technology development projects.

DOE supports development of more cost effective environmental compliance technologies by:

- **Providing access to the technical resources of National Laboratories and research centers**
- **Developing information on technology performance and potential environmental impacts for use in regulatory and industry decision making**
- **Performing bench-scale and pilot projects to demonstrate the technical feasibility of more advanced, cost effective environmental compliance technologies**
- **Removing technical and regulatory barriers to using advanced, innovative technologies that can reduce environmental compliance costs and improve industry's environmental performance**

DOE's technology development projects address:

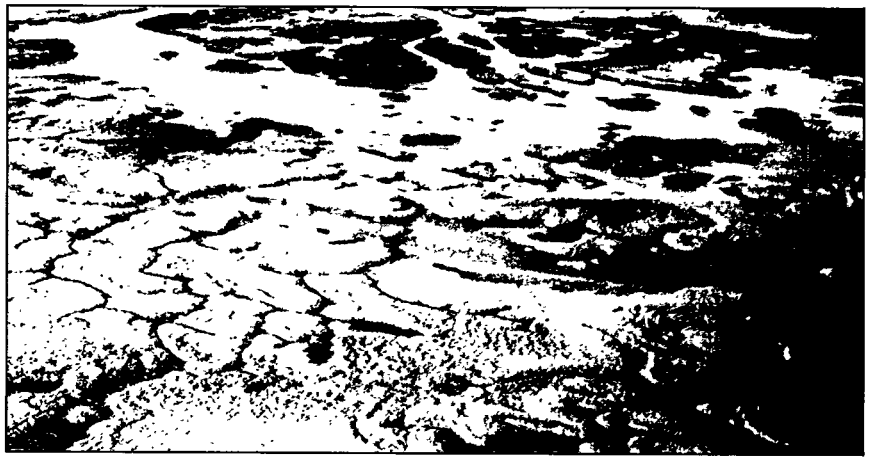
- **Drilling and production waste management**
- **Air emissions detection and control**
- **Produced water treatment and disposal**
- **Management of naturally occurring radioactive materials**
- **Remediation of contaminated sites**
- **Wetlands and other sensitive environments**

Drawing on a National Laboratory's unique expertise: methane leak detection

A new methane detection technology could cut losses for the industry and reduce emissions of methane, a powerful greenhouse gas. Sandia National Laboratories are applying expertise to the development of a video camera to detect leaking methane. The camera will use specialized computer chips and advanced portable lasers to provide images of methane at very low flow rates from a distance of 40 meters. Also under development is a more powerful laser that could boost the range to 100 meters.

Treatment and disposal of naturally occurring radioactive material

Treatment and disposal of naturally occurring radioactive material (NORM) is a high priority issue for both regulators and operators. Several States are developing regulations for NORM treatment and disposal, and EPA is considering development of national regulations. At the same time, some companies that have conducted or proposed NORM disposal projects have run into considerable public opposition.



DOE is currently funding a project to provide scientific data needed for risk based regulatory development and to develop a low cost NORM treatment and disposal technology. A field pilot test of an on-site treatment and disposal technology will attempt to cut NORM disposal costs in half by eliminating the need for off-lease transport and transfer of ownership of NORM wastes. Cumulative cost savings for industry by 2010 could amount to over $500 million. Concurrently, Argonne National Laboratory will conduct quality assurance, monitoring, and independent assessment of risks from NORM disposal to ensure that measurements are reliable. The project also includes a NEPA analysis in advance of the field pilot testing to guarantee that reliable information on environmental and health risks is readily available to regulators and the public.

Addressing sensitive environments: protecting and restoring the Nation's wetlands

A significant portion of the Nation's oil and gas resources are under or adjacent to wetland areas. DOE projects have included efforts to assess the environmental constraints of expanding oil and gas reserves in Louisiana wetlands, to examine the feasibility of wetlands mitigation banking, and to evaluate the use of cyclocranes and other innovative transport methods to support drilling and production of oil and gas in wetlands. One effort by Southeastern Louisiana University employs unique temperature controlled mesocosm facilities to simulate hydrologic conditions found in wetlands, to evaluate the beneficial use of drill cuttings in creating or restoring wetlands.

Produced water treatment and disposal technologies

Produced water is the largest waste stream generated from oil and gas exploration and production. Efforts sponsored by DOE to address produced water treatment and disposal include:

- Developing a low cost method for testing the toxicity of produced water
- Demonstrating the mechanical and economic feasibility of disposing of produced water through underground injection in an environmentally safe manner, using deep, low pressured gas reservoirs
- Evaluating alternative technologies for treating produced water prior to discharge in the offshore environment
- Developing lower cost methods for treatment and disposal in specific regions. Technologies involved range from high tech membranes to low cost, low volume systems that small operators can construct with cheap, readily available materials
- Turning produced water in California into potable water, a valuable resource

Other technology development projects include:

- Assisting the State of Ohio in field testing of various bioremediation techniques for crude oil contaminated sites as the basis for regulatory development
- Testing washability of produced solids from offshore and coastal facilities and crude oil tank bottoms
- Assessing techniques for evaluating and restoring abandoned drilling and production sites in support of the Nation's first industry-funded environmental cleanup and education program, administered by the Oklahoma Energy Resources Board

The fossil energy team: collaborating on the Oil and Gas Environmental Research and Analysis Program

Planning and implementation of the Oil and Gas Environmental Research and Analysis Program reflects the collaborative nature of the program itself, drawing as it does on DOE staff in Tulsa, Oklahoma, and Washington, DC. A number of environmental projects funded by other fossil energy programs also contribute knowledge and technology to the program, including research on refinery wastewater discharges, the environmental performance of advanced transportation fuels, and the remediation of hydrocarbon-contaminated sites.

Like any organization, DOE is made up of people — people who care about having a healthy domestic oil and gas industry and a healthy environment. Unwilling to sacrifice one for the other, DOE staff members are committed to finding real solutions that allow the Nation to benefit from both a strong economy and a clean environment.

Oil and Gas modeling systems support DOE in maximizing benefits from RD&D and policy programs

Where should DOE focus research, development, and deployment (RD&D) investments to yield the greatest benefits to the Nation? How will proposed environmental legislation or tax policy initiatives affect domestic oil and gas exploration and development? How effectively are oil and gas programs meeting their goals?

Decision makers in the Department of Energy, other Federal agencies, Congress, and State and local governments require timely, accurate quantitative information as they consider RD&D and policy questions affecting U.S. energy resources. To provide this information, DOE has developed a program of modeling and quantitative analysis that simulates the exploration, production, processing, and delivery methods of the domestic oil and gas industry. Using engineering and detailed economic analysis models, estimates are made of potential economic recoveries of domestic oil and gas over a wide range of technologies, economic criteria, and legislative and regulatory environments.

Models provide DOE and its customers with unique quantitative and modeling capabilities that cannot be found anywhere else, producing information required for effective development of our Nation's natural resources.

PROVIDING ACCURATE, TIMELY INFORMATION FOR PROGRAMMATIC AND POLICY DECISION MAKING

SIMULATION

QUANTITATIVE

OIL AND GAS

MODELING AND

ANALYSIS PROGRAM

Unique DOE models support informed decisions by government and industry

Metrics are essential to support ongoing assessments that will help assure prudent investment of DOE energy R&D funds with the goal of maximizing public benefits.

–Task Force on Strategic Energy Research and Development, June 1995

DOE has a responsibility for stewardship of our natural resources and for expending appropriated funds to support environmentally sensitive development of these resources for the benefit of the general public. Stewardship of our oil and gas resources includes ensuring their effective and efficient development, while minimizing environmental impact. DOE focuses its RD&D and policy efforts on major constraints to domestic recovery whose removal will yield substantial incremental oil and gas reserves for public benefit.

DOE has developed a unique suite of oil, gas, and programmatic models that are essential to satisfying its responsibilities. The models are maintained and enhanced by the Office of Fossil Energy (FE), and provide DOE with capabilities necessary to successfully plan, implement, and manage a complex RD&D and policy program, focusing on areas that most benefit its customers. While models of varying degrees of sophistication are available outside of DOE, none is suitable for evaluating the potential benefits of differing technologies, economic criteria, and legislative and regulatory environments over the entire U.S. resource base. FE's models are designed to evaluate these conditions.

VALUE TO CUSTOMERS

FE continues to maintain and improve the oil and gas models to reflect current and future program objectives. The models have significant applications for DOE and its customers.

Primary uses of the models within DOE are:

- **To assist the Office of Fossil Energy and the Department in prioritizing oil and gas RD&D initiatives. Models are also used to develop budget support documentation by estimating the relative costs and benefits of different RD&D approaches to solve exploration, production, environmental, and processing problems facing the oil and gas industry.**
- **To identify and quantify benefits accrued through the RD&D programs.**
- **To support the oil and gas policy analysis responsibilities of the Department and other Federal agencies by providing quantitative and analytical tools to assess the costs and benefits of a wide range of policy initiatives affecting the Nation's petroleum industry. These initiatives include financial issues (e.g., changes to the Federal tax code affecting the petroleum industry or royalty relief on Federal lands), environmental regulations affecting the industry, and issues of access to lands currently under moratoria from development.**

DOE also uses these models to provide analytical support to many other customers outside of DOE who do not have such capabilities.

- The U.S. Congress relies on these models to analyze the costs and benefits of legislative initiatives that impact domestic oil and gas production and reserves. For example, they were used to evaluate a proposed enhanced oil recovery tax credit for tertiary oil recovery projects. This evaluation resulted in the passage of the Enhanced Oil Recovery Tax Credit Act of 1991, providing a 15 percent tax credit for qualifying EOR projects. In another case, the models were used to evaluate the repeal of transfer rules relating to accelerated depletion allowances for independent producers. This analysis resulted in simplification of depletion allowance provisions in the Federal tax code.
- Local and State governments rely on the models to assess the costs and benefits of financial or regulatory reforms on their oil and gas industries. To date, 11 States have reformed their production tax structures based on analyses provided by DOE's models, in efforts to revive their oil and gas industries.
- Oil and gas operators use the models to identify marginal properties with potential for additional recovery through application of improved technologies. Public versions of TORIS (Total Oil Recovery Information System) databases and models are routinely used by majors and independent oil companies in prospect evaluation and strategic planning. These models provide unique analytical capabilities that many operators do not have on their own. Independent and small operators, in particular, may not have the resources to develop such capabilities.
- Professional organizations such as the Petroleum Technology Transfer Council, the Independent Petroleum Association of America, the Interstate Oil and Gas Compact Commission, the National Petroleum Council, and others also rely on these models. DOE analytical systems have significant applications in technology transfer and resource evaluation for less sophisticated operators, particularly small independent producers.
- Other Federal agencies responsible for managing Federal lands with oil and gas deposits use DOE models for technical and analytical support. For example, evaluations conducted for the Department of the Interior, Bureau of Land Management, supported formulation of an effective transfer payment strategy to increase oil production from Federal lands. The evaluations resulted in royalty reduction for marginal oil leases and heavy oil production. Another evaluation for the Department of the Interior, Minerals Management Service, analyzed remaining oil resources in Federal offshore territories in the Gulf of Mexico. It identified the need for further technology development to capitalize on oil production opportunities in the area before the resource is lost to abandonment.
- DOE has also used these models to support the Department of the Treasury and the National Economic Council in assessing the potential costs and benefits of proposals to provide tax relief for marginal wells and to revise the accounting and tax treatment for geological and geophysical expenses incurred in the petroleum production process. In addition, DOE is currently supporting the Bureau of Land Management in assessing potential benefits of royalty relief for marginal gas wells.
- DOE has also used its models to advise the Environmental Protection Agency on the costs and benefits of proposed environmental regulations affecting the petroleum industry.

Oil and Gas Modeling and Analysis Program

Drivers

- Fossil Energy (FE) needs information from modeling and analysis to make wise and efficient choices for spending appropriated funds to maximize the benefits of its oil, gas, and environmental RD&D programs to the public.
- FE's and DOE's budget decision makers need high quality information on how varying levels of budgetary funding will affect the benefits that can be derived from oil and gas RD&D programs, so that they can choose appropriate funding levels that maximize the benefits of these programs versus the costs of their implementation.
- Policymakers in DOE and in other Executive branch agencies, in Congress, in State energy and environmental agencies, and in the petroleum industry need quantitative and modeling analyses to assist them in determining the relative benefits and costs of a wide range of policy initiatives affecting the petroleum industry.
- FE requires models specifically designed to evaluate the potential benefits of differing technologies, economic criteria, and legislative and regulatory environments over the entire U.S. resource base. Other models available outside of DOE do not provide the required capabilities.

Vision

By 2010, DOE's oil and gas models will be fully integrated so they can be run in unison to simulate integrated oil and gas operations. The models will continue to be recognized and relied on by DOE, Congress, other governmental agencies, industry, and others as reliable and timely analytical tools for quantitative and modeling simulations of the petroleum industry.

Mission

Provide high quality modeling and quantitative analyses in a timely manner to support FE and DOE in achieving their stated goals and objectives.

Strategies

- Maintain and enhance a unique set of oil, gas, and programmatic models with capabilities that are not found elsewhere.
  - Ensure that model coverage is consistent with RD&D and policy program scopes by continually upgrading and improving models to expand regional coverage and to reflect the impacts of new technologies, economic conditions, and regulatory environments.
- Provide quantitative analyses that apply the set of models effectively to provide timely, accurate information that meets the specific requirements of customers.
  - Analyze the potential impacts of the oil, gas, and related environmental RD&D programs on current exploration, production, and utilization of our petroleum resources.
  - Provide policymakers with accurate and timely quantitative analyses of legislative and regulatory initiatives affecting the petroleum industry to ensure that these initiatives are cost effective and beneficial to the industry and the Nation.

Measures of Success by 2010

- Results of the quantitative and modeling analyses provide timely and useful information as needed.
- Results of the analyses reflect the entire suite of program elements and model their interactions as well as their direct impacts.
- Models undergo peer reviews on a regular basis to ensure that they are of high caliber and acceptable to knowledgeable experts.

Analytical Models

FE's suite of analytical models comprises the following:

- **TORIS — the Total Oil Recovery Information System — couples engineering models with detailed economic models to estimate potential economic recovery over a wide range of extraction technologies and economic criteria. The system's extensive databases of geological reservoir properties, production levels, and engineering criteria support detailed analyses. TORIS results are used to focus DOE's oil RD&D programs on potentially high benefit areas, to develop budgetary insights to support program development, and to assess the effectiveness of reaching DOE's RD&D goals and objectives. TORIS is operated by DOE's National Petroleum Technology Office in Tulsa, Oklahoma.**
- **COPM — the Crude Oil Policy Model — provides quick yet accurate results in analyzing different policy options. COPM relies on TORIS for its basic data on production and economics. This modeling system is operated by the Office of Natural Gas and Petroleum Technology in DOE headquarters.**
- **GSAM — the Gas System Analysis Model — is a comprehensive system for analyzing natural gas exploration, extraction, storage, distribution, and utilization characteristics. Like TORIS, GSAM contains engineering models coupled with detailed economic models to estimate recovery and utilization of natural gas over a wide range of technical and economic conditions. GSAM results are used to focus DOE's RD&D related to gas supply to potentially high benefit areas, to develop budgetary insights to support program development, and to assess the effectiveness of reaching DOE's RD&D goals and objectives. GSAM also provides modeling and analytical capabilities to support DOE's gas policy initiatives. GSAM is operated by the Federal Energy Technology Center at Morgantown, West Virginia.**
- **CRIP — Change Resource Implementation and Probability, a program metrics model — is used to estimate potential benefits of specific oil related RD&D projects implemented by DOE. This comprehensive modeling system enables DOE to evaluate its progress toward achieving stated goals and objectives. CRIP is operated by DOE's National Petroleum Technology Office in Tulsa, Oklahoma.**

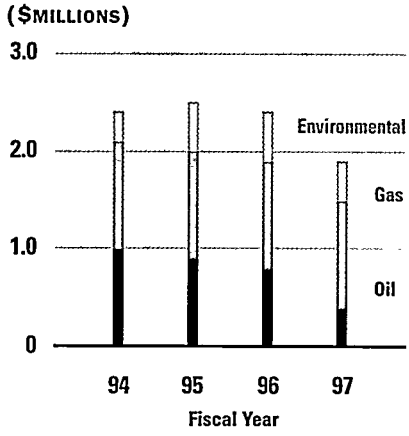
Strategies for the Future

FE has been developing oil and gas models since 1984, and will continue to maintain and improve the models, making them increasingly effective and responsive to changing requirements. Model maintenance includes updating geologic, technical, and cost data on a regular basis.

The original modeling system focused solely on enhanced oil recovery technologies in the lower-48 States. Since then, DOE models have been expanded and refined as needed, and as funds and information have become available, to include the entire domestic oil and gas industry. Planned upgrades and improvements will expand the models to cover the expanded scopes of the RD&D programs. Coverage will include offshore regions, as well as capabilities in exploration, environmental, and refining technologies.

In addition, new data and data sources must be discovered to advance oil and gas operations analyses. The modeling and database activities are in the forefront of technology development because much of the data necessary to improve the modeling system do not exist at this time.

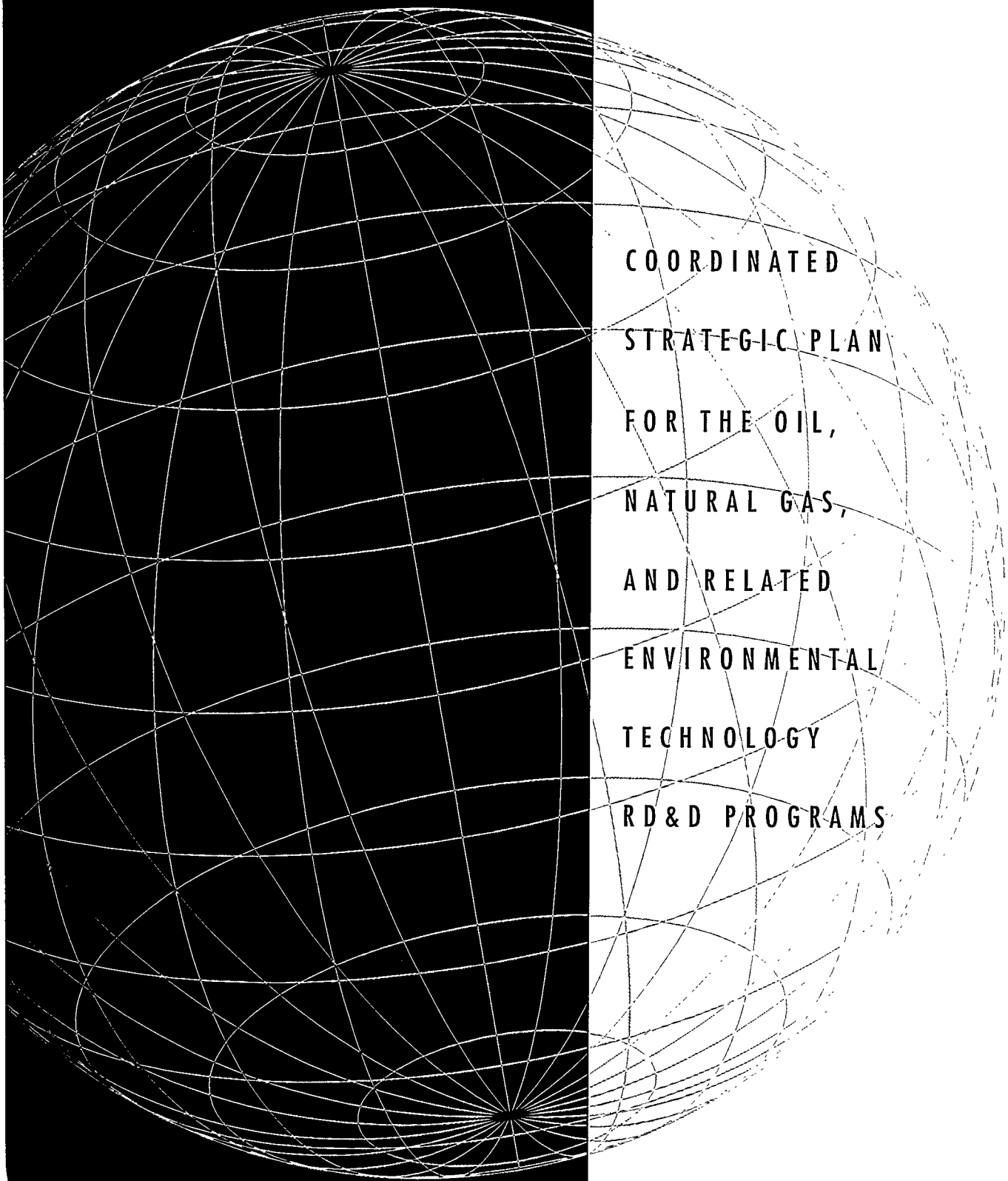
Oil and Gas Modeling and Analysis Program Budget*



*These budget numbers are included in the budgets of the other program areas.

FE will continue to maintain and improve its analytical models, making them increasingly effective and responsive to changing requirements.

STRATEGIC PLAN



COORDINATED

STRATEGIC PLAN

FOR THE OIL,

NATURAL GAS,

AND RELATED

ENVIRONMENTAL

TECHNOLOGY

RD&D PROGRAMS

STRATEGIC PLAN

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PLEASE NOTE: THIS VERSION IS A REPRINT OF THE DOCUMENT ORIGINALLY PUBLISHED IN AUGUST 1996.

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Introduction

The United States depends on oil and gas for approximately 63 percent of the energy it consumes. Many forecasts project that relatively low oil and gas prices and high U.S. dependency on these fuels will continue well into the next century. The economic benefits of having strong oil and gas industries that create export-related jobs supports the competitive economy required for global market competition in the twenty-first century and simultaneously provides low-priced domestic oil and gas fuels. A coordinated strategy has been developed to help achieve the Department of Energy's Oil Technology, Natural Gas Research, and related Environmental Research, Development, and Demonstration (RD&D) Program goals that support projected demand. Further, because of tightening budgets and generally reduced implementation resources, the strategy was formed to help attain the goals and attendant economic benefits using minimum resources and without unacceptable environmental costs or national security risks.

This is a coordinated plan for all oil technology, natural gas supply, and related environmental RD&D program activities. Stakeholder recommendations contained in the following documents were considered: the National Petroleum Council (NPC) studies, "RD&D Needs of the Oil and Gas Industry" and "Future Issues — A View of U.S. Oil and Natural Gas to 2020"; the Petroleum Technology Transfer Council's "Technology and Related Needs of U.S. Oil and Natural Gas Producers"; the report of the Yergin Task Force on Strategic Energy Research and Development; and relevant information from other sources.

Program drivers stem from defined Federal Government roles to maintain reliable domestic energy supplies at reasonable costs; increase the value of Federal lands and U.S. Treasury revenues by maximizing production; provide science and technology leadership; enhance global market opportunities for U.S. energy technologies; and serve as a catalyst for industry, State, and other Federal agency partnerships. Program activities are consistent with the scope of research needs analyzed by NPC in its RD&D Needs report, and encompasses the entire "systems approach" from natural resource identification to refinery and gas processing facility output.

The Oil Technology Program's supply portion includes RD&D in four program areas as outlined in the fiscal year 1996 budget:

- Exploration and Production Supporting Research
- Recovery Field Demonstrations
- Exploration and Production Environmental Research
- Processing Research and Downstream Operations

The Natural Gas Research Program's supply portion covered in this plan include:

- Exploration and Production (formerly Resource and Extraction)
- Storage
- Natural Gas Processing (comprised of Natural Gas-to-Liquids and Upgrading)
- Environmental Research/Regulatory Impact Analysis

Mission

The U.S. Department of Energy's (DOE) Office of Fossil Energy, in concert with customers, undertakes and promotes activities and policies through its oil technology and natural gas supply programs to enhance the efficiency and environmental quality of domestic oil and natural gas exploration, recovery, processing, transport, and storage. The success of these programs will help our Nation achieve a reliable and economic oil and natural gas supply and enhance U.S. technology leadership while protecting the environment.

Vision 2020

Oil and natural gas reach their full potential in contributing to the Nation's national security, economic growth, and environmental quality. The United States remains the world leader in oil and natural gas technologies; advanced U.S. technologies are sold and used worldwide. A customer-driven, public-private partnership is recognized as a key contributor to the development of technologies, regulatory streamlining, and policies that support increased supplies of oil and gas.

Customers

DOE's first-line customers — those directly involved — include:

- Oil and gas producers
- Service companies
- Energy marketers
- State and Federal agencies
- Universities
- Private research organizations
- Refiners
- Gas processors
- Pipeline companies
- Gas distributors
- Power generators
- Industry/producer associations
- Congress
- Native American Nations
- Oil and gas marketers
- Financial community
- Trade associations

DOE recognizes that the ultimate customer is the consumer. First-line customers serve ultimate consumers in the following market sectors:

- Transportation
- Agriculture
- Commercial
- Residential
- Industrial
- Electricity Generation

DOE's work with customers reflects the Government Performance and Results Act of 1993 and the Department's Outreach Strategy.

Government Performance and Results Act of 1993

Extensive stakeholder involvement in the development and ongoing assessment of coordinated oil and gas programs will be consistent with requirements of the Government Performance and Results Act (GPRA) of 1993. The purpose of this Act is to reduce waste and inefficiency and increase customer satisfaction in Federal programs. The GPRA calls for development of strategic plans which cover 5 fiscal years (to be updated every 3 years); a comprehensive mission statement linked to ongoing operations; general goals and objectives and how they will be achieved; a description of key external factors that could affect achievement of the goals; and annual program evaluations to be used in establishing or revising general goals and objectives. GPRA also requires consideration of the views and suggestions of those entities potentially affected by or interested in the program.

Outreach Strategy

A primary purpose of DOE's outreach program is to build strong relationships and frequent dialogue with industry. Departmental outreach efforts will enable industry and other stakeholders to: (1) provide input concerning needs and priorities; (2) identify areas for effective customer-driven, public-private partnerships; and (3) better utilize results of DOE-supported work.

Outreach activities establish vital relationships and two-way communications between a program's managers, implementers, and customers. In 1996, DOE developed a national and regional outreach network, involving teams composed of managers and staff from Headquarter's Oil and Gas Program and Policy offices and product and project managers from the Field. The network will serve as a framework for facilitating and coordinating outreach efforts in a cost-effective manner.

DOE's outreach teams parallel the structure established by the Petroleum Technology Transfer Council (PTTC) in 10 producing regions. There are also two non-PTTC regions (consuming only), and one overall national coordination activity. Each regional outreach team is responsible for understanding the region; knowing the industry and other key players; understanding regional resources, challenges, and needs; and marshalling DOE's resources. These team members combine expertise in technology, policy and regulatory analysis, and information and economic analysis.

A number of approaches will be used to establish relationships and develop the communications desired from outreach activities. These approaches include:

- Meeting with and listening to a variety of industry organizations, such as technical associations, the Gas Research Institute, American Petroleum Institute, National Petroleum Refiners Association, American Gas Association, Petroleum Environmental Research Forum, and others;
- Working with the PTTC in using its regional centers, producer networks, and problem identification activities;
- Participating in national and regional conferences and workshops where research and other industry needs are discussed; and
- Coordinating with other Federal Government agencies having related interests, such as the U.S. Geological Survey, Minerals Management Service, Bureau of Land Management, and the Environmental Protection Agency, as well as State and local agencies.

Information exchanged through these efforts will be used to develop coordinated strategic and implementation plans and budgets for the Oil Technology, Natural Gas Research, and related Environmental RD&D Programs. The dissemination of results (technology transfer) will emphasize delivering user-friendly information and products that meet the needs identified by the outreach program. In serving as a resource for industry and others on oil and gas matters, the coordinated programs will become the preferred points-of-contact for information and assistance in dealing with the Federal Government in areas such as the availability of research funds, environmental concerns, and royalty or tax matters. These information exchange activities will strengthen partnerships between DOE and its customers. Pursuing this approach to outreach will build and expand on industry-identified priorities by:

- Finding solutions to industry-identified problems and implementing them through proactive partnerships among industry and Federal, State, and local governments;
- Using cost-benefit analyses and risk-based solutions in the regulatory decision-making process; and
- Better coordinating policy development and regulatory activities with industry and Federal, State, and local agencies.

Current Situation

For more than a century, oil and gas industries have been essential to the economic growth, high standards of living, and national security of the United States. The U.S. leads the world in petroleum production and processing technologies, which provide high-paying jobs for Americans both domestically and abroad. In 1995, oil and gas accounted for two-thirds of total U.S. energy consumption.

Technology has changed the U.S. resource base over the last decade. Oil and gas resource estimates have increased, and at the same time, the cost of converting the resource base to producible reserves has decreased to less than $5/barrel today compared to $8 to $9/barrel in 1987. Several technological developments contributed to lowering the cost of augmenting natural gas and oil reserves. Advances in three-dimensional (3-D) seismic techniques enabled geologists to discover hydrocarbons beneath salt domes in the Gulf of Mexico, and improvements in platform design reduced the cost of developing deep-water resources. These technological innovations resulted in cost-effective development of U.S. offshore reserves and led to a significant increase in exploratory activity in the Outer Continental Shelf (OCS) during 1994 and 1995. The 3-D seismic techniques also greatly improved the success rate for onshore drilling, reducing the cost per barrel of recovery.

Today, the United States is considered a mature oil province where oil which is easily found and produced is rapidly being depleted. Domestic oil production is at its lowest level in 40 years, but substantial natural gas and oil resources, remaining and undiscovered, can be recovered with advanced technology. U.S. oil and gas reserves represent about a 9-year supply of domestic production. However, according to the NPC's recently updated estimates, U.S. reserve extensions and "undiscovered recoverable" resources are equivalent to a 35-year supply of oil and a 59-year supply of gas at current production rates.

Natural gas, a clean-burning and domestically abundant fossil fuel, is an increasingly important component of the Nation's energy portfolio. Natural gas is now recognized by many as the fuel of choice in the long-term transition to a sustainable energy future. Proved reserves of dry natural gas are 164 trillion cubic feet (Tcf), a slight increase from the previous year. Large offshore discoveries, several in deep water, contributed to this increase and to maintaining the reserve base. According to the Energy Information Administration's (EIA) Annual Energy Outlook 1996 (AEO-96), economically recoverable Lower-48 natural gas resources are estimated at 1,040 Tcf with 1990 technology and 1,696 Tcf with advanced technology in 2015.

In the 1980s and 1990s, the natural gas industry has moved from a heavily regulated utility service to a more competitive commodity supplier and has become increasingly more responsive to competitive market dynamics. Changes in Federal and State public policy are recognizing the benefits of increased gas use and energy competition. Before industry restructuring, producers sold gas mainly to interstate pipeline companies. Now, producers sell significant amounts of gas to marketers or directly to end users, and consequently, significantly less to pipeline companies.

In 1995, total dry natural gas production was 18.9 Tcf and consumption was 21.7 Tcf, both increased 4 percent from 1994. Imports totaled 2.8 Tcf, almost all from Canada. Compared to a year ago, gas consumption increased in all end-use sectors, with the highest gain in the utility sector. Natural gas prices have been relatively flat during the first quarter of 1996 and remain well above the unusually low level of the first quarter of 1995. The average wellhead price in March 1996 was $2.04 per thousand cubic feet (Mcf), compared to $1.54 for 1995.

Crude oil continues to be the primary source for transportation fuels. The United States is experiencing declining domestic reserves and production, and increasing imports. Proven U.S. oil reserves are estimated at 22.5 billion barrels, about 0.5 billion barrels less than last year. Revisions and large discoveries occurred in 1995 for the Gulf of Mexico; the 0.7 billion-barrel Mars field was the largest deep-water discovery in the Gulf in 25 years. According to EIA/AEO-96, economically recoverable Lower-48 oil resources are estimated at 106 billion barrels with 1990 technology and 142 billion barrels with advanced technology in 2015.

The Gulf of Mexico is one of the most exciting areas in terms of exploration and drilling. Increasing prospects and new discoveries in the Gulf have brought major producers back to domestic exploration, which has been primarily dominated by independents. In May 1996, total footage drilled for oil and gas was almost 11 million feet, up 45 percent from May 1995.

Domestic oil production in 1995 was 2.4 billion barrels, as the declining production trend continued. Alaska accounted for a quarter of U.S oil production despite a 73,000 barrel/day decrease compared to 1994. Industry estimates that in 1995, Gulf of Mexico oil production was increased by 100,000 barrels/day, more than enough to offset the Alaskan decrease but not enough to offset the Lower-48 onshore oil production decline. In 1995, domestic consumption, in terms of petroleum products supplied, was 6.5 billion barrels, almost the same as 1994. Oil imports totaled 2.6 billion barrels during 1995 and are projected to continue increasing. This volume represents 52 percent of U.S. crude oil usage.

The average composite crude oil price (refiner acquisition cost) in 1995 was $17.24/barrel, compared to $15.59/barrel in 1994. The average price in April 1996 was $21.61/barrel.

Higher oil prices have resulted in increased domestic activity. The number of drilling rigs operating in the United States in the first half of 1996 was almost 10 percent higher compared to the previous year.

Planning Assumptions

The following assumptions, based on information contained in EIA publications, "Annual Energy Review 1995" and AEO-96, were considered in developing the goals and strategies of the coordinated Oil Technology, Natural Gas Research, and related Environmental Technology Programs. These assumptions are consistent with the outlook through 2015 presented as EIA's Base Case in the AEO-96, specifically with respect to supply, price, and technology development for oil, gas, and competitive fuels. A revolutionary change in any of these variables would alter this strategic plan.

- U.S. oil and gas consumption, in absolute terms, will continue to increase despite energy efficiency improvements. Demand for transportation fuels will rise as a larger vehicle population and increased travel more than offset anticipated improvements in average fleet efficiency.
- Between 1980 and 1993, as gas supplies became more certain and regulations on end uses were removed, natural gas markets expanded — a trend that is expected to continue.
- Historically, technological progress has expanded the economically recoverable oil and natural gas resource base and reduced effective exploration and development costs. The extent to which this trend is likely to continue is uncertain and will depend on future rates of technology development and deployment.
- The prices of both oil and gas are expected to rise, but remain relatively low, through 2015. Oil prices are projected to average $25.43 per barrel in 2015 (1994$). The natural gas wellhead price is projected to be $2.57 per thousand cubic feet in 2015 (1994$).

Program Drivers

The following plans were used to provide information for this coordinated plan:

DOE Strategic Plan — "Fueling A Competitive Economy"

National Energy Policy Plan

Natural Gas Strategic Plan

Draft Oil Strategic Plan

Draft Update Natural Gas Multi-Year Plan

Oil Multi-Year Plan

International Strategic Plan

New Outreach Strategy

This coordinated strategic plan also considers recommendations from the following reports: NPC's studies, "RD&D Needs of the Oil and Gas Industry" (1995), "Future Issues — A View of U.S. Oil and Natural Gas to 2020" (1995), and "The Potential for Natural Gas in the United States" (1992); the Yergin Task Force Study on Strategic Energy Research and Development (1995); the Petroleum Technology Transfer Council survey, "Technology and Related Needs of U.S. Oil and Natural Gas Producers" (1996); the Gas Research Institute's annual baseline projection of U.S. energy supply and demand (1996), and its annual 5-year research and development plan (1996). Summaries of these reports and studies are contained in Appendix A.

Strategic Issues

Strategic issues have been defined to represent the key barriers or obstacles that must be overcome to realize DOE's vision for its oil and gas, and related environmental RD&D programs.

National Security

- The growing demand for oil products will increase U.S. dependence on petroleum imports.
- The United States is a mature oil producing region, but it is more difficult and more costly to produce domestic oil than imported oil.
- The world's oil supply is concentrated in politically unstable regions, which poses a national security threat.

Technology

- Available funding limits industry and government RD&D and the commercialization of advanced oil and natural gas exploration, recovery, refining, gas processing, storage, transmission, utilization, and environmental technologies.
- The widely varying characteristics of reservoirs and associated exploration, production, and processing methods result in the need to consider many diverse problems. The cost of technologies that address these problems must be reduced to ensure economic supply.
- Advances in exploration and production technologies to enhance cost competitiveness of natural gas are needed to maintain increased use of gas in a competitive energy price environment.
- Sufficiently accurate and timely information is necessary to support well-informed oil and gas supply decisions.

Environmental Constraints

- Environmental protection is vital to national and global prosperity.
- A reduction in the environmental impact of oil and natural gas exploration, production, and processing is essential to allow development of environmentally sensitive areas with high resource potential.
- Environmental constraints increase the cost of operations.

Economic Strength

- Future economics of oil and natural gas supplies may limit capital investments, new or expanded markets, infrastructure maintenance and development, and new technology development.
- The oil and gas industry has shifted its spending emphasis from basic and applied R&D to technical services.
- The involvement of major integrated oil and gas companies in domestic production (especially oil production) has been declining, leaving a less technology-oriented industry responsible for meeting domestic oil and gas needs.
- Without access to international markets, the U.S. petroleum industry may not be able to maintain its position as a leader in and exporter of technology and knowledge services.

Policy/Regulatory

- Restructuring in natural gas and electricity industries increases the need for coordinating Federal, State, and local policies affecting natural gas from reservoir to end use.
- Natural gas can significantly increase its role in the domestic energy resources portfolio with new policies and regulatory reforms at the Federal, State, and local government levels.
- Environmental regulations often do not reflect a sound scientific assessment of risk and an economic analysis of costs and benefits.
- Legal and other related problems in leasing new prospects will hamper resource development.

Program Goals and Strategies

For the purpose of strategic coordination of the component programs, goals and strategies have been grouped into major technology groupings: reservoir life extension; advanced drilling, completion, and stimulation systems; advanced diagnostic and imaging systems; effective environmental protection; emerging processing technology applications; and crosscutting program areas. Appendix B contains a table which cross references these technology groupings to current program budget categories.

Reservoir Life Extension

Reservoir Life Extension focuses on coordinating the Oil Technology and the Natural Gas Supply Programs' activities in research, development, and demonstration of advanced technology for extraction of hydrocarbons from known (discovered) oil and gas reservoirs and for improving natural gas storage. These activities provide improved technology and/or more efficient methods to recover more of the 150 billion barrels of discovered but unproduced domestic oil resource and the more than 500 Tcf of discovered natural gas, and for balancing the storage system that provides up to 30 percent of gas supply during peak months.

Goals

- Conduct research to develop and demonstrate tools and methodologies that permit oil and gas operators to recover hydrocarbons from known reservoirs not producible by current technology;
- Assist the storage industry to increase deliverability and capacity and to develop more accurate and timely gas measurement;
- Conduct, with industry, pilot-scale and field-scale demonstrations of proven laboratory technologies;
- Support university research on extraction technologies and recovery-process modeling to ensure a supply of well-trained workers while developing the scientific basis for promoting major technology breakthroughs applicable to oil, gas, and other industries; and
- Increase recovery of oil and gas from Federal lands.

Strategies

In partnership with stakeholders, DOE seeks to:

- **Develop, demonstrate, and transfer to industry new, improved, and cost-effective advanced oil and gas recovery technologies and methodologies evolving from reservoir class projects and secondary gas recovery projects;**
- **Develop, demonstrate, and transfer to industry advanced reservoir management techniques and technologies to enhance production from economically marginal wells;**
- **Develop, demonstrate, and transfer reservoir characterization methodologies and technologies to enhance the operation and improve the development of gas storage in depleted oil and gas reservoirs;**
- **Work with industry associations to provide focused technology workshops, information resource centers, and computer-based information for oil and gas producers and storage operators; and**
- **Revisit the Oil Reservoir Class Program and include natural gas resources.**

Performance Indicators

The Oil Technology and Natural Gas Supply Programs will evaluate performance upon completion of the following:

In the Near-Term, by 2000

- **Development of novel chemical technology for water shut-off and improved injectant sweep;**
- **Demonstration of reservoir management technologies in economically marginal fields in the Midwest, Eastern Gulf of Mexico, and North Midcontinent regions of the United States;**
- **Demonstration and transferal to industry of advanced technologies to increase production from fluvial-dominated deltaic reservoirs, shallow shelf carbonate reservoirs, and slope and basin clastic reservoirs;**
- **Complete establishment of a regional network of PTTC resource centers so they are fully industry supported;**
- **Complete integration of a national network of geoscience data repositories, assuring industry access to more than 2 million record sets of information and wellbore samples that would otherwise be lost;**
- **Demonstration of modeling capability and complete data requirements to show the impact of price and policy changes on the entire oil and gas system from reservoir to end use;**
- **Demonstration of fracture stimulation technology and improved remedial treatment technology to restore long-term deliverability from conventional underground gas storage reservoirs;**
- **Establishment of increased gas reserves through advanced technologies and methodologies demonstrated in secondary gas recovery projects; and**
- **Identification of market needs for natural gas storage in growing market areas.**

In the Mid-Term, by 2005

- Demonstration and transferal to industry of technology for carbon dioxide (CO_2) flooding of fractured shale reservoirs;
- Development and transferal to industry of computer programs for improved extraction project design, including enhanced UTCHEM, microbial enhanced oil recovery simulator, and a streamlined simulator for miscible processes;
- Demonstration and transferal to industry of remote sensing technology, (high resolution aeromagnetics and 3-D magnetic intensity projection) for predicting and detecting fracture locations in low permeability gas reservoirs;
- Demonstration and transferal to industry of a computer model to predict fluid flow in heterogeneous gas reservoirs;
- Demonstration of ultrasonic meter performance to improve gas measurement and reduce operational costs;
- Development of shear wave technology to determine the seismic signature and properties of fractured gas reservoirs; and
- Demonstration and transferal to industry of directional drilling technology for low permeability gas reservoirs in the Greater Green River Basin.

In the Long-Term, by 2010

- Development and demonstration of thermal technologies to produce the currently uneconomic heavy oil resources in the onshore Gulf of Mexico area;
- Development and testing of novel chemical and gas injection technology for recovery of the immobile oil resource that is not producible using current technology;
- Technology workshops provided to more than 90,000 independent producers through PTTC;
- Demonstration and transferal to industry of remote sensing technology for predicting and detecting the location of fractures in oil and gas reservoirs; and
- Demonstration and transferal to industry of directional drilling technology for low permeability gas reservoirs development in other Western basins.

Advanced Drilling, Completion, and Stimulation Systems

Advanced Drilling, Completion, and Stimulation (DCS) Systems focus on research, development, and demonstration of technologies that increase the net present value of produced oil and gas over the life-cycle of the producing well. DCS, a major program driver, can account for 30 to 70 percent of the initial capital cost of exploration wells, and advanced technologies can have a major impact on drilling operation economics.

Goals

This program area focuses on developing tools and techniques to drill, complete, and stimulate oil and gas wells required to produce the over 400 Tcf of natural gas and the more than 40 billion barrels of oil EIA's AEO-96 estimates will be produced domestically by the year 2015. Program goals are to:

- Assist industry with developing a balanced portfolio of DCS technologies that will match diverse geologic settings under development;
- Assist the drilling industry in developing new technology products that reduce costs, increase exploration success, minimize formation damage, and improve the producibility of wells;
- Develop, demonstrate, and deploy new technologies that will enhance general industry acceptance and use of technologies designed to reduce cost and improve productivity of oil and gas wells; and
- Coordinate with Gas Research Institute's (GRI) drilling program and other collaborative DCS groups such as the Drilling Engineering Association, the Completion Engineering Association, Natural Gas and Oil Technology Partnership, and other industry RD&D groups.

Strategies

The overall strategy is to conceive, develop, demonstrate, and deploy advanced drilling, completion, and stimulation products through laboratory confirmation and field testing in diverse high-potential geologic settings. Technology products and techniques being developed must provide higher net present value over the life cycle of the producing well. To achieve its goals, the Oil Technology Program and the Natural Gas Supply Program will:

- Design, fabricate, and test innovative drilling surface and subsurface instrumentation, hardware, software, and drilling fluids;
- Develop advanced hydraulic fracture technology to reduce damage and/or improve productivity of wells;
- Design, fabricate, and test innovative completion hardware, perforation techniques, and cementing processes;
- Participate in Drilling Engineering Association and Completion Engineering Association projects that will contribute to program efforts; and
- Develop revolutionary drilling systems in partnership with other government and industry groups.

PERFORMANCE INDICATORS

For Advanced Drilling, Completion, and Stimulation Systems, DOE will evaluate performance upon completion of the following:

In the Near-Term, by 2000

- Use of tool-hardened near-bit sensors for real-time drilling and reservoir information in difficult drilling environments having a "meantime-between-failure" rate of greater than 100 hours;
- Demonstration of slimhole, coiled-tubing products for drilling and completing wells with a minimum of a 25 percent cost savings over conventional methods;
- Commercialization of steerable air percussion measurement-while-drilling (MWD) systems in priority basins;
- Commercialization of coiled-tubing and steerable air percussion drilling systems;
- Completion of at least three technology demonstrations of integrated underbalanced motor MWD systems in priority basins;
- Demonstrations of cost effective domestic drilling rig retrofit components or systems;
- Development and commercialization of light weight mud for underbalanced drilling;
- Promotion of industry use and funding of the Fracturing Fluid Characterization Facility designed to test new hydraulic fracturing systems;
- Development, testing, and demonstration of high efficiency, non-damaging hydraulic fracture fluids and stimulation technologies for reservoirs up to 25,000 feet in depth;
- Commercialization of CO_2 sand fracturing in reservoirs representing 10 percent of the fracturing market;
- Development of an axial force transfer model for coiled-tubing drilling;
- Development of a performance model of positive displacement motors;
- Development of a model to predict and mitigate fatigue failure in top-drive rigs;
- Development of ways to predict and mitigate casing damage induced by reservoir compaction;
- Development and field testing of a novel Fast-Neutron Monitor; and
- Development of Electro-Osmosis technology to improve bit penetration rates in formations with clay problems.

In the Mid-Term, by 2005

- Completion of a feasibility demonstration project of an advanced drilling concept resulting in a greater than 50 percent improvement in drilling efficiency;
- An increase in domestic use of underbalanced drilling technology from 15 percent to 50 percent of the market;
- Development and commercialization of new DCS products that reduce cost and improve efficiency sufficiently to compete in the energy marketplace; and
- Successful commercialization of high efficiency, non-damaging stimulation technologies in priority basin deployment supply demonstrations.

In the Long-Term, by 2010

- Complete development of revolutionary drilling systems through collaborative efforts with GRI.

Advanced Diagnostics and Imaging Systems

Advanced Diagnostics and Imaging Systems focus on finding undiscovered oil and gas resources by using remote imaging, advanced instrumentation, and computational technology. This area also focuses on developing new ways to measure reservoir properties, increasing the accuracy of currently measurable properties, and developing tools and interpretive techniques to measure currently unmeasurable properties. Advanced diagnostic and imaging systems will be increasingly used for defining when to drill in discovered resources rather than for finding undiscovered resources. Likewise, independent operators will be using these technologies for making development decisions.

Goals

Advanced Diagnostics and Imaging Systems seek to develop technology that will improve the success rates and cost efficiencies of finding new fields and developing producing fields. These technologies are required to ensure a longer-term economic supply of domestic oil and gas needed to meet projections of EIA's AEO-96, which are over 400 Tcf of natural gas and more than 40 billion barrels of oil by the year 2015. The activities in this area are important to finding and economically developing the U.S. Geological Survey and Mineral Management Service resource estimates of 600 to 1,200 Tcf of undiscovered natural gas and 60 to 100 billion barrels of undiscovered oil in the United States. Program goals are to:

- **Conduct research to develop technologies needed for deeper and higher temperature reservoirs, providing U.S. technology leadership worldwide in geoscientific diagnostics and imaging systems, thereby, increasing technology exports that contribute to high-paying U.S. jobs;**
- **Conduct research to develop and deploy technologies that can provide a picture of underground resources and their environment, resulting in fewer dry holes, better usage of natural phenomena (such as fractures) to increase well productivity, and development of more effective well patterns, which can reduce the overall amount of required drilling fluids, thereby protecting the environment; and**
- **Enhance oil and gas production, including that from Federal lands, by developing technologies that will continue to provide technical, environmental, and economic justification for exploiting these resources.**

Strategies

In partnership with stakeholders, DOE seeks to:

- **Develop technologies and tools to measure important rock properties that are currently not measurable, and increase accuracy of measurement technologies;**
- **Develop technologies that increase resolution and applicability of rock pore-scale to geologic basin-scale imaging;**
- **Develop user-friendly exploration technologies for independent producers;**
- **Apply existing state-of-the-art computational technologies to advance seismic imaging and reservoir and production modeling; and**
- **Maintain an analysis and planning program (a crosscutting, integrated network of reservoir performance models and reservoir and project data-bases), which support program planning, analysis, and quality assurance.**

Performance Indicators

The success of Advanced Diagnostics and Imaging Systems will be gauged through the following tangible measures:

In the Near-Term, by 2000

- **Complete development and transfer of risk-based exploration decision-making software;**
- **Complete development of advanced seismic acquisition and processing technology to improve resolution of complex subsalt reservoirs; and**
- **Complete development of advanced data processing and simulation methods for applying advanced computing technology.**

In the Mid-Term, by 2005

- **Development of technologies for single-well seismic acquisition and processing;**
- **Development and demonstration of cross-well seismic technologies for use in both consolidated and unconsolidated formations;**
- **Development of models of fractured reservoirs for improved recovery design; and**
- **Development of and transferal to industry of improved scale-up techniques to accommodate pore- to core-scale heterogeneities in fast, large-grid simulators.**

In the Long-Term, by 2010

- **Development and transferal to industry of exploration analyses for high-priority basins;**
- **Development and transferal to industry of well logging and geological modeling techniques for in-situ permeability determination; and**
- **Development and transferal to industry of improved rock-mechanics measurement and modeling technology.**

Effective Environmental Protection

Effective Environmental Protection focuses on technologies and practices that reduce the threat to the environment and decrease the cost of effective environmental protection and compliance. The activities in this area fall under four program elements: risk assessment, regulatory streamlining, technology development, and program planning and analysis.

Risk Assessment: The activities in this element, the largest in terms of budget, address the industry priority of providing sound scientific information to support risk-based regulation. These activities assess and mitigate environmental risks posed by oil and gas exploration and production. DOE serves as a source of credible data that has been successful in influencing the development of regulation based on environmental risk, and cost and energy impacts. This has resulted in considerable cost savings for industry.

Regulatory Streamlining: This element supports the industry priority of reducing unreasonable and unnecessary compliance and reporting requirements, as well as the goals of the Vice President's National Performance Review. Such streamlining can reduce costs to oil and gas operators as well as to government agencies. It is accomplished through interagency cooperation, partnerships and dialogue among industry, States, Tribes, the public, and other affected parties, and a willingness to try innovative approaches. This activity includes outreach to stakeholders both to educate them on environmental issues and to assess their needs as a basis for determining program priorities.

Environmental Technology Development: This element includes the research, development, demonstration, and transfer of environmental compliance technologies and practices to oil and gas operators to improve environmental performance and lower costs for producers. Activities are aimed at demonstrating methods and technologies related to drilling and production waste management, including air emissions detection and control, produced water treatment and disposal, management of solid wastes and wastes containing naturally occurring radioactive materials, as well as remediation of contaminated sites. Technologies are often regional in nature, addressing specific technical needs in such areas as the Rocky Mountains, the Gulf of Mexico, Appalachia, and California. Technology transfer is an integral part of this activity, in both individual project efforts, and wider, coordinated networks such as the PTTC. The program also works cooperatively with the other oil and gas R&D programs to encourage development of environmentally sound technologies and leverage the efforts of the environmental program with relevant research in other areas.

Program Planning and Analysis: This element both develops information on industry and environmental trends for program planning purposes and conducts cooperative efforts with industry, States, and Federal agencies to promote environmentally sound gas and oil resource recovery. Many of these activities are regional in nature to address environmental constraints that exist in particular parts of the country. A large part of this effort supports the continuous review and improvement of existing and proposed environmental legislation, regulation, and policies that may affect natural gas and oil supply.

GOALS

The Effective Environmental Protection activity area seeks to maximize industry recovery of U.S. oil and gas resources by reducing the cost of effective environmental protection. In doing so, the program addresses all four of the previously identified national level goals of the oil and gas RD&D programs. In addition, the environmental program's specific goals are to:

- Enable industry to reduce compliance costs and improve environmental performance;
- Expand the capabilities of State and Federal governments to make more cost-effective, risk-based regulatory decisions promoting sound science and common sense; and
- Improve communication and technology transfer among industry, government, Tribes, and the public toward balancing national energy, economic, and environmental objectives.

STRATEGIES

In partnership with stakeholders, DOE seeks to:

- Promote dialogue, education, collaboration, and innovative problem solving;
- Work with States and Federal agencies to streamline regulations;
- Develop credible scientific and technical information to serve as the basis for risk-based regulation and compliance, including economic and energy impact analyses and tools for regulators to make risk-based decisions;
- Develop new, lower-cost environmental compliance technologies;
- Promote sound environmental practices through outreach and assistance to industry; and
- Work cooperatively with States, Federal agencies, and industry to leverage efforts to accelerate progress toward reducing the costs of effective environmental protection.

PERFORMANCE INDICATORS

The success of the Effective Environmental Protection program will be gauged through the following tangible measures:

- Adoption and implementation of program products by industry, Tribes, States, and Federal agencies;
- Reduction in costs of environmental compliance, both for specific technologies and for the industry as a whole;
- Initiation of specific efforts that use dialogue, collaboration, and consensus in regulatory decision-making; and
- Changes in State and Federal regulations and policies that reduce duplication and overlap, simplify compliance, and eliminate unnecessary requirements.

Emerging Processing Technology Applications

The Emerging Processing Technology Applications activity area encompasses two program elements. Natural Gas includes Low Quality Gas Upgrading, Coal Mine Methane Technology (demonstration of capture and utilization methods), and Gas-to-Liquids Conversion; Oil Technology includes Processing (pollution prevention, environmental compliance, and upgrading technology development).

Goals

The Emerging Processing Technology Applications activity area, through the Oil Technology and Natural Gas Supply Programs, seeks to enhance a diverse, secure domestic supply of oil and natural gas fuels by improving oil refinery efficiency and gas technologies that convert uneconomic or low quality gas to valuable commercial products. The specific program goals are to:

- **Develop cost-effective technologies for upgrading contaminated natural gas to pipeline quality or direct use and for converting natural gas to higher hydrocarbon liquid fuels or chemical precursors;**
- **Develop technologies to effectively capture gas from coal mines, increase productivity and mine safety, and reduce the escape of gas into the atmosphere; and**
- **Contribute to energy security by continuously generating and transferring to the refining industry new technologies and thermodynamic data that will lead to a streamlined regulatory framework, and at the same time lower the environmental impact and waste fraction percentages in a barrel of crude oil and increase efficiencies by 2 to 3 percent by 2000.**

Strategies

In partnership with industry, research, develop, and implement technologies and approaches and processes for upgrading uneconomic heavy oil and gas, which include: novel polymeric or ceramic membranes; novel adsorbents; heavy oil and residual upgrading; refinery processes that maximize transportation fuels; and hybrid technologies.

In partnership with stakeholders, DOE seeks to:

- **Develop and transfer to industry, gas-to-liquids conversion technologies based on research on catalytic and noncatalytic processes;**
- **Develop technologies to enhance the cost effectiveness of collecting and using gas released in coal mining;**
- **Work with industry to develop improved, cost-effective, and environmentally acceptable heavy oil and residual upgrading and processing technologies to maximize the output of transportation fuels;**
- **Develop advanced measurement instrumentation for collecting emissions data and collect data for developing risk-based regulations;**
- **Develop thermodynamic and chemical data about crude oils, especially heavy crudes, to improve refinery efficiencies; and**
- **Assure U.S. leadership regarding natural gas upgrading, coal mine methane recovery, and gas conversion technologies for products, information, and methodologies.**

Performance Indicators

The success of Emerging Processing Technology Applications will be gauged by the following tangible measures:

In the Near-Term, by 2000

- Development of heavy oil and residuum upgrading technology that reduces coke formation;
- Development of technology for improved acid-gas removal from natural gas at 25 percent lower cost than current technology; and
- Complete pilot-plant testing of breakthrough gas-to-liquids technology to convert unmarketable Alaskan and other remote natural gas to high quality transportation fuels.

In the Mid-Term, by 2005

- Development of improved analytical methodology for analysis of heavy oils; and
- Development of advanced measurement instrumentation to improve environmental data on emissions and wastes.

In the Long-Term, by 2015

- Development of new catalysts with improved selection and yields for processing crude oil fractions;
- Application of advanced natural gas-to-liquids conversion technology in Alaska to provide increased liquid fuels necessary to keep the Alaska pipeline volume at required levels;
- Development of technology for improved nitrogen removal from natural gas at 25 percent lower cost than current technology;
- Development of bioremediation technologies for heavy crudes;
- Deployment of cost-effective technologies for coal mine methane to recover and utilize one-third of the resource from longwall mining operations; and
- Transferal of environmental technologies for reducing air emissions (16 million tons of CO_2 and 1,250 tons of ammonia) and solid waste management (coke reduction by 2.5 percent) to the refining industry to improve operating conditions and to prevent closure of smaller refineries.

Crosscutting Program Areas

Crosscutting Program Areas encompass the following program elements: Outreach, Planning and Analysis, and International. These activities support all other program areas to assure that programs are responsive to industry and other stakeholder needs and are targeting research areas that will most benefit the Nation, and assuring that U.S. technology continues to be internationally competitive.

Goals

The crosscutting program areas support the other program areas by assuring that:

- A strong and continuous dialogue exists with industry and other stakeholders, providing guidance for program planning and evaluation of program results;
- Program planning is based on accurate data on the oil and gas resource, supply and utilization trends, industry activity, and R&D needs;
- Legislative, regulatory, and policy initiatives in oil and gas supply are based on the best available information;
- The domestic industry has access to research conducted in other countries; and
- Increased international marketing opportunities are available for U.S. oil and natural gas supply technology.

Strategies

The crosscutting areas use the following approaches to support the Oil Technology, Natural Gas Supply, and related Environmental Technology Programs:

- Encourage stakeholder communication through regional outreach teams of Headquarters and Field representatives with technical expertise across all program areas, coordinating with PTTC, the Interstate Oil and Gas Compact Commission (IOGCC), GRI, and other government, industry, and technical organizations with related interests; and participate in national and regional technical meetings (information exchanged through these efforts will be used in the development of program plans and budgets);
- Work with industry organizations and regulators to improve understanding of the energy and environmental situation and foster improved regulatory and policy decision-making;
- Develop and maintain reservoir-level databases and exploration models of production technology impacts, including: Total Oil Recovery Information System (TORIS), Gas Information System (GASIS), Crude Oil Policy Model (COPM), and Gas Systems Analysis Model (GSAM), to identify, characterize, quantify, and model the most attractive resource targets and measure technology impacts and to support program planning and policy development; and
- Promote international awareness of U.S. capabilities and interests, foster international partnerships, and create opportunities for U.S. industry to market services and equipment by sponsoring international conferences and establishing bilateral and multilateral agreements for exchange of data and technology, and by supporting international efforts of other parts of the DOE and other Federal agencies.

Performance Indicators

The success of Crosscutting Program Areas will be gauged through the following tangible measures:

In the Near-Term, by 2000

- **Synchronization of oil and natural gas computer models to assure consistent national resource assessments;**
- **Complete development of the Appalachian Basin and offshore Gulf of Mexico atlases of reservoir properties and make these and other previously developed atlases available to industry; and**
- **An increase in the number of persons and organizations using Oil Technology and Natural Gas Supply RD&D Program products and other resources.**

In the Mid-Term, by 2005

- **Update of process performance computer models capable of simulating advanced technologies; and**
- **Complete research exchanges with Western Hemisphere nations that have expertise in improved heavy oil recovery.**

In the Long-Term, by 2010

- **U.S. and worldwide commercialization of technologies developed through oil and gas RD&D programs; and**
- **An increase in the number of international partnerships dedicated to supply research and technology development.**

Appendix A

National Petroleum Council, "RD&D Needs of the Oil and Gas Industry" (1995)

The report contains the following recommendations for DOE:

- **Use the study in the realignment, program development, spending priorities, and budgeting activities;**
- **Focus research on areas of technology needs that cannot be effectively conducted in the private sector;**
- **Analyze expenditures to match industry's needs to the unique capabilities of the National Laboratories;**
- **Provide continuity for logical, cost-effective completion of ongoing, short-term projects;**
- **Place greater emphasis on prioritizing DOE programs based on industry's needs and participation. Improved processes and mechanisms for participation are also needed;**
- **Develop a project definition system, which uses broadly based industry input to prioritize and recommend RD&D;**
- **Remove barriers to collaboration; e.g., DOE needs to simplify administrative procedures, reduce paperwork, and accelerate turnaround time to bring technology to application; and**
- **Do not allow government laboratories to become technical services organizations competing with industry.**

The theme of these recommendations is to establish a process that embodies the new paradigm of user-driven technology development in oil and gas RD&D.

The report contains a survey of NPC members that identifies their high priority technology needs based on potential impact of these technologies on company performance in terms of cost reduction and gains in domestic production and efficiency. NPC member survey results were used as a starting point to re-examine existing program emphasis and direction and to establish an ongoing dialogue with industry to redirect the oil and gas supply program.

In response to the NPC study, the Department analyzed its oil and gas programs and projects to determine if they address industry's priority technology needs as identified in the NPC study. Of 176 technology areas surveyed, NPC identified 36 as high priority. Analysis indicated that DOE's fiscal year 1995 oil and gas programs addressed 22 of the 36 high priority areas. Fourteen high priority areas were not addressed by the Department's oil and gas programs. Nine of these are in Deepwater Offshore and Arctic areas. Forty percent of the Department-wide and 49 percent of Fossil Energy oil and gas fiscal year 1995 research, development, and demonstration funds were spent on the NPC's identified high priority areas. The Department uses this information and other inputs as the basis for ongoing discussions with industry to plan and evaluate oil and gas programs with the goal of addressing priority industry needs consistent with national interests.

■ NATIONAL PETROLEUM COUNCIL, "FUTURE ISSUES — A VIEW OF U.S. OIL AND NATURAL GAS TO 2020" (1995)

This report recommends that industry and government:

- **Encourage responsible development of domestic resources;**
- **Encourage development of as wide a range as possible of foreign import sources;**
- **Use sound science, cost-benefit analyses, and goal-oriented mechanisms for regulating industry;**
- **Encourage science, economics, and energy education;**
- **Improve and expand communication with stakeholders to more effectively resolve issues; and**
- **Improve coordination of policies.**

These recommendations were also used as a starting point in re-examining existing program emphasis and direction and in establishing an ongoing dialogue with industry to redirect the oil technology and gas supply programs.

■ NATIONAL PETROLEUM COUNCIL, "THE POTENTIAL FOR NATURAL GAS IN THE UNITED STATES" (1992)

The 1992 NPC Study, "The Potential for Natural Gas in the United States," has been an integral and important element in the planning and prioritization of both the DOE and GRI gas supply programs. A key finding of this study is that the abundant domestic natural gas resources can be produced and delivered at prices that allow market expansion and continued resource development. This finding depends on development of advanced supply technologies to reduce costs, as an increasing fraction of gas is supplied from more complex resource areas. Advancements in drilling technologies needed to continue the historic 3 percent per year decline in drilling costs is an essential element of the advanced technologies development.

■ YERGIN TASK FORCE STUDY ON STRATEGIC ENERGY RESEARCH AND DEVELOPMENT (1995)

The Task Force recommended that DOE:

- **Identify opportunities for streamlining R&D management and for eliminating overlapping management contracts, duplicative laboratory programs, marginal and overlapping research projects and facilities, and programs not directly related to strategic DOE R&D missions;**
- **Benchmark R&D management practices against "best practices" in the private sector and elsewhere in government and adopt these practices where practicable;**
- **Develop an integrated strategic plan and process for energy R&D, and use this process to determine funding priorities and manage a diverse energy R&D portfolio, through:**
  - **A balance of basic research and applied R&D (including industry co-funded demonstrations); and**
  - **Near and long-term R&D to provide continuing return on investment and to contribute to the health and vitality of domestic energy industries;**
- **Assure that Federal energy-related R&D investments serve to promote strategic goals, including U.S. economic strength, energy security, environmental quality, and science and technology leadership;**
- **Base and prioritize Federal R&D programs on the systematic application of measurable cost-benefit criteria tied to strategic national goals;**
- **Evaluate more widespread use of peer-reviewed competitions as a basis for awarding support in more applied strategic energy R&D programs;**
- **Make leveraging dollars through shared co-funding with industry the norm for near- to mid-term energy R&D programs;**
- **Continue to invest in energy-related research at universities, recognizing the strategic value of the research and its contribution to development of scientific and technological human resources for the future; and**
- **Consolidate energy RD&D programs to avoid duplication of effort and scattered management objectives.**

■ PETROLEUM TECHNOLOGY TRANSFER COUNCIL, "TECHNOLOGY AND RELATED NEEDS OF U.S. OIL AND GAS PRODUCERS" (1996)

This report underscores a fundamental message that current technology transfer mechanisms have not been able to increase the awareness, use, and adaptation of cost-effective technologies by most of the oil and gas producing industry, especially independent producers. The report's key message is that the mission of technology transfer efforts must be to accelerate and expand producers' awareness, understanding, access to, and acceptance of current and emerging, cost-effective technologies. Broad problems and needs identified include:

- **Inadequate well and reservoir level geologic and production data, case studies, and analogs to enable effective analysis and implementation of existing and emerging technologies;**
- **Insufficient producer access to or awareness of regulations and requirements for environmental compliance and associated financial liabilities;**
- **Insufficient availability of or awareness of tools, technologies, and approaches for cost-effective environmental protection and regulatory compliance;**
- **Inadequate producer awareness, understanding of, and access to advanced seismic and remote sensing technologies for exploration and reservoir development;**

- Insufficient awareness of availability, performance, and economics of improved drilling and completion technologies such as horizontal drilling, coiled-tubing, slimhole, air drilling, and extended-reach drilling;
- Need for cost-effective, environmentally safe technologies to manage water channeling; reduce water cut; increase recovery; and address related corrosion, scale, and other problems;
- Inadequate education in and understanding of applications of reservoir management, logging, simulation, and characterization tools;
- Inadequate awareness, applications, performance, and economics of currently available technologies and operating approaches to remediate wells; reduce operating costs; and improve or sustain economic production; including primary, secondary, and improved oil and natural gas recovery technologies; and
- Need for improved technology transfer mechanisms to inform producers objectively about the availability, application, history, potential costs and benefits, and potential performance of technologies that address their priority problems and needs.

■ ANNUAL GAS RESEARCH INSTITUTE BASELINE PROJECTION OF U.S. ENERGY SUPPLY AND DEMAND (1996)

This report presents GRI's summary analysis of gas supply, distribution, and utilization, which highlights the results of the prior decade and key factors that impact future projections. GRI's assessment of the impact of advanced supply technology developments are included in the document. The key point of this report is that gas demand will grow significantly in the next 20 years but wellhead prices will remain low — lower than prior year projections. This places greater emphasis on the development of advanced technologies that reduce production costs.

■ ANNUAL GAS RESEARCH INSTITUTE 5-YEAR RESEARCH AND DEVELOPMENT PLAN (1996)

This plan presents a summary of the current and future GRI programs and budgets for supply, operations, and end-use technologies. This information provides an opportunity for assuring that GRI and DOE gas supply and gas utilization programs are complementary and avoid duplication. The document also ensures that appropriate support is given to essential technology areas.

Appendix B

Relationship of New Technology Groupings to Current Budget Categories

New Technology Group	Oil Program Current Budget Category	Gas Program Current Budget Category
Reservoir Life Extension	• Extraction • Field Demonstration • Technology Transfer	• Secondary Gas Recovery • Storage Technology
Advanced Drilling, Completion, and Stimulation	• Drilling	• Drilling, Completion, and Stimulation
Advanced Diagnostics and Imaging Systems	• Reservoir Characterization • Exploration • Natural Gas and Oil Technology Partnership	• Resources / Reserves Assessment • Low-Permeability Formations
Effective Environmental Protection	• Environmental and Regulatory	• Environmental and Regulatory
Emerging Processing Technology Applications	• Oil Processing/Downstream Operations	• Low-Quality Gas Upgrading • Gas-to-Liquids Conversion • Coal-Mine Methane Technology
Crosscutting Program Areas	• Planning and Analysis	• N/A

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