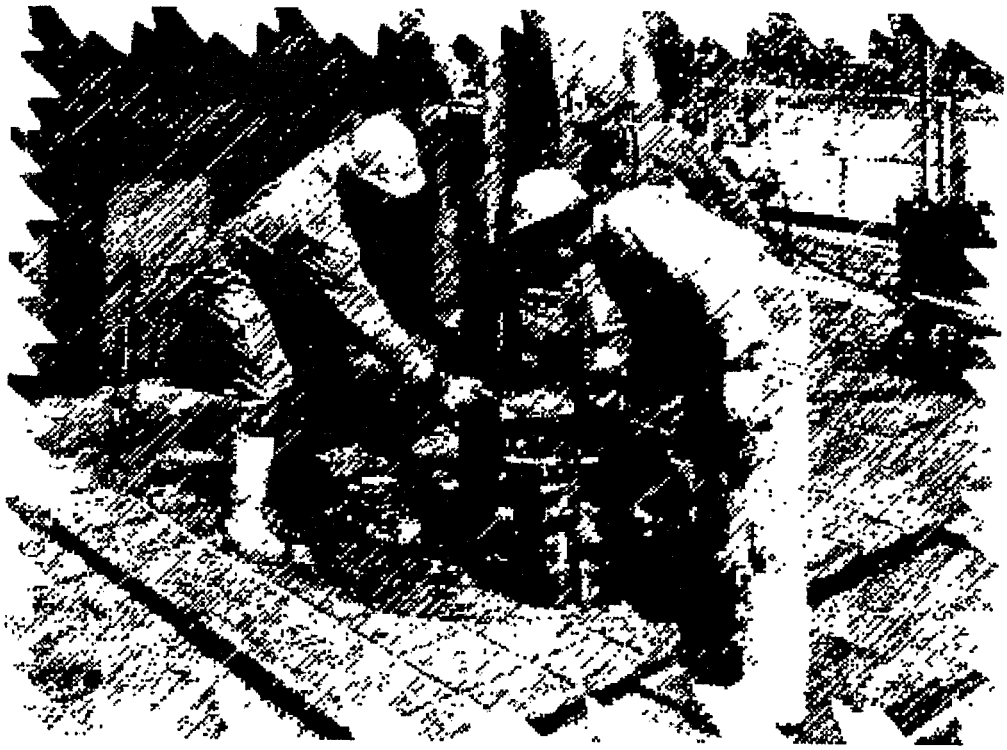
MULTI-YEAR PROGRAM PLAN

DOE/FE-0371

NATURAL GAS



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Department of Energy
Washington, DC 20585

To Our Readers:

This document comprises the Department of Energy's Natural Gas Multi-Year Program Plan. The research, development, and demonstration (RD&D) program activities crosscut the Offices of Fossil Energy, Energy Efficiency and Renewable Energy, Energy Research, and the Energy Information Administration. Specific activities are carried out and funded either independently by each Office or jointly, depending on the Office mission, program focus, crosscutting programmatic relationships, and budgetary considerations.

The Multi-Year Program Plan consists of the following technology areas: Natural Gas Supply, Delivery and Storage, Power Generation, Industrial, Residential and Commercial, Natural Gas Vehicles, and the Environment. The overall RD&D program strategy has been developed by a Department-wide planning Committee charged with ensuring that all natural gas programs are conducted with a single strategic focus to provide a united and integrated program to the natural gas industry and stakeholders.

I would like to give special recognition to Albert Yost, Federal Energy Technology Center, for his efforts as the Chairman of the Natural Gas Multi-Year Program Plan development task force, and the Department-wide program staff for their contributions.

We invite your comments and questions regarding this report or the programs described therein. The Committee and the individual program area contacts are listed inside the back cover of this report.

Sandra L. Waisley

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DOE/FE-0371

NATURAL GAS MULTI-YEAR PROGRAM PLAN

U.S. DEPARTMENT OF ENERGY

Office of Fossil Energy

Office of Energy Research

Office of Energy Efficiency and Renewable Energy

Energy Information Administration

December 1997

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Acronyms and Abbreviations

A

ABSIM	Absorption Simulation
AC	Alternating Current
AEO	Annual Energy Outlook
AGA	American Gas Association
ANL	Argonne National Laboratory
AOF	Absolute Open Flow
ASHRE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
ATS	Advanced Turbine System

B

BAGI	Backscatter Absorption Gas Imaging
BTS	Office of Building Technology, State and Community Programs
Btu	British Thermal Unit

C

CAAA	Clean Air Act Amendments of 1990
CANMET	Canada Center for Mineral and Energy Technology
CCNG	Consortium on the Conversion of Natural Gas
CENPES	Centro de Pesquisa e Desenvolvimento
CFC	Chlorofluorocarbon
CFCCs	Continuous Fiber Ceramic Composites
CGA	Canadian Gas Association
CIT	Chemical Industry Team
CNG	Compressed Natural Gas
COPc	Coefficient of Perfomance for Cooling
COPh	Coefficient of Performance for Heating
CRADA	Cooperative Research and Development Agreement

D

DC	Direct Current
DCC	Double Condenser Coupling
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation

E

EE	Office of Energy Efficiency and Renewable Energy (DOE)
EIA	Energy Information Administration (DOE)
EOB	Extreme Over Balanced
E&P	Exploration and Production
EPACT	Energy Policy Act of 1992
EPRI	Electric Power Research Institute

F

FE	Office of Fossil Energy
FERC	Federal Energy Regulatory Commission
FETC	Federal Energy Technology Center (DOE)
FY	Fiscal Year

G

GASIS	Gas Information System
GAX	Generator Absorber Heat Exchanger
GGRB	Greater Green River Basin
GRI	Gas Research Institute
GSAM	Gas Systems Analsysis Model
GTI	Gas Technology Information
GSAM	Gas Systems Analysis Model

H

HCFC	Hydrofluorocarbon
HD	Heavy Duty

HQ	Headquarters
HVAC	Heating, Ventilation, and Air Conditioning

I

IAQ	Indoor Air Quality
IEA	International Energy Agency
ICGTI	International Center for Gas Technology Information
IGT	Institute of Gas Technology
ILEV	Inherently Low Emission Vehicle
INEEL	Idaho National Engineering and Environmental Laboratory
IOGCC	Interstate Oil and Gas Compact Commission
IRP	Integrated Resource Planning
ISS	Integrated Storage System

K

kW	Kilowatt

L

LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LHV	Low Heating Value
LiBr	Lithium Bromide
LNG	Liquefied Natural Gas
LQNG	Low Quality Natural Gas
LWSA	Low Weight Solid Additive

M

Mcf	Thousand Cubic Feet
MCFC	Molten Carbonate Fuel Cell
MMTce	Million Metric Tons of Carbon Equivalent
MRF	Meter Research Facility
MW	Megawatt
MWD	Measurement-While-Drilling
MWX	Multiwell Experiment

N

NAFTA	North American Free Trade Agreement
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NGU	Natural Gas Upgrading
NH_3	Ammonia
NIPSCO	Northern Indiana Public Supply Company
NORM	Naturally Occurring Radioactive Materials
NO_x	Nitrogen Oxide
NPC	National Petroleum Council
NREL	National Renewable Energy Laboratory
NUGs	Non-Utility Generators
N_20	Nitrous Oxide

O

OATT	Office of Advanced Automotive Technologies
OCH	Oxyhydrochlorination
OEAS	Oxygen-enriched Air-staging
OECD	Organization for Ecnomic Cooperation and Development
OHVT	DOE Office of Heavy Vehicle Technologies
OIT	DOE Office of Industrial Technologies
ORNL	Oak Ridge National Laboratory
OTT	DOE Office of Transportation Technologies

P

PEM	Proton Exchange Membrane
PEMFC	Proton Exchange Membrane Fuel Cell
PNGV	Partnership for a New Generation of Vehicles
ppm	Parts per Million
PTTC	Petroleum Technology Transfer Council
POX	Partial Oxidation

Q

quad	Quadrillion Btu

R

RAM	Reliability-Availability-Maintainability
R&D	Research and Development
RD&D	Research, Development, and Demonstration
ROP	Rate of Penetration

S

SBIR	Small Business Innovations Research
SCERDC	South Carolina Energy and Research Development Center
SFE	Staged Field Experiment
SIC	Standard Industrial Classifications
SING	Spark-Ignited Natural Gas
SNL	Sandia National Laboratory
SOFC	Solid Oxide Fuel Cell
SWRI	Southwest Research Institute

T

TAD-OPTR	Thermoacoustic Driver-Orifice Pulse Tube Refrigerator
TAHP	Thermally Activated Heat Pump
TBD	To Be Determined
Tcf	Trillion Cubic Feet
T/E	Thermal-to-Electric
TRI	Toxic Release Inventory
TRIT	Turbine Rotor Inlet Temperature
TSD	Thermally Stable Diamond
2-D	Two Dimensional
3-D	Three Dimensional

U

ULEV	Ultra Low Emission Vehicle
USAQ	United States Air Quality
USGS	United States Geological Survey

V

VISTA	Vortex Inertial Staged Air
VMT	Vehicle-Miles-Traveled
VOC	Volatile Organic Compounds

W

WGC'96	World Gas Conference '96

V

VSP	Vertical Seismic Profile

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1.0 Executive Summary

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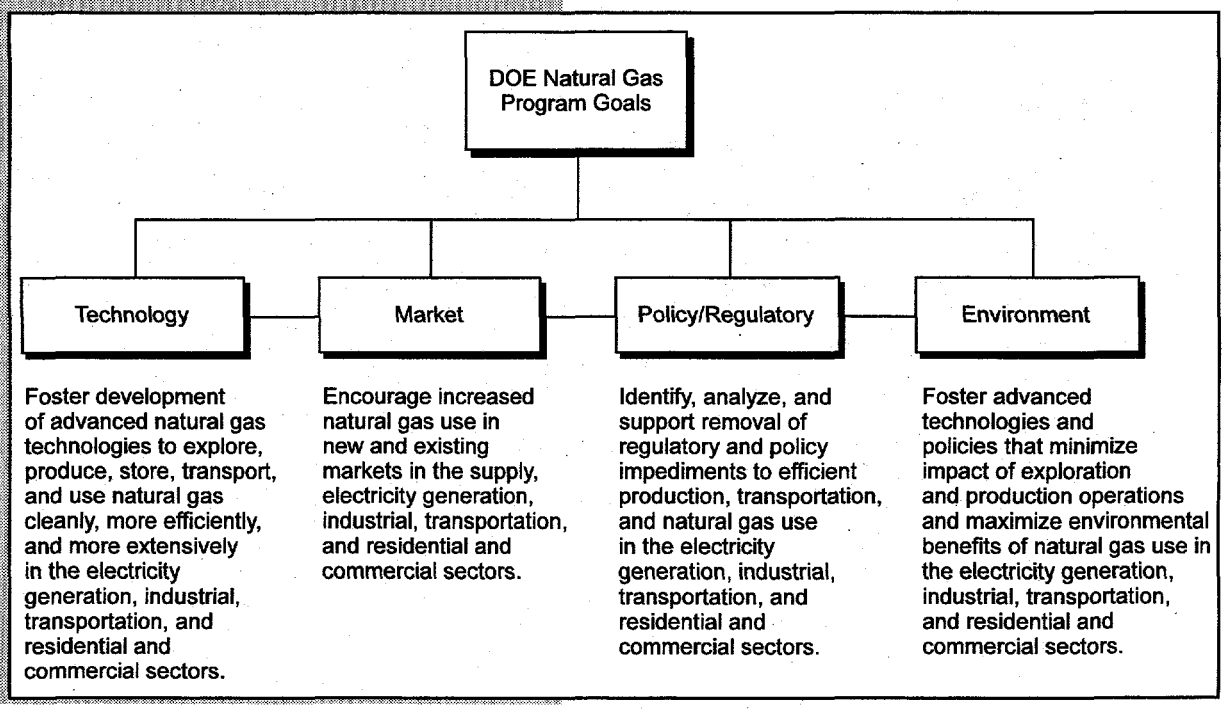
EXECUTIVE SUMMARY

1.1 INTRODUCTION

This document comprises the Department of Energy (DOE or the Department) Natural Gas Multi-Year Program Plan, and is a follow-up to the "Natural Gas Strategic Plan and Program Crosscut Plans," dated July 1995.

DOE's natural gas programs are aimed at simultaneously meeting our national energy needs, reducing oil imports, protecting our environment, and improving our economy. The Natural Gas Multi-Year Program Plan represents a Department-wide effort on expanded development and use of natural gas and defines Federal government and U.S. industry roles in parternering to accomplish defined strategic goals. The four overarching goals of the Natural Gas Program are to: (1) foster development of advanced natural gas technologies; (2) encourage adoption of advanced natural gas technologies in new and existing markets; (3) support removal of policy impediments to natural gas use in new and existing markets; and (4) foster technologies and policies to maximize environmental benefits of natural gas use. The program structure and goals are presented in Exhibit 1.

Exhibit 1 - DOE Natural Gas Program Goals.



1.2 Historical Trends

General Overview

Natural gas, a relatively clean-burning and domestically abundant fossil fuel, is an important component of the Nation's energy portfolio. Once viewed as a diminishing short-term resource, natural gas now is recognized as the fuel of choice in the long-term transition to a more sustainable energy future in the 21st century. Reports published by independent agencies, as well as the Department of Energy, have contributed to a better understanding of the U.S. domestic natural gas resource base, and allayed fears of shortages. For example, the National Petroleum Council (NPC) in their report, *The Potential for Natural Gas in the United States* (1992), estimated the recoverable gas resource base for the Lower-48 States, including offshore, at 1,295 trillion cubic feet (Tcf)—sufficient gas resources to meet U.S. demand, at current levels, for about 60 years. This estimate is conditional on advanced technologies to convert much of the gas resources-in-place into recoverable resources. In fact, the NPC estimate reflects an expected 25 percent expansion in remaining unproven recoverable resources in the Lower-48 States, which are expected to be available only through improved technology without regard to cost.

Technology and efficiency improvements have provided many benefits to gas consumers and industry. Natural gas consumption in 1996 reached 22 Tcf, the highest level since the 22.1 Tcf recorded in 1973 and 5.7 Tcf, or 35 percent, more than just 10 years earlier. Domestic production in 1996 continued the upward trend evident since 1986, reaching 18.8 Tcf, the highest level since 1981.

Domestic producers enjoyed a great deal of success in meeting the challenges of expanding output despite lower prices. Expanded supplies resulted in a period of generally lower prices. Between 1987 and 1996, gas wellhead prices have averaged $2.01 per thousand cubic feet (Mcf), which is 48 percent below the 1983 peak of $3.89 per Mcf.[1]

Strong industry performance in 1996 is expected to continue at least for the near term. Gas proved reserves[2] increased from 1993 to 1996, the first sustained increase in gas reserves since 1967. Proved reserves are significant as an indicator of future gas production potential. The growth in reserves shows a response to the greater number of gas exploratory wells, which have more than doubled since 1992.

A key aspect of recent industry experience has been the sometimes difficult transition, since the mid-1980s, from a heavily regulated industry to one in which natural gas is viewed as a competitive commodity. The story of the natural gas industry since the early 1980s has been one of extensive change and considerable success. The natural gas industry and markets have undergone a radical alteration to practices and performance during the past decade because of technological and institutional changes.

The next section provides an overview of regulatory and legislative changes affecting natural gas markets. This is followed by a discussion of major industry segments, and trends and measures that demonstrate the impact of technological changes within this altered institutional framework.

Changing Market Dynamics

The recent transition in the natural gas industry to a reduced regulatory environment has significantly affected business operations. The current industry is much more efficient than that of the early 1980s, but is affected by greater complexity in operations and contracting. Today's market reflects substantial changes in the industry since the mid-1980s.

The core of the natural gas industry consists of markets where the commodity itself is

[1] All prices in the Historical Trends section are in 1996 dollars.

[2] *Improved reserves* are the estimated quantities of natural gas that analysis of geological and engineering data demonstrate, with reasonable certainty, to be recoverable in future years from known reservoirs under existing economic and operating conditions.

priced and traded. The natural gas industry before 1985 was highly regulated from the wellhead to the burnertip. This system operated under numerous rules, policies, and guidelines. One important consequence was that prices tended to be fairly stable on both a monthly and annual basis, but they were not an effective signal of market conditions. The goal of improving price signals from the consumer to the supplier has been accomplished through legislative and regulatory initiatives, which included deregulation of wellhead prices and open access to the pipeline transportation system.

Since the mid-1980s, the Federal Energy Regulatory Commission (FERC) has issued a series of orders designed to further competition. These efforts began with Order No. 436 (1985) and culminated in Order No. 636, called the Restructuring Rule. Order No. 636 was issued in April 1992 and implemented in November 1993. It required interstate pipeline companies to separate (or "unbundle") all of their services. Under the Order, interstate pipeline companies were required to separate their merchant and transportation functions by November 1, 1993. Unbundling supply activities is an essential procompetitive action. It restricts the extension of monopoly power from one phase of supply, such as transportation, into other markets, such as storage or sales to end-users. Regulation of interstate transportation continues, but pipeline companies are no longer allowed to bundle natural gas sales with transportation services.

Gas can now be obtained from many sources and transported along numerous pipelines. Marketing companies have developed to provide marketing and supply aggregation services previously supplied by pipeline companies. Oversight of gas sales and marketing activities has been significantly reduced, but sales by interstate pipeline companies and interstate transportation remain subject to FERC jurisdiction. Gas purchases are essentially free from regulation, while transportation and storage remain subject to FERC jurisdiction.

Purchasers and sellers now operate in a market that can react rapidly to changes in supply and demand conditions. Advantages to firms in the industry from increased market flexibility are partially offset by the complexity of contracting for purchases and sales, and uncertainty about future gas prices. The extensive nature of earlier regulations limited negotiating flexibility and the associated contractual complexity. Contracting arrangements now include short-term spot contracts, longer-term contracts, futures contracts, and the exchange of futures for physicals. Gas can be purchased under fixed-price contracts or indexed to spot prices, futures prices, or alternate fuel prices. While the competitive market structure ensures that supply and demand conditions are balanced, there is also potential for significant price volatility, with price risk for both sellers and purchasers resulting from sudden unexpected price changes. Achieving the goals of one firm generally requires concessions to the other party, such as adjustments to price, assumption of risk, or quality of service. The challenge of contract negotiations in today's markets stands in marked contrast to the relative simplicity of earlier times.

Market Competition and Prices

The movement to a more competitive environment greatly increased price responsiveness. The evolution of the market since 1980 is reflected in three distinct phases of wellhead price behavior, which correspond roughly to the periods up to 1984, 1984 through 1987, and from 1987 to the present (Exhibit 2). As reported by the Energy Information Administration (EIA), average annual wellhead prices grew by almost a dollar between 1980 and the three year plateau of 1982-1984, when prices ranged between $3.86/Mcf and $3.90/Mcf. Prices fell steadily between 1984 and 1987 as many companies shed their long-term supply contracts that were priced above the market. As more pipeline companies became solely providers of transportation service, they renegotiated many of their long-term, high-

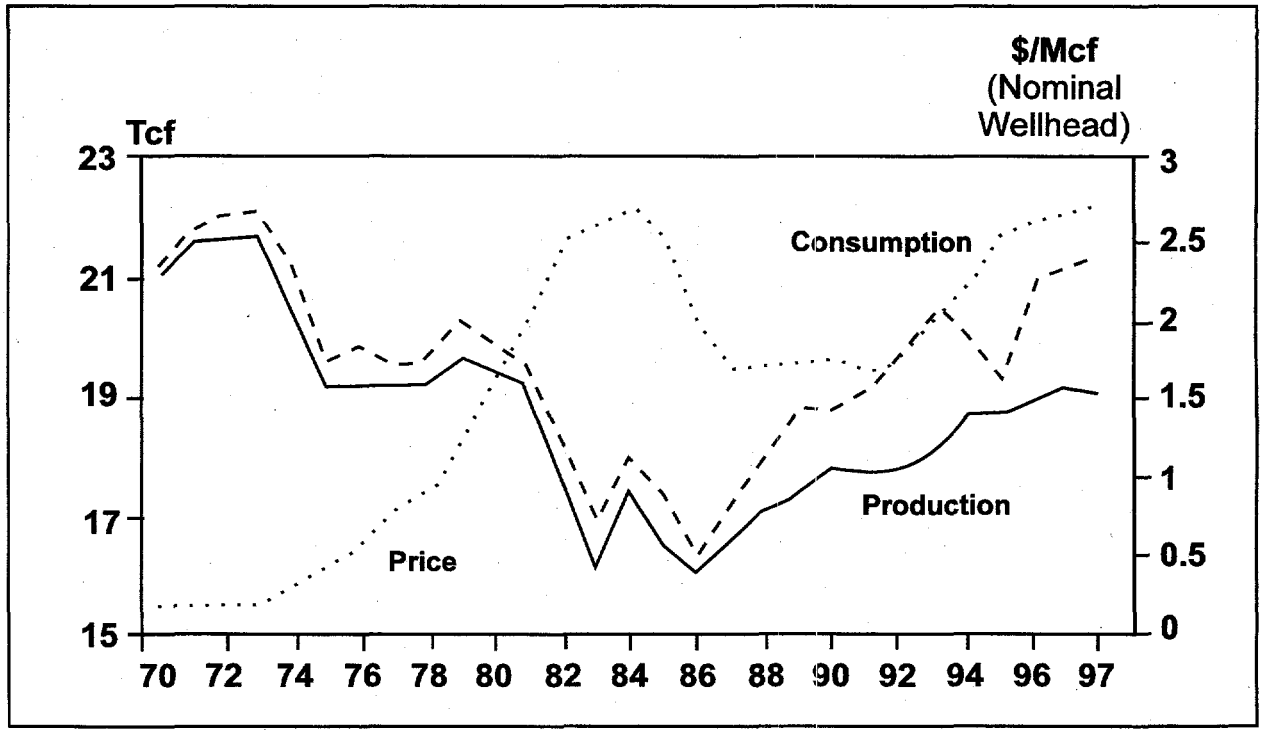
priced contracts with producers. Additional competitive pressure was introduced into gas markets with the virtual collapse of petroleum product prices in early 1986. With gas prices no longer propped up by long-term contracts, wellhead prices began to fall. Prices fell to $2.22/Mcf in 1987. Thereafter, prices have averaged $2.01/Mcf, which is slightly more than half the 1983 peak of $3.90/Mcf. This trend is expected to continue with relatively low gas wellhead prices projected through 2015. Prices are projected to be $2.12/Mcf in 2002; $2.21/Mcf in 2007; and $2.38/Mcf in 2015.[3]

Price differentials from the wellhead to the end-use delivery point have declined gradually for all classes of customers since the mid-1980s, indicating efficiency improvements in transmission and distribution. However, the greater portion of the decline in delivered prices results from the decrease in wellhead prices. Additionally, price differentials tend to fluctuate less than the wellhead price, thus the pattern in delivered prices tends to track that of wellhead prices, as shown in the average delivered prices for residential consumers and electric utilities. The outlook for natural gas prices shows a slight increase in wellhead prices, with further declines in delivered price differentials. The net result is a decline in gas prices through 2015 for residential customers, although electric utilities face a slight rise by 2015.

Gas Supply

The expected success from continued technological improvements has been reflected in recent natural gas resource assessments. This perspective is encouraged by recent industry performance. Production in 1996, at 18.8 Tcf, was more than 2.7 Tcf higher than the 16.1 Tcf produced ten years earlier (Exhibit 2). The 1996 production volume was the highest level since 1981. This recent trend in gas supply continues into the future according to EIA projections. U.S. natural gas production is expected to expand by another 7 Tcf to a total of 26.1 Tcf by 2015. This level of domestic production is

Exhibit 2 - Natural Gas Trends (1970-1997).



[3] All projected volumes and prices are from the *Annual Energy Outlook 1998*, Energy Information Administration, (December 1997).

conditional on continued improvements in technology at a rate comparable to that observed today. While continuation of this long-term trend may be a reasonable assumption for analysis, the source of supporting research and development activity is not identified.

The importance of technology improvement is seen particularly in a number of supply sources that were not economically or technically feasible even ten years ago, such as offshore deepwater production. Production from the entire Gulf of Mexico in 1996 increased 8.2 percent over 1995 volumes. Production from the deepwater region in the Gulf of Mexico expanded as new fields, such as the Mars project, initiated production. Some fields, such as Shell's Auger project and others that started during 1995, were able to produce for an entire year, adding to the growing offshore production total.

The trend for increasing gas production from the offshore Gulf of Mexico is expected to continue during the next few years. The Mensa project, in a record 5,400 feet of water, is expected to begin production in 1997. The depth of this project eclipses the deepwater record set in 1989 at 1,760 feet with the Joliet field. These technical accomplishments are impressive in themselves, and each milestone results in the expansion of future production opportunities as another technical barrier is overcome. The extension of recovery opportunities into deep water has established the deep offshore as an area of considerable national significance and one that clearly requires continued development and deployment of new technologies.

A second source of increased supply is gas from coalbed formations, which began producing significant marketed gas volumes only in the late-1980s. Natural gas production from coalbed methane fields continued to grow in 1996 as projects initiated mainly in the early- to mid-1990s matured through the dewatering phase into higher rates of gas production. Coalbed formations contributed almost 1 Tcf, roughly 5 percent, to U.S. production in 1996.

Continued production growth from coalbeds, however, is not likely in light of the precipitous drop in new wells completed in coalbed formations since termination of the production tax credit at the end of 1992. New well completions in coalbed formations averaged 244 in 1995 and 1996, compared with 1,325 from 1990 through 1992.

Natural gas market dynamics have changed dramatically as the industry adjusts to a more flexible and efficient market with deregulated wellhead prices and open access to the transportation network. Better price signals from end-users to suppliers and the ability to negotiate contracts and services more freely have resulted in competition that requires firms to focus on cost containment and greater productivity.

1.3 Natural Gas Policy

The Administration's policy is to increase our use of natural gas so as to maximize its economic, environmental, and national security benefits.

Increased natural gas usage will reduce our economic dependence on foreign energy suppliers. The vast majority of natural gas consumed in the U.S. is domestically produced, and almost all imports come from Canada, one of our partners in the North American Free Trade Agreement (NAFTA). U.S. gas reserves will be sufficient to meet domestic demand at current levels for about 60 years, and our NAFTA partners also have large reserves.

Natural gas is the cleanest burning of all fossil fuels, emitting lower levels of pollutants that contribute to smog, acid rain, and the greenhouse effect. Gas combustion does not create solid waste. It is delivered safely, reliably, and invisibly through a network of pipelines, the construction of which has little, if any, lasting effect on the environment.

DOE's *Sustainable Energy Strategy: Clean and Secure Energy for a Competitive Economy* (July 1995) discusses the Administration's approach toward

implementation of its natural gas policy. The major implementation strategies are to:

- Develop advanced natural gas technologies
- Provide incentives for increased exploration and production
- Stimulate end-use markets
- Continue regulatory reforms that reduce costs and increase efficiency

The Administration supports providing appropriate revenue-neutral incentives to increase natural gas exploration and production. DOE's ongoing *Domestic Natural Gas and Oil Initiative* encompasses a variety of actions to substitute domestically produced natural gas for foreign oil. A proposal to reduce the royalty rate for onshore marginal natural gas wells is also being assessed. The proposal has potential to conserve resources, improve ultimate recovery of finite resources, increase the domestic natural gas resource base, and promote natural gas production. The measure would be similar to the "Stripper Program" rule currently in effect for oil.

By purchasing natural gas vehicles for Federal fleets, providing tax incentives, and encouraging use of natural gas for electric power generation, the Administration is working to stimulate markets for natural gas use. The Energy Policy Act of 1992 established targets for purchase of alternative fuel vehicles by the Federal government. A 1993 Executive Order increased these targets. By the end of Fiscal Year (FY) 1994, the Federal government had purchased 6,700 natural gas vehicles.

The Administration supports continued regulatory reform throughout the Federal government to reduce the cost of natural gas exploration and production and to increase efficiency in natural gas markets. The current Federal and State regulatory framework lacks sufficient incentives for cost-effective pollution control and adoption of promising technologies. These regulations are often complex, redundant, and inflexible. Industry faces increased regulatory uncertainty and high compliance costs, while Federal, State, and local governments also spend more than necessary on implementing and enforcing regulations.

The Administration supports regulatory reforms to ensure a more robust secondary market for interstate natural gas pipeline capacity, to promote efficient and fair pricing of natural gas transportation service, and to expedite construction of new facilities to ensure reliable natural gas delivery. DOE continues to support States that are examining their regulations to bring the benefits of competition to retail natural gas markets.

1.4 DOE RD&D Program for Natural Gas

In the past, DOE natural gas programs were focused mainly on technology development, with only minor consideration of market and policy issues. Now, the focus of DOE natural gas programs has shifted to an integrated "systems approach," which addresses "reservoir to end use" technology needs, regulatory constraints, and market opportunities for increasing gas use. Expanding natural gas use in the U.S. presents many challenges and opportunities that include expanding the domestic resource base, developing new ways to use natural gas to maximize economic efficiency, and establishing policies and regulations to allow gas to compete with other fuels in new and existing markets. DOE's natural gas program focus is primarily on the near- and mid-term impacts on industry and consumers; reducing costs system-wide; enhancing efficient use of natural gas; reducing environmentally detrimental emissions; and increasing reliability of gas supply and deliverability.

The Department also is participating in the coordination and reform of Federal, State, and local government statutes and regulations to increase competition in energy markets. DOE policy and regulatory initiatives focus on four key areas: (1) market

efficiency, (2) market opportunities, (3) reducing regulatory impediments to gas use, and (4) encouraging consistency in Federal, State, and local regulatory oversight of the industry. Restructuring of the natural gas industry and potential restructuring of the electricity industry will affect future technology development choices and impact program budgets. The Department will need to perform further analysis of the impact Federal, State, and local regulations and electric power industry restructuring will have on the Department's ability to realize its vision for natural gas.

The Administration supports development of advanced natural gas technologies which increase the economically efficient use of natural gas. The Federal budget has supported advanced gas technology research, development, and demonstration (RD&D), thereby helping the Nation attain environmental and economic goals. Natural gas funding continues to be concentrated on technology RD&D. To support this new approach, DOE is forging stronger relationships with stakeholders. Jointly funded natural gas RD&D projects are ongoing in partnership with the Gas Research Institute (GRI), the Electric Power Research Institute (EPRI), industry, academic institutions, the National Laboratories, and other Federal agencies. These partnerships are intended to foster U.S. technical leadership and accelerate technology development and deployment, achieve national environmental goals, and define DOE's role in technology commercialization.

DOE is working with the natural gas industry to develop new production and end-use technologies. Remaining natural gas reservoirs are more difficult to develop because of their depth and size, hardness of the rock, impermeability, or the quality of the natural gas they contain. DOE and industry are developing new advanced drilling system technologies to induce fractures and to locate and drill through natural fractures. As for end-uses, DOE and its industrial partners are working to develop and deploy natural gas equipment for residential and commercial air conditioning, natural gas vehicles, high efficiency industrial gas turbines, and fuel cells that chemically convert natural gas to electricity at efficiencies of 50 to 60 percent.

New gas turbines and combined cycle technology are among the most attractive technologies for new electric generation capacity. Under the auspices of *The Climate Change Action Plan*, DOE has been funding projects to accelerate commercialization of high-efficiency gas technologies, such as fuel cells. DOE has entered into joint ventures with utilities, research organizations, and technology developers, and has funded demonstrations and market entry initiatives. DOE and EIA have also been working to address concerns about the long-term reliability of natural gas supplies by providing timely data on the availability and deliverability of natural gas supplies.

Environmental policies have become and will remain one of the most important considerations undertaken by DOE when assessing the future of natural gas markets. DOE recognizes the environmental benefits of natural gas, a cleaner-burning fuel, relative to the other fossil fuels.

1.5 Program Mission and Goals

The Program mission, as defined in the DOE Natural Gas Strategic Plan, is to undertake and promote activities, in partnership with DOE's stakeholders, and establish policies to maximize the Nation's ability to supply, transport, and use natural gas to encourage growth, enhance national security, and improve the environment.

The program goals are presented in Exhibit 3.

1.6 DOE Multi-Year Program Crosscut Plan

DOE's natural gas RD&D program activities crosscut the Offices of Fossil Energy, Energy Efficiency and Renewable Energy, Energy Research, and Policy, and the Energy Information Administration. Specific

activities are carried out and funded either independently by each Office or jointly, depending on the Office mission, program focus, crosscutting programmatic relationships, and budgetary considerations. The overall program strategy has been developed by a Department-wide planning Committee charged with ensuring that all natural gas programs are conducted with a single strategic focus to provide a united and integrated program to the natural gas industry and stakeholders.

In developing the Natural Gas Strategic Plan, the Committee established seven technology panels in the following focus areas: Natural Gas Supply, Delivery and Storage, Power Generation, Industrial, Residential and Commercial sectors, Natural Gas Vehicles, and the Environment. Each panel, comprising members from program offices and representative industry observers, developed a program strategic plan that reflects the strategic direction and goals provided in the Department-wide Natural Gas Strategic Plan.

1.7 Crosscutting Fundamental Research Related to Natural Gas

Basic research is currently being de-emphasized in the natural gas industry, raising questions about the adequacy of technological developments to maintain stable reserves, prices and markets. As a result, the Federal Government will need to maintain or increase its role in fundamental research in all areas of the natural gas industry. The Department of Energy historically has a number of broad-based research programs which have significance for the natural gas system, although they are not funded as parts of the directed natural gas program. They are distributed among various offices including the Office of Energy Research, the Office of Fossil Energy, the Office of Energy Efficiency and Renewable Energy, the Office of Environmental Management, and the Office of Defense Programs.

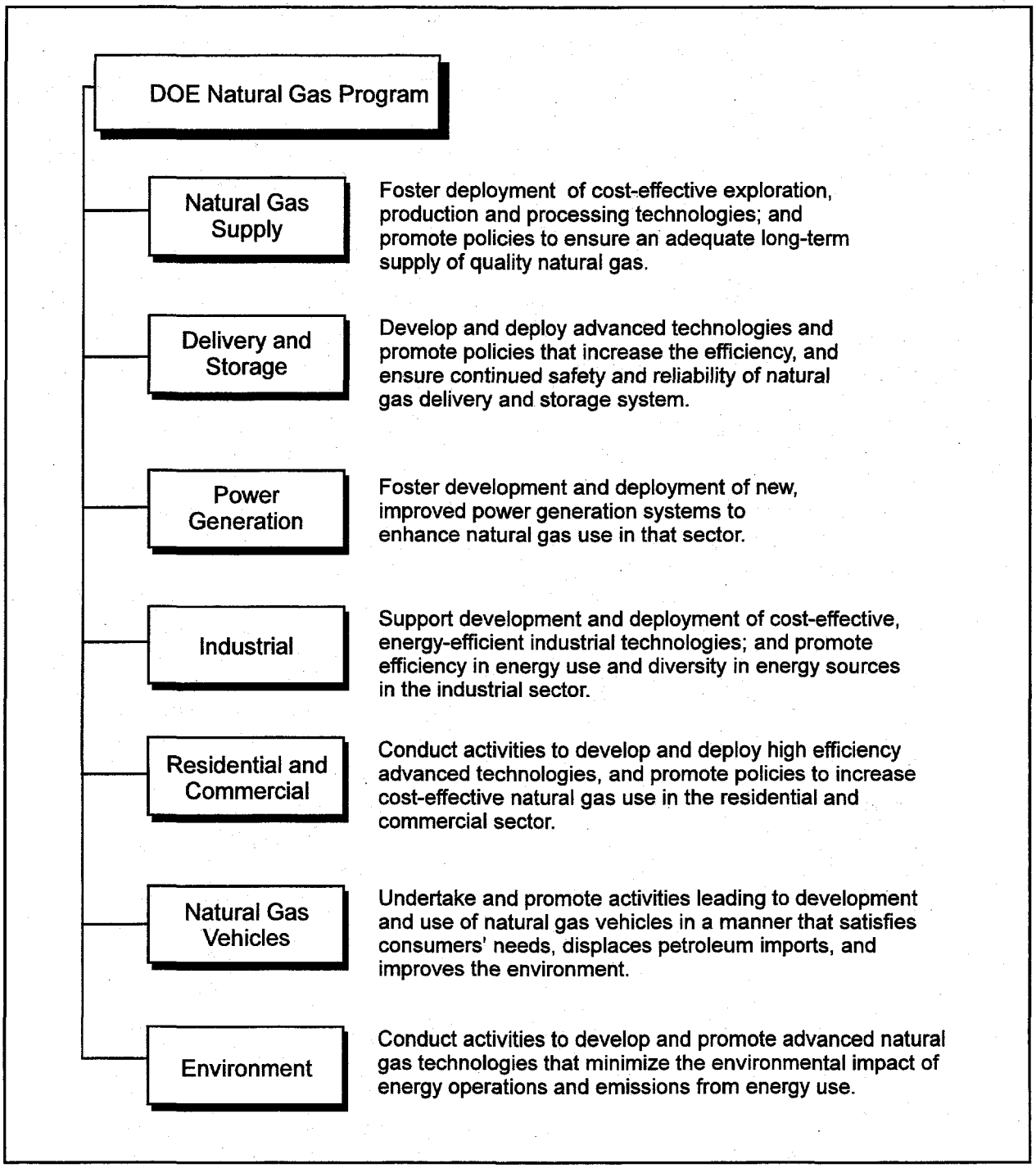
Because basic research is not directed at specific end users, it is best discussed in the context of its technical area rather than its funding source. Basic research in atmospheric, water and solid waste chemistry will underlie improved environmental technologies and regulatory decisionmaking. Geosciences research, funded across a wide spectrum of topics, contributes to improved potential for natural gas resource development. Material sciences and chemical sciences research improves the efficiency, durability and safety of the natural gas system. Other research activities, directly funded as parts of the natural gas program, are described in other parts of this report.

DOE, through its National Laboratory system and broad grant programs to university-based researchers, provides support to all energy industries. User facilities at the laboratories are regularly used by industry participants for diverse efforts, which few companies can afford individually. In the future, these user facilities will have higher profiles than they do now.

Cooperative research and development agreements between the National Laboratories and industrial partners are a major success story and have increasingly provided mutual benefits to both parties. Future partnerships, including those involving university-based researchers, on issues of interest to industry will be a major component of companies' basic research portfolios, and will feed into the more focused applied research activities that companies will maintain on their own. DOE and other Federal agencies, through their Small Business Innovative Research programs, are incubating basic research developments in the business sector that will have direct applicability to fossil fuel applications, but which are not part of the directed natural gas program.

DOE-funded researchers are leaders in global research issues that cannot be the focus of individual companies, but which form the context of the regulatory environment in

Exhibit 3 - Natural Gas Program Elements and Goals.



which they operate. Such research includes climate change, urban ozone, and environmental waste mitigation standards.

Atmospheric Chemistry

The Office of Energy Research maintains a basic research program in atmospheric chemistry through its Office of Biological and Environmental Research. This research seeks to understand the atmospheric chemistry processes related to energy emissions (and their by-products) into the environment (e.g., sulphur, nitrogen oxides, ozone, carbon dioxide). The components of the research are: (a) mid-latitude tropospheric ozone studies, (b) aerosol influences on clouds and climate forcing, (c) pollution-influences on stratospheric ozone and associated effects on surface uv-b radiation, and (d) assessment of the influence of methane and NO_x (primary emissions when methane is burned as fuel) and other greenhouse gas emissions on the global environment. The basic research portfolio has as its mission to understand fundamental atmospheric processes. To do this, it is necessary to understand atmospheric science, both where energy emissions are significant and where they are not.

Environmental Remediation

Although its primary focus is on remediation of DOE-generated waste, the Office of Environmental Management, through its Office of Technology Development, has been a pioneer in funding basic research on characterization, remediation and monitoring many kinds of wastes, including non-aqueous phase liquids. Information on research in this area can be obtained from the Office of Technology Development.

Geosciences

The Engineering and Geosciences Division of the Office of Basic Energy Sciences, Office of Energy Research, funds fundamental research in geomechanics, geochemistry, geophysics and hydrology. The program emphasizes research on processes that control responses of natural systems. These include multiphase fluid flow in porous and fractured rock systems, technology and processing improvements for geophysical imaging, and basic thermodynamic studies of geochemical systems, including those with organic components. Further information on the program can be obtained from the Geosciences Research Program in its annual "Summaries of FY 1997 Geosciences Research", or on its web site at URL address *http://www.er.doe.gov/production/bes/geo/geohome.html*.

Energy Materials

The Division of Material Sciences in the Office of Basic Energy Sciences, Office of Energy Research, annually coordinates publishing the summary volume of the Energy Materials Coordinating Committee. This Committee is tasked to present an overview of DOE material sciences activities drawn from all DOE research programs. It includes subcommittees on six materials areas of particular importance to the Department: (1) electrochemical technologies, (2) metals and intermetallics, (3) radioactive waste containers, (4) semiconductors, (5) structural ceramics and (6) superconductivity. The annual reports are available from the Material Sciences Division, Office of Basic Energy Sciences, Office of Energy Research.

The metals and intermetallics areas have broad applications for the natural gas system as exploration expands in difficult environments, pipeline transport networks become more extensive, and downstream activities increase. The performance parameters, economics, environmental acceptability and safety of energy production, transmission and conservation technologies are limited by behavior and performance of materials used in these energy technologies. As a basic research program, which is applicable to many energy areas, it seeks to understand the synergistic relationships between synthesis, processing, structure, properties, behavior, and operational performance. Research in this area is funded by a number of offices within DOE, including

the Office of Energy Research, the Office of Fossil Energy, The Office of Energy Efficiency and Renewable Energy and the Office of Defense Programs. Further detailed information is available from the relevant program offices, such as Summaries of FY 1997 Research in Material Sciences, available from the Division of Material Sciences, Office of Energy Research.

Chemical Sciences

Through its Division of Chemical Sciences in the Office of Basic Energy Sciences, the Office of Energy Research provides broad support for fundamental, molecular level understanding of the chemistry underpinning natural gas technologies. These programs include: (1) combustion research to use natural gas resources more efficiently, (2) catalysis research to provide environmentally benign approaches to improve conversion efficiency in production of products and chemical feedstocks from natural gas, (3) research on thermophysical and transport properties of complex mixtures, (4) separations research to improve efficiency of these energy-intensive processes, and (5) research in analytical chemistry to provide the foundations for improved process sensing and control.

The Division also manages a number of national user facilities, including the Combustion Research Facility at Sandia National Laboratory, Livermore, California. Some of the activities relevant to natural gas technologies are cooperatively supported with the Office of Energy Efficiency and Renewable Energy and the Gas Research Institute. Further information on the Chemical Sciences Division can be found in DOE publication "Summaries of FY 1997 Research in the Chemical Sciences," available on the World Wide Web at the following address: *http://www.er.doe.gov/production/bes/chm/chm.html.*

Advanced Research in Fossil Energy

The Office of Advanced Research and Technical Development in the Office of Fossil Energy funds research at National Laboratories and universities focused on fundamental understanding of materials and processes in energy generation. This includes fossil fuel processing and distribution environments, among others. Current research areas include ceramics (composite structural ceramics, catalyst supports, solid state electrolytes, and membranes), new alloys (aluminides, advanced austenitic steels, and coatings and claddings) and corrosion research.

1.8 EIA Natural Gas-Related Activities

The increasing complexity and competitiveness of the natural gas industry requires extensive and comprehensive decisionmaking information for the industry itself, as well as for Federal and State programs. A significant issue confronting realization of the natural gas program goals outlined in the DOE Strategic Plan is the need for widely available, accurate and timely natural gas information to support informed decisionmaking.

The Energy Information Administration promotes understanding of energy markets, industries and major policy issues through the compilation, validation, development and dissemination of information. This information includes reported data from survey operations, other data collection, the results of aggregation and analysis of these data, and short- and mid-term projections of energy markets. EIA information programs represent work products with applications for natural gas research within DOE. However, many of these information products are neither directed at nor funded for natural gas research alone.

EIA maintains comprehensive natural gas data series that cover reserves, production, storage, consumption, flows, and prices. These data are published in various hardcopy

reports such as the *Natural Gas Annual*, the *Natural Gas Monthly*, the *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves* report, and the *Monthly Energy Review*.

EIA publishes numerous analytical reports on a wide range of issues, including assessments of energy supply and price trends and other market-related events; impacts of technology changes on future energy markets; the energy-economic impact of environmental quality goals; and changes in the electric power industry under restructuring. Numerous studies are focused on issues specific to natural gas. Assessments of monthly natural gas wellhead productive capacity in the lower-48 States are published in the series, *Natural Gas Productive Capacity for the Lower-48 States*. *Natural Gas 1996: Issues and Trends* provides a summary of recent developments in the industry over the previous year, and also highlights issues relating to contracting for transportation capacity, the emergence of market centers, changes to natural gas producers, and the effects on consumers of changes to their access to natural gas services. Technology impacts of Gulf deep water projects, electricity restructuring efforts and potential impacts on the natural gas industry, deliverability of the natural gas distribution system, and short-term pricing issues are also being analyzed.

For broader energy market issues, the *Short-Term Energy Outlook* provides projections of energy supplies, demands and prices for the upcoming two years, while the *Annual Energy Outlook (AEO)* presents long-term forecasts through 2020. The 1998 *AEO* is the latest, and it includes projections under alternative economic and oil price scenarios, as well as technology cases targeted at isolating impacts of alternative technology outcomes on energy markets.

Many decisionmakers and analysts need quick access to timely and accurate information. The EIA has improved many of their products by making them available for access and downloading on the Internet at *http://www.eia.doe.gov*. Release of these data and reports immediately on the EIA Internet site means that a wider set of customers have ready access to this information, often prior to the availability of the printed reports. Established in July 1995, the site currently averages more than 30,000 unique users per month. New products on the EIA Internet site include the EIA *Geographical Information System-Natural Gas*, a system providing data and analytical information on natural gas pipeline and storage capacity and deliverability. In 1997, EIA instituted the *Natural Gas Weekly Market Update*, a quick summary of timely events relating to spot and futures prices, and storage and weather developments.

EIA strategic goals are directed at providing timely and accurate information for a broad range of customers. Improvement to analytical efforts is being addressed through various outreach efforts intended to form stronger partnerships with DOE program offices, other Federal and State agencies, and industry participants including producers, transmission and distribution companies, and consumer groups. A key element in this outreach effort is the recent institution of roundtable meetings with selected participants providing opportunities for discussion of analytical needs of the users of EIA products.

2.0 FY 1996-1998 Budget Overview

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FY 1996-1998 Natural Gas RD&D Program Crosscut Budget

FY 1996-1998 BUDGET OVERVIEW

Natural Gas Program Sectors	Department-Wide			GRI 1997 Actual	Fossil Energy			Energy Efficiency			Energy Research		
	FY 96	FY 97	FY 98		FY 96	FY 97	FY 98	FY 96	FY 97	FY 98	FY 96	FY 97	FY 98
Exploration and Production	19.7	22.0	21.9	38.0	14.2	14.0	13.9	-	-	-	5.5	8.0	8.0
Delivery and Storage	1.1	1.0	1.0	23.8	1.1	1.0	1.0	-	-	-	-	-	-
Utilization	168.5	174.0	182.6	59.6	94.1	102.5	92.9	69.6	67.2	85.4	4.8	4.3	4.3
Combustion Systems	6.0	5.1	5.7	14.0	-	-	-	1.4	1.0	1.6	4.6	4.1	4.1
Buildings--Heating and Cooling	7.2	8.3	8.7	2.4	-	-	-	7.2	8.3	8.7	-	-	-
Gas Turbines	62.8	75.0	83.9	1.1	36.8	46.6	45.0	26.0	28.4	38.9	-	-	-
Natural Gas Vehicles	15.1	13.4	16.7	7.6	-	-	-	15.1	13.4	16.7	-	-	-
Fuel Cells	56.8	55.3	46.6	1.0	52.5	50.1	40.2	4.3	5.2	6.4	-	-	-
Gas-to-Liquids	3.2	4.2	6.3	-	3.2	4.2	6.3	-	-	-	-	-	-
Low-Quality Gas Upgrade	1.3	1.3	1.1	-	1.3	1.3	1.1	-	-	-	-	-	-
International Gas Technology Center	0.3	0.3	0.3	-	0.3	0.3	0.3	-	-	-	-	-	-
Materials Technologies	10.4	7.9	6.9	-	-	-	-	10.4	7.9	6.9	-	-	-
Other	5.4	3.2	6.4	33.5	-	-	-	5.2	3.0	6.2	0.2	0.2	0.2
Environmental/ Regulatory Impact	5.3	3.6	4.3	8.8	2.9	2.6	3.3	-	-	-	2.4	1.0	1.0
Other - GRI only (processing/resource base crosscut)	-	-	-	16.2	-	-	-	-	-	-	-	-	-
Total	194.6	200.6	209.9	146.4	112.3	120.1	111.1	69.6	67.2	85.4	12.7	13.3	13.3

Note: Totals above do not match individual projects due to periodic allocations of funds and procurement sensitive information.

3.0 Multi-Year Program Plan

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3.1 Natural Gas Supply

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NATURAL GAS SUPPLY

3.1.1 TECHNOLOGY SUMMARY

OVERVIEW

High resource estimates have caused natural gas to be regarded as an abundant and economically competitive domestic energy resource. This perception, along with the increasing competitiveness of natural gas, has contributed to increased demand for natural gas throughout the United States. This interest is increasing internationally, particularly in the western hemisphere under the *Summit of the Americas* activities. This interest acknowledges the environmental benefits of natural gas, especially regarding issues related to global warming.

The total size of the "economically" recoverable Lower-48 natural gas resource base has been estimated by the Energy Information Administration (EIA) to be 1,046 Tcf with current technology, and 1,355 Tcf with advanced (2020) technology (EIA's Annual Energy Outlook 1998). This can be compared to the "technically" recoverable natural gas resource base estimated by the National Petroleum Council at 1,065 Tcf with current technology, and 1,295 with advanced technology.

Current proved domestic reserves of natural gas are 165 Tcf, including Alaska. Proved reserves are composed of natural gas primarily from conventional, less geologically complex reservoirs.

The restructuring of the U.S. oil and natural gas industry continues to have an effect on technology advancement. In addition, the amount of capital available for research and development continues to decline. Environmental compliance and other operating costs are increasing; therefore, these higher costs, combined with low wellhead prices, constrain operating profit margins, which result in premature abandonments of natural gas wells and leases.

Department-Wide Program

DOE's Natural Gas Supply program is administered through the Offices of Fossil Energy, Energy Efficiency and Renewable Energy, Energy Research, and Policy. For the Office of Fossil Energy, individual projects are implemented through the offices of the Federal Energy Technology Center in Morgantown, West Virginia and Pittsburgh, Pennsylvania. Projects are cost-shared with industry at varying levels of participation depending on the type of project and the associated risk, i.e., industry cost-sharing percentage is lower for basic research projects and is higher for technology demonstration projects.

The program includes exploration, production, and processing research, development, and demonstration (RD&D), as well as extraction and processing-related environmental research. To better serve the needs of DOE stakeholders, the Department-wide program now uses an integrated "systems approach" to address the issues related to technology, market, policy, and the environment, from the reservoir to ultimate consumption.

The Department is committed to improving and expanding the integration, coordination, and partnering of Federal and non-Federal efforts in these areas.

Furthermore, the Department's traditional natural gas supply program has been expanded to actively seek additional partnerships with stakeholders, such as the Gas Research Institute, Petroleum Technology Transfer Council (PTTC), National Advanced Drilling and Excavation Technology program, Interstate Oil and Gas Compact Commission, and the North American Coalbed Methane Forum. The objectives of these partnerships are to increase the effectiveness of the DOE program, and to increase the synergy between the Department and these efforts. The Department is equally committed to increasing the synergy in-house between fundamental geoscience and environmental research and applied aspects of RD&D and deployment. Integrating and optimizing Federal efforts with non-Federal efforts is at the core of this goal.

Key Trends

- Technological advances continue to enhance industry's ability to find and develop new natural gas reserves at competitive prices.
- Technological advances continue to minimize the impact of natural gas exploration, production, and processing operations on the environment.
- Industry interest in exploration technology has increased, and recent technological advances in deepwater drilling have opened up additional offshore areas as potential new discovery sites.
- Reducing the costs of exploration, production, and processing operations has been a key driver for research, development, and demonstration projects. However, future advances will likely be smaller due to declining investments.
- Significant technological advances for natural gas processing are resulting in cost-competitive technologies for production of high quality fuels and premium chemicals.
- Natural gas company RD&D spending has been, and will continue to be, constrained by low prices and industry restructuring trends.
- Low natural gas wellhead prices are reducing industry investment in new technology development, which may adversely affect long-term gas supplies.
- Natural gas demand continues to increase, while the level of drilling activities remains subject to price swings.
- The Administration continues to support natural gas as an increasingly

important fuel option in the U.S. energy supply portfolio.

- The Administration continues to promote and enter into partnerships with the natural gas industry to develop advanced natural gas technologies.
- Environmental regulations and ensuing compliance costs continue to increase.
- Industry interest in environmental compliance technology continues to increase.

Technology

- Advanced technology will be required to help natural gas continue as a cost-competitive energy source into the next century.
- Advanced natural gas technology is needed to offset the decline in production expected after technical limits of currently available technology have been reached.
- The applicability of a technology tested under one set of geologic/reservoir conditions to another set of conditions may require refinements based on localized geologic and engineering evaluations in order to maximize new applications of the technology.
- The diverse nature of natural gas reservoirs (onshore, offshore, low permeability formations, deep reservoirs, Devonian shale, coalbed methane) and associated exploration, production, and processing problems require addressing many divergent problems simultaneously.
- Decreasing investments in technology RD&D by the private and public sectors adversely affect the rate of technology development.
- Low natural gas prices could prevent industry from achieving projected technology advancement rates and incremental supply and reserves attributed to application of advanced technology.
- Supply will come from a variety of geologic settings, each possessing a unique set of technological barriers which must be overcome in order to ensure long-term supply.
- The cost of exploration, production, and processing technologies must be reduced in order to ensure an abundant supply.
- New technology may be beyond the financial capacity of undercapitalized producers. Cost-effective second generation advanced technologies are needed for their widespread deployment.

Market

- Continued low wellhead prices and uncertainty about future wellhead prices may lead to increased well abandonment.
- Lack of timely information on availability and performance of new technologies by operators, the service sector, equipment vendors, and consultants reduces the deployment rate of new and/or advanced technologies.
- Low prices and uncertainty about future prices inhibit new projects (e.g., new wells) and/or advanced technology.
- Unless gas producers, especially independents, deploy new and advanced exploration and production technologies, and explore new domestic frontiers, adequate projected supply levels may not be realized.
- Market deployment of DOE-sponsored technologies and products must be expanded in order to help achieve production levels required to meet long-term gas demand.

- Advanced technology must be adapted to current and foreseeable low-to-moderate wellhead prices and show tangible benefits in that price environment.

Key Planning Assumptions

Technology

- Deployment of advanced technology for natural gas E&P operations will reduce exploration and production costs, and result in stable long-term supply.
- Continued technology advances will be needed, as future natural gas supplies will come from both deeper and more geologically complex reservoirs requiring specialized technology.
- More "low quality" natural gas supplies will come from both deeper and more geologically complex reservoirs requiring specialized technology.
- DOE and its stakeholders will continue to enter into partnerships in the development of more environmentally benign exploration, production, and processing technologies.

Market

- U.S. natural gas demand will increase to 24.08 Tcf in 2000 and 28.84 Tcf in 2010, as projected by the Energy Information Administration's *Annual Energy Outlook 1998.*
- The supply of natural gas from reservoirs is sustainable over the long-term.
- Increased demand for natural gas will deplete the highest quality, most easily accessible resources more rapidly. This will cause greater interest in that part of the resource base which is: constrained and/or under moratoria, harder to produce or more difficult to explore (i.e., fractured reservoirs), of lower than acceptable quality, and/or more remote from the marketplace.
- DOE RD&D programs, in coordination with other Federal and non-Federal efforts, will result in advanced technology that will help natural gas remain competitive as a fuel option in the United States.
- As major producers shift their interests overseas, smaller domestic producers most likely will be the companies that develop low permeability tight gas reservoirs and fractured reservoirs, which currently have marginal economics or present exploration difficulties.
- Demand will increase for more environmentally acceptable transportation fuels that are economically competitive with petroleum-derived fuels.

Policy & Regulatory

- The Administration's policy to maximize cost-effective use of natural gas will continue, thereby increasing the need for greater long-term supply.
- Areas currently under federal E&P moratoria (including the Arctic National Wildlife Refuge and offshore areas) will not be developed.

Environment

- Environmental concerns will continue to limit exploration of ecologically sensitive exploration areas.

Program Activity Summary

The Natural Gas Supply program includes five main areas: (1) Exploration and Production; (2) Natural Gas Processing; (3) Natural Gas and Oil Technology Partnership; (4) Fundamental Geoscience; and (5) International Center for Gas Technology. This combination of programs represents the full spectrum of activities that comprise the natural gas supply system.

The **Exploration and Production** program includes three product lines: (1) Drilling,

Completion, and Stimulation; (2) Low Permeability Formations Development; and, (3) Resources and Reserves Assessment.

The Drilling, Completion & Stimulation product line focuses on reducing costs and improving process efficiencies in reaching and recovering natural gas from various types of geological formations in an environmentally benign manner. It also addresses the barriers associated with the cost-effective completion and stimulation of natural gas wells in various types of geologic settings. The current program includes projects related to increasing the penetration rate during drilling operations, improvements in measurement-while-drilling, and improving the design of hydraulic fractures.

The Low Permeability Formations Development product line will develop and demonstrate economical and efficient tools and techniques for recovering natural gas from geologically complex, low permeability reservoirs containing large volumes of natural gas. Included are projects involving the intersection of naturally occurring fracture systems, and the demonstration of cost-effective production technology in low permeability formations.

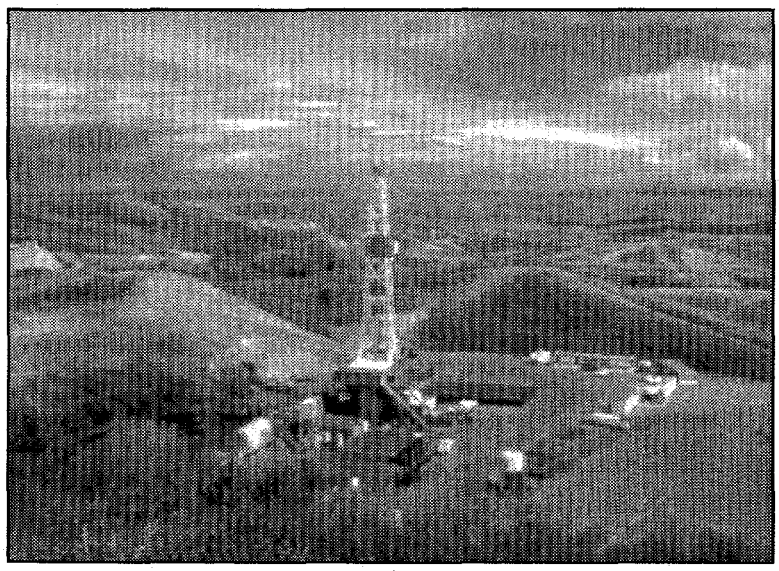
The Resources and Reserves Assessment product line focuses on identifying, characterizing, quantifying and modeling the most attractive targets upon which to focus the exploration and production research effort. This is a diverse effort involving projects related to databases and modeling, improving recovery from mature fields, basin analysis, and technology transfer.

The **Natural Gas Processing** program comprises three areas: (1) Coalmine Methane; (2) Low Quality Natural Gas Upgrading; and (3) Gas-to-Liquids.

The Coalmine Methane activities focus on the capture of methane associated with coal mining. This effort involves demonstration of current technology to improve the penetration rate of this technology into the coal mining industry.

The Low Quality Natural Gas Upgrading product line focuses on developing techniques for removing large quantities of impurities from raw, natural gas, thus upgrading the quality of the gas to a more pure stream of methane and without poisonous concentrations of hydrogen sulfide.

The Gas-to Liquids conversion product line focuses on developing economical techniques to convert natural gas streams into more easily transportable liquid forms of



Development Wells in Anshutz Ranch East Field, Utah-Wyoming Border

hydrocarbon fuel, either liquefied natural gas or chemically stable liquid hydrocarbons as alternatives to oil-based transportation fuels.

The **Fundamental Geosciences Program** is one facet of a broad-based geoscience research program emphasizing fluid-flow (e.g., geothermal, hydrocarbon, groundwater) in porous and fractured geologic media. The issues requiring investigation include: (1) the rate and nature of natural gas and oil generation from organic-rich sediments; (2) stability of natural gas in the subsurface; (3) origin and development of secondary porosity; (4) evolution of fracture systems with particular emphasis on potential reservoir and seal rocks; and (5) geophysical imaging for characterization of reservoirs and related rocks.

Program Funding

FY 1996-1998 Crosscut Budget Summary ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Drilling, Completion, and Stimulations	5.049	5.393	2.971
Low Permeability Formation Development	4.176	4.128	4.578
Resources and Reserves Assessment	3.922	3.927	4.293
Coalmine Methane	0.375	0.000	0.965
Low Quality Gas Upgrading	1.343	1.093	0.715
Gas-to-Liquids	2.885	5.066	3.150
Natural Gas and Oil Technology Partnership	1.000	1.000	1.000
International Center for Gas Technology	0.314	0.312	0.318
Fundamental Geosciences Research	5.500	3.800	3.800
Total	**24.564**	**24.719**	**21.790**

3.1.2 Project Descriptions

3.1.2.1 Drilling, Completion, and Stimulation

Background

This activity supports the DOE Strategic Plan by developing, testing, and fostering widespread deployment of advanced gas well *drilling, stimulation, and completion* products and technologies. New products and processes will benefit the domestic industry by reducing up-front capital requirements and/or improving cash flow profiles over producing well life. Advanced technologies also result in a smaller environmental "footprint" from drilling operations. These impacts are especially important in times of low wellhead natural gas prices and projected growth in natural gas demand. Progress towards the product line goal is considered essential by DOE, the Gas Research Institute, American Gas Association (AGA), and the industry in meeting the primary natural gas production requirements of the Nation. Economic growth will also be supported as new products and technologies are exported/deployed on a worldwide basis by U.S. companies.

Major Goals

The product line goal is to increase the net present value of oil and gas reserves over the life cycle of the producing wells by means of improvements in drilling, completion, and stimulation technologies and equipment as achieved by:

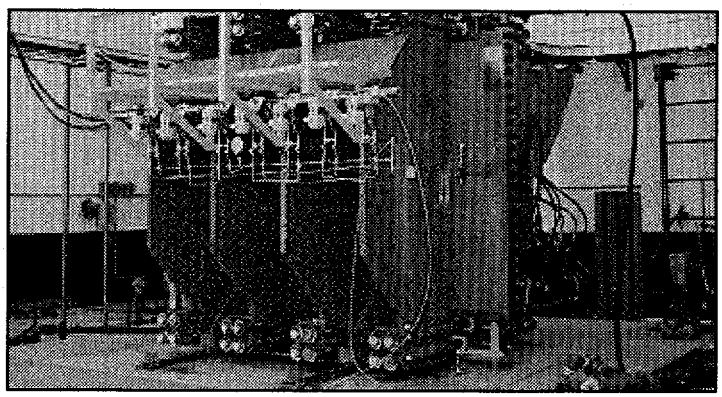
- Assisting petroleum industry in drilling research and development for near/mid-term product development;
- Encouraging demonstrations of new technologies and methods which enhance project profitability; and
- Co-participating with industry in development of completion and stimulation technologies and methodologies that look promising for improving reservoir development economics.

Project Objectives

Key project objectives are as follows:

- Underbalanced drilling fluid, model, and systems to facilitate wider technology application through a state-of-the-art drilling foam model, a low-weight solid additive (LWSA) system, a closed loop circulation system, and an electromagnetic based measurement-while-drilling (MWD) system.

Fracturing Fluid Characterization Facility



- High rate-of-penetration (ROP) drilling systems using conventional drilling fluids to introduce alternative drilling systems (e.g., directional air hammer and mud hammer) to reach target intervals in less time and at a lower cost.
- Advanced stimulation processes to improve process understanding and optimize applications. Complement large-scale laboratory experiments with field-based research and development (R&D). Fluid rheology, propellant transport, and fracture geometry are evaluated and minimum formation damage fracturing is being field tested with gas well operators.
- Advanced revolutionary drilling systems to introduce and investigate revolutionary drilling concepts that have the potential for reducing drilling time by 50 percent.
- Drilling rig equipment to enhance an aging rig inventory with capabilities adequate for present-day demands.
- Advanced well completion technology to ensure wellbore integrity in all wellbore geometries and maximize access to producing zones.

Expected Benefits

The primary expected benefits are:

- An economic gas supply to meet the 25-30 Tcf/year demand projected for the 21st century.
- Safe, efficient, and environmentally sound recovery technologies.
- Increase confidence in gas supply by continued success in reserve replacements and improved extraction and supply efficiencies.

Planned Products

Planned products are:

- Evaluation of the accomplishments at M-Sites and further field testing of selected technologies.
- Field testing of a fracture geometry imaging tool using geophone arrays in the Cotton Valley formation with an industry consortium.
- Field testing of the downhole pump for high pressure jet-assist drilling and evaluation of the likelihood of achieving an acceptable mean time between failure for commercialization.
- Field testing of slimhole high power motors/thermally stable diamond (TSD) bits.
- Field testing of light weight solid additives for underbalanced drilling applications using mud.
- RD&D focused at fracturing fluid and process barrier issues important to industry at the Fracturing Fluid Characterization Facility.
- Development and field testing of a prototype slimhole, coil tubing, steerable air-percussion drilling system.
- Design, development, and field testing of an integrated underbalanced directional drilling system using positive displacement motors and electromagnetic measurement while drilling.
- 15 additional CO_2/sand fracturing technology demonstrations in target basins.
- Field testing of a conventional size steerable air percussion drilling system.
- Initial development of promising industry-proposed revolutionary drilling systems.

Strategy (FY 97 Funding: $5.393 Million)

Program strategy emphasizes new thrusts into the underbalanced drilling technology , measurements while drilling, and advanced drilling, which have been in the planning process for some time.

Recent Accomplishments

- Directional drilling with a percussion air hammer was developed and successfully tested in cooperation with Smith Tool Company. Results show this new technology has the potential for doubling the penetration rates in air-drilled directional and horizontal boreholes.
- An electromagnetic MWD system was licensed to Sperry Sun Drilling Service after DOE's development support to Geoscience Electronics.
- Introduced a "dry stimulation" process to domestic producers to avoid formation damage in water-sensitive strata. Results showed that post-fracturing production is multi-fold and capable of flowing within two days.
- Completed design, fabrication, and testing of a high-power slimhole motor that should increase drilling rates and reduce costs.
- Completed fabrication of first generation near-bit directional module prototypes for measuring real-time position of the bit. This tool should reduce the risks of drilling horizontal wells out of zone.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Drilling	**3.438**	**2.463**	**0.900**
Steerable Air Percussion (Smith)	0.648	0.000	0.300
Slim Hole Drilling (Maurer)	0.349	0.000	0.000
Underbalanced Directional Drilling (Sperry-Sun)	0.975	0.042	0.500
Underbalanced Drilling Product (Maurer)	0.262	0.000	0.100
High Power Down-Hole Pump (Flow Drill)	0.980	0.000	0.000
Advanced Drilling System (TBD)	0.200	1.467	TBD
MWD/LWD Development (TBD)	0.000	0.928	TBD
Underbalanced Drilling Development (TBD)	0.000	0.000	TBD
Conventional Mud Hammer (TBD)	0.000	0.000	TBD
Steerable Mud Hammer (TBD)	0.000	0.000	TBD
DEA-101/44 Participation (Maurer)	0.024	0.026	0.000
Completion	**0.043**	**0.700**	**TBD**
Multistrata Study (College of West Virginia)	0.043	0.000	0.000
Advanced Completion System (TBD)	0.000	0.700	TBD
Stimulation	**1.367**	**1.219**	**1.800**
Fracture Fluid Characterization (University of Oklahoma)	0.800	0.719	0.300
Multiwell Site (CER)	0.067	0.400	0.000
CO_2/Sand Fracturing (PCS)	0.300	0.000	1.000
Advanced Stimulation (Union Pacific)	0.200	0.000	0.500
Stimulation Optimization (Stim-Lab)	0.000	0.100	0.000
Support	**0.201**	**1.011**	**0.271**
GSAM Modeling (ICF)	0.000	0.082	0.100
Technology Modeling (in-house)	0.201	0.194	0.000
Drilling, Completion, and Stimulation (Exhibits)	0.000	0.005	0.171
National Laboratory Partnership (LANL/LLNL)	0.000	0.730	TBD
Total	**5.049**	**5.393**	**2.971**

Cost Sharing ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Drilling	**1.480**	**0.743**	**0.350**
Steerable Air Percussion (Smith)	0.252	0.117	0.117
Slim Hole Drilling (Maurer)	0.174	0.000	0.000
Underbalanced Directional Drilling (Sperry-Sun)	0.419	0.018	0.215
Underbalanced Drilling Product (Maurer)	0.047	0.047	0.018
High Power Down-Hole Pump (Flow Drill)	0.588	0.000	0.000
Advanced Drilling System (TBD)	--	0.329	TBD
MWD/LWD Development (TBD)	--	0.232	TBD
Underbalanced Drilling Development (TBD)	--	--	TBD
Conventional Mud Hammer (TBD)	--	--	TBD
Steerable Mud Hammer (TBD)	--	--	TBD
DEA-101/44 Participation (Maurer)	--	--	--
Completion	--	--	--
Multistrata Study (College of West Virginia)	--	--	--
Advanced Completion System (TBD)	--	--	--
Stimulation	**0.583**	**0.359**	**TBD**
Fracture Fluid Characterization (University of Oklahoma)	0.400	0.359	0.000
Multiwell Site (CER)		--	--
CO_2/Sand Fracturing (PCS)	0.117	0.000	TBD
Advanced Stimulation (Union Pacific)	0.066	--	--
Stimulation Optimization (Stim-Lab)	--	--	--
Support	--	--	--
GSAM Modeling (ICF)	--	--	--
Technology Modeling (in-house)	--	--	--
Drilling, Completion, and Stimulation	--	--	--
National Laboratory Partnership (LANL/LLNL)	--	--	--
Total	**2.063**	**1.102**	**0.350**

TBD: To be Determined

Schedule

Projects	1997	1998	1999	2000	2001	2002
Drilling						
Steerable Air Percussion (Smith)						
Slim Hole Drilling (Maurer)						
Underbalanced Directional Drilling (Sperry-Sun)						
Underbalanced Drilling Product (Maurer)						
High Power Down-Hole Pump (Flow Drill)						
Advanced Drilling System (TBD)						
MWD/LWD Development (TBD)						
Underbalanced Drilling Development (TBD)						
Conventional Mud Hammer (TBD)						
Steerable Mud Hammer (TBD)						
DEA-101 Participation (Maurer)						
Completion						
Multistrata Study (College of WV)						
Advanced Completion System (TBD)						
Stimulation						
Fracture Fluid Characterization (University of Oklahoma)						
Multiwell Site (CER)						
CO_2/Sand Fracturing (PCS)						
Advanced Stimulation (Union Pacific)						
Stimulation Laboratory (TBD)						
Support						
GSAM Modeling (ICF)						
Technology Modeling (In house)						
DCS (TBD)						
National Laboratory Partnership (TBD)						

3.1.2.2 Low Permeability Formation Development

Background

As new discoveries from conventional supplies decline, future supplies of natural gas will increasingly have to come from low permeability (tight) reservoirs. The National Petroleum Council's (NPC) 1992 natural gas study estimated 349 Tcf of gas resource in tight sand formations in major basins throughout the United States. Areas containing significant resources/reserves include the Greater Green River Basin (GGRB), Piceance, Wind River, Uinta, and Anadarko Basins. Under current limitations in exploration and production technology, only a small portion of this vast resource is economic to develop at current gas prices. According to the 1992 NPC study, technology must continue to evolve for natural gas to fulfill its role in the United States' energy picture.

Gas production from low permeability formations is hindered by the formations' capability to allow gas to flow to the wellbore. Hence, economic production of natural gas can only occur where the flow path to the wellbore is enhanced. Geologic processes have created natural fractures in most formations that provide channels for gas to flow. In formations where the natural fracture network is extensive and dense, economic production can be achieved without wellbore enhancements. However, most low permeability formations require hydraulic fracturing to connect the wellbore to the majority of the formation to allow commercial production.

DOE and GRI have been conducting collaborative research to build industry confidence in the gas production potential of major tight gas sand basins. The effective application of production technology to the complex fractured geology of tight gas sand formations is governed by new knowledge on the subject which was not state of the art. Accordingly, DOE's multiwell experiment (MWX), a comprehensive production technology field laboratory in the Piceance Basin, produced extensive knowledge on tight sandstone production and transferred this technology to the producing community. In addition, GRI's Staged Field Experiments and Advanced Stimulation Technology Deployment Program have developed stimulation technology and transferred that technology to industry as well. Together, DOE and GRI worked at the MultiSites (former MWX location) to validate the microseismic mapping technique to image hydraulic fractures.

Current DOE research under the Low Permeability Formation Development product line is focused on advanced imaging and diagnostics technologies to detect and characterize natural fracture networks and verification tests of production technologies to prove undeveloped and underdeveloped gas resources locked within low permeability reservoirs.

Major Goals

The goal of the Low Permeability Formation Development product line is to develop technologies that will help industry increase production and reserves from low permeability formations to assure an adequate supply of natural gas well into the future. Specific goals include:

- Improve remote and in-situ techniques to detect and characterize natural fracture systems as well as various reservoir characteristics.
- Verify production technologies in basins with large tight gas sand resources/ reserves.

Project Objectives

A key objective is to develop and demonstrate, in partnership with industry, efficient development strategies for low permeability gas formations. Research efforts will be concentrated on natural fracture detection to increase the success rate of drilling economic wells and on production verification tests to improve the efficiency of

tight gas sand recovery. Work will be developed and demonstrated in priority basins and extrapolated to other basins throughout the United States.

Expected Benefits

- Ultimate recovery of gas in existing low permeability fields will increase through a better understanding of the natural fracture-production relationship.
- Dry holes (or uneconomic producers) will be reduced because of better methods to detect "sweet spots" of enhanced fracture systems.
- Tight gas sands production and reserves will increase from the demonstration and application of efficient development strategies.

Planned Products

- Methodologies to locate and define favorable production areas within tight gas sand basins nationwide.
- Techniques for the detection and mapping of fractured zones based on engineering, geological, and geophysical principles utilizing an integrated approach.
- Case studies of efficient and economic production technology from high angle and horizontal wells.
- Case studies of innovative stimulation techniques for improved recovery of gas.
- A hydraulic fracture imaging system that accurately maps fracture properties to help optimize treatments and gas recovery.

Strategy (FY 1997 Funding: $4.128 Million)

Natural Fracture Detection and Mapping

Natural fracture detection and mapping continues to be a major area of research. The main thrust has been in validating different approaches to detect natural fracture systems in areas that are well characterized by prior drilling and production. These research projects will culminate with verification tests in areas of little or no production. The final strategy is to provide a commercial service to use these technologies. Also, research will begin to advance to the next generation of fracture detection, moving from a more qualitative assessment of fracture systems to a more quantitative assessment to identify fracture properties (e.g., spacing, aperture), and fracture/pore space fluid properties.

Production Technology

Another major area of research will be to develop and demonstrate new production technologies for the efficient development of low permeability gas formations. DOE will verify technologies by conducting cost-shared tests in cooperation with industry and GRI. Industry involvement will facilitate transfer of technology. There are currently two major projects: the GGRB Production Test with Union Pacific Resources, and the Wind River Exploration and Stimulation Test with the Institute for Energy Research (IER) in cooperation with Synder Oil. The GGRB project will focus on horizontal well technology while the Wind River project will focus on detecting sweet spots (areas of over pressurization with enhanced porosity and permeability) and improved stimulation technologies. Successful applications of these technologies will lead to further testing in other basins while DOE continues to pursue opportunities for testing other promising technologies.

Recent Accomplishments

Coleman Research Corporation and Blackhawk/Geometrics Inc., completed analysis of a three-dimensional (3-D), P-wave seismic survey using azimuthal analysis of amplitude versus offset methods to determine areas of high natural fracture density and fracture orientation. An 80 percent success rate was obtained in distinguishing commercial production from non-commercial production from existing wells in the Maddin Gas Field, Wind River Basin, Wyoming.

Advanced Resources International has mapped subtle reverse faults that are responsible for natural fracture-based, high productivity trends within the tight gas sand formations at the Rulison Field, Piceance Basin, Colorado. Estimated ultimate recoveries (EURs) of gas for wells within the high productivity trends are over 2 Bcf whereas EURs are below 1 Bcf outside the trend. The methodology integrated analyses of remote sensing, aeromagnetic and seismic surveys, and basin analysis. Additional work using the same methodology at the adjoining Mamm Creek Field/Hunter Mesa Unit has contributed significantly to Synder Oil's rationale for locating new wells.

Lawrence Berkeley Laboratory completed well-to-well shear wave seismic surveys and well testing at the Conoco Test Site in Oklahoma, at a joint research site with Massachusetts Institute of Technology (MIT) in the Antrim Shale in Michigan, and at the Royal Center gas storage field in Indiana. Results have indicated that near wellbore changes in natural fracture apertures during pressure fluctuations and different fluid types within the fracture system can be detected. This methodology shows promise of commercialization within a few years.

Work at the DOE/GRI Multi-Site in the Piceance Basin, Colorado, validated the microseismic technology for determining properties of hydraulic fractures. Heights were confirmed by the use of a downhole array of inclonometers; lengths were confirmed by fracturing into a deviated lateral well located 300 feet ahead of the fracture; and azimuth was validated by comparing the azimuth in the intersecting lateral with the microseismic azimuth. It is anticipated that a commercial service using the microseismic technology to determine hydraulic fracture properties will be available by the year 2000.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Production Technology	**1.430**	**1.577**	**1.950**
Greater Green River Basin Production Test (UPR)	1.370	0.379	1.950
Wind River Basin Exploration & Stimulation Tests (IER)	0.000	1.198	0.000
Microseismic Hydraulic Fracture Diagnostic Tests (B&A)	0.000	0.000	TBD
Multi-Strata Tests (College of West Virginia)	0.060	0.000	0.000
Natural Fracture Detection	**2.497**	**1.658**	**1.575**
Fractured Reservoirs Detection (Coleman)	1.095	0.378	0.530
Fractures Detection Optimization (ARI)	1.100	0.662	0.470
High Resolution Verticle Seismic Profile for Fracture Characterization (LBL)	0.150	0.238	0.200
Evaluation of Fracture Diagnostic Methods (LBL)	0.040	0.190	0.150
Geotechnical Research (SNL)	0.112	0.190	0.225
Support	**0.249**	**0.893**	**1.053**
GSAM Modeling (ICF)	0.040	0.091	0.000
Gas Hydrates Research (USGS/Naval Research Lab.)	0.000	0.340	0.300
Geotechnical Support (EG&G)	0.209	0.192	0.310
National Laboratory Partnership (INEL/LLL)	0.000	0.270	0.270
Special Projects (DOE)	0.000	0.000	0.173
Total	**4.176**	**4.128**	**4.578**

Cost Sharing / In-Kind Contributions ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998 Estimate
Production Technology	**2.289**	**0.000**	**3.255**
Greater Green River Basin Production Test (UPR)	2.289	0.000	1.595
Wind River Basin Exploration & Stimulation Tests (IER)	N/A	N/A	1.660
Microseismic Hydraulic Fracture Diagnostic Tests (B&A)	N/A	N/A	TBD
Natural Fracture Detection	**0.870**	**0.600**	**0.780**
Fractured Reservoirs Detection (Coleman)*	0.100	0.100	TBD
Fractures Detection Optimization (ARI)	0.770 0.780**	0.500	
Total	**3.159**	**0.600**	**4.035**

* Contributions in prior fiscal years totaled $1.950 million.

** $780,000 for a potential 3-D seismic survey

Schedule

Projects	1997	1998	1999	2000	2001	2002
Production Technology						
Greater Green River Basin Production Test (UPR)						
Wind River Basin Exploration & Stimulation Tests (IER)						
Microseismic Hydraulic Fracture Diagnostic Tests (B&A)						
Advanced Technology for Efficient Low Permeability Development Tests (TBD)						
Natural Fracture Detection						
Fractured Reservoirs Detection (Coleman)						
Fractures Detection Optimization (ARI)						
High Resolution VSP for Fracture Characterization (LBL)						
Evaluation of Fracture Diagnostic Methods (LBL)						
Geotechnical Research (SNL)						
Advanced Diagnostic Field Tests (TBD)						
Next Generation Fracture Detection (TBD)						
Support						
GSAM Modeling (ICF)						
Gas Hydrates Research (USGS/Naval Research Lab)						
National Laboratory Partnership (INEL/LLL)						
Geotechnical Support (EG&G)						

VSP: Verticle Seismic Profile

3.1.2.3 Resources and Reserves Assessment

Background

The vast and abundant resource base has barriers to exploration and production that must be assessed in order to systematically apply the advanced technology that can convert the resource base to proved reserves. According to the National Petroleum Council's 1992 study, almost one-third of the technically recoverable resource base is contained in low permeability formations (approximately 400 Tcf). The quality of data available for characterizing the resource base and for prioritizing exploration and production barriers varies from marginal to good.

Different groups have need for similar information, but for different uses. Coordination between these groups such as DOE and Interior, the States, and industry must be improved. Data collection and data quality control is expensive. Therefore, issues with the data are discovered and addressed as models, and databases are developed. The two principal targets for increasing recovery from known fields are: (1) untapped reservoir compartments of gas within established fields; and (2) bypassed gas and partially drained zones in existing wells.

Originally this program was designed to characterize and quantify natural gas in low permeability formations; in promising but geologically poorly-defined occurrences (i.e., deep gas, convergent margins, and gas hydrates); and in secondary recovery of natural gas from heterogeneous formations in producing field areas.

The program is currently focused on three aspects of natural gas resource and reserves. These are: resource characterization and reserves analysis of tight gas formations; secondary natural gas resource and recovery; and natural gas information and analysis products and systems.

Major Goals

- Complete development of natural gas atlases.
- Stimulate recovery of secondary natural gas.
- Characterize the domestic natural gas resource base, thereby stimulating exploration, development, and production.
- Prioritize barriers to exploration and production associated with this resource base.
- Develop a methodology for assessing the risk associated with developing the natural gas resource base.
- Coordinate efforts in basin analysis with the U.S. Geological Survey.

Project Objectives

Objectives of this project are to: characterize both low permeability formations and in-field secondary gas targets in support of the development of a portfolio of technologies and methodologies for increasing their recovery; develop database information to reduce cost in natural gas exploration and development; and analyze the resource base and develop a system to quantify, characterize, and prioritize the most promising natural gas targets.

Expected Benefits

- Research results could accelerate conversion of the resource base currently undiscovered to economic reserves.
- Improved understanding of gas resources distribution in some of the most prolific basins in the U.S. will help reduce the economic risk associated with industry investments.
- Increased exploration and production success due to more efficient development of reservoirs, extension of field limits, and better assessment of opportunities for intrafield exploration

and development of mature gas provinces.

- Improved understanding of ultra-deep water areas of the Gulf of Mexico.
- Increased recovery from complex, mature sandstone reservoirs.
- Expanded portfolio of recovery methodologies will increase ultimate gas recovery from complex reservoirs.

Planned Products

- Completion of the Atlas of Major Appalachian Gas Plays and the Northern Gulf of Mexico Gas and Oil Atlas (Volumes 1 and 2), and associated data discs and CD-ROMs.
- Development of a gas database system, Gas Information System (GASIS), containing the regional pedigreed data sets from which natural gas atlases covering the various gas producing regions of the U.S. will be produced.
- Development of a directory, as part of GASIS, for existing natural gas databases and/or information centers. The directory will contain information relevant to the gas industry and provide communication links necessary for effective user access to these databases and/or information centers.
- Development of an analytical tool, Gas Systems Analysis Model (GSAM), to exploit the upgraded data sets to determine the impact of changes in policy, regulatory environment, and advanced technology on the resource base and proven reserves.
- Development of a market analysis to improve the development of the atlases, GASIS, GSAM, and the basin analyses.
- Completion of preliminary geological studies by the USGS in the Big Horn Basin of Wyoming.
- Topical reports.
- Technology transfer workshops.

Strategy (FY 1997 Funding: $3.927 Million)

- Improve access to and quality of available geologic and engineering data for identifying investment opportunities and assessing risk associated with economic investments in the natural gas resource base.
- Develop modeling capability for use in assessing the impact of regulatory, environmental, and tax policies; and technological advances on the long-term supply of natural gas.
- Conduct analyses to determine resource and reserve potential of natural gas reservoirs, and develop methodologies for extraction of the resource.
- Increase access to information and technology development.
- Conduct additional secondary gas recovery studies in a basin outside the Gulf Coast of Texas by transferring results learned in the Gulf Coast Basin studies, and validate this approach.

Recent Accomplishments

- Completed preliminary version of the Atlas of Major Appalachian Gas Plays.
- Continued development of the Gas Systems Analysis Model.
- Completed preliminary work on the Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs.
- Continued development of the Gas Information System.
- Initiated assessment of secondary gas recovery/reserve growth potential in the Permian Basin for carbonate reservoirs.
- Completed USGS geological studies in the Wind River Basin of Wyoming.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Geologic Data Integration	1.650	1.269	1.445
Natural Gas Markets (K&M)	0.150	0.068	0.050
Gas System Analysis Model - GSAM (ICF)	0.550	0.391	0.400
Gas Information System - GASIS (EEA)	0.600	0.508	0.400
Wind River Basin Analysis (USGS)	0.350	0.302	0.300
Basin Center Gas (USGS)	0.000	0.000	0.195
Deep Reservoir Studies (USGS)	0.000	0.000	0.100
Reserve Growth	1.222	1.176	0.923
Secondary Gas Recovery - TX (BEG)	0.800	0.831	0.0
Secondary Gas Recovery - Appalachia (WV Consortium)	0.000	0.232	0.268
Reserve Growth (University of Texas)	0.050	0.108	0.155
Reserve Assessment (Scioto)	0.372	0.005	0.000
Secondary Gas Recovery-Offshore (BEG)	0.000	0.000	0.500
Technology Support	1.050	1.482	1.925
Offshore Assessment (Marine Board)	0.025	0.025	0.025
Technology Transfer (PTTC)	0.700	0.742	0.742
Advanced Technology (INEEL)	0.000	0.000	0.480
Program Planning (HQ)	0.000	0.019	0.000
In-House (FETC/Systems)	0.325	0.267	0.259
Systems Analysis (HQ)	0.000	0.079	0.129
Technology Support (EG&G)	0.000	0.100	0.100
Coalmine Methane Studies	0.000	0.250	0.000
Special Projects	0.000	0.000	0.190
Total	3.922	3.927	4.293

Cost Sharing

Secondary Gas Recovery (BEG): 60 percent.

Schedule

Projects	1997	1998	1999	2000	2001	2002
Geologic Data Integration						
Natural Gas Markets (K&M)						
Gas System Analysis Model (ICF)						
Gas Information System (EEA)						
Basis Analysis (USGS) MT, WY, ND, and NM						
Reserve Growth						
Secondary Gas Recovery - TX (BEG)						
Secondary Gas Recovery - Appalachia (WV Consortium)						
Reserve Growth (University of Texas)						
Reserve Assessment (Scioto)						
Technology Support						
Offshore Assessment (Marine Board)						
Technology Transfer (FETC/Pittsburgh)						
Advanced Technology (INEEL)						
Program (FETC)						
In-House (FETC/Systems)						
Systems Analysis (HQ)						

3.1.2.4 Coalmine Methane

Background

Methane emissions from coal mines are a significant source of greenhouse gases. The U.S. Environmental Protection Agency (EPA) estimates that in 1988 about 9.0 to 12.6 million metric tons of carbon equivalent (MMTce) was released from methane emissions of 60 mines classified as large and gassy (>0.5 million tons of coal per year and >500 cubic feet of methane per ton of coal). EPA further estimates that 19.2 to 30 MMTce will be released from coal mines in 2000.

Coalmine methane is distinguished from *coalbed* methane in that coalmine methane is an environmental issue which must be controlled, while coalbed methane is an abundant source of natural gas supply which must be enhanced.

Under current Fossil Energy programs, technologies have been and are currently being developed and demonstrated for recovery and utilization of energy gases. The private sector has identified many of these technologies for reducing methane emissions associated with coal mining. These technologies include the use of high-efficiency gas turbines, gas fuel cells, internal combustion engines, and up-grading processes for the methane gas to be used in gas pipelines.

Major Goals

The overall implementation strategy for the program is to conduct feasibility studies, field testing, demonstration, and eventual commercialization. The goal of the program is to expand existing research efforts to broaden the range of cost-effective technologies/methods for recovering methane associated with mining. It is expected that after the demonstration phase, coal mining companies or other industry firms will invest in equipment to utilize gas generated from mining operations.

Project Objectives

Both the Phase I feasibility study and the Phase II detailed conceptual design for a proposed technology demonstration at a mine site will be a collection, assessment, and planned use of existing field and technology data from coal mining activities, particularly data related to methane emissions from mining operations.

As part of the President's Climate Change Action Plan and its goal of reducing greenhouse gas emissions, DOE will support outreach, cost-shared demonstration, and market entry projects to investigate and apply new and existing technologies for capturing and using energy gases related to the coal mining process.

Current contractors and projects in this research area are:

- *Northwest Fuel Development, Inc.,* a service company to the coal, gas, and electric utility industry is working with Peabody Development Company at the Federal #2 Mine in northern West Virginia to capture mine ventilation air for gas turbine use in local power supply.
- *Jim Walters Resources Inc.,* a coal mining company in Alabama is focused on using gob gas for power generation with gas turbine technology.
- *Noumenon Corporation,* a natural gas producer in West Virginia is designing an upgrading demonstration for using gob gas from longwall mining operations.
- *West Virginia University Research Corporation,* a consortium of the mining industry, State agencies, and academia, is investigating use of gob gas from mining operations for power generation at a local mine site in southwestern Pennsylvania.

- *Energy Research Corporation,* a fuel cell manufacturer in Connecticut, is working with a coal mining company in eastern Ohio to use coalmine methane for generating power at the local mining operation.

Expected Benefits

Any and all technologies used in this DOE-industry effort will be value added to the goal of improving air quality and reducing greenhouse gases, such as methane. This effort is a design phase that focuses on the feasibility of using existing technologies and assessing the applicability by industry of a certain technology to a specific coal mining site.

Planned Products

This effort is a paper study on a conceptual design that will detail all aspects of a field demonstration of a particular technology, such as gas turbines or fuel cells, with coalmine methane as the fuel source.

Strategy

Funding of $1 million requested for this program in the FY 97 budget was not approved by Congress. The five ongoing projects are presently completing a design phase of the applied technology to be demonstrated at a mine site.

Time and investment for methane recovery and utilization technologies selected for mine demonstration will likely vary for each of the alternatives selected. For any given technology to be regularly used in mining operations, about 5 years is expected to be required. Individual mine demonstrations should be completed in three years. Adopting successful technology for use in a significant share of mining operations would require another two years. Total additional funds required, including the FY 98 request of $0.963 million, are estimated to be $4 million. For any given mine demonstration project, the industry cost-sharing contribution will be greater than the Federal funds required.

FY 98: Funding of $0.963 million has been appropriated this program in the FY 1998 budget. This amount will allow for completion of the design phase for the applied technologies and preliminary site preparation of those projects selected to the field demonstration phase.

FY 99: Funding of $2 million will be needed. The industrial partners in this joint effort will be expected to contribute 51 percent cost sharing in each of the projects selected to continue into the field demonstration phase. This amount of joint-funding will allow those projects selected for the field demonstration effort to proceed with the acquisition of those technologies to be demonstrated at the project mine site.

FY 2000: Funding of $1 million will be needed. This will allow the industry partners to prepare and install the equipment and technology(s) at the mine site for testing.

Recent Accomplishments

Completed Phase I feasibility study effort FY 95. Initiated five Phase II conceptual design studies FY 96.

Program Funding

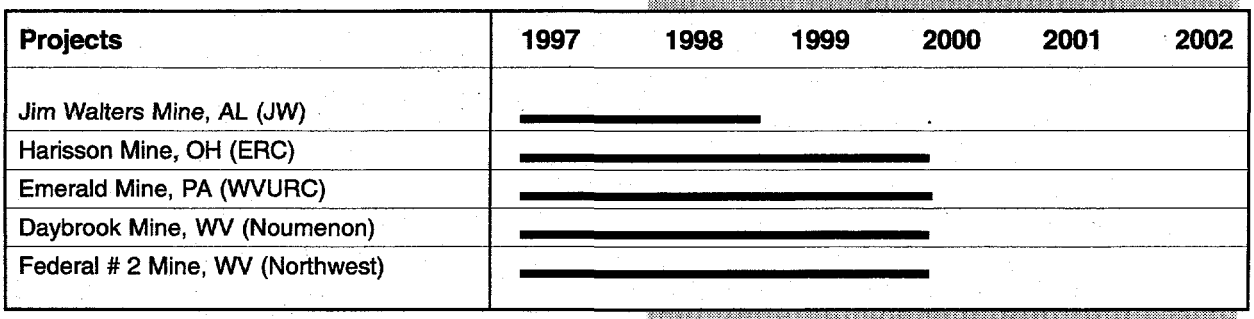
DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Jim Walters Mine, AL (JW)	0.075	0	0.193
Harisson Mine, OH (ERC)	0.075	0	0.193
Emerald Mine, PA (WVURC)	0.075	0	0.193
Daybrook Mine, WV (Noumenon)	0.075	0	0.193
Federal # 2 Mine, WV (Northwest)	0.075	0	0.193
Total	**0.375**	**0**	**0.965**

Cost Sharing ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998 Estimate
Jim Walters Mine, AL (JW)	0.013	0	0.033
Harisson Mine, OH (ERC)	0.013	0	0.034
Emerald Mine, PA (WVURC)	0.018	0	0.046
Daybrook Mine, WV (Noumenon)	0.006	0	0.013
Federal # 2 Mine, WV (Northwest)	0.075	0	0.037
Total	**0.125**	**0**	**0.163**

Schedule



JW: Jim Walters Resources, Inc.

ERC: Energy Research Corporation

WVUER: West Virginia University Research Corporation

3.1.2.5 Low-Quality Gas Upgrading

Background

Considerable quantities of low quality natural gas (LQNG) exist in the United States. In general, LQNG use will depend on effective and economical separation of hydrocarbon and non-hydrocarbon components, with degree of separation required depending on the particular use and transportation requirements. High inerts (i.e. nitrogen) are normally undesirable because of needless pipeline shipment costs. On the other hand, non-hydrocarbon component(s) may be marketable, such as nitrogen and/or carbon dioxide for enhanced oil recovery operations, and salable elemental sulfur is recoverable from hydrogen sulfide contaminants.

Important issues that need to be resolved for LQNG separation technologies are: (1) cost of fuel needed to drive the separation and the need to increase the energy efficiency of the process, and (2) high unit cost of gas conditioning if gas is processed in scaled-down quantities. Consequently, there is a need to develop new separation concepts that can yield significant efficiency improvements and cost reductions. Novel membrane applications, solvent absorption and adsorption fundamentals, and the thermodynamics and chemistry of natural gas mixtures are viable research areas.

LQNG upgrading research activities include: (1) parallel research on novel passive and facilitated-transport polymeric membrane concepts to increase the selectivity, permeability, and long-term stability under practical operating conditions; (2) developing novel adsorbents and absorbents and evaluating them in a pressure, temperature, and/or vacuum swing mode; (3) advancing novel hybrid LQNG separation technologies, and developing adaptive technology for field application; and (4) conducting process and economic evaluations of membranes, adsorbents, absorbents, and other single and hybrid technologies as they apply to upgrading LQNG to pipeline specifications.

Major Goals

The goals of the Natural Gas Upgrading (NGU) products team are: (1) to develop advanced cost-efficient methods of upgrading (to pipeline quality) contaminated natural gas; (2) to foster necessary field evaluation, and testing of advanced upgrading technologies and subsequent industry adoption of the improved technology, and (3) to increase utilization of higher hydrocarbons as fuels conversion products at a level which helps to displace imported oil.

About one-third of U.S. gas resources fall below pipeline quality in composition and normally require some upgrading, although some can be brought to specification with careful blending of non-contaminated gas. Applicability of alternative treatments varies with the mix of impurities and the gas flow volume to be treated.

Changes are needed in separation technologies to process selected new supply sources economically as well as to increase gas processing efficiency and reduce costs. Conventional gas separation technology is often exceedingly costly for processing very sour (hydrogen sulfide) and high nitrogen content natural gas. Advanced natural gas upgrading technologies will assist in increasing available U.S. natural gas reserves, in separating natural gas from inert cushion gas in gas storage operations, and in upgrading gas to meet specific quality requirements for end-use applications, including most chemical conversion processes. These require sulfur-free gas to avoid process catalyst poisoning.

Research efforts have been initiated to develop selected new or improved membrane separation processes that remove and recover sulfur compounds with less environmental impact than conventional approaches, and others that remove nitrogen from natural gas at lower costs.

Project Objectives

The objective of the NGU program is to develop and field validate within 10 years, polymeric membrane and novel hybrid gas separation technologies that will advance economical utilization of low-quality natural gas. Emphasis is on membrane products because of their lower cost, modularity and smaller size than traditional adsorption and absorption gas separation techniques.

Expected Benefits

Within 10 years, the NGU program expects commercialization of polymeric membranes for carbon dioxide and hydrogen sulfide (acid gas) removal from natural gas. Costs for nitrogen separation from natural gas should be improved by one-half over existing conventional cryogenic technology. Transfer of these technologies to 50 percent of gas treatment design engineers should be accomplished.

Planned Products

LQNG contains impurities such as carbon dioxide, hydrogen sulfide, and nitrogen that must not exceed adopted pipeline limits [maximum 4 percent CO_2 plus N_2, 4 parts per million (ppm) of S] for pipeline quality natural gas. Advanced technology efforts to separate impurities from natural gas more effectively are as follows:

- Develop and characterize thin, composite, enhanced, transportation-exchange membrane films for removal of carbon dioxide and hydrogen sulfide, and conduct field tests.
- Conduct laboratory-scale testing of advanced polyimide membranes for separating carbon dioxide, hydrogen sulfide, water vapor, and nitrogen from contaminated natural gas by selective permeation. Evaluate the economics of these processes.
- Develop inorganic sol-gel thin film membranes that combine small pore diameters, narrow pore size distributions, and tailored pore surface chemistries, which are useful for separating gases by such mechanisms as molecular sieving or prevaporation.
- Develop an advanced membrane gas separation technology for economical removal, recovery, or disposal of sulfur from sulfur-contaminated natural gas, i.e., economically upgrade sulfur contaminated gas to pipeline specifications, and recover or properly dispose of the sulfur or sulfur compounds in an environmentally acceptable manner.
- Develop an advanced absorption gas separation technology for economical removal, recovery, or disposal of sulfur from sulfur-contaminated natural gas; i.e., economically upgrade sulfur contaminated gas to pipeline specifications, and recover or properly dispose of the sulfur or sulfur compounds in an environmentally acceptable manner.
- Develop a high-efficiency absorption gas separation process for separating hydrogen sulfide and water vapor from contaminated natural gas.
- Utilize a membrane separation technology or a pressure swing adsorption/ absorption separation process for upgrading gob gas for on-site fueling purposes, such as coal drying and power generation, while meeting the new clean air standards of the Clean Air Act Amendments of 1990 (CAAA), and specifications for pipeline-quality natural gas, or both.
- Develop an economical, efficient, novel, liquid absorbent process to produce pipeline-specification natural gas from nitrogen-contaminated gas at the wellhead. This absorbent will be designed to have a high affinity for nitrogen and little or no affinity for methane or any other hydrocarbons present.

- Develop an economical, efficient, hollow-fiber, membrane natural gas dehydration process to produce pipeline-specification natural gas from raw wellhead natural gas. This membrane will be designed to be robust, economical, and reduce methane losses.
- Conduct process and economic evaluations of the above and other advanced competing gas separation processes that upgrade low quality gas to pipeline specifications.
- Provide a field demonstration of an advanced gas separation technology that economically removes and recovers or disposes of sulfur from sulfur-contaminated natural gas; i.e., economically upgrades the sulfur contaminated gas to pipeline specifications, and recovers or properly disposes of the sulfur or sulfur compounds in an environmentally acceptable manner.

Strategy (FY 97 Funding: $1.1 Million)

- Continue second phase, laboratory of two advanced nitrogen removal processes.
- Continue field validation of high efficiency acid gas solvent upgrading process utilizing structured packing.
- Expand database for biochemical regeneration of Redox solution in hydrogen sulfide removal.
- Continue coordination evaluation and research into advanced LQNG upgrading with the Gas Research Institute.

Recent Accomplishments

- Demonstration of natural gas denitrogenation using methane permeable membranes is technically and economically feasible.
- N-Formyl Morpholine has shown great potential for treating subquality natural gas.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Upgrading Natural Gas via Organic Membranes (Syracuse University)	0.020	0.000	0.000
Upgrading Natural Gas via Sol-Gel Membranes (SNL[1])	0.125	0.124	0.125
LQNG Sulfur Removal/Recovery No. 1 (MTR[2], Inc.)	0.050	0.000	0.000
Upgrading Natural Gas via High Efficiency Contactors (IGT[3], GRI[4])	0.150	0.100	0.000
Nitrogen Removal from Natural Gas (MTR)	0.678	0.050	0.085
Nitrogen Removal from Natural Gas (SRI)	0.000	0.540	0.300
Microbial Redox Reoxidation (Texas A&M, GRI)	0.050	0.050	0.100
Advanced Hybrid Gas Separation (TBD)	--	--	TBD
Bioprocessing for Sulfur Removal (Arctech)	0.050	0.050	0.050
Offshore Natural Gas Assessment	0.020	0.000	0.000
Gas Research Support (In-house)	0.200	0.055	0.055
Upgrading Support (TBD)	0.000	0.000	TBD
GSAM (ICF)	0.000	0.124	0.000
Total	**1.343**	**1.093**	**0.715**

[1] SNL: Sandia National Laboratories
[2] MTR: Membrane Technology Research, Inc.
[3] IGT: Institute of Gas Technology
[4] GRI: Gas Research Institute

Cost Sharing ($ in Millions)

Performer	Projects	FY 1996	FY 1997	FY 1998 Estimate
IGT & GRI	High Efficiency Contactors	0.000	0.200	0.000
Arctech	Bio Process for Sulfur Removal	0.050	0.050	0.050
MTR, SRI	Nitrogen Removal	0.000	0.500	0.300
SNL	Sol-Gel Membranes	0.000	0.250	0.250
Total		**0.050**	**0.950**	**0.600**

Schedule

Projects	1994	1995	1996	1997	1998	1999
Upgrading Gas via Polyimide Membranes						
Upgrading Gas via Sol-Gel Membranes						
LONG Sulfur Removal/Recovery						
Upgrading Gas via High Efficiency Contactors						
Microbial Redox Reoxidation						
Nitrogen Removal						
Advanced Hybrid Gas Separation						
Bioprocessing for Sulfur Removal						

3.1.2.6 Gas-to-Liquids

Background

Supplies of natural gas, domestic and worldwide, are abundant. However, many of these natural gas reservoirs are located in relatively remote areas and high transportation costs tend to prohibit extensive use of this resource. In order to offset these costs, efficient and lower cost natural gas conversion processes must be identified and developed.

Gas-to-liquids conversion technologies use chemical or physical methods to convert natural gas to a liquid form suitable for ready transport or direct use. Conversion is accomplished in one of two ways: (1) compression and refrigeration, in which the gas is liquefied cryogenically and subsequently regasified for later use, and (2) 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.

Both methods of conversion are relatively costly and inefficient. Therefore, cost reduction of either of these conversion methods, by process or chemical improvements, would clearly have a significant favorable economic and energy efficiency impact on the natural gas, fuel and chemical markets.

Major Goals

The goal of this program is to economically convert natural gas, primarily methane, to readily transportable hydrocarbon liquids and/or higher value petrochemicals in a simplified one- or two-step process. This will be achieved by the following routes:

- Eliminate intermediate conversion steps during the conversion of natural gas to higher value petrochemicals and improve natural gas conversions and product selectivities for these processes.
- Develop conversion processes which operate at lower temperatures and pressures, thereby decreasing both capital and operating costs of the reactor systems.
- Introduce novel, cost-effective technologies to existing processes to lower capital and operating costs.

Project Objectives

In partnership with industry, develop and demonstrate advanced technologies and processes for economical conversion of methane to liquids that can be used as fuels or chemical feedstocks. This will increase available sources of supply for liquid transportation fuels and reduce demand for crude oil derived liquid transportation fuels.

Expected Benefits

Near-Term

Leads to discovery, development, and proof-of-concept of new chemistry for direct and indirect conversion of methane-rich gases to environmentally desirable liquid fuels and to new techniques to liquefy and transport gas from remote well locations without pipeline access.

Mid-Term

Encourages or promotes construction of commercial plants based on new direct and indirect conversion processes.

Planned Products

- Initiation of a major research effort to develop oxygen ion transport ceramic membranes for the conversion of natural gas to syngas.
- Scale-up of the Thermoacoustic Driver-Orifice Pulse Tube Refrigerator (TAD-OPTR) to produce 500 gallons per day of liquefied natural gas (LNG).
- Determine economics of conversion plant costs in Alaska.

Strategy (FY 97 Funding: $5.066 Million)

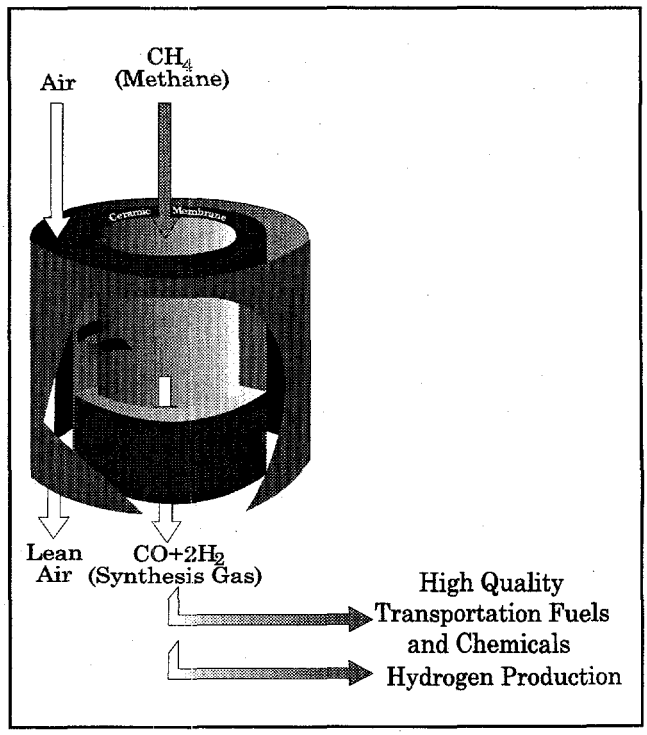
The research strategy is carried out through two coordinated activities, one focusing on the direct (one-step) conversion of natural gas to either a liquid "gas" or to a hydrocarbon liquid of different composition; the other concentrating on indirect (two-step) conversion methods, whereby natural gas is transformed to reactive intermediates such as syngas (CO and H_2), or acetylene, and subsequently converted to desired liquids.

- *One-Step Natural Gas-to-Liquids*: This is a multidisciplinary research effort focused on the development of economic, direct conversion processes to convert natural gas to higher value liquid fuels or to a dense liquid "gas" at low temperature and pressure. Activities include theoretical and experimental investigations of catalytic and non-catalytic conversion processes. Specific objectives of the research are to: (1) derive fundamental information and concepts about chemical reactions during conversion; (2) enhance conversion rates and selectivity; and (3) improve separation and recovery of the products. In addition, research is being conducted to advance the economics of physical conversion of natural gas, directed towards enhancing remote gas marketability.
- *Two-Step Natural Gas-to-Liquids*: This research is focused on developing a scientific and engineering knowledge base for industry use in manufacturing hydrocarbon fuels and chemicals from natural gas. Currently, the three most advanced two-step conversion technologies are: (1) partial oxidation; (2) oxyhydrochlorination; and (3) oxidative coupling. The program seeks to accomplish innovative improvements over the state-of-the-art conversion technologies through staged development from laboratory scale to bench scale and finally to proof-of-concept scale.

Recent Accomplishments

- Demonstrated production of 100 gallons per day of liquefied natural gas using the Thermoacoustic Driver-Orifice Pulse Tube Refrigerator.
- Completed preparation of a draft report comparing pipeline costs with liquefied natural gas production costs.
- Completed preliminary economic evaluation of the oxyhydrochlorination natural gas conversion process.
- Developed and tested a bench scale prototype plasma quench reactor for the conversion of natural gas to higher hydrocarbons. Significant improvements over prior tests were achieved.
- Completed economic and process evaluation of modular offshore natural gas conversion plants and gathering line prospects.

Ceramic Membrane Technology for the Conversion of Natural Gas to Synthesis Gas



Program Funding

DOE Historical Spending ($ in Millions)

Performer	Project	FY 1996	FY 1997	FY 1998
FETC	In-House Research	0.300	0.228	0.200
K&M	Offshore Natural Gas Assessment	0.080	0.000	0.100
Lawrence Berkeley National Laboratory (LBNL)	Catalytic Conversion by Coupling Chemical Reactions and Separations	0.000	0.113	0.150
Idaho National Engineering and Environmental Laboratory (INEEL)	Feasibility Study to Evaluate Plasma Quench Technology for Natural Gas Conversion Applications	0.277	0.297	0.350
University of Oklahoma	Enhancement of Methane Conversion Using Electric Fields	0.000	0.180	0.100
Los Alamos National Laboratory (LANL)	Thermoacoustic Natural Gas Liquefier	0.450	0.396	0.400
Idaho National Engineering and Environmental Laboratory (INEEL)	North Slope of Alaska Natural Gas Resource Development and Utilization Study	0.191	0.990	0.100
Energy International	Conversion of Associated Natural Gas to Liquid Hydrocarbons	0.130	0.000	0.000
Lawrence Berkeley National Laboratory (LBNL)	Oxidative Coupling Catalyst Development	0.100	0.000	0.000
Burns and Roe Site Contractor - PGH	Technical Support	0.000	0.085	0.000
Dow Corning Phase I	Methyl Chloride via Oxyhydrochlorination of Methane	0.068	0.000	0.000
Colorado School of Mines	Development of Vanadium-Phosphate Catalysts for Methanol Production by Selective Oxidation of Methane	0.060	0.000	0.000
Massachusetts Institute of Technology	Conversion of Light Hydrocarbon Gases to Metal Carbides for Production of Liquid Fuels and Chemicals	0.089	0.050	0.000
SRI International	Oxidative Coupling - Fullerene	0.045	0.000	0.000

Continued

Program Funding

DOE Historical Spending ($ in Millions) (continued)

Performer	Project	FY 1996	FY 1997	FY 1998
Worcester Polytechnic Institute	Methane Coupling by Catalytic Membrane Reactor	0.106	0.000	0.000
Institute of Gas Technology	Carbon Disulfide	0.225	0.000	0.000
University of California - Davis	Light Hydrocarbon Conversion - Superacid Catalysis	0.087	0.000	0.000
Argonne National Laboratory (ANL)/Amoco	Ceramic Membranes for Methane Conversion (CRADA)	0.325	0.000	0.000
CANMET	Consortium on the Conversion of Natural Gas (CCNG)	0.050	0.050	0.050
Dow Corning Phase 2	Methyl Chloride via Oxyhydrochlorination (OCH) of Methane: A Building Block for Chemicals and Fuels from Natural Gas	0.302	0.000	0.000
APCI, et al.	Engineering Development of Ceramic Membrane Reactor Systems for Converting Natural Gas to Hydrogen and Synthesis Gas for Liquid Transportation Fuels	0.000	2.677	0.800
Argonne National Laboratory (ANL)	ITM Support	0.000	0.000	0.700
Pacific Northwest Laboratory (PNL)	ITM Support	0.000	0.000	0.200
TBD	Exploratory Research	0.000	0.000	TBD
Total		**2.885**	**5.066**	**3.150**

Cost Sharing ($ in Millions)

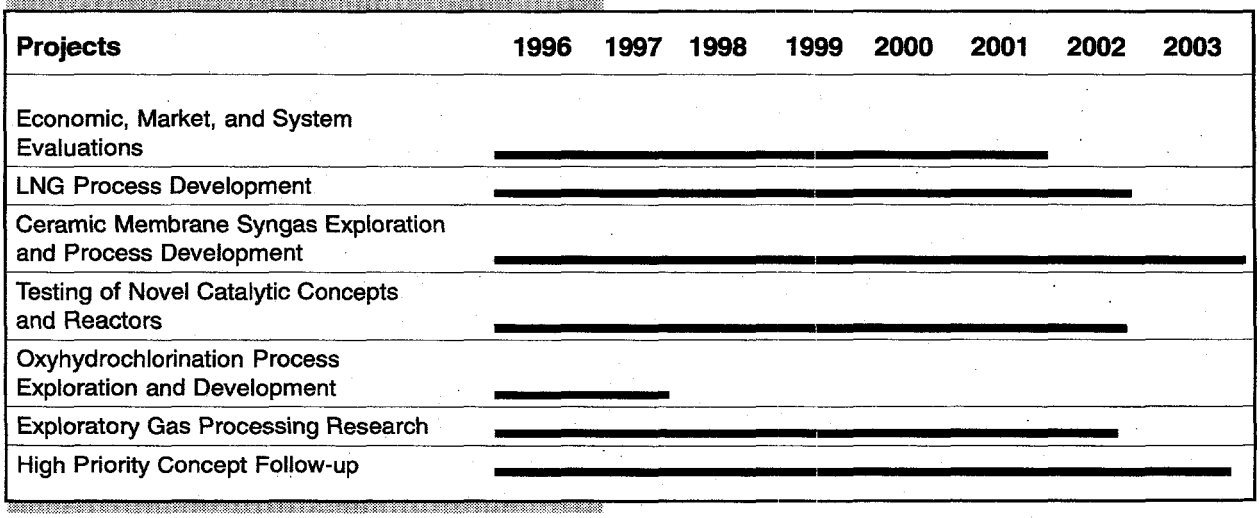
Performer	Project	FY 1996	FY 1997	FY 1998 Estimate
FETC-Morgantown	Assessments and Economics	--	--	--
K&M	Offshore Natural Gas Assessment	--	--	--
Lawrence Berkeley National Laboratory (LBNL)	Catalytic Conversion by Coupling Chemical Reactions and Separations	--	--	--
Idaho National Engineering and Environmental Laboratory (INEEL)	Feasibility Study to Evaluate Plasma Quench Technology for Natural Gas Conversion Applications	--	--	--
University of Oklahoma	Enhancement of Methane Conversion Using Electric Fields	0.088	--	--
Los Alamos National Laboratory (LANL)	Thermoacoustic Natural Gas Liquefier	--	--	--
Idaho National Engineering and Environmental Laboratory (INEEL)	North Slope of Alaska Natural Gas Resource Development and Utilization Study	--	--	--
Energy International	Conversion of Associated Natural Gas to Liquid Hydrocarbons	--	--	--
Lawrence Berkeley National Laboratory (LBNL)	Oxidative Coupling Catalyst Development	--	--	--
Burns and Roe Site Contractor - PGH	Technical Support	--	--	--
Dow Corning Phase I	Methyl Chloride via Oxyhydrochlorination of Methane	0.100	--	--
Colorado School of Mines	Development of Vanadium-Phosphate Catalysts for Methanol Production by Selective Oxidation of Methane	--	--	--
Massachusetts Institute of Technology	Conversion of Light Hydrocarbon Gases to Metal Carbides for Production of Liquid Fuels and Chemicals	--	--	--
SRI International	Oxidative Coupling - Fullerene	0.008	--	--

Continued

Cost Sharing ($ in Millions) (continued)

Performer	Project	FY 1996	FY 1997	FY 1998 Estimate
Worcester Polytechnic Institute	Methane Coupling by Catalytic Membrane Reactor	0.063	--	--
Institute of Gas Technology	Carbon Disulfide	--	--	--
University of California - Davis	Light Hydrocarbon Conversion - Superacid Catalysis	--	--	--
Argonne National Laboratory (ANL)/Amoco	Ceramic Membranes for Methane Conversion (CRADA)	--	--	--
CANMET of Natural Gas (CCNG)	Consortium on the Conversion	0.500	0.500	0.500
Dow Corning	Methyl Chloride via Oxyhydrochlorination (OCH) of Methane: A Building Block for Chemicals and Fuels from Natural Gas	--	0.000	0.000
Program Opportunity Notice	Engineering Development of Ceramic Membrane Reactor Systems for Converting Natural Gas to Hydrogen and Synthesis Gas for Liquid Transportation Fuels	--	2.677	0.800
Argonne National Laboratory (ANL)	ITM Support	--	--	--
Pacific Northwest Laboratory (PNL)	ITM Support	--	--	--
TBD	Exploratory Research	--	--	TBD
Total		**0.759**	**3.177**	**1.300**

Schedule



3.1.2.7 Natural Gas and Oil Technology Partnership

Background

New technologies are needed to produce more gas from domestic reservoirs while safeguarding the environment and working within today's economic constraints. The past decade has seen a dramatic shift in funding emphasis within the U.S. petroleum industry which has had to reevaluate all aspects of its business, including R&D and technology investments. Initiated in 1988 as the Oil Recovery Technology Partnership, the Natural Gas and Oil Technology Partnership has responded through a mechanism of collaborative projects to bring the capabilities of DOE's National Laboratories to the industry. This industry-driven program establishes active industry interfaces through review panels and forums that define industry needs, provide annual project reviews, and recommend priorities of new proposals and ongoing projects.

Major Goals

Transfer technologies derived from DOE-funded weapons and energy research and make the capabilities, expertise, equipment, and facilities of the national laboratories available to the petroleum industry.

Develop new, innovative mechanisms for interactions with industry to expedite this transfer.

Maintain close coordination with industry to ensure that industry needs are being addressed.

Project Objectives

Conduct a slate of joint industry-National Laboratory projects which address industry needs in four technology areas, each of which is critical to improved natural gas supply and which is aligned with a technical research area in DOE's Petroleum Technology Program:

- Diagnostic and imaging technology
- Drilling, completion, and stimulation technology
- Oil and gas recovery technology, and
- Environmental technology (exploration and production related)

Such projects include application of state-of-the-art computing and associated technologies to improve the acquisition, processing, and interpretation of geologic, geochemical, geophysical, and engineering data required to optimize exploration and development of natural gas and oil fields and reservoirs.

Expected Benefits (Near- and Long- Term)

Partnering among industry, national laboratories and the Federal government will result in accelerated market entry of new technologies, will reduce risks associated with technology development, and will enhance competitiveness of the U.S. industry. Specific benefits include: leveraged R&D funds; shared R&D risk; access to state-of-the-art exploration and production (E&P) knowledge, expertise, and facilities; interactions with the DOE national laboratories; and effective technology transfer.

Planned Products

Increased emphasis and support towards natural gas exploration and production in all four of the Partnership's technology areas outlined above. The kinds of future technical products resulting from multiple Partnership projects should reflect the range of accomplishments listed below.

In FY 97, the Partnership had three of its projects funded through the natural gas program at FETC. These projects are addressing improved well completion techniques in gas wells through a better understanding of perforation dynamics in geological media; improvements in coiled tubing drilling with small-diameter bottom hole assemblies capable of underbalanced directional drilling for minimal formation

damage in gas producing formations; and techniques for locating geopressured hydrocarbon reservoirs in soft clastic sediments through identifying associated pressure seals. In addition, most of the advanced seismic processing projects in the Partnership have direct applications for improving drilling success rates in complex geological structures such as the Gulf of Mexico.

Strategy (FY 97 Funding: $1.0 Million)

Aggressively support the Partnership's unique paradigm with an increasing shift in emphasis and support towards natural gas exploration and production.

Recent Accomplishments

Recent accomplishments from over 60 joint industry-national laboratory projects include the following: computational tools for advanced reservoir management; improved natural and hydraulic fracture mapping technology; technology improvements for independents (spanning such diverse areas as artificial lift hardware to data information systems); increasing the effectiveness of hydraulic fracturing; new codes which predict near-well effects controlling production (such as perforation damage and wellbore stability); advanced borehole seismic source and receiver systems; algorithms for processing very large complex seismic data sets in a massively parallel computing platform; methodologies and techniques for improved, efficient seismic imaging of complex, hard-to-resolve regions, such as reservoirs below salt sheets in the Gulf of Mexico; and ties with the Petroleum Technology Transfer Council (PTTC) for enhanced technology transfer.

Cost Sharing

Cost sharing is a requirement of the joint projects conducted under this program; it generally occurs in the form of in-kind cost sharing. While no minimum level is specified, industry's in-kind overall cost share has averaged more than fifty percent over the life of the program.

Schedule

Each project under the Partnership program has its own individual schedule and milestones.

The Partnership review cycle has been recently revised to occur in the first quarter of the fiscal year.

Program Funding

DOE Historical Spending ($ in Millions)

Source of Funds	FY 1996	FY 1997	FY 1998
Fossil Energy	1.0	1.0	1.0
Total	**1.0**	**1.0**	**1.0**

3.1.2.8 International Center for Gas Technology Information

Background

Today, a variety of organizations collect information about energy and technology, but none of these organizations exclusively focuses on natural gas technology. Furthermore, there is no international clearinghouse to facilitate exchange of such information among participants and potential users of technology. There are substantial efforts underway throughout the world to improve gas production technologies, transportation, and utilization. An inventory of new technological concepts awaits introduction into the marketplace, and experience is being gained with field testing and early introduction of new practices and equipment in a number of locations around the world. The body of information gained in these activities is being communicated, but usually only in bilateral exchanges among the most active participants.

International Energy Agency (IEA), founded in 1974, is the energy forum for 21 industrialized countries. Among its other activities, IEA helps member countries set up collaborative projects for RD&D of energy related technologies. In October 1990, IEA sponsored a conference in Lisbon, Portugal, on emerging natural gas technologies. The main conference recommendation was that an International Center for Gas Technology Information (ICGTI) be established. In response, DOE and the Danish Ministry of Energy agreed to present a joint proposal for formation of the Center. DOE asked GRI to be the focal point for forming the Center.

The international natural gas community recognizes the need for better access to information about gas technologies and for enhanced RD&D cooperation and technology transfer in gas supply, transportation, and utilization. Many interested participants need access to a comprehensive source of information in order to improve coordination of investments in RD&D, more rapidly and broadly disseminate both research results and early marketplace experience with new technologies, and facilitate adoption of proven technologies over wider geographic markets.

ICGTI represents an effort through the Department and the Gas Research Institute for the U.S. natural gas industry to exercise its appropriate leadership in the global gas industry.

Major Goals

ICGTI's primary mission is "to provide an international forum on gas technology information so that gas technologies are transferred and global gas market needs are met efficiently." In accomplishing this, the Center developed an Internet-based technology information exchange, GTI Online (*http://www.icgti.org*). In the first nine months of 1997, ICGTI built GTI Online into an important new source of gas technology and related information, including more than 10,000 technical entries. By the end of 1997, a complete record of the World Gas Conference (WGC) will be exclusively available on the GTI Online site and a technology directory of 6,000 companies serving the global gas industry will be available.

The Center does not contemplate funding or managing any RD&D projects. The Center is a nonprofit organization funded by those member countries desiring to participate. Policy guidance and strategic direction come from the International Executive Committee of sponsoring IEA members. Gas Technology Information, Inc., a joint cooperation between GRI and the Danish Technology Center, is the current legal entity acting as the Operating Agent for the Center.

Project Objectives

The objective of this project is to promote widespread commercialization of gas-related technologies by providing a continuing international forum for increased information dissemination and international cooperation and collaboration concerning gas technologies.

Expected Benefits

- Promotes technology information exchange geared toward accelerated technology transfer.
- Provides high-value information on gas technology development and market trends to companies searching for solutions to real-world industry problems.
- Helps technology and know-how suppliers identify relevant gas markets.
- Leverages U.S. R&D investments through connections to other technology developers around the world.
- Demonstrates U.S. leadership in the global gas industry.

Planned Products

GTI Online will expand the key components of this technology information exchange, adding 7,500 technical files to the system. Through an agreement with the International Gas Union, GTI Online will be the exclusive Internet location of the proceedings and related documents of WGC '97.

GTI Online is adding a Technology Directory that will provide ICGTI members with data on thousands of firms active in the global gas industry. Phase I, implemented in Fall 1997, provides basic data for approximately 6,000 companies. Phase II, in 1998, will involve adding basic data on additional companies and more in-depth information on the Phase I companies. The goal is to make this Technology Directory one of the major reference sources for the global gas industry.

Strategy (FY 97 Funding: $0.312 Million)

The key strategy of ICGTI is to combine advanced communication techniques, information technologies, and gas industry expertise in order to serve senior executive of gas companies and of companies supplied by the gas industry and, especially, professionals working in engineering and marketing positions for the global gas industry.

In the two years since the Center was formally established at a signing ceremony at OECD Headquarters in Paris, France, ICGTI has made important progress in gaining visibility for the U.S. natural gas industry in the international natural gas industry. The original six charter member nations (Denmark, Japan, Portugal, Russia, Spain and the United States) has expanded to an "electronic village" with more than 500 companies from 14 participating nations. Moreover, visitors from more than 50 nations have used the open sections of GTI Online that are made available to the global gas industry at no charge.

Recent Accomplishments

Headquarters operation of the Center has been successfully established in the United States, co-located with the Washington-area offices of the Gas Research Institute. The Center has added its first member from Latin America, Brazil. At a recent set of meetings at CENPES, the R&D center for Petrobras, many ideas and opportunities for the sharing of technology information were identified.

The ICGTI-Canadian Gas Association (CGA) Leak Detection Workshop was held in Toronto, Canada in November 1997, and follow-up activities will take place through electronic discussions within the GTI Online system. GTI Online has become an important new source of technical information for the global gas industry.

Since mid 1997, visits to GTI Online have exceeded 100,000 per month, clearly making this an important new focal point of the global gas industry.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
ICGTI	0.314	0.312	0.318
Totals	**0.314**	**0.312**	**0.318**

Cost Sharing

The Center is jointly funded by the Department of Energy and a variety of sources from the other 14 ICGTI nations and Columbia Gas Systems as a U.S. corporate sponsor. The DOE contribution is leveraged at more than a three-to-one factor. Additional companies and countries are exploring participation in the Center.

Current participants include Australia, Brazil, Canada, Denmark, Finland, Japan, the Netherlands, New Zealand, Portugal, Russia, Spain, Sweden, United Kingdom, and the United States.

3.1.2.9 Fundamental Geosciences Research

Background

This is one facet of a broad-based geoscience research program emphasizing fluid-flow (e.g., geothermal, hydrocarbon, groundwater) in porous and fractured geologic media. The issues requiring investigation include: (1) the rate and nature of natural gas and oil generation from organic-rich sediments; (2) stability of natural gas in the subsurface; (3) origin and development of secondary porosity; (4) evolution of fracture systems with particular emphasis on potential reservoir and seal rocks; and (5) geophysical imaging for characterization of reservoirs and related rocks.

Major Goals

- *Origin:* Obtain and interpret geochemical and isotopic data on the limits to oil and gas generation in deeply buried sediments during and subsequent to diagenesis.
- *Migration:* Develop basic understanding of fluid flow in porous and fractured rocks through laboratory, field, computational, and modeling studies.
- *Entrapment:* Provide the foundation for understanding of scale-dependent reservoir heterogeneity and anisotropy.
- *Exploration:* Develop new and improved high resolution geophysical techniques and approaches for imaging subsurface fluid-bearing reservoirs.
- *Production:* Provide new concepts and information on rock fracture and failure under in-situ conditions to improve drilling methods; develop sensor systems for geophysical imaging capability ahead of the bit as a basis for adaptive drilling.

The integrating theme is to reduce exploration and drilling costs and improve the environment through better understanding of the geologic host for the gas resource.

Project Objectives

The program conducts fundamental studies on the origin, migration, and entrapment of natural gas for improved understanding of geologic factors controlling and limiting availability of this resource.

Strategy (FY 97 Funding: $3.8 Million)

The program strategy is to support fundamental research activities at the Nation's academic institutions and DOE laboratories. Much of this research is broad and generic.

Expected Benefits

Limited near-term impacts are anticipated because of the basic nature of the research. However, new insights are rapidly applied by scientists and engineers in industry as a result of communication by publication in the open literature and presentations at regional, national, and international professional meetings.

Mid-term impact is well illustrated by contributions in previous years which have been transferred to industry, such as:

- Computational model for petroleum generation routinely used in industry;
- Downhole seismic sources and receivers undergoing commercialization; and
- Technique for nondestructive determination of in-situ stress commercially available.

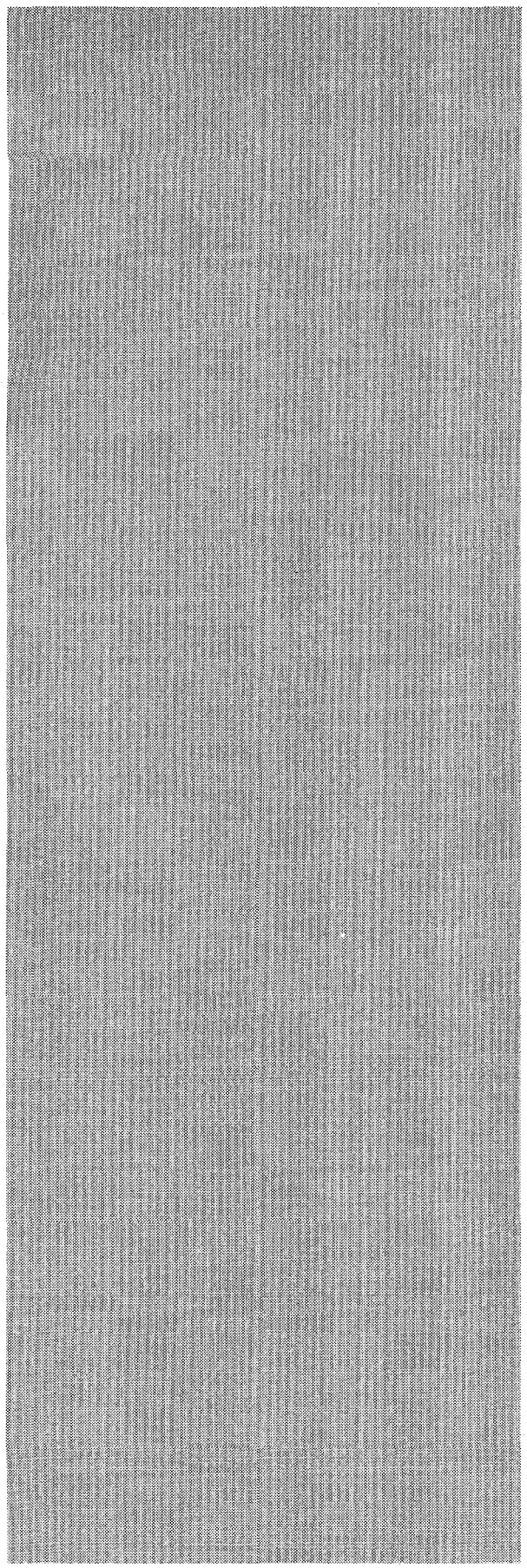
Recent Accomplishments

- Determined experimentally the pressure-volume-temperature relationships in C-O-H-N mixtures at conditions comparable to those in reservoirs.
- Concluded that rare gas isotopic composition in some reservoirs strongly suggests importance of long-distance fluid transport.
- Demonstrated existence of an alternative, catalytic pathway to the origin of natural gas from carbonaceous sedimentary rocks rich in transition metals.
- Developed technique for determination of pore structure, and surface texture, at the 10 micrometer scale in sedimentary rocks using synchrotron computed X-ray microtomography in collaboration with Mobil.
- Development of a fast algorithm for estimating formation permeability from Stoneley wave logs.
- Demonstrated effect on seismic velocity of the quantity and location of solid phases in the pores of sedimentary rocks, such as gas hydrates, for increased understanding of marine seismic reflection data.
- Sponsored workshop on High-Performance Computing in Seismology under the auspices of the National Academy of Sciences/National Research Council Committee on Seismology.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Fundamental Geosciences Research	5.5	3.8	3.8
Total	**5.5**	**3.8**	**3.8**



3.2 Delivery and Storage

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DELIVERY AND STORAGE

3.2.1 TECHNOLOGY SUMMARY

OVERVIEW

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. Adequate, responsive, and cost-efficient underground storage is a vital part of maintaining the confidence level of natural gas consumers. Stored gas can supplement pipeline capacity during periods of heavy demand and serve as backup supply during an interruption in wellhead production. Today there are more than 17,000 gas storage wells at 375 sites around the country.

Increased access to underground storage will allow more extensive use of the interstate pipeline system. Following deregulation and FERC Order 636, most interstate storage became open access, with up to 90% now available to natural gas transportation customers. New storage facilities have also been built, largely salt caverns where natural gas can be injected and withdrawn on a continuing basis throughout the year.

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 Annual Energy Outlook 1998 forecasts that electric generation demand for natural gas will grow by 4.24 Tcf between 1996 and 2010. This is the consuming sector that places highest demands on deliverability. Four U.S regions that have substantial growth rates for generation gas are New England, Mid Atlantic, South Atlantic, and East North Central. The total deliverability

growth needed for these four regions is 6,180 MMcfd, adding 12 percent to existing storage deliverability. Other regions have less need for storage than these four because of either their lower growth rate or their proximity to gas production. Much of this needed deliverability can be obtained by improvement of existing storage facilities and the balance by adding facilities.

Department-Wide Program

The Department of Energy is working with industry to help ensure a safe, reliable, and cost effective supply of natural gas. Through the Natural Gas Delivery and Storage Program, DOE promotes the development of advanced technologies and methods to enhance and expand the delivery and storage system.

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.

Advanced technology 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. 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 will intensify with impending electric utility sector restructuring. The gas industry also must 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.

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.

Program Activity Summary

Program efforts are primarily focus on the four cost-effective technologies and engineering practices described below.

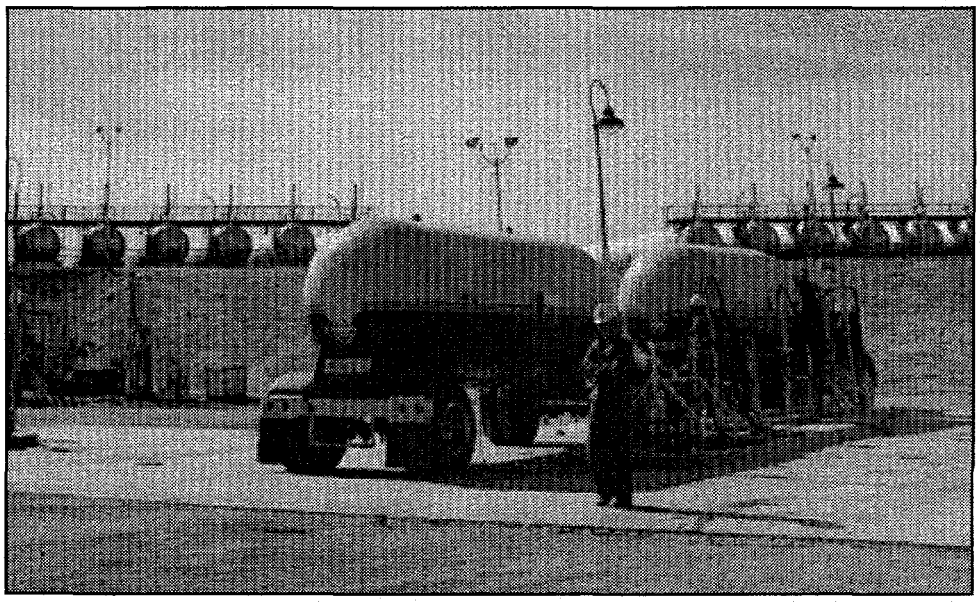
- *Deliverability Enhancement*: The objective is to reduce the costs associated with storage well deliverability decline and to increase deliverability from storage to support the projected market growth to 28.84 Tcf by 2010. Deliverability losses averaging 5 percent annually are costing the industry in excess of $100 million annually for remedial measures. Increasing deliverability is the key to providing customers with cost-effective storage service under Federal Energy Regulatory Commission (FERC) Order No. 636. Implementation of a variety of technologies and operating practices are needed to achieve deliverability targets and reduce potential field problems. The R&D efforts include development of preventative methods and technologies, improvements of current remedial

measures (e.g., acidizing and reperforating), development of novel hydraulic fracturing techniques, and the effective use of horizontal wells.

- *Advanced Storage*: The power generation sector accounts for nearly 2 Tcf of the projected growth in natural gas demand. Gas-fired power generation represents a major growth market for the natural gas industry. A recent study conducted for the Gas Research Institute, "Current Market Drivers and Probable Trends in the Utilization of Natural Gas Storage," concluded that peak day requirements for most industrial and regional segments will increase, flexibility in storage services will be critical, and a need for cost-effective peaking service is evident. Research efforts include investigation of alternative storage facilities, e.g., lined rock caverns, refrigerated mined caverns, and gas storage as hydrates, and improvements in salt formation storage. This research will ensure that gas demand can be met by a reliable and efficient gas storage and delivery system.

- *Improved Gas Measurement*: An important component of gas storage is the gas metering facility which is used to monitor gas injection and flow rates. The difference in these rates are used to establish gas storage inventories. The industry is in need of advanced gas meters. Improved accuracy and reliability of gas measurement will lead to increased operational efficiency at storage facilities because of more accurate inventories. Cost savings will be realized through reduced installation and operation costs. Research efforts are directed at testing and evaluating ultrasonic meters to provide an industry standard for their use. Ultrasonic meters have many advantages over conventional orifice and turbine meters. Metering research will eventually lead to the development of a total energy flow or direct energy meter which will deliver real-time gas flow and energy content data.

- *Reservoir Management*: There are over 370 underground storage facilities in operation in the United States. Gas is stored in depleted oil and gas reservoirs and aquifers in the majority of these facilities. Working gas (gas that can be delivered to customers) and deliverability is not always optimized at every facility because of the complex geology of the reservoir and/or because



Delivery Station in a Refinery

of the way the field had been developed prior to being converted for storage. The major goal of the reservoir management project area is to increase the efficiency of storage operations. Research efforts are focused on reservoir characterization and engineering assessment of storage facilities through partnerships with industry. Activities include increasing capacity and deliverability using horizontal wells, qualifying storage fields for the use of delta pressuring (increasing maximum pressure) as a means of increasing capacity and deliverability, and developing new technologies to identify (e.g., advanced methane detection systems) and prevent gas loss.

FY 1996 - 1998 Crosscut Budget Summary ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Deliverability Enhancement	0.577	0.322	0.350
Advanced Storage Concepts	0.157	0.512	0.252
Gas Measurement	0.144	0.001	0.245
Reservoir Management	0.100	0.100	0.100
Natural Gas Deliverability Model (DELIVER)	0.111	0.050	0.050
EIAGIS-NG Geographic Information System	0.150	0.100	0.100
Total	**1.239**	**1.085**	**1.097**

3.2.2 Project Descriptions

3.2.2.1 Deliverability Enhancement

Background

There are over 17,000 existing gas storage wells in the United States. According to a 1993 study conducted for the Gas Research Institute (GRI) "State-of-Technology Assessment and Evaluation of Gas Storage Well Productivity Enhancement Techniques," these wells are losing, on average, 5.2 percent per year of their capability to inject and withdraw natural gas. The storage industry is offsetting this loss through various remediation treatments and by drilling new wells at a cost of over $100 million per year. Roughly two-thirds of the cost to restore lost deliverability and one-third of the deliverability offset come from infill/replacement wells. Thus, there is great potential for restoring capability of existing wells that are not being treated, and to reduce the cost of deliverability enhancement by reducing the number of infill/replacement wells.

Excluding new wells or delta pressuring, the GRI report identified fracture stimulation technology as having the greatest potential for increasing well deliverability. However, fracturing represents less than 5 percent of the revitalization treatments performed by the storage industry. In FY 95, DOE initiated a Fracture Stimulation Field Demonstrations project to test new and novel fracture stimulation technologies to restore lost deliverability. Three technologies that are being tested under this project are liquid CO_2/sand, tip screenout, and extreme overbalanced treatments (surging and perforating).

However, not all wells are suited for and/or require fracture stimulation to restore lost deliverability. Hence, a means to determine the causes of lost deliverability, i.e., damage mechanisms, and thus, define the best approach to remediate the damage, is required. The GRI initiated a field study "Investigation of Storage Well Damage Mechanisms" to determine the root causes of lost deliverability. DOE funding in FY 1996 expanded the study from 8 fields to 12 fields to provide a better representation of the entire storage industry.

Major Goals

The major goal of the deliverability enhancement project area is to provide a cost-effective means to increase deliverability of the natural gas storage system. Goals specific to individual project areas include: advanced fracture stimulation technology to provide a better and longer lasting deliverability enhancement than other techniques; develop a methodology to deduce storage well damage mechanisms and determine the best remedial treatment; and develop improved remedial treatment technologies, e.g., acidizing, and coiled-tubing cleanout.

Project Objectives

Fracture Stimulation Field Demonstrations: field test new or improved cost-effective fracture stimulation technologies and techniques that can restore lost injection and withdrawal capability in existing underground gas storage wells.

Investigation of Storage Well Damage Mechanism: determine the mechanisms responsible for loss of deliverability in gas storage wells in a number of geologic environments; define testing procedures to deduce damage mechanisms; and provide a basis for defining procedures to prevent or remediate damage.

Expected Benefits

Improved stimulation treatments and better application of technology through an increased understanding of damage mechanisms will lead to cost effective deliverability enhancement. Deliverability of the gas storage system will increase due to better deliverability enhancement. Cost of storage service will be lower because of

better application of technology and reduced withdrawal and injection costs.

Planned Products

- New and better fracture stimulation technologies, e.g., CO_2/sand fracturing and extreme overbalanced (EOB) perforation.
- A new computer model to design and analyze EOB treatments.
- A GRI report that identifies the damage mechanism found in storage wells. The major damage mechanisms that have been identified are bacteria and inorganic precipitates, e.g., sulfates and iron compounds.
- Improved remedial treatment technologies to treat damage mechanisms such as bacteria and inorganic compounds.
- Two videos highlighting the results of the damage mechanism study and the importance of deliverability.

Strategy (FY 97 Funding: $0.322 Million)

Increasing deliverability has become the highest priority for storage operators since FERC Order 636. Hence, deliverability enhancement has been and will continue to be a major research area for DOE. Past and present research will continue to focus on ways of improving technology or developing new cost-effective technology to improve deliverability.

Recent Accomplishments

At the Galbraith field, located in Jefferson County, Pennsylvania, fracture stimulation with liquid CO_2 and proppant demonstrated immediate, dramatic improvements in deliverability. Two of the three wells had improvements of six- and seven-fold in absolute open flow (AOF) at maximum reservoir pressure. These were the first ever CO_2/sand stimulations in a gas storage reservoir.

At Huntsman field, located in the Cheyenne County, Nebraska, the project introduced fracturing technology to an operator who had no prior fracturing experience. Deliverability was improved by 16 MMscfd in the first well by rigorously applying pre-fracture diagnostics to improve job design and overcome the unfavorable conditions of a thin caprock and high reservoir permeability.

At the Donegal field, located in Washington County, Pennsylvania, high formation in-situ stresses and a thin-bedded lithology combined to prevent effective hydraulic fracturing. This brought the introduction of EOB fracturing to the gas storage industry for application in wells that are difficult to stimulate. Rigorous data analysis and job design demands precipitated a major advance in software specifically tailored for the simulation and design of EOB techniques. This unique software has the potential to develop into a commercial product benefiting the worldwide oil and gas industry.

Work under a GRI/DOE cofunded project on damage mechanisms has identified bacteria and inorganic precipitates, e.g., iron compounds, sulfates, and carbonates, as the leading cause of deliverability reduction. Other damage mechanisms discovered were oils (both compressor and naturally occurring), production chemicals, mechanical obstructions, stimulation fluids, and sanding.

Program Funding

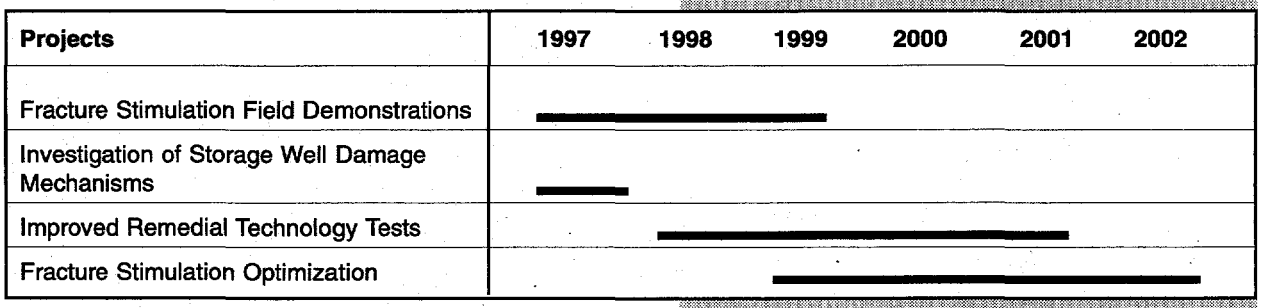
DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Fracture Stimulation Field Demonstrations	0.355	0.144	0.100
Damage Mechanism	0.222	0.178	0.000
Improved Remedial Technology Tests	0.000	0.000	0.250
Total	**0.577**	**0.322**	**0.350**

Cost Sharing ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998 Estimate
Fracture Stimulation Field Demonstrations	0.255	0.766	0.693
Damage Mechanism	0.800	0.600	N/A
Improved Remedial Technology Tests	N/A	N/A	0.500
Total	**1.055**	**1.366**	**1.193**

Schedule



3.2.2.2 Advanced Storage Concepts

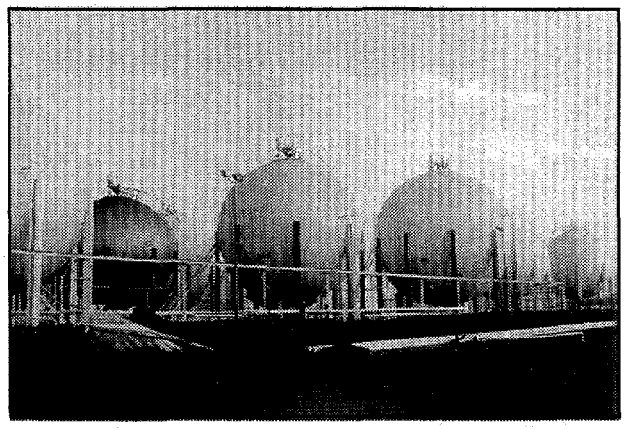
Background

The Gas Research Institute's 1995 Annual Baseline Gas Projection predicted an increase in total U.S. gas demand of over 5 Tcf between 1994 and 2010. Traditional storage and pipeline capacity will be used to deliver most of this projected growth in gas demand to the end-use sectors. However, there are certain market areas where alternatives to conventional storage may be required.

The power generation sector accounts for nearly 2 Tcf of the projected growth in natural gas demand. Gas-fired power generation represents a major growth market for the natural gas industry. However, the large, high-pressure, highly variable loads required for individual power generators can be difficult to serve, particularly for natural gas pipelines. The presence of local gas storage may reduce the need for additional pipeline facilities to meet these requirements.

The New England region and the South Atlantic region have a combined projected growth of over 1.5 Tcf of natural gas. With the exception of the State of West Virginia, conventional underground gas storage is almost nonexistent in these two regions. Hence the need for alternatives to conventional storage facilities may be warranted, especially to serve the peaking needs of these two areas.

Storage Tanks in a Refinery



Lastly, a recent study conducted for the Gas Research Institute, "Current Market Drivers and Probable Trends in the Utilization of Natural Gas Storage", consisted of a survey of natural gas storage users and providers to determine current needs for various types of storage services and probable trends for the next five years. The study concluded that peak day requirements for most industrial and regional segments will increase, flexibility in storage services will be critical, and a need for cost-effective peaking service is evident.

In FY 95, DOE initiated a study, "Natural Gas Storage-End Use Interaction," to determine future need for storage, and identify areas of the U.S., where alternatives to conventional storage would be required. A major part of the project was to improve modeling capabilities of the Gas Systems Analysis Model (GSAM), being developed under another DOE contract (see Section 3.1.2.3), to better model the storage sector, including peaking services.

In FY 96, DOE initiated a Program Research Development Announcement for advanced storage concepts. Feasibility studies, conceptual designs and cost analyses will be conducted for four different alternative storage applications. The areas of research include: (1) lined rock cavern storage; (2) refrigerated mined cavern storage; (3) improved salt cavern storage; and (4) gas storage as hydrates.

Major Goals

The overall goal of this project area is to ensure that gas demand throughout the year 2010 can be met by a reliable gas storage and delivery system. Goals specific to individual project areas include:
(1) develop an analytical tool to evaluate natural gas storage requirements under various technological, economical, and market conditions; and (2) increase market penetration of advanced or alternative gas storage facilities that will meet the growing

needs of the natural gas industry and end-use customers and can demonstrate reduced cost of natural gas to end-users at or below the cost of natural gas currently available.

Project Objectives

Natural Gas Storage-End Use Interaction: Identify market needs for natural gas storage in new and growing natural gas market areas through the year 2010. This research will: (1) identify market areas and end-use sectors where new natural gas underground storage capacity and deliverability is required and can be economically employed; and (2) analyze technical and economic impact of advances to conventional underground gas storage.

Advanced Storage Concepts: Demonstrate technical feasibility, develop conceptual designs, and conduct cost analyses for innovative natural gas storage concepts that fully demonstrate commercialization potential to meet the projected needs of the natural gas industry and the end-use markets of the U.S. through the year 2010.

Expected Benefits

Natural gas usage will increase in market areas where gas demand has been very low or non-existent. Gas prices in these areas will be lower.

Planned Products

- New facilities using advanced gas storage technologies.
- An analytical tool, the Gas Systems Analysis Model, for evaluation of the gas storage and delivery system.

Strategy (FY 97 Funding: $0.512 Million)

Gas demand forecasts have projected a 2 Tcf growth in gas-fired power generation, a 1.5 Tcf growth in the New England and South Atlantic areas where conventional underground storage is nonexistent, and the increasing need to provide cost effective peaking services. New research was initiated in FY 97 to maintain a reliable and efficient delivery and storage system. Innovative storage systems will provide cost-effective gas service to areas where conventional storage does not exist or cannot meet the needs of the end user.

Recent Accomplishments

The Gas Systems Analysis Model was enhanced to include a gas storage module. This allows technology and economic forecasts to be conducted to determine future technology requirements of gas storage. Recommendations for improvements to GSAM were made to better model the storage and delivery system.

Four contracts will be awarded to investigate advanced storage concepts. The areas of research include: (1) lined rock cavern storage; (2) refrigerated mined cavern storage; (3) improved salt cavern storage; and (4) gas storage as hydrates.

Program Funding

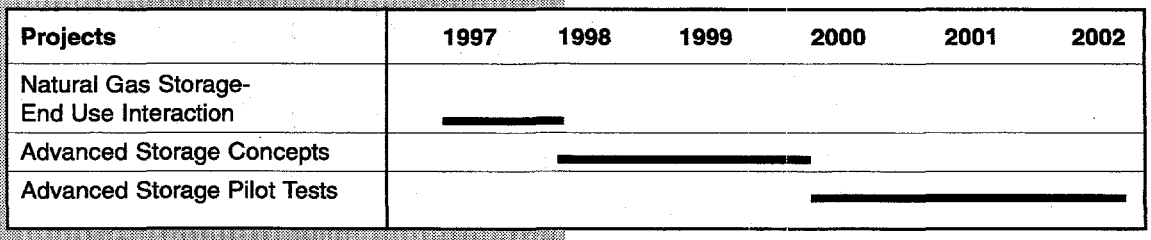
DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Natural Gas Storage–End-Use Interaction	0.157	0.042	0.000
Advanced Storage Concepts	0.000	0.470	0.252
Total	**0.157**	**0.512**	**0.252**

Cost Sharing ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998 Estimate
Natural Gas Storage–End-Use Interaction	0	0	N/A
Advanced Storage Concepts	N/A	0	0.200
Total	**0**	**0**	**0.200**

Schedule



3.2.2.3 Gas Measurement

Natural gas storage is vital to the delivery of gas throughout the United States. Gas is injected into storage fields during periods of low demand (Summer) and withdrawn from storage during periods of high demand (Winter). During periods of peak demand, gas storage provides as much as 30 percent of total gas demand. Approximately 2 Tcf of gas is injected into and withdrawn from storage each year. Therefore, it is extremely important to accurately measure the amount of gas at each storage facility, considering that at $2/Mcf, the value of this gas is $8 billion annually.

Storage operators use biannual pressure measurements in conjunction with metered gas volumes to maintain inventory at each storage facility. Measurement errors cause deliverability problems, especially near the end of the storage withdrawal season. Orifice meters are typically used to measure gas flow at storage facilities. The rate of gas flow is measured by placing a constriction (orifice plate) in the pipeline and measuring the pressure drop across the plate. These meters can only measure gas flow in one direction, therefore, two meter runs are required, one for injection and one for withdrawal. Orifice meters must be calibrated in the field and require frequent maintenance. There are many variables that can cause measurement errors.

Ultrasonic meters have many advantages over orifice meters including: no moving parts, no pressure drop, bi-directional metering capability, proven accuracy, very low maintenance, self calibrating, and high repeatability. Therefore, ultrasonic meters can provide significant capital and operating cost savings through: (1) eliminating the need for two meter runs (bidirectional), (2) savings in compression (no pressure drop), (3) reducing maintenance and calibration, and (4) increasing the efficiency of storage operations by providing more accurate measurement.

The Gas Research Institute is conducting ultrasonic meter evaluation testing for natural gas flow applications at GRI's Meter Research Facility (MRF) at Southwest Research Institute (SWRI). The tests will provide guidance on performance, installation, and operation of ultrasonic meters and support an ongoing industry standards development effort. However, meter testing being conducted by GRI will not address many of the issues involving gas storage field applications.

In FY 97, DOE began research to address specific storage application issues that will complement and build upon the testing by GRI. Under DOE supported research, SWRI will test bidirectional flow, the effect of an upstream thermowell, and meter accuracy at very low flow rates. In addition, industry will be providing data from field installations, which will be evaluated and documented.

Major Goals

The overall goal is to provide accurate, real-time measurement of gas at gas storage facilities. Goals of individual projects include providing data for development of an industry standard and, if necessary, improve ultrasonic meter performance.

Project Objectives

Ultrasonic Meter Testing and Evaluation: Test and evaluate ultrasonic meters with respect to specific issues encountered in gas storage field applications. This research will provide data necessary to develop an industry standard for ultrasonic meter use and will identify additional testing and improvements to the meters that may be necessary.

Expected Benefits

Improved accuracy and reliability of gas measurement will lead to increased operational efficiency at storage facilities because of more accurate inventories. Cost savings will be realized through reduction in installation and operation costs.

Planned Products

- Industry standard for using ultrasonic meters
- Reports on performance of ultrasonic meters under laboratory conditions (MRF) and field conditions
- Real-time, direct energy meter.

Strategy (FY 97 Funding: $0.001 Million)

Gas measurement is important not only financially but also from an operational point of view, since more accurate inventories will help storage operators to more efficiently manage their asset. DOE initiated research on ultrasonic meters in FY 97 because of the tremendous potential these meters have to offer to the storage industry. Research will continue on ultrasonic meters while new research on advanced gas measurement technologies, e.g., a direct energy meter, will be initiated.

Recent Accomplishments

Ultrasonic meters have been received from two major manufacturers for testing at the MRF. Testing of the effect of a thermowell has been completed. Testing for bidirectional flood and low-flow rates has been initiated.

CNG Transmission Corporation and Columbia Gas Transmission have agreed to provide field performance data on ultrasonic meters for evaluation by Southwest Research Institute. CNG is planning to install two 12-inch ultrasonic meters at its Bridgeport, WV storage facility and expects them to be operational for the upcoming injection season. Columbia is installing a 20-inch multipath ultrasonic meter at its Victory storage facility in Marshall Co., WV. Both companies are running the meters in series with existing orifice meters for comparison.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Ultrasonic Meter Testing and Evaluation	0.144	0.001	0.145
Advanced Gas Measurement	0.000	0.000	0.100
Total	**0.144**	**0.001**	**0.245**

Cost Sharing ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998 Estimate
Ultrasonic Meter Testing and Evaluation	0.225	0.245	0.600
Advanced Gas Measurement	N/A	N/A	0.000
Total	**0.225**	**0.245**	**0.600**

Schedule

Projects	1997	1998	1999	2000	2001	2002
Gas Measurement						
Ultrasonic Meter Testing and Evaluation						
Advanced Gas Measurement						
Direct Energy Meter						

3.2.2.4 Reservoir Management

Background

There are over 370 underground storage facilities in operation in the United States. Gas is stored in depleted oil and gas reservoirs and aquifers in the majority of these facilities. Working gas (gas that can be delivered to customers) and deliverability (rate) is not always optimized at every storage facility because of complex reservoir geology or because of field development prior to it being converted for storage.

Since FERC Order 636, operational efficiency and deliverability are becoming increasingly important. The storage industry is beginning to use horizontal wells to increase deliverability of storage fields and to investigate re-engineering of storage operations to provide peaking services in addition to baseload services.

The storage industry must be able to optimize both individual well treatments and overall field performance, including the possibility of expanding the field's current capabilities. This means being able to identify which and how many wells require deliverability restoration, comparing the economic benefits of a well treatment program versus new infill or replacement wells (including horizontal wells), or a combination of both. Geologic modeling and reservoir simulation is a cost effective means of conducting a full field evaluation and determining optimum field performance. Once a reservoir has been characterized and a geologic model of the field developed, reservoir simulation provides a cost efficient means to analyze many operating scenarios.

In FY 94, 95 and 96, DOE/FETC initiated three Cooperative Research and Development Agreements (CRADAs) with industry (National Fuel Gas Supply Corporation, Equitrans, Inc., and Northern Indiana Public Service Company) to conduct reservoir characterization and engineering assessment studies.

Major Goals

The major goal of the reservoir management project area is to increase efficiency of storage operations. Specific goals include: increase use of geologic modeling and reservoir simulation studies for optimizing field performance; and demonstrate importance of horizontal wells to increase deliverability.

Project Objectives

Reservoir Characterization and Engineering Assessment: Through industry and FETC partnerships, demonstrate importance of geologic modeling and reservoir simulation for optimizing development and operation of gas storage fields.

Expected Benefits

Capacity and deliverability of storage fields will increase through more efficient storage operations.

Planned Products

Technical papers, reports, and workshops providing case studies.

Strategy (FY 97 Funding: $0.1 Million)

Since DOE began research in storage in FY 1994, three CRADAs have been initiated to show importance of geologic modeling and reservoir simulation to improve storage efficiency and to demonstrate the potential of horizontal wells. Work will continue on these CRADAs while DOE pursues other research to help improve the operational efficiency of storage reservoirs.

Recent Accomplishments

A horizontal well drilled by Northern Indiana Public Service Company (NIPSCO) as part of a Cooperative Research and Development Agreement with DOE was a big success and will greatly enhance the economics of their storage operation. Initial flow tests indicate that the horizontal well will significantly enhance gas deliverability

from the Royal Centers field, located in Cass County, Indiana, and will allow gas use from an area of the storage field that was not accessible from present vertical wells. The project success can be attributed to a coordinated effort between NIPSCO, DOE, and GRI contractors and an integration of geologic modeling and seismic surveying.

Program Funding

DOE Historical Spending ($ in Millions)

Project	FY 1996	FY 1997	FY 1998
Reservoir Characterization / Engineering Assessment	0.100	0.100	0.100
Total	**0.100**	**0.100**	**0.100**

Cost Sharing ($ in Millions)

Project	FY 1996	FY 1997	FY 1998 Estimate
Reservoir Characterization / Engineering Assessment	0.350	0.612	0.150
Total	**0.350**	**0.612**	**0.150**

Schedule

Projects	1997	1998	1999	2000	2001	2002
Reservoir Characterization/ Engineering Assessment						
Improved Operational Efficiency						

3.2.2.5 Natural Gas Deliverability Model (DELIVER)

Background

Key policy issues and emergency planning require estimates of regional or State deliverability capability within the national network of interconnected delivery systems. Analytical procedures for estimating wellhead productive and pipeline capacities exist elsewhere, but the Natural Gas Deliverability Model (DELIVER) comprises a comprehensive framework to analyze gas deliverability issues within a coordinated network.

Major Goals

Development of a PC-based system for analysis of the U.S. gas delivery network capability to handle changes in supply or demand patterns, planned pipeline or storage expansion, or disruptions to gas supply or the delivery system.

Project Objectives

- Develop a user-friendly system that can readily analyze gas deliverability with quick turnaround.
- Provide useful tabular and map displays of deliverability solutions to support further analysis or for inclusion in analysis reports.

Expected Benefits

- Enhances ability of DOE to address questions relating to the gas industry's ability to deliver natural gas on a regional or State basis.
- Complements the Gas System Analysis Model (GSAM) to provide the capability to evaluate seasonal and peak day supply and consumption and other issues at a more disaggregated level than is considered in the GSAM model.

Planned Products

- A PC-based analysis tool with updated data to address issues of national, regional, or State-level deliverability issues.
- An analysis report on the capability of the natural gas delivery system to supply gas to consumers under normal conditions and conditions of selected scenarios. The deliverability analysis will proceed for both the current network and the domestic network with planned capacity expansion.

Strategy (FY 97 Funding $0.05 million)

The project strategy is to: (1) develop a deliverability model with an updated database to include major capacity expansion projects, and (2) use the model to assess the capability of the natural gas delivery system to supply natural gas to consumers under a wide range of conditions.

Recent Accomplishments

Completion of an operational model in 1996 incorporating the responses from Beta-testing of the model. This version of DELIVER is based on 1994 data.

Program Funding

DOE Historical Spending ($ in Millions)

Project	FY 1996	FY 1997	FY 1998
DELIVER	0.111	0.050	0.050
Total	**0.111**	**0.050**	**0.050**

3.2.2.6 EIAGIS-NG Geographic Information System

Background

EIAGIS-NG is a PC-based geographic information system that allows natural gas analysts and others to select natural gas pipeline systems and associated databases through a menu driven operation and have the selected data mapped and displayed on a monitor. The system allows the user to rapidly modify and manipulate a pipeline/site map display and perform various geographic search operations as well as generate data summary and execute statistical routines.

The EIAGIS-NG grew as a response to radical changes that have occurred in the natural gas industry since the late 1980s and those that are anticipated through the end of this decade. These changes make the need for a system that can visually reflect and focus upon the relative locations of major pipeline interconnections and market center/hubs imperative. It is important for interested parties to be able to evaluate and track the potential impact of pipeline development as it affects the transmission of supplies to market areas. Additionally, the ability to simply locate and display geographic information concerning one or more pipelines systems is often key to providing an accurate picture and complete analysis of specific query. The EIAGIS-NG system provides these capabilities to the analyst.

Major Goals

- Develop a PC-based mapping and database system focusing upon the natural gas pipeline network within North America. The system provides industry analysts with the capability to graphically examine interrelationships among the pipelines and associated energy facilities. It allows the users to quantify and qualify the capabilities of natural gas pipelines to deliver gas from supply sources, including storage, to consuming areas.
- Develop a user-oriented geographic information system to provide almost instantaneous retrieval and display of natural gas pipeline location and infrastructure data.
- Build a series of relational databases and map files which would provide analysts (and others) with access to information on how gas is received, transported, stored, and consumed.
- Build a system which would allows users to quickly locate pipeline disruptions and other situations and to analyze the impact of these on consuming areas.

Project Objectives

- Provides rapid access to pipeline network information and facility locations not previously available.
- EIAGIS-NG will provide the ability to track new pipeline projects and access their impact upon the future of the natural gas transmission and distribution network.

Expected Benefits

- EIA and DOE will have immediate access to: (1) maps for over 150 inter and intrastate natural gas pipeline systems; (2) the locations of interstate pipeline compressor stations, interconnections, receipt and delivery points, (3) the locations of existing, proposed, or abandoned underground storage sites, and (4) many other energy related facilities.
- Analysts will be able quickly to extract, format, and display geographically requested natural gas data and perform statistical manipulations not previously available. Map displays and other graphical presentations of analytical results may be saved as a system option.

- Analysts will have the capability to develop new ways to display and present data on a geographical or relational basis for further analysis or incorporation into reports.
- Tracking of events and situations within the natural gas industry will be facilitated.

Planned Products

Products and analyses developed from the EIAGIS-NG system will be used extensively in the EIA "National Gas Deliverability on the Interstate Natural Gas Pipeline System" report scheduled for completion in the latter part of 1997.

In conjunction with the execution of several (1997) natural gas projects, EIAGIS-NG's capabilities are being broadened to include pipeline load-factor analysis as a key feature of the system.

Strategy (FY 97 Funding: $0.1 Million)

The basic EIAGIS-NG system has been operational since April 1997. Its major components—programs, map files, databases, and documentation—have been completed. Currently, the system is undergoing some enhancements and upgrades to adapt to changing technological needs (e.g., Internet integration). A significant effort also is directed at maintenance of system maps and databases. The EIAGIS-NG has been designed to expand into other natural gas-related areas, such as oil product pipelines and electrical transmission lines.

Recent (FY 1996) Accomplishments

- Completed an enhancement to the EIAGIS-SD (storage deliverability) subsystem of EIAGIS-NG that permitted output from the Gas System Analysis Model (GSAM) to be processed into a regional map display and bar graph. The work was performed for DOE/Fossil Energy's Federal Energy Technology Center (Morgantown, WV).
- Completed upgrades to the mapping process that included an interactive SQL query routine. Also developed interface programs for several new databases included in the system, for instance, the Nehring Field/Reservoir database and annual gas/oil/electrical databases.
- Completed the revision of several system administration program processes that improved capabilities of the EIAGIS-NG database administrator to maintain the overall system and to audit the integrity of the system components (i.e., data dictionary and database control files).

Program Funding

DOE Historical Spending ($ in Millions)

Project	FY 1996	FY 1997	FY 1998
EIAGIS-NG	0.150	0.100	0.100
Total	**0.150**	**0.100**	**0.100**

DOE/Fossil Energy provided $100,000 in FY 95 and $50,000 in FY 96 for EIAGIS-SD (Storage Deliverability) development.

3.3 Power Generation

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POWER GENERATION

3.3.1 TECHNOLOGY SUMMARY

Activities in the area of Power Generation are focused on developing cleaner, more efficient systems for both utility and industrial electric power generation. Although the target fuel is natural gas, systems are being developed for use of coal, biomass, and other fuels. Two types of systems, fuel cells and advanced turbines, are being addressed in programs conducted within the Office of Fossil Energy and the Office of Energy Efficiency and Renewable Energy.

A fuel cell (Exhibit 4) is an electric power generator made with parts similar to the common storage battery. Unlike a battery, it will continue to provide power as long as air and fuel is supplied. The air and fuel are combined electrochemically in the fuel cell to produce electricity without combustion. Individual fuel cells are connected in varying numbers of stacks to match the particular power application. The fuel cell systems produce very high quality DC electricity that can be used directly or efficiently converted to AC power. Fuel cells have been used for many years in space vehicles for on-board electric power, and have recently begun to find applications for commercial power and transportation.

Gas turbines (Exhibit 5) are heat engines that use a high temperature, high pressure gas from a combustor. Part of the heat supplied by the gas is used to rotate a generator and produce AC electricity. Much of the remaining thermal energy can be used to create steam for industrial processes or additional electricity.

Because they are compact, lightweight, and simple to operate, gas turbines have found many applications in aircraft, power generation, and industrial cogeneration. Today's industrial and utility gas turbine systems have benefited from incremental changes in existing designs. Turbine manufacturers and DOE are sharing the cost of high-risk research and development aimed at revolutionary but achievable advances.

Exhibit 4 - A Fuel Cell is Similar to a Battery But It Does Not Have to be Recharged.

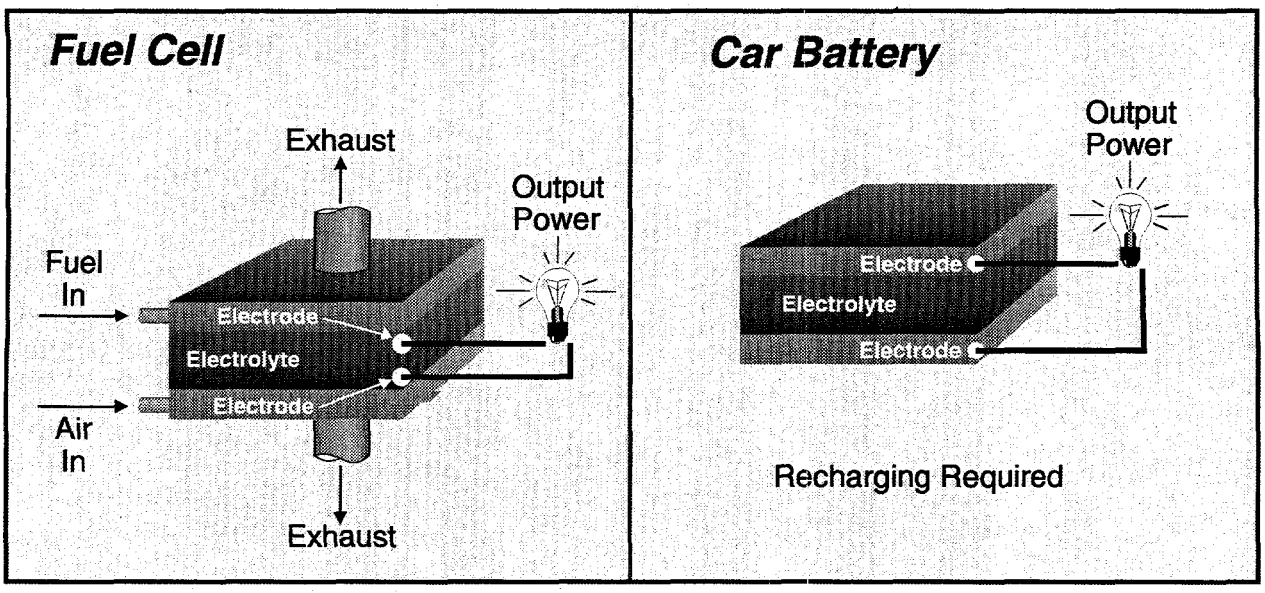
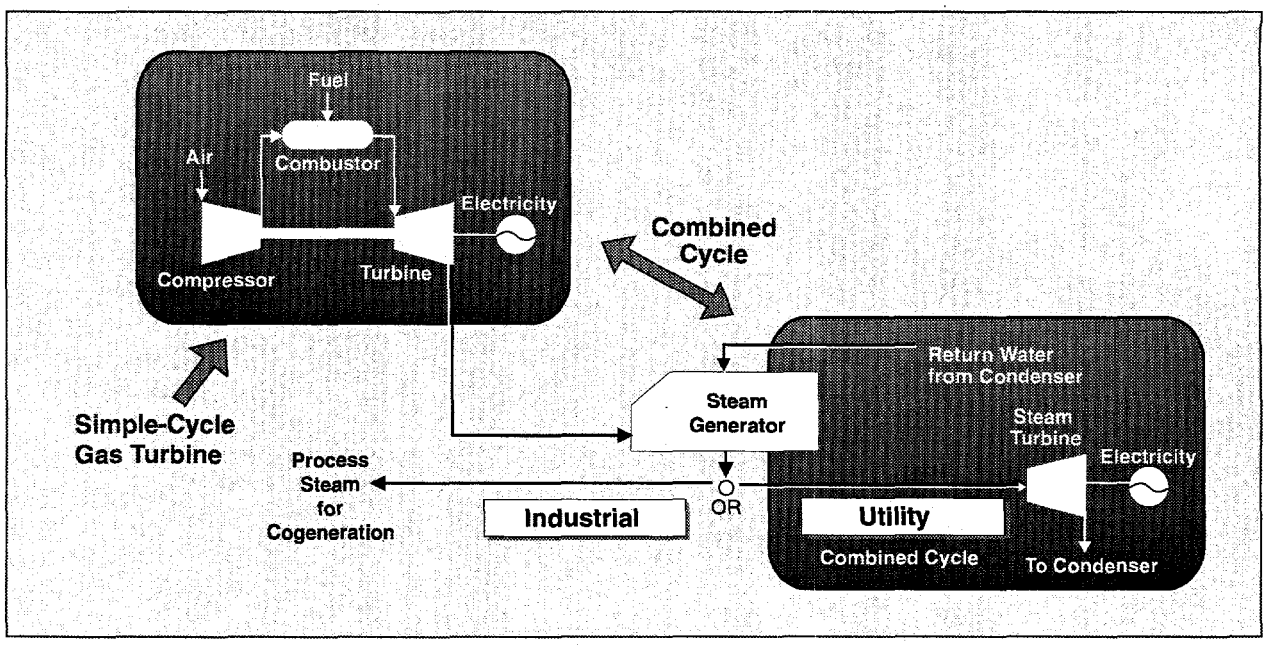


Exhibit 5 - A Gas Turbine Engine Consists of a Compressor, Combustor, and Turbine in Series. A Combined Cycle Power Plant Uses Both a Gas and a Steam Turbine.



The focus of these efforts is shown in Exhibit 6 (utility systems).

Because of their potential for ultra-high efficiencies and extremely low emissions, fuel cell and advanced turbine systems are expected to contribute substantially to future growth in electric power demands. Their inherent siting flexibility permits them to be installed in both conventional settings or to be located much closer to their loads (Exhibit 7). In countries like the United States, where transmission and distribution systems are near capacity limits and stringent emissions standards prevent the siting of conventional power generators, systems consisting of fuel cells, advanced turbines, or combined units could be deployed in a distributed generation mode, close to the load requirements.

The Department-wide power generation programs for natural gas-fired systems are described in detail in the program descriptions for fuel cells and advanced turbines.

FY 1996-1999 Crosscut Budget Summary ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998	FY 1999 Request
Fuel Cells	51.20	48.80	40.20	42.20
Advanced Turbines	57.57	71.20	79.60	76.00
Total	**108.77**	**120.00**	**119.80**	**118.20**

Exhibit 6 - Utility Advanced Turbine Systems.

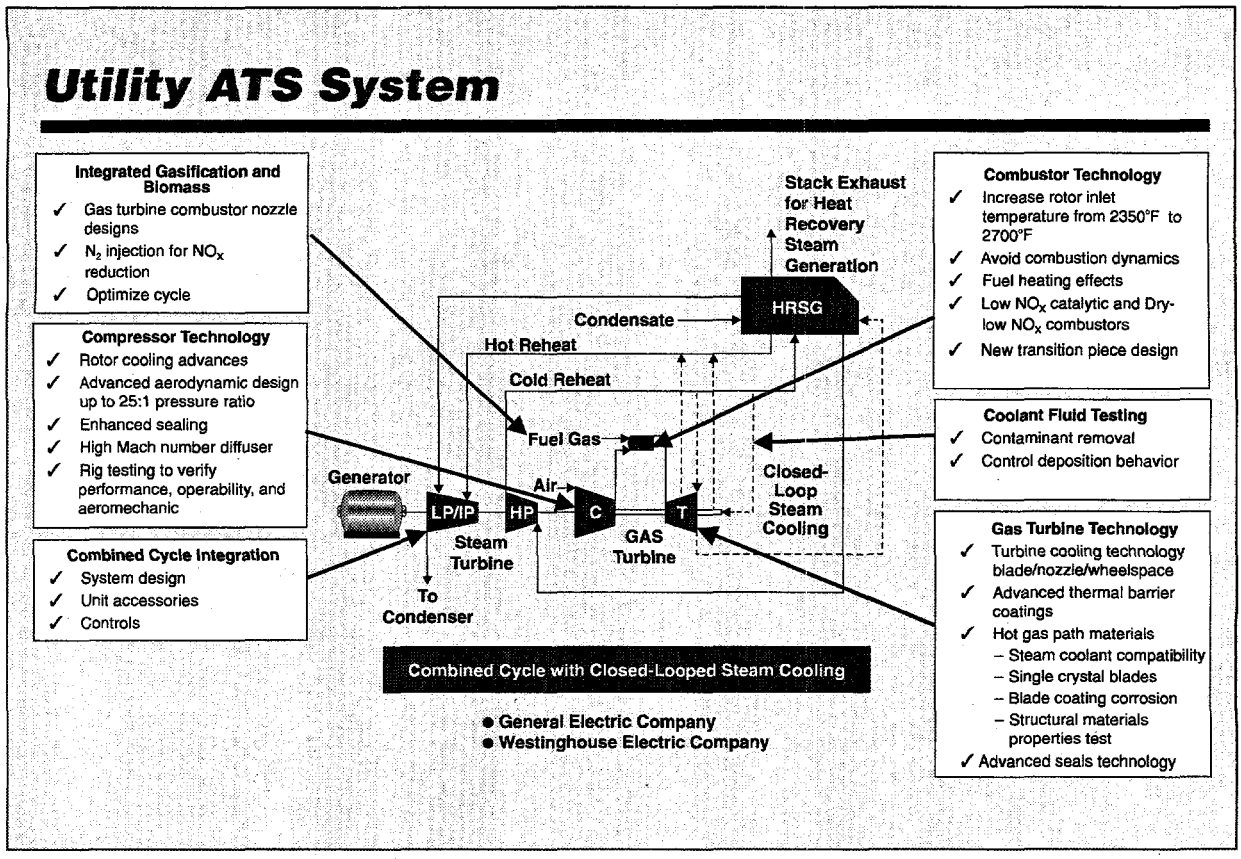
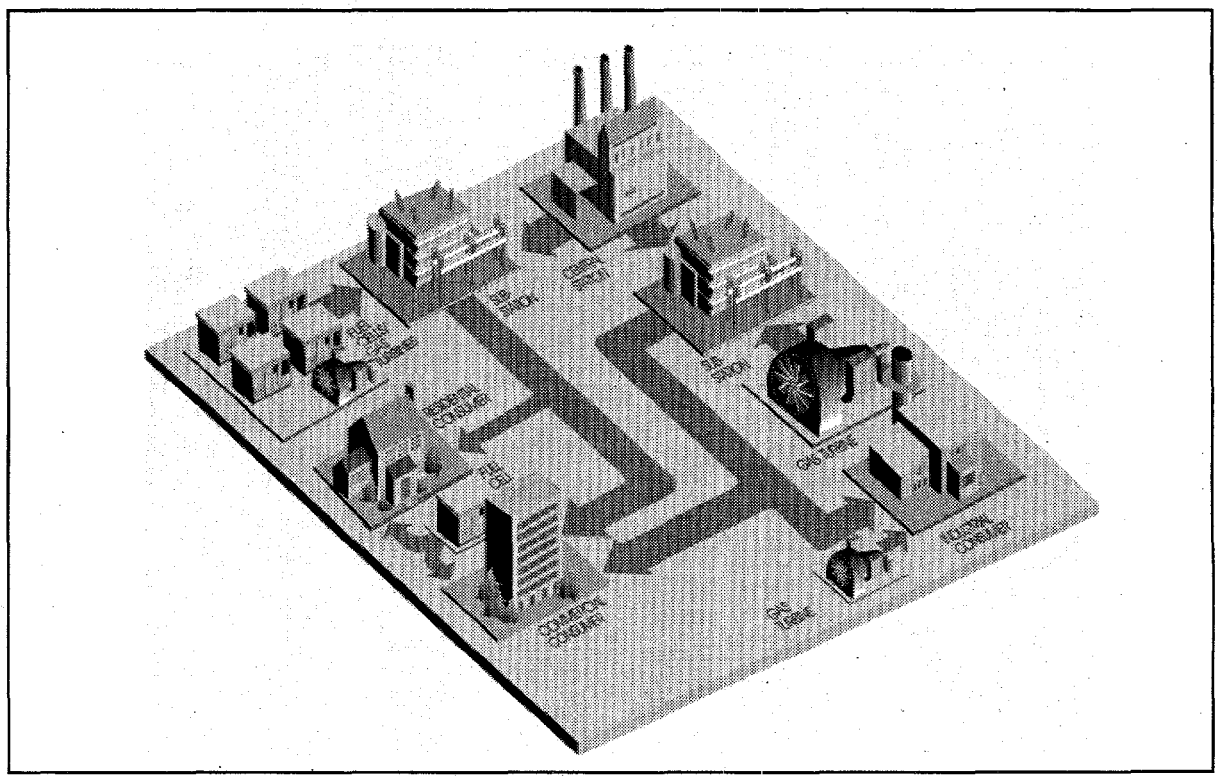


Exhibit 7 - Distributed Generation Provides Options to Improve Electric Distribution.



3.3.2 Project Descriptions

3.3.2.1 Fuel Cells for Power Systems

Background

Fuel cell power systems are emerging power generation technologies for efficient, economical and environmentally acceptable production of electricity. In some applications the heat by-product can also be efficiently used in cogeneration. Fuel cells produce electricity through electrochemical oxidation of a fuel. They can be operated on a variety of fuels, including natural gas, coal gas, land fill gas, and renewable fuels. First market entry units are fueled by natural gas. Fuel cells offer opportunity for a major new domestic manufacturing industry to be strongly competitive in the international market. A description of fuel cell technology is contained in *Fuel Cells - A Handbook*, Revision 3, U.S. Department of Energy, Office of Fossil Energy, January 1994.

The Department of Energy, Office of Fossil Energy is a leading sponsor of U.S. fuel cell technology for stationary applications. The Office of Fossil Energy is also an active member in the coordinated National Fuel Cell Program, a domestic program whose membership has interests in many fuel cell technologies. Other U.S. organizations providing major support for this program are the Department of Energy, Office of Energy Efficiency and Renewable Energy, the Department of Defense, National Aeronautics and Space Administration, Electric Power Research Institute, Gas Research Institute, and gas and electric utilities as well as the companies developing the fuel cell technologies and other private, State, and local interests.

The sponsoring organizations meet periodically to coordinate the program, ensuring that any technology gaps are bridged and that duplication of projects does not occur. The sponsoring organizations also orchestrate the bi-annual Fuel Cell Seminar, attended by participants from all over the world. For more information on the 1998 Fuel Cell Seminar, contact Courtesy Associates, Inc., Washington, D.C., (202) 973-8671.

There is world-wide interest in fuel cell technology and in its development which is indicated by broad international participation in fuel cell seminars and other similar technical meetings, by fuel cell technical literature, and by visits to international developers. Japan has a strong, well-organized fuel cell program sponsored by the Japanese Ministry of International Trade and Industry and by the Japanese private sector. A number of significant efforts are being focused on a variety of fuel cells within the European Commission and within individual countries in Europe. The Canadian government is also providing significant support for development of fuel cells. Russia and South Korea have begun active fuel cell programs as well.

Major Goals

The goal of the fuel cell program is to develop fuel cell power plant technology for use in electric utility, on-site cogeneration, distributed generation, industrial, and commercial sectors, producing high efficiencies and economic and environmental benefits. The focus of the development is to strengthen technology to a mature, cost-effective level where the developers can furnish viable commercial fuel cell power systems and the new domestic industry can strongly compete in the international fuel cell market.

Program Objectives

The objectives of the fuel cell program are:

- By 2002, have market-ready advanced fuel cell systems with efficiencies higher than 60 percent for use on natural gas for multi-kilowatt on-site cogeneration, low megawatt distributed power, and multi-megawatt central station markets.

- By 2005, adapt advanced fuel cell systems for use with coal-derived fuel gas to enhance coal-based system efficiencies in the 50 percent range.
- By 2010, develop and validate coal-fueled advanced fuel cell systems with near-zero emission of pollutants.
- By 2010, develop and validate advanced hybrid-cycle systems combining fuel cells and advanced gas turbines with efficiencies in excess of 70 percent on natural gas and with near-zero emission of pollutants.

Expected Benefits

- *Environmental*: Widespread use of fuel cell power plants offer significant environmental benefits. The prospects are substantial of reducing criteria pollutants well below current New Source Performance Standard levels, reducing noncriteria pollutants such as CO_2 and acid rain precursors, and reducing thermal emissions to the environment. These reductions are achieved through the ultra-high efficiency and the inherently low emissions of fuel cell systems. Furthermore, fuel cell systems are expected to exhibit extremely quiet operation.
- *Efficiency*: Fuel cells are unique in that they offer high efficiency even at part-load and in small sizes. Advanced fuel cell generation systems can be designed with electric efficiencies in the 50 to 60 percent range and would extend to over 70 percent in a combined cycle with gas turbines. Use of available by-product heat from a fuel cell power system could augment total energy utilization to about 85 percent.
- *Economic*: A new fuel cell industry could be expected to produce high quality jobs and product exports. Modular fuel cell systems would allow ideal generator/load matching, thereby significantly reducing generation capital costs. Fuel cell systems are ideal for the distributed generation mode, obviating the need to expand transmission lines and eliminating long transmission line losses.
- *System Reliability*: Currently operating market entry phosphoric acid fuel cell units are exhibiting about 95 percent availability. Advanced fuel cells are expected to equal or better this mark.
- *Power Quality*: Fuel cells provide high quality power with no spikes, surges, or electrical noise; hence, they are ideal for sensitive equipment.

Planned Products

Each of three advanced fuel cell developers is planning to develop a fuel cell system that is suitable for entry into the fuel cell power market. Unique systems, representative of each developer's market entry unit, will be built and verified by operation at field sites by utilities. In the molten carbonate fuel cell (MCFC) program, one manufacturer is developing a system for on-site cogeneration applications, and another company is developing a system for multi-megawatt distributed generation applications. The solid oxide fuel cell (SOFC) developer is focusing on a fuel cell with gas turbine combined cycle system for central power. Near-term planned products are listed below:

- Field test of 250 kW to 1 MW MCFC power plants fueled by natural gas (2000)
- Field test of a 1-2 MW SOFC-with-gas-turbine power plant fueled by natural gas (2000)
- Initial commercial production of two natural gas-fueled MCFC power plants (2002)
- Initial commercial production of a natural gas-fueled SOFC power plant (2002)

Strategy (FY 98 Funding: $40.2 Million)

The fuel cells program is included as part of DOE's overall Gas Research Program. Gas-fueled fuel cells will be developed before coal-fueled fuel cells, and gas-fueled fuel cells will most likely be placed into use years before a coal-fueled fuel cell system could be fully developed. Research conducted by the Fossil Energy fuel cells program is applicable to both coal and gas-fueled fuel cells; the fuel cell program is currently developing gas-fueled applications. Although advanced fuel cell systems achieved high efficiencies and ultra low emissions in development field testing with gaseous fuels, the systems must be further scaled up to commercial size power plants and demonstrated to have acceptable capital cost and long operating life.

The strategy of this program is to support development, integration, scaleup, and commercial scale demonstration of molten carbonate and solid oxide fuel cell power plants with private sector cost sharing. Cost-sharing in major activities ranged from 30 percent to slightly over 50 percent in recent years, depending on the nature of the activity. Product improvement and cost reduction activities in molten carbonate and solid oxide systems are under way and are expected to result in commercially ready power systems. New systems will be explored to take advantage of synergistic effects between major components in combined cycle systems.

Work is under way to characterize fuel cell and gas turbine combinations to realize major increases in system electric efficiencies. In addition, outreach to the private sector is facilitated by stimulating interactions among manufacturers, suppliers, and potential users. Activities will be continued for basic and applied research on materials, processes, and components applicable to fuel cell systems to achieve steady progress in improving these technologies. This effort provides supporting technology as well as evaluation of improvements.

The advanced research activity supports program objectives by studying critical enabling science and technology topics related to research on fuel cells, to better understand the basis of the underlying processes involved, and to explore novel concepts. Results of the investigations are used by those who develop, design, manufacture, and operate fuel cell systems including the MCFC and SOFC systems discussed above. Advanced research of superclean fuel cell power systems seeks to capitalize on their intrinsic high efficiency and environmentally benign characteristics, emphasizing research on electrochemistry, catalysis, interconnections, and materials interactions for molten carbonate, solid oxide, and advanced devices.

The DOE Fossil Energy program is coordinated with GRI and EPRI fuel cells programs through periodic meetings and informal communication. The GRI and EPRI programs emphasize application to gas and electric utility industries and provide synergistic support of the DOE program, which emphasizes development of critical technologies.

Recent Accomplishments

Phosphoric acid fuel cell systems have reached commercial status and market entry units are being manufactured for various applications. Production of more than one-hundred fifty 200-kW units has been accomplished. Reliable operation is under way at sites around the world.

Advanced molten carbonate and solid oxide integrated systems have been successfully operated at the 25-kW to 2-MW scale. A field test of a 250-kW molten carbonate system was conducted in San Diego, California (see Exhibit 8) and a 2-MW molten carbonate system has completed field testing in Santa Clara, California (see Exhibit 9). Twenty-five kilowatt solid oxide systems have been successfully tested (see Exhibit 10) and field testing of a 100-kW solid oxide fuel cell system is underway. Accomplishments expected in FY 1998 include:

MCFC – On-Site cogeneration Design:

- Test a 75-kW MCFC stack at San Diego Facility using commercial design repeat parts.
- Install modifications at the San Diego Facility to enable it to function as a Power Plant Verification Facility.
- Manufacture 250-kW MCFC stack using commercial design repeat and non-repeat parts for testing at the San Diego facility.

MCFC – Distributed Generation Design:

- Complete MCFC market entry design subscale stack test series.
- Execute the first MCFC market entry tall stack test.
- Determine MCFC market entry product size.
- Finalize market entry plant design.

SOFC – Fuel Cell/Gas Turbine Combined Cycle Design:

- Start site testing of 100-kW SOFC field unit.
- Start pressurized test of SOFC cell bundle.
- Complete manufacture of SOFC cells for 250-kW combined cycle unit.
- Qualify SOFC sintered fuel electrode process for low cost cell production.

For information on each major fuel cell project, see the fuel cell web site, at *www.fe.doe.gov/program.html*.

Program Funding

Program implementation is through the Federal Energy Technology Center (Morgantown, WV). Most of the activities are through cost-shared contracts with private industry interested in commercializing these power plants. Some supporting research is also performed by the National Laboratories and by universities. The table below shows appropriated and requested funding. DOE requested slightly lower funding for FY 98 in response to having to balance fiscal restraints with program needs.

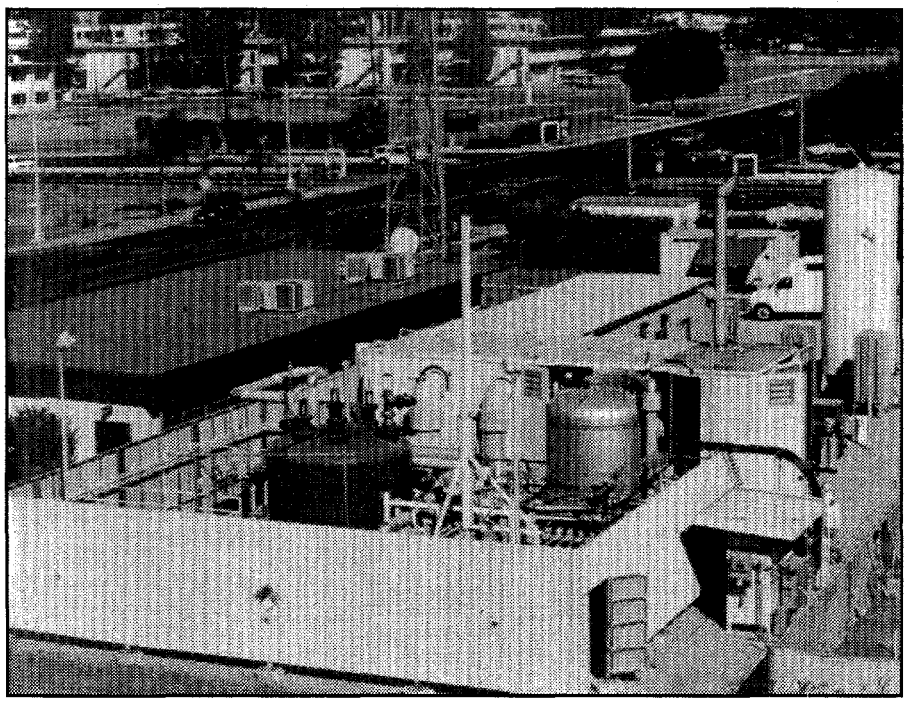


Exhibit 8 - Two Hundred Fifty Kilowatt MCFC Field Test at San Diego, California.

Exhibit 9 - Two Megawatt MCFC Field Test at Santa Clara, California

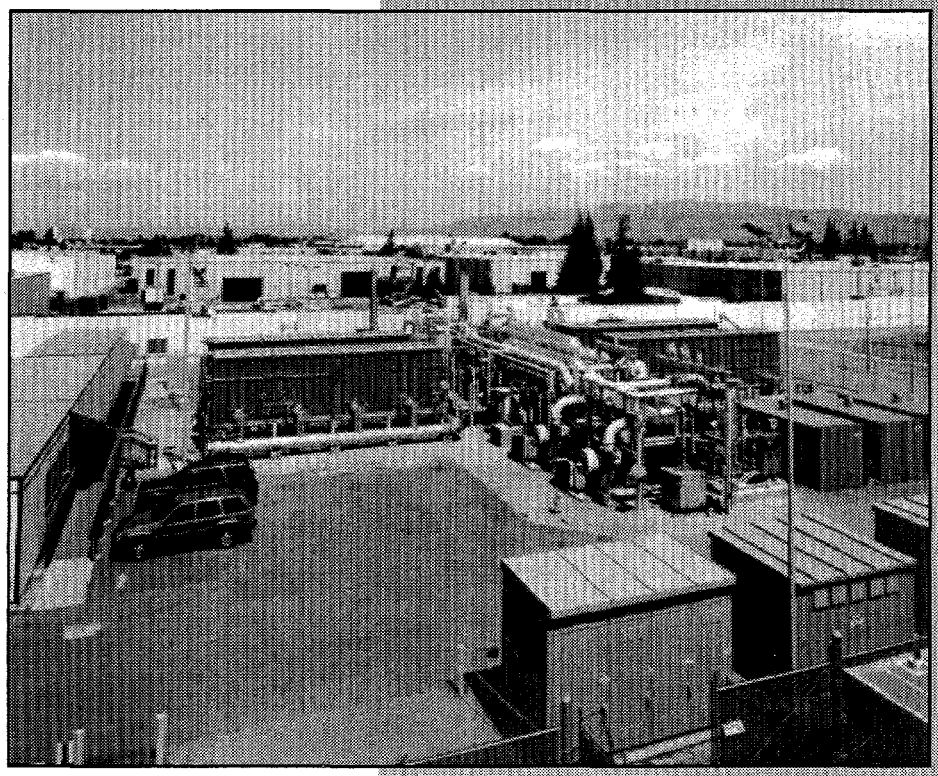
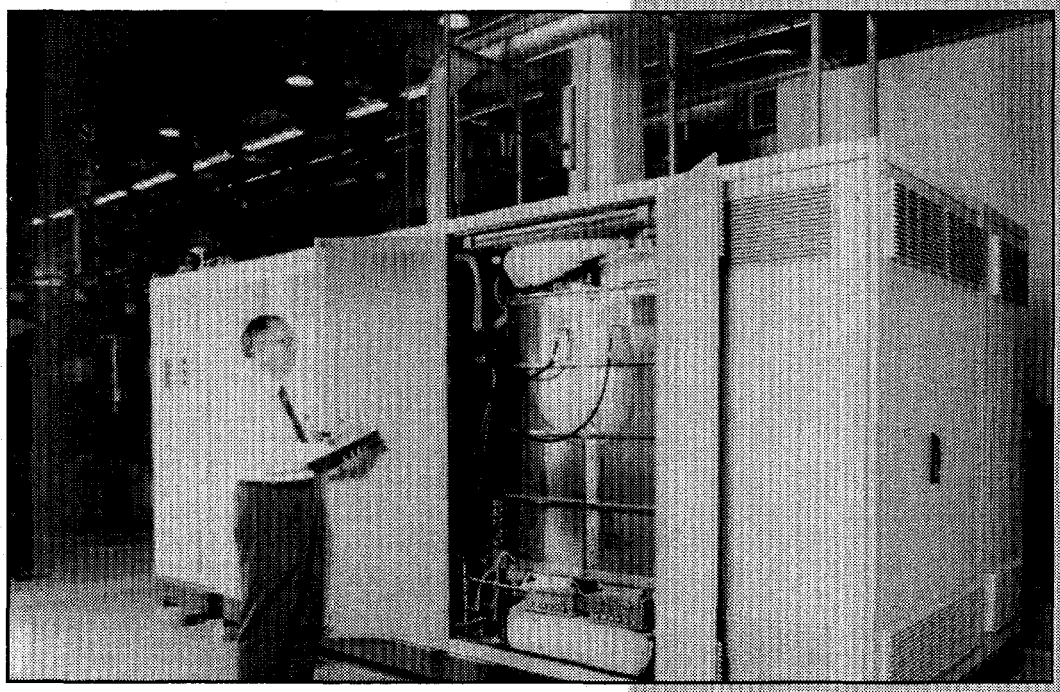


Exhibit 10 - Twenty-Five Kilowatt SOFC System.



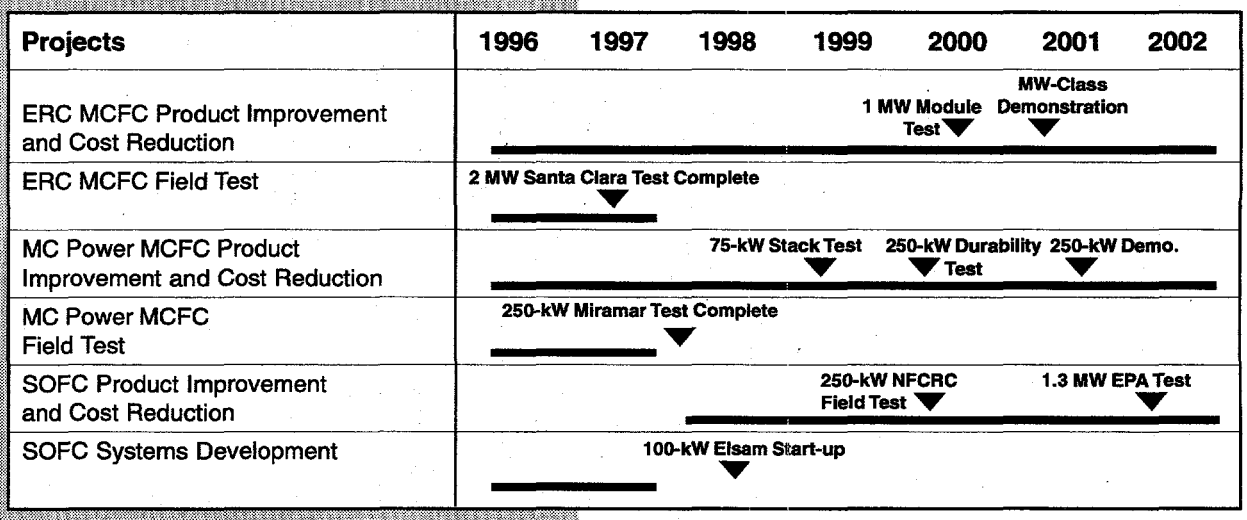
DOE Historical Spending ($ in millions)

Projects	FY 1996	FY 1997	FY 1998
Fuel Cell Systems Development	49.9	47.6	39.0
Advanced Research	1.3	1.2	1.2
Total	**51.2**	**48.8**	**40.2**

Cost Sharing (percent of project cost)

Projects	FY 1996	FY 1997	FY 1998 Estimate
Solid Oxide Fuel Cell	50	50	50
Molten Carbonate Fuel Cell	33	33	33

Schedule



3.3.2.2 Advanced Turbine Systems

Background

The Advanced Turbine System (ATS) Program was initiated in April 1993 to develop more efficient gas turbine systems for both utility and industrial electric power generation (including central station, distributed generation, and cogeneration). The program will provide base-load power systems for commercial at the offering at the beginning of the 2000s. Although the target fuel is natural gas, advanced turbine systems will be adaptable to coal and biomass firing. The ATS Program is marshalling resources of the Nation's gas turbine manufacturers, the electricity utility industry, and the university community, as well as government and private sector R&D sponsors and laboratories.

The ATS Program is the joint responsibility of the Department of Energy's Fossil Energy (FE) and Energy Efficiency and Renewable Energy (EE) offices. The Fossil Energy office has primary responsibility for the development and demonstration of utility systems, while EE has the lead role for industrial systems. There is also a very significant technology base element of the program. EE has the responsibility for material studies in the technology base area, and FE is responsible for managing an industry-driven consortium in which universities conduct generic research and development supporting the advanced turbine system development. The FE program will develop advanced turbine system technology for coal-based systems, while EE will assure that ATS technology is available for biomass systems.

This program consists of four elements:

Program Element I is Innovative Cycle Development. This element included two parts:

- Program Definition Planning Studies: In this phase (completed 1993) gas turbine manufacturers performed scoping studies to identify incentives and defined technical issues and resource requirements for developing natural gas-fired turbine systems.
- Contracts were awarded to gas turbine manufacturers to develop conceptual design of gas- fired advanced turbine systems that can be adopted for coal firing. This was completed in 1994.

Program Element II is Utility System Development. The three phases of this element are:

- Phase II - Component Design and Testing (completed in 1997).
- Phase III - Utility Full-Scale Component and Integrated Subsystem Testing (completed in 1998).
- Phase IIIR - Utility System Demonstration (to be completed in 2002).

Program Element III is Industrial System Development.

- The Office of Energy Efficiency and Renewable Energy is responsible for this element.

Program Element IV is Technology Base Development (to be completed in 2001)

- The aim of this element is to support advanced turbine systems development by conducting research and development on gas turbine issues, including materials evaluation, materials development, coating development, manufacturing process development, heat transfer model testing, component testing, computer code development, combustion testing, combustion testing, and field test data reduction. Research and development on specific proprietary hardware development (for example, high flow expanders) is not considered appropriate for the Technology Base

program element. Sub-elements of the Technology Base Development include, Industry/University Consortium, Materials/Manufacturing Technology, Federal Energy Technology Center In-house Studies and Coal Applications.

Major Goals

The goals of the ATS Program are:

- Ultra-high efficiency power generation systems firing natural gas. Industrial systems (those with a compressor inlet airflow less than 25 pounds per second) are expected to show a 15 percent increase in efficiency, compared to 1991 vintage systems. Utility systems (compressor inlet airflow 25 pounds per second and higher) are required to feature system efficiencies over 60 percent, on a lower heating value basis.
- Emissions of nitrogen oxides (NO_x) less than 10 parts per million at 15 percent oxygen.
- Busbar energy cost 10 percent less than today's advanced gas turbine systems.
- Adaptability to coal or biomass fuels
- Reliability equivalent to today's advanced systems.
- Availability for market in the year 2002.

Project Objectives

The Federal Energy Technology Center (Morgantown) implements the ATS Program through contracts and financial assistance to turbine manufacturers, universities, national labs, and utilities. The most important projects are listed below:

Westinghouse Electric and General Electric are designing the utility-scale system and Asea Brown Boveri is focused on continued turbine concept development activities. All three developers are also continuing tests to prove the required technology.

Ninety two universities, under the direction of the South Carolina Energy and Research Development Center (SCERDC), have been actively involved in applied research in ATS-related technology areas.

Oak Ridge National Laboratories (ORNL) directs subcontractors to develop and demonstrate ATS related manufacturing technologies. The Office of Fossil Energy is supporting the Materials and Manufacturing element of the ORNL activity and the Office of Energy Efficiency and Renewable Energy is supporting the Thermal Barrier Coating element.

The Federal Energy Technology Center (Morgantown) is conducting applied and fundamental research relative to gas turbine technology, as well as providing support cycle studies and proposal evaluations by modeling innovative power cycles.

Expected Benefits

Advanced gas turbines will provide the capability of generating electric power at efficiencies of over 60 percent and with NOx emissions of well below 9 ppm, allowing them to be sited even in environmentally restricted areas such as California. These public benefits would be derived with actually a reduction in the cost of electricity. Under the deregulated electric power market, the efficiency advantage of the ATS presents opportunities for the merchant plant to be a low cost electricity producer and therefore operate at a high dispatch factor. The fuel cost savings of an ATS compared to the next best technology can be over $2 Million per year. Power generation produces over 1/3 of all greenhouse gas emissions in the United States. Replacing old inefficient power plants with gas-fired ATS combined cycle plants can reduce greenhouse gas emissions by 60 percent. The successful development of ATS can provide the economic benefits of lower cost of electricity and improved return on investment of owners while benefiting our environment with reduced air emissions.

Successful development of these very advanced turbines will assure continuing U.S. leadership in this highly competitive global industry and assure the U.S. of maintaining a large fraction of the international turbine sales with commensurate support of U.S. jobs and a very favorable impact on U.S. balance of payments. The program also benefits hundreds of small companies and universities as subcontractors across the country. The major utility gas turbine developers rely upon and employ numerous small businesses to develop and test the ATS. For example, General Electric, one of the major manufacturers, has its primary facility for the manufacture and assembly of gas turbines in Greenville S.C. and Charlotte N.C., while a number of vendor facilities across the U.S. are utilized to fabricate advanced design components. Both GE and Westinghouse employ up to 35,000 total U.S. employees related to power generation technologies. The program generates U.S. jobs to maintain U.S. leadership in the world turbine industry. In addition to direct GE employment, indirect employment by suppliers of heavy industry parts to GE's turbine systems is estimated at between 3,000 to 3,700. More than 90 percent of the manufacturing value of GE gas turbines and generators are of U.S. origin. Westinghouse employes a comparable level of U.S. suppliers for their ATS system.

Under the technology base program, a profound impact has been made on the U.S. university engineering capabilities. Currently there are 92 universities participating in this program, each proposing and performing research which is of high quality and directly relevant to the ATS technology. The SCERDC program will not only develop improved university capability, but will support the maintenance of that capability for years to come as well as providing for sustained education in science and technology. FETC and National Laboratory scientists are partnering with industries and universities to overcome the critical technical barriers to achieve the ATS program goals. To achieve the aggressive objectives of the ATS program, technology advancements are needed in materials, cooling technology, aerodynamic performance and sealing, heat transfer, and combustion. All these technology advancements are being addressed in the technology base program. Technology already developed under the program is being incorporated into existing turbine products to reduce air emissions and fuel consumption in operating power plants.

Planned Products

FE's ATS Program will develop ultra-high efficiency, environmentally-superior, and cost-competitive gas turbine systems for base-load application in utility and independent power producer markets. These gas turbines will operate at higher turbine inlet temperatures than utility turbines of today. Pictures of the Westinghouse Electric Corporation and the General Electric Company Turbines are shown in Exhibits 11 and 12.

Strategy (FY 98 Funding: $79.6 Million)

The ATS Program is being completed under an extension of Phase III(R). This is based on the need to increase chances of market entry success, while balancing risk management with funding availability. Phase IIIR will develop and complete full-scale testing of two ATS products with EE and Westinghouse. These firms will arrange industry-funded pre-commercial demonstrations. This will enable DOE to retain an affordable turbine technology based program for application to Vision 21 coal-based systems, and permit the newly developed gas-based researchers to compete in near-term global markets.

Recent Accomplishments

- Granted awards to 9 universities on the fourth round of awards by South Carolina Energy Research and Development Center on ATS research topics including combustion, heat transfer, and thermal barrier coatings.

Exhibit 11 - General Electric Company Advanced Gas Turbine.

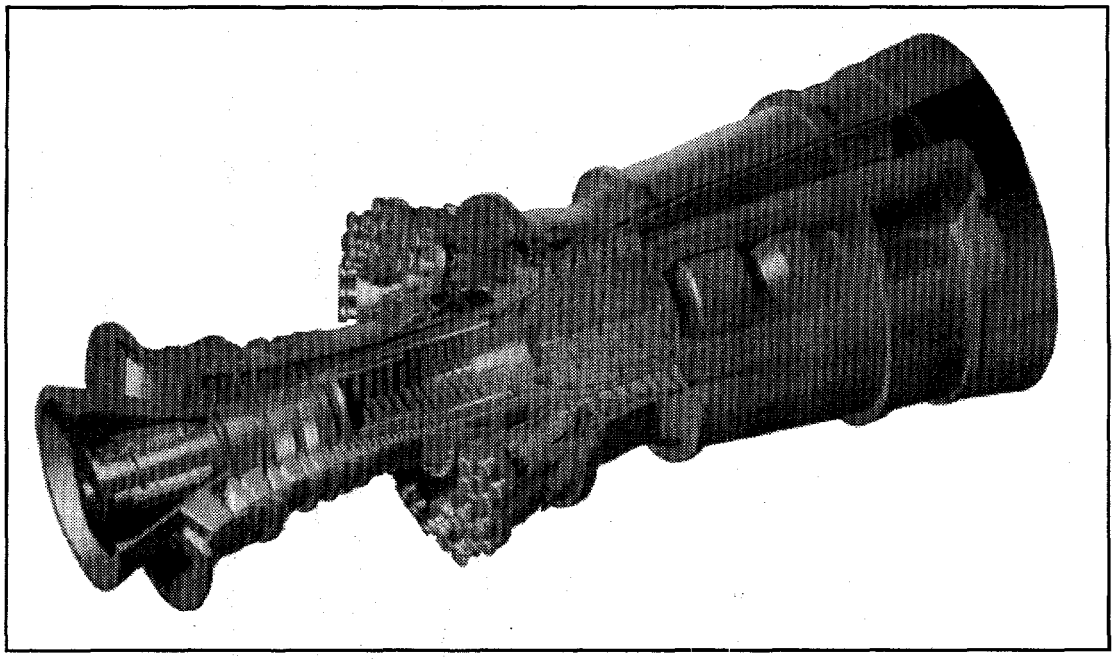
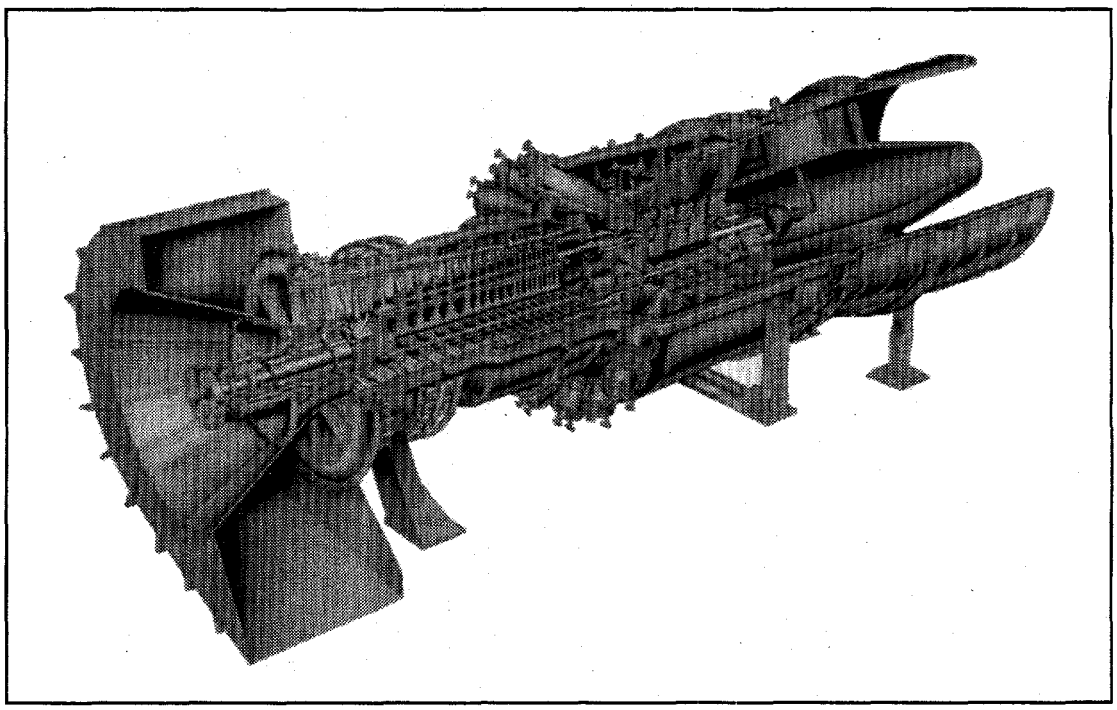


Exhibit 12 - Westinghouse Electric Corporation Advanced Gas Turbine.



- The Federal Energy Technology Center's (Morgantown) Process Engineering Division completed modeling of the cycles selected by the ATS contractors.
- Westinghouse Electric Corporation and General Electric Company completed component design and subscale testing.
- Westinghouse Electric Corporation and General Electric Company initiated cooperative agreement to conduct critical ATS full-scale component and subsystem testing.
- The General Electric Company tested a full-scale Rich-Quench Lean Combustor for coal applications at temperatures up to 2,300 °F. This combustor is designed to permit relatively low NO_x emissions with coal fuels.
- Westinghouse Electric Corporation completed testing of a catalytic combustor designed to produce ultra low NO_x emissions.

Cost Sharing

To ensure maximum efforts, the program will be accomplished by leveraging the funding and resources of all interested parties. Participants will be selected competitively. Overall program cost-sharing is approximately 34 percent.

Program Funding

DOE Historical Spending ($ in Millions)

The FY 99 budget request is based on budget constraints imposed upon all of the Fossil Energy programs.

Program	FY 1996	FY 1997	FY 1998	FY 1999 Request
Fossil Energy	35.97	46.60	45.00	43.00
Energy Efficiency and Renewable Energy	21.60	24.60	34.60	33.00
Total	**57.57**	**71.20**	**79.60**	**76.00**

Schedule

Projects	1996	1997	1998	1999	2000	2001	2002
General Electric Utility ATS (31176)				Complete FSNL Designs; Begin FSNL Testing		Complete FSNL Testing Final Report	
Westinghouse Utility ATS (32267)				Complete FSNL Designs	Complete FSNL Testing		Complete FSNL Testing
FETC In-House R&D	Begin high pressure/fuel flexibility studies and complete flashblock, instability, and humid air combustion studies					Transition into Vision 21	
Manufacturing and Materials (ORNL)	Complete Phase I Materials Development/initiate Phase 2				Complete Phase 2	Transition into Vision 21 Materials	
University/Industry Consortium (SCERDC)			New Awards	New Awards		Transition into Vision 21	

3.4 Industrial

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INDUSTRIAL

3.4.1 Technology Summary

Overview

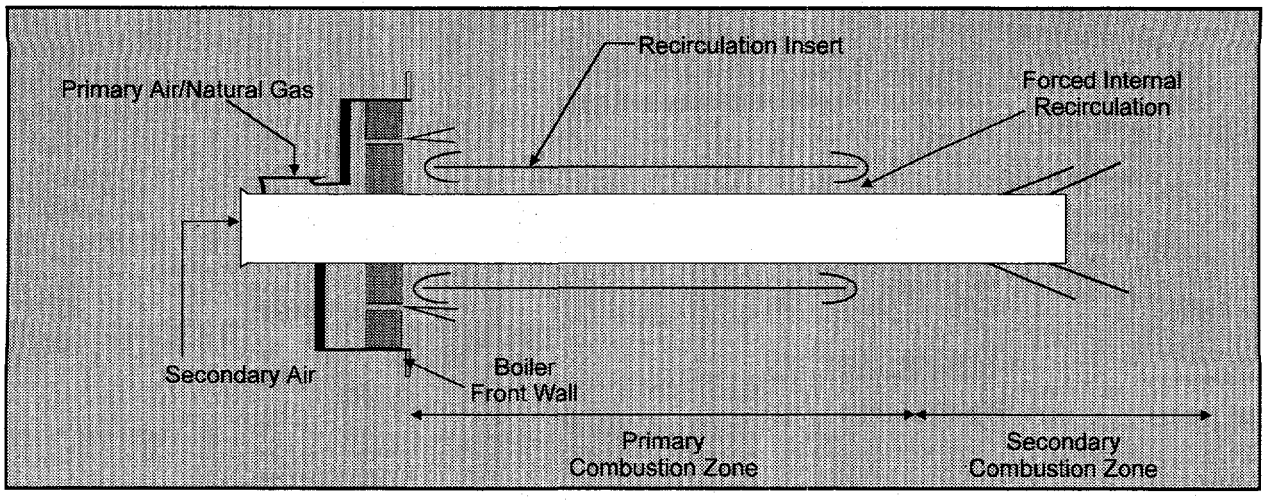
The industrial sector is an important market for the natural gas industry. Eight major gas consuming industries—iron and steel, chemicals, petroleum refining, food processing, textiles, pulp and paper, glass, and aluminum—account for 90 percent of industrial gas consumption. These eight industries represent a wide variety of products, processes, and uses of natural gas.

Natural gas consumption in the industrial sector has been increasing 6 to 7 percent annually since 1986, but slowed to a growth rate of 4 percent, yielding a total consumption of 7.5 trillion cubic feet (Tcf) in 1992. However, in 1993 total consumption reached 7.9 Tcf, an annual increase of 6 percent. Industrial sector consumption in 1993 represented 43 percent of the U.S. gas demand. Much of the increase during the previous six years can be attributed to natural gas consumption by nonutility generators (NUGs).

While natural gas consumption in industry has been increasing, consumption per customer has decreased steadily and dramatically for the past 20 years. Average consumption per industrial customer in 1993 was only 31 percent of the 1973 level. This illustrates the shifting industrial base and decreasing energy intensity of industrial processes.

Natural gas is used both as a raw material in the chemical industry and as a fuel in other industrial applications. Approximately 27 quadrillion Btu of energy were used in manufacturing in 1993, about 80 percent of the amount in all industrial Standard Industrial Classifications (SICs). Within manufacturing, energy use is concentrated in a relatively small number of SICs. Pulp and paper, metals, chemicals and petroleum refining, stone, clay and glass, and food processing account for over 90 percent of all the energy used in manufacturing.

Exhibit 13 - Forced Air Circulation Burner.



The manufacturing sector spent over $130 billion on energy in 1990, and $30 billion on treatment, storage, and disposal of waste. This represents about 6 percent of the value of all manufactured products sold. In the last 10 years, energy has become less important to U.S. industry investment decisions because natural gas, electricity, and imported oil have been readily available at attractive prices, and energy costs have been declining.

Manufacturing industries use the bulk of natural gas in the industrial sector primarily for process heating and steam generation (including cogeneration). Process heating uses of natural gas are extremely diverse, and include glass melting; heating and melting of metals; calcining and drying of minerals, foodstuffs and chemicals; liquid heating; and waste incineration and vitrification. Much of the boiler portion of the steam generation market and some process heat applications, such as fluid heaters in refineries, have dual-fuel capability and are extremely competitive fuel markets.

On the other hand, users prefer natural gas in many process heating applications because it burns cleaner and is easy to use. Investments in technology development are vital to make industry more cost-competitive.

Department-Wide Program

The Office of Energy Efficiency and Renewable Energy (EE) supports research, development, and demonstration (RD&D) efforts that can improve the Nation's energy future. In coordination with the Offices of Fossil Energy, Energy Research, and Policy, EE concentrates its efforts on improving energy efficiency and productivity in the industrial sector of the economy. In order to be certain that its programs continue to be responsive to the long-term needs of its customers, EE has launched the "Industries of the Future" initiative. This initiative strengthens collaboration between industry and government and promotes the leveraging of R&D resources. Industries of the Future is a process in which industry participants, facilitated by DOE, create a vision that reflects the diverse technological, economic, and environmental drivers that are shaping the future of their industries. The vision provides a framework for shaping major advancements in technologies according to their potential for improving industrial efficiency, energy and materials use, and environmental protection.

Industry "Visions of the Future" documents have been developed by the most energy intensive industries in the U.S. These include chemicals, steel, glass, aluminum, metal casting, and forest and paper industries. These industries account for over

90 percent of the energy used in the U.S. manufacturing sector. Each Vision document was developed by an industrial champion and subjected to peer review with others in the industry. These documents characterize the industry today, identify trends and drivers, and characterize the industry 25 years in the future. The Industries of the Future strategy will nurture a more holistic perspective through intra- and interagency alliances within government including the Department of Energy, the National Aeronautics and Space Administration (NASA), Department of Defense (DoD), Department of Commerce (DOC), and Department of Transportation (DOT), as well as State and local governments, and non-government organizations such as the Gas Research Institute (GRI) and the Energy Power Research Institute (EPRI).

Program Activity Summary

Industries of the Future (Energy Efficiency): An objective of this program is to support implementation of high-efficiency natural gas technologies, which provide cost-effective, energy-efficient, environmentally viable solutions for industry to meet new regulations and improve process efficiency. The program has initiated workshops and industrial interactions aimed at identifying research and development activities that will increase energy efficiency and economic competitiveness. Future efforts within Energy Efficiency for industrial utilization of natural gas will be directly related to the "Visions of the Future" strategy for energy-intensive industries. Specific activities are underway for natural gas technology application in aluminum, chemicals, agriculture, forest products, metal casting, glass, steel, and refining.

After each industry prepares its vision and signs the compact with DOE, plans are initiated to develop a technology roadmap that sets milestones for achieving the goals articulated in the strategic vision. The roadmap identifies current technologies and barriers, options and pathways. It lists technical requirements and targets, sets technology priorities, and establishes the research agenda.

The roadmap establishes industry's portfolio of near-, medium-, and long-term technology research, development, and deployment activities to address the challenges and opportunities identified in the strategic vision document.

Improved Combustion Efficiency (Energy Efficiency): The cost-effective minimization of combustion emissions while at least maintaining, if not increasing, the efficiency of combustion from gas-fired combustion systems is the overall goal of industrial combustion research. The program uses combustion fundamentals to address this goal and pursue new combustion concepts with favorable energy and environmental characteristics that can be developed into end-user equipment. Cost-effective minimization of NO_x emissions in the combustion process is the ultimate goal.

Hydrogen Research and Development (Energy Efficiency): Hydrogen is one of the most suitable energy sources for technological and environmental perspectives of the next century. Hydrogen provides a flexible way of storing and using electric energy, diversifies energy supply sources, and can reduce the effects of pollution linked to the use of fossil fuels. The program will develop the concept of absorbing carbon dioxide in the reaction zone of a steam methane reformer using adsorbent material. The objective is to develop high efficiency, lower temperature conversion processes for hydrogen using natural gas as the feedstock to accelerate interest in near- and mid-term energy applications for hydrogen.

Fundamental Chemical Research (Energy Research): The catalytic mechanisms for synthesis of higher molecular weight hydrocarbons and other organic compounds from methane as well as chemical processes on surfaces during combustion are not well understood. The program focuses on supporting fundamental, experimental, and theoretical research on the chemistry relating

to catalysis of methane, and the factors affecting combustion of methane in flames, industrial combustors, and internal combustion engines.

Advanced Turbine Systems (Fossil Energy, Energy Efficiency): The program goals are to design, develop, and demonstrate advanced turbine systems that will be ultra-high efficiency, environmentally superior, and will produce electricity costing 10 percent less at the busbar. Improvements in component materials and combustor, and turbine and system design will be integrated into systems utilizing compressor intercooling, high temperature, multi-stage gas turbines and high performance steam generators and turbines. While system design will differ between manufacturer and target application, the program will address aeroderivative and heavy-frame turbine designs. The efficiency goal for the utility class gas turbine is 60 percent for the industrial turbine; an improvement of 15 percent is sought over current models. Emissions of NO_x carbon monoxide (CO), and unburned hydrocarbons are to be reduced to less than 10 ppm.

Cogeneration (Energy Efficiency, Fossil Energy, Energy Research): Gas turbines are used internationally for electrical service, cogeneration, mechanical power drives, and offshore power generation. Nationally, there is about 65,000 megawatts of operating gas turbine capacity. The objective of this program is to insert ceramic components in critical locations of stationary gas turbines for cogeneration service, achieving considerable fuel savings and reduced emissions. Benefits of ceramic components include: more than 40 percent thermal efficiency; ultra-low NO_x potential with a ceramic combustor; engine cost reductions by replacement of cooled single crystal and directionally solidified parts with uncooled ceramics; and lower cost per installed kilowatt of capacity.

Continuous Fiber Ceramic Composites (Energy Efficiency): The objective of this program is to develop advanced structural materials with improved high-temperature, wear-resistant, and noncorroding characteristics that open up new opportunities because of their ability to perform in environments and under operating conditions that would destroy currently available metals and ceramics. Potential benefits include approximately 2.22 quadrillion Btu reduction in the annual national energy consumption, and 0.98 million tons/year of NO_x and 110 million tons/year of carbon dioxide (CO_2) emission reductions.

Advanced Industrial Materials (Energy Efficiency): Materials are necessary in every phase of manufacturing from raw materials through synthesis and processing, to industrial or commercial application, and ending as waste or recycled material for reuse. Advanced materials are not only critical for product development, but are also essential for improving manufacturing processes and reducing energy consumption. Industries engaged in fabrication and assembly of consumer products also will benefit significantly from using advanced materials to improve process efficiency and productivity through reduced life cycle energy use, higher processing temperatures, increased component and system lifetimes, and reduced downtime.

FY 1996-1998 Crosscut Budget Summary ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Continuous Fiber Ceramic Composites (CFCCs)	4.40	4.20	4.20
Aluminum Industry	0.00	0.827	0.961
Chemical Program	13.00	10.00	13.50
Industrial Cogeneration	21.00	25.00	35.00
Glass Combustors Industry	1.60	1.50	0.75
Advanced Combustion Systems	1.30	1.30	1.00
Fundamental Chemical Research Related to Natural Gas	4.80	4.30	4.30
Fundamental Engineering Research Related to Natural Gas	0.20	0.27	0.27
Advanced Industrial Materials Program	8.30	6.30	6.07
Total	**54.60**	**53.70**	**66.05**

Program Schedule

Projects	1997	1998	1999	2000	2001
Industries of the Future					
Hydrogen Research and Development					
Fundamental Chemical Research					
Cogeneration					
Advanced Turbine Systems					
CFCCs					
Advanced Materials					

3.4.2 Project Descriptions

3.4.2.1 Continuous Fiber Ceramic Composites

Background

The U.S. industrial sector has a critical need for materials that are light, strong, corrosion resistant, and capable of performing in high-temperature environments. Although many traditional ceramics perform well at high temperature, they typically fail in a catastrophic manner while in service. Continuous Fiber Ceramic Composites (CFCCs) are being developed to overcome this problem by incorporating continuous ceramic fiber into a ceramic matrix. This results in high strength, high temperature materials that exhibit a tough behavior.

Major Goals

The major goal of the Continuous Fiber Ceramic Composites program is to advance processing methods for reliable and cost-effective ceramic composite materials to a point at which industry will assume the full risk of development and commercialization. Continuous fiber ceramic composites are lighter, stronger, and more damage tolerant than other materials available for high temperature use. Industries that use CFCC components in their applications will realize substantial energy, economic, and environmental benefits, including lower maintenance, faster reaction rates, and decreased operating costs.

DuPont Lanxide Composites Inc., is constructing both silicon carbide CFCC components, using the chemical vapor infiltration process, and aluminum oxide CFCC components for incorporation into a variety of high-temperature, heat management and power generation equipment.

Project Objectives

The CFCC program is a collaborative effort between industry (Allied Signal Aerospace Team, ARC/American Team, Babcock and Wilcox Team, Dow Corning Team, DuPont Lanxide Team, General Electric Team, and Textron Specialty Metals Team), national laboratories, universities, and government to develop advanced composite materials for industrial applications. Participation by industry (which cost shares in this effort 24-35 percent) is vital and ensures the research agenda is based primarily on economic and performance criteria. Projects include:

- Chemical Vapor Infiltration
- Sol Gel Impregnation
- Polymer Impregnation and Pyrolysis
- Heat-Management Equipment
- Directed Metal Oxidation Process (DIMOX)
- Toughened Silcomp
- Gaseous Nitradation

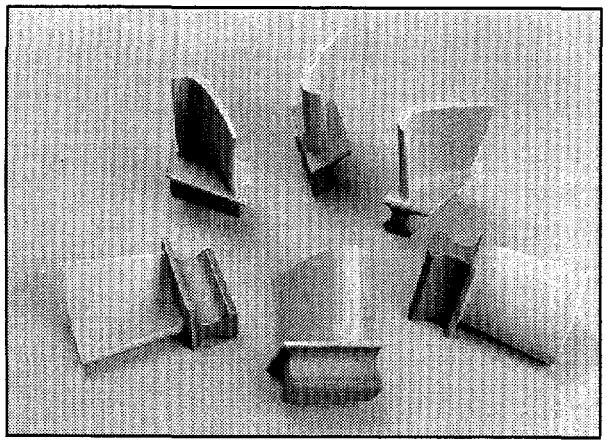


Exhibit 14 - Allied Signal AS800 Silicon Nitride Blades That Have Run 950 Hours in an Industrial Engine Test by Solar Turbines, Inc., ARCO Western Energy, Bakersfield, California.

Expected Benefits

By the year 2010, the CFCC program (as a whole) will provide the following annual benefits:

- 600 trillion Btu of energy savings.
- 980,000 tons of NO_x emissions avoided.
- 119 million tons of CO_2 emissions avoided.
- CFCC component sales of $850 million, adding over 8,000 industrial sector jobs.

Planned Products

- CFCC components for land-based gas turbines.
- CFCC pump components.
- CFCC applications for diesel engine valve guides.
- Hot gas filters.
- Ceramic composite radiant burner tubes.

Strategy (FY 97 Funding: $4.2 Million)

To continue to partner with Industry and material suppliers to develop industrial CFCC applications.

Recent Accomplishments

Porous radiant burners, in contrast to conventional flame-type industrial burner technology, transfer as much as 50 percent of their energy input directly to the process load in the form of infrared radiation.

Hot gas filters are used for high efficiency particulate and contaminant removal in the temperature range of 300°C to 1,000°C.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
CFCCs	4.40	4.20	4.20
Total	**4.40**	**4.20**	**4.20**

3.4.2.2 Aluminum Industry

Background

Aluminum is a light-weight, high-strength, corrosion-resistant, and readily recyclable material. It is an essential ingredient for making, maintaining, and improving products that modern society requires and developing nations demand. Aluminum is critical for many markets vital to the U.S. economy. Transportation, aerospace, defense, building and construction, food and beverage packaging, transmission of electricity, consumer durables, machinery and equipment all depend to a significant degree on a consistent supply of competitively priced, technically rich aluminum products.

The aluminum industry comprises three principal sectors. The *raw materials sector* produces alumina (the ore of aluminum) and primary and secondary molten metal and ingot. It is dominated by the Bayer (refining) and Hall-Heroult (smelting) processes. The *semifabricated sector* produces sheet, plate, foil, forgings, castings, wire, rod, bar, extrusions, elemental and alloyed powders, along with a wide variety of alumina-based chemical products. The third sector, *finished products,* uses products from the first two to manufacture a wide variety of consumer/ commercial products, varying from aircraft, automobiles, building curtain walls, windows and doors to fire retardants and packaging for food products.

Project Objectives

Although several of the key drivers may influence each of the three aluminum industry sectors, each possesses unique scientific and technical needs. For example:

- The *Raw Materials sector* is characterized by relatively established underlying processes. Research, development and engineering for this part of the industry is likely to focus on reducing costs via improved operating, energy and environmental efficiencies. Also, some challenging opportunities have been identified for breakthrough primary technologies to improve the century-old Bayer and Hall-Heroult processes.
- The *Semifabricated sector* will likely focus on lowering costs and improving performance, quality and environmental acceptability via the development and application of advanced manufacturing processes and technologies.
- In the *Finished Product sector,* the opportunity may hinge on increased integration of materials and on enhanced process, product design, and enabling technologies to create the products 21st century consumers will demand. A natural gas related effort in this area is the development of an Innovative vertical floatation melter and scrap dryer.

Major Goals

The Energy Research Company (ERCo), and a British company, Stein, Atkins, and Stordy (SAS), started development of a natural gas fired vertical floatation type melter which will increase melting energy efficiency.

Expected Benefits

An increase in melting energy efficiency by 40-80 percent and reduction in emissions of NO_x, SO_x, VOC, particulates, and organics existing in the aluminum scrap.

Planned Products

- Technology Roadmap: The Technology Roadmap identifies performance targets prioritized R&D needs, and timetables segmented by raw materials, semi-fabricated products, and finished products.
- By 2002, a U.S. processing plant owned by IMCO, Recycling Inc., will commercialize the melter in the U.S., while SAS will commercialize the melter in England.

- Air Products and Chemicals, Inc., along with Argonne National Laboratory, Roth Brothers, and Brigham Young University, will develop and demonstrate a novel, high-efficiency, high-capacity, low-NO_x combustion system integrated with an innovative low-cost, on-site vacuum-swing-absorption (VSA) oxygen generation. This integrated burner/oxygen supply system will offer enhanced productivity, high energy efficiency, low operating costs, and low NO_x emissions.

Strategy (FY 97 Funding: $0.827 Million)

To continue to work with industry in defining needs via a technology roadmap and invest in R&D to make their vision a reality.

Recent Accomplishments

SAS provided ERCo with results of their single particles study, using various particles representing aluminum scrap, enabling ERCo to design and probe the operation of the melter. By 1999, these two developers will have completed the design, fabrication, and testing of a pilot scale melter using scrap aluminum and possibly feedstocks from other candidate industries.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Aluminum Industry	0.000	0.827	0.961
Total	**0.000**	**0.827**	**0.961**

3.4.2.3 Chemical Program

Background

The chemical vision focuses on four areas, each of which is developing a technology roadmap. The chemical industry is more diverse than virtually any other U.S. industry. Chemicals are the building blocks of products that meet our most fundamental needs for food, shelter, and health, as well as products vital to the high technology world of computing, telecommunications, and biotechnology. Chemicals are a keystone of U.S. manufacturing and are essential to a large range of industries such as pharmaceuticals, automobiles, textiles, furniture, paint, paper, electronics, agriculture, construction, appliances, and services.

More than 70,000 different products are registered. More than 9,000 corporations develop, manufacture, and market products and processes in the following categories designated as the Standard Industrial Classification 28:

- Industrial inorganic chemical
- Plastics, materials, and synthetics
- Drugs
- Soap, cleaners, and toilet goods
- Industrial organic chemicals
- Agricultural chemicals
- Miscellaneous chemical products

Project Objectives

Natural gas related projects include:

- Advanced membrane devices.
- Polymers for membrane separation in the chemical industry.
- Catalytic membrane for the production of chemicals from natural gas and petroleum.
- Hollow fiber membrane based on encapsulation of novel chemical absorbents for ammonia and acid gases.
- New chemical science and engineering technology.
- Supply chain management.
- Information systems.
- Manufacturing and operations.

Major Goals

- Improve operations, with a focus on better management of the supply chain.
- Improve efficiency in the use of raw materials, the reuse of recycled materials, and the generation and use of energy.
- Continue to play a leadership role in balancing environmental and economic considerations.
- Aggressively commit to longer term investment in R&D.
- Balance investments in technology by leveraging the capabilities of government, academia, and the chemical industry as a whole through targeted collaborative efforts in R&D.

Expected Benefits

Benefits are based upon the portfolio of 21 chemical industry/Office of Industrial Technologies (EE) cost shared projects, based upon the Quality Metrics for the year 2010.

- Energy saved 0.4×10^{15} Btu's or $1.48 billion.
- Carbon reduction of 0.4 million tons.

Planned Products

- Include new recycling processes for plastics.
- New bioprocesses for the production of polymers.
- New membranes.
- New catalysis.

Strategy (FY 97 Funding $10.0 Million)

To continue to work with industry to develop a technology roadmap.

Recent Accomplishments

The Chemical Industry Team (CIT) has accomplished much over the past year in addition to supporting the chemical industry's visioning process. *CIT Highlights for 1996* include continuing to help industry articulate its strategic vision in technology "roadmaps." These roadmaps will identify technical pathways from current technologies to advanced technologies needed to achieve the vision; and will serve as the basis for setting priorities and establishing the industry's research agenda. The CIT has also been busy establishing and maintaining numerous R&D partnerships with companies, universities, and other organizations located across the country. This year the CIT projects involved almost 100 working partnerships in over 30 states.

In addition, over the past several years CIT-supported projects have resulted in a number of commercialized technologies. In 1996, the CIT saw completion and commercialization of the "Scrap Tire Recycling" project. This effort developed a new surface treatment for finely ground tire rubber that can be used to manufacture high value composites which, in turn, replace petroleum-derived polymers. This newly treated material greatly increases wheel traction on wet surfaces and will put some of the 70 million scrap tires sent to stockpiles each year to good use.

Schedule

- Chemical Industry solicitation, Summer 1997.
- Roadmap completed, Computational Fluid Dynamics, Fall 1997.
- Roadmap completed, Catalysis, Fall 1997.
- Roadmap workshop, Separations, First Quarter 1998.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Chemical Program	13.0	10.0	13.5
Total	**13.0**	**10.0**	**13.5**

3.4.2.4 Industrial Cogeneration

Background

Gas turbines are used internationally for electrical service, cogeneration, mechanical power drives, and offshore power generation. Nationally, there are about 65,000 MW of operating gas turbine capacity. Upgrading this capacity through routine overhaul of existing equipment or use of ceramics in new gas turbines will have a significant impact on the fuel burned and emissions generated. Efforts include development of an advanced industrial gas turbine, retrofit of ceramic components in an industrial turbine, and advanced materials and manufacturing.

Project Objectives

To complete development and demonstration of ultra-high efficiency natural gas turbine systems for commercial offering to electric utilities, independent power producers, and industries by 2000.

Major Goals

- Boost system efficiency to 60 percent (LHV) or above for utility combined cycle systems and 15 percent over existing industrial systems.
- Reduce cost of electricity by 10 percent compared to conventional systems.
- Lower nitrogen oxide emissions to 8 parts per million (ppm), and less than 20 ppm carbon monoxide without the use of post-combustion emission controls.
- Offer reliability-availability-maintainability (RAM) that equals or exceeds current turbine systems.

Expected Benefits

The partnership of industry, government and universities created by the ATS program provides a blend of technical know-how, market understanding, research capabilities, and financial resources required to make revolutionary advances in gas turbine technology. These advances will yield significant benefits to the nation, including:

- Cleaner air emissions.
- Reduction of 52 tons/year of greenhouse gases.
- Lower carbon monoxide and unburned hydrocarbon emissions per MW.
- Reduced fuel consumption.
- Higher efficiencies will save an estimated 1 Tcf of natural gas annually, providing a lower cost of electricity. A single percentage point increase in fuel efficiency can reduce lifecycle operating costs of a typical 400-500 MW combined cycle plant by $15 to $20 million, lowering the cost of electricity by as much as 10 percent.
- The worldwide market for industrial gas turbine systems (3 to 20-MW) has doubled since 1985. Market growth of this rate is expected to continue at least through 2010.
- Rising demand for electricity both here and around the world places gas turbines in a crucial position. Expectations are that a large portion of new electric and cogenerating capacity additions will be gas turbines. The domestic market potential for advanced gas turbine systems could be as high as $5 billion/year after 2000 and the total world market could reach $1 trillion annually by 2010.

Planned Products

- Development of a new generation of gas turbines for cogeneration, utility, mechanical drive, and small power production applications (2001) (joint program with Fossil Energy).
- Ceramics for stationary gas turbines.
- Advance materials thermal barrier coatings.

Strategy (FY 97 Funding: $25 Million)

The program consists of three phases and features industry led development teams, including ceramic component manufacturers, end-users of gas turbines, and university and National Laboratory support activity.

Recent Accomplishments

Phase II has been completed. Allison Engine Company, Solar Turbines, Westinghouse and General Electric have been selected to develop prototype engines for testing during Phase III.

Solar Turbines with Allied Signal, and Dupont Lanxide has completed 744 hours of a 2,000-hour test of ceramic components in an industrial gas turbine [1850 ºF Turbine Rotor Inlet Temperature (TRIT)] at full load at Solar Turbines California facility. To date, this has been the longest test of ceramic components in an industrial gas turbine. Parts tested included a CFCC combustor liner and silicon nitride blades. Unoptimized NO_x levels were typically around 15 ppm and CO less than 5 ppm. A 4,000-hour test at 2,050 ºF TRIT is scheduled for the Fall of 1997.

Program Funding

DOE Historical Spending ($ in Millions)

Cost share is approximately 45 percent averaged over the life of the program.

Projects	FY 1996	FY 1997	FY 1998
	21.0	25.0	35.0
Total	**21.0**	**25.0**	**35.0**

Schedule

Projects	1997	1998	1999	2000	2001	2002
ATS						
Ceramic						
Materials						

3.4.2.5 Glass Combustion Industry

Background

The U.S. glass industry is an important component of the U.S. economy. It employs more than 150,000 workers in skilled jobs, and generates 21 million tons of consumer products each year with an estimated value of nearly $24 billion. This industry is broken into four distinct segments: flat, container, fiber, and specialty. The glass industry includes both major corporations and small family businesses that are spread out across the Nation, with a strong presence in California, Illinois, New York, West Virginia, Pennsylvania, and Ohio.

The glass industry vision identified four areas for technology development: production efficiency, energy efficiency, environmental protection and recycling, and innovative uses. The glass industry has set up a committee structure for implementing the vision, with subcommittees for each of the four areas.

The efforts specifically addressing natural gas utilization are:

- High heat transfer natural gas combustion system
- Oxygen-enriched air-staging (OEAS) technology for glass furnace combustion space models
- An integrated batch and cullet preheater system

Project Objectives

High Luminosity Low-NO_x Burner: The Institute of Gas Technology is developing a high-luminosity low-NO_x burner that internally modifies the fuel prior to combustion, as well a controls fuel/air mixing to substantially increase the formation of soot within the flame. This process enhances the luminosity of the flame, thereby increasing heat transfer rates and decreasing flame temperature. Consequently, the furnace production rate and thermal efficiency are increased and NO_x formation is reduced.

OEAS Technology for Sideport Furnaces: Oxygen and air-staged combustion are two methods that the industry typically uses to reduce NO_x. While oxygen use eliminates nitrogen which can form NO_x, it is costly and can increase energy consumption. The air staging method costs less, but is less effective.

The Institute of Gas Technology has developed OEAS technology, an advanced combustion modification technique which combines the two methods to control NO_x formation. By reducing the oxygen available in the flame's high-temperature zone and improving flame temperature uniformity, NO_x formation is controlled and heat transfer to the glass is improved, without interrupting furnace operation or adversely affecting product quality. By injecting oxygen near the exit port, complete combustion and heat release within the furnace are assured.

The OEAS technology has been successfully retrofitted to several endport furnaces in the U.S. and has achieved NO_x levels below 2 lbs. per ton (50-70 percent reduction). Efforts have now been initiated to apply the OEAS technology to sideport glass melting furnaces, which are used for 65 percent of U.S. glass production. The OEAS technology is being demonstrated on a six-port pair sideport furnace at Owens-Brockway's Vernon facility.

Integrated Batch and Cullet Preheater System: Corning will demonstrate and test the technical viability, system reliability, and economic benefits of batch and cullet preheating oxy-fuel combustion furnaces. An advanced raining bed technology developed by Tecogen/Thermo Power Corporation will be tested to preheat batch and cullet and to recycle condensables and particulate matter in the exhaust stream.

Two commercial demonstrations will be performed — one in a 5 tons-per-day specialty glass furnace and another in a 175 tons-per-day soda lime furnace producing consumer ware. In addition, conceptual designs will be prepared for batch and cullet preheat systems

in fiberglass, container glass, and flat glass furnaces.

Major Goals

- Production costs at least 20 percent below 1995 levels.
- Process energy use reduced from present levels by 50 percent towards theoretical energy use limits.
- Recycle 100 percent of all glass products.
- Recover 100 percent of reasonably available consumer glass.
- Reduce air/water emissions by a minimum of 20 percent.

Expected Benefits

High Luminosity Low-NO_x Burners: These burners offer many benefits to the glass industry:

- Reduced Emissions — Even when utilizing lower-cost industrial oxygen, NO_x emissions could be reduced up to 90 percent.
- Reduced Costs — The burner provides cost-effective compliance with emissions regulations. Additionally, existing furnaces can be retrofitted without major modifications.
- Increased Efficiency and Productivity — While improving furnace control, production rate and system thermal efficiency could be increased up to 20 percent.
- Reduced Space Requirements — The technology provides a compact furnace system for glass melters, and smaller flue gas cleaning equipment.

The high-luminosity low-NO_x oxygen/natural gas burner technology will be applicable to high temperature heating and melting systems in energy-intensive industries including glass, iron and steel, non-ferrous metals, and cement.

OEAS Technology: Oxygen-Enriched Air Staging technology for sideport furnaces offers the glass industry important advantages in the face of increasingly restrictive regional emissions regulations. Currently, regenerative glass melters use very high air-preheat temperatures, which result in extremely high NO_x levels. While there are no federal regulations on NO_x at this time, these melters are increasingly being placed under strict regional regulations. To enable glass producers to meet these regulations, the OEAS project is working to reduce the NO_x emissions from regenerative sideport glass melting furnaces from 10 lbs. per ton of glass produced to below 3 lbs. per ton. Without such a cost-effective solution, companies may be forced to shut down additional facilities.

The OEAS technology will benefit the glass industry by achieving:

- Reduced Waste — Total waste production is expected to be reduced by 10 thousand tons per year, a 31 percent reduction.
- Energy Savings — IGT estimates saving 28 percent of the energy used in conventional technology, representing 150 million Btus per year.
- Reduced Emissions — NO_x levels will be reduced by 50-70 percent, thereby enabling glass producers to meet the most stringent environmental regulations through the year 2000.
- Reduced Costs — This is a highly cost effective means of meeting emission regulations without increasing fuel consumption. Capital and operating cost are moderate compared to competitive technologies. Additionally, the technology will reduce oxygen production costs.

The OEAS technology has applications for regenerative glass melting furnaces in the container and float glass industries, as well as for other high-temperature processes such as metal melting.

Integrated Batch and Cullet Preheater: The Corning integrated batch and cullet preheat system can help the glass industry maintain the lowest possible production costs while achieving stringent emission standards. This system offers both of these benefits and more:

- Energy Savings — Since the batch and cullet is partially heated when introduced to the furnace, less energy must be added. Analysis reveals an estimated 15 percent increase in energy savings (natural gas), a total of 3 billion Btu, per year.
- Reduced Waste — Combustion-related waste will be reduced by an estimated 17,500 tons per year. Through increased unit life, the annual non-hazardous waste from spent refractories will also be reduced.
- Reduced Emissions — Lower product costs through lower energy costs will increase market share and job demand. Additionally, existing furnaces are easily retrofitted.
- Increased Efficiency — This unit contains no inventory of batch material within the heat exchanger. Material falls freely through the system, eliminating the possibility of plugging.

Batch and cullet preheating (Exhibit 15) can be applied to furnaces in all four glass market sectors: float, container, fiber, and specialty. Corning Engineering, which is responsible for internal and external implementation, will introduce the preheater technology to U.S. manufacturers once it is demonstrated. Initially, Corning will apply the technology to oxy-fuel installations. As the technology is proven and process benefits quantified, it may be applied to conventional air-fuel furnaces.

Strategy (FY 97 Funding: $1.5 Million)

Continue to work with industry on R&D needs to realize their vision.

Recent Accomplishments

Glass roadmapping workshop report.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Glass Combustion Industry	0.161	1.500	0.750
Total	**0.161**	**1.500**	**0.750**

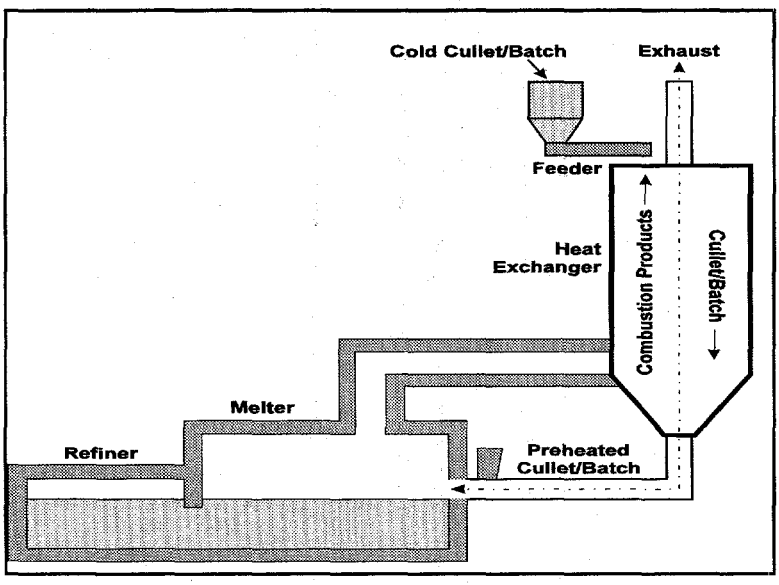


Exhibit 15 - Integrated Batch and Cullet Preheater.

3.4.2.6 Advanced Combustion Systems

Background

The cost-effective minimization of combustion emissions, while at least maintaining, if not increasing, the efficiency of combustion from gas-fired combustion systems, is the overall goal of industrial combustion research. The program uses combustion fundamentals to address this goal and to pursue new combustion concepts with favorable energy and environmental characteristics that can be developed into end-user equipment.

Project Objectives

Develop a new generation of burners capable of realizing single-digit NO_x emissions without post-combustion control, while keeping all emissions low. The efficiency will be equal to or better than today's best. The natural gas related projects include:

- Radiation stabilized burner.
- Vortex inertial staged air (VISTA) burner development for very low NO_x emissions in furnaces and boilers.
- Forced internal recirculation burner.
- Dilution of oxygen combustion.

Major Goals

Each of the four projects is using one or more approaches to realize the single-digit NO_x target. In general, they are:

- Demonstrating the selected approaches using laboratory scale facilities,
- Scaling-up to pilot size, and for some projects using actual operating industrial boilers and furnaces, and
- Demonstrating or operating industrial systems.

Expected Benefits

The combustion systems being developed are expected to reduce NO_x emissions by over 110,000 tons/year and capital costs by nearly $3 billion relative to meeting the same emissions targets using post-combustion systems.

Consequently, greenhouse gases will be reduced. For example, up to 8 percent less CO_2 will be produced due to increased efficiency, and because there is no need for an ammonia based add-on NO_x control system, there will be no N_2O emissions.

Planned Products

New low-emission burners will be developed for specific boiler or furnace markets serving the refining, chemical, steel, aluminum and other industries.

Strategy (FY 97 Funding: $1.3 Million)

The strategy includes: (1) utilizing recently identified high heat burner materials that can survive the high temperature industrial process environment, and increase overall process efficiency while significantly reducing emissions; and (2) retrofitting this new burner type to current generation industrial heaters and conduct a demonstration to show industry the value of this concept.

Recent Accomplishments

- Achieved 4,000 hours with half-scale burners (over five months) at steam reformers temperature without significant degradation.
- Completed design of burner controls.
- 6 ppm NO_x realized in developmental test on working boiler.
- Obtained approval of design, field test plan, safety plan, and all requirements for installation of burners in host site (Air Products) reformers.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Advanced Combustion	1.30	1.30	1.00
Total	**1.30**	**1.30**	**1.00**

Schedule

- Complete developmental test: December 1997.
- Start host site demonstration: April 1998.
- Complete host site demonstration: September 1998.

3.4.2.7 Fundamental Chemical Research Related to Natural Gas

Background

The catalytic mechanism for synthesis of higher molecular weight hydrocarbons and other organic compounds from methane are not sufficiently understood for optimal use of methane as a resource for liquid hydrocarbon fuels and chemical feedstocks. More detailed information is required on methane dissociation, partial oxidation, and molecular fragment recombination reactions to effectively utilize catalytic processes.

Chemical processes on surfaces during combustion are poorly understood and rarely investigated. Semi-empirical theories are needed to represent complex combustion reaction mechanisms by simplified, but fundamentally correct, representative metareactions. Such chemical theories will be incorporated into fluid dynamic models of combustion.

Project Objectives

To conduct fundamental investigations relating to catalysis of methane, partial oxidation, and factors affecting combustion of methane in flames, industrial combustors, and internal combustion engines.

Major Goals

- Characterize activation of carbon-hydrogen bonds by metals and metal complexes as a function of their electronic properties and structure.
- Characterize reactive pathways of radical intermediates in oxidation and coupling reactions and develop predictive theories for enabling the suppression of radical intermediates in partial oxidation of methane for portable transportation fuels and as a feedstock for Fischer-Tropsch synthesis.
- Develop semi-empirical theories for representation of complex reaction mechanisms by prototypical metareactions, and for temperature and pressure dependence of their rates.
- Develop general theories, principles, and methods of measurement for characterizing the reactions of prototypical combustion species at surfaces, temperatures, and pressures characteristic of combustion systems.

Expected Benefits

- Allows chemistry to be more readily incorporated into turbulence and mixing models through the use of semi-empirical theories for simpler and more reliable description of combustion and complex chemical processes.
- Allows design decisions on combustion devices for minimizing emissions of unwanted byproducts and maximizing combustion efficiency by characterizing surface combustion processes.
- Allows more efficient discovery of new catalytic systems for more optimal use of natural gas resources through theories for C-H activation and molecular fragment recombination at surfaces.

Planned Products

Development of critical data, descriptive and predictive theories, and measurement methods for fundamental processes in catalysis and combustion. These will be conveyed to DOE technology programs through jointly sponsored workshops, contractor meetings, personnel exchanges, and reports, and to the broad technical community through publication in the archival, peer-reviewed literature.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Fundamental Chemical Research	4.8	4.3	4.3
Total	**4.8**	**4.3**	**4.3**

Strategy (FY 97 Funding: $4.3 Million)

The program strategy will focus on supporting fundamental, experimental, and theoretical research at universities and National Laboratories. In general, proposals are unsolicited and are prepared by individual investigators. A major effort on fundamental combustion science is underway at the combustion research facilities at the Sandia and Livermore National Laboratories.

3.4.2.8 Fundamental Engineering Research Related to Natural Gas

Background

To conduct fundamental studies on transportation and other processes involving natural gas, which may lead to improved design methodologies.

Project Objectives

Improved analysis of flows in pipelines and heat exchangers with high heat fluxes.

Major Goals

This research is a facet of a broad-based engineering research program emphasizing heat and fluid transport, process diagnostics and control, and engineering analysis. Specific goals are:

- Determine dryout limits for heat exchanges applicable to power plants using heated tubes with natural gas as the heat source; and
- Improve modeling of pipeline flows of gases and liquids.

Expected Benefits

- Improves models of chemical, mass, and heat transfer processes suitable for systems applications, testing, and evaluation.
- Develops capabilities for enhanced design and operation of pipelines and power plants utilizing natural gas.

Planned Products

- Publication of scientific and technical reports in the professional literature.
- Development of patents.
- Completion of new technology transfer to the private sector.

Strategy (FY 97 Funding: $0.270 Million)

The program strategy is to conduct studies combining computational modeling with experiments designed to test and refine modeling methodologies. Specific research topics include Gas-Liquid Flows in Pipelines, and Dryout in Horizontal and Almost Horizontal Heated Tubes.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Gas-Liquid Flows in Pipelines	0.100	0.120	0.120
Dryout in Horizontal/ Heated Tubes	0.100	0.150	0.150
Total	**0.200**	**0.270**	**0.270**

3.4.2.9 Advanced Industrial Materials Program

Background

The program goal is to support development and commercialization of materials to improve productivity, product quality, and energy efficiency in major process industries.

Project Objectives

The advanced industrial materials program investigators in the DOE National Laboratories are working closely with approximately 100 companies, including 15 partners in CRADAs. Research and development is being performed in a wide variety of materials technologies, including intermetallic and metallic alloys, ceramic composites, metal composites and polymers.

The program supports the Industries of the Future effort of Office of Industrial Technologies (OIT) including the major energy consuming process industries-aluminum, chemicals, forest products, glass, metalcasting, refineries, and steel. Recently, the Advanced Industrial Materials program began working with carbon products forging, heat treating, and welding cross-cutting industries. Each of these industries has decided to develop a vision, roadmap and implementation plan, and OIT is working on ways to integrate these industries into the "Industries of the Future."

Major Goals

- To expand the applicability of this technology, better characterize the process and facilitate further industrial applications of the technology.
- To determine causes of failure of composite tubes in Kraft recovery boilers and to develop new materials to eliminate failures. This work addresses a critical technical problem for reasons of productivity, energy efficiency and worker safety.
- To further develop and commercialize the use of nickel aluminide in furnace furniture and thereby provide advantages of increased furnace furniture life and higher permitted operating temperatures.
- To develop centrifugally cast nickel aluminide for transfer rolls in steel reheat furnaces. This is another application in which the excellent high-temperature properties of the nickel aluminide material family offer advantages.
- To enable boiler operators to mitigate damage to their systems and to estimate the extent of damage associated with a given set of operating conditions.

Expected Benefits

- In the first year, a set of experiments will be performed to characterize variability in material/process interactions and their role in process control.
- Efforts will focus on corrosion and residual stress determination of the behavior of various materials for applications in digestors and boiler components, including composite tubes and splash plates of black liquor injector nozzles.
- Nickel Aluminide castings for heat treating trays will be prepared and evaluated under a CRADA with GM Saginaw.
- A subcontract will be issued to Stanford Research Institute for development of flexible mullite coatings for application on metal, ceramic, glass, or polymer substrates.

Planned Products

Assessments of materials needs and opportunities in the process industries are being made to improve the relevance of materials research. The assessments are being used for program planning and setting of priorities; this is being followed by support work to satisfy those needs.

Strategy (FY 97 Funding $6.3 Million)

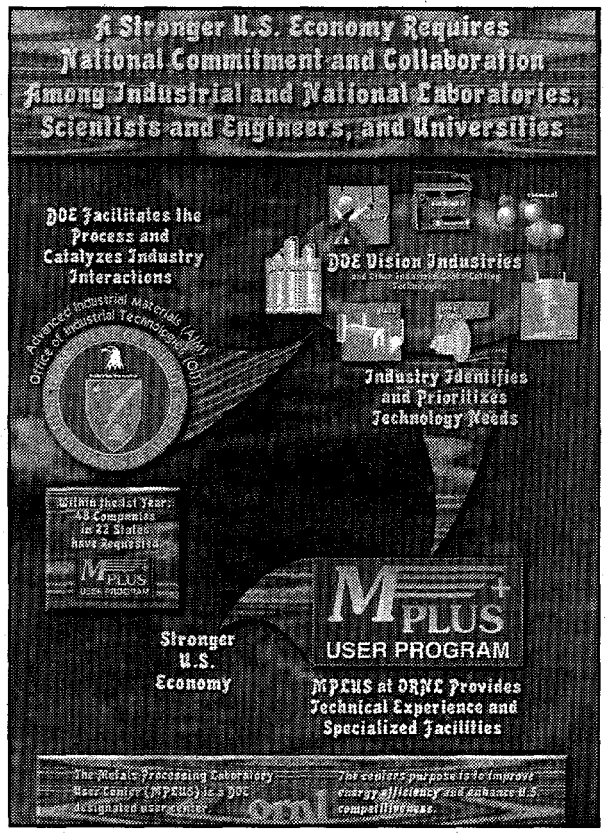
Continue to work with Industry on R&D needs to realize the vision.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Advanced Industrial Materials Program	8.30	6.30	6.07
Total	**8.30**	**6.30**	**6.07**

MPLUS User Program Pamphlet



Metals Processing Users (MPLUS) Center is Located at DOE's Oak Ridge National Laboratory

3.5 Residential and Commercial

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RESIDENTIAL AND COMMERCIAL

3.5.1 TECHNOLOGY SUMMARY

OVERVIEW

DOE's Residential and Commercial program, within the Office of Energy Efficiency and Renewable Energy, undertakes activities to develop advanced natural gas technologies and promotes policies to increase economically efficient use of natural gas in commercial and residential buildings. The program supports cost-shared research, development, and commercialization of high-efficiency gas-fired heating, cooling, and major appliance technologies. Through partnerships with industry and stakeholders, the program aims at improving building sector energy performance, environmental quality and occupant productivity, and establishing U.S. leadership in a growing world marketplace for building equipment and appliances.

DEPARTMENT-WIDE PROGRAM

In 1995, residential and commercial buildings in the U.S. used 32.7 quadrillion Btu of primary energy, 36 percent of U.S. total primary energy consumption. Residential buildings consumed 18.4 quadrillion Btu of energy in 1995, while commercial buildings used 14.3 quadrillion Btu. More than 32 percent of the energy used in the buildings sector was supplied by natural gas, either directly or through the generation of electricity, representing 48 percent of all natural gas consumed in the U.S. Space heating is the single largest end-use energy demand within buildings, accounting for 36 percent of residential building energy consumption and 15 percent of commercial building energy consumption. Space cooling and ventilation represents an additional 17 percent of commercial building energy use. The buildings sector is responsible for two-thirds of the Nation's electricity demand, with air conditioning the largest contributor to peak loads.

In addition to the $220 billion of direct costs that energy represents to consumers, building energy use contributes significantly to air and

water pollution and depletion of the earth's non-renewable natural resources. Carbon dioxide emissions attributable to primary energy use in U.S. buildings constitute 35 percent of the U.S. and 9 percent of the global totals. In addition, energy use in buildings is responsible for 47 percent of U.S. sulfur dioxide emissions and 22 percent of nitrogen oxide emissions.

Dramatic improvements are being made in the efficiency of many aspects of energy use in the nation's buildings. However, these improvements are being overpowered by strong sectoral growth and increased demand for energy services, which have led to significant increases in overall energy demand, with concomitant cost increases to consumers and damage to the environment. There are currently more than 76 million residential buildings and 4.8 million commercial buildings in the U.S., which together contain over 250 billion square feet of floorspace, and 38 million new residential and commercial buildings will be constructed between now and 2010. The number of households has grown by 25 percent since 1980, while residential primary energy demand has increased by 22 percent. Over the same period, commercial floorspace has increased by 39 percent, accompanied by primary energy demand growth of 35 percent. Use of energy consuming equipment and appliances is increasing dramatically at home and work. Further, demand growth is expected to continue. The Energy Information Administration projects an increase of 4.0 quads by 2010, a 12 percent increase. This increase would require investment in an additional 30 gigawatts of electricity generating capacity, costing approximately $20 billion in capital that could be applied to other more productive and employment-intensive investments.

The Office of Building Technology, State and Community Programs (BTS) provides technology leadership to make U.S. buildings more efficient, comfortable, affordable, and sustainable. The goal of BTS is to limit non-renewable energy use in buildings through cost-effective improvements in energy efficiency and expanded use of renewable energy. This will be accomplished by developing new, cost-effective, environmentally-benign technologies and stimulating use of the best new and currently available technologies. An integrated, three-component strategy is used to bring about the required improvements: (1) research, development, and demonstration and practical application of advanced energy-efficient and renewable energy technologies; (2) appliance and building codes and standards; and (3) market outreach and conditioning. The Administration, through the National Science and Technology Council, has designated the buildings and construction industry as one of nine priority areas for federally assisted research.

Program Activity Summary

The Residential and Commercial program focuses on cost-shared research and development of advanced technology for heating, cooling, and ventilating buildings and partnerships with industry to accelerate the introduction of new technology. It seeks to: (1) support development of cost-effective advanced natural gas technologies for space conditioning and water heating; (2) promote and accelerate natural gas technologies to meet the provisions for air quality goals; (3) support deployment and integration of advanced utilization technologies, including cogeneration systems using fuel cells in the buildings sector; and (4) advance the state-of-the-art in computing and information technologies to assist in full integration of natural gas systems.

The program goals are to reduce energy use in space heating and cooling by 50 percent, when the program's advanced technology has fully penetrated the market, and to eliminate ozone-depleting refrigerants while increasing energy efficiency, all while improving comfort and productivity of buildings and reducing emissions. Within residential buildings, advanced gas-fired heat pump technologies now being developed have the potential to

double the efficiency of conventional equipment used for space heating and cooling, and for water heating. Advanced chillers and small-scale fuel cells are two technologies under development that will improve commercial building energy performance while dispatching electricity with natural gas during the Summer peak demand periods. Advanced desiccant technology will allow increased ventilation for improved air quality, as required by ASHRAE standards, while also reducing energy consumption.

Partners in the Department's efforts to address natural gas-fired building equipment include small business R&D firms, manufacturers, utilities, and professional organizations. The DOE program is coordinated with R&D activities of the Gas Research Institute (GRI), the American Gas Association (AGA), and the Electric Power Research Institute (EPRI). GRI has a multimillion dollar research program that is focusing on building equipment and appliance energy performance and is closely coordinated with DOE. Similarly, AGA supports advanced natural gas cooling and dehumidification technology R&D. DOE, the natural gas industry, and EPRI are conducting research on fuel cells for building applications.

Lower operating costs, compared to competing fuels, and expanded distribution systems contribute to the competitiveness of natural gas for space heating and water heating applications. However, the higher first-costs that are typical for natural gas-fired cooling technologies and appliances compared to competing equipment often act as a purchase barrier, particularly in new construction markets.

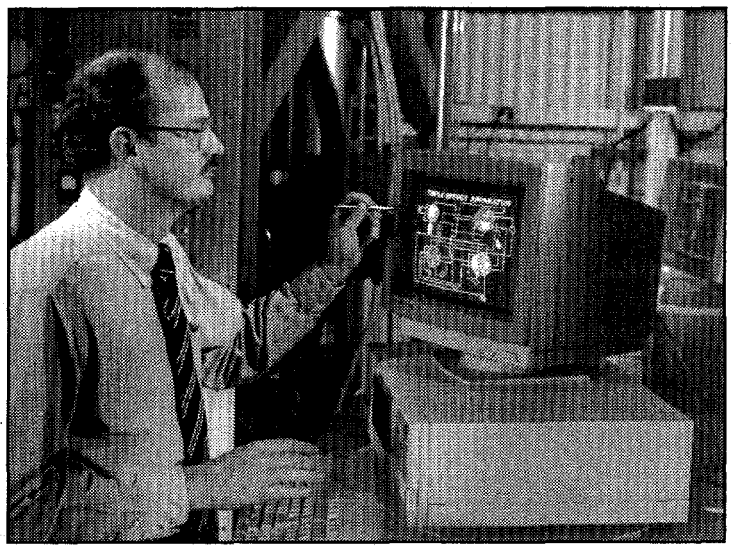
Section 127 of the Energy Policy Act of 1992 (EPACT) specifically directs DOE to assess the potential for development and commercialization of natural gas-driven building appliances, including heating and cooling equipment, that are substantially more efficient than those required by Federal or State laws, and to recommend specific actions that DOE could take in assisting utilities and appliance manufacturers in product development and commercialization. In implementing the requirements of EPACT Section 127, a significant part of DOE's program will target technical and market obstacles that impede adoption of advanced building equipment and appliance technologies. Joint DOE/industry participation in efforts to develop and deploy high performance natural gas-driven products is a critical element in fostering use of natural gas within the buildings sector.

Program Schedule (1995-2002)

FY 1995

- Initiated two contracts to evaluate new and emerging desiccant technologies with teams consisting of a desiccant manufacturer and an heating, ventilation, and air conditioning (HVAC) system manufacturer.
- Completed a marketing study on fuel cell cogeneration in buildings and conducted two industry workshops to guide program planning.

Oak Ridge Researcher Uses a Computerized Simulation Tool to Analyze an Advanced Absorption Chiller



FY 1996

- Completed a preliminary assessment of the application of the Generator Absorber Heat Exchanger (GAX) absorption technology in small commercial buildings.
- Awarded four Small Business Innovation Research (SBIR) contracts to conduct research on critical technical problems related to development of PEM fuel cell applications in buildings.

FY 1997

- Initiation of fabrication of a full production model of a 400-ton natural gas Double Condenser Coupling absorption chiller using DOE's advanced Double Condenser Coupling (DCC) technology at York International.
- Award of three cost-shared contracts for the development of fuel cells for buildings.
- Transfer of the Absorption Simulation (ABSIM) computer design model for absorption heat pumps to industry.

FY 1998

- Completion of R&D on two new natural gas absorption heating/cooling products with 40 percent higher efficiency than existing technologies.
- Completion of a study of liquid desiccant systems and development of an R&D plan.

FY 1999

- Initiation of testing a laboratory prototype version of a natural gas heat pump using advanced absorption technology.
- Market introduction of an advanced DCC chiller for large commercial applications.
- Finalize analysis of "Figure of Merit" for desiccant wheel configurations, designs, and materials and publication of results for use by system designers.

FY 2000

- Market introduction of the GAX absorption heat pump for residential applications.
- Development and introduction of design tools for desiccant system development and applications studies.

FY 2001

- Market introduction of a desiccant-based ventilation-air preconditioner integrated into a modular HVAC system.

FY 2002

- Completion of "first-generation" prototype 50 kW PEM fuel cell for buildings.

FY 1996-1998 Crosscut Budget Summary ($ in Millions)

Programs	FY 1996	FY 1997	FY 1998
Thermally Activated Heat Pumps	6.0	6.4	5.5
Advanced Desiccant Technology	0.0	1.5	2.1
Fuel Cells for Buildings	0.0	1.0	1.0
Total	**6.0**	**8.9**	**8.6**

3.5.2 Project Descriptions

3.5.2.1 Thermally Activated Heat Pumps

Background

Heating, ventilation, air conditioning, and refrigeration equipment in U.S. residential and commercial buildings use 15 quads of primary energy, or nearly half of all building energy consumption. Air conditioning is also the single leading cause of electric system peak loads. Energy use in buildings also has serious environmental impacts, contributing one-third of U.S. greenhouse gas emissions. Refrigerant fluids used in building air conditioning systems are major contributors to stratospheric ozone depletion.

The Thermally Activated Heat Pump (TAHP) can revolutionize the way buildings are heated and cooled. Using natural gas as the fuel of choice, it offers an efficient alternative to space conditioning in both residential and commercial buildings. It enables highly efficient heat pump cycles to replace the best natural gas furnaces, reducing energy use by as much as 50 percent, while also providing gas-fired air conditioning. In large commercial-size absorption chillers, energy efficiency can be improved by 50 percent with advanced high-temperature cycles and novel fluids. The principal thrust of the program is system development and deployment, field testing, and commercialization of systems.

Major Goals

The project will develop and introduce to the market new gas-fired heat pumps and chillers for use in residential and commercial buildings that are 50 percent more energy efficient than the best technology presently available; specifically:

- An advanced commercial-size (DCC) $LiBr/H_2O$ absorption chiller in 1999.
- A residential-size absorption heat pump for use primarily in northern climates in 2000.
- A second-generation residential-size absorption heat pump with improved cooling performance for use in southern climates in 2005.

Project Objectives

The objective of this project is to develop and commercialize a new generation of advanced absorption cycle heat pumps and chillers for residential and commercial space conditioning operating on natural gas.

Expected Benefits

Gas-fired absorption heat pumps and chillers are adaptable nationwide in both new and retrofit applications in residential and commercial buildings. With full market penetration, this technology can reduce primary energy use for space heating, space cooling and water heating by 4 quads by the year 2020, while also reducing substantially the electric load peaking problem experienced by electric utilities during summer cooling. It will reduce emissions of CO_2 and other environmental pollutants from heating and cooling systems by over 60 percent, without using ozone-depleting CFC and HCFC refrigerants. It will also increase international competitiveness of U.S. industry through globally marketable technology and products.

Planned Products

This project will lead to the introduction of three specific hardware systems for space conditioning of buildings: an absorption heat pump for use primarily in heating of residential and small commercial buildings, a second-generation, "Hi-Cool" heat pump with improved cooling performance, and a $LiBr/H_2O$ absorption chiller for use in large commercial buildings. In the course of this work, it will also produce improvements in

system components, including materials and fluids. A computerized design tool for absorption systems will be made available for use by industry.

Strategy (FY 97 Funding: $6.4 Million)

Thermally activated heat pumps can achieve significant penetration in all three distinct heating, ventilation, and air-conditioning markets: residential, small commercial, and large commercial. Since the residential market has the greatest potential for energy savings, it is the primary emphasis of the program. Large commercial technology is pursued in parallel, as funding allows. The small commercial market will be addressed in the future by building on the residential technology base.

For the residential market, the strategy is to develop two levels of technology sequentially . The "first generation" technology is the Phillips Engineering Company's Generator Absorber Heat Exchanger (GAX) absorption cycle, or the equivalent. The primary market will be in the northern half of the country, due to the good heating performance of the GAX system. The main thrust of the TAHP program is on the residential GAX effort.

The second-generation, "Hi-Cool" residential absorption heat pump technology will expand the residential market to include the southern cooling-dominated region. The improved level of cooling performance can only be achieved with major new advancements in absorption technology or with an engine-driven system. The program strategy is to pursue technology screening efforts at a high level, in parallel with the first generation GAX effort, to determine the most attractive "Hi-Cool" technology. The program's primary focus is to take advantage of new technologies and share new developments between the programs to bring the latest tools to a marketable state.

The technology of large commercial chillers is quite different from that of residential heat pumps and requires separate development efforts. The program is continuing to work with a major U.S. manufacturer in the development, testing, and commercialization of an advanced Double Condenser Coupled (DCC) commercial $LiBr/H_2O$ chiller, which is expected to be 50 percent more efficient than the Japanese-designed chillers now being built and sold in the United States. This DOE-patented DCC technology is being pursued at a rapid pace consistent with its potential for near-term commercialization.

Supporting research is carried out in key technical areas to enable current concept developments to proceed and to form the basis for future advanced concepts with even higher energy saving potential. The work is carried out through industry cost-shared programs with major manufacturers and small business establishments, R&D firms, universities and national laboratories, in close coordination with the Gas Research Institute (GRI) and major gas utilities.

Major activities underway in FY 97 are:

- Phillips Engineering Company is completing the design optimization of the GAX absorption heat pump, which uses NH_3/H_2O as the working fluid, and will begin testing a complete prototype heat pump at Oak Ridge National Laboratory (ORNL). The target Coefficient of Performance for heating (COPh) is 1.6 and the Coefficient of Performance for cooling (COPc) is 0.7. The R&D program is funded by DOE and cost-shared by the Gas Industry Consortium, made up of the Gas Research Institute and several major gas utilities. In May 1997, a U.S. manufacturer of gas-fired air conditioners announced that it is preparing to market a GAX chiller in 1998, as a prelude to its development of a GAX heat pump.
- A major HVAC equipment manufacturer is beginning tests on a prototype 400-ton DCC $LiBr/H_20$ chiller for COPc of 1.4 or better. The major development focuses on materials of construction, absorption fluids additives for heat and

mass transfer, and corrosion abatement at high- temperature operation of the lithium bromide/water system.

- Two contractors have been selected and are beginning to develop advanced concepts for a second-generation, "Hi-Cool" residential absorption heat pump. This advanced heat pump will have a 30 percent improvement in cooling performance, based on previous development of absorption concepts.
- Development and transfer to industry will continue on the Absorption Simulation (ABSIM) computer program. There is no publicly available computer model for the design or analysis of absorption cycles using NH_3/H_2O. The introduction of ABSIM will provide a "first-generation" computer model for the design engineer and research specialist comparable to computer models used in electric heat pump design.

Recent Accomplishments

- Completed a comprehensive design and cost analysis of the GAX heat pump.
- Completed a comprehensive market study for the commercial GAX heat pump.
- Completed a preliminary study of the design, layout, and cost of a manufacturing plant for the production of the GAX heat pump.
- Completed design and began fabrication of a prototype DCC large commercial chiller with York International.
- Studies at the University of Maryland and Pennsylvania State University were completed, with several potential high-temperature refrigerant additives identified. This information is being shared with HVAC equipment manufacturers.

Schedule

- Develop and commercialize the GAX absorption heat pump for residential applications by 2000, and for small commercial applications by 2003, in collaboration with Phillips Engineering Company, the gas industry, and equipment manufacturers.
- In collaboration with industry, introduce to the market an advanced DCC absorption $LiBr/H_20$ chiller for large commercial applications. (1999)
- Complete component development and begin system development by 2002 for the second-generation "Hi-Cool" heat pump, as a step leading to introduction of a residential-size absorption heat pump. (2005)

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Residential Absorption Heat Pump	3.7	4.2	4.3
"Hi-Cool" Heat Pump	1.1	0.9	0.9
Computer-Aided Design	0.2	0.2	0.0
Large Commercial Chiller	1.0	1.1	0.3
Total	**6.0**	**6.4**	**5.5**

Cost Sharing (Percentage / $ in Millions)

	FY 1996	FY 1997	FY 1998 Estimate
Percentage	33	33	35
Total ($)	**2.0**	**2.1**	**1.9**

3.5.2.2 Advanced Desiccant Technology

Background

Conventional vapor-compression refrigeration cooling systems cannot effectively handle high humidity loads. This leads to installation of oversized compressors for dehumidifying incoming air and then re-heating dry air to achieve some level of comfort, an approach which is costly but often still inadequate. Desiccant systems can supplement the performance of conventional air conditioners by working together to meet the temperature and humidity loads of the building. Compressor size can be reduced and excess chiller capacity can be eliminated, resulting in reduced energy consumption but improved air quality and occupant comfort.

However, to be acceptable in the market, desiccant-based air conditioning systems have to overcome several problems:

- *Cost*: Desiccant systems are commonly perceived as an expensive, inefficient space conditioning technology. Although advancements in desiccant material and equipment design have improved performance and reliability and reduced the cost of desiccant equipment, further cost reductions and technical improvements are needed to allow these systems to compete successfully in the broader commercial and residential building markets.
- *Information*: Capacity and operating efficiencies for desiccant and vapor compression equipment are not expressed in equivalent terms. To permit product comparison and specification, a set of standardized test procedures and certification criteria are needed for desiccant-based systems, along with design tools to allow evaluation and optimal configuration of equipment. Conventional comfort standards, based primarily on temperature, must be revised to incorporate responses caused by humidity and indoor air quality.
- *Physical Size*: The relative size of equipment using desiccant components is larger than comparable vapor compression systems. Size reduction would make desiccant technologies more acceptable and cost-effective for mainstream HVAC equipment markets.

This project works with industry to identify and remove barriers and expand the technology into broader space-conditioning markets, where its full energy savings potential and contribution to improved indoor air quality can be realized. An industry-led program is critical to the success of the technology. In response, DOE is collaborating with the U.S. Air Quality (USAQ) Consortium and gas industry to accelerate this process.

Major Goals

The project will assist industry in developing and commercializing desiccant technology to be integrated into 10 percent of the air conditioning market by 2005 and 25 percent by 2010, allowing buildings to achieve indoor air quality improvements resulting from increased ventilation requirements, without any corresponding increase in energy consumption.

Project Objectives

The objective of the gas-fired desiccant cooling program is to bring manufacturers of desiccant systems together with manufacturers of HVAC systems to accelerate the incorporation and commercialization of improved desiccant technology into broader markets for comfort conditioning in commercial and residential buildings, leading to the introduction of new, marketable desiccant products under recognizable HVAC brand names. The project will provide information and procedures to facilitate the design and selection of desiccant systems by HVAC engineers. It will also assist in training of end-users and market promotion of desiccant-based HVAC equipment.

Expected Benefits

Desiccant systems can decouple latent and sensible heat loads in building space conditioning systems and improve quality of ventilation air. Desiccants offer many advantages over conventional HVAC cooling systems, including: improved indoor air quality (IAQ), reduced energy bills, reduced peak demand on summer peaking electric utilities, load-shifting of natural gas use in summer months, utilization of waste heat, reduced use of ozone-depleting chemicals, reduced emissions of global-warming gases, more comfortable working/living conditions, and reduced remodeling requirements.

The unique advantages of desiccant-based equipment over conventionally used vapor-compression air conditioning systems can be shown for any building where significant amounts of replacement air is required. Desiccant technology is successfully being used in various niche markets throughout the U.S. where it can solve several problems that cannot be handled by conventional systems alone. Applications include:

- *Supermarkets*, by reducing frost build-up on refrigerated cases and frozen food products, thereby extending product shelf life and extending the interval between energy-consuming defrost cycles.
- *Hotels and dormitories*, where large volumes of outdoor air are needed to make up for bathroom exhaust air, and where frequent showers and baths generate humidity too high for the conventional room air conditioner to handle, causing moisture damage to carpeting, draperies, and furnishings.
- *Nursing homes and hospitals*, which need large quantities of outdoor air for health and odor maintenance, humidity control in operating rooms for antiseptic reasons, and maintenance of relative humidity levels below 50-60 percent relative humidity for comfort of staff and patients.
- *Large retail stores and shopping malls*, where it is critical to maintain customer comfort over a wide range of occupancy levels.

The commercial market will be driven by requirements of the new ASHRAE Standard 62-89R, Ventilation for Acceptable Indoor Air Quality, which calls for increased use of outside "fresh air" for ventilation, improved air quality, and healthier conditioned spaces. Desiccants will allow the increased ventilation requirements to be met without any corresponding increase in energy consumption.

Specific benefits expected from this project are:

- Reduction in energy consumption by 0.1 quads annually by 2005 and 0.4 quadrillion Btus annually by 2010; and
- Reduction in carbon dioxide emissions by 6 million tons annually by 2005 and 24 million tons annually by 2010.

Planned Products

This project will develop and commercialize hybrid desiccant-based cooling systems for improvement of indoor air quality without any corresponding increase in energy consumption. It will also provide the following information, which will facilitate the incorporation of desiccant technology into HVAC system design:

- Development and implementation of standard test and performance ratings and product certification procedures for desiccant systems, using test conditions that are indicative of real-world field operations;
- Development of a "figure of merit" for desiccant wheel comparison;
- Development of design tools for integrated desiccant-based systems;
- Development of a data base for the comparison of hybrid desiccant/HVAC equipment with vapor compression cooling equipment.

Strategy (FY 97 Funding: $1.5 Million)

Initial emphasis will be on development of solid desiccant for integrated roof-top commercial markets such as schools, hospitals, hotels and office buildings where moisture control, ventilation and indoor air quality are major problems but first costs becomes less of an issue. Desiccant systems will be designed that can treat humidity and latent heat prior to sensible cooling, thereby significantly reducing the need for larger tonnage air conditioners. Reduced latent load allows for a reduction in duct sizing, air handling equipment, and chiller capacity, resulting in significantly lower capital investment and operating cost. Desiccants will be needed for rigorous code compliance if the prescriptive provisions of ASHRAE 62-89R are adopted.

Feasibility studies will be conducted on liquid desiccant systems to determine the major impact they will have in applications for HVAC and IAQ markets.

ASHRAE Standard 62-1989R requires supplying more ventilation air than the previous standard in most commercial buildings. Minimum ventilation rates are required to provide IAQ acceptable to human occupants and avoid adverse health effects. ASHRAE Standard 90.1 has reduced building envelope loads, with improved thermal insulation and high-efficiency lighting equipment placing more emphasis on latent rather than sensible heat loads. However, conventional air conditioners were not designed to handle increased ventilation rates or latent loads, and cannot comply with the required standard without dramatically increasing energy consumption.

Desiccant systems can effectively and efficiently reduce the latent-load component for existing buildings to offset potential reduced capacity from refrigerant conversions or the need to provide increased electric service to maintain cooling capacity. Because of design changes required by ASHRAE 62-89R and 90.1, new desiccant system design must be benchmarked against conventional systems that meet the requirements of the ASHRAE standards.

There are significant technical issues that must be resolved before desiccant systems can be successfully integrated into broad building space conditioning markets, such as:

- A need for "hard" data on overall system cost and performance tradeoffs
- A need for broad performance maps for desiccant wheels and materials
- A need to develop experience in controlling both temperature and humidity in buildings
- Material science for integration of desiccant systems with the HVAC heat exchanger for temperature matching
- Analytical modeling capability for understanding system heat and mass transfer
- Computer models for system integration and operation

Project work in FY 97 will help to address these issues. Specifically:

- Field evaluation of an advanced desiccant system developed by an industry team will provide side-by-side performance comparisons with conventional equipment and determine the data required for future product improvements and re-engineering. Six test sites have been selected. Using testing and rating procedures prepared by the manufacturer, ORNL and National Renewable Energy Laboratory (NREL) technical staff will monitor the field testing.
- Testing is underway on a desiccant-based air pre-conditioner developed by an industry team to determine and analyze applications that would best benefit from this design approach. The system separates outdoor-air latent

loads from sensible loads that can be conveniently handled by conventional vapor-compression cooling equipment.

- NREL is testing desiccant wheel cartridges donated by five desiccant wheel manufacturers. The test program will characterize various existing dehumidifiers and use the date to establish a baseline performance date base for existing technologies. The baseline performance data will provide technical support for the drafting of realistic performance test methods and for field monitoring of advanced components in collaboration with desiccant equipment manufacturers.
- Algorithms from NREL's and ORNL's testing programs are being provided to manufacturers and software developers for inclusion in the design software.
- NREL, in conjunction with a major manufacturer, initiated a study of liquid desiccant dehumidifiers.

Recent Accomplishments

In a joint effort with industry, DOE initiated contracts to evaluate new and emerging desiccant technologies by two teams, each consisting of a desiccant manufacturer and an HVAC system manufacturer.

NREL has established a facility for testing desiccant wheels under a wide range of realistic operating conditions.

Schedule

- Complete technical support for development of industry-wide test procedures and rating and certification methods in conjunction with ASHRAE and the Air Conditioning and Refrigeration Institute. (1998)
- Complete study of liquid desiccant systems and develop an R&D plan. (1998)
- Finalize analysis of "Figure of Merit" for desiccant wheel configurations, designs, and materials and publish results for use by system designers. (1999)
- Complete design tools for product development and applications. (2000)
- Introduce to the market a desiccant-based ventilation-air preconditioner integrated into a modular HVAC system. (2001)
- Develop and commercialize inexpensive sensors and equipment controls that optimally combine temperature level measurements with humidity and IAQ assessment, to fully exploit the potential for new indoor comfort standards and energy saving potential of desiccant-based air conditioning equipment. (2001)
- Develop a liquid desiccant system for integration with HVAC applications. (2002)

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Advanced Components and Applications	0.0	0.5	0.9
System Development Demonstration	0.0	1.0	1.2
Total	**0.0**	**1.5**	**2.1**

Cost Sharing (Percentage / $ in Millions)

	FY 1996	FY 1997	FY 1998 Estimate
Percentage	--	40	38
Total ($)	**0**	**0.6**	**0.8**

3.5.2.3 Fuel Cells for Buildings

Background

On-site uses of natural gas in residential and commercial buildings, for such functions as space heating and water heating, are directly responsible for 37 percent of U.S. natural gas consumption. However, the buildings sector also consumes about two-thirds of all electricity generated in the U.S., for servicing a wide range of space-conditioning and appliances loads. Generating this electricity for buildings consumes an additional 11 percent of U.S. natural gas consumption. On a primary energy basis, the buildings sector accounts for 36 percent of total U.S. energy consumption from all sources. Consequently, the large direct and indirect fossil fuel requirement to provide anticipated building energy needs is the driving force behind DOE's efforts to develop high-efficiency end-use equipment as part of its technology development strategy. High-efficiency building cogeneration systems using fuel cells is a key technology option for improving building energy efficiency.

DOE recognizes that successful development and commercialization of fuel cell cogeneration systems in buildings will require support and commitment of both manufacturers and potential end-users. To this end, the initial focus will be on developing the proton exchange membrane fuel cell (PEMFC) by addressing key technologies unique to building applications, and by using the large technology base being developed for transportation and military programs. Successful development of fuel cell technologies for buildings will dramatically reduce primary energy consumption in buildings and will significantly reduce electric/gas utility infrastructure needs, with associated cost savings.

It is important to note that the Fuel Cell for Buildings program will provide strategic support for the transportation fuel cell program by focusing on those near-term technologies that are common and synergistic to the automotive program. The buildings program will provide an accelerated commercialization path for the PEMFC and a near-term market for the technologies. In large part, cost reduction of fuel cell components in the buildings program will lead to reduced cost for components in the automotive program. The availability of near-term, multiple markets for the technologies greatly reduces the business risks associated with the development, thereby enhancing the level of industry commitments and participation in transportation, military, and stationary power applications.

Major Goals

This program will develop and demonstrate a "first-generation" prototype PEMFC for buildings in 2002, leading to market introduction by 2004. In addition, the technology base will have been laid for a second-generation system with lower cost, longer life, and greater adaptability to cogeneration use in buildings.

Project Objectives

The objective of the Fuel Cells for Buildings program is to develop key technologies for PEMFCs that are unique to building applications, cost-effective, and efficient, and that will provide a coupling between the fuel cell and the building suitable for cogeneration, supplying both the electric and thermal load requirements of the buildings. Where possible, this program will adapt technologies being developed for the PEMFC in transportation and military programs that are applicable to use in buildings.

Expected Benefits

The widespread use of fuel cell waste heat for cogeneration in buildings will reduce consumption of primary fuels by the building sector by a factor of two over current practices. Additional national benefits include:

- Significant reductions in CO_2 emissions as the result of the large reduction in primary energy use.

- Positioning United States industry as leaders in this dynamic technology area (as evidenced by the attention being given to its development in Japan and Europe) with associated implications for worldwide sales and domestic job creation.
- Reduction in the need for electric utility infrastructure (generating, transmission and distribution) with associated cost reductions in the delivery of electric services.

The impact of cogeneration system waste heat is an important consideration in evaluating system economics. Besides cogeneration, fuel cells will provide additional opportunities, including the use of distributed fuel reforming and direct-current (DC) appliances to further enhance cost-effectiveness and energy savings of system economics.

Planned Products

This work will produce a "first-generation" prototype 50-kW PEMFC installation by 2002, followed by a commercial product by 2004. Development study will begin in 1999 on an advanced, second-generation system.

Strategy (FY 97 Funding: $1.0 Million)

The program will focus initially on commercial buildings, due to a combination of their more favorable load characteristics, particularly high electric rate structures, the economies of scale associated with equipment implementation (particularly controls and fuel processing), and consistency with the capacity range being developed for transportation applications (50 to 300 kW). Successful development of the technology for commercial applications will provide a basis for addressing the large market potential in residential buildings.

The commercial building sector consists of over 4.5 million buildings, of which almost 4.2 million are occupied. Servicing the electric and thermal needs of these buildings accounts for more than 13 quads of primary energy consumption. Office, health, lodging, mercantile and education collectively account for over 50 percent of the total energy consumption in this sector. Of equal importance for assessing cogeneration potential is the typical energy use per building. On this basis, the most energy intensive buildings are used for *health care, lodging and education,* in that order.

The design and evaluation of cogeneration systems must take into account the daily and seasonal variations in both electric and thermal loads. Of particular importance for system design and economics is the coincidence of electric and thermal loads, since production of these two energy forms are simultaneous within a cogeneration unit. Two of the most important design strategies for cogeneration are:

- *Thermal-to-Electric (T/E) Ratio*: A measure of the ratio of the annual thermal loads of the building to its annual electric loads. A low T/E ratio implies relatively little use for reject heat developed by the cogeneration systems in space/water heating functions.
- *Electric Capacity Factor*: The ratio of the kWh used annually in the building to that which would be used if the building operated 100 percent of the time at peak load. A high capacity factor implies a relatively steady electric load, and a low capacity factor implies a highly variable electric loads. The annual T/E ratio for the selected buildings ranges from about 0.1 for office buildings (i.e., little use of waste heat) to over 0.5 for high usage buildings. As would be expected, the T/E ratios are considerably higher in a northern climate than in the south, due to space heating requirements in the north. The highly seasonal nature of such loads is, however, a significant challenge in system design.

The Fuel Cell for Buildings program began in FY 97, based on groundwork laid by program-planning workshops and a market study. The advances made in the Automotive Fuel Cell program and buildings-related projects funded through the Small Business Innovations Research (SBIR) Program will provide information for the development of a near-term "First Generation" fuel cell appropriate for building applications. Initial focus will be on selective research and component modification for building applications to include:

- Steam reforming of methane for PEMFC, which is not being done by other programs.
- Carbon monoxide clean-up, which is critical to mitigating catalyst poisoning problems.
- Cost reduction engineering to bring fuel cell cost near $1,500-2,000/kW.
- Heat exchanger development for efficient use of waste heat for cogeneration.
- Improved bearing and seals for air compressors and expander to reduce parasitic power.

The FY 97, Program Research and Development Announcement for Integrated Fuel Cell Systems and Components for Transportation and Buildings resulted in the award of three cost-shared contracts with industry for development of fuel cells for cogeneration in buildings.

Recent Accomplishments

Two "Fuel Cell/Integration for Buildings Program" workshops were held to identify applications, technical problems, and policy issues, with attendance by more than 50 specialists from industry, universities, and government.

Arthur D. Little, Inc., produced an extensive "Cost/Performance Requirements and Markets" study that provided further program planning guidance.

In FY 96, four Phase I contracts were awarded through the SBIR program to do research in four separate technologies, as follows:

- Novel proton exchange membrane materials to reduce crossover of methanol into the hydrogen fuel stream.
- Natural gas reformer clean-up system for the PEM fuel cell, to remove CO from the fuel stream.
- Development of anodes that are CO tolerant, to mitigate the problem of catalyst poisoning.
- Develop low-cost bi-polar plates for PEMFC.

The results of this research will be incorporated into the development of a 50-kW laboratory test PEMFC.

Schedule

Successful completion of the "first-generation" PEM fuel cell activity will provide:

- A complete methane steam reformer for testing in a breadboard 50-kW PEMFC (1999).
- A complete laboratory engineering prototype 50-kW PEMFC for system-level testing (2000).
- First-generation prototype 50-kW PEMFC for buildings (2002).

This schedule will lead to a commercial product based on the "first-generation" PEMFC by the year 2004. It will also provide substantial technical, business, and market acceptance of the 50-kW PEMFC in support of the transportation application which will be working in parallel to solve those problems unique to the automotive application. Cost reduction engineering in both programs will greatly help reduce cost structure and further accelerate marketability of the PEMFC.

In FY 99, work will begin on an advanced, "second-generation" PEMFC that will greatly extend the useful life, will operate at atmospheric pressure, have a significantly lower cost per kW and be more adaptable to building applications. Advances that will be made to the PEMFC will give the "second-generation" PEMFC the following characteristics:

- Useful operating life in excess of 40,000 hours.
- Advanced reforming techniques for natural gas, i.e., partial oxidation (POX).
- Membranes that will operate at higher temperatures for better, more diverse cogeneration applications.
- Packaging modifications for reduced size and weight.
- Reduction of the "market clearing price" for the PEMFC to $1,000-1,500/kW.
- Operation at atmospheric pressure.
- Improved anode/catalyst loading.
- Maximum heat transfer capability.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Fuel Cells for Buildings	0	1.0	1.0
Total	**0**	**1.0**	**1.0**

Cost Sharing (Percentage / $ in Millions)

	FY 1996	FY 1997	FY 1998 Estimate
Percentage	--	40	40
Total ($)	**0**	**0.4**	**0.4**

3.6 Natural Gas Vehicles

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NATURAL GAS VEHICLES

3.6.1 TECHNOLOGY SUMMARY

OVERVIEW

Natural gas (in both compressed and liquefied form) use in vehicles is a promising alternative fuel in terms of cost-competitiveness, domestic sources, vehicle performance, and potentially low emissions of criteria pollutants and greenhouse gases. Significant environmental and energy efficiency benefits are possible. Natural gas combustion results in no emissions of lead or visible particulates and almost no toxic emissions. There would also be major reductions in most other key pollutants (especially non-methane hydrocarbons) and greenhouse gases (provided that methane is adequately captured and controlled during extraction from wells). Use of natural gas in its gaseous or liquid form is extremely efficient, compared with use of petroleum-based transportation fuels, when the total life-cycle of the fuel is considered (extraction, processing, and final use in a vehicle).

A significant increase in natural gas use in vehicles will not be possible unless it is economically viable and attractive to consumers in terms of safety and fueling. Acceptance of natural gas vehicles depends on total costs that are competitive with traditional fuels. Total costs consist of both direct and indirect costs. Direct costs are associated with capital and operational costs and are more easily addressed by R&D, in contrast to indirect costs, which are harder to quantify. Indirect costs include hedonic costs (for example, inconveniences associated with fueling or lack of fueling sites), cost of environmental emissions, cost of energy security, and perceived or real future supply constraints.

As a first approximation of economic feasibility, operational costs of a natural gas vehicle must be low enough to offset the additional capital costs inherent in natural gas on-board-fuel-storage systems compared with those for gasoline or diesel fuel. (Currently, approximately one-half of the incremental capital cost of a natural gas

vehicle is due to the cost of its on-board fuel storage.) Operational costs consist of cost of the fuel used by the vehicle (affected by vehicle configuration and engine efficiency), maintenance costs, and costs associated with vehicle replacement (durability). Fuel cost itself is important and includes the cost of fuel extraction, processing, distribution infrastructure, and taxes. Safety is reflected in direct insurance costs and indirect costs associated with personal injury and property damage. This plan addresses technologies that reduce direct costs and some indirect costs, such as ease or difficulty of fueling.

Critical R&D needs for natural gas vehicles, identified through discussions with industry stakeholders, universities, and national laboratories are as follows:

- Lower capital cost of natural gas vehicles.
- Improved vehicle efficiency (especially engine efficiency) and improved component durability and reliability (which affect operational costs).
- Improved safety and means to ensure integrity of vehicle fuel system.
- Improved fuel availability (fueling infrastructure).

Medium- and heavy-duty fleets that are centrally fueled are the logical niche for early market entry of natural gas in transportation. The advantages of clean-burning natural gas in air-quality nonattainment areas is seen as a key benefit. As natural gas infrastructure expands to supply fleet operations normally centrally-fueled, additional markets (like taxis and automobiles) can be accommodated as publicly accessible fueling stations are added to the distribution base. Tractor trailers (Class 8 trucks) offer a promising near-term application of LNG technology. Locomotives also provide an early market entry for LNG.

Department-Wide Program

The transportation sector of the United States faces major energy, environmental, and economic challenges. Petroleum is used to supply 97 percent of the transportation sector's energy needs, and transportation consumes approximately two-thirds of the Nation's oil demand. The number of vehicles and miles driven continue to increase. As a result, U.S. oil import demands continue to rise – oil imports are expected to rise from 8 million barrels per day (bpd) in 1995 to almost 10 million bpd in 2010. Worldwide oil reserves are becoming more concentrated in few countries, many of which are politically unstable and are opposed to U.S. interests. Emissions from transportation sources cause concern related to air quality and global warming potential. Also, there are concerns about U.S. ability to compete with imported cars and trucks which are perceived to be technologically superior to U.S. products.

DOE's Office of Transportation Technologies (OTT) and other Federal programs are working toward a "revolution" in transportation technologies which will enable significant reductions in petroleum use and move toward a cleaner, sustainable, geographically-distributed fuels base. DOE is coordinating transportation technology

Natural Gas Van at a Fuel Pump

activities involving the combined effort of industry, national laboratories, universities, and fuel suppliers.

Program Activity Summary

OTT's vehicle-related R&D is divided into two customer-focused offices: (1) Office of Heavy Vehicle Technologies (OHVT) and (2) Office of Advanced Automotive Technologies (OAAT). The overall goal of OHVT is to develop, by 2004, the enabling technologies needed to achieve fuel flexibility, ultra-low emissions, and 10 mpg efficiency in Class 7 and 8 trucks, while simultaneously devolving these technologies to Class 1 through 6 trucks, with Class 1 and 2 trucks achieving at least a 35 percent mpg improvement over current gasoline fueled trucks. The overall goal of OAAT is to research, develop, and validate technologies that will enable domestic market introduction of light vehicles which have (a) several times the fuel economy of current, comparable conventional vehicles, (b) fuel flexibility, (c) emissions that comply with statutory limits projected to be in place when the vehicles are available for the marketplace, and (d) other attributes, such as price, that render them competitive with conventional products.

FY 1996-1998 Crosscut Budget Summary ($ in Millions)

Program	FY 1996	FY 1997	FY 1998
OHVT Natural Gas	6.79	7.24	8.00
OAAT Natural Gas	0.65	1.52	2.65
Total	**7.44**	**8.76**	**10.65**

Program Schedule

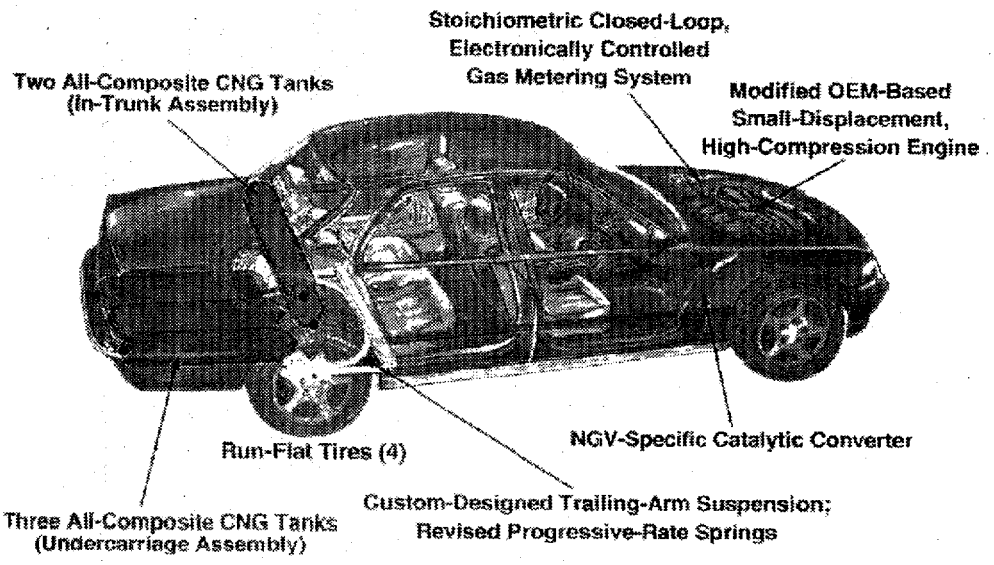
The following program schedule outlines the major milestones within the natural gas R&D portion of OTT's technology portfolio.

Program/Milestones	Year		
	2000	2004	2006
Office of Heavy Vehicle Technologies (OHVT)			
Engine	Advanced spark-ignited natural gas engine	Advanced natural gas engine, diesel-like thermal efficiency	
Storage	More comprehensive liquefied natural gas (LNG) tank standards		
Office of Advanced Automatic Technologies (OAAT)			
Vehicle system	5% improved fuel economy compressed natural gas (CNG) vehicle		10% improved fuel economy CNG vehicle
Joint OHVT/OAAT			
Storage	"Smart" CNG tanks	Improved CNG tank materials	Improved fuel system integrity
Fueling Infrastructure		Lower-cost fueling stations	

3.6.2 Project Descriptions

The Office of Heavy Vehicle Technologies (OHVT) and Office of Advanced Automotive Technologies (OAAT) carry out the natural gas vehicle-related R&D within the Office of Transportation Technologies (OTT). OHVT focuses on the development of fuel-efficient, fuel-flexible, environmentally acceptable, and economical heavy vehicles (Class 1-8 trucks, transit and school buses, off-highway vehicles, inland marine vessels, and locomotives). OAAT focuses on development of advanced automobiles. The following sections are divided into heavy vehicle R&D, administered by OHVT, and automotive R&D, administered by OAAT.

Advanced Natural Gas Vehicle
Artist's Concept



The Johns Hopkins University Applied Physics Laboratory

3.6.2.1 Heavy Vehicle R&D

Background

The transportation sector will continue to be the single largest user of petroleum in the U.S. as the demand for goods and services continues to grow into the next century. Currently, over 8 million barrels of oil are consumed each day by highway vehicles. Oil use is split evenly between automobiles and trucks (Class 1-8). Many Class 3-6 trucks are commercial vehicles that are centrally fueled; half by gasoline, and half by diesel fuel. Most Class 7-8 trucks run on diesel fuel. Because of concerns over fine particulate matter and nitrogen oxide emissions from diesel engines, natural gas has been cited as a potential alternative fuel having low particulate matter and nitrogen oxide emissions that can be used in modified heavy duty diesel engines.

Because natural gas burns cleanly, lower maintenance costs are projected for natural gas compared to diesel fuel. Drawbacks to using natural gas in heavy duty engines are lower efficiency than diesel fuel, and a lesser energy-density (as CNG) than diesel fuel, resulting in a lower range between fuelings. Another barrier is high first costs -- a heavy duty natural gas engine (including storage tank) costs about $15,000 more than a comparable diesel engine. While natural gas in liquefied form largely solves problems associated with range between fuelings (as it is more energy dense than CNG), problems associated with storage of cryogenic liquid must be addressed.

Major Goals

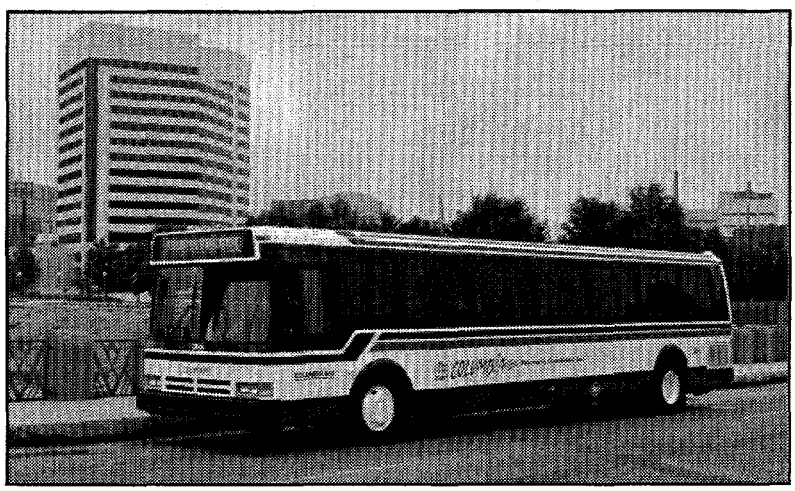
The goal of natural gas vehicle R&D for heavy vehicles (trucks, buses, off-highway vehicles, inland marine vessels, and railroad locomotives) is *to develop technologies that will enable the use of liquefied natural gas, compressed natural gas, and adsorbed natural gas (where applicable) in heavy vehicles with diesel-like thermal efficiency, ultra-low emissions, acceptable range, convenience of fueling, safety, and level of acceptance, including life-cycle costs similar to those of diesel-powered heavy vehicles.* Many Class 3-6 trucks are commercial vehicles that are centrally fueled, while many Class 7-8 trucks are tractor-trailers and refuse haulers. While the OHVT natural gas program is divided into two broad categories (Class 3-6 trucks and Class 7-8 trucks), other applications are served as well. Buses have engine systems common to trucks and are an integral part of the program. With modifications, many technologies developed for trucks could also be applied to inland marine vessels and locomotives. Therefore, natural gas inland marine engines and locomotives are also important elements of the program.

Project Objectives

The objectives for Class 3-6 trucks are as follows:

- By 2000, improve the full-load thermal efficiency of the typical spark-ignited natural gas engine from the existing 38-40 percent while meeting or exceeding emission standards for gasoline vehicles for that model year.
- By 2004, develop diesel-like thermal efficiency for a natural gas engine (about 45 percent thermal efficiency at full load) while meeting or exceeding

Natural Gas Powered Bus



emission standards for gasoline commercial heavy-duty trucks for that model year.

The objectives for Class 7-8 trucks are as follows:

- By 2000, assist industry and the appropriate agencies in developing appropriate safety standards for on-board LNG, including the issue of long-term on-board storage.
- By 2004, improve the full-load thermal efficiency of the natural gas engine from the current 38-48 percent while meeting or exceeding emission standards for heavy-duty trucks.

The objectives related to CNG are as follows:

- By 2000, develop "smart" CNG tanks that provide real-time sensing of important tank parameters, such as structural integrity, and are capable of responding appropriately to hazardous deterioration. R&D needs are in the area of sensor signal processing, system integration, and performance validation.
- By 2004, develop improved metallic and nonmetallic structural fuel tank materials that improve CNG containment.
- Develop tank standards of construction to improve the current fuel-system integrity standard from 15 years to 20 years by 2006.

The objective related to fueling infrastructure is as follows:

- By 2004, reduce the cost of fueling stations by 50 percent from 1996 levels.

Expected Benefits

Argonne National Laboratory estimated benefits of natural gas in the truck market. Assuming advanced CNG engines enter the market in 2004, peak market share for CNG in medium trucks (Class 3-6) is estimated to be 9 percent. Of centrally-fueled Class 3-6 trucks in EPACT Metropolitan Statistical Areas, the technology would capture a 33 percent peak market share. Petroleum displaced under this scenario would be 10,000 barrels of oil (equivalent) per day in 2010, and 50,000 barrels of oil (equivalent) per day in 2020. Particulate matter emissions would be reduced at the same time.

By avoiding imported oil, the balance of trade improves. Approximately one job is created for each 50 barrels per day of avoided oil imports, based on a study of advanced automotive parts by Argonne National Laboratory. Applying this factor to the heavy vehicle natural gas program, about 1,000 new jobs would be created by 2020.

Planned Products

Engines

- Improve basic understanding of design parameter effects (such as combustion chamber geometry, injection characteristics, and ignition characteristics) on performance and in-cylinder NO_x production.
- Develop improved metering components and control strategies for metering natural gas to optimize engine performance under a wider range of speeds and loads typical for heavy duty applications.
- Develop improved ignition systems (spark ignition, pilot ignition, and ignition-assists for direct injection).
- Develop "feed forward" sensors that enable engines to optimize performance for any fuel used.
- Develop reliable, lean misfire detection sensors and systems.
- Reduce throttling losses through the use of "skip-fire," Miller cycling, intake air heating, exhaust gas recirculation, and turbocharger waste-gate control.

- Develop improved control strategies and systems for advanced sensors and actuators.
- Develop improved nonfouling micro-pilot lube-oil injectors.
- Develop alternative fuels for pilot ignition engines (e.g., dimethyl ether).
- Develop a reliable, high-pressure fuel injector or common rail fuel system for direct injection of natural gas.
- Improve waste heat recovery.
- Develop novel enrichment techniques, such as on-board reforming, to produce a hydrogen-rich fuel for leaner operation.

Vehicle Fuel Systems – LNG

- Develop methods that would reduce or eliminate vapor releases.
- Develop a small, low-cost, high-pressure (3-4 kpsi) LNG pump for direct injection of natural gas.
- Develop "rapid pressure build" technology for *low-pressure* LNG (~100 psi) applications.

Vehicle Fuel Systems – CNG

- Develop a small on-board, cost-effective, high-pressure (3 kpsi) CNG compressor for direct injection technology.
- Develop lower-cost, lighter-weight CNG tanks.
- Develop cost-effective tank manufacturing techniques.
- Develop conformable CNG tanks and integrate them into vehicle structure.
- Develop improved adsorption techniques to increase on-board storage capacity for CNG.

Safety

- Assist industry and appropriate agencies in developing standards for handling, storing, and odorant "tagging" of LNG to ensure acceptance.
- Assist in development of a single, concise document that communicates LNG fundamentals, hazards, and safety measures to officials responsible for local siting of LNG fueling stations.

Fueling Infrastructure

- Continue to develop LNG corridors.
- Support city gate expansion to LNG development.
- Develop lower-cost LNG pumps and meters/dispensers.
- Develop small-scale, high-efficiency, lower-cost CNG compressors through the use of new materials and improved designs.
- Reduce costs by improving auxiliary components like oil separators, filters, dryers, sensors, and fuel dispensers.

Strategy (FY 97 Funding: $7.24 Million)

OHVT's R&D on natural gas trucks will initially have two thrusts: (1) LNG- and CNG-fueled heavy-duty Class 7-8 trucks that are centrally fueled, and (2) CNG-fueled Class 3-6 commercial vehicles (including buses). In addition to trucks, OHVT will develop natural gas-related technologies specific to railroad locomotives, off-highway vehicles, and inland marine vessels.

The strategy is to focus on developing technology and infrastructure to enable market entry of natural gas vehicles into those applications that are centrally fueled. The majority of centrally fueled vehicles are located in air-quality nonattainment areas, and clean-burning natural gas will have positive environmental consequences in these areas. It is envisioned that the commercialization of natural gas in vehicles will proceed from centrally-fueled urban buses (as CNG and LNG) to centrally-fueled Class 3-6 commercial trucks (as CNG), as well as to centrally-fueled Class 8 trucks (as LNG).

Finally, natural gas technologies will be developed for railroad locomotives (as LNG) and for off-highway vehicles and inland marine vessels (as either CNG or LNG). Activities will be closely coordinated with the natural gas program in OAAT where there is mutual interest, such as engine NO_x control and CNG fuel system, safety, and fueling infrastructure.

Recent Accomplishments

The following section summarizes recent accomplishments in two key areas of natural gas use in heavy vehicles.

Advanced Natural Gas Engine, Diesel-Like Thermal Efficiency—Development of a commercially viable, direct-injection (DI) natural gas engine in a four-stroke diesel cycle is seen as a key enabling technology to meeting the "stretch" goal of achieving diesel-like thermal efficiency in natural gas engines. Progress has been made over the past year in this area by Caterpillar on their model 3516 multi-cylinder engine (4.3 liters/cylinder, 16 cylinders). As of 1996, the engine has accumulated a total of 225 hours and has been to 1,500 rpm and 1,475 kW (95 percent of rated diesel power). Based on results, the key area needing improvement is the sealing of high-pressure natural gas inside the gas injector, and the glow plug ignition system. R&D in this area will begin in 1997. Also, comprehensive durability and emissions data will be obtained.

Advanced Spark-Ignited Natural Gas Engine—An ultra-safe, ultra-low emissions alternative fuel school bus, using a CNG-fueled, spark-ignite engine, was developed and is undergoing prototype testing by Southwest Research Institute. A key portion of this project is refinement of the natural gas engine. Lean operation of the engine was improved. The control system algorithms were improved for better steady-state and transient operation. In addition, various fuel metering devices, new methods for wastegate control, knock and misfire detection, and catalyst condition monitoring were investigated.

Program Funding

The following table summarizes DOE program funding required to implement the heavy vehicle plan. Industry cost-share is expected to be 50 percent.

Budget Estimate ($ in Millions)

R&D Category	FY 1998	FY 1999 Estimate
Engine R&D	**6.00**	**4.50**
Compression-Ignition Heavy-Duty Engines[a]	1.00	0.70
Spark-Ignition Heavy-Duty Engines[a]	5.00	3.40
Inland Marine LNG Engines	--	0.20
Locomotive LNG Engines	--	0.20
Vehicle Fuel System	**1.35**	**1.05**
CNG Storage	0.40	0.35
LNG Storage	0.75	0.60
Storage Systems Analysis	0.20	0.10
Safety/Systems Integration	**0.65**	**0.55**
Integrated Fuel Delivery/Storage	0.40	0.30
Advanced Sensors	0.25	0.15
In-Use Inspection Technology	--	0.10
Fueling Infrastructure	**--**	**0.20**
Small-Scale Fueling Station Development	--	0.10
Compressor Technology	--	0.10
Education and Training	--	--
Total	**8.00**	**6.30**

[a] Compression ignition and spark ignition refer to engine family from which the natural gas engine is derived, not necessarily the engine cycle.

SCHEDULE

The schedules are depicted in the following tables.

Technical Targets and Schedule: Class 3-6 Trucks			Year	
Parameter	**Units**	**Current Natural Gas Practice**	**2000**	**2004**
Engine Incremental Cost [a]	Dollars	1,000-5,000 [b]	400-2,000	150-750
Engine Efficiency at Full Load [c]		38% (SING) [d]	40% (SING)	45%
Emissions	g/bhp-h	1.4 NO_x 0.5 NMHC 2.0 CO [e] 0.03 PM	Meet or exceed EPA standards	Meet or exceed EPA standards
Engine Durability	Miles between overhauls	Better than gasoline or comparable with diesel	Better than gasoline or comparable with diesel	Better than gasoline or comparable with diesel

[a] Excludes cost of on-board fuel storage tanks. On-board fuel storage tank cost is a function of tank type, production volume, and number of tanks used per vehicle.

[b] Upper value based on estimate provided for Class 7-8 trucks by Caterpillar, Inc., Peoria, Illinois (April 1997). Lower value based on an incremental cost estimate for a CNG automobile engine relative to a conventional automobile engine.

[c] Based on lower heating value of fuel. Efficiency at half-load is approximately 90 percent of full-loadefficiency.

[d] Spark-ignited natural gas.

[e] Estimate provided by Cummins Engine Company, Indianapolis, Indiana (April 1997).

Technical Targets and Schedule: Class 7-8 Trucks			Year
Parameter	**Units**	**Current Natural Gas Practice**	**2004**
Engine Incremental Cost [a]	Dollars	5,000 [b]	1,000
Engine Efficiency at Full		38% (SING)	48%
Emissions	g/bhp-h	1.4 NO_x 0.5 NMHC 2.0 CO [c] 0.03 PM	Meet or exceed EPA standards
Engine Durability	Miles between overhauls	500K (comparable to diesel)	> 500K (comparable to diesel)

[a] Excludes cost of on-board fuel storage tank. Cost of on-board fuel storage tank is a function of tank type, production volume, and number of tanks used per vehicle. Cost targets for on-board fuel storage tanks are listed in the following table.

[b] Estimate provided by Caterpillar Inc., Peoria, Illinois (April 1997).

[c] Estimate provided by Cummins Engine Company, Indianapolis, Indiana.

Safety, Fuel System, and Fueling Infrastructure Goals and Schedule			Year		
Parameter	**Units**	**Current Practice**	**2000**	**2004**	**2006**
Safety, Overall	Relative to diesel	Insufficient data	Equal	Equal	Equal
	Relative to reformulated gasoline	Insufficient data	Equal or better	Equal or better	Equal or better
Vehicle Fuel Tank Monitoring (in use inspection)		Off-line	In-situ, smart tanks	In-situ, smart tanks	In-situ, smart tanks
Vehicle Fuel System Integrity	Years	15	17	19	20
Vehicle Fuel System Cost	Dollars/gallon gasoline equivalent	$100	$60	$45	$37
CNG Fueling Infrastructure Cost	Dollars relative to petroleum fuel	5X	5X	2.5X [a] (validated in 2003)	< 2.5X [b]
Fuel Quality	ASTM or equivalent standard		Meet agreed-upon standard	Meet standard & eliminate contamination	Meet standard & eliminate contamination

[a] Corresponds to a CNG compressor cost of less than $500/standard cubic feet per minute (scfm) of gas delivery, a dispenser cost of less than $15,000 (2-hose), and a dryer cost of less than $200/scfm treated.

[b] Corresponds to a CNG compressor cost of less than $300/scfm, a dispenser cost of less than $11,000 (2-hose), and a dryer cost of less than $150/scfm treated.

3.6.2.2 Automotive R&D

Background

There are over 150 million automobiles operating on U.S. highways. An overwhelming percentage of these vehicles operate on gasoline--about 4.5 million barrels of oil per day (as gasoline) are consumed by automobiles. While fuel efficiency and emissions per automobile have improved over the past two decades, the increased number of automobiles and vehicle-miles-traveled (VMT) has caused increased petroleum consumption and overall emissions from personal transportation use. Direct use of natural gas in passenger cars (as CNG) could significantly reduce reliance on imported petroleum, and reduce emissions of criteria pollutants and greenhouse gases. However, barriers to acceptance of CNG include short driving range between refuelings, high cost (especially the cost of fuel tanks), high methane emissions under certain conditions, and lack of fueling infrastructure.

Major Goals

The goal of natural gas vehicle R&D within OAAT is *to develop technologies that will enable dedicated compressed natural gas automobiles to be similar to gasoline automobiles in cost, range, fueling convenience, safety, and level of acceptance.*

Project Objectives

The objectives related to engine technology and vehicle costs are as follows:

- By 2000, validate technologies that improve fuel economy by 5 percent (miles per gallon equivalent), increase range to 300 miles, and reduce incremental vehicle purchase cost to $3,000, compared to equivalent gasoline-fueled automobiles, without reducing vehicle performance.
- By 2006, validate technologies that improve fuel economy by 10 percent (miles per gallon equivalent) and reduce incremental vehicle purchase cost to $1,500, compared to equivalent gasoline-fueled automobiles, without reducing vehicle performance.

The objectives related to CNG are as follows:

- By 2000, develop "smart" CNG tanks that provide real-time sensing of important tank parameters, such as structural integrity, and are capable of responding appropriately to hazardous deterioration. R&D needs are in the area of sensor signal processing, system integration, and performance validation.
- By 2004, develop improved metallic and nonmetallic structural fuel tank materials that improve CNG containment.
- Develop tank standards of construction to improve the current fuel-system integrity standard from 15 years to 20 years by 2006.

The objective related to fueling infrastructure is as follows:

- By 2004, reduce the cost of fueling stations by 50 percent from 1996 levels.

Expected Benefits

If CNG automobiles achieve a 2 percent share of the fleet by 2010, petroleum consumption will be reduced by about 80,000 barrels of oil (equivalent) per day. For a 5 percent share of the fleet by 2020, petroleum consumption would be reduced by about 250,000 barrels of oil (equivalent) per day. Assuming approximately one job is created for each 50 barrels per day of avoided oil imports (based on an Argonne National Laboratory study of advanced automotive parts), about 5,000 new jobs would be created by 2020 as a result of a successful CNG automobile market.

Planned Products

Engines

- Develop combustion chambers that support "mixed-mode"[1] operation.
- Develop medium pressure (~500 psi) injectors with high reaction speed.
- Develop improved ignition systems.
- Develop catalysts capable of supporting the alternately stoichiometric and lean-combustion modes of "mixed-mode."
- Develop "feed forward" sensors that enable engines to optimize performance for any fuel used.
- Develop reliable, lean misfire detection sensors and systems.
- Reduce throttling losses through the use of "skip-fire," Miller cycling, intake air heating, and exhaust gas recirculation.
- Develop improved control strategies and systems.
- Develop a bi-fuel catalyst.
- Improve waste heat recovery.
- Develop novel enrichment techniques, such as on-board reforming, to produce a hydrogen-rich fuel for leaner operation.

Vehicle Fuel Systems–CNG

- Develop lower-cost, lighter-weight CNG tanks.
- Develop cost-effective tank manufacturing techniques.
- Develop conformable CNG tanks and integrate them into vehicle structure.
- Develop improved adsorption techniques to increase on-board storage capacity for CNG.

Fueling Infrastructure

- Develop small-scale, high-efficiency, lower-cost CNG compressors through use of new materials and improved design.
- Reduce costs by improving auxiliary components like oil separators, filters, dryers, sensors, and fuel dispensers.

Strategy (FY 97 Funding: $1.52 Million)

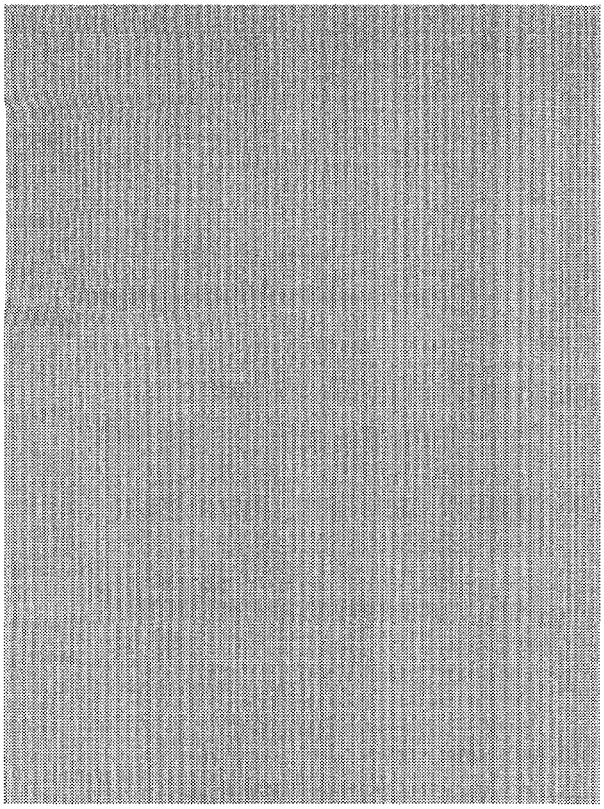
Natural gas vehicle R&D within OAAT will focus on on-board fuel storage, efficiency improvements, and fueling infrastructure. Activities will be closely coordinated with the natural gas program in OHVT where there is mutual interest, such as safety-related technologies, CNG fuel system development, and fueling infrastructure development. In addition, R&D will be coordinated with the Partnership for a New Generation of Vehicles (PNGV).

Recent Accomplishments

The following is an example of recent accomplishments in natural gas use in automobiles.

Advanced Natural Gas Vehicle—In 1996, OTT unveiled an innovative concept for natural gas vehicles offering a range nearly double that of prior models and within 15 percent of comparable gasoline models, and a reclamation of most of the trunk space lost to the CNG tank in current retrofit designs. The vehicle was designed by a team of research organizations, component suppliers, and a vehicle manufacturer. The team assembled a high-compression, small-displacement replacement engine that increased fuel efficiency, which, in turn, increased vehicle range. The rear suspension was redesigned so that fuel tanks could be installed with minimal intrusion into vehicle cargo space. The other technology improvement was incorporation of "run flat" tire technology which does away with the

[1]The term called "mixed-mode" refers to an engine combustion process whereby the engine alternates between stoichiometrics operations and lean burn operations, depending on engine speed and load.



traditional spare tire, effectively increasing cargo space. This proof-of-concept vehicle has demonstrated its ability to meet both stringent Ultra Low Emission Vehicle (ULEV) emission standards and consumer demands for performance and convenience. Future work will focus on development of an integrated storage system (ISS) which replaces the "strapped together tanks" approach to natural gas storage, and an improved fuel injection system.

Schedule

The technical targets and schedules are depicted in the following tables:

Program Funding

The following table summarizes DOE program funding required to implement the automotive plan. Industry cost-share is expected to be 50 percent.

Budget Estimate ($ in Millions)

R&D Category	FY 1998	FY 1999 Estimate
Engine R&D	**0.45**	**0.50**
Mixed-Mode Operation	--	0.25
Efficiency Improvements	0.25	0.25
Advanced High-Efficiency Components	0.20	--
Vehicle Fuel Storage System	**1.80**	**1.00**
Lower-Cost Materials	0.20	0.50
Cost-Effective Tank Manufacturing	0.20	0.50
First Generation Integrated Vehicle Storage	0.60	--
Advanced CNG	0.80	--
Fueling Infrastructure	**0.40**	**0.50**
Compressor	0.275	0.25
Auxiliary Equipment	0.125	0.25
Total	**2.65**	**2.00**

Schedule

The technical targets and schedules are depicted in the following tables.

Natural Gas Automobiles			Year		
Parameter	**Units**	**Current Practice**	**2000**	**2004**	**2006**
Vehicle Incremental Cost [a]	Dollars	4,000	3,000	2,000	1,500
Vehicle Fuel Efficiency [b]	MPGE [c]	Equal to gasoline	+ 5%	+ 8%	+ 10%
Range	Miles	150	300	380	380
Emissions	CA/Federal standard	ULEV/ILEV	ULEV/ILEV	ULEV/ILEV	ULEV/ILEV

[a] Includes incremental cost of engine and fuel system, including tanks, and assumes high-volume production.

[b] Assumes natural gas automobile has same interior space and cargo volume as a conventional vehicle.

[c] Miles per gallon, gasoline equivalent.

Safety, Fuel System, and Fueling Infrastructure Goals and Schedule			Year		
Parameter	**Units**	**Current Practice**	**2000**	**2004**	**2006**
Safety, overall	Relative to reformulated gasoline	Insufficient data	Equal or better	Equal or better	Equal or better
Vehicle fuel tank monitoring (in use inspection)		Off-line	In-situ, smart tanks	In-situ, smart tanks	In-situ, smart tanks
Vehicle fuel system integrity	Years	15	17	19	20
Vehicle fuel system cost	Dollars/gallon gasoline equivalent	100	60	45	37
CNG fueling infrastructure Cost	Dollars relative to petroleum fuel	5X	5X	2.5X [a] (validated in 2003)	< 2.5X [b]
Fuel quality	ASTM or equivalent standard		Meet agreed-upon standard	Meet standard & eliminate contamination	Meet standard & eliminate contamination

[a] Corresponds to a CNG compressor cost of less than $500/standard cubic feet per minute (scfm), of gas delivery a dispenser cost of less than $15,000 (2-hose), and a dryer cost of less than $200/scfm treated.

[b] Corresponds to a CNG compressor cost of less than $300/scfm, a dispenser cost of less than $11,000 (2-hose), and a dryer cost of less than $150/scfm treated.

3.7 Environment

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ENVIRONMENT

3.7.1 TECHNOLOGY SUMMARY

OVERVIEW

The primary mission of DOE's Oil and Gas Environmental Research and Analysis Program is to ensure that environmental protection efforts make technical, environmental, and economic sense. DOE is well-positioned between industry and regulators to champion balanced, cost-effective approaches to environmental protection and energy resource development. The Environmental Research and Analysis Program pursues improvements to the regulatory process, supports development of new technologies, and exercises key responsibilities for energy policies that encourage efficient oil and gas recovery and processing and ensure adequate, secure energy supplies.

To support more informed regulatory decisionmaking, the environmental program facilitates dialogue among Federal officials, State regulators, industry representatives and other stakeholders. Through its program activities, the environmental program provides assessments of costs or risks and benefits, lending an independent voice to policy debates. DOE also characterizes technical, analytical, and regulatory 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 development of new technologies. DOE supports such development by 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 fully capture, but that will be obvious only on a national scale.

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 enables the environmental program to generate maximum benefits for the Nation.

Department-Wide Program

The Office of Fossil Energy (FE) provides policy direction on issues related to natural gas and undertakes studies related to regulatory obstacles that unnecessarily impede development of cost-effective gas use, impacts of emissions from vehicles and general use of fossil fuels, and broad economic impacts of activities proposed by the Administration or by Congress.

DOE's Office of Energy Efficiency and Renewable Energy (EE) invests in RD&D activities for use of natural gas technologies. Through partnerships with industry, EE develops and deploys innovative gas use technologies in the transportation, industrial, utility, and building sectors. Program objectives include: analyzing combustion optimization and catalysts, emphasizing emission reductions for natural gas and other alternative fuels; developing industrial technologies to help manufacturers meet current and future environmental regulations and quality objectives; and developing methodologies for gas Integrated Resource Planning (IRP) and coordinating with States. Environmental benefits of these technologies are greater efficiency and reduction in harmful air emissions (such as NO_x and CO_2) and other environmental effluents.

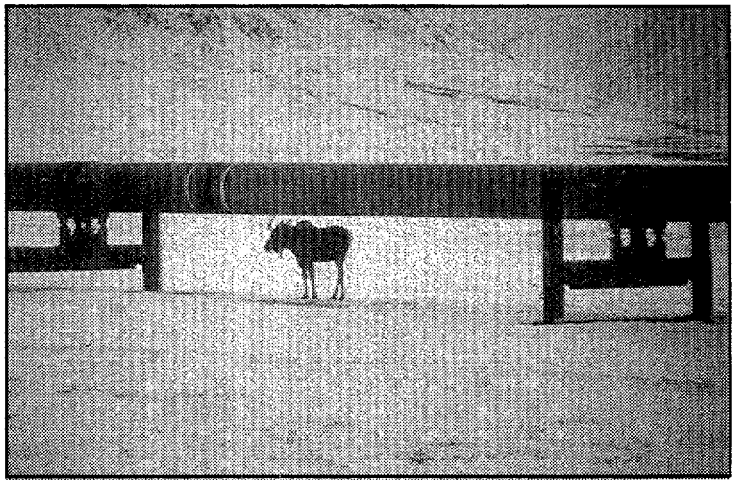
DOE's Office of Energy Research (ER) conducts fundamental research on the role of methane in global climate change, primarily through two initiatives: (1) development of improved global circulation models as the basis for global climate studies; and (2) studies of background methane emissions from agricultural activities and natural sources such as rice paddies, boreal peat bogs, and ruminant animals.

The Energy Information Administration, through its data collection, analysis, and forecasting programs, provides current and future market trends for natural gas from wellhead to burnertip.

Fossil Energy's environmental efforts focus on upstream oil and gas operations, and include four main activities: (1) fostering an understanding of environmental and energy challenges in the oil and gas exploration and production (E&P) sector, (2) streamlining regulatory requirements applicable to oil and natural gas exploration and production, (3) promoting risk-based decision making to help prioritize issues related to the E&P sector, and (4) developing lower cost environmental compliance and pollution reduction technologies for the E&P sector. Fossil Energy's gas program currently emphasizes RD&D in the areas of NORM, air emissions, waste treatment/disposal, and wetlands restoration.

Priority issues for these offices will change over time as legislative and regulatory agendas evolve, new knowledge develops, opportunities arise, and available technologies and industry practices change.

A View of the Trans Alaska Pipeline



Program Activity Summary

The natural gas environmental program is focused on analyzing data to identify environmental constraints to gas resource recovery. It also supports aggressive outreach and technology transfer efforts to identify stakeholder needs and communicate availability and potential of new technologies to improve environmental performance and to resolve environmental constraints. This program also includes characterization of health and environmental risks posed by gas exploration and production operations; development and demonstrations of technologies to improve economics and environmental performance of gas exploration and production operations; and downstream gas compliance technologies.

FY 1996-1998 Crosscut Budget Summary ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Fostering Understanding of Environmental and Energy Challenges	0.327	0.310	0.458
Streamling Regulatory Requirements	0.395	0.320	0.300
Promoting Risk-Based Decisionmaking	0.468	0.315	0.428
Developing Lower-Cost Environmental Compliance Technologies	1.850	2.125	2.081
Total	**3.040**	**3.070**	**3.267**

Program Schedule

Projects	1996	1997	1998	1999	2000	2001	2002
Fostering Understanding of Environmental and Energy Challenges							
Streamlining Regulatory Requirements							
Promoting Risk-Based Decisionmaking							
Developing Lower-Cost Environmental Compliance Technologies							

3.7.2 Project Descriptions

As highlighted in the budget summary, the Oil and Gas Environmental Research and Analysis Program divides its many functions into four key activity areas. These four activity areas, while not mutually exclusive, provide a useful framework for conceptualizing the design and implementation of projects undertaken by the environmental program. The four activity areas are:

- Fostering Understanding of Environmental and Energy Challenges
- Streamlining Regulatory Requirements
- Promoting Risk-Based Decisionmaking
- Developing Lower-Cost Environmental Compliance Technologies

Each of these four areas and examples of specific recent projects that fall within each are described in the following subsections.

3.7.2.1 Fostering Understanding of Environmental and Energy Challenges

Background

The collaborative process is a core component of all DOE Oil and Gas Environmental Research and Analysis Program activities. This involves building trust through sharing ideas and information, and the hard work of creating consensus, identifying needs, and finding solutions. When contentious issues are identified, the Office of Fossil Energy often serves as a facilitator between diverse parties such as industry, States, other Federal agencies, and the general public.

Major Goals

The major goals of DOE's efforts to foster understanding of environmental and energy challenges are to develop tools and analysis that can be used to illustrate to a broad audience links between costs of environmental protection and costs of natural gas production, highlighting benefits of appropriate environmental regulation and technology.

Project Objectives

Specifically, this project area seeks to:

- Provide the analytical basis for quantitatively demonstrating links between costs of environmental protection and natural gas production costs by developing analytical tools and applying them to analyzing cost/supply relationships under alternative cost and technology scenarios.
- Develop and report the inter-relationships between environmental production costs, gas production costs, and related supply impacts.
- Evaluate and report on relationships between environmental protection costs and potential abandonment rates of the Nation's marginal oil and gas wells and the resources associated with them.
- Assess potential environmental risks and resource recovery impacts of the Nation's orphaned and idle wells.
- Communicate information regarding relationships among environmental protection costs, gas production costs, environmental risks, and resource and supply implications to public and private decision makers and the general public.

Expected Benefits

The benefits of public education and fostering an understanding of links between environmental protection and energy production are substantial. Through its advocacy of legislative and regulatory initiatives within the government, the environmental program is often able to prevent the costly mistakes of ill-informed environmental regulation.

Based on the Office of Natural Gas and Petroleum Technology's report entitled "DOE Oil and Gas Environmental Program Metrics: Analysis and Results," significant benefits can be expected from FE activities related to regulatory advocacy and consensus building. In fact, DOE expects that through these functions, it could accrue present value benefits of greater than $3 billion through 2010.

Planned Products

- Development of the Gas Systems Analysis Model's (GSAM) Environmental Module to incorporate environmental costs and benefits into its analysis of regulatory and technological changes affecting the gas industry.
- 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.

Strategy (FY 97 Funding: $0.310 Million)

DOE's approach is to work with States and others to identify and address environmental challenges to sustained or increased gas production within States or regions. DOE will provide technical and economic analyses related to environmental and energy production interactions. DOE will communicate results of those analyses to States, other Federal agencies, and other stakeholders to provide rational, neutral inputs for policy debates.

Recent Accomplishments

FE's environmental program has been an active participant in the Green River Basin Advisory Committee. This committee is a forum for discussion and cooperative decisionmaking among oil and gas industry representatives, environmental organizations, hunting and fishing advocates, and local and State officials. This committee was created by the Secretary of the Interior to develop recommendations to assist the Bureau of Land Management make decisions that ensure timely development of oil and gas resources, as well as protect wildlife and other environmental resources that exist in the Greater Green River Basin area of Colorado and Wyoming.

Fossil Energy is also currently working on issues related to industry's cost of compliance with increasingly stringent environmental regulations. FE actively supports research and development of new technologies that could increase industry's environmental compliance with these newer regulations at lower costs than currently possible. FE also supports development and use of economic analyses to identify optimal allocation of limited energy resources and to assess potential social costs and benefits of proposed programs and regulations affecting the oil and gas industry.

DOE is developing an environmental module to be incorporated into its Gas Systems Analysis Model model. This environmental module will allow DOE to estimate the costs and benefits associated with various environmental regulation and technology. In addition, because the environmental module will function as part of the larger GSAM, it will allow DOE to estimate the ripple effects of environmental technology and regulatory changes on natural gas production at virtually any level of aggregation (e.g., reservoir, state, nationwide).

Cost Sharing ($ in Millions)

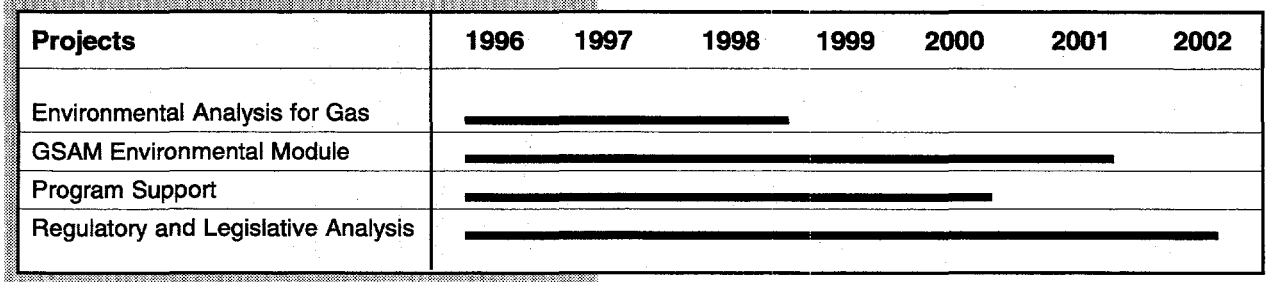
Most of the work performed in this area is conducted by the Department of Energy through its headquarters staff and support contractors and by the Federal Energy Technology Center and its on-site management and operating contractors. Unlike technology research, development, and demonstration efforts, cost sharing is not an expected element of funding for analytical work of this nature.

Program Funding

DOE Historical Spending ($ in Millions)

DOE Office	FY 1996	FY 1997	FY 1998
Environmental Analysis for Gas	0.000	0.060	0.025
GSAM Environmental Module	0.150	0.150	0.110
Program Support	0.177	0.000	0.033
Regulatory and Legislative Analysis	0.000	0.100	0.290
Total	**0.327**	**0.310**	**0.458**

Schedule



3.7.2.2 Streamlining Regulatory Requirements

Background

Cooperative streamlining efforts focus on simplifying regulation without compromising environmental protection, and on eliminating duplicative, unnecessary, or overlapping regulations. 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. The Oil and Gas Environmental Research and Analysis Program 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.

Major Goals

As part of its regulatory streamlining activities, the environmental program is investigating areas where the myriad of Federal, State, and local environmental regulations affecting E&P activities can be streamlined to avoid overlapping requirements. DOE has undertaken these activities as part of its responsibility, as directed by Presidential Executive Order 12866, to reform and make more efficient the current regulatory process. By promoting regulatory efficiency, both private and public resources can be freed to pursue more beneficial activities.

Project Objectives

There are three primary objectives of the environmental program's regulatory streamlining activities: (1) to reduce regulatory duplication; (2) to promote Federal and State cooperation in environmental regulation; and (3) to reduce regulatory barriers to the use of more efficient technologies.

Expected Benefits

The potential benefits of regulatory streamlining are enormous. By reducing the number of redundant environmental compliance regulations placed on natural gas producers, significant reductions in compliance costs can be realized. Based on the Office of Natural Gas and Petroleum Technology's report entitled "DOE Oil and Gas Environmental Program Metrics: Analysis and Results," present value benefits (through 2010) attributable to FE's regulatory streamlining efforts could be approximately $2.9 billion.

Planned Products

- Applied research on salt cavern disposal of naturally occurring radioactive materials (NORM).
- States Air Emission Compliance Manual.

Strategy (FY 97 Funding: $0.320 Million)

DOE's approach is to reduce redundancy of environmental regulations through: (1) establishment of a dialogue between various State and Federal regulators, (2) conduct of basic research that can serve as inputs for policy debates, and (3) development of regulatory/technical guidance documents that can help gas producers to comply with the myriad of environmental regulations in the most cost-effective manner possible. DOE's focus is both on reducing redundancy and burden of future environmental regulations, while ensuring a healthy environment, and on improving the gas industry's ability to effectively comply with existing regulations.

Recent Accomplishments

DOE has supported the Interstate Oil and Gas Compact Commission (IOGCC) to improve State programs for regulating the management of oil and gas wastes. DOE is also sponsoring IOGCC's Public Lands Project, which is 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.

In an effort to improve environmental performance, DOE is also working with States and industry to ensure that industry understands its current environmental compliance responsibilities. This effort includes developing modern, on-line permitting and environmental compliance advisory systems; developing environmental guidance manuals and compliance handbooks for the States of Colorado, Kentucky, New Mexico, Texas, and Wyoming, which summarize all environmental requirements in a single document; and developing guidance and workshops for small operators facing new requirements. These efforts are being undertaken to simplify environmental compliance for industry while improving environmental performance.

DOE is also actively involved with other regulatory streamlining projects, frequently acting as a facilitator between industry, States, and other Federal agencies to identify burdensome and overlapping regulations. Examples of these activities 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 innovation.
- Facilitating dialogue between States and the EPA on Community Right-to-Know and expansion of Toxic Release Inventory (TRI) requirements for oil and gas exploration and production through the Interstate Oil and Gas Compact Commission.
- Assisting the Bureau of Land Management with a National Performance Review of its onshore oil and gas regulatory program. This effort includes initiatives to simplify regulations for oil and gas operations on Federal lands, and incentives for increasing oil and gas production.

DOE is also working to eliminate existing regulatory barriers to use of innovative, more cost-effective technologies. For example, DOE is promoting use of synthetic drilling fluids, which were originally developed in response to prohibitions on discharge of conventional oil-based fluids and increasing restrictions on the discharge of mineral oil based fluids. Synthetic fluids offer increased drilling efficiency in addition to offering significant environmental and safety advantages over conventional fluids. The use of this new technology, however, is hampered due to the narrow construction of existing regulations. DOE is working with the Environmental Protection Agency and the Minerals Management Service to further evaluate synthetic drilling fluids and to eliminate any unnecessary regulatory barriers to their use and discharge.

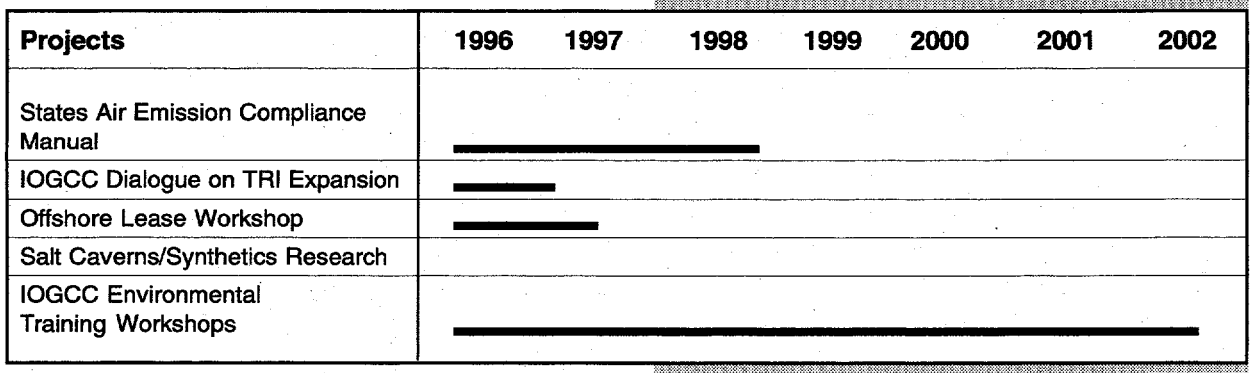
In addition to promoting synthetic drilling fluids, DOE is sponsoring research on the potential use of salt caverns for disposal of nonhazardous oil field waste. DOE is sponsoring this research based on preliminary analysis showing that salt caverns, currently used for storage of crude oil, natural gas, and hydrocarbon products, may offer a lower-risk alternative to landfill and surface pit disposal of oil field wastes. DOE supports development of a regulatory structure to allow this practice as an alternative to riskier disposal methods.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
State Air Emissions Compliance Manual	0.050	0.000	0.000
IOGCC Dialogue on TRI Expansion	0.040	0.000	0.000
Offshore Lease Workshop	0.005	0.000	0.000
Salt Caverns/Synthetics Research	0.150	0.160	0.150
IOGCC Environmental Training Workshops	0.150	0.160	0.150
Total	**0.395**	**0.320**	**0.300**

Schedule



3.7.2.3 Promoting Risk-Based Decisionmaking

Background

DOE assesses environmental risks associated with oil and gas E&P operations and develops data and tools to support risk-based regulation 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. The primary goal of the promotion of risk-based decisionmaking is to encourage use of credible science in the regulatory process.

Major Goals

DOE's Oil and Natural Gas Environmental activities seek to expand the capabilities of State and Federal government to make more cost-effective, risk-based regulatory decisions—promoting the application of sound science and common sense to the regulatory process. Ultimately, achievement of these goals should result in changes in State and Federal regulations and policies that will reduce environmental compliance costs and make more of the domestic resource base economical to produce.

Project Objectives

DOE conducts technical studies that provide input into policy debates by quantifying risks, thereby allowing costs and risks of future legislation and regulation to be weighed. The environmental program's major risk-related objectives are to continue to provide credible data, analytical tools, and guidance to States, other Federal agencies, and industry.

Expected Benefits

By adding credible scientific data on risks, costs, and benefits associated with various regulatory and technological decisions, DOE plays an important role that would otherwise go unfilled. The impacts of DOE's risk analysis work are important because they provide input for regulatory streamlining activities and for activities related to fostering an understanding of environmental and energy challenges.

In addition, by conducting applied research on risk assessment, DOE is uniquely positioned to provide guidance to the industry on emerging issues of risk such as the proper handling and disposal of radiologically contaminated materials.

Planned Products

- Radiological Risk Assessment Guidance Document for use in quality assurance during NORM disposal technology demonstration projects.
- *Eliminating Unnecessary Compliance Costs: Exemption from Area of Review Requirements:* Current Safe Drinking Water Act regulations require oil and gas producers to conduct a quarter-mile Area of Review analysis of disposal and injection wells. Under certain conditions, however, variances from this expensive requirement can be granted. DOE has supported the University of Missouri-Rolla in developing a system to be used by regulators to determine when such variances are appropriate. DOE is currently working with California, Kansas, Oklahoma, and Texas to implement this methodology.

Strategy (FY 97 Funding: $0.315 Million)

DOE's approach is to provide sound, scientifically based inputs related to risk assessment. DOE will support applied research related to emerging safety/risk issues in the gas production sector. This research will be transferred to the private sector in the form of guidance documents and technical assistance. In addition, over the longer term, DOE will continue to support

efforts to develop more realistic and accurate means of assessing and quantifying environmental and human health risks associated with natural gas production.

Recent Accomplishments

A current area of focus of the environmental program is the risk posed by naturally occurring radioactive materials. The environmental program's NORM work is primarily conducted at Argonne National Laboratory (ANL). As part of this work, a guidance document for conducting radiological risk assessments was developed to assist industry in the assessment and management of risks associated with exposure to NORM.

In addition to designing guidance documents for performing risk assessments, the environmental program is providing funding for additional studies to estimate the health and environmental risks associated with discharges of produced water and sand in the Gulf of Mexico region. Data on NORM, heavy metals, and hydrocarbons in water, sediment, and biota are being collected and evaluated. Health related impacts are being studied through field collections and analyses of commercially and recreationally important fish and shellfish tissues. Additionally, information on seafood catch, consumption, and use patterns for the Gulf of Mexico are being gathered and analyzed. The facilities being studied as part of this research include both offshore and coastal facilities in the Gulf Coast region. For the coastal sites, studies to determine the rate of ecological recovery of affected bays and wetlands are being undertaken to determine the long-term ecological risks posed by oil and gas production activities. Finally, all of these inputs are being used to inform decision making and to allow for a rational analysis of the costs and benefits of existing and proposed Federal and State effluent guidelines.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Radiological Risk Assessment	0.468	0.315	0.328
Tank Bottom Analysis	--	--	0.100
Total	**0.468**	**0.315**	**0.428**

Schedule

Projects	1996	1997	1998	1999	2000	2001	2002
Radiological Risk Assessment							

3.7.2.4 Developing Lower-Cost Environmental Compliance Technologies

Background

DOE supports development of more cost-effective environmental compliance technologies through its ongoing relationship with the national laboratories, through evaluation of technology performance, development of bench-scale and pilot demonstration projects, and by helping to remove regulatory barriers to development of these technologies. DOE's focus is on development of environmentally and economically beneficial technologies that could not be justified by a single company or a small group of companies. Some of these technologies have longer-term payoffs or higher risks than the private sector is willing to assume. In addition, because many benefits of these technologies are diffuse and societal in nature, individual companies are not likely to invest in their development. In addition, individual companies are often responsive to environmental regulations, rather than proactive in developing technologies that may reduce the need for future regulation.

Major Goals

DOE's primary goal in developing lower-cost environmental compliance technologies is to fill this crucial research and development niche that would go unfilled if left solely to the private sector. DOE strives to identify promising technologies that are unlikely to be developed in the private sector because the benefits are longer-term, the benefits of such technologies are diffuse but substantial, or for which future regulation could be reduced through the proactive development and implementation of technology.

Project Objectives

DOE seeks to develop technologies that would otherwise go undeveloped by the private sector because of long payback periods or diffuse benefits. Following development of these technologies, DOE will transfer these technologies to the private sector and will provide technical assistance to bring the new technology into field use. In addition, DOE will provide analytical data to environmental regulators to ensure that the newly developed technologies are approved for use.

Expected Benefits

DOE's actions in developing and transferring environmental technologies to the private sector can have both immediate and long-term benefits for society. Although the benefits of these technologies might not outweigh the costs for a single company, when the benefits are spread across the entire industry they become cost-effective. By moving forward state-of-the-art in environmental compliance, DOE not only helps the environment, but also ensures that domestic natural gas production can be sustained or increased.

Planned Products

- Development of an improved, remote-sensing methane leak detection system. This technology uses the Backscatter Absorption Gas Imaging (BAGI) technique combined with pulsed lasers and focal-plane array cameras to improve the ability to locate methane leaks by a factor of 100.
- Pilot project to demonstrate use of injected produced water into a gas reservoir to improve gas recovery and production economics with decreased disposal costs and improved environmental compliance.
- Pilot demonstration project by Greenhill Petroleum to prove that cuttings from gas exploration and development operations can be successfully used to reestablish wetlands in areas of old operations. Furthermore, this project hopes to demonstrate that native vegetation can be supported without adverse effects. The ultimate goal of the project is to gain approval by

the State for this alternative disposal method that reduces costs and improves the environment.

- Conduct bench-scale and field-scale testing of NORM treatment and disposal and simultaneously transfer radiological risk assessment guidance to the private sector.
- Development of NEPA compliance documents for both the bench-scale and field-scale NORM disposal demonstration projects.

Strategy (FY 97 Funding: $2.125 Million)

DOE's approach is to fund development of environmentally and economically beneficial technology. Following development of these technologies, DOE supports both bench-scale and field-scale demonstration projects to help these technologies gain acceptance. Finally, DOE works with both State and Federal regulators (e.g., providing them with performance data from demonstration projects) to ensure the new technologies will be approved for use.

Recent Accomplishments

DOE has continued to conduct applied research and development of cost-effective environmental technologies. DOE is continuing the process of technology transfer and the process of negotiation with State and Federal regulators to ensure that newly-developed technologies will be accepted for full-scale use. A number of examples illustrate DOE's recent accomplishments in this area.

The environmental program is currently sponsoring a project that demonstrates the effectiveness of injecting produced water to improve natural gas recovery. This project not only increases effectiveness of production, but also improves production economics by reducing water disposal costs and improving environmental compliance.

DOE is also sponsoring both applied research and a pilot technology demonstration of the viability and cost-effectiveness of using drill cuttings from gas exploration and development to reestablish wetlands in areas of old production operations. In addition, the project will attempt to demonstrate that native vegetation can be supported through such activities without any adverse environmental effects. Finally, this pilot project will generate data that will be used to help convince State regulators that this process should be allowed to both reduce disposal costs and provide environmental benefits.

Another significant area of DOE-sponsored environmental research is development of advanced methane leak detection technologies to improve both the speed and efficiency with which the natural gas industry is able to detect and respond to natural gas leaks. As mentioned above, DOE is supporting research into remote-sensing technologies that use the Backscatter Absorption Gas Imaging technique combined with pulsed lasers and focal-plane array cameras to improve the leak detection rate.

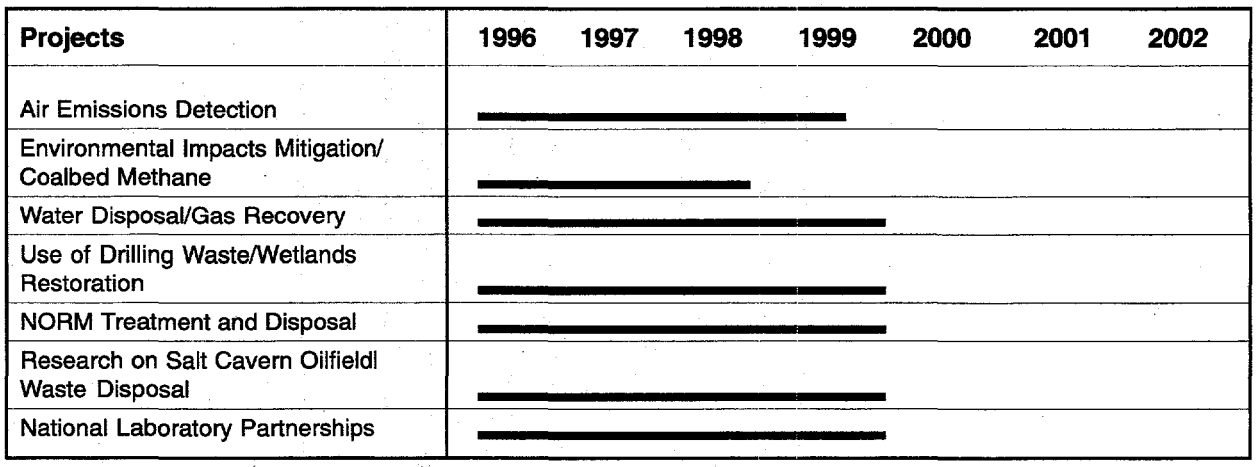
DOE's single largest technology development area is currently the development of improved methods for treatment and disposal of NORM waste. While there is currently limited regulation of NORM waste, DOE expects treatment and disposal of NORM to become an increasingly important regulatory and technological issue in the coming years. Based on this expectation, DOE is currently funding a number of separate research projects related to NORM treatment and disposal. The environmental program is funding bench-scale treatment and disposal tests for NORM waste. In addition, DOE is facilitating the field-testing of various NORM disposal techniques, as well as providing risk assessment, quality assurance, and safety oversight for the test projects.

Program Funding

DOE Historical Spending ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998
Air Emission Detection	0.239	0.153	0.189
Environmental Impacts Mitigation/Coalbed Methane	0.086	0.000	0.100
Water Disposal/Gas Recovery	0.085	0.031	0.125
Use of Drilling Waste/ Wetlands Restoration	0.155	0.175	0.291
NORM Treatment and Disposal	1.260	1.525	0.926
Research on Salt Cavern Oilfield Waste Disposal	0.025	0.091	0.000
Laboratory Partnership	0.000	0.150	0.450
Total	**1.850**	**2.125**	**2.081**

Schedule



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ER: Office of Energy Research

FETC: Federal Energy Technology Center

HQ: Headquarters

PO: Office of Policy and International Affairs