Gas
STORAGE
Program

Meeting Peak Demand for Natural Gas Supply

OIL AND GAS RD&D PROGRAMS

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

But, will this system continue to meet peaks in demand into the next century? At the same time forecasters are predicting increased demand for clean-burning, abundant natural gas, the gas industry faces unprecedented challenges. Extensive restructuring, driven primarily by Federal regulatory changes, has transformed the heavily regulated industry of the past into an intensely competitive, market-driven industry. Deregulation has placed significant demands on the gas delivery and storage system; market forces and competition are now the primary factors influencing change in the natural gas marketplace. New demands will intensify with impending state and Federal electric utility restructuring. Restructuring of the electric power industry in the United States is expected to have a major influence on business practices in the natural gas industry.

The gas industry also must address the need for pipeline system expansion in response to anticipated growth in electric utility demand for natural gas in the southeast, northeast, midwest; and the westward shift in gas supply. This trend raises important challenges for the gas industry, concerning the pipeline and storage system's capability to move and deliver gas, while planning maintenance for an aging system infrastructure. Despite the reliability of the U.S. energy infrastructure, challenges exist for sustaining system deliverability and reliability as our Nation approaches the next millennium.

Challenges facing the natural gas pipeline and storage industry require significant industry investment in R&D, at a time when the gas industry is focusing its resources on reducing costs and improving profits in a competitive marketplace. The Department of Energy is working with industry to improve the efficiency of the natural gas infrastructure and ensure system reliability, flexibility, and deliverability. Through its Gas Storage Program, DOE promotes the development of advanced technologies and methods to enhance, protect, and expand the delivery and storage system. Industry partnerships and cooperative technology research efforts will increase gas system deliverability, thereby contributing to our Nation's energy security, economic competitiveness, and environmental goals.

Gas Storage Program

The natural gas storage system provides a vital link between production and end-use. Advanced technologies will be a key factor in meeting challenges facing the natural gas pipeline and storage industry.

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

Federal deregulation has imposed fundamental changes in the natural gas industry structure. A key aspect of the Federal Energy Regulatory Commission (FERC) Order No. 636 deregulation is the unbundling of gas transportation service from the supply function, which can no longer be included into the supplier rate base. The gas pipeline industry must now provide each of their services individually and at increasingly competitive prices.

Gas storage is the primary means of managing fluctuations in supply and demand, and is an essential component of an efficient and reliable interstate natural gas transmission and distribution network. Gas storage is used for two primary purposes: to meet seasonal demands for natural gas (base-load storage), and to meet short-term peaks in demand (peaking storage), which can range from a few hours to a few days. To ensure that adequate natural gas supplies are available to meet seasonal base-load customer requirements in winter, industry injects large amounts of gas into underground storage reservoirs from April through October. During these nonheating season months, gas demand declines as temperatures rise. During the heating season, industry supplements pipeline capacity from the producing regions with supplies from storage to meet demand. Gas withdrawn from working gas storage can supply up to 30 percent of daily gas demand in winter months.

Storage enables greater system efficiency by allowing more level production and transmission flows throughout the year. Because of this leveling effect, storage decreases the amount of new transmission pipeline needed to connect the producing regions to the marketplace by 50 percent. The pipeline company itself can avoid the need to expand transmission capacity from production areas. This can be achieved by using or establishing new storage facilities in market areas where there is a strong seasonal variation to demand.

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

Government Role

The natural gas system infrastructure is vital to the security, economic prosperity, and social well-being of the Nation. DOE is working with industry to ensure that the gas delivery and storage system continues to provide a reliable, cost-effective supply of natural gas well into the next century.

Through its Gas Storage Program, DOE supports the development of advanced technologies and methods to enhance deliverability, increase system efficiency, and maximize gas storage capacity. Transmission and local distribution companies (LDCs) are facing growing competitive challenges. The allowable regulated rate of return on the gas storage asset may act as a disincentive for LDCs non-field gas storage well maintenance and enhancement R&D. In addition, state regulatory restructuring may be a further disincentive to research and development investment by LDCs in gas storage technologies because technology R&D may not be considered part of any stranded capital cost settlement.

Electric power restructuring will require the development of advanced on-site storage for distributed power generation to sustain peak electric deliverability and system reliability, and to reduce disruption of service. The regional demand potential for gas may exceed the capability of the storage industry to develop advanced storage concepts. DOE's gas storage research program focuses on developing non-traditional sources for gas storage. This provides a national knowledge base for new storage systems and technologies.

The objective of the program is to advance deliverability-enhancement technology to provide more efficient utilization of the Nation's gas storage assets in response to the growing gas demand for power generation and for reliable natural gas supply.

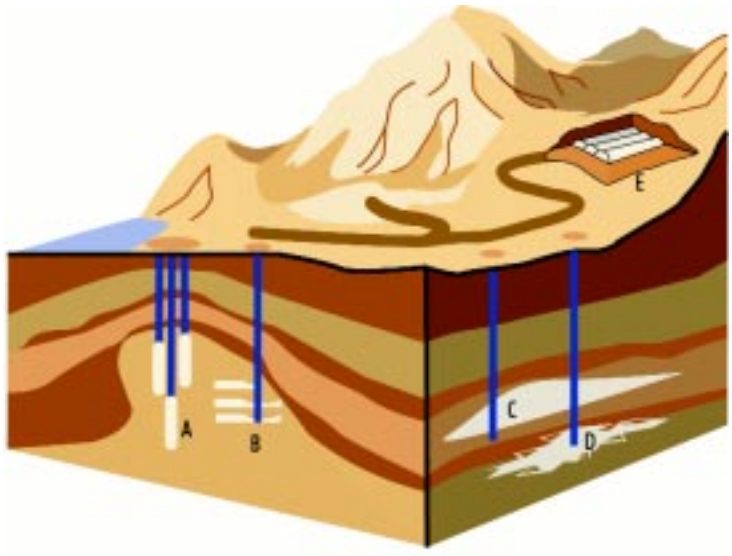
End-use customers gain from such system efficiency with reduced overall costs of service. Storage also allows continuous service even when production or pipeline transportation services are interrupted. In 1992, for example, storage enabled continuous service despite damage to gas production facilities caused by Hurricane Andrew.

Industry will need to expand the existing gas storage system to meet anticipated future demand for gas, which is forecasted to increase by as much as 6 Tcf by 2010 and 10 Tcf by 2020. This rising demand raises concerns about the system's ability to meet peak requirements in the future.

Gas Storage Must Address Shifts in Supply and Consumption.

Natural gas is distributed to virtually every region of the country through an extensive system made up of more than 1.3 million miles of pipeline, meters, compressor stations, and approximately 410 storage reservoirs. The gas industry currently has the capability to deliver approximately 75 Bcf per day during peak periods. In 1997, total working gas storage capacity from U.S. gas storage sites was 3.8 Tcf. These sites are heavily concentrated in and near major eastern and midcontinent markets.

The significant shift in natural gas supply and consumption patterns expected by 2010 will create a need for new natural gas pipeline transmission and storage facilities. With the anticipated decline in production from the southwest central region, additional transmission and storage capability will be required to move gas from the Rocky Mountains and Canada to neighboring regions and to expanding markets in the northeast, southeast, and California.



Resources for underground storage include: (A) salt caverns, (B) mines, (C) aquifers, (D) depleted reservoirs, and (E) hard rock caverns. Depleted reservoirs are the most common and the least experience to develop, operate, and maintain. Aquifers are usually used when depleted reservoirs are not available. Salt cavern storage offers high deliverability.

Industry Issues

- *Development of novel and advanced fracture stimulation technologies*
- *Improved gas flow metering and energy measurement technologies*
- *Advanced storage technologies to meet the needs of new and growing industrial and power generation markets*
- *Re-engineering of underground gas storage reservoirs to increase operational flexibility*
- *Optimization of deliverability of gas to consumers via low-cost gas storage systems*
- *Improved methods and lower costs for storage system operation and maintenance*
- *Extended useful life of underground storage reservoirs*
- *A better understanding of reservoir damage mechanisms*
- *Development of liquefied natural gas "peak-shaving" technology*
- *A distributed storage system to increase gas system deliverability and service reliability*

The Role of DOE

The gas storage industry currently spends over $100 million annually for deliverability enhancement ($80 million for deliverability revitalization and $20 million for gas storage field infill drilling). New and novel advanced stimulation and revitalization technologies could reduce these maintenance costs by 20 percent. In sharp contrast, less than $3 million per year is spent on gas storage technology research and development ($1.6 million by Gas Research Institute and $1 million by DOE). DOE and GRI projects focus on high-priority technology needs as identified by industry.

The Gas Industry RD&D Initiative Group,* in its January 1998 report, *Funding Recommendations to the U.S. Department of Energy for Natural Gas Research, Development, and Demonstration,* highlighted transportation and storage needs as part of a broad program of technology developments recommended for government support. Specific storage needs cited include:

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

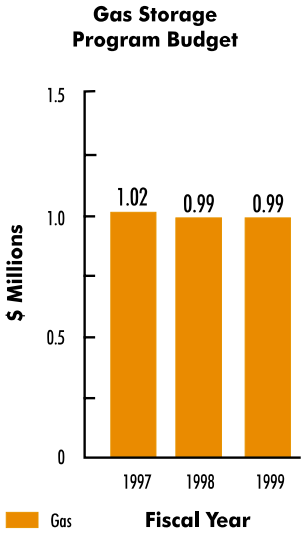
The National Petroleum Council, in its 1995 study, *Research, Development, and Demonstration Needs of the Oil and Gas Industry,* ranked technologies for well deliverability restoration and reservoir management as high priority needs in both the short- and long-term.

** Formed in 1989 specifically to address issues affecting accelerated natural gas research and technology development. The group comprises 37 natural gas companies and six RD&D trade organizations.*

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

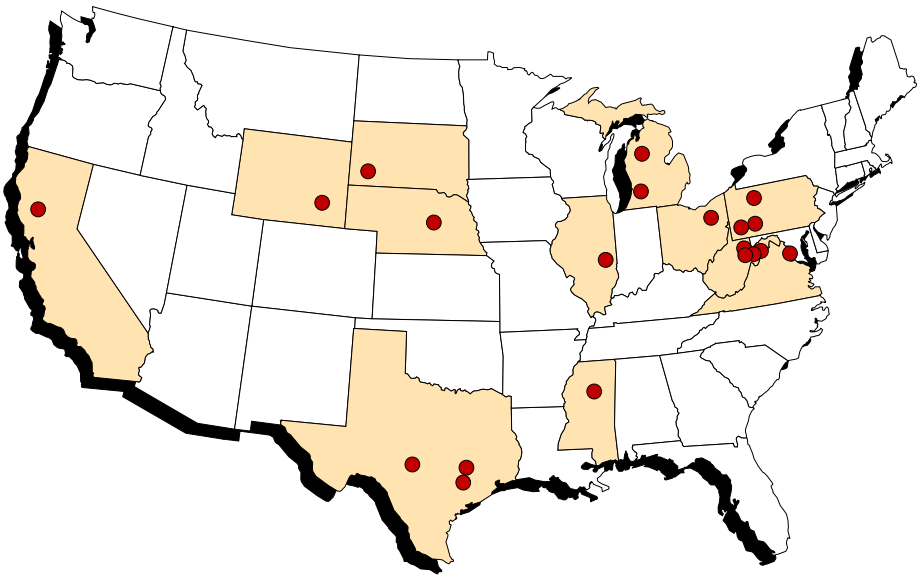
Joint DOE-industry projects are selected for their potential application throughout the gas industry. Current technology development efforts include:

- Novel and advanced fracture stimulation technologies and improved remediation treatments that will increase storage reservoir deliverability and help to offset the reported 5.2 percent annual decline in deliverability;
- The development of improved gas flow metering and energy measurement technologies that will provide real-time, automated monitoring of pipeline gas flow and energy content, increasing system deliverability, and optimizing gas sales to customers; and



Project Sites

The Gas Storage Program currently involves 21 projects in 12 States.



Drivers

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

Goals

- Develop advanced natural gas storage, transmission, and distribution technologies to enhance operational flexibility and deliverability of the Nation's gas storage system.
- Provide a cost-effective, safe, and reliable supply of natural gas to meet demand in new and expanded market regions.
- Advance technologies and methods to increase the efficiency and reliability of the natural gas gathering, transmission, storage, and distribution system.

Gas Storage Program

Strategies

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

Measures of Success

By 2010, DOE and industry partnerships will provide 255 Bcf/year of additional natural gas storage well deliverability, which will yield a more efficient gas market by improving gas storage service to consumers.

- New and novel storage well revitalization technologies will increase deliverability and reduce costs of storage well revitalization and deliverability maintenance by $25 million per year.
- Advanced storage technologies (lined rock caverns, refrigerated mined caverns, or others) will be used to meet the projected 400 Bcf growth in peak gas demand in regions of the U.S. without conventional gas storage options.
- Ultrasonic meters will be widely used at U.S. storage facilities because of their increased accuracy, lower installation costs, reduced operating costs, and better inventory control. These meters will save gas consumers $200 million dollars annually in unaccounted gas losses from storage facilities.
- Direct energy meters with real-time flow measurement and energy content monitoring technologies will increase pipeline capacity utilization and improve system reliability.

- Advanced storage technologies that will meet the specific storage needs of new and growing industrial and power generation markets, specifically the short-term or hourly requirements of the power generation sector.

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

Potential Benefits

Development of advanced technologies that meet industry needs would result in a more efficient natural gas storage system and benefit both industry and consumers. The gas storage industry would benefit 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 (i.e., access to gas storage currently not available), while residential customers would benefit from lower costs for service.

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

Relationship to Other DOE Programs

Once natural gas is produced, the gas delivery and storage system provides the link between wellhead and burner tip. 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 and reservoirs.

Program Areas

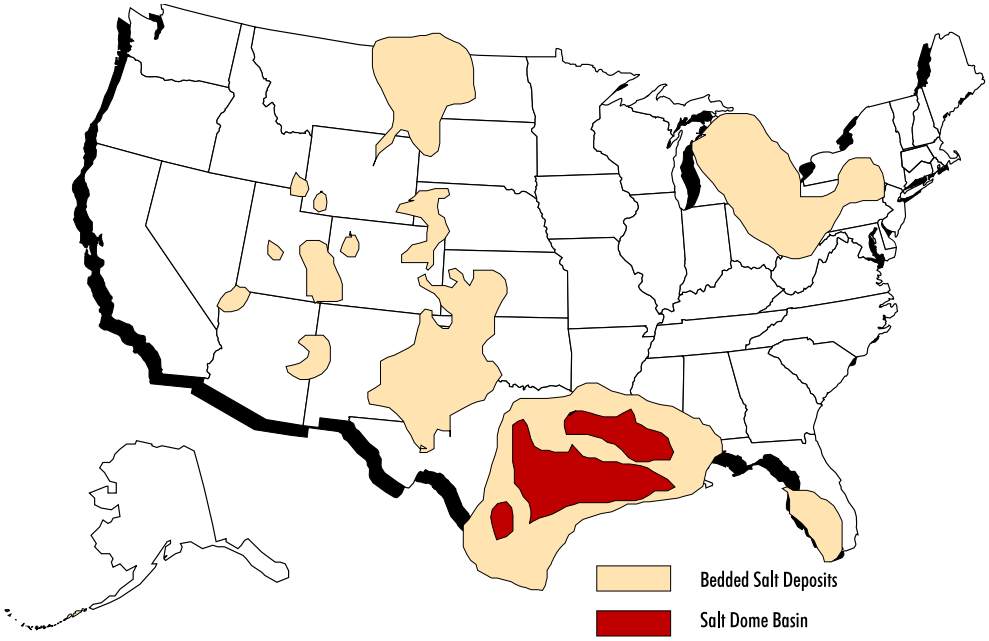
Program areas are:

- Reservoir Management
- Storage Well Deliverability Enhancement
- Advanced Storage Concepts for power generation and other end-users
- Gas Measurement and Metering

Southern California Gas Company's Gas Well Storage Field in Alisa Canyon, California

Major Salt Cavern Gas Storage Fields

Salt cavern storage, (currently 27 sites in the U.S.) is well suited for meeting dramatic swings in natural gas demand because of its high deliverability.



Reservoir Management

A horizontal well, drilled by Northern Indiana Public Service Company (NIPSCO) as part of a Cooperative Research and Development Agreement (CRADA) with DOE, has enhanced the economics of its storage operation. Initial flow tests showed that the horizontal well significantly improved gas deliverability from the Royal Centers gas storage field in Cass County, Indiana. The horizontal well provides access to gas and utilization of gas from an area of the storage field that was isolated from its vertical wells. Project success is attributed to the coordinated efforts of NIPSCO, DOE, and GRI contractors to integrate the geologic modeling and seismic surveying that was used to characterize the field.

Liquefied Natural Gas Storage Tank

Storage Well Deliverability Enhancement

Research in this area focuses on technology projects that reduce storage well maintenance costs and enhance deliverability from storage wells. Project partner, Advanced Resources International, is demonstrating the application of advanced fracture stimulation technologies to revitalize existing underground gas storage wells. The new and novel fracture stimulation technologies for revitalization of existing gas storage wells are: (1) tipscreenout* – short, highly-conductive, hydraulically induced fractures; (2) liquid Carbon Dioxide/Sand fracturing; (3) extreme overbalance – fracturing with a rapid pulse of high pressure nitrogen; and (4) high-energy gas fracturing using solid fuel propellant.

Many storage wells decline in deliverability after several years of production/injection cycling and require remediation to establish deliverability. The gas storage industry spends approximately $80 million annually to revitalize existing wells, but current revitalization methods, such as mechanical cleaning, blowing/washing, acidizing, and perforating, often provide only limited, temporary delivery restoration. New and novel advanced fracture stimulation technologies show high potential for long-term deliverability improvement at moderate cost.

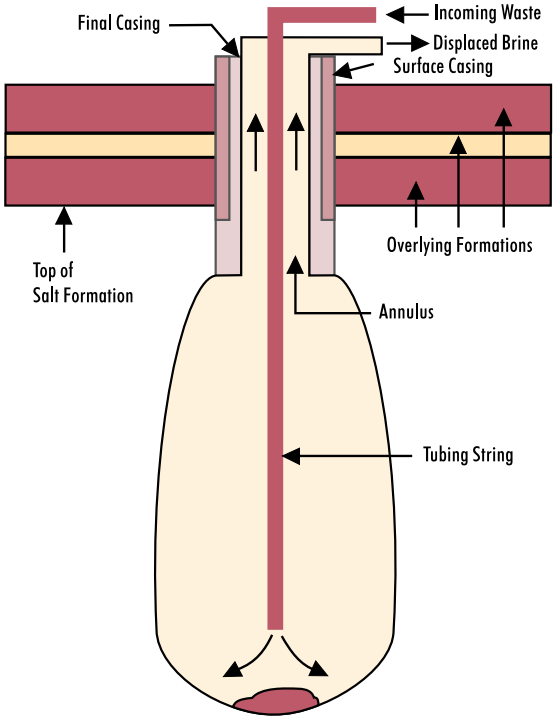
** Tipscreenout: pressurization and injection of proppant further from the wellbore for better fracturing and oil and gas production.*

Field testing of the tipscreenout fracture, extreme overbalanced fracturing, and Carbon Dioxide/Sand fracturing technologies has been completed in six gas storage fields in Nebraska and Pennsylvania. Follow-up monitoring and data analysis from these demonstrations will provide guidance and methodology for other gas storage field operators to use advanced fracturing technologies to optimize both individual well treatments and overall field performance, and to minimize deliverability losses.

Not all storage wells can benefit from fracture stimulation technology. ONGPT and the Gas Research Institute teamed with Halliburton Energy Services to provide damage assessment guidelines for storage field operators to identify the cause of capacity losses in their wells. These guidelines help operators to select an appropriate remediation, leading to more cost-effective treatments. The next step in this work is now underway, focusing on characterizing the geochemical conditions that promote the damage and lead to the decreased performance, identified by Halliburton; and designing and successfully demonstrating practical and cost-effective, preventative or remedial techniques.

Advanced fracturing technology was introduced to an operator with no prior fracturing experience at the Huntsman gas storage field in Cheyenne County, Nebraska. Deliverability was improved by 16 Mmcf in a storage well by rigorously applying pre-fracture diagnostics to improve job design, and to overcome the limiting conditions of thin caprock and high reservoir permeability.

High formation in-situ stresses and a thin-bedded lithology were combined to prevent effective hydraulic fracturing at the Donegal gas storage field in Washington County, Pennsylvania.



An idealized cavern in a salt dome formation. DOE research is investigating ways of increasing working gas.

Extreme overbalanced (EOB) fracturing was introduced to the gas storage industry at this site for application in wells with conditions that are difficult to stimulate by hydraulic means. The rigorous data analysis and job design demands in the Donegal field prompted 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 benefitting the worldwide oil and gas industry.

Fracture stimulation with liquid carbon dioxide and proppant demonstrated immediate dramatic improvements in deliverability at the Galbraith gas storage field in Jefferson County, Pennsylvania. Two of three stimulated wells had improvements of six- and seven-fold in absolute open flow at maximum reservoir pressure. These were the first ever carbon dioxide/sand fracturing stimulations in a gas storage reservoir.

A GRI/DOE co-funded project completed research on 33 wells in 12 gas storage fields to identify the damage mechanisms responsible for losses in well deliverability. Bacteria and inorganic precipitates (iron compounds, sulfates, and carbonates) were identified as the leading cause of deliverability reduction in the wells studied. Other damage mechanisms identified were oils (both compressor and naturally occurring), production chemicals, mechanical obstructions, stimulation fluids, and sanding. Damage assessment guidelines were established for use by storage field operators to identify the cause of capacity losses in their wells.

Success Story

Storing Chilled Gas in Hard Rock

PB-KBB of Houston, Texas, merged advanced mining technologies and gas refrigeration techniques to develop conceptual designs and cost estimates. The company will demonstrate the commercialization potential of storing chilled natural gas in a 5 Bcf, conventionally-mined, hard rock cavern facility. The refrigerated mined cavern storage concept provides a multi-cycle, high-deliverability peaking option to LNG for regions of the U.S. without salt cavern storage.

Advanced Storage Concepts for Power Generation and Other End-Users

The energy industry forecasts that the Nation's total power generation requirements will increase by 20 percent in the next decade, and that natural gas will supply as much as 40 percent of that increase. The EIA forecasts that gas demand in the industrial market will increase 5 to 10 percent by 2005. The New England and South Atlantic regions have a combined projected growth of 1.7 Tcf of gas by 2010.

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

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

Innovative natural gas storage concepts are required to meet the needs of the natural gas industry and end-use customers through the year 2010. Advanced gas storage concepts research will consist of feasibility studies aimed at demonstrating the potential for full-scale field development and commercialization. These studies will focus on the technical and economic merits of the advanced storage concepts, with respect to their intended market areas and end-users. New and innovative natural gas storage concepts will be the focus, instead of re-engineering of existing underground natural gas storage facilities. These new or improved storage methods will provide storage in areas where conventional storage is not available or does not meet the requirements of end-users.

Current projects addressing these needs are investigating the feasibility and commercialization potential of storing natural gas in: "Lined Rock Caverns" (LRC), "Refrigerated Mined Cavern Storage" (RMC), "Natural Gas Hydrates as a Storage Medium" (Hydrates), and "Improved Modeling of Salt Cavern Design and Integrity" (Salt Cavern). The LRC project is exploring the engineering and economics of constructing facilities in Atlanta, Georgia (4 Bcf of working gas) and in Boston, Massachusetts (2 Bcf of working gas). An RMC study, completed for a 5 Bcf working gas facility, in the Baltimore/Washington, D.C. metropolitan area, shows that the concept is economically competitive with LNG

on a single cycle basis, and is superior to LNG when the benefits of multi-cycle, baseload planning, and daily and monthly balancing capabilities are considered. Initial results from the salt cavern study indicate that minimum working gas pressures in most existing salt cavern storage facilities can be lowered 10 percent without compromising cavern stability. Extrapolating these results across the "in-place" industry would result in a 17 Bcf increase in storage capacity, with no changes to existing infrastructure. Work is ongoing to confirm these results.

The Hydrates project is exploring novel methods of efficiently and economically forming and decomposing gas hydrates as a storage medium. Theoretically, 181 standard cubic feet of gas can be stored per cubic foot of hydrate.

ULTRASONIC METER

Instromet 8" Q. Sonic-3 Path Custody Transfer Meter
Photo courtesy of Instromet, Inc.

Gas Measurement and Metering

Using ultrasonic meters to measure natural gas flow

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

- Bi-directional testing for undisturbed flow conditions over a range of gas pressures and temperatures;
- Testing to evaluate thermowell effects on ultrasonic meter performance;
- Low range testing, conducted at pressures below 200 pounds per square inch (psi), to check the accuracy and repeatability of ultrasonic meters down to about 0.2 percent of the rated flow capacity; and
- Compilation and evaluation of field performance data from industry trials.

Ultrasonic metering technology offers significant cost savings for industry, including potential installation savings of 35 to 55 percent over typical orifice/turbine meter transmission measurement stations. Projected operating and maintenance cost savings

range from $9,000 to $15,000 primarily due to fuel gas savings from pressure loss reduction.

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

Accurate Energy Content Measurement

Virtually all natural gas produced in the U.S. is used as fuel. As such, its intrinsic value lies in its heating value. However, because of the lack of low-cost, reliable instrumentation for measuring energy content or energy flow rate, natural gas traditionally has been bought, sold, and transported on the basis of volume. Gas composition and energy content are currently determined by periodically analyzing sampled gas from the pipeline.

With the advent of deregulation and open access in the gas pipeline industry, large-volume, long-term commodity gas contracts gave way to more small-volume, short-term transportation contracts, taking gas "packages" from many supply and storage fields with widely varying gas qualities. These gas packages lose their identity when mixed in the pipeline, and the purchaser receives whatever is in the pipeline at the time of need. Without economical means for continuously (real-time or near real-time) measuring the quality of gas entering and exiting the pipeline, neither the supplier nor the end-user can assure quality of the commodity exchange. Also, gas supplies cannot be blended to assure conformity to a quality standard. End-users withdraw gas on the basis of energy needs. If the energy content is low, end-users simply withdraw (and pay for) more gas than anticipated.

DOE will explore ways to reduce the costs of energy measurement-capital, operating and maintenance, while maintaining and/or improving measurement accuracy. The answer may lie in a totally new metering concept or in the refinement of the existing approach of combining energy content measurement and flow rate measurement. Benefits from improved energy content measurement accuracy include: more equitable transactions with fewer disputes, better quantification of unaccounted gas attributed to leakage, and more accurate inventories of pipeline (line pack) and storage well gas, which can improve deliverability and efficiency of operations for a given system capacity.

Success Story

Ultrasonic Meter Tested for Accuracy

Southwest Research Institute (SwRI) has shown that ultrasonic flow meters can provide the required accuracy necessary for use at gas storage facilities. Over the last 18 months, tests have shown the ultrasonic meter is extremely accurate at high flow rates, can accurately measure gas flow in both directions, and is basically insensitive to changes in temperature. The testing also showed that the effect of a thermowell (needed to provide temperature data) located upstream of the meter is very small.

The ultrasonic meter can revolutionize the gas energy industry by dramatically reducing capital and operating costs associated with measuring gas composition. The industry requires detailed, real-time energy composition data, and the ultrasonic meter has the potential to reduce the reliance on the traditional gas chromatograph meter for conducting gas composition assays at every custody transfer location.