SECTION 1.0
Introduction

1.1 OVERVIEW

The U.S. Department of Energy's National Energy Technology Laboratory (DOE/NETL) hosted a one-day collaborative workshop on Natural Gas Storage research and development (R&D) in Pittsburgh, Pennsylvania, on November 29, 2001. The purpose of the workshop was to develop a roadmap of the technologies needed to improve conventional storage field performance and to supply the anticipated demand for natural gas to fuel power generation plants using advanced storage concepts. Participants were asked to recommend priorities for natural gas storage R&D and to explore ways in which DOE can collaborate with industry and others to accomplish priority R&D in public/private partnerships.

The information gathered on industry's technical challenges and needs will help provide a foundation for a roadmap to guide natural gas storage R&D in industry and government and to guide R&D solicitations. Identifying and developing these solutions will ensure that the U.S. natural gas storage infrastructure will continue to meet the needs of consumers for decades to come.

1.2 WORKSHOP PROCESS

Fifty-one participants from 39 organizations representing a cross-section of interests and expertise from industry and academia participated in the workshop (see Appendix B). Discussions of technology challenges, needs, and actions took place in three separate facilitated groups. Two groups focused on conventional storage issues, while the third group concentrated on gas storage for power generation and remote off-pipeline issues. Each group developed a list of challenges and barriers to improved natural gas storage. Participants then developed opportunities for R&D that could provide means of overcoming these barriers. The top R&D needs were selected through a consensus process, and implementation strategies were developed for each. These strategies include the following: component R&D activities and steps; capabilities, tools, facilities, and resources; collaborations, partners, and government role; geographic benefits; and impacts for deliverabiliy and cycling, cost savings, safety and security, capacity, environmental, and reliability.

1.3 WORKSHOP RESULTS

1.3.1 Summary

Figure 1 summarizes the results of the three work groups. Integrity assessment and reservoir characterization are major crosscutting R&D needs among the groups. The development of new methods for creating storage reservoirs with proof-of-concept testing and reservoir management including optimization are prevalent, too. Each of these needs is discussed below.

Integrity needs should address the technical risk associated with the long-term geotechnical integrity of bedded salt caverns including deformation and roof leaks. Component activities include failure analysis and definition, with inspection and monitoring feedback for better assessment and control. Other integrity issues deal with development of advanced casing inspection tools capable of assessing pipe condition for metal loss and remaining strength. Component activities include developing correlations between log interpretations and strength of materials to determine wellbore integrity. Better integrity assessment would have positive safety and environmental impacts.

Reservoir characterization R&D should evaluate capacity and deliverability with an emphasis on using seismic technology applications for better characterization and monitoring with coupled reservoir and

surface simulators. Integration of industry technologies could attack the problem. For example, E&P tools could be applied to storage problems by reversing the focus from production to injection and cycling issues. Advanced data interpretation will help identify damage and optimize performance. Potential impacts for deliverability, cost, capacity, and reliability are enormous for all locations, both new and old.

New methods for creating storage reservoirs must be pursued, although the cost impact will likely to be minimal given proof-of-concept development expenses. The continued R&D into lined rock caverns is warranted given successful breakthroughs in Sweden and feasibility progress. Other potential new methods include thermal re-excavation and liquefaction and new locations such as abandoned coal mines.

Reservoir management R&D should develop a method for brine disposal and prevent and handle hydrates formed during operations. Activities include basic chemistry, computational flow and fluid dynamics, and thermodynamic studies. There would be good cost savings with brine disposal. Development of a downhole barrier to gas migration would have a beneficial impact on capacity, and it would be widespread especially for aquifer operations.

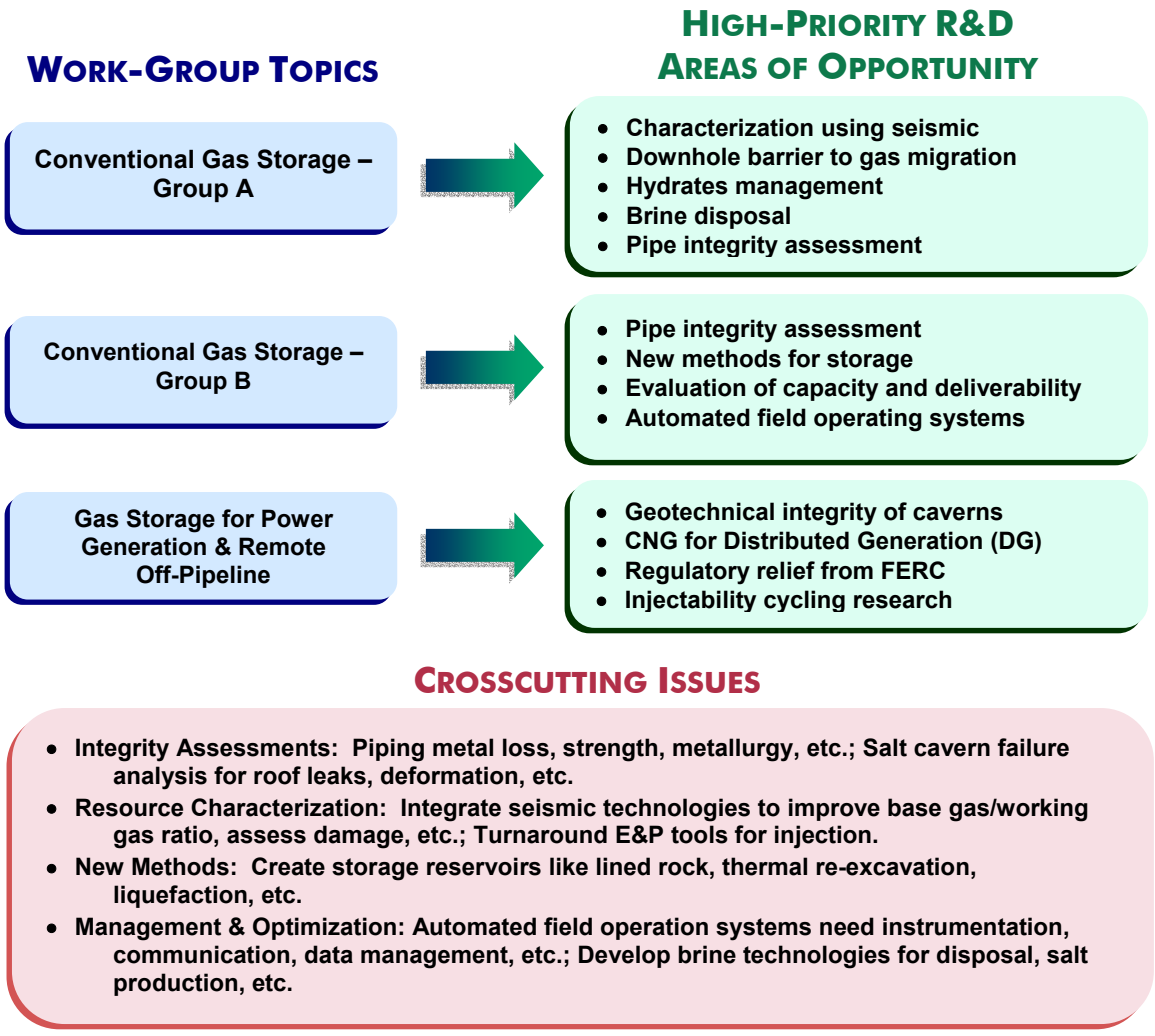

Figure 1. Overview of Gas Storage Workshop Results

1.3.2 Key Challenges and Barriers

The past decade has brought about significant changes to the natural gas storage industry. Due to environmental restrictions, natural gas has become the fuel of choice for new power plant developments, particularly to meet summer peaking loads. As a result, the injection season has become longer and cycling rates have become higher. Growing consumer demand and unpredictable weather fluctuations have increased market volatility. Storage operators are required to stretch the limits of their aging facilities beyond their original design capabilities to meet these needs. Despite the growing demand and increasing gas prices, the industry is wary of investing capital to build new storage due to the uncertainty and risk involved. All of these factors have challenged the status quo within the natural gas storage industry. However, they also present new opportunities for growth for the industry.

Reservoir Characterization

Identifying and characterizing reservoirs continues to present a major challenge to the expansion of storage capacity. Three-dimensional seismic technology is expensive and does not adequately characterize formation properties, such as heterogeneities. Nor does it identify gas-filled porous bodies in reef structures. Unconventional storage reservoirs hold promise; however, more data are needed before they can be used in commercial operations. Plus, they often need expensive modifications before they can be useful.

Wellbore Integrity

Damage at the wellbore can cause unpredictable effects, resulting in downtime and lost revenue. The source and mechanisms of wellbore damage are not well understood because of the lack of tools available to collect data. Wellbore condition is not frequently monitored because of the lack of diagnostic techniques.

Reservoir Management

Reservoir management encompasses a wide range of issues. For instance, high levels of expensive cushion gas are needed to ensure deliverability. Inventory levels are difficult to verify without downtime, and non-intrusive monitoring systems are unavailable. Gas migration poses safety hazards as well as lowers the efficiency of the system. Gas hydrate formation is not well understood, and hydrogen sulfate removal is quite expensive. Furthermore, the operation and maintenance costs to maintain the integrity of aging facilities are rising at an incredible rate.

Market Conditions & Regulatory Environment

As mentioned above, consumer and industrial demand is growing at a steady pace. However, the market continues to show significant volatility due to weather unpredictability and other factors. Regulations on the power generation industry deter utilities from building storage reservoirs. Air emissions limitations restrict injection, and reservoir pressures are limited in most states, reducing storage capacity. The cost of pipeline use is on the rise for utilities, who must compete with entities whose expenses are often subsidized.

Cycling and Injectability

The current natural gas storage infrastructure was originally designed for seasonal service, not for year-round injection and withdrawal. Existing facilities were not designed to handle short-notice injection or withdrawal. Injection flow rates are limited by pipeline constraints. Furthermore, skin damage in high rate storage wells limits peak rates.

1.3.3 R&D Priorities and Implementation

The research priorities delineated here, if developed and implemented, promise to help the natural gas storage industry to surmount the tremendous obstacles they currently face and to guide them successfully into the future. While all the research opportunities available hold value, four in particular surface as the top research priorities. These priorities possess the most potential in addressing the industry's needs over the next fifteen years. The descriptions here also outline the key technical elements needed to achieve each goal, as well as the resources and collaborations critical to implementing the strategy. Government, industry and academia all have a role to fill in accomplishing these objectives and ensuring the reliability of the natural gas storage infrastructure for years to come.

Top Priority Research Needs
➢ Develop advanced methods of assessing, monitoring and improving wellbore and geotechnical integrity.
➢ Develop innovative and non-intrusive techniques to identify, characterize and enhance storage reservoirs.
➢ Develop means of optimizing field operations through automation, hydrates control, and improved base gas to working gas ratio.
➢ Develop cost-effective solutions to the technical issues affecting the unique natural gas storage needs of the power generation industry.

R&D Priority

Develop advanced methods of assessing, monitoring and improving wellbore and geotechnical integrity.

Description	Key Technical Elements
Wellbore integrity continues to be a critical factor in natural gas storage operations, particularly as existing sites begin to age. In order to significantly improve operations, the industry needs advanced methods of economically assessing and monitoring characteristics of wellbore integrity, including metal loss, stress (delta pressure), remaining strength, and other parameters of pipe condition. Enhanced inspection tools that could immediately identify and diagnose problem areas would prevent accidents, reduce downtime, and increase overall reliability. Further, an analysis of the primary sources and mechanisms of wellbore damage, as well as research into methods of preventing this damage and improving wellbore integrity, would enhance the lifespan of existing and future storage reservoirs. Advanced materials specifically designed for storage applications would further improve the strength and longevity of wellbore structures.	• Baseline study of wellbore damage mechanisms and impacts, particularly on deliverability • Benchmark evaluation of current inspection and monitoring tools • Development and dissemination of best practices for preventing wellbore damage • Piping thickness surveys and metallurgical analyses • Development of correlations between log interpretations and materials stress and strength • Advanced data interpretation • Strength of materials modeling • Non-destructive evaluation and other techniques to determine the type and extent of wellbore damage • Remote sensing technologies • Design parameter characterization • Advanced materials research • Demonstration projects

Implementation Strategy

Resources	Government Role	Potential Partners
• Tool research • Industry logs • Burst test results • Pipe correlation data	• Provide funding • Coordinate research • Technology transfer • Facilitate implementation	• American Petroleum Institute • Interstate Oil & Gas Compact Commission • American Society of Mechanical Engineers • Society of Petroleum Engineers • Southwest Research • Battelle • Universities • Service companies • National laboratories

R&D Priority

Develop innovative and non-intrusive techniques to identify, characterize and enhance storage reservoirs.

Description	Key Technical Elements
Expanding the roster of storage reservoirs is essential to ensuring the future supply of available natural gas for residential and commercial use. New technologies must be developed that can economically and non-destructively locate and identify geologic formations that would serve as good storage reservoir candidates, including rock caverns, aquifers, salt caverns, and man-made structures such as abandoned mines. Once these formations have been identified, seismic and alternative technologies are needed to characterize the various properties of the structure, such as capacity, porosity, and permeability, and assess its value as a storage reservoir. Lastly, economic methods of altering the structure to make it more suitable to natural gas storage would enhance its efficiency and significantly add value to the reservoir. Some of these techniques include brine disposal methods, sealing methods, refrigeration and thermal re-excavation. These developments would open up a vast array of new storage sites, optimize existing storage efficiency, and reduce the geographic imbalance of available storage across the U.S.	• Geographic benchmark/baseline study • Regional geological feasibility cost-benefit analyses • Controllable, non-surface seismic and alternative, non-invasive technologies • Remote sensing technologies • Fine-resolution geophysical modeling and simulation • Sealant materials studies • Brine disposal methods • Development of excavation techniques • Refrigeration research • Reservoir performance optimization studies • Diagnostic techniques to identify good stimulation candidates • Demonstration projects

Implementation Strategy

Resources	Government Role	Potential Partners
• Geological studies • Drilling techniques research • Reservoir models	• Provide funding • Coordinate research • Technology transfer from Department of Defense	• U.S. Geological Survey • State geological societies • Universities • Construction and operating companies • State agencies • National laboratories

R&D Priority

Develop means of optimizing field operations through automation, hydrates control, and improved base gas to working gas ratio.

Description	Key Technical Elements
Reservoir management presents a continuing challenge and increasing expense for the natural gas storage industry. High base gas to working gas ratios reduce deliverability; lowering cushion gas requirements would increase the available supply of natural gas across the country. Discovering and demonstrating lower-cost, alternative cushion gases would also make more natural gas available for use. Automating system operations in order to monitor inventory levels, gas migration, hydrate development, and reservoir pressure and capacity would significantly reduce down-time and improve the cost-effectiveness of storage operations. Developing advanced barriers to gas migration would minimize the amount of gas lost to the environment, thereby improving the safety and reliability of the system. Hydrates formation also complicates operations substantially; methods of preventing and handling hydrates would also contribute to improving the industry. Integration of these techniques in order to optimize field operations would go a long way in ensuring the ability of the U.S. natural gas storage infrastructure to meet future demands.	• Survey and analysis of existing field practices • Developments in instrumentation, communication technology, and remote sensing technologies • Advancements in data storage, integration, mining, analysis, and overall management • Applications of artificial intelligence to natural gas storage operations • Material and chemical studies of candidates for gas migration barriers • Studies of barrier placement • Computational fluid dynamics analyses • Research into the phase behavior and formation of hydrates • Optimization studies • Long-term geotechnical integrity studies • Injection and cycling studies • Reservoir management model • Demonstration projects

Implementation Strategy

Resources	Government Role	Potential Partners
• Basic chemical studies • Flow loop studies • Field test results • Artificial intelligence • Process controls	• Provide funding • Coordinate research • Technology transfer	• Computational Fluid Dynamics Consortium • Chemical companies • Universities • Storage field operators • National laboratories • Software developers

R&D Priority

Develop cost-effective solutions to the technical issues affecting the unique natural gas storage needs of the power generation industry.

Description	Key Technical Elements
The power generation industry's requirements for natural gas storage differ significantly from residential and commercial consumers. Electric peaking loads demand higher cycling and injection rates than conventional uses. These loads have strained existing storage reservoirs beyond their technical design limitations. Studies are needed to assess the long-term impacts of these uses and to develop measures to prevent damage. Design parameters need to be developed so that the existing infrastructure can be retrofit to accommodate the power industry's needs and so that new storage can be constructed to withstand these pressures. Proximity to power generation facilities has recently become a necessity as more gas-fired plants have been built and transportation more limited. Advances in on-site compressed natural gas storage would improve the cost-effectiveness of this option. Economic incentives and relaxing of regulatory limitations would allow power generators to develop nearby underground storage reservoirs. Support for distributed generation infrastructure would put the energy source closer to the end-user, thereby minimizing losses and improving efficiency. Economic models to optimize commodity transportation and storage would enhance the power generation industry's efficient use of natural gas and minimize strains on the country's storage infrastructure, ensuring the future availability of the resource.	• Development of pipeline, dispatch and storage models • Economic optimization models • Sensitivity analyses • Cycling and injection impact assessments and reservoir models • Development of design parameters for power generation's storage needs • Research on compressed natural gas storage options • Regulatory and policy analysis • Distributed generation and compressed natural gas marketing feasibility studies • Technology transfer between production and storage applications • Advanced control systems for more flexible injection and withdrawal cycles • Risk assessment tools • Demonstration projects

Implementation Strategy

Resources	Government Role	Potential Partners
• ISO regional studies • Economic models • Industry logs	• Provide funding & incentives • Coordinate research • Regulatory development	• State regulators • Office of Economic Development • FERC • Pipeline and storage companies • EPA