U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory

Roadmap Update II

Natural Gas Infrastructure R&D Delivery Reliability Program

Workshop Proceedings

Phoenix, Arizona
February 8, 2004

NETL

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CONTENTS

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EXECUTIVE SUMMARY

The Department of Energy has undertaken the Natural Gas Delivery Reliability Program to ensure the integrity, operational reliability, safety and security of the nation's natural gas infrastructure. The National Energy Technology Laboratory's Strategic Center for Natural Gas (SCNG) conducts research and development workshops in order to enlist industry insights and expertise for the planning and implementation of program activities. Industry input to program planning is vital to developing a program framework that provides critical public benefits while meeting industry needs. These roadmapping workshops serve to identify key areas of concern that can benefit from federal R&D support. Continual communication with industry and other stakeholders assures that the program is progressing appropriately and if necessary, mid-course corrections can be made.

At the beginning of fiscal year 2004, the Natural Gas Delivery Reliability Program had a portfolio of 45 active projects with a total program value exceeding $29 million. Review and assessment of these projects was a primary goal of the roadmap workshop held in Phoenix on February 8, 2004 – the third in a series of collaborative workshops. This workshop was driven by dynamic new developments over the past two years including the war on terrorism, new regulations governing the integrity and inspection of the nation's gas pipeline system, and expectations of expanded infrastructure to support increased demand and foreign imports of liquefied natural gas. The participants, working in 2 parallel groups, specifically addressed two key questions.

- *What are the key trends and drivers that affect natural gas infrastructure with a focus on the past 2 years?*
- *What are the key R&D needs that affect the natural gas infrastructure?*

The first Natural Gas Delivery Reliability Program R&D roadmap workshop was held in Houston in January 2000. This workshop identified technology gaps and objectives for the infrastructure reliability program. As a result of this initial effort, a portfolio of thirty-one new projects was funded in fiscal year 2001. A second workshop was held in January 2002. The primary focus of this first update to the infrastructure roadmap was to address high-priority issues surrounding the security and assurance of the

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nation's natural gas infrastructure following the events of 9/11/2001. This workshop generated new priorities and needs, which were the focus of a second solicitation in March 2002.

In the Phoenix workshop, five major areas were identified as high-priority for R&D.

- Cost-effective construction techniques for pipe placement and removal
- Monitoring and measuring gas quality accurately and economically
- Development of reliable multi-function compressor technology
- Improved inspection tools for non-piggable mains
- Security concerns and conducting vulnerability assessments

The first two—cost-effective new construction and gas quality—deal with new issues not previously identified in the earlier workshops. The third, compressors, contains new R&D considerations as well as existing priority needs. The last two—sensors and security—reemphasize priorities from previously identified topics.

These workshop results are a critical input for program review and evaluation efforts, helping to ensure that the program remains responsive to industry needs and enhances the public benefits of R&D for assured delivery reliability.

The future of the nation's natural gas delivery system depends on vision, planning and determination. The SCNG will provide the leadership to bring together government, industry, academia and the nation's R&D community to provide the technological foundation to ensure the integrity, operational reliability, safety and security of the nation's natural gas infrastructure.

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1. INTRODUCTION

The President of the United States, in his May 2001 National Energy Policy, highlighted the need to repair and expand our energy infrastructure as one of five energy challenges facing the United States. The Natural Gas Delivery Reliability Program is the Office of Fossil Energy initiative that responds to the President's challenge. Implemented by the SCNG at the Office of Fossil Energy's National Energy Technology Laboratory, the program is working to identify operational factors that influence reliability, with a focus on R&D that maintains and enhances consistent reliability while enabling the capability to meet future demand.

> ". . . natural gas consumption will rise rapidly, as electric utilities make greater and greater use of this environmentally-friendly fuel. We will need newer, cleaner and safer pipes to move larger quantities of natural gas– up to 38,000 new miles of pipe, and 263,000 miles of distribution lines."
>
> *George W. Bush*
> *May 17, 2001*

A. BACKGROUND

Reliability of the natural gas transmission and distribution (T&D) network across the United States is essential to ensure the availability of clean, affordable energy to our homes, businesses and industries. A number of factors, including an aging infrastructure, increasing energy demand, increasing reliance on gas-generated electricity, increasing dependence on imported liquefied natural gas (LNG), utility deregulation and gas industry restructuring, and increased security concerns stressed the current infrastructure. Technology development is necessary to ensure a continued high level of integrity and reliability and to keep pace with increasing demand and the need for additions to the present system. Significant market-driven reductions in private sector R&D have contributed to concern over the existing gas infrastructure across the United States. The Department of Energy has undertaken the Natural Gas Delivery Reliability Program to ensure the integrity, operational reliability, safety and security of the nation's natural gas infrastructure. Program drivers are as follows.

- The availability of clean energy as a prerequisite to United States economic strength.
- Natural gas accounting for one-fourth of the nation's energy consumption.
- Domestic natural gas offsetting increases in dependence on petroleum imports.
- Market conditions causing a reduction in industry R&D.

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- The United States maintaining global leadership in natural gas technology.
- Natural gas as a partial solution to greenhouse gas emission reductions.

Delivering natural gas from well to burner tip is an enormous enterprise. The majority of the natural gas consumed in the United States is produced at remote sites. It must then be transported to consumers through more than 250,000 miles of transmission pipelines with the help of bulk-storage reservoirs and thousands of compressors. This gas is sold to marketers, large commercial and industrial consumers, and distribution companies for delivery to consumers over a network of more than 1 million miles of local distribution pipelines. It is an aging infrastructure overall, and the integrity of this pipeline/storage/compressor system must be maintained and enhanced. Advanced inspection, remote sensing, materials and operational technologies for delivery systems must be developed to meet the large projected increases in natural gas usage. All of this must be accomplished safely and with minimal environmental impact to assure an uninterrupted supply of affordable clean energy.

The vast, mostly underground T&D system and the natural gas powered compressors that provide the force to move the gas have proven to be incredibly safe, reliable, and efficient. The present system is working well supplying natural gas to over 175 million industrial, commercial, and residential customers. Several emerging issues, however, indicate a clear need for federal attention to guarantee the continued health of the natural gas T&D network. The volume of gas moved through this system will only increase because the yearly demand for natural gas is projected to grow from 23 trillion cubic feet presently to over 31.4 trillion cubic feet by 2025 (more than a 35 percent increase) according to the Energy Information Administration in its Annual Energy Outlook 2004. Moreover, the traditional seasonal consumption patterns are changing due to the increased use of gas for electricity generation, and this increase will require expansion of the existing infrastructure. The National Petroleum Council, in its 1999 study, predicts that roughly 40,000 miles of new gas transmission lines and almost 275,000 miles of distribution mains will be needed by 2015. To further complicate the future, there have been recent changes in the natural gas market from deregulation and a rapid pace in mergers and acquisitions. These changes put pressure on prices at the consumer level and have forced T&D companies to focus on short-term cost cutting at the expense of R&D, which will test the system's potential to serve expanding future markets. Another

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pressing change is the treat from terrorism and the need for security and surveillance. The vast gas network is vulnerable to sabotage beyond our current capabilities to monitor and police.

B. Program Goals and Benefits

The goal of the Natural Gas Delivery Reliability Program is to develop technologies that will maintain and enhance the integrity, operational reliability, safety and security of the nation's natural gas infrastructure. Specific objectives are as follows.

- Ensure integrity by developing advanced technology to prevent damage or service disruption by quickly detecting and diagnosing defects, leaks and failures.
- Focus the program on public benefit R&D that results in readily apparent deliverability advantages for consumers.
- Maintain operational reliability by increasing pipeline capacity and enhancing the flexibility and responsiveness of the network to react to changes in long term demand.
- Improve infrastructure efficiency using new analytical tools.
- Protect the environment by fostering new technologies that reduce or eliminate fugitive emissions, and minimize environmental impacts resulting from construction activities.
- Increase the efficiency of construction, operation and maintenance practices.
- Develop and demonstrate advanced security concepts that enhance the nation's energy assurance.

Achieving these objectives will result in a viable technology foundation than can provide broad public benefits for our nation's future natural gas transportation and delivery network. To enhance technology development and operations improvements, the SCNG will collaborate with the private sector in implementing best practices and utilizing industry know-how. Appendix A provides an overview presentation of the Natural Gas Delivery Reliability Program

Meeting Program Goals Will Provide Broad Program Benefits

Potential program benefits include the following:

- Increased integrity, operational reliability, safety and security of the of the nation's natural gas infrastructure.
- Provide industry with new capabilities to meet the predicted growth in demand.
- Reduced greenhouse gas emissions resulting from pipeline and equipment leakage.
- Minimize environmental impact by providing new tools for construction and rehabilitation.
- Enhanced U. S. economic competitiveness, technology leadership and energy security.

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2. ROADMAP UPDATE II: CONSOLIDATED RESULTS

Since the first roadmap update of January 2002, many new developments have occurred including our nation's war on terrorism. Input was needed to ensure that the roadmap and the portfolio of projects are adequately representing the needs of the industry and are positioned to best use the government's role for public interest. Participant input from this workshop will be used to assure the best opportunities for program support are identified and pursued, thus enhancing the public benefits of R&D innovation for assured deliverability.

In a continuing effort to update and reassess the program's portfolio of projects, forty experts from industry and government attended the roadmap update workshop to provide technology-focused insights regarding current issues facing the natural gas infrastructure. The workshop examined both near-term and long-term technology needs and provided valuable feedback on the existing infrastructure roadmap priorities and the portfolio of projects supported by NETL. Appendix B provides a listing of workshop participants.

The participants, working in 2 parallel groups, specifically addressed two key questions:

- *What are the key trends and drivers that affect natural gas infrastructure with a focus on the past 2 years?*
- *What are the key R&D needs that affect the natural gas infrastructure?*

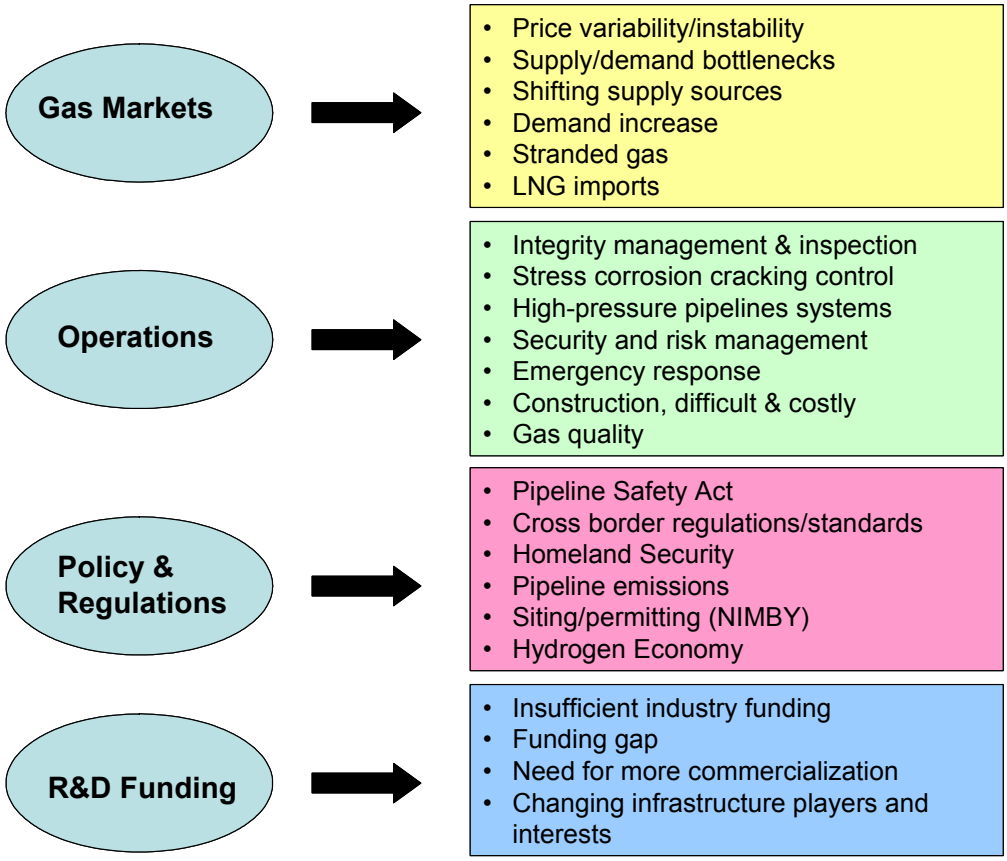
This section provides the consolidated results of the two work groups. The detailed results of the two groups are presented in Section 3.

A. KEY TRENDS AND DRIVERS

The key trends and drivers identified by the participants included general topics such as market and pricing variability, regulatory compliance and environmental issues, security and risk management protection, increased pipeline capacity and efficiency, and cost efficiency. Specific topics covered a very broad range, from near-term issues such as integrity management and inspection in an aging infrastructure to longer-

term issues such as transition to a hydrogen economy. Common trends and drivers identified are shown in Figure 1.

Figure 1. Trends and Drivers Affecting the Natural Gas Infrastructure



B. R&D Priorities and Opportunities

Participates both reviewed the results of earlier workshops and generated new ideas. Each group voted on the new needs that were generated, as well as on the existing needs that had already been identified. The intent for the latter voting was to assess the baseline of what are currently considered top priorities.

In general, industry still considers important those R&D needs identified as high priority during previous workshops. The relative importance on security issues seen in earlier workshops was less evident at this workshop. This is likely due to two factors. First, many of the earlier needs were derived from the first roadmap update workshop, which had as its principal focus infrastructure security and assurance. Further, this workshop occurred shortly after 9/11. Second, considerable public- and private-sector attention has been given to security and assurance over the past several years. Of somewhat greater importance at this workshop were leak detection and inspection technologies. The emphasis in these areas can be attributed to recent regulatory changes requiring greater gas pipeline integrity management and inspection in high-consequence areas. Improvements in compressor efficiency and performance also were of higher importance compared to past workshops. A primary driver for this is the desire to increase throughput

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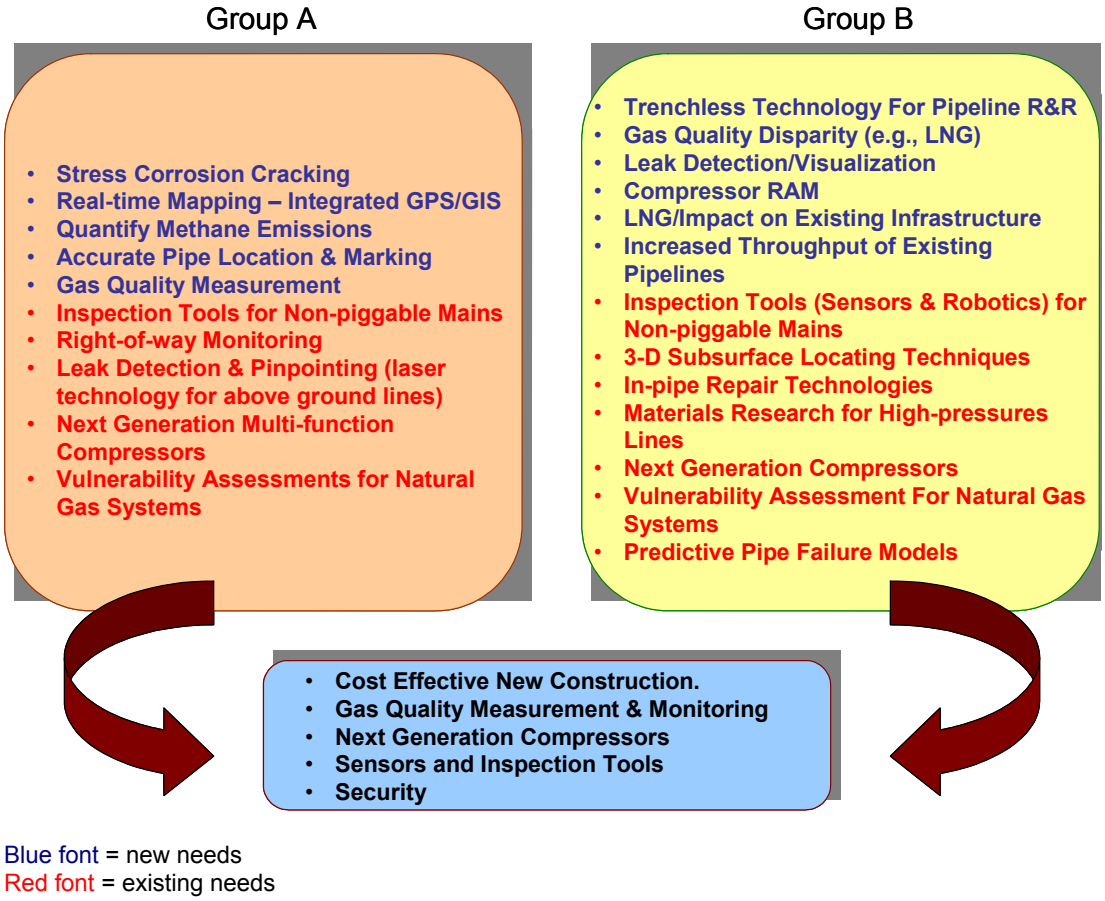
through existing pipeline infrastructure in order to defer new construction, which is costly and requires significant lead time.

Figure 2 summarizes the high-priority needs—existing and new—identified by each group as well as the crosscutting needs identified by both groups.

Figure 2. High-Priority R&D Needs



Blue font = new needs
Red font = existing needs

The common high-priority R&D needs fall into five general areas discussed below. The first two—cost-effective new construction and gas quality—deal with new issues not previously identified in the earlier roadmapping efforts. The third, compressors, contains new R&D considerations as well as existing priority needs. The last two—sensors and security—reemphasize priorities from previously identified topics.

- **Cost Effective New Construction** – Industry requires cost effective ways to get pipe in the ground expeditiously. A major objective must be cost reduction of all aspects such as the replacement and rehabilitation of aging plastic systems with trench-less method, high pressure pipe, or even just locating and marking pipe. In addition, it would be useful to promote some sort of regulatory compliance streamlining or facilitation. Although the latter is outside the realm of the SCNG, it nevertheless is vital for construction.
- **Gas Quality** – Monitoring and measuring gas quality (BTU content) accurately and economically is essential for fuel

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management and could increase pipeline capacity by 10-15 percent. Delivering gas that meets various end-use performance requirements will require good business management, especially given the disparity of domestic and foreign sources. LNG imports will compound this problem due to typically higher BTU content. Gas quality also impacts piping machinery integrity.

- **Compressors** – There is an ongoing priority to improve compressors and develop a next generation of advanced multi-function compressor technology. Compressor reliability, availability and maintainability (RAM) improvements are critical for pipeline system responsiveness and for increasing throughput of the existing infrastructure. Moreover, emission control aspects will be essential to meeting environmental constraints.
- **Sensors** – Improved sensor technology is needed for both internal and external inspection of T&D systems. The inability to access non-piggable mains prohibits the use of conventional assessment tools. A key R&D need is to develop a sensor that will inspect without actual penetration. In addition, there is a priority need for advanced robotic platforms for deploying advanced sensors in non-piggable transmission mains. Sensor systems capable of real-time monitoring and inspection are needed. Ideally, such systems will perform multi-attribute inspection (e.g., leak detection and integrity inspection for corrosion cracking) and be integrated with GPS/GIS capabilities for pinpointing and mapping of problem areas. These systems are essential for cost-effective inspection as well as pipeline security and early warning response initiatives. Remote systems that can preclude costly excavation and potential pipeline damage are desired.
- **Security** – Conducting a vulnerability assessment for the natural gas systems remains a high priority for understanding and initiating a coordinated response to identified needs. Identifying and assessing potential threats and how to respond are critical for maintaining operational efficiency.

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3. ROADMAP UPDATE II: WORK-GROUP DETAILED RESULTS

In order to enable full participation and in-depth input from all workshop attendees, participants were divided into two groups. Both groups addressed the same issues and generated parallel product sets. The groups first addressed what key trends and drivers are affecting the natural gas infrastructure, with particular emphasis on changes in the two years since the January 2002 *Roadmap Update I*.

Group A Participants

NAME	ORGANIZATION
Dick Benson	LANL
Rick Blake	Lawrence Livermore Lab.
Bruce Campbell	GTI
Sam Clowney	El Paso Pipeline Group
Dan Driscoll	US DOE-NETL
Christopher Freitas	US DOE- FE
Mike Hightower	SNL
Winston Johnson	El Paso Pipeline Group
Karl Lang	SAIC
Marti Marek*	Southwest Gas
Jim Merritt	DOT
Graham Midgley	Heath Consultants, Inc.
John Mowery	Ariel Corporation
Bruce Nestleroth	Battelle
Gerald Paulus	City of Mesa
Patricia Squires	Enbridge Gas Distribution
Vic Viteri	Clean Energy Systems

* Report out person

FACILITATOR: JACK EISENHAUER, ENERGETICS, INC.

With this information setting the stage, both groups then addressed the question of what the R&D needs are that can provide solution paths for these program drivers. Using the identified needs from the two prior workshops (*Natural Gas Infrastructure Roadmap*, 2002 and *Roadmap Update I*, January 2002) as a starting point, the groups identified new needs that respond to the changes of the past two years. To develop a consensus on high-priority R&D needs, both groups voted on two priority sets, one for previously identified needs and one for new needs. The following sections highlight these two priority sets and provide the complete, detailed work-group products.

A. GROUP A PRODUCTS

New Needs

Participants prioritized new research needs using 3 votes apiece. There was one new top vote getter with 5 votes, two new needs got 3 votes each, and an additional six new needs got 2 votes each.

- Corrosion stress cracking – we don't know what we don't know (5 votes)
- 3rd Party – Integrated GPS with GIS for real time mapping (3 votes)

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- Leak Detection – Quantify methane emissions (3 votes)
- General – Accurate pipe location (2 votes)
- 3rd Party – Cost effective pipe feature for locating and marking (2 votes)
- Smart Pipe – Cost effective high pressure pipe (2 votes)
- Compressors – Research to improve reliability and efficiency
- Fuel Measurement – Monitor & measure gas quality economically (2 votes)
- Other – Financial recovery efficiency & reliability projects (2 votes)

Previous Needs

Categories of previous needs are automation technologies, sensors, robotic inspection systems, 3rd party damage, leak detection, underground imaging, repair technologies and tools, smart pipe technology, pipe liners, compressors, modeling, corrosion, and other. Participants prioritized existing research needs using 4 votes apiece for individual topics under these categories. There was one top vote getter with 5 votes, two needs got 4 votes each, and an additional four needs each received 3 priority votes.

- Sensors – Inspection tools for non-piggable mains (5 votes)
- 3rd Party – Right of way monitoring (4 votes)
- Leak Detection – Cost effective leak detection and pinpointing (4 votes)
- Leak Detection – Develop laser technology for above ground lines (3 votes)
- Compressors – Improve compressors and next generation (3 votes)
- Compressors – Advanced multi-function compressor technology (3 votes)
- Other – Conduct vulnerability assessment for natural gas systems (3 votes)

Table 1 presents the complete set of the issues and drivers that were identified. Table 2 presents the complete set of R&D needs that were identified and prioritized.

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GROUP A

TABLE 1 - WHAT ARE THE KEY TRENDS AND DRIVERS THAT AFFECT NATURAL GAS INFRASTRUCTURE?

MARKET AND PRICES	OPERATIONAL AND BUSINESS NEEDS	TECHNOLOGY	REGULATIONS, CODES, ENVIRONMENTAL ISSUES	INDUSTRY STRUCTURE
▪ Natural gas price transparency suspect ▪ Price/demand variability/instability ▪ New federal regulations on coal plants and increased demand for natural gas and gas plants ▪ Bottlenecks between supply and demand centers ▪ Market profile changes ▪ Sources of natural gas supply shifting from SW/SE U.S. to NW U.S. & Canada	▪ Integrity Management ▪ Data integration/ communication ▪ High pressure distribution pipe ▪ Sensor technology for compressor equipment ▪ Pipeline integrity – new tools ▪ New pipeline construction difficult – up rate ▪ Stress corrosion cracking issues ▪ Trend to higher pressure pipelines ▪ Increasing understanding of need for risk management - Plastic - Steel ▪ Inspection for all defect types. B31.85 ▪ System monitoring and control issue ▪ Development of natural gas storage both non-traditional underground and safety of above ground ▪ Include need for compression flexibility ▪ Machinery life extension	▪ Advanced reciprocating compressor technology (Gas Machinery Research Council) efficiency/reliability ▪ Cheaper distributed compressors and sensors (radio frequency identification)	▪ Air quality issues associates with natural gas combustion ▪ More government regulations to meet ▪ Sustainability buss ▪ New infrastructure for stranded gas reserves, environmental/ecological issues ▪ Demand for electricity continues to increase and natural gas fills role for peak power ▪ Antiquated regulations that don't align with new materials technologies ▪ No incentives for increased fuel efficiency	▪ Technology funding constraints (utility) ▪ Deterioration of knowledge base ▪ Incentive regulations/ performance based rates and productivity improvements

GROUP A

TABLE 1 - WHAT ARE THE KEY TRENDS AND DRIVERS THAT AFFECT NATURAL GAS INFRASTRUCTURE? (CONTINUED)

GAS QUALITY	SECURITY AND RISK MANAGEMENT PROTECTION	PUBLIC POLICIES
▪ LNG gas quality ▪ Gas quality (BTU values)	▪ LNG imports and safety, security, reliability	▪ Public education vs. NIMBY - Construction - LNG ▪ President's reference to the hydrogen economy ▪ Cross-border issues (Regulatory standards) ▪ More emphasis needed on commercialization

GROUP A
TABLE 2 – KEY R&D NEEDS THAT AFFECT NATURAL GAS INFRASTRUCTURE

INSPECTION TECHNOLOGIES				REMOTE SENSING		
AUTOMATION TECHNOLOGIES	**SENSORS**	**ROBOTIC INSPECTION SYSTEM**	**GENERAL**	**3RD PARTY DAMAGE PREVENTION**	**LEAK DETECTION**	**UNDERGROUND IMAGING**
✓ Improved system for data acquisition ✓ *Develop low- cost standard communi-cation equipment (plug & play)* ● ●	✓ Develop multifunc-tional sensors, residual life, damage, mapping ✓ In-line inspection tool ● ✓ *Inspection tools for non-piggable mains* ● ● ● ● ● ✓ *Develop magnetic flux leakage tools for better pit geometry* ● ☐ **Small internal inspection tools (2" maws)** ▲	✓ *Advanced robotic technology for non-piggable trans-mission mains*	☐ **General inspection method to objectively set re-inspection intervals** ▲ ☐ **Inspection for pipeline wellness for new pipelines. Help NIMBY problem** ▲ ☐ **Accurate pipe location and description of effects (stress corrosion cracking)** ▲▲	✓ System of sensors and communication devices to detect when someone is near ● ● ☐ Develop warning systems on excavation equipment ● ✓ *Right-of-way monitoring* ● ● ● ● ✓ *Develop suite of cost-effective surveillance techniques* ✓ *Develop smart pipe technology w/wireless remote sensing devices* ● ☐ **Integrated GPS with GIS, for real time mapping that is immediate and accurate** ▲▲▲ ☐ **Cost effective pipe feature locating & marking radio frequency identification** ▲▲ ☐ **Emergency response abatement** ▲	✓ Laser optical methane and ethane detectors w/speed and accuracy ● ● ✓ Cost-effective leak detection and pin-pointing ● ● ● ● ✓ *Develop laser technology to detect leaks in above ground lines* ● ● ● ✓ **Quantify methane emissions** ▲▲▲	✓ Underground inspection technology to aid construction and repair ✓ 3-D subsurface facility locating techniques ● ● ✓ Develop better imaging for locating underground pipes ✓ More sophisticated underground directional drilling technology ✓ Sensors to guide boring tools to detect other facilities ✓ Locatable plastic (non-metallic) pipe (imbedded material tag) ✓ *Boring equipment with real-time damage detection* ☐ **Harmonic drill, directional boring, tools that use harmonic resonance to drill through soil but not through pipe**

Bullets
✓ = DOE project(s) exists that address this need
☐ = No DOE project exists for

Voting
Green Dots = priority vote for existing needs
Red Triangles = priority vote for new needs

Type
Regular = Natural Gas Infrastructure Roadmap, June 2000
Italic = *Roadmap Update I, January 2002*
Bold = **Roadmap Update II, February 2004**

GROUP A
TABLE 2 – KEY R&D NEEDS THAT AFFECT NATURAL GAS INFRASTRUCTURE (CONTINUED)

MATERIALS DEVELOPMENT			OPERATIONAL TECHNOLOGIES			
REPAIR TECHNOLOGY AND TOOLS	**SMART PIPE TECHNOLOGY**	**PIPE LINERS**	**COMPRESSORS**	**MODELING**	**CORROSION**	**FUEL MEASUREMENT**
✓ *Robotics repair of internal corrosion* ✓ *Lower the cost of in-the-pipe repair technologies using new design*	✓ Smart pipes that are self-healing and self-monitoring ☐ High pressure plastic pipe materials ● ☐ Develop high pressure composite pipe ☐ Materials optimization: new composites, corrosion resistant, high pressure, low cost ● ● ✓ *Take sensing to level of "skin" for intelligent pipelines* ✓ *Materials research for high pressure lines* ● ☐ **Cost effective higher pressure distribution pipe** ▲▲	✓ Lining technology to upgrade low pressure lines to higher pressure ● ☐ Development of smart, multifunctional pipeline coating	✓ Improve compressors and next generation compressors ● ● ● ✓ Lower cost emission control compressor engines ● ● ✓ Modeling algorithms for compressor station components ✓ *Advanced multi-function compressor technology* ● ● ● ☐ **Improved sensors for compressor machinery** ▲ ☐ **Research to improve compressor reliability & efficiency** ▲▲ ☐ **Lower emission comp. equipment without after treatment** ▲ ☐ **More flexibility comp. equipment** ● ☐ **Advanced engine designs to burn new species fuel (partially oxidized to reduce environmental protection)**	✓ Develop predictive pipe failure models ● ✓ *Develop information exchange protocols* ✓ *Forecasting system of generation and LDC dispatching* ☐ **Cross company pipeline modeling to determine interconnect opportunities to increase capacity** ▲ ☐ **Data integration technology** ▲ ☐ **Develop non-parametric statistical tools/techniques to monitor real time compressor performance and degradation**	☐ **Stress corrosion cracking; we don't know what we don't know** ▲▲▲▲▲ ☐ **Corrosion – internal/external and ways to avoid** ☐ **Above ground corrosion** **- Risers** **- MSA**	☐ **Monitoring and measuring gas quality economically** ▲▲ ☐ **Low cost energy measurement technology to accurately measure BTU – this could increase pipeline capacity 10-15%** ▲ ☐ **Gas quality analysis** ▲

Bullets
✓ = DOE project(s) exists that address this need
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GROUP A
TABLE 2 - KEY R&D NEEDS THAT AFFECT NATURAL GAS INFRASTRUCTURE (CONTINUED)

OTHER	NEW AREAS	
OTHER	**SECURITY SURETY**	**TECHNOLOGY IMPLEMENTATION/ ACCELERATION**
☐ Study how to improve permitting process ☐ More realistic economic model for analyzing construction benefit and risk ✓ Develop novel on-site storage technology ✓ Develop improved storage facilities ● ☐ **Financial recovery – efficiency and reliability projects** ▲▲ ☐ **Cumulative effects on row** ☐ **Distributed storage – residential, commercial point of use storage** ▲ ☐ **Pipeline construction technology that responds to environmental concerns (footprint)** ▲	✓ *Secure SCADA* ✓ *Conduct vulnerability assessment for natural gas systems* ● ● ● ✓ *National emergency warning system* ● ✓ *Nationwide energy control system to be activated in an emergency*	☐ **Process for code changes for new technologies quickly and rationally** ☐ **How do we move research projects to commercialization more rapidly** ☐ **Academic programs to train people for NG industry or funding research** ▲ ☐ **Miniature – Nano-technology for internal pipe inspection – what's available**

Bullets
✓ = DOE project(s) exists that address this need
☐ = No DOE project exists for this need

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B. GROUP B PRODUCTS

New Needs

There were several crosscutting issues in the group. Funding or the future lack thereof was of importance, with several participants outspoken on the issue, desiring commitment from DOE for a long-term solution to pending R&D funding halts. Another pervasive need is the general idea of developing quicker and cheaper pipeline installation techniques, although this is not considered by DOE to fall within the program mission.

Group B Participants

NAME	ORGANIZATION
Rodney Anderson	US DOE-NETL
Rick Baker	US DOE-NETL
Robert Bass	Southwest Research Inst.
Paul Brooks	Pacific Gas & Electric
Jeff Colwell	Battelle
Gene Crawford	Memphis Light Gas & Water
John DeVenz	Enbridge Gas Distribution
Glyn Hazelden*	GTI
Frank McRae	City of Mesa
Jeff Moore	Dresser-Rand Company
George Ragula	Public Service Elec. & Gas
Eric Thomas	Southern Natural Gas Co.
Robert Torbin	Foster-Miller, Inc.
George Vradis	Northeast Gas Association
Jay Willer	GTI
Ted Williams	AGA
Jeff Wright	FERC

* Report out person

FACILITATOR: KEVIN MOORE, ENERGETICS, INC.

Categories of new needs included security surety, gas quality, construction, major objectives, and R&D funding. The latter two are general crosscutting categories rather than specific topics for prioritization. Participants prioritized the new research needs using 3 votes apiece. There was one top vote getter with 9 votes, two needs got 5 votes each, and another 5 needs got 4 votes each.

- Construction - Need cost effective ways to get pipe in ground and timely (9 votes)
- Construction- Cost effective R&R of aging plastic pipe w/ trenchless (5 votes)
- Gas Quality - Disparity of gas quality domestic and foreign (5 votes)
- Leak Detection - Visualization (4 votes)
- Compressors - Increase efficiency and economics of compressors (4 votes)
- Compressors - Improve RAM of compressors (4 votes)
- Other - LNG infrastructure & impact on existing pipelines (4 votes)
- Other - More throughput with existing pipelines T&D (4 votes)

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Previous Needs

Categories of previous needs are automation technologies, sensors, robotic inspection systems, 3rd party damage, leak detection, underground imaging, repair technologies and tools, smart pipe technology, pipe liners, compressors, modeling, corrosion, and other. The security category was amended to add surety and therefore considered a new category. Participants prioritized old existing research needs using 4 votes. There was one top vote getter with 7 votes and an additional 6 needs that each received 4 votes:

- Sensors - Inspection tools for non-piggable mains (7 votes)
- Robotic - Advanced robotic technology for non-piggable transmission mains (4 votes)
- Underground - 3-D subsurface facility locating techniques (4 votes)
- Repair - Lower the cost on in-the-pipe repair technologies (4 votes)
- Smart Pipe - Materials research for high-pressures lines (4 votes)
- Compressors - Improve compressors and next generation (4 votes)
- Security - Conduct vulnerability assessment for natural gas (4 votes)

Table 3 presents the complete set of issues that were identified. Table 4 presents the complete set of R&D needs that were identified and prioritized.

GROUP B

TABLE 3 - WHAT ARE THE KEY TRENDS THAT ARE AFFECT NATURAL GAS INFRASTRUCTURE?

R&D FUNDING	COST EFFICIENCY	REGULATORY COMPLIANCE & INTEGRITY	INCREASED PIPELINE CAPACITY AND EFFICIENCY	PIPELINE SECURITY SURETY	COMPRESSION TECHNOLOGY RELIABILITY, MAINTAINABILITY
▪ Insufficient Industry R&D funds to make-up for GTI FERC Funding ending in 2004 ▪ Funding R&D GAP ▪ Changing players in infrastructure R&D funding and organizational interests	▪ Looking for labor saving technologies where money is spent especially surveying ▪ Cost effective technologies ▪ Cost effective replacement and rehabilitation of aging plastic pipe distribution systems utilizing trench-less methods ▪ Growing application of data interwire integrity techniques and need for analysis and validation like MFL data ▪ Alternative high pressure pipe materials - lower cost installation & O&M - i.e., composite plastic ▪ Guided boring technologies like keyhole	▪ Pipeline Safety Act 2003 – Inspections in high consequence area ▪ Detection, characterization and response to threats to pipeline integrity caused by Office of Pipeline Safety integrity rule ▪ Regulations on integrity management presenting significant costs of compliance ▪ Office of Pipeline Safety rule on pipeline integrity ▪ Advances sensors	▪ Perception/projection for 32 TCF demand. Not enough capacity in current pipeline ▪ Need cheaper and quicker pipe in ground ▪ Increased gas demand and power generation - Increase efficiency and throughput of existing pipelines ▪ Need for spare pipeline capacity – variable rated compression ▪ More throughput with existing pipelines ▪ 30 TCF moved out in time 2015 – 2020 ▪ How do we capture more gas supply with new technology from old and new sources	▪ Rapid response/ recovery for terrorist or natural disasters = delivery surety ▪ Establishment of Department of Homeland Security gas infrastructure security ▪ Utility infrastructure security is becoming an issue since 9-11 (hacking into SCADA) ▪ Emergency response - system shut-down - damaged - not damaged	▪ Replacement of aging compressors (many 30+ years old), no replacement parts ▪ More efficient and less emitting compression drivers

GROUP B
TABLE 3 - WHAT ARE THE KEY TRENDS THAT ARE AFFECT NATURAL GAS INFRASTRUCTURE? (CONTINUED)

GAS QUALITY	HYDROGEN	CATHODIC PROTECTION	LEAK SURVEY SYSTEMS	FACILITIES LOCATORS	LNG
▪ Disparity of gas quality and conflict with pipeline standards How to reconcile e.g., LNG condensable liquids interchange- ability of gas	▪ Conversion to hydrogen based energy system - natural gas conversion and infrastructure	▪ Advanced CP data management concepts to extend life of steel infrastructure.	▪ Advanced gas leak survey systems - laser, visualization, aerial	▪ Underground imaging of buried structures high reliability - Underground "x-ray" ▪ Underground facility location of non-gas and electric facilities	▪ Increased use of LNG in future ▪ Proper infrastructure to handle LNG imports

GROUP B
TABLE 4 - KEY R&D NEEDS THAT AFFECT NATURAL GAS INFRASTRUCTURE

INSPECTION TECHNOLOGIES			REMOTE SENSING		
AUTOMATION TECHNOLOGIES	**SENSORS**	**ROBOTIC INSPECTION SYSTEMS**	**3RD PARTY DAMAGE PREVENTION**	**LEAK DETECTION**	**UNDERGROUND IMAGING**
✓ Improved system for data acquisition ✓ *Develop low cost standard communica-tion equipment (plug & play)*	✓ Develop multifunction al sensor, residual life, damage, mapping ● ● ✓ In-line inspection tool ✓ *Inspection tools for non-piggable mains* ● ● ● ● ● ● ● ✓ *Develop magnetic flux leakage tools for better pit geometry*	✓ *Advanced robotic technology for non-piggable transmission mains* ● ● ● ●	✓ System of sensors and communication devices to detect when someone is near ● ● □ Develop warning systems on excavation equipment ● ● ✓ *Right-of-way monitoring* ✓ *Develop suite of cost-effective surveillance techniques* ✓ *Develop smart pipe technology with wireless remote sensing devices* ●	✓ Laser optical methane and ethane detectors w/speed and accuracy ● ● ✓ Cost-effective leak detection and pinpointing ● ✓ *Develop laser technology to detect leaks in above ground lines* □ **Visualization** ▲ ▲ ▲ ▲	✓ Underground inspection technology to aid construction and repair ✓ 3-D subsurface facility locating techniques ● ● ● ● ✓ Develop better imaging for locating underground pipes ● ● ✓ More sophisticated underground directional drilling technology ● ✓ Sensors to guide boring tools to detect other facilities ● ● ✓ Locatable plastic (non-metallic) pipe (imbedded material tag) ✓ *Boring equipment with real-time damage detection*

Bullets
✓ = DOE project (s) exists that address this need
□ = No DOE project exists for this need

Voting
Green Dots = priority vote for existing needs
Red Triangles = priority vote for new needs

Type
Regular = Natural Gas Infrastructure Roadmap, June 2000
Italic = *Roadmap Update I, January 2002*
Bold = **Roadmap Update II, February 2004**

GROUP B
TABLE 4 - KEY R&D NEEDS THAT AFFECT NATURAL GAS INFRASTRUCTURE (CONTINUED)

MATERIALS DEVELOPMENTS			OPERATIONAL TECHNOLOGIES		
REPAIR TECHNOLOGIES AND TOOLS	**SMART PIPE TECHNOLOGY**	**PIPE LINERS**	**COMPRESSORS**	**MODELING**	**CORROSION**
✓ *Robotics repair of internal corrosion* ✓ *Lower the cost of in-the-pipe repair technologies using new design* ● ● ● ●	✓ Smart pipes that are self-healing and self-monitoring ☐ High pressure plastic pipe materials ● ☐ Develop high pressure composite pipe ● ☐ Materials optimization: new composites, corrosion resistant, high pressure, low cost ✓ *Take sensing to level of "skin" for intelligent pipelines* ✓ *Materials research for high pressure lines* ● ● ● ●	✓ Lining technology to upgrade low pressure lines to higher pressure ☐ Development of smart, multifunctional pipeline coating	✓ Improve compressors and next generation compressors ● ● ● ● ✓ Lower cost emission control compressor engines ✓ Modeling algorithms for compressor station components ✓ *Advanced multi-function compressor technology* ● ● ☐ **Increase efficiency and therefore economies** ▲▲▲▲ ☐ **Improve RAM reliability, availability, maintainability** ▲▲▲▲ ☐ **Variable rated compression** **- spare capacity** ▲	✓ Develop predictive pipe failure models ● ● ● ✓ *Develop information exchange protocols* ✓ *Forecasting system of generation and LDC dis-patching* ● ● ☐ **Data integration & analysis, e.g., magnetic flux leakage**	☐ **Advanced CP cathodic protection technologies** ▲

Bullets
✓ = DOE project (s) exists that address this need
☐ = No DOE project exists for this need

Voting
Green Dots = priority vote for existing needs
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GROUP B
TABLE 4 - KEY R&D NEEDS THAT AFFECT NATURAL GAS INFRASTRUCTURE (CONTINUED)

OTHER	NEW AREAS				
OTHER	**SECURITY SURETY**	**GAS QUALITY**	**CONSTRUCTION**	**Major Objectives***	**R&D Funding***
☐ Study how to improve permitting process ☐ More realistic economic model for analyzing construction benefit and risk ● ✓ Develop novel on-site storage technology ✓ Develop improved storage facilities ● ☐ **Hydrogen infrastructure for dispersion, delivery and combustion and standards** ▲ ☐ **LNG infrastructure and impact on existing pipelines** ▲▲▲▲ ☐ **More throughput with existing pipelines T&D**▲▲▲▲	✓ *Secure SCADA systems* ● ● ✓ *Conduct vulnerability assessment for natural gas systems* ● ● ● ● ✓ *National emergency warning system* ✓ *Nationwide energy control system to be activated in an emergency* ☐ **Response recovery phase** ▲	☐ **Disparity of gas quality domestic and foreign conflict with pipeline standards - how reconcile** ▲▲▲▲▲ ☐ **End-use performance** ☐ **Piping and machinery integrity performance** ☐ **Energy content measure**	☐ **Need cost effective ways to get pipe in ground and timely** ▲▲▲▲▲▲▲▲▲ ☐ **Guided boring technology** ▲ ☐ **Cost effective replacement and rehabilitation of aging plastic pipe systems with trench-less method** ▲▲▲▲▲	▪ Improved deliverability, security, operational efficiency - reduced costs - regulatory compliance	▪ Amount and dependability limits long-range planning ▪ Future funding sources

* non-voting needs

Bullets
✓ = DOE project (s) exists that address this need
☐ = No DOE project exists for this need

Voting
Green Dots = priority vote for existing needs
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Type
Regular = Natural Gas Infrastructure Roadmap, June 2000
Italic = *Roadmap Update I, January 2002*
Bold = **Roadmap Update II, February 2004**

4. Evolution of the Program Portfolio

The DOE National Energy Technology Laboratory's Strategic Center for Natural Gas conducts roadmap workshops in order to enlist industry insights and expertise for the planning and implementation of program activities. Industry input to program planning is vital to developing a program framework that provides critical public benefits while meeting industry needs. These roadmapping workshops serve to identify key areas of concern that can benefit from federal R&D support. Continual communication with industry and other stakeholders assures that the program is progressing appropriately and if necessary, mid-course corrections can be made.

Industry input to program planning is vital to developing a program framework that provides critical public benefits while meeting industry needs.

Natural gas is an environmentally friendly energy source. It is the least carbon-intensive fossil fuel and it represents low capital cost for power plants that use it as fuel for electricity generation. Many electric utilities affected by the Clean Air Act are planning to replace high-sulfur coal with natural gas to meet air emission standards. But natural gas must still be found, produced and transported, and there are many environmental challenges in the production, delivery and end use of the resource. Land access, pipeline construction and air emissions are issues being addressed to ensure our nation's demand for natural gas is satisfied in an environmentally friendly manner.

This program is based on extensive dialogue with industry through workshops and other collaborative mechanisms. The evolution of the program's R&D portfolio has been predicated on stakeholder input, and significant groups have repeatedly attended workshops to provide this input. Industry stakeholders include major pipelines and transmission companies such as, but not limited to, Columbia, City of Mesa, Dominion, Duke, El Pasco, Enbridge, Equitable, KeySpan, NiSource, Pacific Gas & Electric, Public Service Electric & Gas, Southern, Southwest, and Williams. Collaborations are ongoing with the Department of Transportation, state governments, industry and academia, including the formation of consortiums. SCNG also interacts with important stakeholder organizations, such as the American Gas Association, the American Public Gas Association, the Gas

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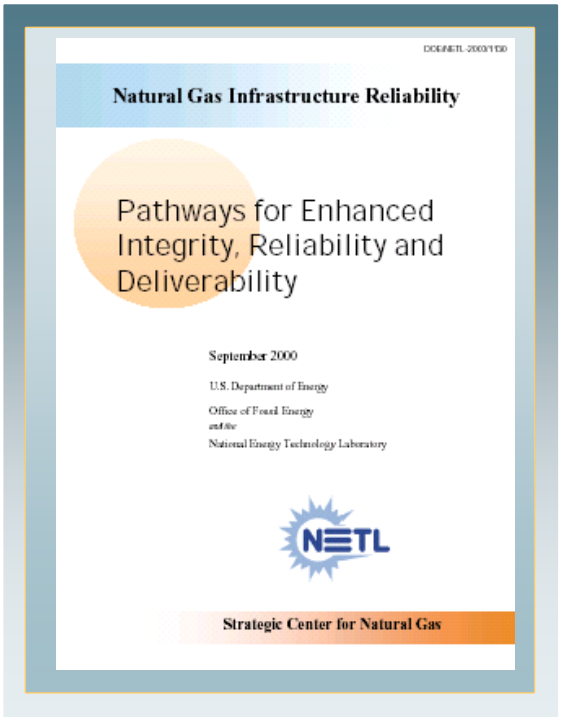
Technology Institute, the Interstate Natural Gas Association of America, and the Pipeline Research Council.



A. Baseline Roadmap

Given the presidential challenge for new technology options, SCNG recognized the need for stakeholder input to address gaps and new objectives for the delivery reliability program. In mid-2000, NETL held two industry workshops to gather input for an infrastructure roadmap. An initial vision brainstorming session with industry executives was held in Houston in January 2000, followed by a roadmapping workshop for technical managers held in St. Louis in June. A combined report was produced as shown and is available in archives on the SCNG website at www.netl.doe.gov/scng/index.html

The core issues addressed by these first workshops included the following.

- **Third-Party Damage to Pipelines** – The primary cause of pipeline accidents is caused by outside forces. Is there a means to warn third parties they are about to damage a pipeline? How can real time detection of facility intrusion be accomplished?
- **Pipeline Integrity Assessment** – How can physical system integrity be monitored in some way? Can remote sensing play a part? Could the data gathered here be a tool to increase service life and/or to extend operating conditions?
- **Detecting Leaks** – How can pipeline leaks be detected and repaired rapidly? Can "smart pipes" provide early leak detection and aid in their own repair?
- **Technology to Assist Boring** – Can we bring improved technology such as robotics or "guided" boring to improve pipeline installation? Can we prevent "guided" boring equipment from colliding with underground facilities?
- **The Location of Underground Facilities** – How do we provide three-dimensional imaging of buried facilities?
- **New Compressor Technology** – These workhorses have remained much the same for years. Can we increase their efficiency, reduce emissions and increase operational flexibility? What is the next generation compressor?

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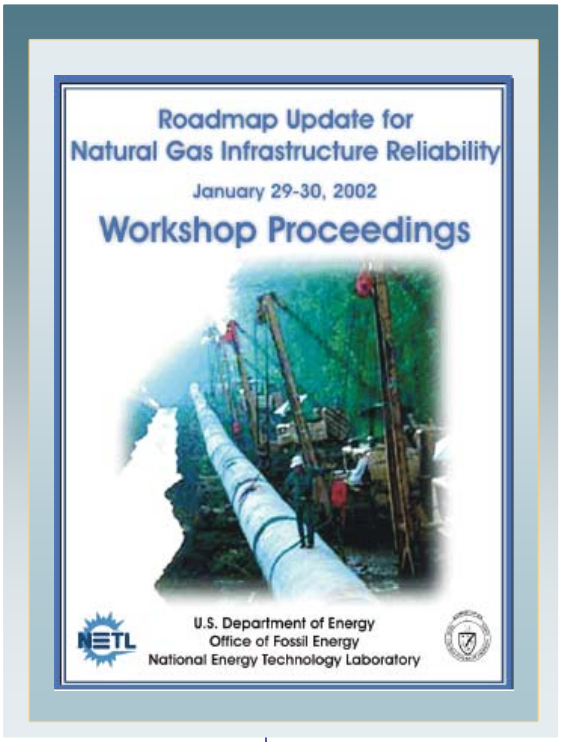
- **Increase Throughput of the Present System** – How do we increase the capacity of our existing pipelines?
- **Environmental impact of pipelines** – How can we build and maintain our infrastructure with minimal ecological impact?
- **Energy Assurance** - How can we protect our energy infrastructure?



Based on this framework, the program selected a portfolio of projects through competitive solicitations to support the first roadmap implementation. In 2001, the Secretary of Energy announced the first-ever Department of Energy projects on natural gas infrastructure research to develop new and advanced technologies. Thirty-one projects were selected for funding in fiscal year 2001 from three procurement actions: a targeted solicitation for gas infrastructure, a broad-based financial assistance (BBFA) solicitation, and a National Laboratory call for proposals. Eight of DOE's national laboratories are actively participating with private industry in developing these new technologies. Included in the array of innovative projects are new ways to detect leaks and corrosion in pipelines (robots, remote sensing, smart pipes); automated warning systems to prevent third party intrusion on pipeline right-of-ways; and methods to retrofit pipeline compressor engines to improve reliability.

B. Roadmap Update I

Another workshop was held in January 2002 to update the infrastructure roadmap to address security and assurance of our nation's infrastructure given its high priority position in homeland security following the events of 9/11/2001. R&D innovations and interdependencies, modeling and integration issues were also addressed. A Roadmap Update report was prepared and is available on the SCNG website. The key aspects of infrastructure security and energy assurance fall within the six areas outlined below.

- The current configuration of the natural gas infrastructure is difficult to protect against physical attacks. The network of pipes, compressor stations, valves, controls, and related utilities is large, diffuse, and remote. While much of the infrastructure is naturally protected because it is located underground, there are plenty of exposed above-ground pipes

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that are unprotected. Compressor stations are often remote and hard to access, making it difficult to respond quickly to problems.

- Automated control systems are vulnerable to cyber attack. The supervisory control and data acquisition (SCADA) systems that control pipeline and compressor operations do not operate securely. There is no hardened, secure communication technology used by the industry that would prevent cyber intrusion. Furthermore, there is no industry standard for secure information and communication protocols, making it difficult for the industry to proceed with a common approach for secure SCADA systems. The protocol for one equipment manufacturer may differ from its competitors.
- Potential threats and vulnerabilities of the natural gas infrastructure are not well understood. The industry does not have a good grasp of the critical nodes and vulnerabilities of the natural gas delivery system because there have been few threat and vulnerability assessments performed, particularly at a regional and national level. In addition, it is not clear what security and classification of information is appropriate for this information.
- The industry has limited ability to detect intrusion and damage from outside forces. There are few technologies available to warn of third-party intrusion, whether it is unintentional (digging near a line) or unintentional (planned terrorism). When intrusion does occur, there is no real-time damage detection that alerts controllers of the event, its location, and severity. Moreover, the lack of an active system to prevent intrusion means that companies can only respond once damage has already occurred.
- The industry has limited tools to evaluate, inspect, and respond to pipeline problems. Tools for inspecting the interior and exterior of pipelines are inadequate to determine potential problems spots or to determine the extent of damage. In addition, there are no robust tools for evaluating pipeline integrity. When damage occurs and repair is needed, companies are unable to excavate quickly without damaging underground utilities. Companies may also have difficulty moving gas to areas of greatest need during a major emergency.
- New security requirements have created new responsibilities for funding secure technologies, sharing information, educating the public, and working with law enforcement agencies.

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In March 2002 a second solicitation addressed the identified new priorities and needs.

C. Current Project Portfolio

The current project portfolio at the end of 2003 is shown in Figure 3 and is presented in detail in Appendix A. A broad mapping of core areas and issues are as follows: Inspection Technologies – automation technologies, sensors, robotics; Remote Sensing – 3rd party damage prevention, leak detection, underground imaging; Materials Development- repair technologies and tools, smart pipe technology, pipe liners; and Operational Technologies – compressors, modeling, corrosion.

There are 45 current active projects with 3 Small Business Innovative Research projects and another 12 completed projects. The total program value exceeds $29 million, with most of the funding dedicated to private sector projects. Industry supported field test are necessary and will begin during the summer of 2004. Implementation strategy has focused on high risk, innovative, and leap-frog technologies.

D. Moving Forward

The future of the nation's natural gas delivery system depends on vision, planning and determination. The SCNG will provide the leadership to bring together government, industry, academia and the nation's R&D community to provide the technological foundation to ensure the integrity, operational reliability, safety and security of the nation's natural gas infrastructure. Through stakeholder workshops, the SCNG has repeatedly and timely elicited program feedback and direction to guide this leadership. In fact, industry has recommended an increase of their participation in these workshops.

The federal government has a unique role in facilitating energy development while simultaneously protecting the environment and conserving our nation's natural resources. Energy development initiatives will be successful only if they adequately address their impact on natural resource values. As energy needs grow, additional innovations will be necessary to continue improving environmental conditions and to meet new environmental challenges. Operational innovations can be employed to protect the environment. The gas industry will use new techniques like "smart" pipes, remote sensing and novel materials to increase the capacity and reliability of existing pipelines while leaving an ever-decreasing environmental

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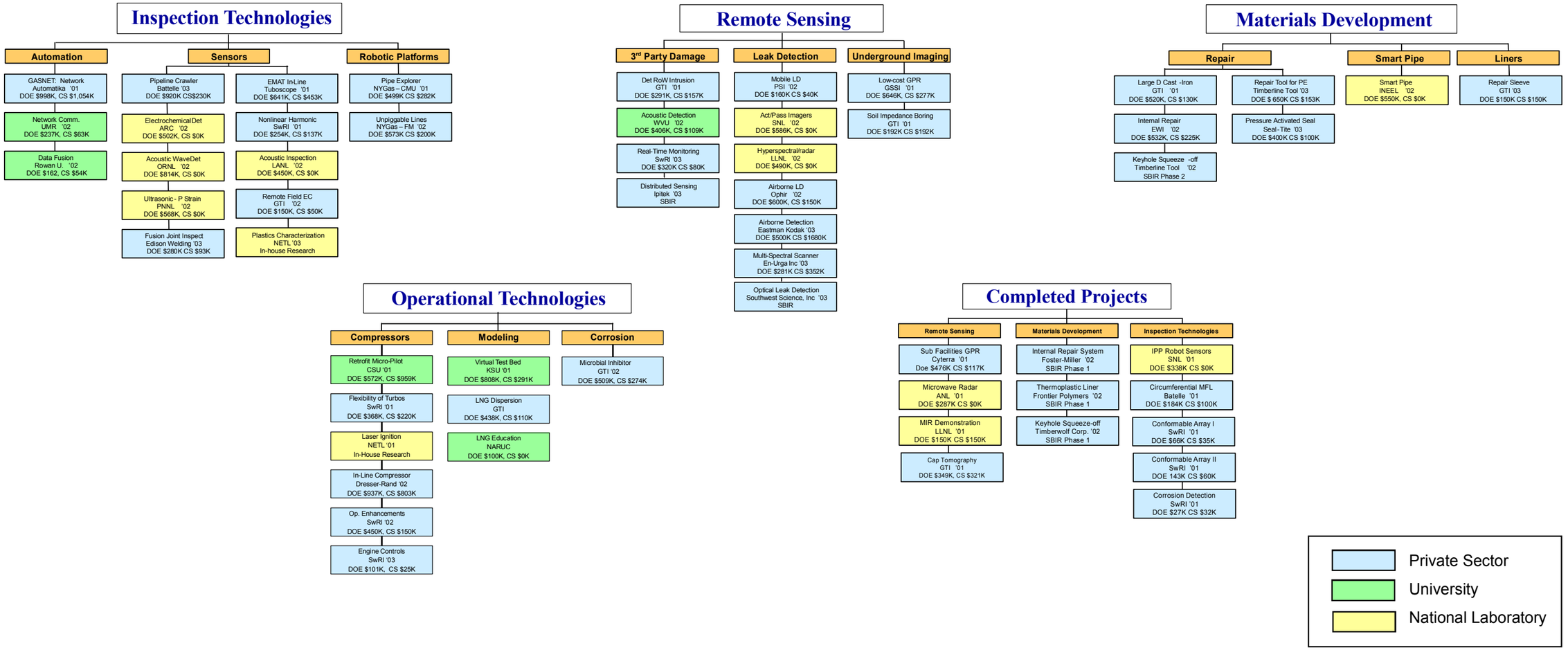
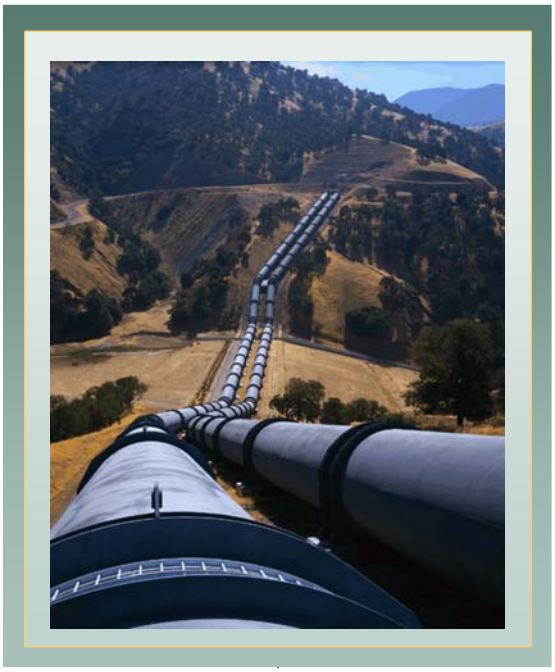


Note: 01, 02 & 03 refer to fiscal year of award

Figure 3. Current Project Portfolio

footprint. Where necessary, new pipelines will be constructed faster and with less environmental impact by using new technologies that do not require trenching in sensitive areas. Air emissions from pipeline operating activities will be captured and sequestered rather than released to the atmosphere. Leaks from natural gas pipelines will be quickly detected by technologies such as remote sensing and repaired before substantial quantities of gas can escape. Pipeline damage by third party intrusions on right-of-ways will be prevented by real time detection methods.



The future of the nation's natural gas delivery system depends on vision, planning, and determination.

The SCNG is committed to a sustainable energy future for the United States, and working collaboratively with industry and academia to assure that preservation of the environment is a priority in all of our natural gas initiatives. Achieving the program vision of developing the technological foundation for our nation's future natural gas delivery system is a major challenge. The program will address the issues of preserving the efficient and safe performance of the natural gas transmission and distribution network as it strives to keep pace with evolving supply, rapidly expanding demand and an aging infrastructure. SCNG will continue to coordinate the Natural Gas Delivery Reliability Program with industry and other stakeholders to identify potential projects and to set priorities with the purpose of maintaining a strong R&D infrastructure in the United States.

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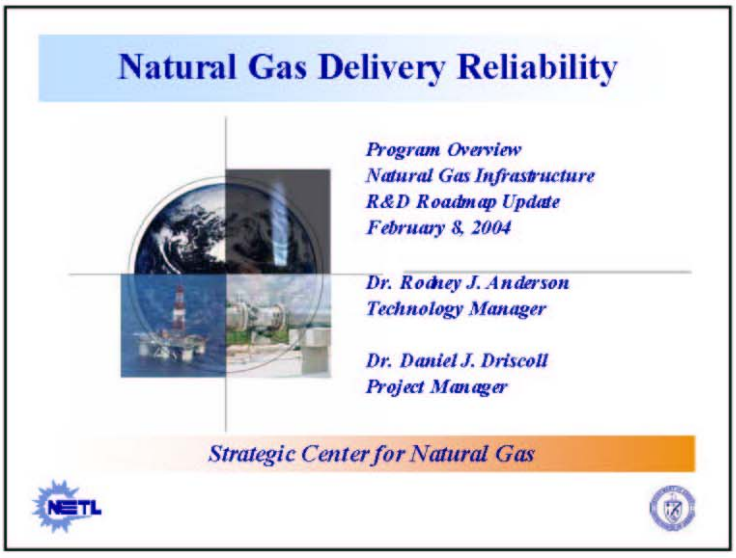
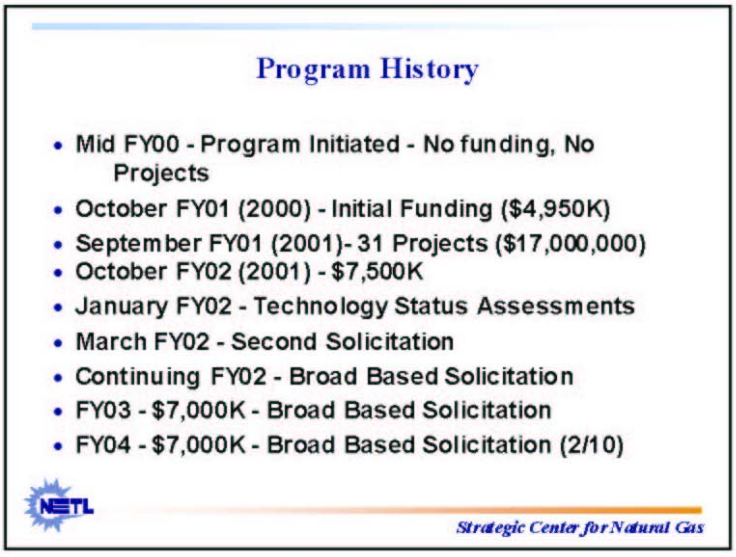
APPENDIX A.
PROGRAM OVERVIEW PRESENTATION





Program Summary

- 45 current active projects (3 SBIR)
- 12 completed projects
- Total program value > $29 million
- Several projects near hand-off phase
- Industry supported field tests necessary
- Commercialization path still difficult
- Industry involvement required

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Delivery Reliability Players/Efforts

Universities, National Labs, Industry

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Implementation Strategy

- Focus on high risk, innovation, and leap frog technologies
- Strong industry participation
  - Input to R&D priorities
  - Feedback on program & project status
  - Collaborations & cost sharing
- Balanced R&D program
  - Distribution, transmission, & storage
- Most funding dedicated to private sector projects
- National laboratory efforts focused on innovation
- Some quick wins to demonstrate progress

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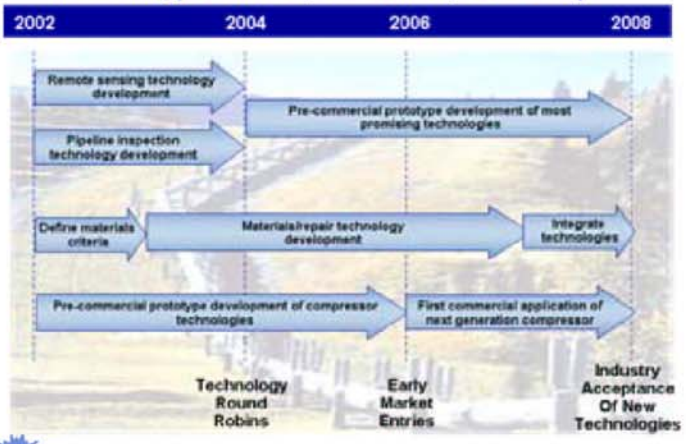
Technology Road Map for Delivery Reliability



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Core Areas & Issues

- **Inspection Technologies**
  - Robotic platforms
  - Sensors
  - Pigs
  - Automation
- **Remote Sensing**
  - 3rd party damage
  - Underground imaging
  - Leak detection
- **Materials**
  - Repair
  - Smart Pipe
  - Liners
- **Operational Technologies**
  - Compressors
  - Modeling
  - Corrosion

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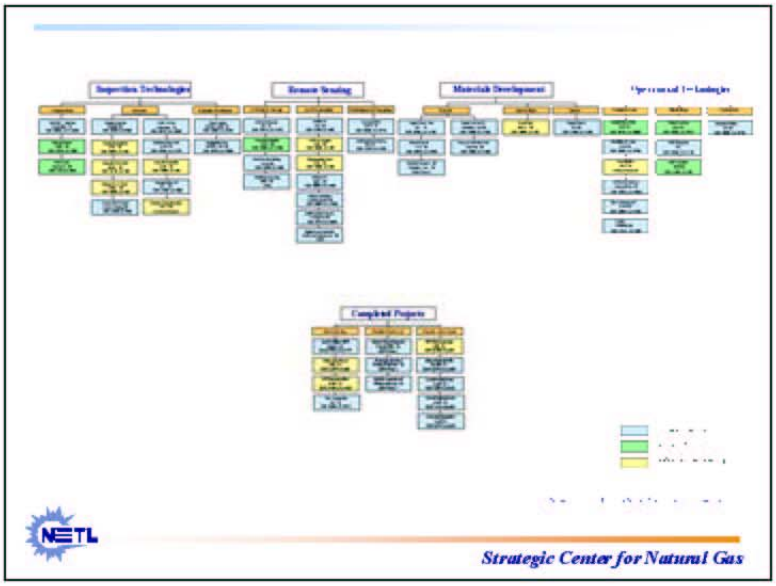

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Inspection Technologies

Develop and integrate innovative sensors to provide enhanced assessments of the status of transmission and distribution facilities. These sensors will be applied in or near the pipe. This includes sensors to detect corrosion defects, stress corrosion cracking, plastic pipe defects, physical damage areas, gas content, gas contamination, and 3rd party intrusion near gas line right-of-ways and facilities as well as development and enhancement of robotic platforms used for pipeline inspection and other related activities.

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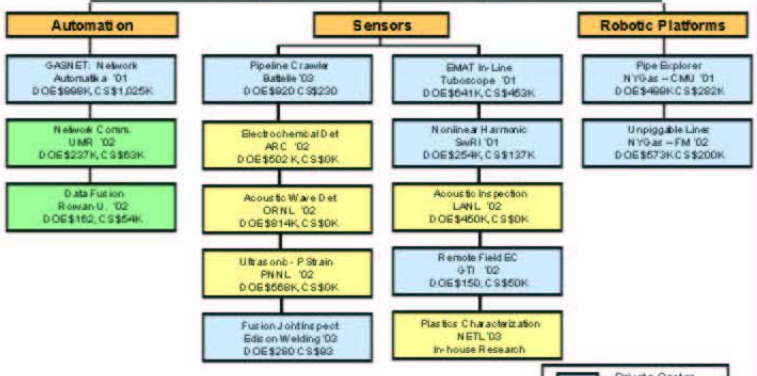
Inspection Technologies



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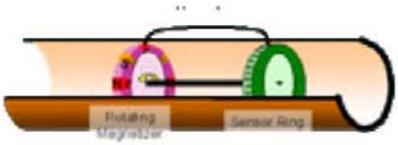
Battelle

- **Title:**
  Innovative Sensors for Pipeline Crawlers to Assess Pipeline Defects and Conditions



- **Description:**
  The project will design and develop Remote Field Eddy Current Sensors to detect internal and external pipeline corrosion. The last phase of the work will attempt to integrate theses sensors with autonomous robotic platforms

Partners:
PRCI and member companies

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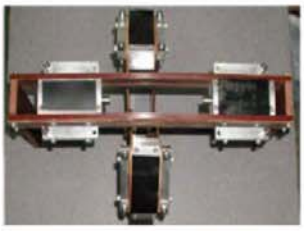
Oak Ridge National Laboratory

- **Title:**
  - New Acoustic Wave Pipe Inspection System



- **Description:**
  - This project will develop and demonstrate a new waveguide pipe flaw detection technique that has the potential to detect pipeline flaws in a single pass at speeds of approximately 2 miles per hour.

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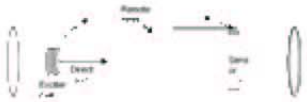
Gas Technology Institute

- **Title:**
  - Remote Field Eddy Current Inspection of Un-Piggable Pipelines



- **Description:**
  - Develop and test an in-line inspection technique for internal and external corrosion utilizing eddy current technology. Eddy current technology could eliminate the coupling problem associated with other inspection methods.

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NYSEARCH/NGA

- **Title:**

  EXPLORER: A Long Range Untethered Live Gasline Inspection Robot System

- **Description:**
  - A long-range untethered visual inspection robot prototype for use in distribution pipelines 6 to 8 inches in diameter, capable of independent movement and communication of 5,000 - 10,000 ft.
- **Partners:**
  - Carnegie Mellon University, Keyspan, Central Hudson Gas and Electric, Consolidated Edison of New York, Niagara Mohawk Power Corporation, New York State Electric and Gas, Orange and Rockland Utilities, Rochester Gas and Electric, NASA

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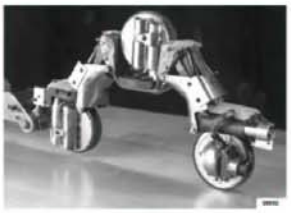
NYSEARCH/NGA

- **Title:**
  Piiglet – A Robotic Inspection Platform and Sensors for Assessing Corrosion and Mechanical Damage in Un-Piggable Transmission Mains



- **Description:**
  - A Pipeline Inspection Robot to overcome the shortcomings of transmission pigs. Self-powered and self-propelled. Capable of carrying a suite of NDE sensors, navigating both horizontally and vertically in both directions. Negotiate mitered elbows and tees as well as back to back bends. Passable through partially ported plug valves. Automatically adaptable, by a factor of two, to changes in pipe diameter
- **Partners:**
  - Foster-Miller, PII North America, Public Service Electric & Gas Company, and Southern California Gas Company

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Inspection Technologies

- **Automation**
  - Automatika "GASNET: Gasline Sensor Network System": Wireless network of small pipeline sensors to monitor the real-time operations. (D)
  - UMR "Pipelines as Networked Communication Links": Strategy for along and through pipe real-time communications. (D)
  - Rowan U "Data Fusion System for the Non-Destructive Evaluation of Non-Piggable Pipes": Techniques for handling and analyzing large quantities of inspection and operating data. (D & T)

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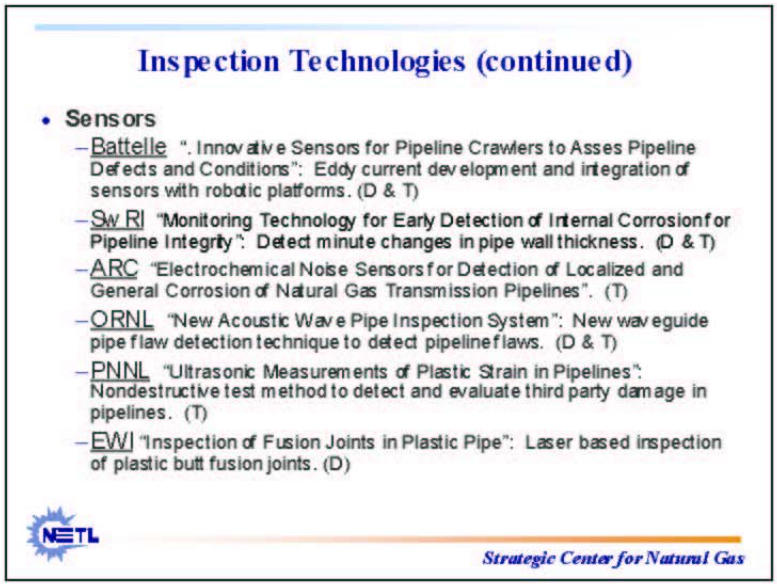
Inspection Technologies (continued)
• Sensors
– Battelle ". Innovative Sensors for Pipeline Crawlers to Asses Pipeline Defects and Conditions": Eddy current development and integration of sensors with robotic platforms. (D & T)
– Sw RI "Monitoring Technology for Early Detection of Internal Corrosion for Pipeline Integrity": Detect minute changes in pipe wall thickness. (D & T)
– ARC "Electrochemical Noise Sensors for Detection of Localized and General Corrosion of Natural Gas Transmission Pipelines". (T)
– ORNL "New Acoustic Wave Pipe Inspection System": New waveguide pipe flaw detection technique to detect pipeline flaws. (D & T)
– PNNL "Ultrasonic Measurements of Plastic Strain in Pipelines": Nondestructive test method to detect and evaluate third party damage in pipelines. (T)
– EWI "Inspection of Fusion Joints in Plastic Pipe": Laser based inspection of plastic butt fusion joints. (D)
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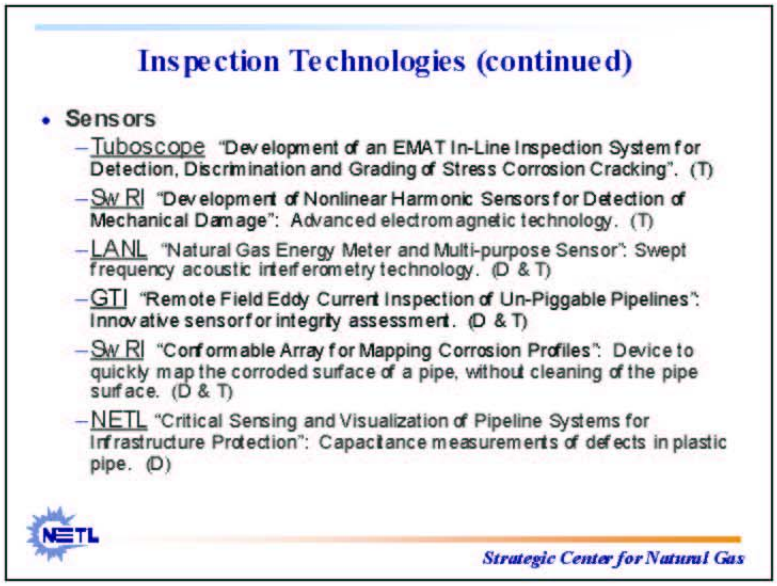
Inspection Technologies (continued)
• Sensors
– Tuboscope "Development of an EMAT In-Line Inspection System for Detection, Discrimination and Grading of Stress Corrosion Cracking". (T)
– Sw RI "Development of Nonlinear Harmonic Sensors for Detection of Mechanical Damage": Advanced electromagnetic technology. (T)
– LANL "Natural Gas Energy Meter and Multi-purpose Sensor": Swept frequency acoustic interferometry technology. (D & T)
– GTI "Remote Field Eddy Current Inspection of Un-Piggable Pipelines": Innovative sensor for integrity assessment. (D & T)
– Sw RI "Conformable Array for Mapping Corrosion Profiles": Device to quickly map the corroded surface of a pipe, without cleaning of the pipe surface. (D & T)
– NETL "Critical Sensing and Visualization of Pipeline Systems for Infrastructure Protection": Capacitance measurements of defects in plastic pipe. (D)
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Inspection Technologies (continued)

- Robotic Platforms
  - NGA-CMU "Design, Construction & Field Demonstration of EXPLORER: Long Range Untethered Live Gasline Inspection Robot System": Autonomous robotic platform to inspect 4 – 8 inch pipelines. (D)
  - NGA-FM "Development of an Inspection Platform and a Suite of Sensors for Assessing Corrosion and Mechanical Damage in Un-Piggable Transmission Mains": Robotic inspection platform for larger diameter pipelines (24 inch). (T)

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Remote Sensing

Develop advanced technologies to detect and identify 3rd party intrusion near gas line right-of-ways and facilities, detect and image metallic and non-metallic underground facilities, detect and quantify natural gas leaks, and other pertinent applications. Remote sensing is expected to be associated with very mobile platforms that can cover extended regions of the facilities quickly. Next generation natural gas leak detection and quantification is expected to focus on very high altitude (>50,000 feet) applications to allow improved, cost effective assessment.

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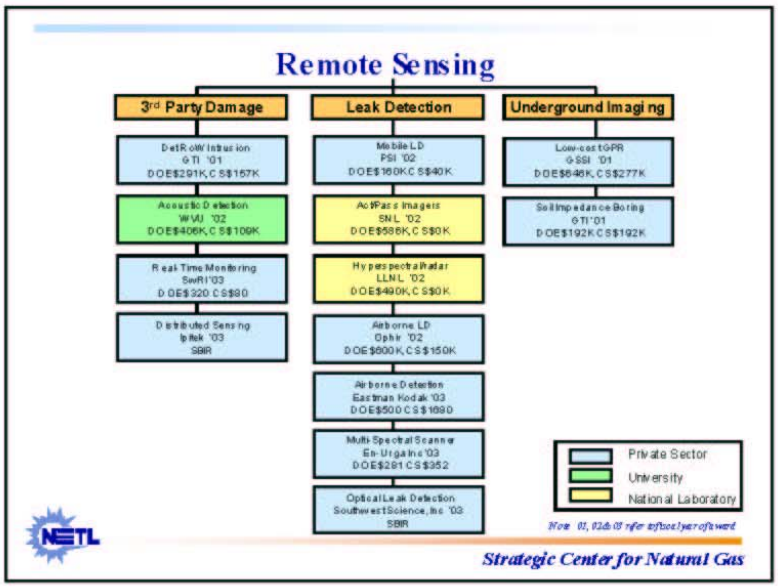
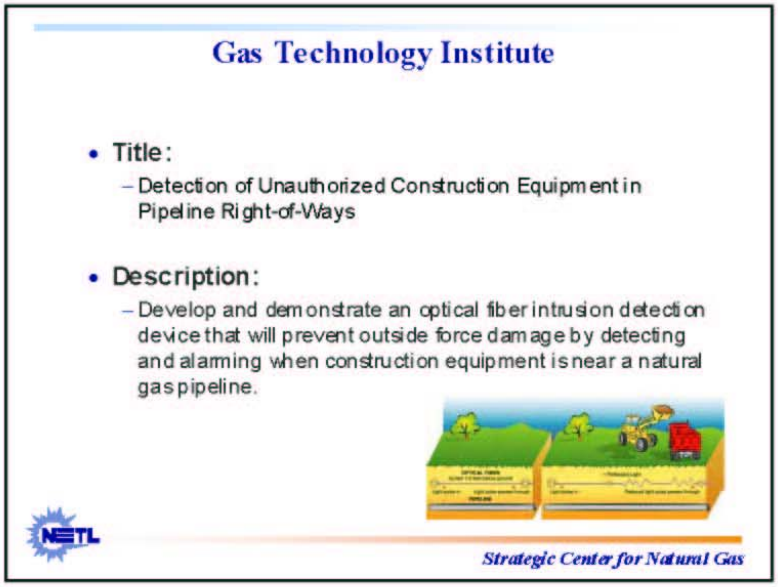

Remote Sensing
3rd Party Damage
Leak Detection
Underground Imaging
Private Sector
University
National Laboratory
Strategic Center for Natural Gas


Gas Technology Institute
• Title:
– Detection of Unauthorized Construction Equipment in Pipeline Right-of-Ways
• Description:
– Develop and demonstrate an optical fiber intrusion detection device that will prevent outside force damage by detecting and alarming when construction equipment is near a natural gas pipeline.
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West Virginia University

- **Title:**
  - Acoustic Detecting and Locating Gas Pipeline Infringement
- **Description:**
  - This project will develop a system to detect the unique sound wave generated when a pipeline break releases a large discharge of gas after being damaged by landslides, excavations, or other disturbances. The system will be designed to monitor the background noise inside the pipe and pick up any sudden new frequencies that might signal a sudden pipeline rupture.

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Physical Science Inc.

- **Title:**
  - Mobile Sensor for Remote Detection of Natural Gas Leaks

- **Description:**
  - Development of mobile gas leak detector technology capable of quantifying and distinguishing natural pipeline gas leaks from other hydrocarbon leaks or ambient methane sources. R&D will focus on extending the performance and applicability of the Remote Methane Leak Detector (RMLD) developed by PSI.
- **Partners:**
  - Heath Consultants

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Ophir Corporation

- **Title:**
  - Airborne, Optical Remote Sensing of Methane and Ethane for Natural Gas Pipeline Leak Detection
- **Description:**
  - This effort builds on Ophir's existing Active Gas Correlation Radiometer (AGCR) technology. The system, operating from either an airplane or a helicopter, will detect and quantify both methane and ethane, independently.
- **Partners:**
  - WBI Holdings, Inc.

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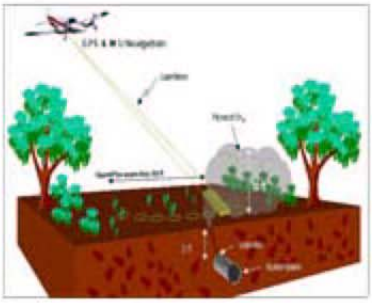
Eastman Kodak

- **Title**
  - Testing of an Advanced Airborne Natural Gas Leak Detection System
- **Description**
  - The objective of this project is to flight test a high-sensitivity, broad-coverage, natural gas leak detection system in an operational environment. The Kodak system will accurately detect and locate small concentrations of natural gas associated with leaks from transmission pipelines with very high confidence.



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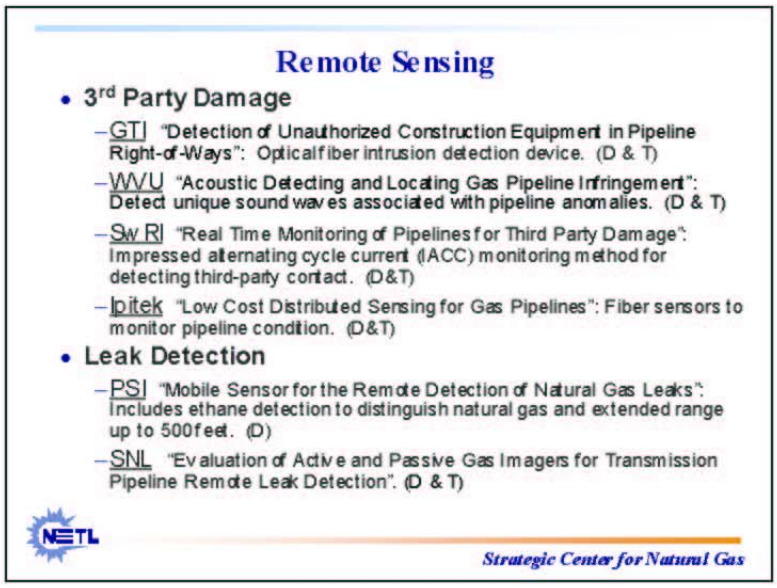
Remote Sensing
• 3rd Party Damage
– GTI "Detection of Unauthorized Construction Equipment in Pipeline Right-of-Ways": Optical fiber intrusion detection device. (D & T)
– WVU "Acoustic Detecting and Locating Gas Pipeline Infringement": Detect unique sound waves associated with pipeline anomalies. (D & T)
– SwRI "Real Time Monitoring of Pipelines for Third Party Damage": Impressed alternating cycle current (IACC) monitoring method for detecting third-party contact. (D&T)
– Ipitek "Low Cost Distributed Sensing for Gas Pipelines": Fiber sensors to monitor pipeline condition. (D&T)
• Leak Detection
– PSI "Mobile Sensor for the Remote Detection of Natural Gas Leaks": Includes ethane detection to distinguish natural gas and extended range up to 500 feet. (D)
– SNL "Evaluation of Active and Passive Gas Imagers for Transmission Pipeline Remote Leak Detection". (D & T)
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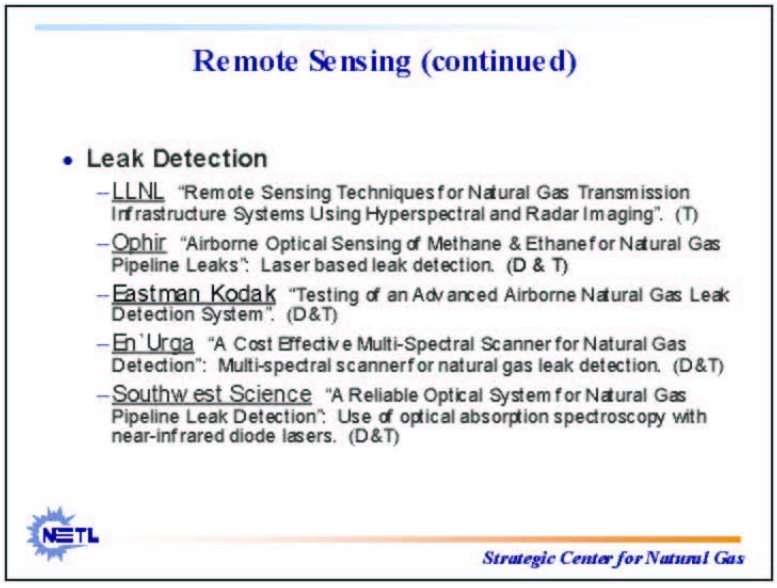
Remote Sensing (continued)
• Leak Detection
– LLNL "Remote Sensing Techniques for Natural Gas Transmission Infrastructure Systems Using Hyperspectral and Radar Imaging". (T)
– Ophir "Airborne Optical Sensing of Methane & Ethane for Natural Gas Pipeline Leaks": Laser based leak detection. (D & T)
– Eastman Kodak "Testing of an Advanced Airborne Natural Gas Leak Detection System". (D&T)
– En`Urga "A Cost Effective Multi-Spectral Scanner for Natural Gas Detection": Multi-spectral scanner for natural gas leak detection. (D&T)
– Southwest Science "A Reliable Optical System for Natural Gas Pipeline Leak Detection": Use of optical absorption spectroscopy with near-infrared diode lasers. (D&T)
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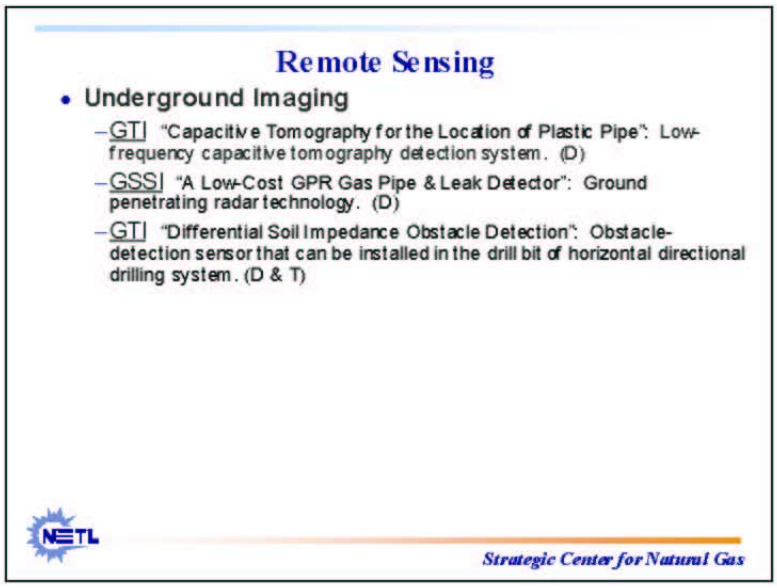
Remote Sensing
• Underground Imaging
– GTI "Capacitive Tomography for the Location of Plastic Pipe": Low-frequency capacitive tomography detection system. (D)
– GSSI "A Low-Cost GPR Gas Pipe & Leak Detector": Ground penetrating radar technology. (D)
– GTI "Differential Soil Impedance Obstacle Detection": Obstacle-detection sensor that can be installed in the drill bit of horizontal directional drilling system. (D & T)
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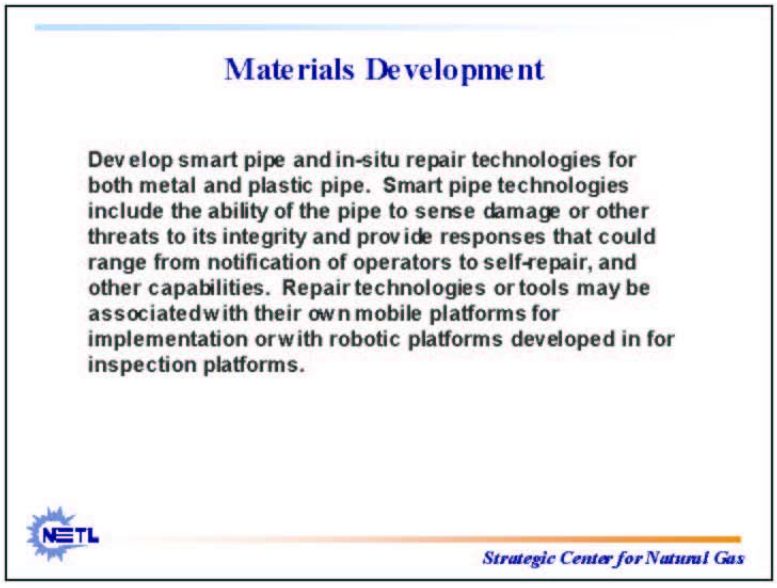
Materials Development
Develop smart pipe and in-situ repair technologies for both metal and plastic pipe. Smart pipe technologies include the ability of the pipe to sense damage or other threats to its integrity and provide responses that could range from notification of operators to self-repair, and other capabilities. Repair technologies or tools may be associated with their own mobile platforms for implementation or with robotic platforms developed in for inspection platforms.
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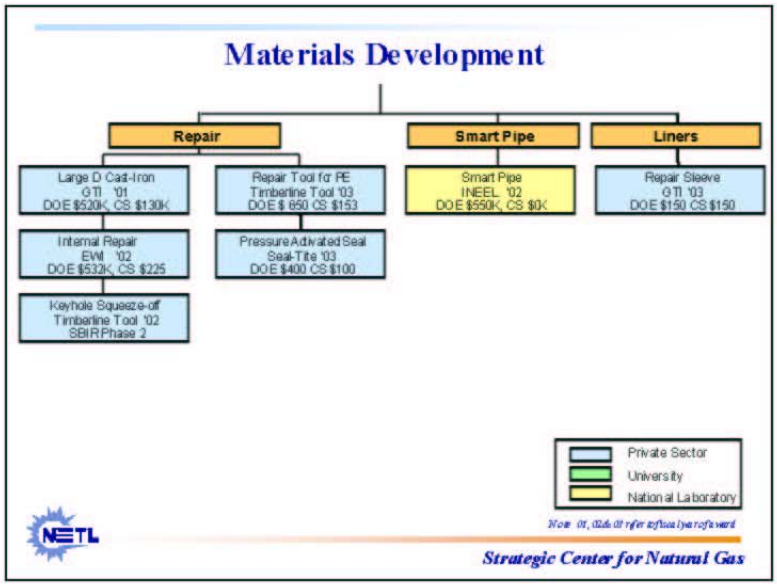
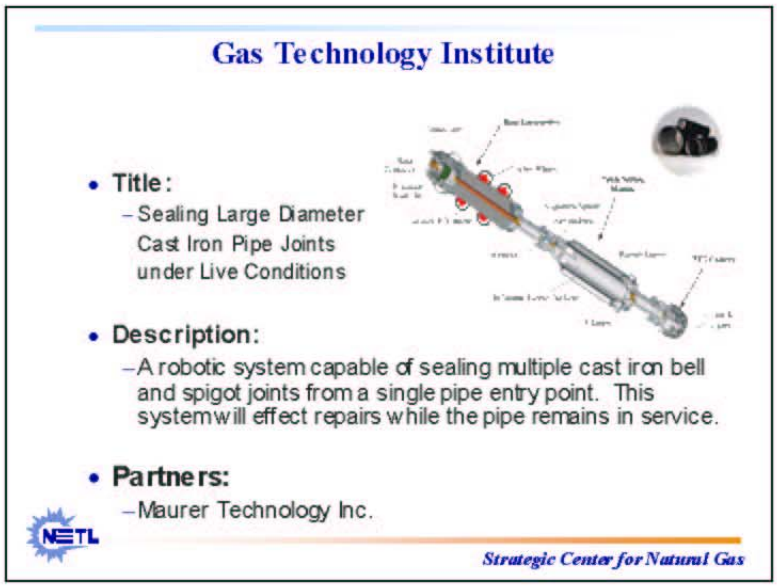

Materials Development
Repair
Smart Pipe
Liners
Large D Cast-Iron
GTI '01
DOE $520K, CS $130K
Repair Tool for PE
Timberline Tool '03
DOE $ 650 CS $153
Smart Pipe
INEEL '02
DOE $550K, CS $0K
Repair Sleeve
GTI '03
DOE $150 CS $150
Internal Repair
EWI '02
DOE $532K, CS $225
Pressure Activated Seal
Seal-Tite '03
DOE $400 CS $100
Keyhole Squeeze-off
Timberline Tool '02
SBIR Phase 2
Private Sector
University
National Laboratory
Strategic Center for Natural Gas


Gas Technology Institute
Title:
Sealing Large Diameter Cast Iron Pipe Joints under Live Conditions
Description:
A robotic system capable of sealing multiple cast iron bell and spigot joints from a single pipe entry point. This system will effect repairs while the pipe remains in service.
Partners:
Maurer Technology Inc.
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Idaho National Engineering and Environmental Laboratory

- **Title**:
  "Smart Pipe"
  Integral Communication, Damage Detection and Multiple Sensor Application in Pipelines

- **Description**:
  Thermally sprayed conductive traces applied in natural gas transmission and distribution pipelines that can be used for pipeline communications, detection and location of damage and as a conductive pathway for attaching or embedding sensors for performance monitoring.

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Materials Development

- Repair
  - GTI "Sealing Large-Diameter Cast-Iron Pipe Joints Under Live Conditions": Tethered robotic system to seal joints. (D)
  - Edison-Welding "Internal Repair of Pipelines": Welding-based internal repair techniques for use with robotic platforms. (D & T)
  - Timberline "Key hole Squeeze-off Tool to Enable Repair of Large (4" to 6") Polyethylene Gas Pipes": SBIR project. (D)
  - Timberline "Development of a Remote External Repair Tool for Damaged or Defective PE Pipe". (D)
  - Seal-Tite "Use of Pressure Activated Sealant Technology to Cure Pipeline Leaks". (T)

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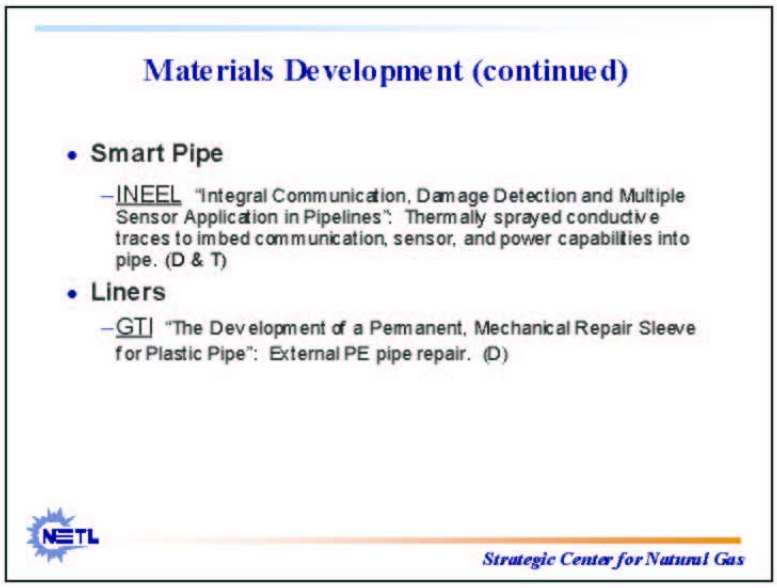
Materials Development (continued)
• Smart Pipe
– INEEL "Integral Communication, Damage Detection and Multiple Sensor Application in Pipelines": Thermally sprayed conductive traces to imbed communication, sensor, and power capabilities into pipe. (D & T)
• Liners
– GTI "The Development of a Permanent, Mechanical Repair Sleeve for Plastic Pipe": External PE pipe repair. (D)
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Operational Technologies
Develop next generation technologies and methodologies that improve the efficiency, reliability, and integrity of transmission and distribution operations. This includes the development of techniques to prevent corrosion or other forms of pipe deterioration, methodologies to optimize system operations to increase capacities of existing facilities, next generation compressors as well as substantial improvements in extant compressors, and other related activities.
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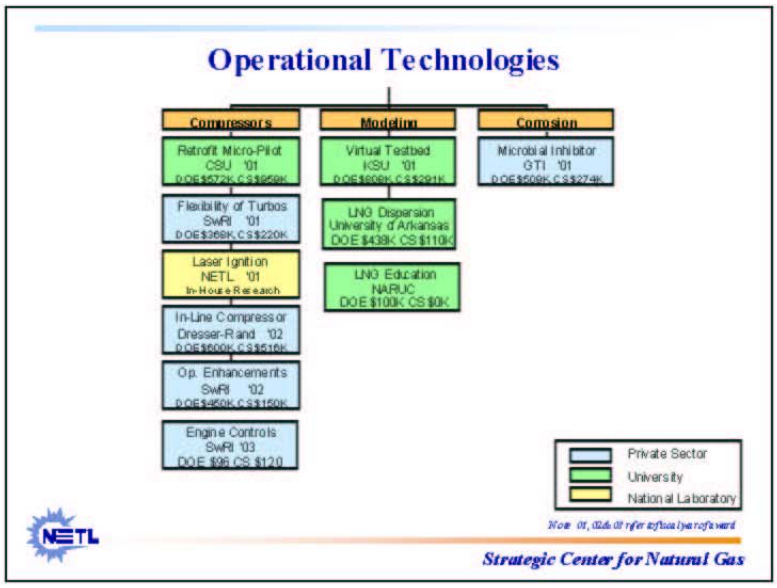
Operational Technologies
Compressors
Modeling
Corrosion
Retrofit Micro-Pilot
CSU '01
DOE $572K CS $658K
Virtual Testbed
KSU '01
DOE $698K CS $291K
Microbial Inhibitor
GTI '01
DOE $508K CS $274K
Flexibility of Turbos
SwRI '01
DOE $368K CS $220K
LNG Dispersion
University of Arkansas
DOE $439K CS $110K
Laser Ignition
NETL '01
In-House Research
LNG Education
NARUC
DOE $100K CS $0K
In-Line Compressor
Dresser-Rand '02
DOE $600K CS $510K
Op. Enhancements
SwRI '02
DOE $450K CS $150K
Engine Controls
SwRI '03
DOE $96 CS $120
Private Sector
University
National Laboratory
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National Energy Technology Laboratory
• Title:
– Laser Spark Ignition for Reciprocating Engines
• Description:
– Effort is targeted to improving the durability and performance of the ignition system for reciprocating engines by means of a Laser Spark Ignition system.
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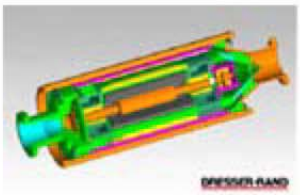
Dresser-Rand Company

- Title:
  - IEMDC - Totally Enclosed In-Line Electric Motor Driven Gas Compressor



- Description:
  - Development of the world's first gas compressor that can be installed directly into the pipeline (possibly underground.) The unit will utilize a direct coupled, variable speed induction motor with magnetic bearings mounted inside the casing of a 10 MW centrifugal compressor.
- Partners:
  - Westinghouse Electro-Mechanical Division (EMD)

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Operational Technologies

- Compressors
  - CSU "Improvement to Pipeline Compressor Engine Reliability through Retrofit Micro-Pilot Ignition System". (T)
  - Sw RI "Increased Flexibility of Turbo-Compressors in Natural Gas Transmission through Direct Surge Control": Incipient Surge Detector. (T)
  - NETL "Laser Ignition System for Reciprocating Engines": Improved engine efficiency, reduced emissions, and reduced operating costs. (T)
  - Dresser-Rand "Enclosed In-Line Electric Motor Driven Gas Compressor": Distributed compressors of this type could increase pipeline capacity up to 20% and increase security. (T)
  - Sw RI " Technologies to Enhance Operation of the Existing Natural Gas Compressor Infrastructure": Incremental performance improvements could reduce fuel costs by 1%. (T)

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Operational Technologies (continued)

- **Compressors**
  - SwRI "Advanced Compressor Engine Controls to Enhance Operation, Reliability and Integrity": NOx emissions control on a two-stroke integral gas compressor engine. (T)
- **Modeling**
  - KSU "Virtual Pipeline System Testbed to Optimize the U.S. Natural Gas Transmission Pipeline": Computer model. (T)
- **Corrosion**
  - GTI "Development of an Environmentally Benign Microbial Inhibitor to Control Internal Pipeline Corrosion": Natural chemical compounds. (D & T)

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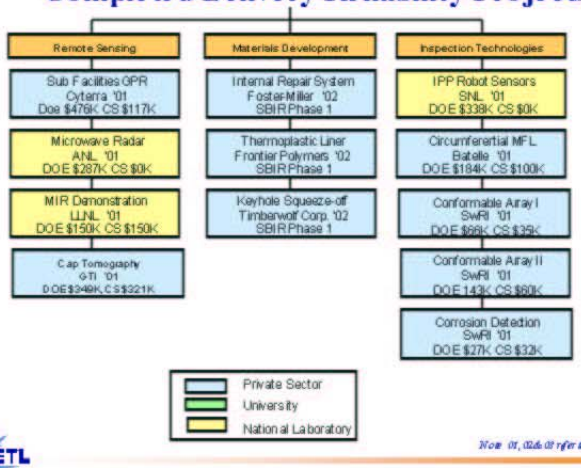
Completed Delivery Reliability Projects



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Accomplishments
• 26 completed projects
– Delivery Reliability: 12 projects in 3 years
– Storage: 14 completed projects in 9 years
• 5 technologies near hand-off status
– Cyterra underground imaging
– Pipe explorer
– SwRI conformable array
– Bishop process
– MDCF salt cavern model
• DOT/OPS collaborations
• Circumferential & axial MFL not sufficient
• Technology status assessments
• Industry recognition of FE program
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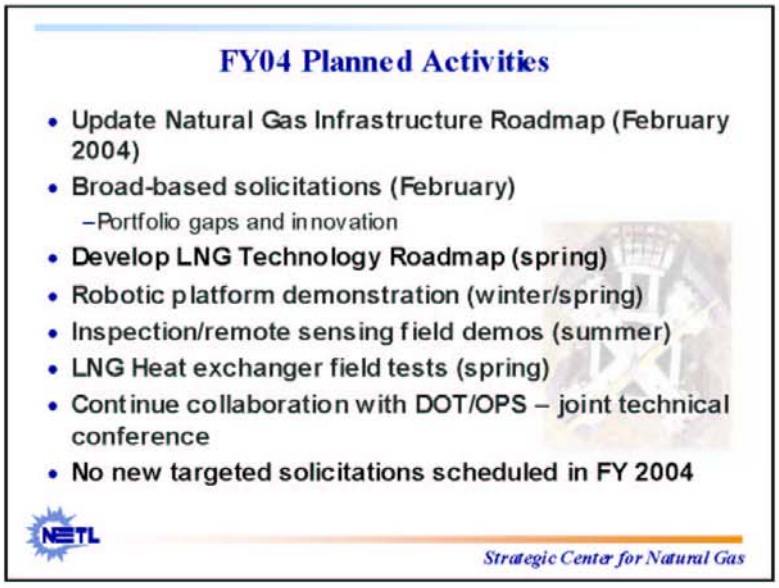
FY04 Planned Activities
• Update Natural Gas Infrastructure Roadmap (February 2004)
• Broad-based solicitations (February)
– Portfolio gaps and innovation
• Develop LNG Technology Roadmap (spring)
• Robotic platform demonstration (winter/spring)
• Inspection/remote sensing field demos (summer)
• LNG Heat exchanger field tests (spring)
• Continue collaboration with DOT/OPS – joint technical conference
• No new targeted solicitations scheduled in FY 2004
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"Where We Are Going" FY04

- Will re-evaluate delivery reliability program and Federal role
- Work with DOT/OPS and NIST to develop MOU and 5-year R&D plan to comply with Pipeline Safety Act of 2002
- Explore collaborations with Minerals Management Service
- No new targeted solicitations scheduled in FY 2004
- Initiate LNG studies
- Investigate role in DOE Hydrogen Program and participate in the development of a DOE Hydrogen Delivery Infrastructure R&D plan

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Internet Location: netl.doe.gov/scng/index.html

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APPENDIX B.
WORKSHOP PARTICIPANTS

NATURAL GAS INFRASTRUCTURE R&D ROADMAP UPDATE II

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