## Field Demonstration of Existing

# Microhole Coiled Tubing Rig (MCTR) Technology

**Final Technical Report**

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# Disclaimer

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# Abstract

The performance of an advanced Microhole Coiled Tubing Rig (MCTR) has been measured in the field during the drilling of 25 test wells in the Niobrara formation of Western Kansas and Eastern Colorado. The coiled tubing (CT) rig designed, built and operated by Advanced Drilling Technologies (ADT), was documented in its performance by GTI staff in the course of drilling wells ranging in depth from 500 to nearly 3,000 feet. Access to well sites in the Niobrara for documenting CT rig performance was provided by Rosewood Resources of Arlington, VA. The ADT CT rig was selected for field performance evaluation because it is one of the most advanced commercial CT rig designs that demonstrate a high degree of process integration and ease of set-up and operation. Employing an information collection protocol, data was collected from the ADT CT rig during 25 drilling events that encompassed a wide range of depths and drilling conditions in the Niobrara. Information collected included time-function data, selected parametric information indicating CT rig operational conditions, staffing levels, and field observations of the CT rig in each phase of operation, from rig up to rig down.

The data obtained in this field evaluation indicates that the ADT CT rig exhibited excellent performance in the drilling and completion of more than 25 wells in the Niobrara under varied drilling depths and formation conditions. In the majority of the 25 project well drilling events, ROP values ranged between 300 and 620 feet per hour. For all but the lowest 2 wells, ROP values averaged approximately 400 feet per hour, representing an excellent drilling capability. Most wells of depths between 500 and 2,000 feet were drilled at a total functional rig time of less than 16 hours; for wells as deep at 2,500 to 3,000 feet, the total rig time for the CT unit is usually well under one day. About 40-55 percent of the functional rig time is divided evenly between drilling and casing/cementing. The balance of time is divided among the remaining four functions of rig up/rig down, logging, lay down bottomhole assembly, and pick up bottomhole assembly.

Observations made during all phases of CT rig operation at each of the project well installations have verified a number of characteristics of the technology that represent advantages that can produce significant savings of 25-35 percent per well. Attributes of the CT rig performance include: 1) Excellent hole quality with hole deviation amounting to 1-2 degrees; 2) Reduced need for auxiliary equipment; 3) Efficient rig mobilization requiring only four trailers; 4) Capability of "Zero Discharge" operation; 5) Improved safety; and, 6) Measurement while drilling capability. In addition, commercial cost data indicates that the CT rig reduces drilling costs by 25 to 35% compared to conventional drilling technology.

Widespread commercial use of the Microhole Coiled Tubing technology in the United States for onshore Lower-48 drilling has the potential of achieving substantially positive impacts in terms of savings to the industry and resource expansion. Successfully commercialized Microhole CT Rig Technology is projected to achieve cumulative savings in Lower-48 onshore drilling expenditures of approximately 6.8 billion dollars by 2025. The reduced cost of CT microhole drilling is projected to enable the development of gas resources that would not have been economic with conventional methods. Because of the reduced cost of drilling achieved with CT rig technology, it is estimated that an additional 22 Tcf of gas resource will become economic to develop. In the future, the Microhole Coiled Tubing Rig represents an important platform for the continued improvement of drilling that draws on a new generation of various technologies to achieve goals of improved drilling cost and reduced impact to the environment.

# Glossary of Terms

| Acronym | Meaning |
|---|---|
| ADT | Advanced Drilling Technologies, Inc. |
| API | American Petroleum Institute |
| BCF | Billion Cubic Feet |
| BHA | Bottom Hole Assembly |
| BOP | Blowout Preventor |
| BTU | British Thermal Unit |
| CD | Compact Disc |
| CSG/CMNT | Casing and Cementing |
| CT | Coiled Tubing |
| CTR | Coiled Tubing Rig |
| CTS | Coiled Tubing Solutions, Inc. |
| DOC | United States Department of Commerce |
| DOE | United States Department of Energy |
| DOT or U.S. DOT | United States Department of Transportation |
| EEA | Energy and Environmental Analysis, Inc. |
| E&P | Exploration and Production |
| EPA | United States Environmental Protection Agency |
| FAQ | Frequently Asked Question |
| GTI | Gas Technology Institute |
| IADC | International Association of Drilling Contractors |
| IcoTA | International Coiled Tubing Association |
| IPAA | Independent Petroleum Association of America |
| IPAMS | Independent Petroleum Association of Mountain States |
| LD BHA | Lay Down Bore Hole Assembly |
| MCTR | Microhole Coiled Tubing Rig |
| MHT | Microhole Technology |
| MIRU-RDMO | Move In Rig Up – Rig Down Move Out |
| Moxie | Name of the CTS Coiled Tubing Rig |
| MWD | Measurement While Drilling |
| NETL | National Energy Technology Laboratory |
| NPC | National Petroleum Council |
| NPV | Net Present Value |
| PBHA | Pick Up Bore Hole Assembly |
| PI | Principal Investigator |
| Psi | Pounds per Square Inch |
| PTTC | Petroleum Technology Transfer Council |
| R&D | Research and Development |
| RD&D | Research, Development and Demonstration |
| ROP | Rate of Penetration |
| RPM | Revolutions per Minute |
| SPE | Society of Petroleum Engineers |
| Tcf | Trillion cubic feet |
| TRG | Total Functional Rig Time |
| UBD | Underbalanced Drilling |
| USGS | United States Geological Survey |

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# Executive Summary

The Gas Technology Institute, with the support of the Department of Energy/National Energy Technology Laboratory (NETL) has completed field performance documentation of coiled tubing (CT) microhole drilling technology in the Niobrara gas play of Kansas and Colorado. The CT technology (also referred to as Microhole Coil Tubing Rig or MCTR technology) has the potential to substantially reduce the costs of drilling and completing oil and gas wells, which is key to increasing future U.S. production.

Natural gas was first discovered in the Niobrara formation in 1912 when a strong flow of gas was encountered while drilling the Goodland No. 1 well near Goodland, Kansas1. The well was plugged and abandoned. Since that first well the Niobrara gas play has undergone several episodes of activity driven by gas prices and improvements in technology. Recently, the development of coiled tubing drilling in combination with a microhole approach to borehole size has helped reenergize activity in this mature gas play.

## Geology and Reservoir Characteristics

The Niobrara formation chalks were deposited during the last major transgression of the western interior Cretaceous sea, which extended from the Gulf of Mexico to the Arctic Ocean. Gas bearing chalk of the upper Cretaceous Niobrara formation is encountered at depths from 1000 to 3000 feet. Gas accumulations in the Niobrara formation generally are related to low relief structural features found along the eastern margins of the Denver geologic basin[2]. The formation is low permeability, underpressured and marginally economic.

## DOE Microhole Drilling Program

The Department of Energy's Tulsa office has designed and is implementing a research program to develop marginal oil and gas resources utilizing microhole wellbores. The overall approach is to develop a portfolio of tools and techniques that will allow the drilling of 3 5/8" holes and smaller enabling through better economics the development of marginal oil and gas resources. The field testing and demonstration of a "fit for purpose" coiled tubing drilling rig is one project within the program. The objective is to measure and document the rig performance under actual drilling conditions. A description of the rig and a summary of its performance in the Niobrara gas play follow.

## Description of the Rig

The coiled tubing drilling rig (designed and built by Tom Gipson with Advanced Drilling Technologies Inc. (ADT)) is a trailer mounted rig with the coil and derrick combined to a single unit. The rig has been operating for approximately one year drilling shallow gas wells operated by Rosewood Resources, Inc., in Western Kansas and Eastern Colorado. The rig operations have continued to improve to the point where it now drills 3,100 foot wells in a single day. Well cost savings of approximately 30% over conventional rotary well drilling have been documented. Improved well performance due to less formation damage as a result of minimizing formation exposure to drilling fluid through fast drilling and drilling operations is another important aspect.

## Efficient Rig Mobilization

The rig moves with 4 trailer loads mitigating mobilization and transportation cost while meeting U.S. Department of Transportation limitations for highway transport. These features allow for smaller access roads and well locations reducing well costs. The rig contains all the equipment needed for drilling operations including a zero discharge mud system, has pipe handling capacity for casing up to7 5/8" and can support a rotary and top drive.

## Small Environmental Footprint

The small size of the rig provides several environmental advantages over a conventional rig. As a result of its efficient design and size the following environmental advantages are realized:

- A small drilling pad (1/10$^{th}$ acre) or no pad under some conditions can be utilized. Smaller access roads are required.
- No mud pit is needed; mud tanks contain the required drilling fluids and are moved with the rig from one location to the next. The only pit required is a small (3'x 6'x 6') pit for drill cuttings. If needed, cuttings are easily hauled off location allowing no pit drilling as needed.
- Smaller equipment yields less air emissions and low noise engines minimize disturbances to the surrounding environment.
- The microhole approach (4 ¾" holes) requires less drilling mud and fluids to be treated and yields fewer drill cuttings.
- The utilization of coiled tubing mitigates the risk of spills due to no drill pipe connections.

## Rapid Drilling

Very high rates of penetration have been achieved by experimenting with bit-downhole motor combinations and by fully utilizing the advantages of coiled tubing drilling. Drilling rates as high as 620 feet/hour have been realized with the average rate of penetration per well in the 400 feet/hour range. This rate of drilling and other rig efficiencies allowed the drilling of a 2850 foot well in approximately 22 hours including all rig moving time, logging, casing setting and cementing and wells drilled at depths of 800 to 2000 feet required only 10 to 19 hours of total functional rig time.

## Good Hole Quality and Cement

The benefits of fast drilling by the ADT rig is augmented by excellent hole quality. All the wells drilled have resulted in a gauge hole with very little hole deviation (1 to 2 degrees - well within State requirements) despite the high penetration rates. Good cement job quality and well bonded cement also derive from the gauge hole quality. As mentioned previously, the Niobrara is an under pressured reservoir and as such is susceptible to formation damage due to fluid loss from drilling operations. The ability of the CT rig to rapidly penetrate the pay zone while avoiding any of the pressure surges observed with conventional drilling helps to mitigate fluid loss that leads to formation damage. This is an important factor given the marginal nature of the resource.

## Rig Capable of Running Casing, Handling Bottomhole Assemblies and Logging Tools –

No auxiliary equipment is required to run casing, log wells or for handling drill collars and bottom hole drilling assemblies. With its derrick, traveling block and rotary table components, all required drilling processes can be performed without additional equipment. While not currently equipped with a top drive, the rig can accommodate one if needed. Drilling with coiled tubing eliminates drill pipe connection time and fewer crew members are required to operate the rig.

## Zero Discharge if Required

The rig has the capability to drill a well with zero discharge of any fluid or other materials if required. The procedure is as follows:

- Rig up on a sealed/booted tarp to contain any overflow or accidental spill.
- No earthen pits are prepared; all cuttings and drilling fluid are confined to tanks with which the rig is equipped.
- A hole is augured for conductor pipe and a boot is placed around the conductor pipe.

Using this process, the ground is protected from any inadvertent spills and all fluids and cuttings are removed from the location. While obviously an added expense, this procedure may be required for drilling in sensitive environmental areas. The small rig size and efficiency of drilling coupled with the zero discharge capability enables drilling in sensitive areas.

## Improved Safety

Safety is always of utmost importance and the conventional drilling rig environment is one where extra caution and safety training is necessary due to the handling of drill pipe and other equipment. The ADT coiled tubing rig significantly reduces drill pipe handling and has less equipment to mobilize from well to well. All of this creates a much safer operating environment which is important during any time of drilling but especially so during today's high rig count when experienced roughnecks are difficult to find.

## Barriers to Microhole Coiled Tubing Drilling

Barriers exist to full utilization of this type of approach to the drilling and completion of marginal resources. Operators have identified the following as concerns that must be addressed for microhole to reach its full potential:

- Production engineers have long-term concerns about the ability to rework wells.
- Handling of significant fluids is an issue in small boreholes.
- There is limited space for downhole mechanical equipment.
- A general lack of experience and familiarity with microhole and coiled tubing drilling of this type was identified as a barrier to usage.
- There is a depth limitation given current coil metallurgy and coiled tubing procedures.
- Coiled tubing is limited in its ability to overcome problems in difficult drilling environments. One example is where fluid loss and severe pipe sticking is encountered. Coiled tubing has limited tensile strength for freeing stuck pipe.

## Technology Trends

Operators pursuing marginal resources are doing so in a new era. Driven by a growing economy, U.S. energy demand is expected to reach record levels in the near future. The higher quality resources have been exploited, increasing the challenge for future developments.

The rate of new technology improvement is beginning to be offset by the increasing challenges created by lower quality reservoir rock and increasing costs from environmental issues.

A concerted technology effort to both better understand marginal oil and gas resources and develop solid engineering approaches (such as the microhole program) is necessary for significant production increases from these widely dispersed resources.

## Introduction

The Gas Technology Institute, with the support of the Department of Energy/National Energy Technology Laboratory (NETL) has completed field performance documentation of coiled tubing (CT) microhole drilling technology in the Niobrara gas play of Kansas and Colorado. The CT technology has the potential to substantially reduce the costs of drilling and completing oil and gas wells, which is key to increasing future U.S. production. In addition, the technology enables a reduced environmental footprint that should result in the ability to access resources in areas where environmental concerns would have been an impediment.

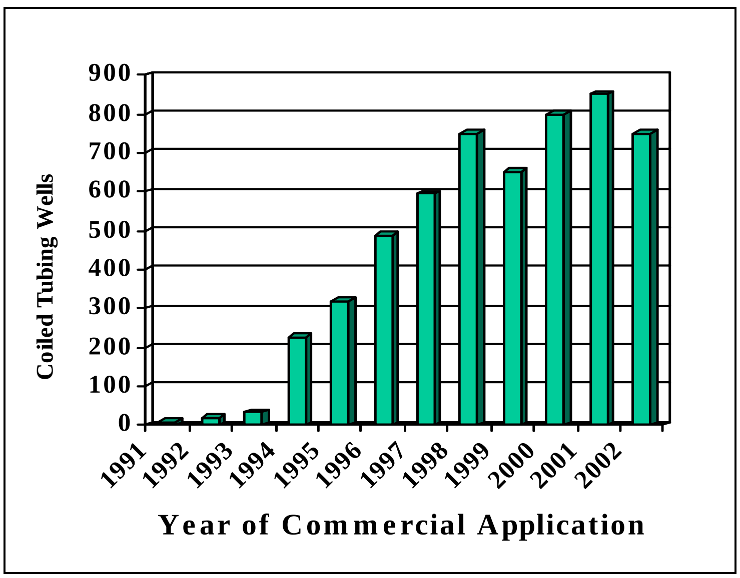
Coiled tubing microhole technology uses a coiled tubing rig and smaller diameter and less cumbersome drilling equipment that greatly reduce drilling time and costs. For this demonstration project, Microhole technology was defined as open hole drilling of 4 3/4 inch holes allowing wells to be completed with 2 7/8 inch tubing as the production casing. Much of the technology is comprised of downsized versions of existing standard diameter drilling equipment, including bits, motors, and bottomhole assemblies (Duttlinger, 2006). Drilling is accomplished utilizing continuous 2 5/8 inch coiled tubing. The bit is powered through turbines that are powered by the mud circulation.

Technologies include “built for purpose” coiled tubing (CT) rigs, specialized bits, and bottom hole assemblies to allow for steering, logging and communication with the surface. Well bores can be vertical or can have substantial horizontal components. Technologies to facilitate longer horizontal components are under development, and include downhole “tractors” to provide additional force on the bit. The small bit diameter not only allows faster rates of penetration, but results in a much lower volume of well cuttings and mud volume, and less expensive tubulars. The rig requires fewer personnel, and is faster to rig up and rig down. A closed mud system means that no mud pits are required.

A significant advantage of CT drilling is that it can be performed in an “underbalanced” mode, resulting in much less formation damage. Research has shown that many tight gas reservoirs are damaged during traditional drilling, resulting in a loss of eventual productivity. By not damaging the formation during drilling, CT often allows better production, whether the reservoir is stimulated or not. Under drilling conditions where overbalanced drilling is required, CT drilling has the advantage of rapid drilling through the pay zone without the pressure surges that accompany jointed drill pipe connections.

One of the most promising mechanical devices in achieving the benefits of well-bore diameter reduction is the coil tubing rig or CTR. Coil Tubing Rig (CTRs) of various commercial designs have made the first incremental reductions in wellbore diameters, though applications have generally emphasized simple vertical, non-steered holes in shallow reserves. As shown in **Figure 1**, CTRs have been in use for well drilling since the

**Figure 1 - Annual Coiled Tubing Drilled Wells (Source; Spears and Associates, April 1993)**



early 1990's and over the past 15 years have increased from a few dozen wells in 1993 to nearly 800 per year by 2000 (Spears and Associates, April 2003). Although, worldwide, more than 8,000 wells have been drilled with a coil (mostly in Canada), the lower-48 of the U.S. has seen a more modest market penetration involving about 300 coiled tubing wells. In recognition of the potential beneficial impact of the technology to U.S. energy and environmental interests, the Department of Energy in collaboration with the oil and gas industry has pursued a Microhole Technology (MHT) Program aimed at developing a number of technologies that enable the drilling of wells with casings less than 4 ½ inches in diameter using coiled tubing drill rigs and downhole tools that are small, easier to mobilize than conventional drill rigs and tools and capable of drilling shallow and moderate depth holes for exploration, field development and long-term subsurface monitoring.

The Gas Technology Institute (GTI), in partnership with Coiled Tubing Solutions (now Advanced Drilling Technologies or ADT) and Rosewood Resources, Inc., has conducted a field test of a state-of-the-art Microhole Coiled Tubing Rig (MCTR) in the Niobrara gas fields (extending across Northwest Kansas and Southeastern Colorado) and conducted technology transfer efforts to augment interest and acceptance of the technology within the natural gas industry. In this effort, GTI has provided overall project management, collected operational data during field testing, prepared the field test documentation and managed the technology transfer aspect of the program. In coordination with the testing, ADT provided the MCTR rig and the rig crew as well as maintenance and operations support during the field testing phase of the project. Rosewood Resources, Inc. served a vital role in providing drilling locations for the test drilling.

The purpose of the MCTR project was to conduct a series of field demonstrations of a commercial microhole drilling rig to objectively measure the performance and capabilities of currently-available microhole technology (MHT) equipment under varied drilling conditions. The work was conducted against the backdrop of anecdotal information on commercial CTRs that suggested that coil tubing drilling could be used at moderate depths at significantly reduced cost compared to conventional techniques. The aim of the MCTR project was to develop an objective information base that could be used to more accurately determine the envelope of conditions where applications of the environmentally friendly technology are clearly feasible and cost-effective with the end result of augmenting interest in the industry for greater use of the technology.

## Background

In concept, microhole technology based on coil tubing uses less cumbersome drilling equipment that enables smaller crews to rig up, drill and rig down for exploration, thereby significantly reducing the costs and risks of drilling wells for gas and oil producers. The smaller drilling operation also reduces drilling waste and minimizes environmental impact, which has been a major obstacle to expanded oil and gas exploration and development in the United States, especially in environmentally sensitive areas.

The coiled tubing rig design concept consists of using a reduced-diameter, continuous coiled tube mounted on a large spool (about 7 ft in diameter) to drill an open hole using a trailer mounted drill rig that supports and feeds the coil into the hole as drilling progresses. Coiled tubing (CT) was first employed for solving an oilfield problem in the 1960's when the California Oil Company and Bowen Tools created the first fully functional CT unit to wash out sand that was obstructing oil flow in its wells. Further development of the technology to enable application to oil and gas exploration and field development did not occur, however, for several decades.

In terms of its effective market penetration into modern E&P practices, coiled tubing (CT) drilling represents a recent innovation that has been used for mostly shallow drilling for oil and gas exploration since the early 1990's (Fultz and Pitard, 1990). Application of the technique was reported in a successful horizontal well case history conducted in 1992 (Ramos, et al.). During this period, field trials and qualitative observations revealed a number of strengths and limitations of the early CT rig designs (Byrom, 1999), the most notable of which was the ability of CT to speed up oilfield operations for certain types of applications. Specific advantages compared to conventional jointed pipe well construction designs and limitations revealed by field application of early CT designs are shown in Table 1.

**Table 1 - Observations from First Generation CT Applications to Oil and Gas Exploration and Production (Source: Byrom, 1999)**

| Advantages | Limitations |
|---|---|
| • Portability and mobility<br>• Ability to drill and trip under pressure<br>• Significantly reduced tripping time for bit or bottom hole assembly changes<br>• Enabled continuous, high-quality telemetry between surface and downhole for real-time data acquisition and control<br>• Continuous drilling fluid circulation while tripping<br>• Ability to drill under pressure<br>• Significantly reduced footprint of the operation<br>• Reduced drill rig labor compared with conventional tripping | • High maintenance requirements for first generation units<br>• Relies on slide drilling because it is not able to rotate the drill stem<br>• Requires a downhole drilling motor (hydraulic or electric powered)<br>• Short tube life<br>• Limited fishing capabilities<br>• High circulation pressures<br>• Low circulation rates |

Some functional components of a CT drill rig are similar to those of conventional drill rigs. Each type of rig has circulating pumps, mud mixing process, mud tanks, solids removal equipment, controls, etc. However, a major strength of the CT system is the ability to mobilize, demobilize and rapidly transport equipment in and out of each drilling site. This ability is enabled by the relatively compact design of the CT assembly which is mounted on six or less trailers. For most CT systems, the distinctive elements of the assembly that are most visible include the reel, injector head, pumping unit, power pack, blowout preventor (BOP), and the control housing; all of these pieces are trailer mounted and easily moved from location to location (Byrom, 1999).

The reel consists of a large drum on which the coiled tubing is wound and unwound during the operation of the rig. The tubing diameter can range from 0.8 to 4 inches. The injector head is the device that provides the force to run the CT down the well and to retrieve it. This piece of equipment features a "goose neck" that straightens the CT and prepares it to be introduced into the well. Supporting these components is the power pack that generates the pneumatic and hydraulic power required for operating the CT rig operation. The BOP is a well control component that allows an operator to isolate the downhole CT as a safety measure. The control house is where the operator monitors well bore pressures, gases, equipment pump rates, fluid volumes, drill rates, speeds, torques, and other parameters related to CT operation. From this center, the operator can make necessary adjustments in equipment operation and can institute several safety interventions if needed.

Considerable redundancy in safety is incorporated in commercial CT rigs as a standard practice. Unlike a conventional drillstring, if the well is under pressure, the entire CT that is not in the hole is also under pressure. To address this situation, several redundant safety devices are incorporated into the CT system design to allow safe well intervention, if needed. First, the BOP, located below the injector and above the wellhead, is controlled from the operator's station and isolates the well with pipe blind, and shear rams. Second, several safety features have been installed in the bottom hole assembly (BHA) for added protection. To prevent leaks from the CT that is not in the hole, one or two check valves can be installed in the BHA. Further safety is provided by an emergency disconnect that allows a CT unit operator to disconnect the CT from the BHA if it becomes stuck (Byrom, 1999).

Downhole equipment for CT drilling can be simple or complex. For simple vertical drilling, equipment may consist of a bit, downhole motor and a few drill collars. A directional bottomhole assembly may consist of a bit, a steering tool to sense and transmit directional data, a bent-housing mud motor, an orientation tool to change the direction of the bit, and an array of optional transducers to obtain log data on bottomhole pressure, weight on bit, bit torque, temperature, and vibrations. Sensing and control devices are usually in a two-way communication with the surface through one or more electric and (often) hydraulic lines inside the coiled tubing (CT). These cables and tubes provide a two-way telemetry and control between the operator and the devices in the bore hole assembly (BHA). Cables and tubes add to the weight of the CT string and can restrict internal flow. However, they also provide an advantage over conventional of improved two-way communication and high-quality real-time data from downhole instruments. Contributing to the success of commercial CT drilling in Canada and around the world has been the value of communication and the integration of real-time data required to make rapid and concise decisions pertaining to drilling operations, underbalanced conditions and directional performance (Elsborg, 1996).

Although CT drilling is conducted with a low weight on bit compared to conventional drilling, improved monitoring and control of downhole equipment continues to improve rates of penetration (ROP) for CT, from below 100 ft per hour in the late 1980's to ROP's over 200 ft per hour less than a decade later (Elsborg, 1996). However, much of the advantage of achieving higher ROPs can be eroded if the complexity of the CT rig requires considerable time for rig up and rig down. Typically, conventional CT units require 5 to 6 truckloads of equipment and possibly more if the drilling is to be done underbalanced. Even for vertical drilling in shallow-to-moderately deep formations, significant time may be required for assembly of the CT rig and for the careful alignment of the injector head with the reel and wellhead equipment. New rigs that are built for purpose have made progress in simplifying mobilization and rig up procedures. Thus, future improvements in efficiency and economics of CT drilling depend on continued progress in not only achieving higher ROP levels but on decreasing operator time components related to maintenance, rig up and rig down.

Notwithstanding the progress made in CT design and overall performance, little market penetration has been achieved for CT drilling services in the lower 48 compared with the rest of the world. Within the U.S., individual CT drilling service firms working in niche applications have obtained valuable knowledge of CT field performance, but very little of this information has been communicated to the oil and gas industry. To date, CT drilling performance has yet to be quantified in a systematic manner that is meaningful across an array of drilling functions, conditions and parameters that affect performance and cost. The purpose of this project was to obtain field measurements of performance and cost on one of the most advanced commercial CT rig designs that has reached new levels of ROP performance, process integration, reduced turn-around times for rig-up/rig-down and ease of mobility. The aim of this project was to supplement industry awareness and increase confidence in the potential applications, capabilities and benefits of CT technology in the challenging arena of expanded oil and gas exploration and development for the lower 48 in the 21$^{st}$ century.

# Statement of Work

## Objective

The overall objective of this project was to evaluate the operating efficiency of a microhole coiled tubing rig for drilling and completing boreholes in oil or gas formations to depths up to 5,000 ft. The rig that was tested was fabricated by Coiled Tubing Solutions Inc. (CTS) and was deployed on many leaseholds owned by Rosewood Resources Inc. (Rosewood). The testing was aimed at evaluating, objectively and subjectively, the performance of the rig as compared to performance of a conventional rotary rig under similar circumstances. Evaluations were to be made on a wide array of CT rig functions and included analyses of mobilization and rig up times and costs, drilling of surface and production holes (time, cost, crew size, safety, environmental factors), running surface casing and cementing (time, cost, crew size, safety, environmental factors, and subjective comparison with conventional rotary rig operation), running production casing (costs, times, efficiencies, safety), logging and evaluation, and demobilization and move out. Factors that were to be evaluated included time, cost, crew size, safety, environmental factors (such as drilling mud control), site access (drill roads, need for drill pad, time to reach drill site with full rig), operational issues (drilling speed, weight on bit, bit RPM, torque requirements, drag, pump pressures, weight-on-bit, fuel consumption), linearity of the hole, ability to control bit direction, and mobilization and demobilization issues (time, crew size, need for external equipment). Subjective observations of operational efficiency were also to be included in the performance analysis. Project goals included extensive videotaping of the CT rig in operation to document performance and provide materials for technology transfer. A second major objective was to initiate technology transfer industry to communicate the capabilities, performance and cost of the CT rig technology to the oil and gas industry.

## Tasks

Within the scope of work, GTI was to evaluate the performance of the CTS coiled tubing rig on drilling leases held by Rosewood Resources. Prior to initiating field work, the GTI/CTS/Rosewood team, with the concurrence of DOE, selected the drilling sites that test the efficiency of the drilling equipment in both shallow and deep formations and under various drilling conditions. Testing was to monitor drilling at sites with depths of 1,000', 2,500 feet, and up to 5,000 and was to be conducted, as available, at leaseholds in the Niobrara formation within Oklahoma, western Kansas, and/or Colorado. The scope of work included the following specific tasks.

- Task 1 – Finalize Test Plan
- Task 2 – CTS Rig Testing and Data Collection
- Task 3 – Technology Transfer
- Task 4 – Final Report Preparation
- Task 5 – Project Management

Descriptions in detail of each of the above tasks are given in the following sections.

### Task 1 – Project Planning

This task was to be comprised of the Planning Phase. This task was to consist of defining the exact wells and locations for the drilling program. This task was to be performed in conjunction with Rosewood Resources and was to include an evaluation of their final year 2005 drilling program and the selection of a portfolio of wells for the research project best suited to achieving the project objectives. The aim of the project planning was to design an equipment performance verification effort for the CTS Microhole Drilling System that could establish an information base that could be used by commercial firms to assess the technical feasibility and economic benefit of implementing the technology in their future exploration and production businesses. Ideally, this information base could be used to attract energy companies to use the new microhole technology and accelerate the benefits of this technique to the industry, the public and to the environment. To construct a database of this nature, the information collected in the field verification study was to cover a range of conditions that potential customers could relate to in their assessment of the technology for future well field development efforts.

Well selection criteria were to be established as part of the planning phase to obtain a meaningful information base on microhole drilling performance and to establish an optimum portfolio of customer-relevant conditions. Selection criteria were to include items such as well depth, drilling problems known to the specific area, casing size requirements based on expected production, surface conditions including required drilling pad size and requirements for protecting crops and fresh water resources. The selection criteria were to be designed to document drilling performance and costs under conditions that have relevance to a wide span of potential oil and gas industry applications.

Working with Rosewood, DOE Project Management and Mr. Tom Gipson, GTI was to prepare a matrix of well drilling parameters and conditions that were projected to be encountered during the field performance trials of CTS equipment. Then, a drilling plan was to be prepared that would identify wells that relate to the characteristics and parameter values of each element of the test matrix. Objectives for each well to be drilled were to be established based on the overall project objectives and wells of opportunity. The final project schedule for drilling of the project wells was to be determined according to both project requirements and area of operations drilling windows. Using these considerations, a test plan document was to be prepared; this plan was called a *“Portfolio of Project Wells, Individual Well Objectives and Drilling Schedule”.*

### Task 2 – Data Collection and Field Operations and Analysis

This task consisted of executing a carefully-designed field effort to measure and document the performance and economics of Coiled Tubing Microhole Drilling equipment. Approximately 15 wells were to be drilled; each of these wells was to relate to an element in the test matrix based on its anticipated characteristics. The characteristics of each well were to be described in a manner that would provide a meaningful contextual framework, yet protect the proprietary aspects of exact locations and business-sensitive planning information. The specific subtasks included in this effort are described in the following sections.

#### Subtask 2.1 – Data Collection and Field Operations

Based on the schedule, test matrix and test plan prepared in Task 1, field operations and data collection were to be performed. The following test protocol steps were to be performed on each of the approximately 15 project wells:

1. Prepare individual well data requirements for all project wells

2. Based on overall project objectives finalize specific well objectives
3. Identify and procure any special testing instruments or services for the well
4. Hold planning meeting with field personnel to define roles and responsibilities and to impress upon all that this is a research experiment requiring quality operations and attention to detail
5. Drill the project well to gather required data
6. Assess results of data gathering, analyze procedures, review with all team members and utilize results for modification of plans for the next project well
7. Repeat procedure at Step 2 for all subsequent project wells

The deliverable for Subtask 2.1 was to be a database consisting of a tabulation of all relevant field data.

#### Subtask 2.2 – Data Analysis

GTI was to compile and assess the field data and perform an evaluation to identify the performance attributes, shortfalls and overall efficacy of microhole drilling in the area of operations. GTI was to compare the CT drilling rig results to those for conventional drilling and compile the results into a format suitable for workshops, publications and the final report. Integral to the analysis was to be a presentation of the results of an estimated 15-well information base with important “take away messages” clearly identified.

### Task 3 – Technology Transfer

Task 3 was to involve activities that contribute to technology dissemination in the oil and gas industry. Major activities were to include participating in industry workshops designed to present the important results of the CTS microhole drilling performance and, if possible, providing a field demonstration of the equipment at an actual site.

### Task 4 – Report Writing

A final report documenting all results of the project was to be prepared according to DOE criteria.

### Task 5 – Project Management

Project management and data collection coordination was to be provided by GTI. Particular attention was to be directed at tracking the progress of the project consistent with achieving project objectives/deliverables within schedule and within budget while maintaining close communication with the DOE Project Manager.

## GTI/CTS/Rosewood Approach

Overall, this project was aimed at documenting the field performance and operating efficiency of an advanced coiled tubing rig in the course of drilling wells at various depths under a range of well-defined conditions. This required the coordinated effort of an R&D organization, an energy developer and CT rig services company to first create and implement a test plan encompassing a range of test conditions to document CT rig performance in the field. The project involved the collection of objective measurements and subjective observations during the drilling of 25 project wells. In addition to direct observations of the quality of well bore construction, waste management, worker safety and environmental footprint resulting from the rig operation, a set of empirical measurements on mechanical operation (e.g. drilling speed, weight on bit, bit RPM, torque requirements, drag, pump pressures, fuel consumption, etc.) were obtained from the CT rig. Equally important, for each well that was drilled with the advanced CT rig, a set of time-function data was obtained to provide detailed information on operational efficiencies. In addition, still photos and videotaping were employed to provide detailed visual information on the CT rig during its set-up, take-down and operation. This multi-faceted effort depended upon the cooperation and combined capabilities of the organizational team of GTI, CTS and Rosewood Resources, Inc. and represents an unprecedented effort in the documentation of commercial MCTR technology under field conditions.

### Roles of Project Team Members

Three organizations participated in the Microhole Coiled Tubing Drilling project: Gas Technology Institute (GTI), Rosewood Resources and Coiled Tubing Solutions (CTS). Coiled Tubing Solutions through the course of the project formed a new company (Advanced Drilling Technologies, Inc. (ADT)) which is located in Yuma, Colorado. ADT served as the project partner replacing CTS. Following is a brief description of each organization and their respective roles in the project.

GTI is a leading research and development organization serving the energy industry. GTI's E&P center has a history of solving the industry challenges and moving the results to the marketplace. GTI's multi-disciplinary research program to coal-bed methane development contributed to the economic development of this resource. For the Coiled Tubing Drilling project, GTI served as overall project manager and documented the performance of the drilling rig in the field. Additionally, GTI had responsibility for technology dissemination assuring widespread distribution of the project results.

Coiled Tubing Solutions (CTS), located in Eastland, Texas, was founded by Tom Gipson in response to a need for a company to build coiled tubing rigs. Mr. Gipson filed a coiled tubing patent in 1987 that helped him pioneer the used of coiled tubing for plug and abandonment work. Mr. Gipson subsequently went on to build or supervise the fabrication of 15 coiled tubing rigs, including 7 of the 24 currently running in Canada drilling gas wells up to 5,000 feet deep. CTS has the ability to prepare the engineering designs and calculations for drilling rigs, and to fabricate the final drilling rigs. CTS formed Advanced Drilling Technologies (ADT) and participated in the project through that entity. ADT is located in Yuma, Colorado. ADT role in the project was to make available the coiled tubing rig and assist GTI in documentation of rig performance. This was accomplished as the rig operated on commercial wells.

Rosewood Resources is a division of Rosewood Corp., and owns oil and gas leases throughout the Gulf Coast, Oklahoma and Colorado. Rosewood drilled over 100 wells in 2005. Rosewood Resources provided access to the leases they were drilling in the Niobrara formation of Northwestern Kansas and Southeastern Colorado. Overall, 23 project wells were provided by

Rosewood for monitoring and documentation of the coiled tubing rig performance. Rosewood also provided advice and information regarding the geology, well completion procedures and other data important to the program.

The table below identifies all of the project participants and their respective roles. PTTC was not a contractual partner to GTI but provided Technology Transfer functions such as workshop opportunities and organizing review meetings.

**Table 2 - Microhole Coiled Tubing Drilling Project Team Members**

| Subcontractors/Industry Partner | Role | Project Role |
|---|---|---|
| Coiled Tubing Solutions (CTS) / Advanced Drilling Technologies (ADT) | Supplier/ Consultant | Experimental Rig Supplier<br>Design/Fabrication consulting<br>Coiled Tubing Costs |
| Rosewood Resources Inc | Leaseholder | Sites for Testing<br>Authorizations for Expenditure<br>Historical drilling costs |
| PTTC | Forum For Tech. Transfer | Outlet for Technology Transfer |
| Department of Energy | Government Partner | Contracting Source |

## Rosewood Geologic Setting

Rosewood owns reserves in the Niobrara formation (see **Figures 2 and 3**), chalks deposited during the last major transgression of the western interior Cretaceous sea, which extended from the Gulf of Mexico to the Arctic Ocean.

The current play extends through Northwest Kansas and Eastern Colorado (**Figure 3**). Gas bearing chalk of the upper Cretaceous Niobrara formation is encountered at depths from 1000 to 3000 feet. Gas accumulations in the Niobrara formation generally are related to low relief structural features found along the eastern margins of the Denver geologic basin (Brown, et al.,1982).

**Figure 2 - Photomicrograph of Niobrara Chalk Formation, Characterized by high porosity (30 to 50%), Low k (.01 to 3 md), Depth = 1500 to 3000 Ft, Biogenic Gas in Low Relief Structures**

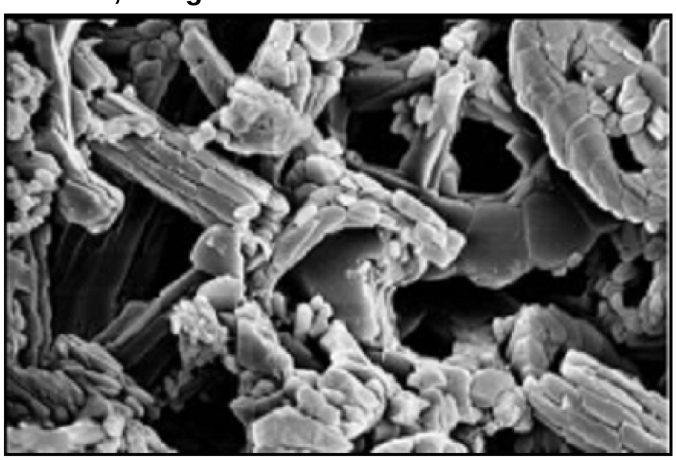
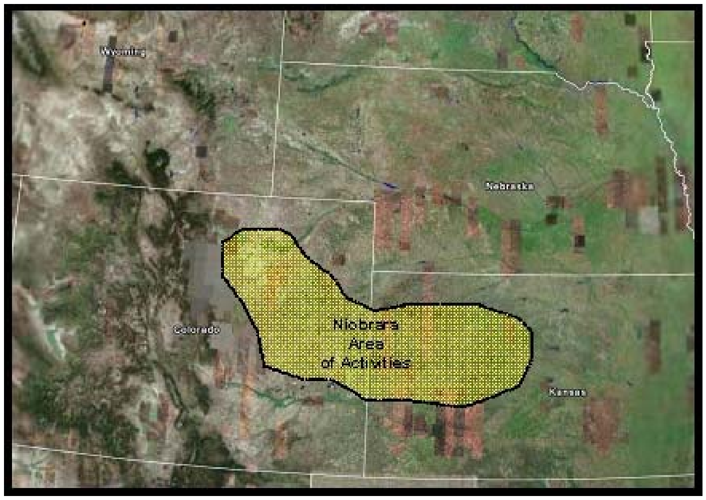


**Figure 3 - Niobrara Gas Play area in Kansas and Colorado**

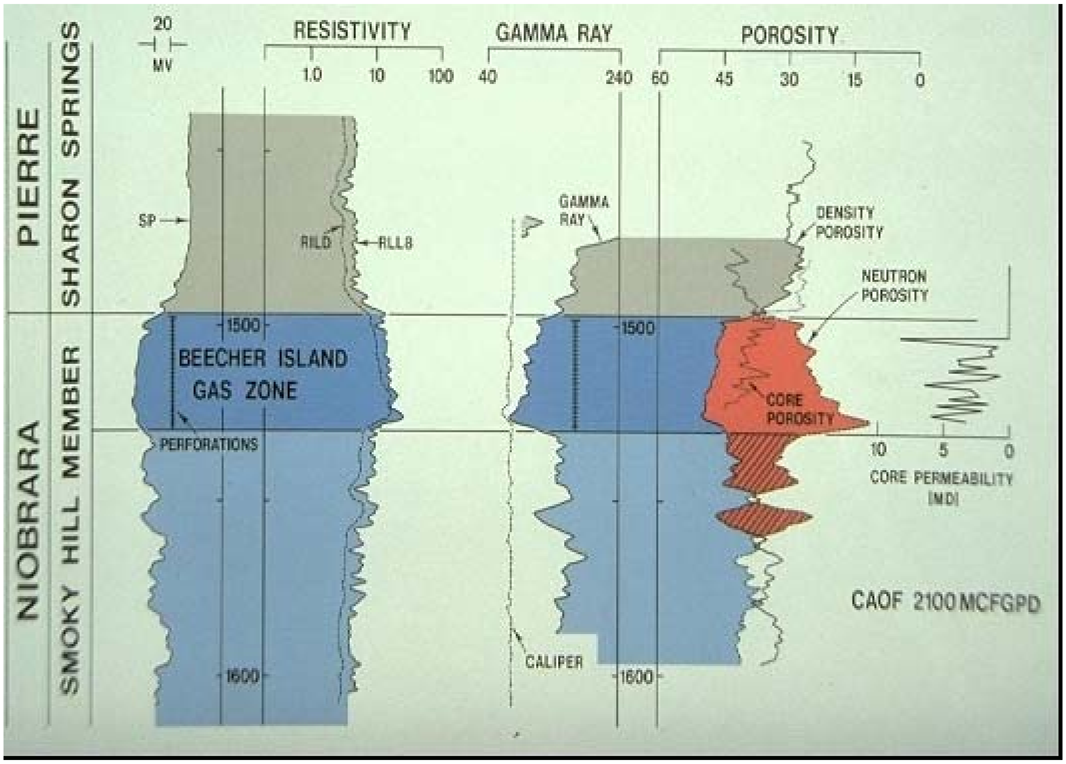



Niobrara gas fields are characterized by high porosity, low permeability and low reservoir pressure. These features are typical of a chalk subjected to modest burial depths (Scholle, 1977). At greater depth, porosity and permeability decrease causing a reduced total pore volume and higher water saturation at a given structural position.

Reported values for porosity in the Niobrara formation range from 30% to 50%, with lower values found at greater depths. Despite the high porosity of the chalk, permeability is inherently low because of the fine grain size. Values for permeability range from 0.01 to 0.3 millidarcies in the fairway with microdarcy permeability found on the fringes. The Niobrara is an underpressured gas reservoir with geostatic pressure gradient ranges from 0.06 to 0.24 psi/ft. In the Goodland, Kansas area, at a depth of 1,000 feet the pressure is only 50 to 60 psi.

Thin pay zones (sometimes near water), low reservoir pressures and low in-situ formation permeability (requiring wells be hydraulically fractured) combine to create a challenging environment for successful field development. Certainly, an efficient low cost approach to well drilling and completion is needed (**Figure 4**). The production stabilizes at 30 to 50 mcf/Day and reserves per well amount to approximately 75 to 125 mmcf with 30 year producing life.

**Figure 4 - Niobrara Formation Logging Showing Pay zone Area**




## CTS Rig Description

The coiled tubing drilling rig used in this study is a trailer mounted rig with the coil and derrick combined to a single unit (**Figures 5 and 6**) and was built by Advanced Drilling Technology (ADT).

The rig has been operating for approximately one year, drilling shallow gas wells operated by Rosewood Resources, Inc., in Western Kansas and Eastern Colorado. Rig operations have continued to improve to the point where it now drills a 3,100 foot deep well in a single day. The rig (**Figure 5**) moves with 4 trailer loads to mitigate mobilization and transportation costs while meeting U.S. Department of Transportation limitations for highway transport. During transit, the rig trailer hosts the drilling rig and reel. The trailer weighs 140,000 lb and is 50 feet long by 12 feet wide. These features allow for smaller access roads and well locations, which in turn reduces well costs. The rig contains all the equipment needed for drilling operations including a zero discharge mud

**Figure 5 - CT Rig in Trailering Position; Rig Trailer with Dimensions of 50' in Length, 12' Wide and 15' in Height**

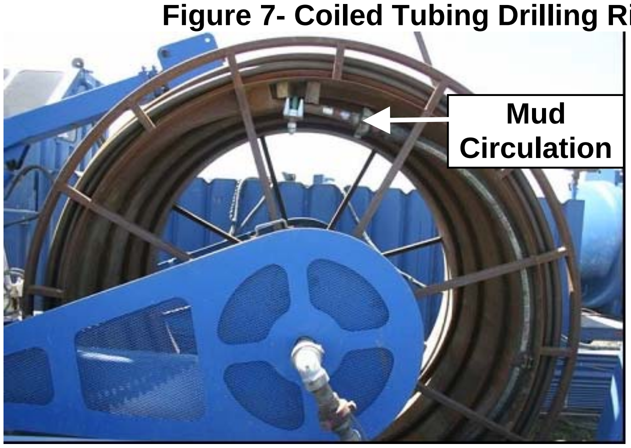
system (discussed later), has pipe handling capacity for casing up to 7 5/8" and can support a rotary and top drive.

The rig trailer is the first trailer to be aligned on the surface hole. The tower is positioned flat on the trailer while transporting the rig, but rises hydraulically when the rig is raised. The height of the crown is 53 feet, when measured from the rig platform (**Figure 6**).

The coiled tubing is mounted on a reel (**Figure 7**) on the rig that can handle 1 to 2 5/8" of coiled tubing size and drill up to 5000 feet from the surface into the formation. Mud and fluid circulation enter the tubing on the surface through swivel mounted on the reel.

**Figure 6 - Coiled Tubing Rig - 53 feet High.**

**Figure 7- Coiled Tubing Drilling Rig Reel Mounted on the Rig Trailer**

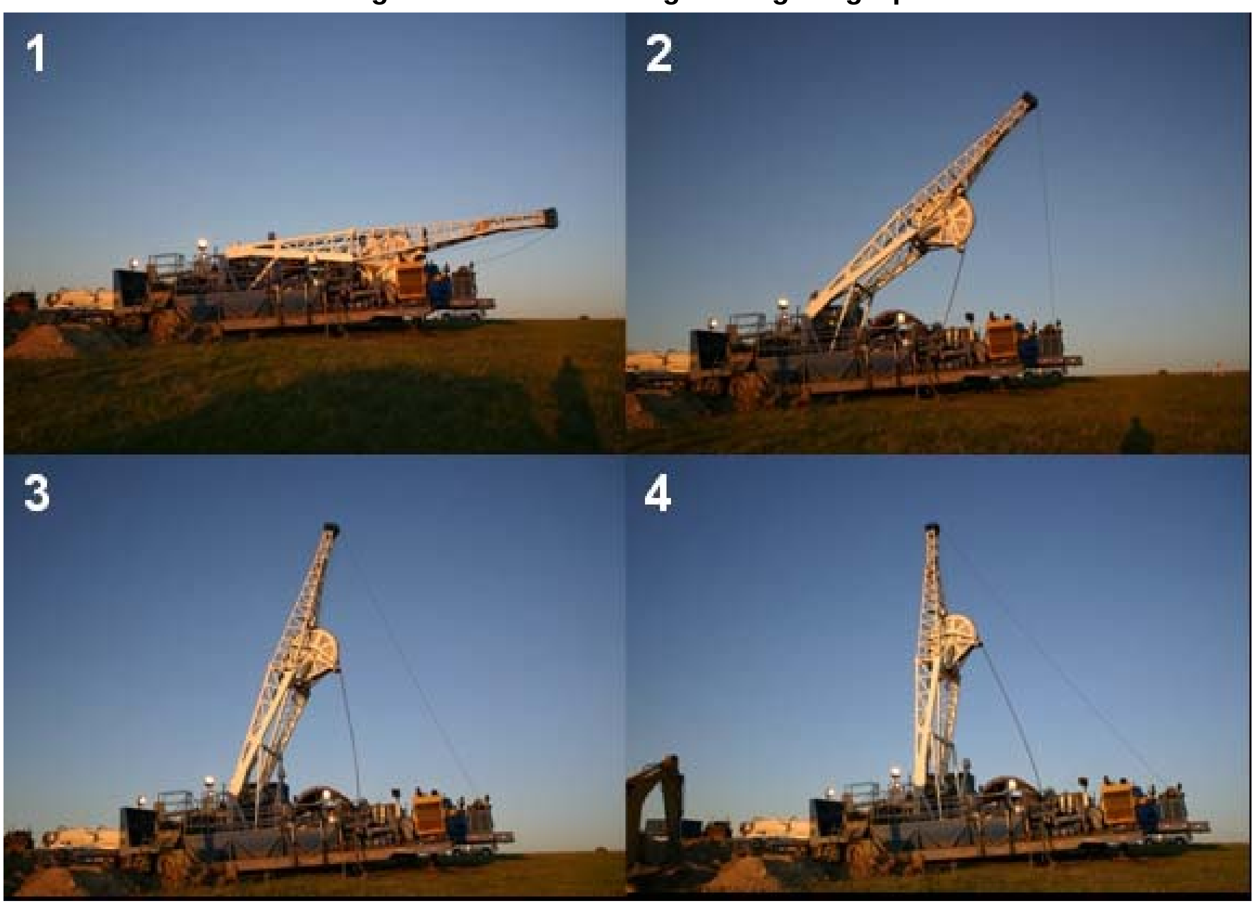



After positioning the rig on the surface hole, the rig can by aligned precisely by hydraulic mechanism that is available in the rig (**Figure 8**).

**Figure 8 - Rig Surface Alignment for Precise Positioning**


Once the rig is aligned on the surface hole, the tower rises up hydraulically from horizontal to vertical position; (Figure 9) shows the elevated stages.

**Figure 9 - Coiled Tubing Drilling - Rig Up**



The Second trailer, which is aligned with the rig trailer is the operator and power trailer, and the dimensions if this trailer is 50 feet long with 10 feet wide and weigh 50,000 lb (**Figure 10**).

**Figure 10 - The Operator Trailer controls and provides power to the Drilling Rig**

**Figure 11 - Operator Trailer aligned next to the Rig Trailer.**


The operator trailer is positioned next to the rig trailer, as shown in **Figure 11**. The trailer holds the fuel tank and generator (**Figures 12 and 13**). The generator consumes approximately 450 gallons per day of diesel fuel. The power supply is much smaller and quieter than a conventional drilling rig.

**Figure 12 - Fuel Tank Mounted on the Operator Trailer**

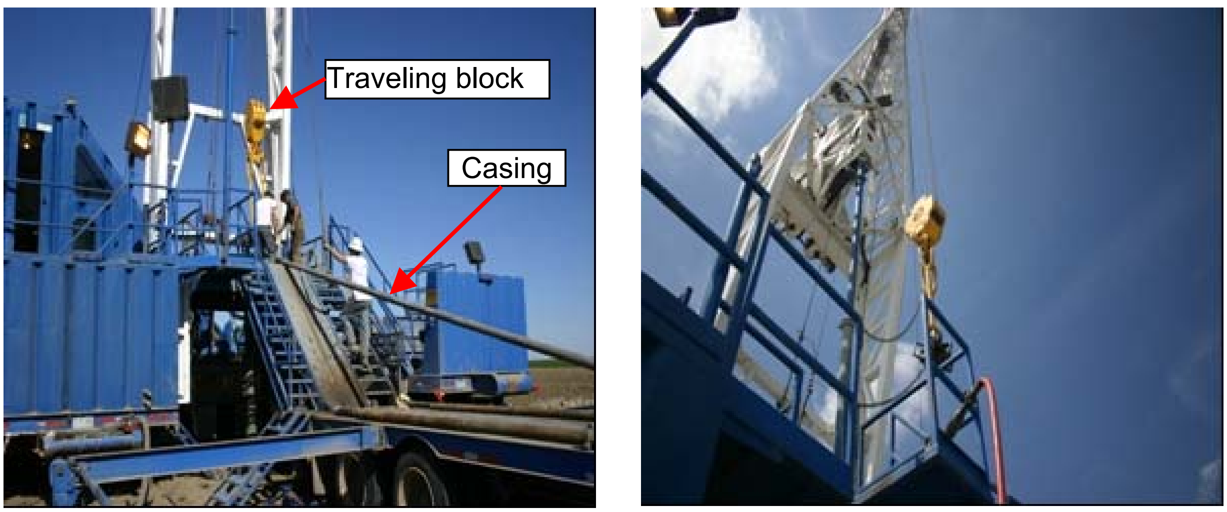
**Figure 13 - Generator on the Operating Trailer**

The operator room includes all of the necessary rig operations and monitoring tools. From this location the operator can control the rig operation from move in, rig up, circulation, connection, BHA, drilling, casing, cementing and logging, and rig-down. **Figure 14** shows the control room (doghouse) from inside with the monitoring instrumentation and viewing window.

The traveling block can be controlled from the operations room. Through the traveling block all the operations associated with raising, lowering or handling the pipes for connections can be controlled, as shown in **Figure 15.** The traveling block improves pipe handling capabilities and eliminates the need for auxiliary equipment to run casing and for make-up of bottomhole assemblies (BHA).

**Figure 14 - View from the CT control room ("doghouse")**

**Figure 15 - The traveling block is controlled from the control room and allows the operator to control all rig operations, including rig up, BHA, casing and logging**




The rig also has a rotary table that allows precise placement of the coiled tubing as well as centralizing the casing as it is installed.

The third trailer is a mud tank with a zero discharge system; the trailer is approximately the same size as the operations trailer - 50 feet long, 10 feet wide and weighing 50,000 lbs. It is aligned on the opposite side of the drilling rig trailer from the operations trailer (**Figure 16**).

The trailer contains the mud tanks, mesh for filtering the cuttings and mud shakers, and mud circulation system, as shown in **Figure 17**

**Figure 16 - Mud Trailer and Zero Discharge System Aligned Next to the Drilling Rig Trailer, on the left hand side of the photograph**

**Figure 17 - Mud Tank Trailer, Mud Shaker and Zero Discharge Mud System**

The rig has the capability to drill a well with zero discharge of any materials. The drill rig and mud sump trailer are placed on a sealed/booted tarp to contain any overflow or accidental spill. In most cases, cuttings and drilling fluid are held in tanks on the mud trailer. Using this process, the ground is protected from any inadvertent spills and all fluids and cuttings are removed from the location. While obviously an added expense, this procedure may be required for drilling in sensitive environmental areas. The mud tanks containing the required drilling fluids are moved with the rig from one location to the next.

**Figure 18 - Mud Pit for Drill Cuttings if needed; The Pit is (3'x 3'x 6')**

The only pit required is a small (3'x 6'x 6') pit (**Figure 18**) to hold the drill cuttings. Alternately, if needed due to environmental concerns, these cuttings (usually amounting to less than 4 tons) can be contained and hauled offsite for disposal.

The fourth trailer is the casing trailer. The dimensions of this trailer are again similar to the operating and mud trailer - 50 feet long, 10 feet wide and weighing 50,000 lb. When the rig is set up on the drilling site, the casing trailer (**Figure 19**) is aligned with the back of the drilling rig.

**Figure 19 - Casing Trailer Aligned on the Back of the Drilling Rig Trailer**

When the drilling rig is set up, the four trailers are integrated for operation. **Figure 20** shows the layout of the four trailers. The casing rig is backed up to the drilling rig when in operation.

**Figure 20 - Integration of the Four Trailers, Casing, Operator, Drilling Rig and Mud Tank**


The CT rig has the following design advantages over conventional drilling rigs:

- The coiled tubing drilling rig has a small foot print. It is approximately 50 feet high and only about 100 feet long, including the drilling trailers and the casing trailer.
- The rig is capable of running casing as well as handling bottom hole assemblies and logging tools
- No auxiliary equipment is required to run casing, log wells or for handling drill collars and bottom hole drilling assemblies.
- With its derrick, traveling block and rotary table components, all required drilling processes can be performed without additional equipment.
- Drilling with coiled tubing eliminates drill pipe connection time and fewer crew members are required to operate the rig. Casing pipes for the selected wells were of 2 7/8” in diameter with each piece of casing being 30’ long. **Figure 21** shows casing in progress, with the casing trailer backed up to the drilling rig. The figure shows handling capability of the coiled tubing drilling rig.

**Figure 21 - Coiled Tubing Drilling Rig handling Casing without Extra Equipment**

With these capabilities, the casing time is cut very short. For example, casing a well to a depth of 1512 feet required only 1 hour and an average of 1 to 3 minutes to connect each casing pipe; these tasks were easily handled by 3 staff members of the rig.

A bottomhole assembly (BHA) can be assembled without any extra equipment. The traveling block allows all necessary pieces of the BHA to be held in place while the BHA is being assembled. A bottomhole assembly can be put together in about one hour, including the bit, multiple drilling collars and the drilling motor, **Figure 22**.

**Figure 22 - Bottom Hole Assembly (BHA) being assembled on Coiled Tubing Drilling Rig**

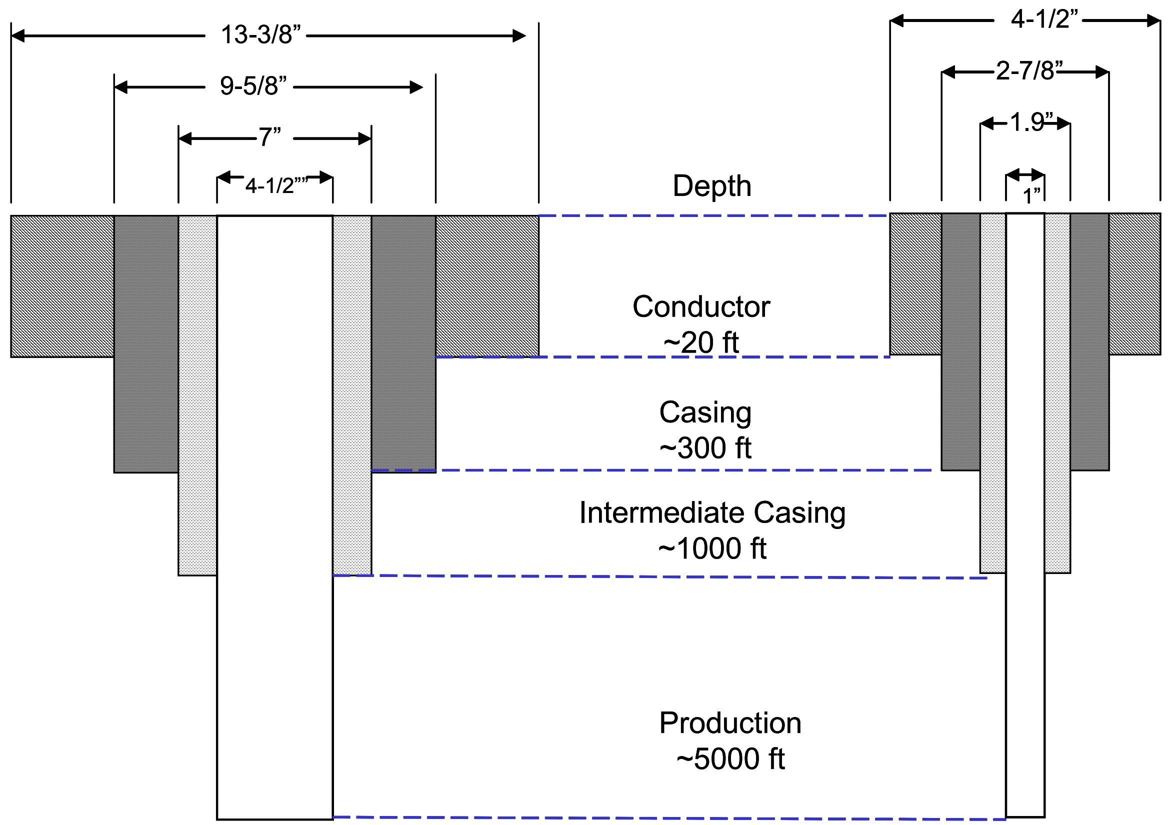

As with the BHA, the logging unit is assembled with simple components and handled with no extra custom-made equipment,. The logging tool is taken from the logging service company truck and lowered down-hole by the traveling block as shown in **Figure 23**.

**Figure 23 - Logging Tool and Logging Trucks**


Coiled tubing has several advantages over conventional drilling rig, one of the comparison that is made is the location and the size required to operate, the well sites are only one-quarter to one-third the size of the conventional drilling pad. The small size of the rig provides several environmental advantages over a conventional rig. As a result of its efficient design and size, the Coiled tubing have environmental advantages such as a small drilling pad (1/10th acre) or no pad under some conditions can be utilized. Smaller access roads are required, no mud pit is needed; mud tanks contain the required drilling fluids and are moved with the rig from one location to the next, the only pit required is a small (3'x 6'x 6') pit for drill cuttings, If needed, cuttings are easily hauled off location allowing no pit drilling as needed, smaller equipment yields less air emissions and low noise engines minimize disturbances to the surrounding environment, the microhole approach (4 ¾" holes) requires less drilling mud and fluids to be treated and yields fewer drill cuttings and the utilization of coiled tubing mitigates the risk of spills due to no drill pipe connections.

A comparison has been made by Albright (2001) between two wells of 5000' deep, one is conventional and the other one is microhole coiled tubing, the result is presented in **Figure 24**.

**Figure 24 - Comparison between conventional and microhole at 5000 feet deep well.**




## Integrated Approach

The Gas Technology Institute (GTI), in partnership with Coiled Tubing Solutions, Inc. (CTS) and Rosewood Resources, Inc., proposed to field test a state-of-the-art Microhole Coiled Tubing Rig and conduct technology transfer efforts to generate interest and gain acceptance for the technology. GTI provided project management, collect operational data during field-testing, prepare the field test documentation, and manage the technology transfer aspect of the program. CTS provided the rig and the rig crew as well as maintenance and operations support during the field-testing. Rosewood Resources, Inc. is the owner that provided drilling locations for the testing program.

The rig shown in Figures 5 and 6 is a state-of-the-art, 2 5/8"coiled tubing rig fabricated by Coiled Tubing Solutions specifically for coiled and microhole drilling to depths up to 5,000 feet. This rig, deployed in August 2004, includes its own Zero Discharge Mud System.

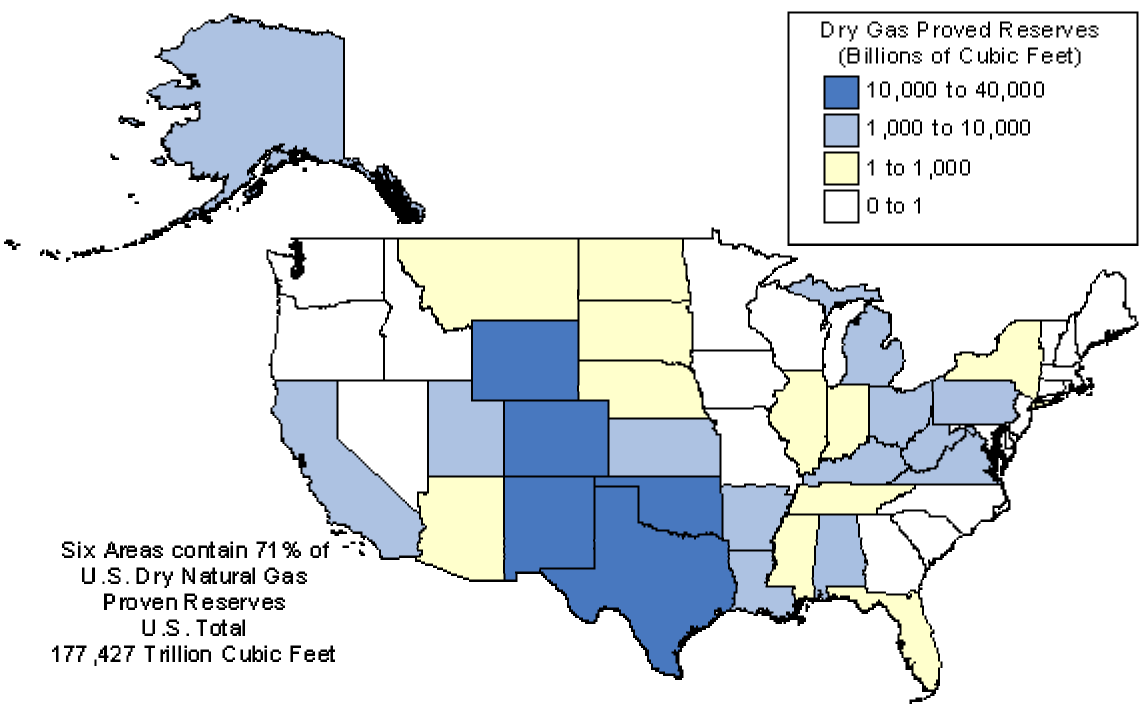
DOE's Oil and Gas Technology Program mission is to invest in long-term research with the potential for high public payoffs (cleaner environment, more secure and stable supplies, lower production costs, and new energy resources).

The CTS 'Coiled Tubing' Rig addresses DOE's goals, as follows:

- The 'Coiled Tubing' Rig has the capability to handle 1" through 3 ½"coiled tubing, has the ability to drill and case surface, intermediate, production and liner holes, and supports both rotary and top drive units.
- The rig is designed to drill as deep as 5,000 and supports both low-cost directional drilling and through-tubing micro-lateral drilling using a directional cutter head
- The rig includes a zero-discharge mud sump system, handles low density, compressible drilling fluids, and includes a sealed containment system under laying the rig to contain any fluids.
- The Rig is able to run 7⅝" range 3 casing
- The Rig is trailer mounted (4 trailers) and meets USDOT limitations for highway transport

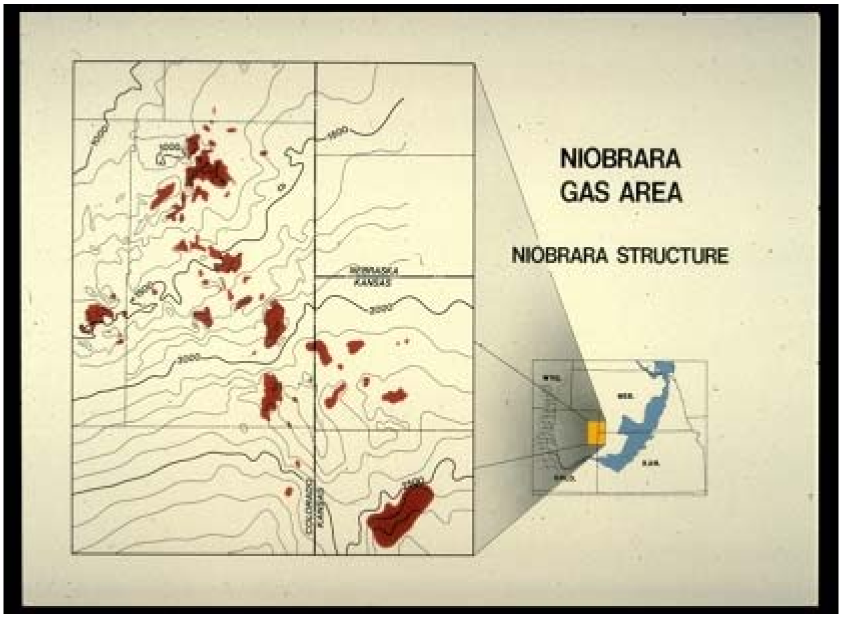
**Figure 25** shows the location of U.S. Natural Gas Reserves, excluding offshore reserves. U.S. oil reserves have a similar distribution, although some states have higher petroleum reserves than those for natural gas.

**Figure 25 - Location of U.S. Natural Gas Reserves**



Rosewood Resources and its parent company, Hunt Petroleum, own reserves in the most productive states, and are currently funding drilling by Coiled Tubing Solutions (CTS) in the Niobrara Gas Area in western Kansas. **Figure 26** sows the Niobrara Gas Area drilling sites in Kansas and Colorado. Preliminary results of the drilling program have been sufficiently successful that Rosewood has extended the drilling program to other leases and has requested a quotation from CTS for a second rig, to be dedicated expressly to Rosewood Resources. This rig was subsequently built and is now drilling in the same Kansas/Colorado area.

**Figure 26 - Rosewood Drilling Locations**




Rosewood Resources drilled multiple sites in Kansas and Colorado. GTI worked with Rosewood to identify multiple locations with varying geology and depth to resource. GTI monitored drilling performance at 25 locations and tested the CTS rig at depths of 1,500 to 3,500 feet.

## Well Drilling and Completion Plan

The well drilling and completion plan included approximately 25 wells in the Goodland, Kansas and Yuma, Colorado areas. The target formation is the Niobrara with well depths ranging from 1500 feet to 3500 feet. The wells are completed as small volume gas wells. The Niobrara is a low permeability chalk formation with high porosity. Development of this area dates back to the 1970's and has been sporadic. Current activity within this economically marginal gas play is based on today's higher gas prices, the latest completion practices and the ability to control well costs.

The planned well drilling and completion utilized the following well prognosis:

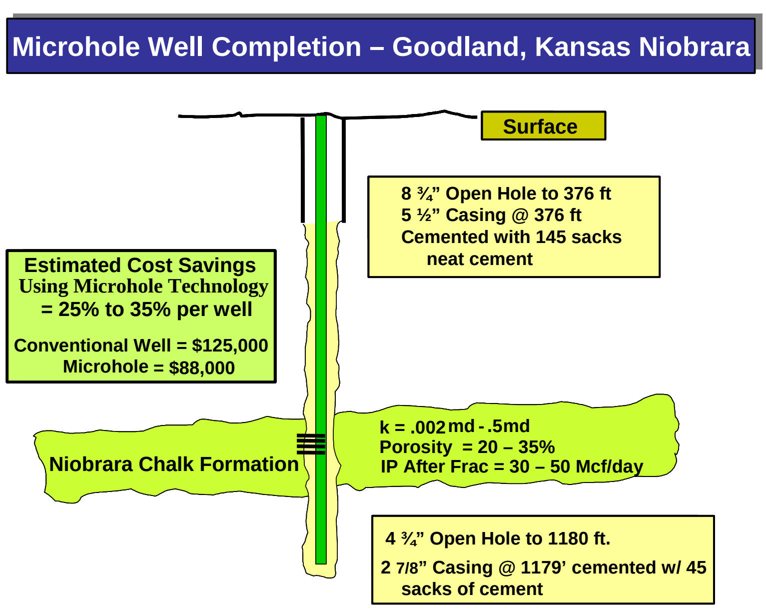
- Well locations and roads (if needed) are prepared prior to COILED TUBING rig arrival. Roads and drilling pad are kept to minimum size
- A local water well rig moved in, rigs up, and drills an approximately 7 inch open hole to a depth below the fresh water formations. Surface casing (5 ½ inch) is set at drilled depth and cemented to surface to protect potable water sources. The depths of the surface casing set points vary by geographic area and are established in conformance to depth requirements of the Kansas and Colorado well permitting agencies.
- The COILED TUBING rig moves onto the location, rig up and initiate drilling.
- Drill a 6 ½-inch hole to a depth adequate to penetrate the Niobrara formation.
- The hole is drilled with fresh water treated with potassium chloride for formation-damage control. Fluid loss is monitored.

- At total depth, open hole logs are run including (neutron, density and resistivity logs).
- If the well is determined to have production potential, 2 7/8 inch casing will be set to total depth and cemented to a depth to cover the top of the Niobrara formation.
- At this point, the COILED TUBING rig was rigged down and moved out to drill the next location.
- A well work over rig is moved onto the well site after allowing adequate time for cement behind the pipe to set.
- The selected logging company truck is rigged up over the well and cased hole logs including a casing collar locater, gamma ray and cement bond log are run.
- If the cement bond is determined adequate, the production zone is selected and perforated with two jet shots per foot. Approximately 10-foot zones are perforated.
- Preparations for performing a hydraulic fracturing stimulation treatment on the well are made including moving onto the location the necessary fluids, proppant and pumping equipment.
- The formation stimulation treatment is performed. A typical treatment in the Goodland, Kansas area includes 50,000 gallons of fracturing fluid and 100,000 pounds of sand proppant. Nitrogen is included in the fluid pumping to assist with fluid clean up after the treatment. The Niobrara formation is a less than normally pressured formation that inhibits fluid clean up by reservoir pressure and volume alone. This aspect of the Niobrara formation is where minimizing drilling time and exposure of the formation to fluids is important.
- After the well stimulation treatment, production tubing (if needed) is run and the well swabbed until it is adequately cleaned up to produce on its own. The workover rig is rigged down and moved off the location.
- Production equipment is installed and the well hooked up to the gas gathering system and production operations begin.

A wellbore schematic of a typical completed Niobrara well is presented as **Figure 27.** The selected area of operations (Goodland, Kansas and Yuma, Colorado Niobrara gas plays) is an excellent area for assessing the efficacy of microhole drilling and developing a case study that can be utilized in many areas of the United States to disseminate microhole drilling advantages. Specifically, the selected area lends itself to assessment of microhole drilling because of the following conditions:

- The Niobrara is an economically marginal gas play requiring strict attention to cost savings. The cost

**Figure 27 - Wellbore Schematic of Completed Niobrara Well For the Goodland, Kansas - Justification for Area of Operation and Well Drilling and Completion Plan**



savings that microhole drilling will enable has direct impact and can be documented.

- The Colorado and Kansas areas of operation are farming areas that require minimization of drilling footprint. The ability to minimize drilling location size and road building enabled by the Coiled Tubing rig has direct economic and environmental impact and can be documented.
- The Niobrara formation is a very low permeability chalk formation. Additionally, it is a severely under-pressured reservoir, with reservoir pressures in the Goodland area about 50 pounds per square inch (psi) at 1200 feet of depth (normal pressure for this depth would be approximately 600 pounds per square inch). Extended exposure of this type of formation to drilling fluids causes formation damage that significantly impedes gas production. The ability to drill, log and case the well with alacrity is enabled by the microhole drilling approach and is amenable to testing and documentation.
- The area of operations and planned wells provide an opportunity for several depth ranges to be tested. The Kansas area will entail testing at 1200 feet and the Yuma, Colorado area will allow depths to 3500 feet. These opportunities will enable documentation of microhole case studies with broad application to other areas in the United States and will enable effective workshops.
- The area of operations being a farming area requires drilling to be conducted within windows of opportunity in the spring and fall, before and after crop planting and harvesting. This requires that drilling be conducted as rapidly as prudent and requires multi-well project planning. This aspect of the project area of operations will have direct relevancy to sensitive locations in the Rocky Mountains and other regions of the country that have “drilling windows” due to wildlife patterns and other environmental constraints. The approaches utilized in this project can be documented for dissemination to other sensitive areas.
- Rosewood Resources has a significant operation in the Kansas and Colorado area, with plans to drill 75 to 100 wells in year 2005. This level of activity and having Rosewood as a partner allows for identification of some special tests or drilling/completion procedures that could be performed during the project. The testing of the Microhole approach to high angle or horizontal drilling, utilization of the approach for drilling water disposal wells, testing of new downhole motors and other approaches to well drilling and completion have potential with this level and type of activity.

In summary, the area of operations due to the geologic conditions, surface constraints and environmental concerns, marginal economics of the prospects combined with the size and type of the project partners (Rosewood) operations and the Coiled Tubing rig justified this area as an excellent test bed for microhole drilling.

## Performance Measurement

A test plan was prepared and reviewed by the GTI/CTS/Rosewood Team prior to rig test initiation. This plan not only included protocols for well construction and completion but also included a list of priority measurements and observations to be taken in all stages of Coiled Tubing Rig Operation from “rig up” to “rig down.” Priority performance parameters that were to be measured included rate of penetration, pump pressure, and time duration for each operation like BHA, casing, cementing, and logging.

### CTS Rig Testing - Data Collection

The GTI team field tested the “Coiled Tubing” Rig to develop information on its capabilities. Testing followed six defined categories of test standards (Table 3). Data availability permitting, this allows comparisons to the times and efficiencies to be compared to conventional rotary rig operations in comparable settings. Rig performance was also documented by videotaping.

**Table 3 - Microhole rig measurements template to be collected by GTI**

| Test Standard | Type of Data Collected |
|---|---|
| 1. Mobilization and Rig Up | • Number of loads and load out schedule<br>• Weight per trailer and total rig weight<br>• Time to rig up to reach operational status<br>• Requirements for external equipment to rig up |
| 2. Drilling Surface or Production Holes | • Trip time<br>• Connection time<br>• Instantaneous and average rates of penetration<br>• Weight on Bit<br>• RPM, Torque and Drag<br>• Pump Pressures and Flow Rates<br>• Mud Properties during drilling<br>• Circulation time<br>• Solids control efficiencies<br>• Vibration (if measurement while drilling is used)<br>• Deviation Survey<br>• Rock Compressive Strength (from sonic log measurements)<br>• General lithology |
| 3. Running Surface Casing and Cementing | • Rig up to run casing time<br>• Connection time<br>• Running time per joint<br>• Cementing rig up and rig down time |
| 4. Logging / Evaluation | • Trip time |
| 5. Running Production Casing and Cementing | • Rig up to run casing time<br>• Connection time<br>• Running time per joint<br>• Cementing rig up and rig down time |
| 6. Rigging Down and Move Out | • Number of loads and load out schedule<br>• Need for external equipment to rig up<br>• Time to rig down to transport status |

Drilling reports from the rig and logs from the service company are available in electronic and hard copy format. Data from the rig were transferred to a data collection form. An example of field data entered into a data collection form is shown in Table 4.

**Table 4 - Typical - Microhole Rig Measurements Collected by GTI Staff**

| Microhole rig measurement to be collected by GTI | | |
|---|---|---|
| **Date:_05/13/05** | | |
| **Well Name:_Duell 3-7** | **County: Sherman, KS** | |
| **Sec : 17 Twn: 7s** | **Rng: 39 w GR.ELEVATION: 3535** | |
| **Operator: Dennis Marchadant** | | |
| **Starting:5:00 AM** | **End:7:30 M____** | |
| **Depth: 1180 ft** | **Location: Cheyenne County, KS** | |
| **1. Mobilization and Rig Up** | Number of loads and load out schedule | 4 Main Total 6 |
| | Weight per trailer and total rig weight | 140,000 lb |
| | Time to rig up to reach operational status | 1 |
| | Requirements for external equipment to rig up | 0 |
| | *Number of staff* | 4 |
| **2. Drilling Surface or Production Holes** | Trip up | 15 minutes |
| | Connection time | 4 minutes |
| | Instantaneous and average rates of penetration | 300 ft/hr |
| | Weight on bit | 6 to 6000 lb |
| | RPM, Torque and drag | 300 |
| | Pump pressure and flow rate | 1300 psi .200 gal/min |
| | Mud Properties during drilling | mud weight 8.7 lb/gal- Visc 34 |
| | Circulation time | 10 minutes |
| | Solids control efficiencies | shale 220 mesh screen |
| | Vibration (if measurement while drilling is used) | na |
| | Deviation Survey | 500 ft depth - ½ ft<br>750 ft depth – 2 ½ ft<br>1000 ft depth-1 ¼ ft |
| | Rock Compressive strength (from sonic log measurements) | NA/ Density and Gamma logs |
| | General lithology | Shale |
| | *Number of staff* | 4 |
| **3. Running Surface Casing and Cementing** | Rig up to run casing time | |
| | Connection time | |
| | Running time per joint | |
| | Cementing rig up and rig down time | |
| | *Number of staff* | |
| **4. Logging/evaluation** | Trip time | 2 |
| | Number of staff | 3 |
| | Logging type | Density and Gamma |
| **5. Running Production Casing and Cementing** | Rig up to run casing time | 5 minutes |
| | Connection time | 3 minutes |
| | Running time per joint | 3 minutes |
| | Cementing rig up and rig down time | 3 1/2 hr |
| | *Number of staff* | 5 |
| **6. Rigging down and move out** | Number of loads and load out schedule | 0 |
| | Need for external equipments to rig up | 0 |
| | Time to rig down to transport status | 1 |
| | Number of staff | 4 |
| **7.BHA** | Bit type | 633 |
| | Assembly | 1 |
| | Time for disassembly | 1 |
| | Number of staff | 2 |

## Database CD

To facilitate the review and use of the information collected by this project that documents the operational performance of the MCTR technology, a Database CD has been prepared and is available upon request from the Gas Technology Institute, Des Plaines, IL. The Database CD includes a spreadsheet of performance data and movie clips of the CT rig in every stage of setup and operation.

For each well drilling event that was observed by GTI staff, a set of data has been collected and is presented in Appendix A; the data in Appendix A represents information from 13 wells. In addition to this information, CTS personnel collected MCTR operations data on an additional 12 wells in the absence of GTI staff using the GTI data collection protocol; this information is presented in Appendix B. Data in both Appendix A and Appendix B cover MCTR conditions and mechanical performance across a number of parameters, including the following:

- Drilling Assembly (BHA)
  - Bit Type
  - Mud Motor
  - Drill Collar
- Mud Record
  - Weight
  - Funnel Viscosity
  - KCL
  - Bicarb
  - Poly
  - Pac
- Deviation Survey
  - For each 500 ft interval
- Depth Interval and shale formation
- Rig Parameters
  - Rotary Speed
  - Weight on bit
- Time Logging
  - Move in and rig up
  - Pick up BHA
  - Drilling time
  - Circulation
  - Logging
  - BHA lay down
  - Casing and Cementing
  - Rig down and move out

For ease of analysis, the information from Appendices A and B are presented in tabular form in an Excel spreadsheet with the title of “MCTR Database.xls” which is included on the Database CD. Using the tabular data, a number of graphs can be examined as shown in the spreadsheet.

**Instructions for Viewing Video Clips** of the CT Rig are as follows:

- Place GTI MCTR Database CD into computer.
- Click the Word Document file called “Easy Access Guide to Video Clips.”
- Click the desired operation for viewing from the bulleted list.

To order the Microhole Coiled Tubing Rig Database CD containing the video clips, submit a request to the following contact:

Kent Perry
Executive Director, Exploration & Production Center
Gas Technology Institute
1700 S. Mount Prospect Road
Des Plaines, IL  60018
kent.perry@gastechnology.org

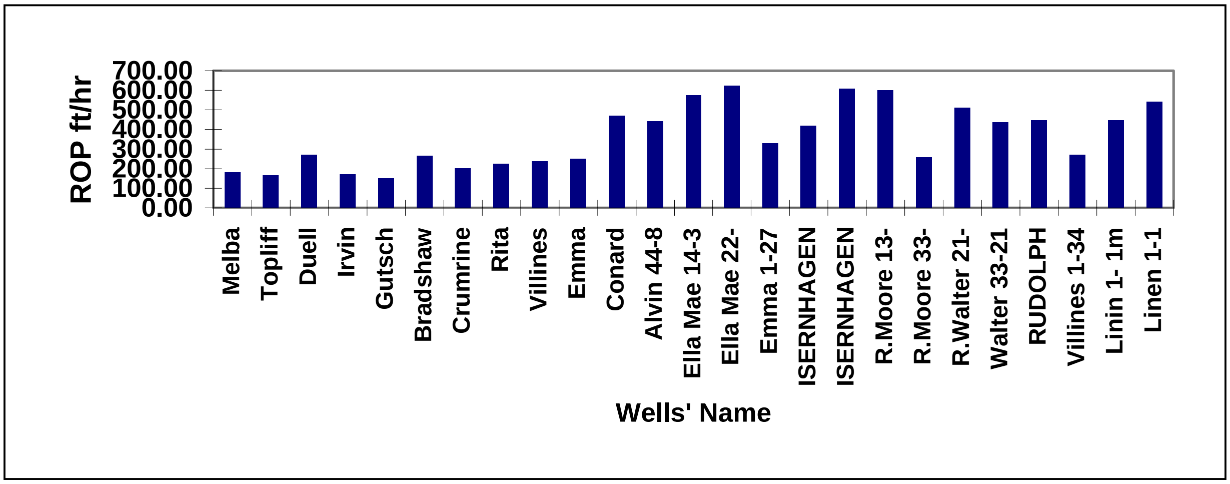
# Results

Results of the drilling effort are summarized in this section. Quantitative measurements include Rate of Penetration and time-function measurements taken from the CT rig at each well. This section also includes qualitative observations by GTI staff that were made in the field during CT rig operation at 13 well sites. These observations include quality of the hole drilled, staff requirements, ease of operation, site disturbance, and apparent environmental footprint.

## Direct ROP and Time-Function Measurements

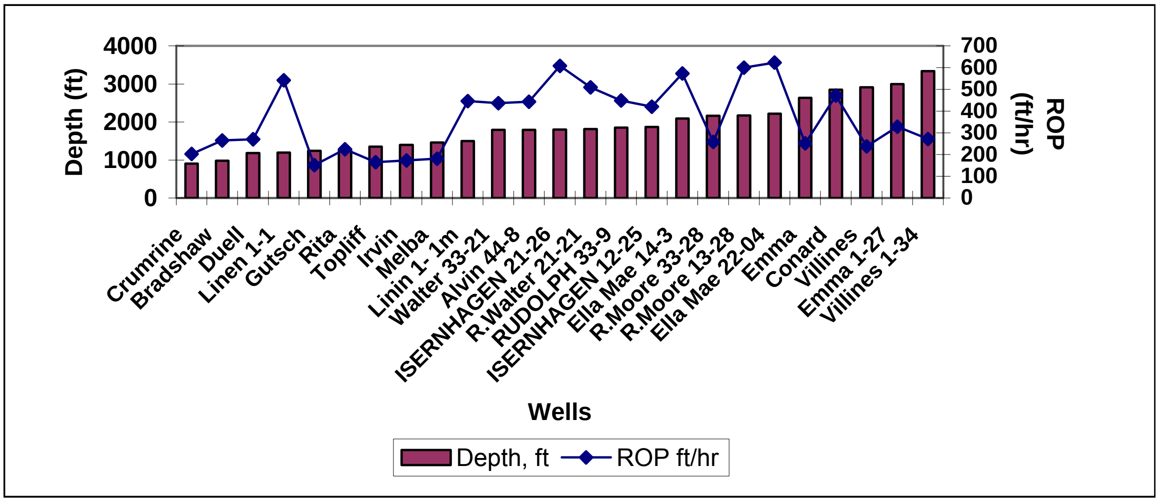
One of the most important performance measurements in well drilling is Rate of Penetration, or ROP. Figure 28 shows the average ROP for each of the wells that were drilled. As shown, the ROP varied between 150 and 600 feet per hour. In this figure, the wells are arranged in the order drilled in the field.

**Figure 28 - Rate of Penetration of Well Drilled with Microhole Coiled Tubing Rig**



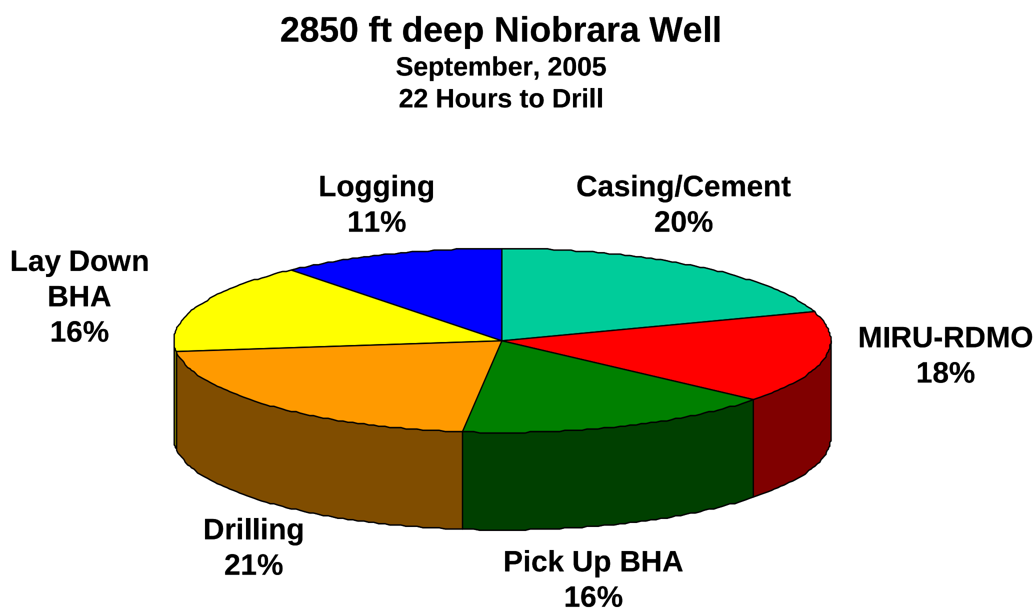

The lack of relationship between ROP and the depth of wells is suggested in **Figure 29.** The vertical bars show the depth of the wells in ascending order, while the superimposed line shows the penetration rate. Well depth varied from less than 1,000 feet to greater than 3,000 feet. It is noteworthy that for the majority of these wells, ROP values between 300 and 623 ft/hr were measured as shown in the plot.

**Figure 29 - ROP and Depth of the Wells**




Performance of the rig was also documented by monitoring how much time is expended on each functional operation. The total functional time used by the CT rig can be broken down into six categories: Rigup, Pick up Bore Hole Assembly (PBHA), Drilling, Lay Down Bore Hole Assembly (LD BHA), Logging, and Casing/Cementing (CSG/CMNT). An example of a CT operational time distribution across these categories is shown in the pie chart of Figure 30 for a 2850 ft deep well drilled in the Niobrara. This well required only 22 hours of total CT functional time; the categories of operation requiring the greatest share of time included drilling and casing/cementing at around 20 percent each.

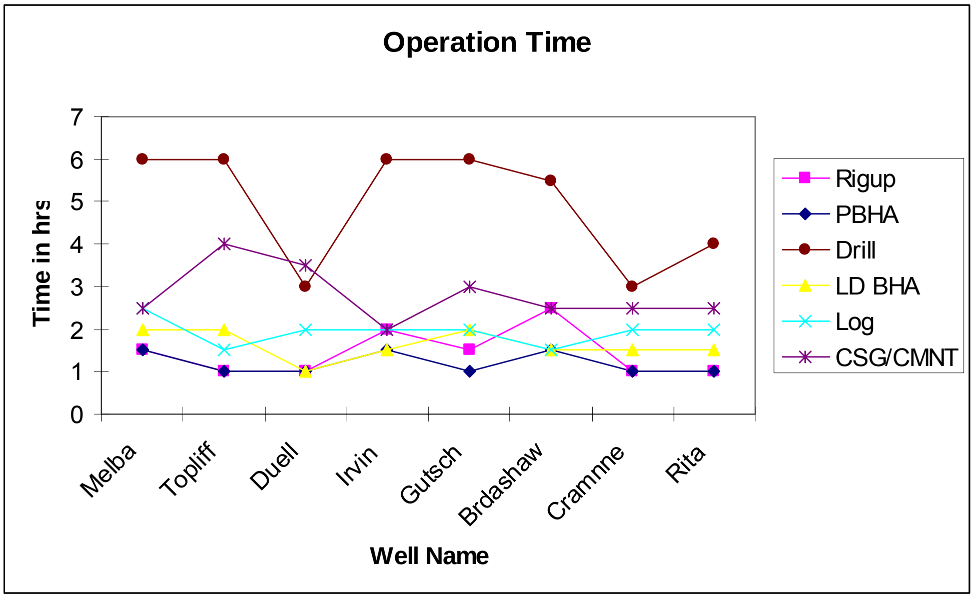
**Figure 30 - Allocation of Drilling Time for 2850' Niobrara Well**



Variations in the times required for the six functional categories can be seen in the line plots of Figure 31 representing data collected from eight wells drilled with the CT rig. From this graph, it can be seen that the variations for the drilling and casing/cementing functions are greater than the other functions; this arises from the fact that these functions are affected to a greater degree by the depth and nature of the well drilled. Also shown in the diagram, the drilling function usually requires only 3-6 hours to accomplish; this is due to the elevated rate of penetration that can be achieved with the CT rig (usually ranging from 300 to 600 ft/hr). Time-function data for all of the observed drilling runs using the CT rig are given in the table of Appendix B.

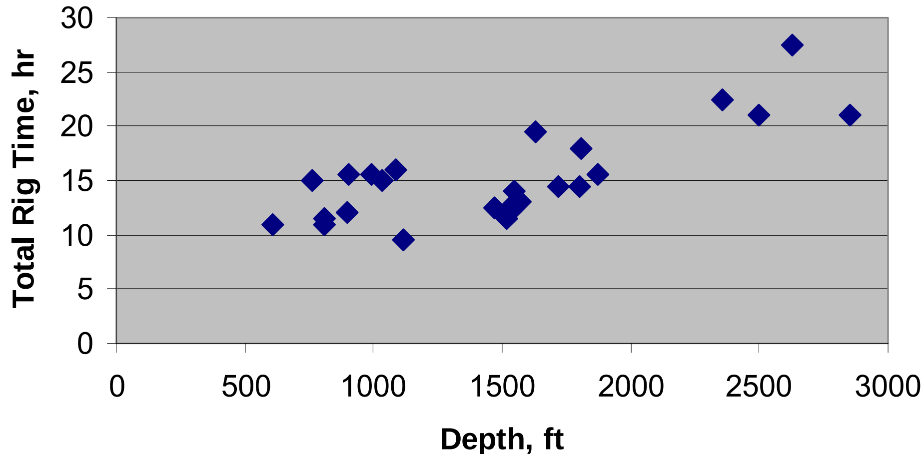
Equally important, the time requirements for nearly all of the other functions were also held to low values of 1-2 hours each (as indicated in Figure 31). The ability of the CT design to achieve time reductions in these categories is due to the high degree of equipment integration that enables the entire CT rig to be comprised of four trailers (instead of five or six) and allows easier setup, alignment, operation, and demobilization.

**Figure 31 - Operation time and Operation for Selected Well to Measure the Well Performance.**




Perhaps the best indicator of overall CT rig performance is the total rig time (TRG) representing the summation of time expenditures in all of the six functional categories. The TRG parameter is plotted with depth of well in Figure 32 for all of the 25 wells of this study that were drilled with the CT rig in the Niobrara. The points plotted in this graph strongly suggest that there is a general nearly-linear relationship between well depth and Total Rig Time. It is noteworthy that for wells as deep as 2,500 to 3,000 feet, the Total Rig Time for the CT unit is usually well under one day.

**Figure 32 - Total Rig Time (In Hours) Versus Well Depth**

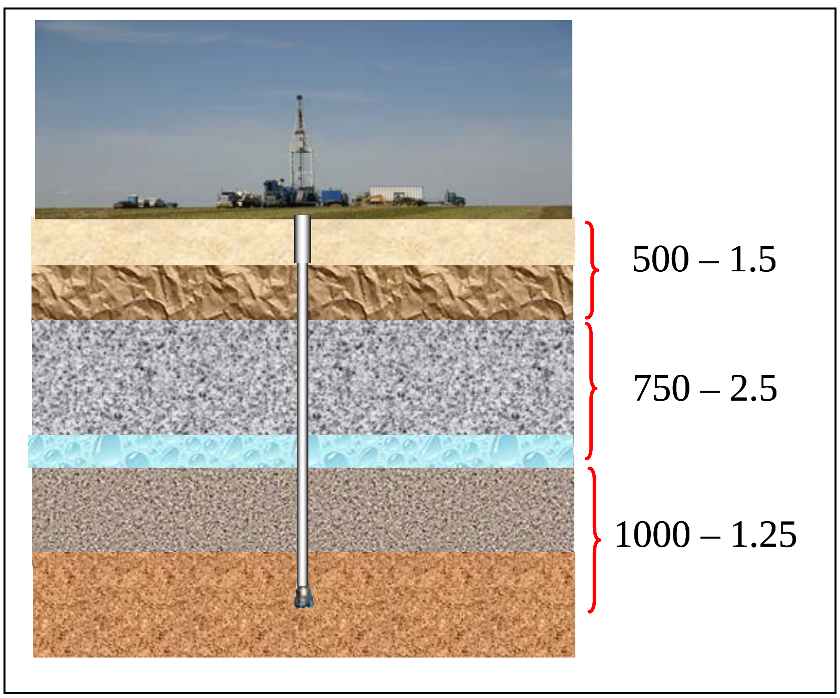



## Hole Quality and Cement

The benefits of fast drilling by the ADT CT rig is augmented by excellent hole quality. All the wells drilled have resulted in a gauge hole with very little hole deviation (1 to 2 degrees - well within State requirements) despite the high penetration rates (**Figure 33**). Good cement job quality and well bonded cement also derive from the gauge hole quality. As mentioned previously, the Niobrara is an under pressured reservoir and as such is susceptible to formation damage due to fluid loss from drilling operations. Both the rapid penetration rate through the pay zone and the lack of any pressure surges caused by conventional drilling pipe connections help to mitigate fluid loss and therefore formation damage. This is an important factor given the marginal nature of the resource.

With Coiled tubing, there is no auxiliary equipment is required to run casing, log wells or for handling drill collars and bottom hole drilling assemblies. With its derrick, traveling block and rotary table components, all required drilling processes can be performed without additional equipment. Drilling with coiled tubing eliminates drill pipe connection time and fewer crew members are required to operate the rig.

**Figure 33 - Microhole Coiled Tubing Hole Quality and Deviation Survey**



## Improved Safety and Environmental Footprint

Observations by GTI staff in the field of the function of the ADT CT rig has verified a number of advantages that have implications for improved safety and environmental compatibility of this emerging generation of drilling technology.

### Safety

Safety is always of utmost importance and the conventional drilling rig environment is one where extra caution and safety training is necessary due to the handling of drill pipe and other equipment. The ADT coiled tubing rig significantly reduces drill pipe handling and has less equipment to mobilize from well to well. All of this creates a much safer operating environment that is important during any time of drilling, but especially so during today's high rig count when experienced roughnecks are difficult to find.

The ADT CT rig incorporates state-of-the art features that provide a number of safeguards during operation. First, the ADT CT rig includes a blowout preventor (BOP) that allows an operator to isolate the downhole section of coiled tubing as a safety measure. The BOP can be actuated from the control house, where the operator monitors well bore pressures, gases, equipment pump rates, fluid volumes, drill rates, speeds, torques, and other parameters related to CT operation. From this center, the CT operator can make adjustments in equipment operation and can implement safety interventions if needed.

As with pervious commercial CT systems, the ADT CT rig incorporates other features that represent considerable redundancy in safety. In addition to the BOP device, several safety features are included in the bottom hole assembly (BHA) for added protection. To prevent leakage from the CT that is not in the hole, one or two check valves can be installed in the BHA. Consistent with current best practices, further safety is provided by an emergency disconnect that allows a CT unit operator to disconnect the CT from the BHA if it becomes stuck.

During the observation of the 25 project wells drilled with the CT rig, there were no conditions that represented a situation where an intervention was required. Each well was drilled with the appropriate precautions under conditions that were well within the operational safety envelope that represents low risk to operators and observers.

### Environmental Footprint

The small size of the rig, the compressed time for rig functions and the drilling mud and cuttings handling system provides several environmental advantages over conventional drilling. As a result of its efficient design and size, GTI staff has noted advantages during the field operation of the ADT CT rig in the course of drilling the project wells:

- A small drilling pad of less than 1/10 acre or no pad under some conditions can be utilized. Modest access roads are required.
- No mud pit is needed; mud tanks contain the required drilling fluids and are moved with the rig from one location to the next. The only pit required is a small (3'x6'x6') pit for drill cuttings. If needed, cuttings are easily hauled off site.
- Smaller equipment yields less air emissions and low noise engines minimize disturbances to the surrounding environment.

- The microhole approach requires less drilling mud and fluids to be treated and yields fewer drill cuttings.
- The utilization of coiled tubing mitigates the risk of spills due to no drill pipe connections.

The area of impact that is left by the CT rig after the well has been installed and after the rig is moved out appears to be minimal. In the observed drilling of 25 project wells, most impacted areas were limited to less than 200 $ft^2$. A typical area of impact after CT rig deployment is shown in Figure 34.

**Figure 34 - Small Rig Size Yields Small Drilling Foot Print**

### Zero Discharge (If Required)

The CT rig has the capability to drill a well with zero discharge of any fluid or solid residues (e.g. cuttings) if required. The procedure is as follows:

- Move the rig in and rig up on a sealed/booted tarp to contain any overflow or accidental spill.
- No earthen pits are prepared; all cuttings and drilling fluid are confined to tanks with which the rig is equipped.
- A hole is augured for conductor pipe and a boot is placed around the conductor pipe.

Using this protocol, the ground is protected from any inadvertent spills and all fluids and cuttings are removed from the location. While obviously an added expense, this procedure may be required for drilling in environmentally sensitive areas. The small rig size and efficiency of drilling coupled with the zero discharge capability enables drilling in many sensitive areas at a reasonable cost.

## Observed Operational Advantages

Based upon field observations, the ADT has a number of operational advantages over conventional drilling technology. These advantages can be summarized as follows

- Reduced Drilling Cost
  - Reduced rig size and staff (as reflected in the example well drilling data of Table 4)
  - Reduced BHA, casing, cement, mud system, time and material to drill hole with small diameter to 5000 ft
  - Ease of data acquisition (like logging)
  - High ROP
  - Support directional drilling
- Reduced Mobilization, Demobilization Cost and site preparation
  - 4-5 trail able unites provide all tools for drilling and drill mud hauling
  - Small drill pad or no drill pad
  - Smaller roads or skid trail access
- Improved Pipe Handling Capacity
  - Uses traveling block and rotary table for making-up BHA component
  - No auxiliary equipment required to run casing
- Measurement While Drilling (MWD)
  - Using microhole coiled tubing, MWD technology can be attached to coiled tubing without concern about pipe joints
- Improved Well bore Transmissivity and Reservoir Delivery
  - Microhole coiled tubing is highly compatible with under-balanced drilling (UBD)
  - UBD improves safety, initial production, and longer period production by minimizing well bore transmissivity damage

# Impact / Benefits on Lower 48 Resource

This section was a collaborative effort between Energy and Environmental Analysis and GTI. GTI contracted with Energy and Environmental Analysis to evaluate the potential impact of coiled tubing on future U.S. gas development and resources. EEA specializes in modeling and forecasting North American gas resources and production. Recently, EEA served as the principal modeling contractor for the 2003 NPC study.[1] EEA worked with the gas industry representatives to develop the resource and technology assumptions that went into that study. EEA also develops its own company forecasts and assumptions about remaining resources and technologies.

The objective of the current study was to build a set of realistic assumptions about the future market penetration of CT microhole drilling in the onshore Lower-48, and to evaluate the impact of the expected improved drilling economics and the potential to tap resources more rapidly and efficiently than with conventional drilling. The primary impact to be evaluated is the potential impact on U.S. gas drilling markets and expenditures over the next 20 years.

Because the technology is still evolving, it is necessary to make assumptions about which portion of the undeveloped resource base could be targeted in a technical sense, and assumptions about what a realistic market penetration could be.

## Potential Resources

EEA has evaluated the potential resource base that could be targeted by coiled tubing microhole drilling in coming decades. While most current applications of this technology are for non-conventional (to date, primarily coalbed and tight gas) reservoirs of less than 5,000 feet vertical depth, future technology advances should allow applications to at least 10,000 feet. Shale gas, shallow oil, and deep tight gas are potential markets in the future.

Another area of consideration not covered in this study is resource access. The CT technology, through a reduced environmental footprint, likely will result in significant additional access to resources that are currently restricted or off limits.

EEA has assessed the U.S. gas resources and potential wells that could be drilled from 0-5,000 ft and 5-10,000 ft. in onshore areas.

The last comprehensive assessment of U.S. developed and undeveloped gas resources was carried out in the 2003 National Petroleum Council study. That study was primarily based on recent USGS assessments for onshore areas, and included the results of USGS assessment work in recent years, primarily focused on the Rockies. The National Petroleum Council (NPC) adjusted the USGS assessed resource base for a number of larger-impact plays. In addition, conventional undiscovered resources were adjusted to include the small field component for each play.

The NPC resource base was characterized for analysis and modeling in the EEA Hydrocarbon Supply Model, which includes an economic characterization of the various categories of conventional and non-conventional resources. Non-conventional resources are categorized in a set of input files that include wells, well recovery, and costs.

Since the 2003 NPC study was published, industry activity has resulted in changes to the NPC-assessed resource base. EEA has developed a resource base that includes re-assessments of emerging resources such as the Barnett Shale and the Powder River Basin coalbeds. It also includes several new assessments of shale gas in new formations.

[1] NPC, 2003, “Balancing Natural Gas Policy,” National Petroleum Council, September, 2003.

**Table 5** summarizes the EEA gas resource base for the U.S. Undeveloped resources include the following categories:

- Old field appreciation
- New fields
- Shale gas
- Coalbed gas
- Tight gas
- Low BTU gas

Bolded entries on the table are assessed resources that differ from NPC. Major changes relative to NPC include a larger assessment for the Barnett Shale in the Fort Worth Basin, the Powder River coalbed play, and tight gas in the Arkla-Tex region. Resource categories that have been added since the NPC study include the Fayetteville Shale and Woodford/Caney shale in the Mid-Continent, and the Woodford Shale in the Permian Basin. The Green River Basin tight gas assessment was reduced. Conventional Gulf of Mexico resources were increased for drilling below 15,000 feet on the shelf.

**Table 6** shows the number of potential non-conventional gas wells and gas resources for onshore Lower-48 depths above 10,000 feet. For each region, the resource is broken out for shale gas, coalbed gas, and tight gas resources by depth interval. Using the current EEA gas resource base and well recoveries and spacing assumptions within the model, a total of 228,000 shale gas wells, 179,000 coalbed wells, and 551,000 tight gas wells remain to be drilled in onshore regions above 10,000 ft. The total non-conventional resource base targeted is 203 Tcf.

## Table 5 - U.S. Gas Resource Base

**Bcf, Dry Total Gas**
**Current Technology**

| Region Number | Region Name | Discovered/ proved | | | Discovered Undeveloped | Unproved | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cumulative Production | Proven Reserves | Ultimate Recovery | Discovered Undeveloped | Old Field Appreciation | New Fields | Shale | Coalbed | Tight | Low-BTU/ other | Unproved Plus Discovered Undeveloped |
| ***United States*** | | | | | | | | | | | | |
| ***Lower-48 onshore*** | | | | | | | | | | | | |
| 1 | Appalachian Basin | 45,887 | 9,396 | 55,283 | 0 | 1,982 | 6,196 | 16,986 | 8,158 | 34,746 | 0 | 68,068 |
| 2 | Black Warrior Basin | 2,648 | 1,283 | 3,931 | 0 | 121 | 1,450 | 0 | 4,465 | 0 | 0 | 6,036 |
| 3 | Mississippi, South Alabama, and Florida | 9,214 | 1,916 | 11,130 | 0 | 4,373 | 11,035 | 0 | 0 | 0 | 0 | 15,408 |
| 4 | Michigan & Illinois Basins | 6,404 | 2,976 | 9,380 | 0 | 2,630 | 7,830 | **7,300** | 1,580 | 0 | 0 | 19,340 |
| 5 | East Texas, South Arkansas, & North Louisiana | 64,515 | 14,198 | 78,713 | 0 | 14,652 | 18,152 | 0 | 0 | **10,400** | 0 | 43,204 |
| 6 | South Louisiana (onshore) | 102,105 | 5,185 | 107,290 | 0 | 6,497 | 24,043 | 0 | 0 | 0 | 0 | 30,540 |
| 7 | South Texas (onshore) | 145,669 | 16,209 | 161,878 | 0 | 34,646 | 39,148 | 0 | 0 | **4,600** | 0 | 78,394 |
| 8 | Williston, Northern Great Plains | 4,490 | 1,286 | 5,776 | 0 | 2,061 | 3,396 | 0 | 0 | 7,660 | 0 | 13,117 |
| 9 | Uinta-Piceance Basin | 4,722 | 7,182 | 11,904 | 0 | 3,824 | 2,063 | *0* | 5,862 | **27,500** | 0 | 39,249 |
| 10 | Powder River Basin | 2,250 | 2,399 | 4,649 | 0 | 957 | 1,478 | *0* | **26,600** | 764 | 0 | 29,799 |
| 11 | Big Horn Basin | 1,860 | 103 | 1,963 | 0 | 535 | 361 | *0* | 0 | 0 | 0 | 896 |
| 12 | Wind River Basin | 3,249 | 2,424 | 5,673 | 0 | 2,000 | 1,635 | *0* | 413 | 0 | 0 | 4,048 |
| 13 | Southwestern Wyoming (Green Rvr B) | 12,829 | 12,703 | 25,532 | 0 | 7,299 | 4,729 | *0* | 1,966 | **38,800** | 14,535 | 67,329 |
| 14 | Denver Basin, Park Basins, Las Animas Arch | 4,238 | 1,980 | 6,218 | 0 | 1,995 | 1,668 | *0* | 0 | 2,019 | 0 | 5,682 |
| 15 | Raton Basin-Sierra Grande Uplift | 153 | 1,213 | 1,366 | 0 | 0 | 37 | *0* | 1,931 | 0 | 0 | 1,968 |
| 16 | San Juan and Albuquerque-Santa Fe Rift | 29,134 | 19,621 | 48,755 | 0 | 5,418 | 671 | *0* | 8,413 | 21,002 | 0 | 35,504 |
| 17 | Montana Thrust Belt and SW Montana | 241 | 28 | 269 | 0 | 48 | 8,280 | 0 | 0 | 0 | 0 | 8,328 |
| 18 | Wyoming Thrust Belt | 3,902 | 741 | 4,643 | 0 | 1,393 | 12,008 | 0 | 0 | 0 | 0 | 13,401 |
| 19 | Great Basin and Paradox | 1,405 | 1,033 | 2,438 | 0 | 995 | 2,714 | 0 | 0 | 0 | 0 | 3,709 |
| 20 | Western Oregon-Washington | 66 | 6 | 72 | 0 | 0 | 1,092 | 0 | 676 | 11,846 | 0 | 13,614 |
| 21 | Anadarko Basin | 141,082 | 17,726 | 158,808 | 0 | 21,378 | **23,000** | **1,000** | 0 | 0 | 0 | 45,378 |
| 22 | Arkoma-Ardmore | 25,596 | 4,788 | 30,384 | 0 | 6,791 | 3,799 | **9,300** | 2,558 | 0 | 0 | 22,448 |
| 23 | Northern Midcontinent | 13,196 | 1,496 | 14,692 | 0 | 4,090 | 2,066 | 0 | 2,295 | 0 | 0 | 8,451 |
| 24 | Permian | 105,398 | 16,376 | 121,774 | 0 | 21,472 | 19,624 | **34,400** | 0 | 0 | 0 | 75,496 |
| 25 | Northern California | 9,241 | 635 | 9,876 | 0 | 2,105 | 3,447 | 0 | 0 | 0 | 0 | 5,552 |
| 26 | Central and Southern California | 22,554 | 1,961 | 24,515 | 0 | 1,090 | 5,878 | 321 | 0 | 0 | 0 | 7,289 |
| | total | **762,048** | **144,864** | **906,912** | **0** | **148,352** | **205,800** | **69,307** | **64,917** | **159,337** | **14,535** | **662,248** |
| ***Lower 48 offshore*** | | | | | | | | | | | | |
| 29 | Eastern GOM Offshore Shelf | 3,528 | 3,421 | 6,949 | 700 | 3,432 | 17,714 | 0 | 0 | 0 | 0 | 21,846 |
| 30 | Eastern GOM Offshore DW Shallow | 0 | 0 | 0 | 0 | 0 | 1,883 | 0 | 0 | 0 | 0 | 1,883 |
| 31 | Eastern GOM Offshore DW Deep | 0 | 0 | 0 | 0 | 0 | 8,996 | 0 | 0 | 0 | 0 | 8,996 |
| 32 | Central & Western GOM Offshore Shelf | 152,158 | 14,765 | 166,923 | 0 | 43,616 | **101,850** | 0 | 0 | 0 | 0 | 145,466 |
| 33 | C & W GOM Deepwater Plio-Pleistocene | 7,443 | 10,983 | 18,426 | 0 | 3,417 | 23,630 | 0 | 0 | 0 | 0 | 27,047 |
| 34 | C & W GOM Deepwater Miocene | 0 | 0 | 0 | 0 | 3,040 | 78,262 | 0 | 0 | 0 | 0 | 81,302 |
| 35 | C & W GOM Deepwater Foldbelts | 0 | 0 | 0 | 0 | 1,059 | 27,085 | 0 | 0 | 0 | 0 | 28,144 |
| 36 | Pacific Offshore | 2,579 | 625 | 3,204 | 0 | 1,035 | 20,654 | 0 | 0 | 0 | 0 | 21,689 |
| 37-39 | Atlantic Offshore | 0 | 0 | 0 | 0 | 0 | 32,817 | 0 | 0 | 0 | 0 | 32,817 |
| | total | **165,708** | **29,794** | **195,502** | **700** | **55,599** | **312,891** | **0** | **0** | **0** | **0** | **369,190** |
| ***Lower 48 onshore total*** | | ***762,048*** | ***144,864*** | ***906,912*** | ***0*** | ***148,352*** | ***205,800*** | ***69,307*** | ***64,917*** | ***159,337*** | ***14,535*** | ***662,248*** |
| ***Lower 48 offshore total*** | | ***165,708*** | ***29,794*** | ***195,502*** | ***700*** | ***55,599*** | ***312,891*** | ***0*** | ***0*** | ***0*** | ***0*** | ***369,190*** |
| ***Lower 48 total*** | | ***927,756*** | ***174,658*** | ***1,102,414*** | ***700*** | ***203,951*** | ***518,691*** | ***69,307*** | ***64,917*** | ***159,337*** | ***14,535*** | ***1,031,438*** |

## Table 6 - Number of Potential Non-Conventional US Lower 48 Well Sites for Microhole Drilling by Depth Interval and Resource Type (EEA, March 2006)

| Region code | Region | Resource Type | Potential Wells Above 10,000 Feet by Interval: 0-5,000 ft | 5- 10,000 ft | Total | Resource above 10,000 ft by Drilling Depth - Bcf: 0-5,000 ft | 5- 10,000 ft | Total | NonConv Resource All Depths Bcf |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Appalachia | Shale | 63,209 | 56,598 | 119,807 | 12,699 | 4,288 | 16,987 | 16,987 |
| | | Coalbed | 39,148 | 0 | 39,148 | 8,406 | 0 | 8,406 | 8,406 |
| | | Tight | 350,268 | 64,860 | 415,128 | 26,647 | 8,087 | 34,734 | 34,734 |
| | | Total | 452,625 | 121,458 | 574,083 | 47,752 | 12,375 | 60,127 | 60,127 |
| 2 | Warrior | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Coalbed | 10,439 | 494 | 10,933 | 4,481 | 120 | 4,601 | 4,601 |
| | | Tight | 0 | 0 | 0 | | | 0 | 0 |
| | | | 10,439 | 494 | 10,933 | 4,481 | 120 | 4,601 | 4,601 |
| 4 | MI-IL | Shale | 75,443 | 0 | 75,443 | 7,273 | 0 | 7,273 | 7,273 |
| | | Coalbed | 0 | 0 | 0 | 1,628 | 0 | 1,628 | 1,628 |
| | | Tight | 0 | 0 | 0 | | | 0 | 0 |
| | | | 75,443 | 0 | 75,443 | 8,901 | 0 | 8,901 | 8,901 |
| 5 | ArklaTX | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Coalbed | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Tight | 0 | 533 | 533 | 0 | 403 | 403 | 10,400 |
| | | | 0 | 533 | 533 | 0 | 403 | 403 | 10,400 |
| 7 | So. TX | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Coalbed | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Tight | 0 | 7,966 | 7,966 | 0 | 2,202 | 2,202 | 4,600 |
| | | | 0 | 7,966 | 7,966 | 0 | 2,202 | 2,202 | 4,600 |
| 8 | Williston | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Coalbed | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Tight | 43,162 | 0 | 43,162 | 7,194 | 0 | 7,194 | 7,660 |
| | | | 43,162 | 0 | 43,162 | 7,194 | 0 | 7,194 | 7,660 |
| 9 | Uinta - Pic. | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Coalbed | 18,166 | 0 | 18,166 | 4,858 | 0 | 4,858 | 5,862 |
| | | Tight | 4,705 | 26,230 | 30,935 | 1,412 | 19,279 | 20,691 | 27,500 |
| | | | 22,871 | 26,230 | 49,101 | 6,270 | 19,279 | 25,549 | 33,362 |
| 10 | Powder | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Coalbed | 69,767 | 0 | 69,767 | 22,187 | 0 | 22,187 | 26,600 |
| | | Tight | 5,228 | 0 | 5,228 | 627 | 0 | 627 | 764 |
| | | | 74,995 | 0 | 74,995 | 22,814 | 0 | 22,814 | 27,364 |
| 12 | Wind River | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Coalbed | 887 | 0 | 887 | 383 | 0 | 383 | 413 |
| | | Tight | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | 887 | 0 | 887 | 383 | 0 | 383 | 413 |
| 13 | Green River | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Coalbed | 5,872 | 0 | 5,872 | 1,216 | 0 | 1,216 | 1,966 |
| | | Tight | 0 | 0 | 0 | 0 | 0 | 0 | 38,800 |
| | | | 5,872 | 0 | 5,872 | 1,216 | 0 | 1,216 | 40,766 |

**Table 6 (continued)**

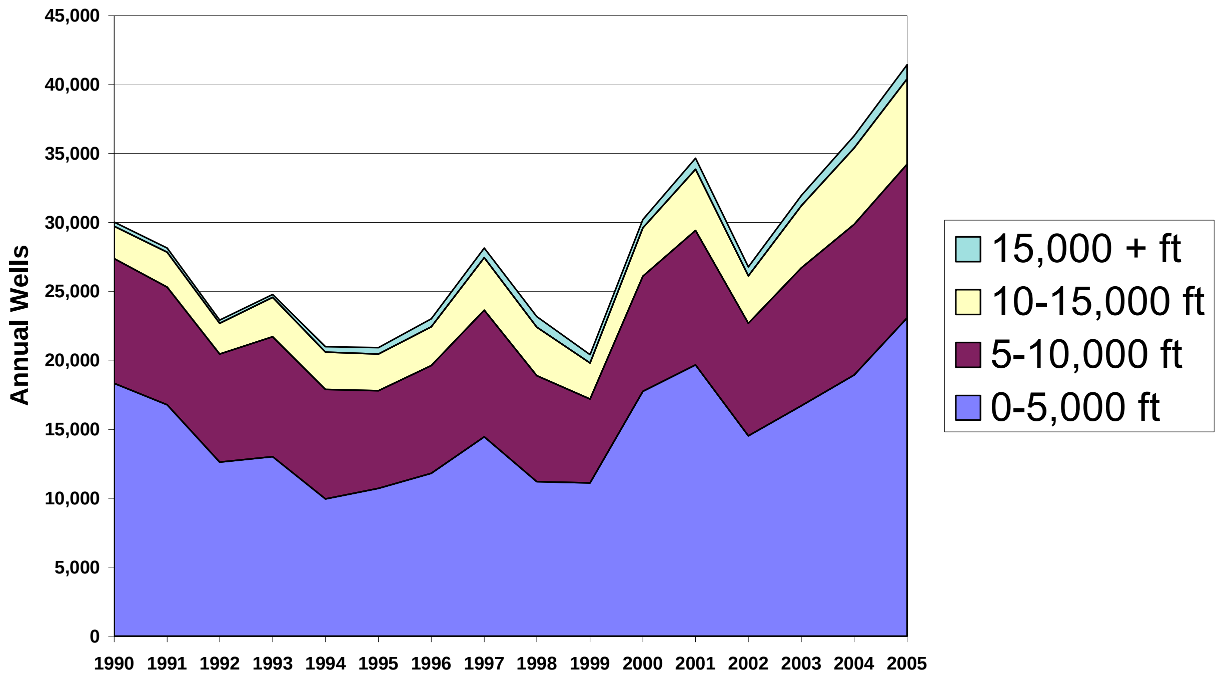
| | Resource Type | Potential Wells Above 10,000 Feet by Interval 0-5,000 ft | 5- 10,000 ft | Total | Resource above 10,000 ft by Drilling Depth - Bcf 0-5,000 ft | 5- 10,000 ft | Total | Total NonConv Resource All Depths Bcf |
|---|---|---|---|---|---|---|---|---|
| 14 Denver | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Coalbed | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Tight | 2,783 | 3,615 | 6,398 | 974 | 1,084 | 2,058 | 2,058 |
| | | 2,783 | 3,615 | 6,398 | 974 | 1,084 | 2,058 | |
| 15 Raton | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Coalbed | 2,200 | 0 | 2,200 | 1,890 | 0 | 1,890 | 1,890 |
| | Tight | 0 | 0 | 0 | | | 0 | 0 |
| | | 2,200 | 0 | 2,200 | 1,890 | 0 | 1,890 | 1,890 |
| 16 San Juan | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Coalbed | 8,414 | 0 | 8,414 | 7,795 | 0 | 7,795 | 8,413 |
| | Tight | 38,452 | 2,766 | 41,218 | 15,349 | 3,532 | 18,881 | 21,002 |
| | | 46,866 | 2,766 | 49,632 | 23,144 | 3,532 | 26,676 | 29,415 |
| 20 OR - WA | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Coalbed | 1,005 | 0 | 1,005 | 697 | 0 | 697 | 697 |
| | Tight | 0 | 0 | 0 | 0 | 0 | 0 | 11,486 |
| | | 1,005 | 0 | 1,005 | 697 | 0 | 697 | 12,183 |
| 21 Anadarko | Shale | 0 | 1,253 | 1,253 | 0 | 1,008 | 1,008 | 1,008 |
| | Coalbed | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Tight | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 0 | 1,253 | 1,253 | 0 | 1,008 | 1,008 | 1,008 |
| 22 Arkoma | Shale | 0 | 13,252 | 13,252 | 0 | 9,267 | 9,267 | 9,267 |
| | Coalbed | 6,832 | 0 | 6,832 | 1,872 | 0 | 1,872 | 2,558 |
| | Tight | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 6,832 | 13,252 | 20,084 | 1,872 | 9,267 | 11,139 | 11,825 |
| 23 N. Midcon. | Shale | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Coalbed | 15,598 | 0 | 15,598 | 2,366 | 0 | 2,366 | 2,366 |
| | Tight | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 15,598 | 0 | 15,598 | 2,366 | 0 | 2,366 | |
| 24 Permian + Ft W. | Shale | 0 | 18,435 | 18,435 | 0 | 23,315 | 23,315 | 34,400 |
| | Coalbed | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Tight | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 0 | 18,435 | 18,435 | 0 | 23,315 | 23,315 | 34,400 |
| 26 C. and S CA | Shale | 0 | 33 | 33 | 0 | 330 | 330 | 330 |
| | Coalbed | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Tight | 0 | 0 | 0 | | | 0 | 0 |
| | | 0 | 33 | 33 | 0 | 330 | 330 | 330 |
| **Total L-48** | **Shale** | **138,652** | **89,571** | **228,223** | **19,972** | **38,208** | **58,180** | **69,265** |
| | **Coalbed** | **178,328** | **494** | **178,822** | **57,779** | **120** | **57,899** | **65,400** |
| | **Tight** | **444,598** | **105,970** | **550,568** | **52,203** | **34,587** | **86,790** | **159,004** |
| | | **761,578** | **196,035** | **957,613** | **129,954** | **72,915** | **202,869** | **293,669** |

## Historic Gas Well Drilling by Depth Interval and Play in the U.S.

EEA gas evaluated statistics published by the API on the number of oil, gas, and dry holes, completed in the U.S.

**Figure 35** shows recent trends in U.S. onshore completions by depth interval. In 2005, there were 41,400 reported or estimated onshore total completions (oil, gas, and dry). Gas completions in 2005 are estimated at 26,600. Gas well completion activity as recently as the late 1990s was at a level of only 11,000 completions.

**Figure 35 - Onshore U.S. Total Well Completions by Depth Interval**




As shown on the charts almost all of the increase in onshore completion activity of the past decade has been in the 0-5,000 and 5-10,000 foot intervals. Most of this increase was coalbed methane. As many as several thousand gas wells per year were completed in the Powder River coalbed play.

EEA has evaluated gas completion statistics for over 200 U.S. gas plays or formations. This analysis has been based upon commercial well completion level analysis and EEA database processing. As part of our economic analysis of each of play, we evaluate EUR per well, depth, and drilling and stimulation costs.

## Onshore Rig Day Rates

**Figure 36** shows average U.S. onshore rig day rates since 1991. The chart shows a relatively constant rate of about $6,000 per day through 2000, followed by a spike in 2001 and a recent climb to historically high levels of over $12,000 per day.

Rig rates have historically been correlated with energy prices. Higher prices lead to greater utilization and more demand, resulting in higher rates. The current surge in day rates reflects higher oil and gas prices and the current supply constrained condition of U.S. markets.

**Figure 36 - Average U.S. Onshore Day Rates for Drilling Rigs**

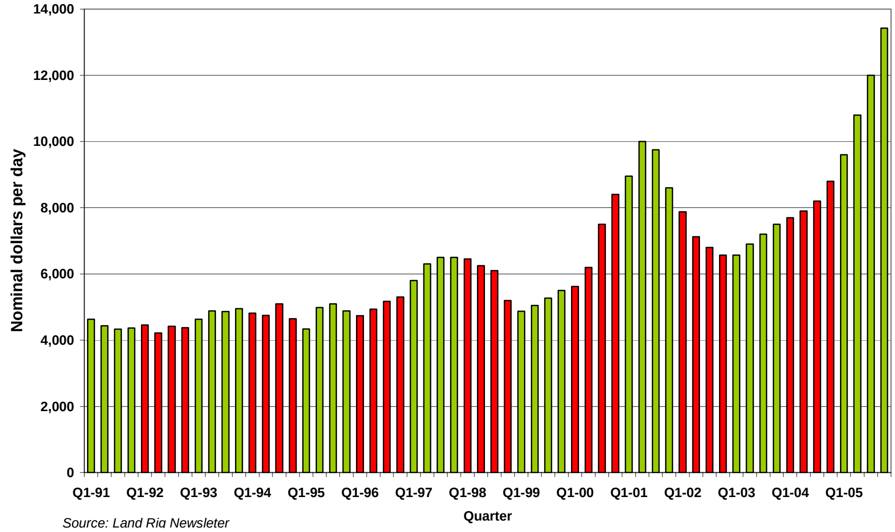
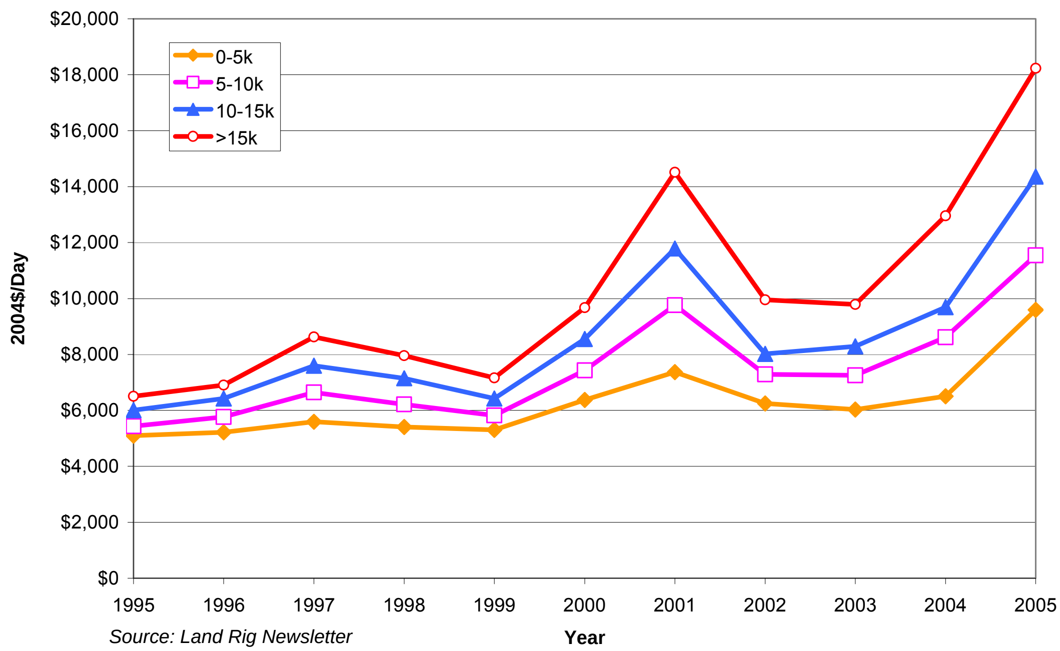



**Figure 37** shows the onshore day rates by depth rating of the rig. The increases in 2004 and 2005 affected all classes of rigs.

**Figure 37 - Onshore Day Rates by Rig Depth Rating**

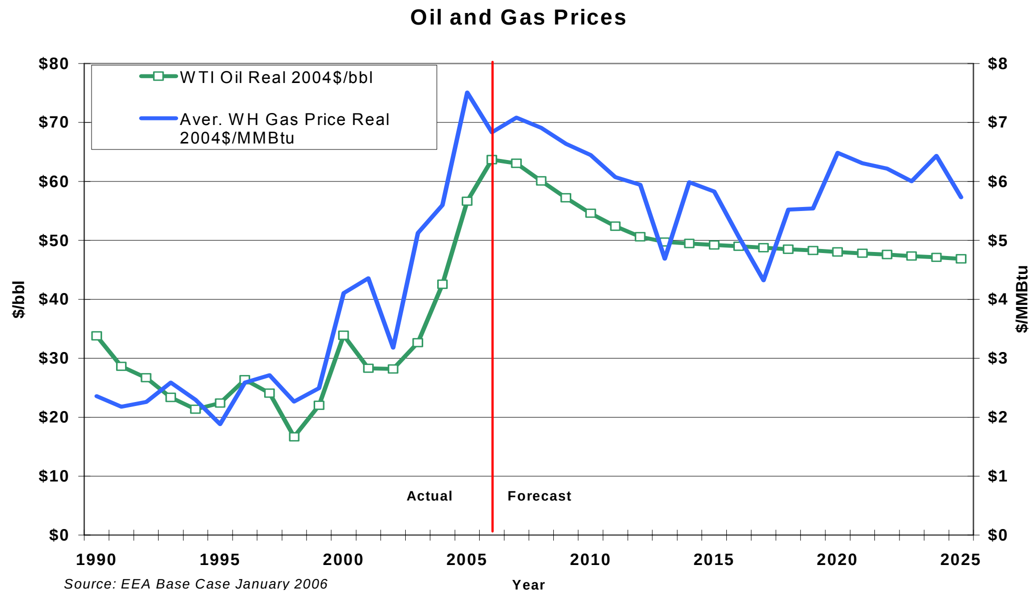


## EEA Price, Drilling Cost, and Activity Forecasts

**Figure 38** presents the current EEA "Basecase" forecast of oil and gas prices through 2025. The wellhead gas price increase since 2004 is forecast to moderate and decline through much of the forecast period in real dollars. Wellhead prices are forecast to decline to a range of approximately $5 to $6 per MMBtu in 2004 dollars over the coming decade.

Oil prices have also greatly increased and are currently over $60 per barrel. EEA is forecasting that oil prices will gradually decline over the coming decade to about $50 per barrel in 2004 dollars.

**Figure 38 - Historic and Forecasted Oil and Gas Prices**

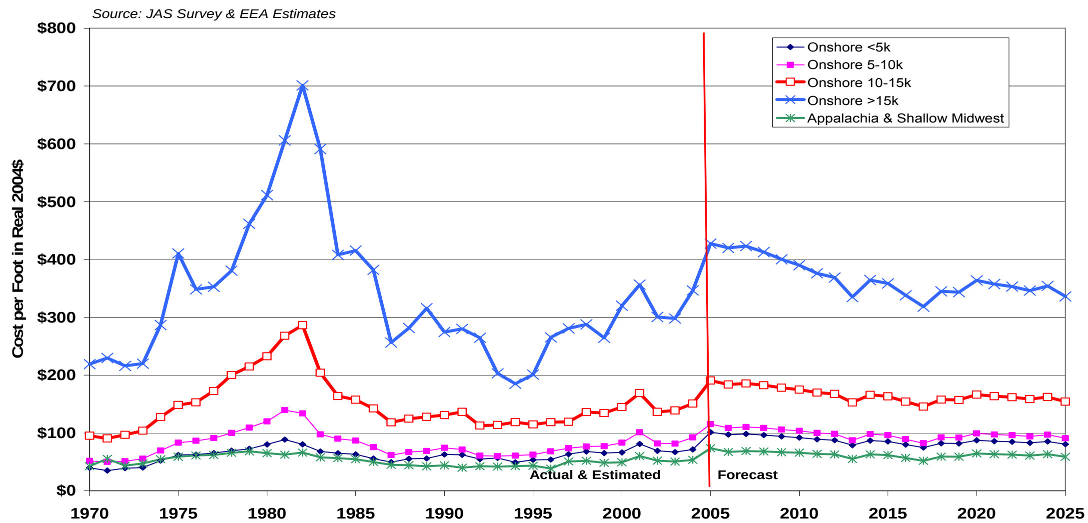



Historical and EEA Basecase forecast drilling costs by depth interval are presented in **Figure 39**. The historic data are from the API Joint Association Survey.[2] The chart shows the national onshore data by depth and a separate plot of Appalachia and the Shallow Midwest costs. The average cost per foot for the 0-5,000 foot interval has been in a range of about $50 to $75 and the cost per foot for 5-10,000 feet has been somewhat higher, about $75 per foot. The Appalachian and Shallow Midwest cost has been below $50 per foot.

Since 2000, total drilling costs have risen for all categories, but not as dramatically in recent years as implied by the day rates. The reason is that operators are becoming more efficient and therefore the number of drilling days has generally declined, partially offsetting the rate increases.

[2] API, 2006, "Joint Association Survey of Drilling Costs, "API, Washington, DC.

**Figure 39 - Historic Onshore Drilling Cost**




**Figures 40 and 41** show the EEA forecast of U.S. onshore drilling activity by depth interval through 2025. As discussed previously, the major recent trend in activity is a large increase in drilling in the 0-5,000 foot and 5-10,000 foot intervals, dominated by coalbed, tight gas, and shale gas drilling. The EEA forecast indicates a continued strong level of annual drilling at about 45,000 wells per year and increasing to 50,000 wells per year.

On a depth interval basis, the forecast calls for a sustained level of drilling in the 0-5,000 foot interval of about 25,000 wells per year, and over 10,000 wells per year in the 5-10,000 foot interval. Overall, drilling levels in the onshore shallower than 10,000 feet will dominate future drilling.

Cumulatively, the forecast drilling activity level of 25,000 wells from 0 to 5,000 feet translates into 500,000 well completions over a 20 year forecast. An activity of approximately 12,000 wells per year in the second depth interval represents 240,000 wells. This is indicative of a very large potential market for microhole drilling.

**Figure 40 - U.S. Onshore Drilling by Depth Interval**

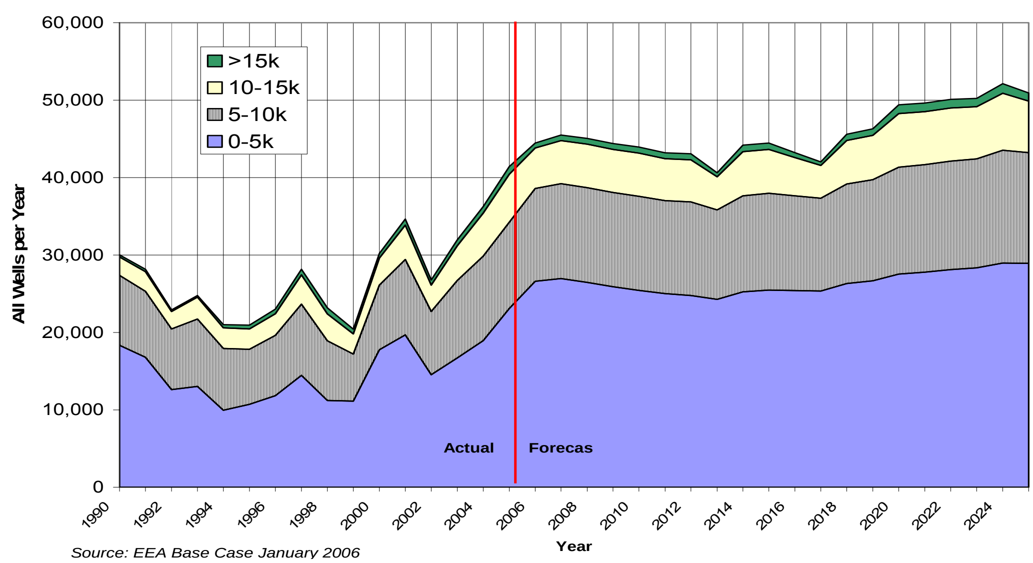


**Figure 41 - U.S. Onshore Footage by Depth Interval**

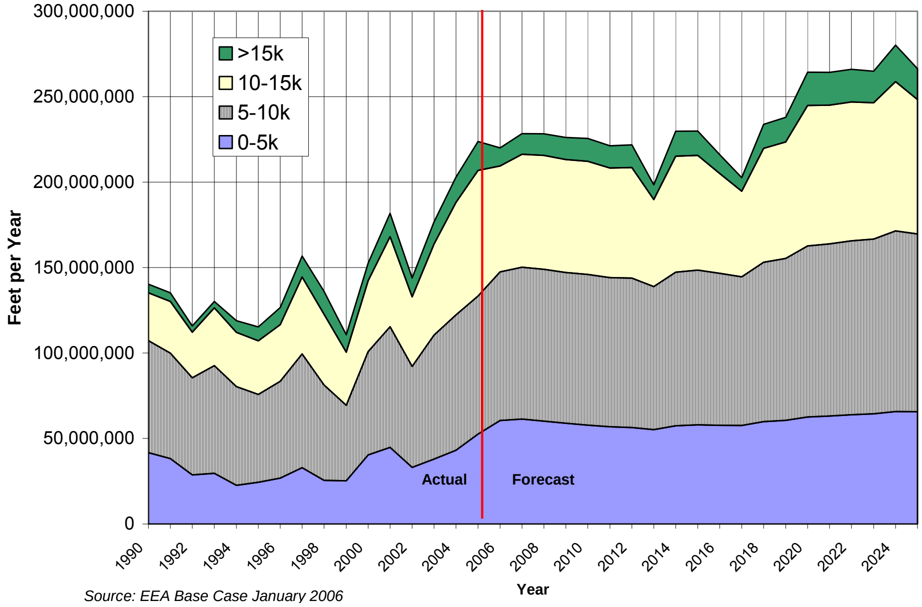
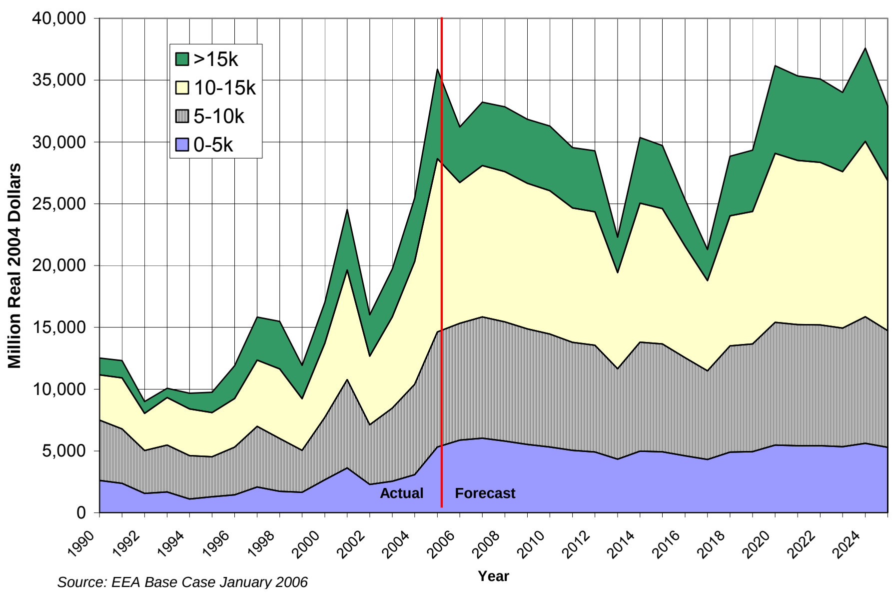



**Figure 42** shows the U.S. onshore drilling expenditures in real 2004 dollars. Until recently, annual drilling expenditures averaged less than $15 billion. In 2005, expenditures surged to over $30 billion. The chart shows that, while recent onshore drilling has been dominated by objectives shallower than 10,000 feet, expenditures for drilling to less than 10,000 feet have been about one-half of the total, or about $15 billion.

The EEA onshore drilling expenditure forecast calls for an overall level of $25 to $35 billion per year with about $15 billion for intervals shallower than 10,000 feet.

**Figure 42 - U.S. Onshore Drilling Expenditures by Depth Interval**



## Analysis of Potential CT Microhole Market Penetration and Impact on Industry

While CT microhole drilling currently represents a very small percentage of U.S. activity, it is possible to develop a set of assumptions about future market penetration and to evaluate the cost savings and impact on the gas industry.

**Table 7** shows the assumptions that were developed for the analysis. In 2006, approximately 92 percent of total drilling was vertical and 8 percent was horizontal. CT microhole drilling will represent less than one percent of total drilling. (Total drilling completions in 2005 were 23,000 from 0-5,000 feet and 11,000 between 5,000 and 10,000 feet).

As shown in the table, the study assumes that microhole drilling will see the initial market penetration for vertical wells in the 0-5,000 foot interval. This will be followed by horizontal drilling from 0-5,000 feet. After 2010, an increasing share of drilling between 5,000 and 10,000 feet will be microhole, with vertical drilling first, followed by more horizontal drilling.

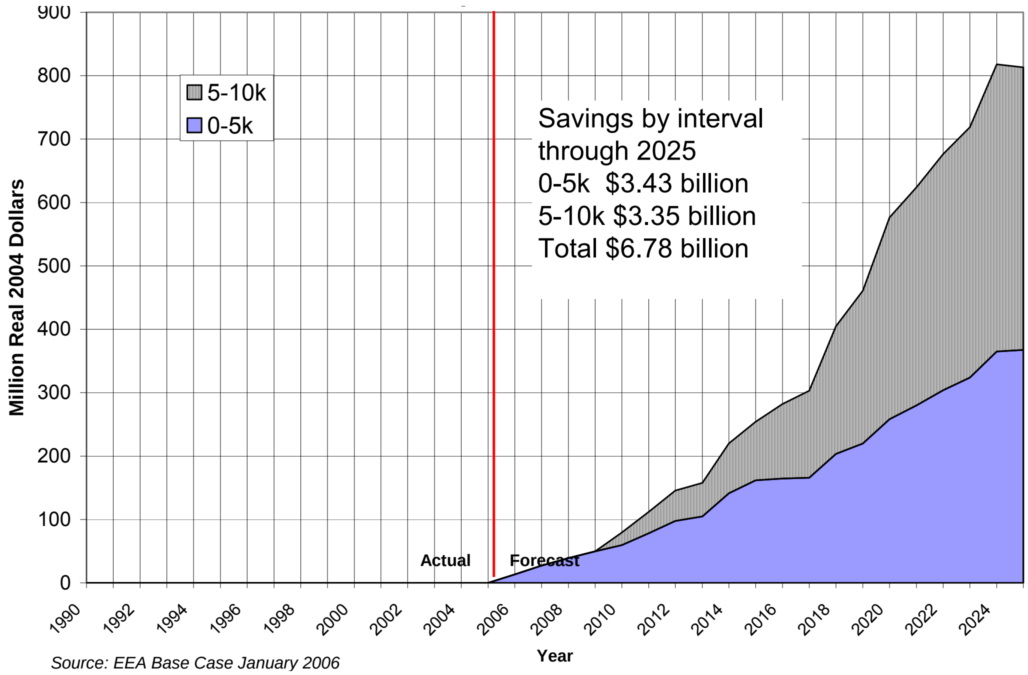
**Table 7 - EEA Assumptions for CT Microhole Market Share – Onshore L-48**

**Scenario for Analysis**
**Percent of Total Well Completions (Gas and Oil)**
**Surface drilling; excludes sidetracks**

| | | 2006 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| Drilling 0-5,000 ft | | | | | | |
| | Percent of all wells vertical | 92% | 87% | 81% | 78% | 78% |
| | Percent of all wells horizontal | 8% | 13% | 19% | 22% | 22% |
| | total | 100% | 100% | 100% | 100% | 100% |
| | Microhole share of vertical wells | 1% | 5% | 15% | 20% | 30% |
| | Microhole share of horizontal wells | 0% | 1% | 5% | 15% | 20% |
| | Vertical microhole share of total wells | 0.92% | 4.35% | 12.15% | 15.60% | 23.40% |
| | Horiz. microhole share of total wells | 0.00% | 0.13% | 0.95% | 3.30% | 4.40% |
| | **Total microhole market share** | **0.92%** | **4.48%** | **13.10%** | **18.90%** | **27.80%** |
| Drilling 5-10,000 ft | | | | | | |
| | Percent of all wells vertical | 92% | 87% | 81% | 78% | 78% |
| | Percent of all wells horizontal | 8% | 13% | 19% | 22% | 22% |
| | total | 100% | 100% | 100% | 100% | 100% |
| | Microhole share of vertical wells | 0% | 1% | 5% | 15% | 20% |
| | Microhole share of horizontal wells | 0% | 0% | 1% | 5% | 15% |
| | Vertical microhole share of total wells | 0.00% | 0.87% | 4.05% | 11.70% | 15.60% |
| | Horiz. microhole share of total wells | 0.00% | 0.00% | 0.19% | 1.10% | 3.30% |
| | **Total microhole market share** | **0.00%** | **0.87%** | **4.24%** | **12.80%** | **18.90%** |

**Figure 43** shows the annual amount of savings through 2025, based upon an average 25% drilling cost reduction relative to conventional drilling. The conventional drilling expenditures are those that were documented previously, as estimated through the EEA Basecase forecast. Annual CT microhole savings reach a level of over $800 million by 2025. Cumulative savings through 2025 are $6.8 billion dollars.

**Figure 43 – Forecast Annual U.S. Microhole Drilling Savings through 2005 by Depth Interval**




Source: EEA Base Case January 2006

## Additions to U.S. Gas Resource Base

Because CT microhole drilling is significantly lower cost than conventional drilling, it will result in development of gas resources that would not have been economic with conventional methods. As discussed previously and shown in T**able 8**, an estimated 203 Tcf of non-conventional gas is assessed to be available for future drilling to depths of 10,000 feet, assuming current technology. Conventional new field resources to 10,000 feet are approximately 101 Tcf, and reserve appreciation to existing fields is 103 Tcf.

Because of the reduced development costs, EEA has estimated that an additional 5.5% of shale gas, 4.4% of coalbed gas, and 9.5% of tight gas will become economic. This translates into an additional non-conventional resource of 14 Tcf. EEA also estimates that an additional 6 Tcf of new fields and an additional 2 Tcf of reserve appreciation will become economic. The total additional gas resource that would become economic is 22 Tcf.

**Table 8 - Estimated Additional U.S. Onshore Gas Resource Made Economic Through Drilling.**

| | 0-5k Resource Tcf | 5-10k Resource Tcf | 0-10k Resource Tcf | Percentage Added Through Lower Costs | Additional Economic Resource Tcf |
|---|---|---|---|---|---|
| **Non-Conventional Gas** | | | | | |
| Shale | 20.0 | 38.2 | 58.2 | 5.5% | 3.2 |
| Coalbed | 57.8 | 0.1 | 57.9 | 4.4% | 2.5 |
| Tight | 52.2 | 34.6 | 86.8 | 9.5% | 8.2 |
| Total | 130.0 | 72.9 | 202.9 | 6.9% | 14.0 |
| **Conventional New Fields** | 39.0 | 62.0 | 101.0 | 5.9% | 6.0 |
| **Reserve Appreciation** | 44.0 | 59.0 | 103.0 | 2.1% | 2.2 |
| **U.S. Onshore Total** | **213.0** | **193.9** | **406.9** | **5.4%** | **22.1** |

## Technology Dissemination

A comprehensive program to disseminate the results of the Microhole field demonstration project was undertaken. This program included a portfolio of dissemination techniques which ranged from press releases to personal communications and others.

Table 9 which follows describes the dissemination activities undertaken during the performance of the project in chronological order. Following the table some of the results of the efforts are summarized and any issues identified.

**Table 9 - Information Dissemination**

| Technology Dissemination Activity | Date | Description |
|---|---|---|
| Article published in American Oil and Gas Reporter. | May, 2005 | Unconventional Gas topic pointing out the importance of new technology and the marginal nature of the resource. Microhole applications to marginal resources emphasized. |
| Brownfield Conference to Producing Community, Denver | September 19, 2005 | Presented Microhole Drilling Project results with linkage as to how they can be utilized to recover marginal oil and gas resources. |
| Press Release to Major Newspaper Energy Editors | September 23, 2005 | Press Release Title: MICROHOLE TECHNOLOGY SUCCESSFUL IN SHALLOW, LOW-MARGIN FIELDS (Attached in Appendix C) |
| Press Release to Oil and Gas Journals and Publications | November 7, 2005 | Press Release Title: Microhole Technology Holds Potential to Increase Domestic Natural Gas and Oil Production - *New drilling approach lowers cost of recovery and lessens environmental impact* (Attached in Appendix C) |
| DOE PTTC Workshop #1 | August 16-17, 2005 | Workshop in Tulsa and Houston to introduce the portfolio of Microhole technologies to the producer community. |
| DOE PTTC Workshop #2 | November 16, 2005 | Workshop in Houston to update the producer community as to the status of the Microhole projects. |
| Article published in Oil and Gas Journal, November 28$^{th}$, 2005 issue. | November 2005 Issue | Drilling Market Focus: Coiled-tubing use growing faster than drilling industry *Oil and Gas Journal,* November 28, 2005 – (Excerpt Only attached in Appendix C) |
| Article published in Hart's E&P publication on Microhole drilling and its application to the Niobrara. | February, 2006 Issue | Article Title: Application of Microhole Coiled Tubing Drilling to the Niobrara Gas Play in Kansas and Colorado (Attached in Appendix C) |

| Technology Dissemination Activity | Date | Description |
|---|---|---|
| DOE PTTC Workshop #3 | March 22, 2006 | Workshop in Houston to update the producer community as to the status of the Microhole projects. |
| EIA Gas Supply Conference | March 28, 2006 | Presented results and impact of Microhole drilling at the EIA conference in Washington with emphasis on Unconventional gas recovery. |
| Hart's Unconventional Gas Conference | March 29, 2006 | Presented results and impact of Microhole drilling at the Hart's Unconventional conference in Washington with emphasis on Unconventional gas recovery. |
| KIOGA Mid-Year Meeting, McPherson, Kansas | April 12, 2006 | Presented the project results to the Kansas Independent Producers at their mid-year meeting. |
| Personal Communications | Ongoing Throughout Project | As a result of the publications, press releases and presentations we fielded numerous phone calls and emails regarding information on coiled tubing drilling. All were responded to by providing more material and/or information. |
| Future Activities – Beyond the project End date that GTI will conduct. | May 19, 2006, Denver<br>May 31, 2006, Ohio<br>June 21, 2006 DEA Workshop, Galveston | Workshops to present Microhole drilling project results to industry in Denver, Ohio and to the DEA at their annual workshop. |

Overall, the technology dissemination activities have generated a significant level of interest in this technology area. Many producers have contacted GTI for more information and access to drilling operations of this type. It is our view that as a result of this dissemination project and with additional development of downhole tools as is underway within the overall DOE Microhole project, that this type of coiled tubing drilling will displace rotary drilling for the 0' to 5000' drilling depth range. Additionally, with time this approach will penetrate the 5000' to 10,000' depth market.

# Summary and Conclusions

The Gas Technology Institute (GTI), in partnership with Coiled Tubing Solutions (now Advanced Drilling Technologies or ADT) and Rosewood Resources, Inc., has completed a field-based test of a state-of-the-art Microhole Coil Tubing Rig (MCTR) in the Niobrara gas fields to determine performance advantages of the ADT CT rig and to estimate the national impact of the technology at full commercial deployment. The ADT CT rig was selected for field performance evaluation because it is one of the most advanced commercial CT rig designs that demonstrates a high degree of process integration and ease of set-up and operation. Employing an information collection protocol, data was collected from the ADT CT rig during 25 drilling events that encompassed a wide range of depths and drilling conditions in the Niobrara. Information collected included time-function data, selected parametric information indicating CT rig operational conditions, staffing levels, and field observations of the CT rig in each phase of operation, from rig up to rig down.

In general, the data obtained in this field evaluation indicates that the ADT CT rig exhibited excellent performance in the drilling and completion of more than 25 wells in the Niobrara under varied drilling depths and formation conditions. Quantitative information that was collected showed the following:

- During field trials, the rate of penetration (ROP) values that were achieved ranged between 150 and 620 feet per hour. In the majority of the 25 project well drilling events, ROP values ranged between 300 and 620 feet per hour. For all but the lowest 2 wells, ROP values averaged approximately 400 feet per hour, representing an excellent drilling capability.
- ROP is not sensitive to the parameter of well depth at values between 500 and 3,000 ft.
- Most wells of depths between 500 and 2,000 feet were drilled at a total functional rig time of less than 16 hours; for wells as deep at 2,500 to 3,000 feet, the total rig time for the CT unit is usually well under one day.
- There is a general, nearly linear relationship between well depth and total rig time.
- About 40-55 percent of the functional rig time is divided evenly between drilling and casing/cementing. The balance of time is divided among the remaining four functions of rig up/rig down, logging, lay down bottomhole assembly, and pick up bottomhole assembly.

Observations made during all phases of CT rig operation at each of the project well installations have verified a number of characteristics of the technology that represent advantages that can produce significant savings of 25-35 percent per well. Attributes of the CT rig performance that were observed and documented in the field are summarized below.

- **Excellent Hole Quality.** All wells observed to be drilled at 25 project wells with the ADT CT rig were of excellent hole quality. All wells that were drilled had resulted in a gauge hole with very little hole deviation amounting to 1 to 2 degrees, well within State requirements. Good cement job quality and well-bonded cement is derived from the gauge hole quality.
- **Reduced Need for Auxiliary Equipment.** No auxiliary equipment is required to run casing, log wells or for handling drill collars and bottom hole drilling assemblies.
- **Efficient rig mobilization.** The rig is transported with 4 trailers, thereby reducing mobilization and transportation costs while meeting U.S. Department of Transportation limitations for highway transport. The CT rig contains all the equipment required for drilling

operations with the pipe handling capacity for casing up to 7 5/8" and supports a rotary and top drive.

- **Zero Discharge Operation.** The rig has a zero-discharge mud handling system and is capable of drilling a well with zero discharge of any fluid or solid residues (such as cuttings) if required. This is a considerable advantage for operations in environmentally sensitive areas.
- **Improved Safety.** The ADT CT rig substantially reduces drill pipe handling and has less equipment to mobilize from well to well. These characteristics translate into a far safer operating environment. The CT rig design also incorporates a number of redundant safety features that further reduce the risk to workers and observers proximal to rig operations.
- **Measurement While Drilling.** Using coiled tubing, measurement while drilling technology can be attached to the coiled tubing without concern about pipe joints.
- **Reduced Drilling Cost.** Commercial service estimates that the CT rig reduces drilling costs by 25 to 35% compared to conventional drilling technology.

Widespread commercial use of the Microhole Coiled Tubing technology in the United States for onshore Lower-48 drilling has the potential of achieving substantially positive impacts in terms of savings to the industry and resource expansion. This impact was assessed in this project using the conservative assumption that CT technology could achieve an average savings of at least 25% per well drilled in the Lower-48 over a twenty-year horizon. The findings of this analysis indicate:

- The likely market scenario for deployment of the technology in the years 2006-2026 will involve the following steps:
    - Initial CT market penetration for vertical wells in the depth range of 0-5,000 feet
    - Then commercial use of CT for horizontal drilling in the depth range of 0-5,000 feet.
    - After 2010, an increasing share of drilling between 5,000 and 10,000 feet will be based on microhole technology.
- Successfully commercialized Microhole CT Rig Technology is projected to achieve cumulative savings in Lower-48 onshore drilling expenditures of approximately 6.8 billion dollars by 2025.
- The reduced cost of CT microhole drilling is projected to enable the development of gas resources that would not have been economic with conventional methods. Because of the reduced cost of drilling achieved with CT rig technology, it is estimated that an additional 22 Tcf of gas resource will become economic to develop.

The Microhole Coiled Tubing Rig design represents the next step in the continued journey of the drilling technology toward smaller bore holes and toward systems that utilize increasingly complex downhole instrumentation for improved control and real-time data acquisition and sensing technology to allow informed decision making by the operator. Since the CT rig design concept by its nature facilitates the use of many of these technological improvements, it follows that there is an advantage to encourage its continued development. In other words, the Microhole Coiled Tubing Rig represents an important platform for the continued improvement of drilling that draws on a new generation of various technologies to achieve goals of improved drilling cost and reduced impact to the environment.

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# Appendix A. Data Collected by GTI Staff during CT Rig Operation

**Well Name: Gutsch 1 – 26**
**Date : 5-15-2005**
**County : Sherman, KS**

| **Depth** | **1245 ft** | |
|---|---|---|
| | **Drilling Assembly** | |
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (8)Drilling Collar (3 ¾”), | 246.07 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 32 centipoise | |
| KCL | 10 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 1 gal/well | |
| **Deviation** | | |
| Depth | Deviation Value | |
| 500 ft | 0.75 ft | |
| 750 ft | 1.50 ft | |
| 1000 ft | 0.75 ft | |
| 1200 ft | 1.25 ft | |
| **Depth Interval** | | |
| 400 ft | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| **Time Log** | | Time, hr |
| 7:00 to 10:30 | Rig up | 3.5 |
| 10:30 to 16:30 | Drill | 6 |
| 16:30 to 18:00 | Pull out | 1.5 |
| 18:00 to 20:00 | Casing | 2 |
| 20:00 to 21:00 | Cement 2% cacal | 1 |
| 21:00 | Plug down | 1 |
| 22:00 | Rig down | |

**Well Name: Irvin 1 - 33**
**Date : 5-14-2005**
**County : Sherman, KS**
**Depth** **1400 ft**

| | **Drilling Assembly** | |
|---|---|---|
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (8)Drilling Collar 3 ¾ | 246.07 length in ft | |
| **Mud Record** | | |
| Weight | 8.8 lbs/gal | |
| Funnel Viscosity | 33 centipoise | |
| KCL | 10 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 1 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 500 | 0.75 ft | |
| 750 | 0.75 ft | |
| 1000 | 1.50 ft | |
| 1350 | 0.75 ft | |
| **Depth Interval** | | |
| 366 | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| **Time Log** | | Time, hrs |
| 19:00 to 5:00 | Rig down wait for the sun | 10 |
| 5:00 to 7:00 | Move rig | 2 |
| 7:00 to 9:00 | Rig up | 2 |
| 9:00 to 10:30 | BHA trip in | 1.5 |
| 10:30 to 16:30 | Drilling till 366, clays slow down | 6 |
| 16:30 to 18:00 | Tooth LD BHA | 1.5 |
| 18:00 TO 20:00 | Logs | 2 |
| 20:00 to 22:30 | Run casing and cementing. | 2.5 |
| | 44 jts, 2 7/8" J-55. 6.50# 8rd csg | |
| 22:30 to 23:00 | Cement w/50 sks STD cement 2% cacal | 1 |
| 23:00 to 24:00 | Set slips Plug down 11:00 PM 1200# release rig | 1 |

**Well Name: Duell 3 – 17**

**Date : 5-13-2005**

**County : Sherman, KS**

**Depth** **1180 ft**

| | | |
|---|---|---|
| | **Drilling Assembly** | |
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (6)Drilling Collar 3 3/4 | 184.42 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 20 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 500 | 1.50 ft | |
| 750 | 2 ½ ft | |
| 1000 | 1 ¼ ft | |
| **Depth Interval** | | |
| 370 to 1180 ft | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| **Time Log** | | Time, hrs |
| 6:00 to 7:00 | Pickup BHA | 1 |
| 7:00 to 8:00 | Safety meeting | 1 |
| 8:00 to 11:00 | Drilling till 1180 ft | 3 |
| 11:00 to 13:00 | Trip and circulate for 15 minutes | 2 |
| 13:00 to 15:00 | Logs- Density and Gamma | 2 |
| 15:00 to 18:30 | Run casing and cementing. | 3.5 |
| | 38 jts, 2 7/8" J-55. 6.50# 8rd csg | |
| 18:30 to 19:30 | Set slips release rig | 1 |

**Well Name: Topliff 1 - 25**
**Date : 6-08-2005**
**County : Sherman, KS**
**Depth** **1400 ft**

| | | |
|---|---|---|
| | **Drilling Assembly** | |
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (6)Drilling Collar 3 3/4 | 184.42 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 10 gal/well | |
| Bicarb | 3 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 500 | *NA | |
| 750 | NA | |
| 1000 | NA | |
| **Depth Interval** | | |
| 360 to 1350 ft | Shale | |
| Rotary Table speed | 200 rpm | |
| WT on bit | 5000 lbs | |
| Mud pressure | 1300 psig | |
| **Time Log** | | Time, hrs |
| **4:30 to 7:00** | Moving | 2.5 |
| 7:00 to 8:00 | Rig up | 1 |
| 8:30 to 9:30 | Pick up BHA | 1 |
| 9:30 to 3:30 pm | drill F/360 T/1350 | 6 |
| 3:30 to 5:30 | POOH L,D,BHA | 2 |
| 5:30 to 7:00 pm | log slb | 1.5 |
| 7:30 to 11:30 | casing and cementing | 4 |
| | 38 jts, 2 7/8" J-55. 6.50# 8rd csg | |
| 12:00 AM | Rig down | |

* NA = Data Not Available

**Well Name: Melba 1-29**
**Date : 6-09-2005**
**County : Sherman, KS**
**Depth 1460 ft**

| | | |
|---|---|---|
| | **Drilling Assembly** | |
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (6)Drilling Collar 3 3/4 | 184.42 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 20 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 500 | 1 ½ ft | |
| 750 | 2 ½ ft | |
| 1000 | 1 ¼ ft | |
| **Depth Interval** | | |
| 375 to 1460 ft | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 5000 lbs | |
| **Time Log** | | Time, hrs |
| 7:00 to 8:30 | Rick up | 1.5 |
| 8:30 to 10:00 | Pick up BHA | 1.5 |
| 10:00 to 4:00 | Drill F/375 T/1475 | 6 |
| 4:00 to 6:00 | Lay down BHA | 2 |
| 6:00 to 8:30 | Logs- Density and Gamma | 2.5 |
| 8:30 to 9:30 | Water Ordering | 1 |
| 9:30 to 12:00 | RHIT 1375 PLUG DOWN @1375 | 2.5 |

**Well Name: Cramnne 1-29**
**Date : 6-15-2005**
**County : Sherman, KS**

| **Depth** | **900 ft** | |
|---|---|---|
| | **Drilling Assembly** | |
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (6)Drilling Collar 3 3/4 | 184.42 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 20 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 200 | 1.00 ft | |
| 400 | 1 ½ ft | |
| 600 | 1 ½ ft | |
| 800 | 1 ¼ ft | |
| 850 | 1 ¾ ft | |
| **Depth Interval** | | |
| 290 to 900 | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| **Time Log** | | Time, hrs |
| 7:00 to 8:00 PM | Rig up Carmine 1-29 | 1 |
| 8:00 to 11:00 | drill 290 to 900 | 3 |
| 11:00 to 11:30 | Circulation | 0.5 |
| 11:30 to 1:00 am | Lay BHA | 1.5 |
| 1:00 to 2:00 am | wait to log | 1 |
| 2:00 to 4 | Logging | 2 |
| 4:00 to 6:30 | Casing | 2.5 |
| 6:30 to 7 | Well head | 0.5 |
| 7 to 7:30 | Survey | 1.5 |
| 7:30 to 6 pm | Rig down and move stuck | 10.5 |
| 6:00 to 7 | Pick up BHA | 1 |

**Well Name: Rita Ihrig 1-29**
**Date : 6-16-2005**
**County : Sherman, KS**

| **Depth** | **1250 ft** | |
|---|---|---|
| | **Drilling Assembly** | |
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (6)Drilling Collar 3 3/4 | 184.42 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 20 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 350 | 1.00 ft | |
| 500 | ¾ ft | |
| 750 | 1 ft | |
| 1000 | ½ ft | |
| 1220 | ½ ft | |
| **Depth Interval** | | |
| 290 to 900 | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| **Time Log** | | Time, hrs |
| 7:00 to 11:00 pm | Drilling 350/1250 | 4 |
| 11:00 to 11:30 | Circulation | 0.5 |
| 11:30 to 1:00 am | Pick up BHA | 1.5 |
| 1:00 to 3:00 am | Logging | 2 |
| 3:00 am to 4:00 | wait on orders | 1 |
| 4: to 6:30 | Casing | 2.5 |
| 6:30 to 7 | Well head | 0.5 |
| 7:00 to 7:30 | Survey | 0.5 |

**Well Name: Bradshaw 1-15**
**Date : 6-13-2005**
**County : Sherman, KS**
**Depth** 1200 ft

| | | |
|---|---|---|
| | **Drilling Assembly** | |
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (6)Drilling Collar 3 3/4 | 184.42 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 20 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 200 | 1.25 ft | |
| 400 | 1 ½ ft | |
| 600 | 1 ft | |
| 800 | ½ ft | |
| 945 | 1 ft | |
| **Depth Interval** | | |
| 200 to 980 | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| **Time Log** | | Time, hrs |
| 7 to 11:30 am | Move on and Rig up | 4.5 |
| 11:30 to 5:00 am | Drill from 220 to 980 Lost circulation at 780 | 5.5 |
| 5:00 to 5:30 | Circulation | 0.5 |
| 5:30 to 7:00 am | Pick up | 1.5 |
| 7:00 to 8:30 | Logs- Density and Gamma | 1.5 |
| 8:30 to 10:30 | Run casing 2 7/8 | 2 |
| 10:30 to 11:00 | Cementing | 0.5 |
| 11:00 to 11:30 | Well head | 0.5 |
| 11:30 to 12:00 | survey | 0.5 |
| 12:00 to 4:00 | Rig down and move | 4 |
| 4:00 7:00 | Rig up Carmine 1-29 | 3 |

**Well Name: Emma 1-27**
**Date : 9-06-2005**
**County : Sherman, KS**
**Depth** **2630 ft**

| Drilling Assembly | | |
|---|---|---|
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (8)Drilling Collar 3 3/4 | 246 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 20 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 500 | ½ ft | |
| 1000 | 1 ft | |
| 1500 | 2 ¼ ft | |
| 2000 | 2 ½ ft | |
| | | |
| **Depth Interval** | | |
| 200 to 980 | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| **Time Log** | | Time, hrs |
| 7 to 1:30 | Drilling | 6.5 |
| 1:30 to 4:30 | POOH LD BHA | 3 |
| 4:30 TO 7:00 | LOG | 2.5 |
| 7: TO 11:30 | Run casing 2 7/8 | 4.5 |
| 11:30 TO 12 | FLANGE WELL | 0.5 |
| 12 TO 2 | RDMO | 2 |

**Well Name: Conrad 1-25**
**Date : 9-4-2005**
**County : Sherman, KS**
**Depth** **2850 ft**

| | | |
|---|---|---|
| **Drilling Assembly** | | |
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (8)Drilling Collar 3 3/4 | 246 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 20 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 500 | 1 ft | |
| 1000 | 1 ft | |
| 1500 | 2 ft | |
| 2000 | 2 ¾ ft | |
| | | |
| **Depth Interval** | | |
| 2200 to 2850 | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| **Time Log** | | Time, hrs |
| 7 to 12 | Drilling | 5 |
| 12 to 3.5 | POOH LD BHA | 3.5 |
| 3:30 TO 6 | LOG WITH SLB | 2.5 |
| 6 TO 7 | Run casing 2 7/8 | 1 |
| 7 TO 10:30 | CEMENT | 3.5 |
| 10:30 11 | FLANGE | 0.5 |
| 11 TO 5:30 | Rdmo ru emma | 6.5 |

**Well Name: Villines 1-34**
**Date : 9-7-2005**
**County : Yuma, CO**
**Depth** **2910 ft**

| **Drilling Assembly** | | |
|---|---|---|
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (8)Drilling Collar 3 3/4 | 246 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 20 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 500 | 1 ft | |
| 1000 | 1 ft | |
| 1500 | 2 ft | |
| 2000 | 2 ¾ ft | |
| | | |
| **Depth Interval** | | |
| 485 to 2910 | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| **Time Log** | | Time, hrs |
| 7 to 7:30 | RIM W /BHA | 0.5 |
| 7:30 TO 6 | DRILL F/415 TO 2910 | 11.5 |
| 6 TO 7 | POOH LD BHA | 1 |
| 7 to 9 | BHA | 2 |
| 9 TO 12 | SCHEN | 3 |
| 12 TO 4 | PLUG WELL | 4 |
| 4 TO 7 | RDMO | 3 |

**Well Name: Linin 1-1m**
**Date : 9-7-2005**
**County : Sherman, KS**
**Depth 1500 ft**

| | | |
|---|---|---|
| | **Drilling Assembly** | |
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (8)Drilling Collar 3 3/4 | 246 length in ft | |
| | **Mud Record** | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 20 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| | **Deviation** | |
| Depth | Dev | |
| 500 | 1.50 ft | |
| 1000 | ¾ ft | |
| 1450 | 1 ¾ ft | |
| | | |
| | | |
| | **Depth Interval** | |
| 385 to 1500 | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| | **Time Log** | Time, hrs |
| 7 to 7:30 | BHA | 0.5 |
| 7:30 TO 10 | DRILL 385 TO 1500 | 2.5 |
| 10 TO 10:30 | CIRCULATION | 0.5 |
| 10:30 TO 12:00 | POOH BHA | 1.5 |
| 12: TO 3:30 | CSG | 3.5 |
| 3:30 TO 4 | FLANGE WELL | 0.5 |
| 4:00 TO 7 | RDMO | 3 |

**Well Name: Linen**
**Date : 8-3-2005**
**County : Sherman, KS**
**Depth** **1200 ft**

| | | |
|---|---|---|
| | **Drilling Assembly** | |
| Bit | 4 ¾ inches | |
| Mud Motor | 15.79 ft | |
| (8)Drilling Collar 3 3/4 | 246 length in ft | |
| **Mud Record** | | |
| Weight | 8.7 lbs/gal | |
| Funnel Viscosity | 34 centipoise | |
| KCL | 20 gal/well | |
| Bicarb | 2 gal/well | |
| Poly | 4 gal/well | |
| Pac | 2 gal/well | |
| **Deviation** | | |
| Depth | Dev | |
| 500 | 1 ½ ft | |
| 1000 | ¾ ft | |
| 1450 | 1 ¾ ft | |
| | | |
| | | |
| **Depth Interval** | | |
| 385 to 1500 | Shale | |
| Rotary Table speed | 300 rpm | |
| WT on bit | 4000/6000 lbs | |
| **Time Log** | | Time, hrs |
| 7 to 9:30 | RU | 2.5 |
| 9:30 to 11 | RIH W/BHA | 1.5 |
| 11 TO 1:30 | DRL 388 TO 1200 | 2.5 |
| 1:30 TO 2:30 | CIRC | 0.5 |
| 2:00 TO 3:30 | TRIP OUT | 1.5 |
| 3:30 TO 5:30 | LOG | 2 |
| 5:30 TO 7 | CSG | 1.5 |

# Appendix B - Tabulated Data Collected from All Test Wells Drilled with the CT Rig.

| | | | | | | ------- Time Increment, hrs ------- | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Well | Depth, ft | Surface, ft | Actual Depth, ft | Time, hrs | ROP ft/hr | Rigup | PBHA | Drill | LDBHA | Log | CSG/CMNT | Total Functional CT Rig Time At Site |
| Melba | 1460 | 375 | 1085 | 6 | 180.83 | 1.5 | 1.5 | 6 | 2 | 2.5 | 2.5 | 16 |
| Topliff | 1350 | 360 | 990 | 6 | 165.00 | 1 | 1 | 6 | 2 | 1.5 | 4 | 15.5 |
| Duell | 1180 | 370 | 810 | 3 | 270.00 | 1 | 1 | 3 | 1 | 2 | 3.5 | 11.5 |
| Irvin | 1400 | 366 | 1034 | 6 | 172.33 | 2 | 1.5 | 6 | 1.5 | 2 | 2 | 15 |
| Gutsch | 1245 | 340 | 905 | 6 | 150.83 | 1.5 | 1 | 6 | 2 | 2 | 3 | 15.5 |
| Bradshaw | 980 | 220 | 760 | 5.5 | 265.40 | 2.5 | 1.5 | 5.5 | 1.5 | 1.5 | 2.5 | 15 |
| Crumrine | 900 | 290 | 610 | 3 | 203.00 | 1 | 1 | 3 | 1.5 | 2 | 2.5 | 11 |
| Rita | 1250 | 350 | 900 | 4 | 225.00 | 1 | 1 | 4 | 1.5 | 2 | 2.5 | 12 |
| Villines | 2910 | 410 | 2500 | 10.5 | 238.10 | 0.5 | 1 | 10.5 | 2 | 2.5 | 4.5 | 21 |
| Emma | 2630 | 1000 | 1630 | 6.5 | 250.77 | 2 | 2 | 6.5 | 2 | 2.5 | 4.5 | 19.5 |
| Conard | 2850 | 494 | 2356 | 5 | 471.20 | 3.5 | 3.5 | 5 | 3.5 | 2.5 | 4.5 | 22.5 |
| Alvin 44-8 | 1794 | 244 | 1550 | 3.5 | 442.86 | 1.5 | 1.5 | 3.5 | 1.5 | 2.5 | 3.5 | 14 |
| Ella Mae 14-3 | 2094 | 374 | 1720 | 3 | 573.33 | 2 | 2 | 3 | 1.5 | 2.5 | 3.5 | 14.5 |
| Ella Mae 22-04 | 2213 | 343 | 1870 | 3 | 623.33 | 2.5 | 2 | 3 | 2 | 2.5 | 3.5 | 15.5 |
| Emma 1-27 | 2999 | 369 | 2630 | 8 | 328.75 | 6.5 | 3 | 8 | 3 | 2.5 | 4.5 | 27.5 |
| ISERNHAGEN 12-25 | 1866 | 396 | 1470 | 3.5 | 420.00 | 1.5 | 1.5 | 3.5 | 1.5 | 1.5 | 3 | 12.5 |
| ISERNHAGEN 21-26 | 1802 | 282 | 1520 | 2.5 | 608.00 | 1.5 | 1.5 | 2.5 | 1.5 | 1.5 | 3 | 11.5 |
| R.Moore 13-28 | 2169 | 369 | 1800 | 3 | 600.00 | 2 | 2 | 3 | 2 | 2 | 3.5 | 14.5 |
| R.Moore 33-28 | 2160 | 355 | 1805 | 7 | 257.86 | 2 | 2 | 7 | 1.5 | 2 | 3.5 | 18 |
| R.Walter 21-21 | 1818 | 288 | 1530 | 3 | 510.00 | 1.5 | 1.5 | 3 | 1.5 | 1.5 | 3 | 12 |
| Walter 33-21 | 1790 | 260 | 1530 | 3.5 | 437.14 | 1.5 | 1.5 | 3.5 | 1.5 | 1.5 | 3 | 12.5 |
| RUDOLPH 33-9 | 1857 | 287 | 1570 | 3.5 | 448.57 | 1.5 | 1.5 | 3.5 | 1.5 | 2 | 3 | 13 |
| Villines 1-34 | 3335 | 485 | 2850 | 10.5 | 271.43 | 0.5 | 1 | 10.5 | 2 | 2.5 | 4.5 | 21 |
| Linin 1-1m | 1500 | 385 | 1115 | 2.5 | 446.00 | 0.5 | 0.5 | 2.5 | 1 | 1.5 | 3.5 | 9.5 |
| Linen 1-1 | 1200 | 388 | 812 | 1.5 | 541.33 | 2.5 | 1.5 | 2.5 | 1 | 2 | 1.5 | 11 |
| Key | | | | | | | | | | | | |
| Names in Bold= | CT Rig Drilling Observed by GTI Staff On Site | | | | Names Not in Bold = | | CT Rig Drilling Data Collected by CTS Staff | | | | | |
| PBHA | Pickup Bottom Hole Assembly | | | | | | | | | | | |
| LDBHA | Lay Down Bottom Hole Assembly | | | | | | | | | | | |
| CSG/CMNT | Casing and Cementing | | | | | | | | | | | |

# Appendix C. Technology Transfer Coordinated by GTI

PTTC TECHNOLOGY CONNECTIONS Rocky Mountain Region

SPE Denver Section

**Denver Section Society of Petroleum Engineers**

**Continuing Education Short Course Offering**

**In Association with PTTC:**

**Microhole Drilling with Coiled Tubing – It's Here and Growing**

***A Half-day Short Course***

**May 19, 2006, 8:30 am – 1 pm**
**Denver Athletic Club, 1325 Glenarm Place, Denver**
**Fee: $95, includes lunch**

**Course Description:** This concise half-day workshop will describe the history and technology of using coiled tubing for drilling shallow grass-roots wells and deep reentries. Case studies will review economic and operational considerations; potential new applications will be discussed.

**Course Content**

- An Overview of the Development of Coiled Tubing Drilling and Current Activities in North America, Movement into Lower 48 (Dwight Rychel, Consulting Petroleum Engineer and PTTC)
- Coiled Tubing Grassroots Drilling of Shallow Unconventional Gas (Kent Perry, GTI)
- Coiled Tubing Re-entry for Reservoir Life Extension – Technology and Case Study from Texas (IPS Procoil)
- Technology Developing in the Department of Energy's Microhole Technology Program & PTTC's Role and Informational Website (Dwight Rychel, PTTC)
- Geological Overview of the Niobara Chalk Natural Gas Play (Lynn Watney, Kansas Geological Survey)
- Coiled Tubing Drilling in the Rockies (Kyle Zemlak, Pioneer Resources)
- Feedback from participants on the potential application in the Rocky Mountain Region
- Lunch (included) and networking will follow the presentations

**Who Should Attend:** The workshop will benefit engineers, geologists, planners, executives; anyone setting strategic direction on plays and the best exploitation techniques.

**Technical questions: Lance Cole 918.241-5801 or Dwight Rychel 918.492.6964**
**Workshop information: Sandra Mark, 303.273.3107**
Register online: www.pttcrockies.org

### Hart's E&P Article – February, 2006

# Microhole Approach to Microdarcy Reservoirs

## Application of Microhole Coiled Tubing Drilling to the Niobrara Gas Play in Kansas and Colorado

**Kent Perry and Samih Batarseh; Gas Technology Institute**

Introduction

Natural gas was first discovered in the Niobrara formation in 1912 when a strong flow of gas was encountered while drilling the Goodland No. 1 well near Goodland, Kansas1. The well was plugged and abandoned. Since that first well the Niobrara gas play has undergone several episodes of activity driven by gas prices and improvements in technology. Recently, the development of coiled tubing drilling in combination with a microhole approach to borehole size has helped reenergize activity in this mature gas play.

Geology and Reservoir Characteristics

The Niobrara formation chalks were deposited during the last major transgression of the western interior Cretaceous sea, which extended from the Gulf of Mexico to the Arctic Ocean. The current play extends through Northwest Kansas and Eastern Colorado (Figure 1). Gas bearing chalk of the upper Cretaceous Niobrara formation is encountered at depths from 1000 to 3000 feet. Gas accumulations in the Niobrara formation generally are related to low relief structural features found along the eastern margins of the Denver geologic basin[2].

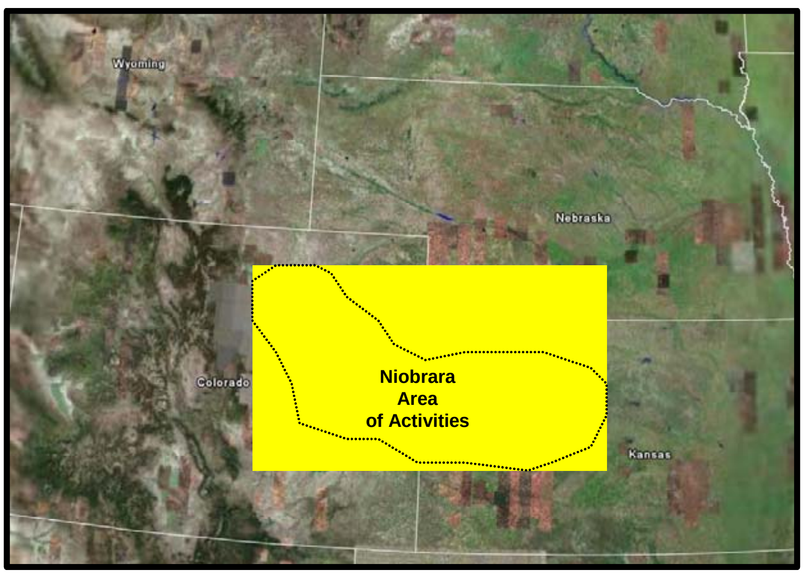


**Figure 1 - Niobrara Gas Play Area**

Niobrara gas fields are characterized by high porosity, low permeability and low reservoir pressure. These features are typical of a chalk subjected to modest burial depths[3]. At greater depth, porosity and permeability decrease causing a reduced total pore volume and higher water saturation at a given structural position. Reported values for porosity in the Niobrara formation range from 30% to 50%, with lower values found at greater depths. Despite the high porosity of the chalk, permeability is inherently low because of the fine grain size. Values for permeability range from 0.01 to 0.3 millidarcies in the fairway with microdarcy permeability found on the fringes. The Niobrara is an underpressured gas reservoir with geostatic pressure gradient ranges from 0.06 to 0.24 psi/ft. In the Goodland, Kansas area, at a depth of 1,000 feet the pressure is only 50 to 60 psi.

Thin pay zones (sometimes near water), low reservoir pressures and low in-situ formation permeability (requiring wells be hydraulically fractured) combine to create a challenging environment for successful field development. Certainly, an efficient low cost approach to well drilling and completion is needed.

**DOE Microhole Drilling Program**

Roy Long, with the Department of Energy's Tulsa office has designed and is implementing a research program to develop marginal oil and gas resources utilizing microhole wellbores. The overall approach is to develop a portfolio of tools and techniques that will allow the drilling of 3 5/8" holes and smaller (see accompanying article) enabling through better economics the development of marginal oil and gas resources. The field testing and demonstration of a "fit for purpose" coiled tubing drilling rig is one project within the program. The objective is to measure and document the rig performance under actual drilling conditions. A description of the rig and a summary of its performance in the Niobrara gas play follow.

**Description of the Rig**

The coiled tubing drilling rig (designed and built by Tom Gipson with Advanced Drilling Technologies Inc. (ADT)) is a trailer mounted rig with the coil and derrick combined to a single unit (Figure 2). The rig has been operating for approximately one year drilling shallow gas wells operated by Rosewood Resources, Inc., in Western Kansas and Eastern Colorado. The rig operations have continued to improve to the point where it now drills 3,100 foot wells in a single day. Well cost savings of approximately 30% over conventional rotary well drilling have been documented. Improved well performance due to less formation damage as a result of minimizing formation exposure to drilling fluid through fast drilling and drilling operations is another important aspect.

**Figure 2 – Advanced Drilling Technologies (ADT) Coiled Tubing Drilling Rig**

### Efficient Rig Mobilization

The rig moves with 4 trailer loads mitigating mobilization and transportation cost while meeting U.S. Department of Transportation limitations for highway transport. These features allow for smaller access roads and well locations reducing well costs. The rig contains all the equipment needed for drilling operations including a zero discharge mud system (discussed later), has pipe handling capacity for casing up to7 5/8" and can support a rotary and top drive.

### Small Environmental Footprint

The small size of the rig provides several environmental advantages over a conventional rig. As a result of its efficient design and size the following environmental advantages are realized:

- A small drilling pad (1/10$^{th}$ acre) or no pad under some conditions can be utilized. Smaller access roads are required.
- No mud pit is needed; mud tanks contain the required drilling fluids and are moved with the rig from one location to the next. The only pit required is a small (3'x 6'x 6') pit for drill cuttings. If needed, cuttings are easily hauled off location allowing no pit drilling as needed.
- Smaller equipment yields less air emissions and low noise engines minimize disturbances to the surrounding environment.
- The microhole approach (4 ¾" holes) requires less drilling mud and fluids to be treated and yields fewer drill cuttings.
- The utilization of coiled tubing mitigates the risk of spills due to no drill pipe connections.

### Rapid Drilling

Very high rates of penetration have been achieved by experimenting with bit-downhole motor combinations and by fully utilizing the advantages of coiled tubing drilling. Drilling rates as high as 500 feet/hour have been realized with the average rate of penetration per well in the 400 feet/hour range. This rate of drilling and other rig efficiencies allowed the drilling of a 2850 foot well in 19 hours including all rig moving time, logging, casing setting and cementing (Figure 3)

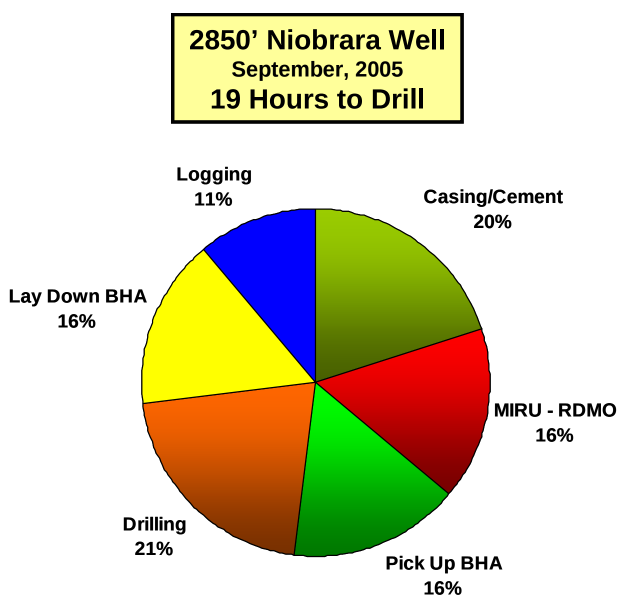


**Figure 3 – Allocation of Drilling Time for 2,850 foot deep Niobrara Well**

**Good Hole Quality and Cement**

The benefits of fast drilling by the ADT rig is augmented by excellent hole quality. All the wells drilled have resulted in a gauge hole with very little hole deviation (1 to 2 degrees - well within State requirements) despite the high penetration rates. Good cement job quality and well bonded cement also derive from the gauge hole quality. As mentioned previously, the Niobrara is an under pressured reservoir and as such is susceptible to formation damage due to fluid loss from drilling operations. Both the rapid penetration rate through the pay zone and the lack of any pressure surges caused by conventional drilling pipe connections help to mitigate fluid loss and therefore formation damage. This is an important factor given the marginal nature of the resource.

**Rig Capable of Running Casing, Handling Bottomhole Assemblies and Logging Tools -** No auxiliary equipment is required to run casing, log wells or for handling drill collars and bottom hole drilling assemblies. With its derrick, traveling block and rotary table components, all required drilling processes can be performed without additional equipment. While not currently equipped with a top drive, the rig can accommodate one if needed. Drilling with coiled tubing eliminates drill pipe connection time and fewer crew members are required to operate the rig.

**Zero Discharge if Required**

The rig has the capability to drill a well with zero discharge of any fluid or other materials if required. The procedure is as follows:

- Rig up on a sealed/booted tarp to contain any overflow or accidental spill.
- No earthen pits are prepared; all cuttings and drilling fluid are confined to tanks with which the rig is equipped.
- A hole is augured for conductor pipe and a boot is placed around the conductor pipe.

Using this process, the ground is protected from any inadvertent spills and all fluids and cuttings are removed from the location. While obviously an added expense, this procedure may be required for drilling in sensitive environmental areas. The small rig size and efficiency of drilling coupled with the zero discharge capability enables drilling in sensitive areas.

**Improved Safety**

Safety is always of utmost importance and the conventional drilling rig environment is one where extra caution and safety training is necessary due to the handling of drill pipe and other equipment. The ADT coiled tubing rig significantly reduces drill pipe handling and has less equipment to mobilize from well to well. All of this creates a much safer operating environment which is important during any time of drilling but especially so during today’s high rig count when experienced roughnecks are difficult to find.

**Barriers to Microhole Coiled Tubing Drilling**

Barriers exist to full utilization of this type of approach to the drilling and completion of marginal resources. Operators have identified the following as concerns that must be addressed for microhole to reach its full potential:

- Production engineers have long-term concerns about the ability to rework wells.
- Handling of significant fluids is an issue in small boreholes.
- There is limited space for downhole mechanical equipment.
- A general lack of experience and familiarity with microhole and coiled tubing drilling of this type was identified as a barrier to usage.
- There is a depth limitation given current coil metallurgy and coiled tubing procedures.
- Coiled tubing is limited in its ability to overcome problems in difficult drilling environments. One example is where fluid loss and severe pipe sticking is encountered. Coiled tubing has limited tensile strength for freeing stuck pipe.

### Technology Trends

Operators pursuing marginal resources are doing so in a new era. Driven by a growing economy, U.S. energy demand is expected to reach record levels in the near future. The higher quality resources have been exploited, increasing the challenge for future developments.

The rate of new technology improvement is beginning to be offset by the increasing challenges created by lower quality reservoir rock and increasing costs from environmental issues.

A concerted technology effort to both better understand marginal oil and gas resources and develop solid engineering approaches is necessary for significant production increases from these widely dispersed resources.

### Historical Technology Development

Marginal oil and gas technology development has evolved significantly over the last forty years. The trend has moved from one of high horsepower approaches to one of precision in all aspects of development. During the 1960's nuclear detonations were being tested with the goal of fracturing or stimulating a large volume of low permeability rock allowing for the recovery of a significant volume of gas from a single wellbore. This technical approach failed for many reasons including the fusing of rock as opposed to fracturing of rock.

During the 1970's and 1980's the approach to marginal oil and gas formations evolved to massive hydraulic fracture treatments. Here the goal was to create very long hydraulic fractures reaching hundreds of feet into the pay zone allowing for the production of large volumes. As research on the topic of hydraulic fracturing progressed, it was determined that extended length fractures were difficult, if not impossible, to create. The lack of formations to serve as fracture barriers to contain the upward growth and the complexity of multiple fractures limited the desired fracture length.

Today the evolution of lateral and horizontal drilling technology is beginning to allow the development of unconventional resources through the placement of smaller (microhole) wellbores into exactly the area and location required for optimum production. Hydraulic fracturing remains an important and necessary well stimulation procedure, but is being done in a highly optimized manner, integrated with unique well completion procedures. Figure 4 illustrates the evolution of these technologies over the past forty years.

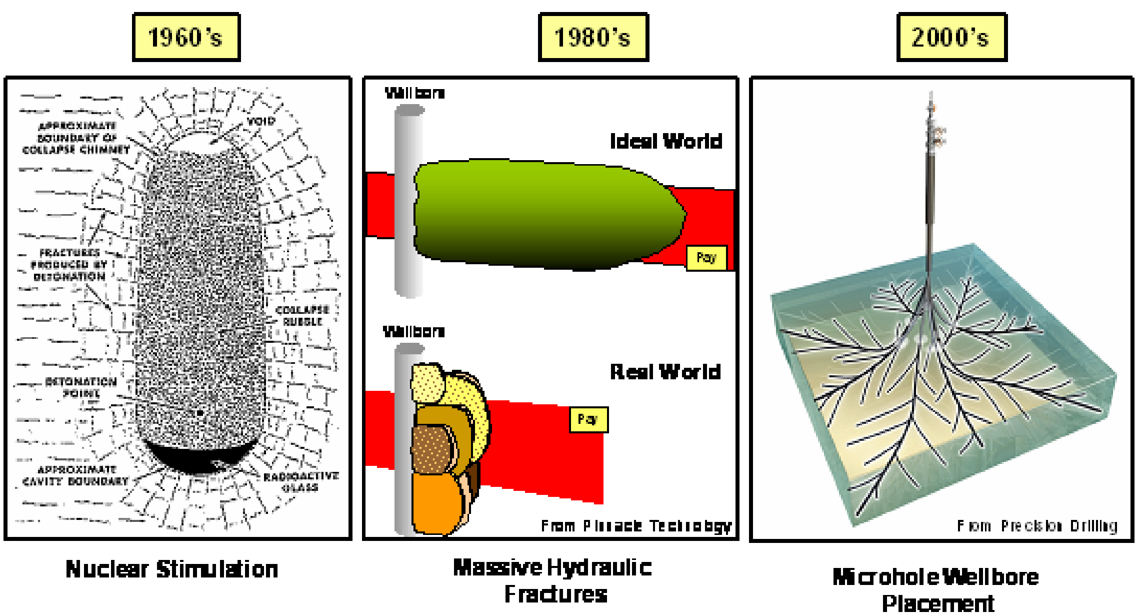


**Figure 4 – Evolution of Drilling Technology over Time**

The trend overall has been from large to small. Hydraulic fracture jobs pumped today are significantly smaller in size, but more effective than those in the 1970s. Microhole technology is being developed by the Department of Energy that will enable efficient placement of wellbores while minimizing the surface and other environmental impact. The evolution of “fishbone” well drilling patterns and the ability to identify, drill, and produce very thin pay zones all add to the “lighter and smaller” and more efficient approach.

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4. Perry, K.F., “Technology Key in Unconventional Gas,” American Oil and Gas Reporter, V48(5): 73-77 (May 2005)

## Press Release

Scheibel Halaska

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### MICROHOLE TECHNOLOGY SUCCESSFUL IN SHALLOW, LOW-MARGIN FIELDS

#### Gas Technology Institute research shows profit possible

**Des Plaines, Ill. — September 23, 2005** — Gas Technology Institute (GTI) of Des Plaines, Ill., with the support of NETL, the U.S. Department of Energy's National Energy Technology Laboratory, announces the successful field-testing of a coiled tubing drilling rig in shallow, low-margin natural gas fields in Kansas and Colorado.

The field tests demonstrate the efficiency of microhole technology, enabling a crew to move in, rig up, drill, rig down and move out within a day, with minimal environmental impact. To date tests have concentrated on Niobrara Chalk reservoirs drilling up to 4.75 inch open holes from 1,000 to 3,000 feet in depth. The wells are being drilled by Rosewood Resources, Dallas, Texas.

"In the 1980s the price of natural gas and crude oil did not make these fields viable," said Kent Perry, executive director of exploration and production research at GTI. "Today, minimal environmental footprint and drill time plus low cost makes microhole technology a viable option in the recovery of petroleum and natural gas from marginal natural gas and oil fields. It's important to note that these gas reserves can be accessed using microhole technology," The United States Geological Survey (USGS) has estimated the potential recovery from the Niobrara Chalk reservoirs to range from 340 billion cubic feet (BCF) to 2,100 BCF, with a mean recovery of 984 BCF. By comparison, the U.S. consumes approximately 25,000 BCF per year.

Microhole technology is not limited to natural gas recovery. With a recent Rand report that the United States is sitting on greater oil shale reserves than the Saudis, and in the wake of recent hurricane impact on off-shore oil rigs and on-shore refineries, this technology could help increase U.S. energy independence, as well as margins for drilling contractors.

Major features of the coiled tubing rig owned and operated by Advanced Drilling Technologies, Yuma, Colorado include:

Efficient Rig Mobilization (4-6 staff members)

- Small environmental footprint
- Rapid drilling
- Good hole quality and cement
- Rig capable of drilling, running casing, tool handling and logging
- Low noise, emissions
- Mud recycle, minimum cuttings and zero discharge if required
- Improved safety

# Press Release

# Microhole Technology Holds Potential to Increase Domestic Natural Gas and Oil Production

*New drilling approach lowers cost of recovery and lessens environmental impact*

**Des Plaines, Ill.** — November 7th, 2005 — Gas Technology Institute (GTI) with the support of the U.S. Department of Energy's National Energy Technology Laboratory, today announced the successful field-testing of a drilling technology that could improve U.S. energy independence.

Microhole technology uses less cumbersome drilling equipment that enables smaller crews to rig up, drill and tear down a drilling rig for exploration, dramatically cutting the costs and risks of drilling wells for gas and oil producers. The smaller drilling operation also reduces drilling waste and minimizes environmental impact, which has been a major obstacle to expanded exploration in the United States, especially in environmentally sensitive areas such as the Arctic National Wildlife Refuge.

GTI and partners Rosewood Resources, Inc. and Advanced Drilling Technologies are currently using microhole technology to successfully drill wells in the Niobrara Chalk Reservoirs in Kansas and Colorado. The U.S. Geological Survey has estimated the potential natural gas recovery from these reservoirs at 340 billion cubic feet (BCF) to 2,100 BCF, with a mean recovery of 984 BCF. The United States consumes approximately 25,000 BCF per year.

"Enough domestic natural gas and petroleum resources exist to help stabilize or lower energy prices in this country, but producers lack the technology to profitably recover most of these difficult-to-reach reserves," said GTI's Kent Perry, Director of Exploration and Production research. "The development of microhole drilling technology helps to create more economical means of petroleum and natural gas exploration in areas once passed over by producers."

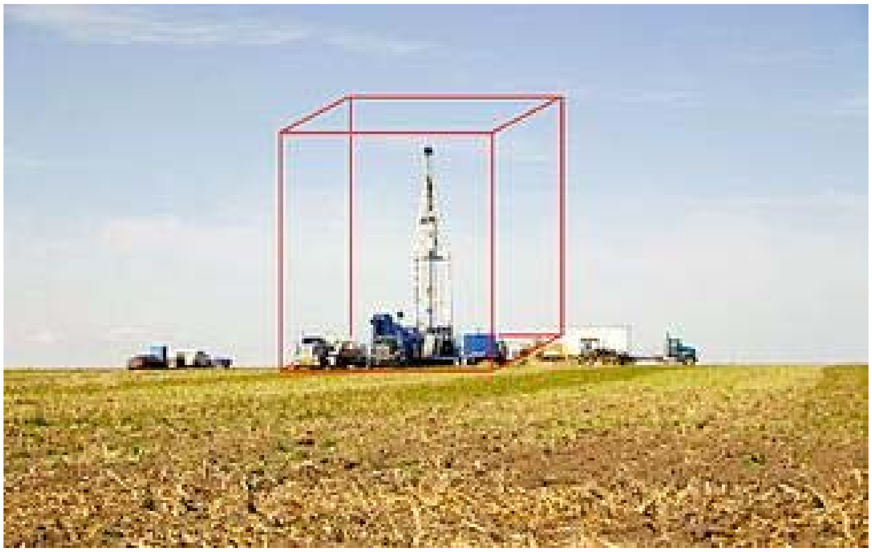
"The benefits in cost savings to the natural gas industry alone could be $8.4 billion during a 15-year period," said Rhonda Lindsey Jacobs, Project Manager, National Energy Technology Laboratory. "The volume of drilling waste could be reduced by 103 million barrels or to one-fifth the amount of waste volumes generated while drilling conventional wells. These targets are worth the government's investment."

The Potential Gas Agency estimates the U.S. natural gas resource at 1,119 trillion cubic feet (TCF) of technically recoverable natural gas, enough to fuel the entire country for approximately 40 years at current consumption rates. New technology such as microhole drilling will enable the conversion of "technically recoverable" resource into "economically recoverable" natural gas.

GTI is the leading research, development, and training organization serving the natural gas industry and energy markets. For more than 60 years, GTI has been meeting the nation's energy and environmental challenges by developing technology-based solutions for consumers, industry and government. Website: www.gastechnology.org

# Drilling Market Focus: Coiled-tubing use growing faster than drilling industry

## *Oil and Gas Journal,* November 28, 2005 – Excerpt Only



*This coiled tubing drilling rig was recently designed by Advanced Drilling Technologies LLC and is shown drilling in Kansas. (Fig. 2; photo from Kent Perry, Gas Technology Institute).*

The DOE is sponsoring field tests of a new zero-discharge CTD rig developed by Advanced Drilling Technologies LLC (Fig. 2). The CTD rig handles 1-in. to 2⅝-in. coiled tubing as well as 7⅝-in. R3 casing and has a 5,000-ft depth capability with 1,000 ft lateral. The trailer-mounted rig can be moved in only four loads and has a zero-discharge capacity mud system.

Art's Tom Gipson told OGJ that they are using the rig to drill in the Niobrara gas area: 17 wells in 2004, as well as 27 wells in western Kansas and 113 so far in northeastern Colorado in 2005.