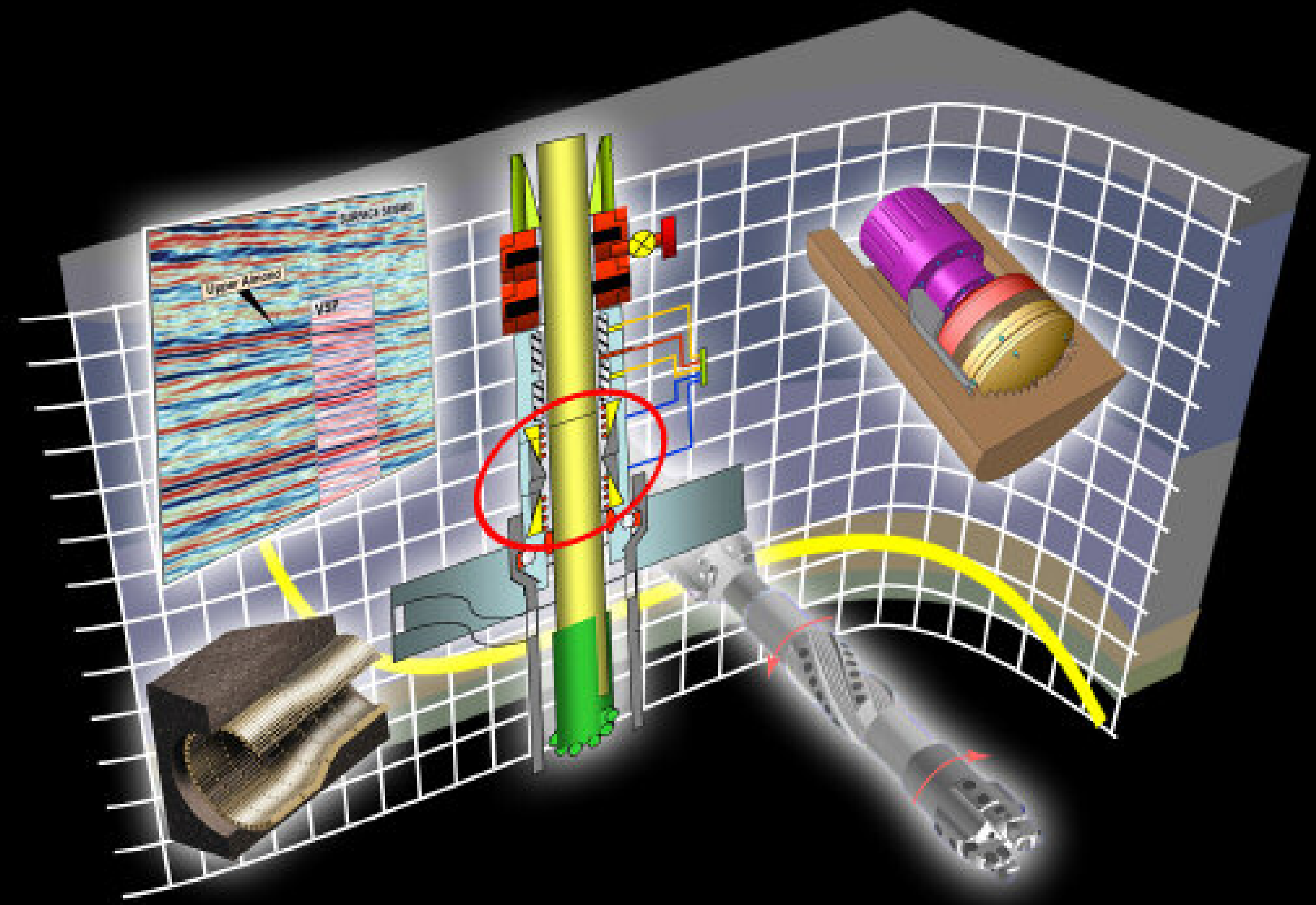
U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory

# Microhole Technology



## a systems approach
**to mature resource development**

# Microhole Technology

## Background

An estimated 407 billion barrels of onshore discovered oil in the U.S. is non-recoverable with current drilling and production technologies. Of that total, 218 billion barrels can be found at the relatively shallow depths of 5,000 feet or less. Even at today's high oil prices, industry-sponsored research remains on the decline, and operators tend to use familiar technologies rather than risk failure with advanced technology. To bridge this technology gap, DOE partners with industry to develop and demonstrate new technologies to access domestic petroleum resources.

The Microhole Technology (MHT) Program is developing a promising suite of technologies that enable drilling of wells with casings less than 4½-inches in diameter using coiled tubing drill rigs that are relatively small and easily mobilized. These technologies have the potential to reduce the cost of drilling shallow- and moderate-depth holes for exploration, field development, and long-term subsurface monitoring.

## Goal

The goal of DOE's MHT Program is to develop cost-effective technologies that enable:

- Development of shallow (<5,000 feet), currently uneconomic oil and gas resources.
- Acquisition of high-resolution, real-time reservoir imaging without interrupting production.
- Reduced environmental impact via lower volumes of drilling fluid, smaller operational footprint and pad/extended-reach drilling.

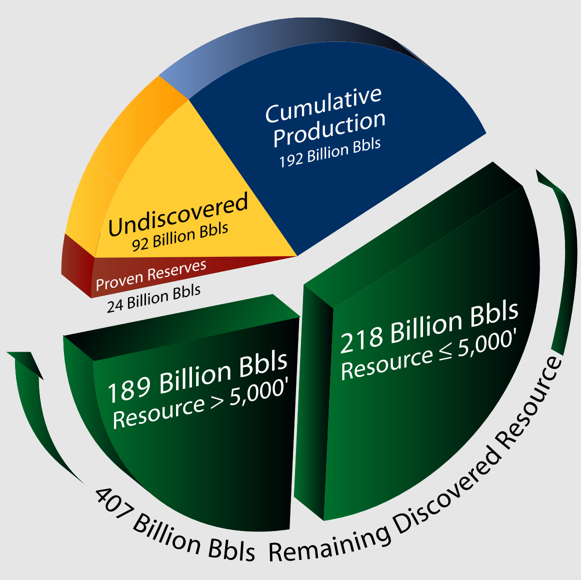
To accomplish these goals the near-term MHT program focuses on two areas of technology development:

- Field demonstrations where existing coiled tubing rigs are showing that economic resource recovery can result from wells with less than 4½-inch casing.
- Development of tools to drill, evaluate, complete, and produce from lateral microholes drilled out of 4½-inch casing.

## A Systems Approach

The key to developing resources in mature complex reservoirs is to recognize that a combination of interrelated technology systems working together toward this common objective will be required. The MHT program employs a systems approach in that it considers the larger picture and takes into account how factors such as technology, research, risk, and the business environment contribute to the overall success or failure of resource development. The systems solutions to resource development must address the following **"resource development drivers"**:

- Reduced reservoir access cost (drilling, including mobilization) to allow more holes to be drilled to penetrate reservoir seals.
- Cost-effective high-resolution imaging to locate bypassed oil and reservoir seals, and allow better management of sweep efficiency in enhanced oil recovery processes.
- Increased drilling efficiency (expressed in more completed wells per week) that will require high penetration rate drilling assemblies.
- Smaller drilling footprints to minimize disruption of landowner activities, especially considering the larger number of wells required for access.




Domestic oil production, proven reserves, and discovered and undiscovered resource.

The systems approach used to achieve the desired near-term results is best depicted in the adjacent MHT Program System diagram shown below. Technologies selected for the program were those that best satisfy the resource development drivers.

Because many of these technologies are recognized by operators or business units within major integrated service companies as having short-term application, they were readily adopted for market development (shown in red). The Advanced Drilling Technologies (ADT ) hybrid coiled tubing drilling rig (shown in green) was used commercially immediately after completion, underscoring the need for the technology. This quickly established commerciality is expected to hasten market penetration for other technologies being developed in the program that support expanded use of ADT's hybrid CT rig. The use of these technologies in combination with leading-edge, high-resolution seismic imaging technologies is expected to be very effective in furthering development of America's mature oilfields.

## Applications

Near-term applications of the microhole technologies being developed include drilling:

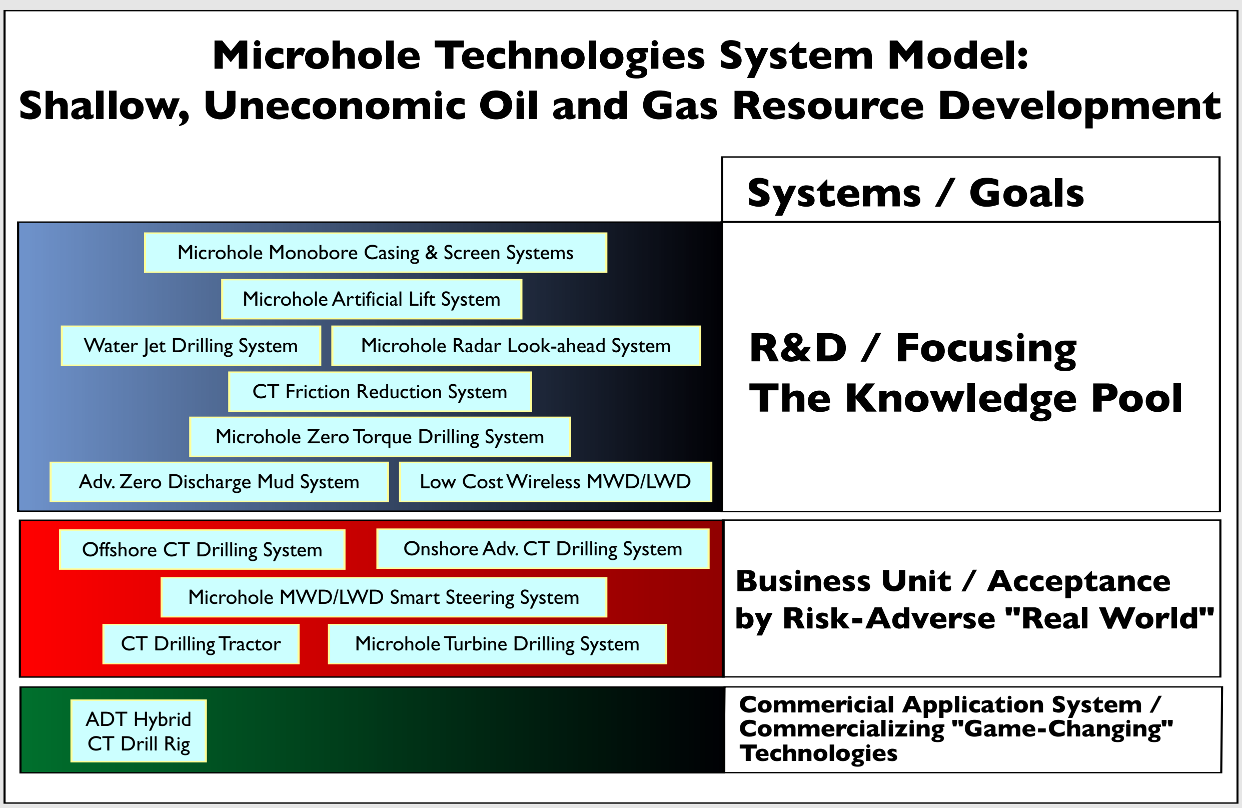
- Shallow development wells with one third the surface location and one third the number of equipment loads when compared with a rotary drilling rig.
- Shallow re-entry wells that allow drilling of multilaterals for economic access into compartmentalized reservoirs.
- Drilling deep exploration tails in existing wells that can cheaply extend the wellbore to evaluate and produce new zones.

Longer-term MHT applications include drilling dedicated wells for continuous reservoir monitoring to enable:

- High-resolution vertical seismic profiling, 4-D seismic imaging of reservoir fluid movement and bypassed oil.
- Low-impact, high-resolution imaging of targets beneath environmentally sensitive areas to allow development via pad/extended-reach drilling.
- Use of passive seismic imaging to take advantage of "free" seismic sources provided by naturally occurring seismic events to provide further resolution for improved reservoir modeling.

## Benefits

The MHT Program's potential benefits to the Nation include lower drilling costs from reduced materials, labor, and support equipment; reduced environmental impact from lower volumes of drilling waste, smaller footprints, and lighter equipment; lower exploration risk from low-cost exploration wells; and increased quality and quantity of high-resolution, dynamic, and continuous reservoir data.



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## *Microhole Smart Steering and Logging-While-Drilling System*

## DE-PS26-03NT15473

### Project Goal

The objectives of this project are to design and build 1) a smart drillbit steering motor integrated with a high-performance downhole motor and 2) a logging-while-drilling (LWD) formation resistivity evaluation sensor that provides real-time information about the rock being drilled. The tools will be designed for deployment in ultra-small diameter wellbores.

### Performer

*Baker Hughes INTEQ*
*Houston, TX*

### Project Results

The project is expected to result in a commercially available 2⅜-inch rib steering motor (RSM) integrated with a high-performance downhole motor and an LWD multiple propagation resistivity (MPR) tool for 3½-inch diameter wellbores. The RSM will enable a long horizontal section to be drilled with improved hole quality and well-path accuracy. The MPR tool will provide real-time information about the rock being drilled so that the well can remain in the optimum reservoir zone for detecting oil.

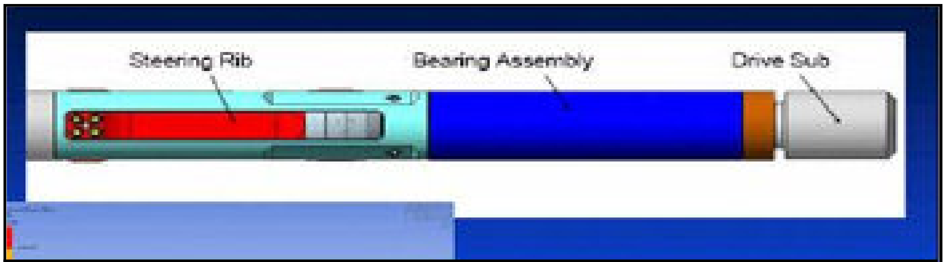
### Benefits

The advanced drilling, steering, and logging bottomhole assembly (BHA) is expected to enable faster drilling, increased well-path accuracy, improved hole quality, and longer horizontal sections. The improvements in drilling and LWD will lead to increased production while decreasing the number of wells needed.

Lower costs and reduced environmental risks of drilling smaller holes with smaller-footprint rigs and minimal drilling fluid volumes make the technology ideal for producing remaining oil in shallow, mature U.S. reservoirs. Step-out wells, lateral deep perforations, and well deepening all can improve recovery of domestic resources.

### Background

State-of-the-art BHAs for coiled tubing drilling of (CTD) 3½-inch diameter (microhole) horizontal wells tend to drill holes that are not smooth and straight. The lack of straightness leads to higher friction when sliding the coil, which limits the maximum horizontal extension that can be drilled with coiled tubing equipment.




Rib steering motor for 2⅜-inch coiled tubing.

Also absent in the currently available CTD BHAs for microholes is a suitable LWD tool. In order to keep the well within the target zone and above the oil-water contact, resistivity measurements taken during the drilling process are needed to provide instantaneous information about the distance to the water boundary. This allows the well to be drilled for maximum recovery and minimum risk of water invasion. Furthermore, such formation evaluation sensors will be able to detect trapped hydrocarbons along the well path.

### Project Summary

A 2⅜-inch diameter RSM is being designed to serve a 3½-inch or smaller diameter hole. Modules are being designed so they fit seamlessly in the commercially available modular 2⅜-inch CoilTrak™, a CTD assembly. Hydraulically powered moveable ribs on the steering motor generate steering forces in every direction, allowing both smooth curves and straight borehole sections to be drilled.

An MPR tool is being developed for microholes that will allow true real-time geosteering with instantaneous steering actions based on resistivity (and gamma) measurements.

Project accomplishments include the development and evaluation of a number of RSM design concepts. One design has been selected for further detailed layout. The final designs of the following functional sub-assemblies have been made: the hydraulic system, motor section (rotor, stator, flex shaft), steering unit (rib body and steering ribs activated by a hydraulic piston), and bearing section (drive shaft and specialized axial and radial bearings). The design of all these sub-assemblies and the complete RSM tool has been finalized, and all parts have been modeled in a 3-D CAD program.

The final design for the MPR tool has been defined. The communication system to transfer resistivity information to the surface consists of a downhole transmitter and a surface receiver. Tests of the system verify that the required 400 kHz and 2 MHz signals can be used successfully in the transmitter-receiver array.

### Current Status (August 2005)

The designs of the RSM and the MPR device have been selected based on calculations, simulations, and manufacturing considerations. A detailed design review of the RSM has been conducted, and the decision has been made to move to manufacturing a prototype tool. The review of the MPR device is nearly complete.

**Project Start / End:** 9-13-04 / 3-31-06
**DOE / Performer Cost:** $738,667 / $183,417
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# *Microhole Wireless Steering-While-Drilling System*

## DE-FC26-05NT15488

### Project Goal

The project goal is to provide a smart steering tool for a modular and economic coiled tubing drilling (CTD) system that allows domestic operators to produce more oil from existing reservoirs. This will be achieved by providing accurate and precise real-time geosteering even under conditions where the rig surface gear and equipment need to be minimized for cost-effectiveness. The following objectives support this goal:

- Develop a 2⅜-inch diameter bi-directional power and communications module (BCPM) as a part of the modular CTD bottomhole assembly (BHA).
- Develop a fit-for-purpose surface control system that communicates with the BHA.

### Performer

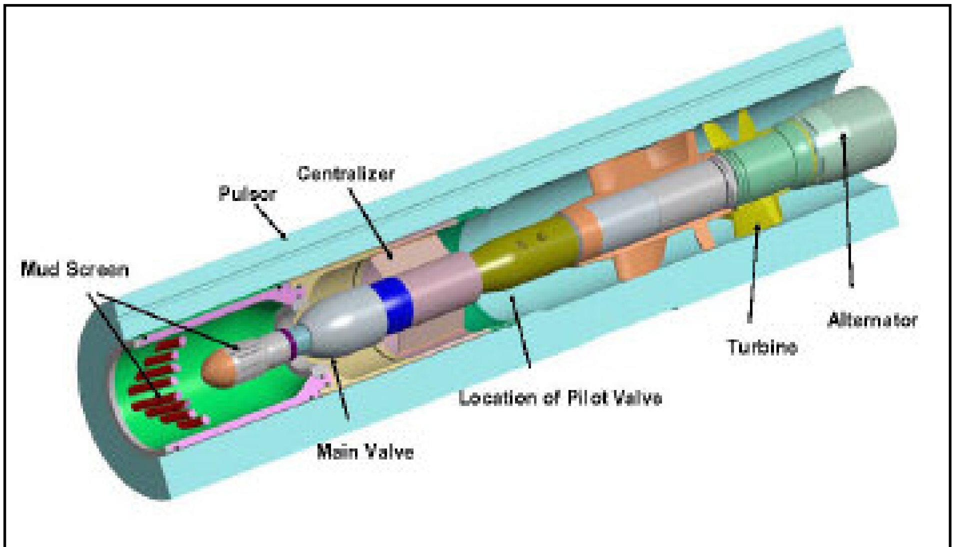
*Baker Hughes INTEQ*
*Houston, TX*

### Project Results

This new project will build on Baker Hughes INTEQ experience in designing, developing, manufacturing, and operating measurement-while-drilling (MWD), logging-while-drilling, borehole telemetry, and various steering devices, including CTD assemblies. The project will develop and test a BCPM that complements the existing modular CoilTrak™ drilling BHA. The system will include a fit-for-purpose surface control system. The availability of the new modules will reduce operational costs.

### Benefits

The new BCPM for the 2⅜-inch steerable CTD BHA will considerably reduce the capital expenditure needed to drill a “smart”, yet relatively shallow, land well. The BCPM eliminates the need for a coil with an electric wire connection, thereby enabling the use of a smart drilling BHA in locations where an electric line is not affordable. The elimination of the electrically supplied coil saves the cost of one complete reel, which could reach about $100,000. In addition, with land rig day rates averaging $30,000 or more, considerable operational savings may be realized if a change in reels (between wired and non-wired) is avoided for special operations, such as cementing or window cutting.




Schematic of the bi-directional power and communications module MWD component. The surface control system communicates via mudpulse signals. The turbine/alternator provides power to other MWD components in the BHA.

### Background

For drilling 3½-inch diameter development wells, CTD technology offers many benefits over rotary drilling. However, insufficient steering accuracy and low borehole quality are often experienced during CTD drilling. Electric wire is currently needed with coiled tubing strings to provide power to the steering tool and for downhole-to-surface communication; however, there are cases where a wired coil requires too high an effort or expenditure.

This project builds on an existing wireless-BCPM for a 6¾-inch tool that integrates an alternator-based electric power supply, an actuator to send information to the surface, and the capability to receive digital signals downhole.

### Project Summary

Project tasks break down into two phases: the system design and the manufacturing and testing phase. The design phase consists of system concept evaluation, draft and detailed design of downhole components, and manufacturing decision.

The manufacturing and testing phase commences after a decision to proceed to manufacturing: This phase consists of manufacture of two prototype 2⅜-inch BCPMs and a surface control system and field testing of the prototypes and evaluation of their performance.

### Current Status (August 2005)

The concept for the wireless steering-while-drilling system has been approved by Baker Hughes management. The next steps are to design the BCPM and control system and then decide whether to continue to the manufacturing phase.

**Project Start / End:** 2-1-05 / 9-31-06
**DOE / Performer Cost:** $760,000 / $253,334
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## *Advanced Mud System for Microhole Coiled Tubing Drilling*

### DE-PS26-03NT15476

### Project Goal

The overall objective of the project is to develop a mud system that is compatible with a coiled tubing drilling (CTD) system to drill microholes for vertical, horizontal, and multilateral drilling and completion applications. The system must be able to mix the required fluids, circulate that mixture downhole, clean and store the returned fluids, and perform these functions in an underbalanced condition with zero discharge and acceptable levels of environmental impact. A secondary objective is to design and test drilling with an abrasive slurry jet (ASJ) drilling system.

### Performer

*Bandera Petroleum Exploration LLC*
*Tulsa, OK*

### Project Results

The basic designs and concepts for the Advanced Mud System have been developed. The results include setting specifications for components of the system, including pumps to convey the drilling fluids downhole, a subsystem to process the returned well fluids, and a method to drill a hole in rock with an ASJ.

### Benefits

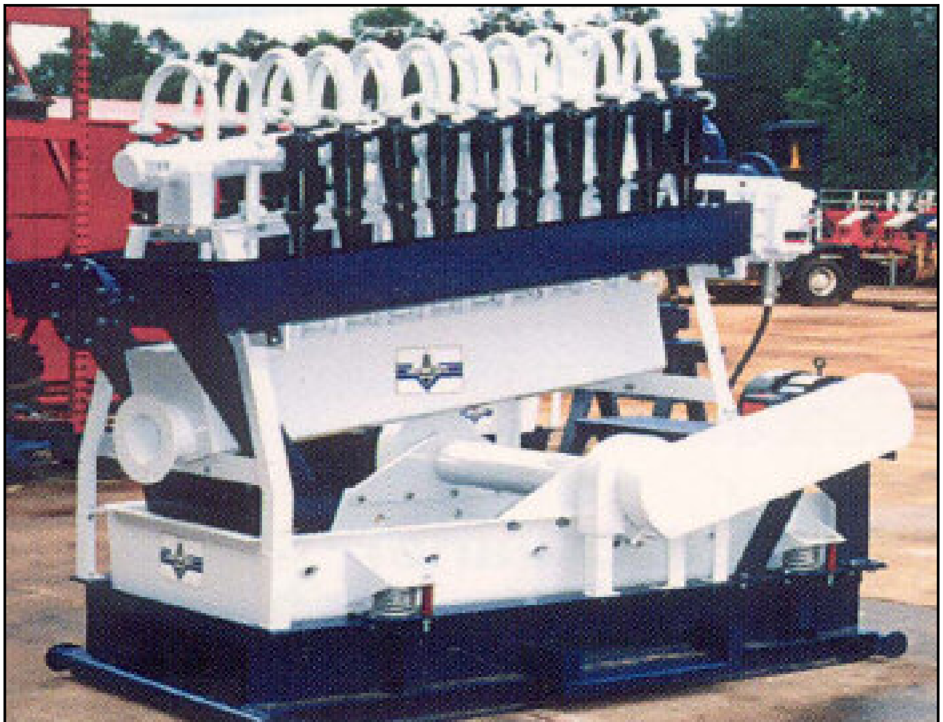
Advances in technology that create more efficient development of hydrocarbon resources help the U.S. to become more energy self-sufficient, create activity and jobs in oil and gas basins, and generate royalty revenue.

More-efficient hydrocarbon development through microhole drilling can be measured in lower finding and production costs and in lower environmental impact when compared with existing conventional technology.

### Background

Microhole drilling offers numerous advantages to develop reserves that are currently bypassed. However, it also presents a new set of equipment and operational hurdles to be solved before all or parts of a microhole CTD system can be commercialized.

One isolated piece of the puzzle is the mud system, which will be a departure from pumps and mud processing equipment currently used on conventional rigs. Proper sizing for a coiled tubing application is a key element for the mud system. The ability to drill holes in rock with abrasive-laden fluids has been of interest to the industry since the 1950s, but there have been equipment or technical limits that prevented its application. The concepts of microhole and coiled tubing drilling make ASJ a promising adjunct, and the logical place to develop the ASJ is within the advanced mud system being developed in this project.



A small-capacity mud processing system for microhole drilling.

### Project Summary

The project accomplishments include:

- Validated drilling synergies for microhole CTD. The requisite hydraulics, mud types, pump types, and mud processing equipment applicable to microhole CTD was confirmed through computer modeling and investigation of industry standards.

- Investigated ASJ drilling. After a literature review of previous work and consideration of microhole CTD parameters, a laboratory demonstration was able to cut a hole in rock larger than the nozzle diameter while continuously delivering abrasives to the downhole tools.

- Set pump specifications and identified available pumps. After defining true operating parameters for mud pumps in microhole CTD, specific manufacturer and models were identified for viable applications.

- Set mud processing parameters and identified mud processing equipment. Mud processing equipment was identified based on drilling fluids and flow rates applicable to microhole CTD and the resulting desired fluid properties.

### Current Status (August 2005)

Concept development and basic design of the CTD mud system has been completed. The next phase will be to manufacture or purchase a prototype mud system and test it.

**Project Start / End:** 8-2-04 / 2-1-07
**DOE / Performer Cost:** $473,600 / $118,400
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*Advanced Monobore Concept CFEX Self-Expanding Tubular Technology*

## DE-FC26-05NT15483

### Project Goal

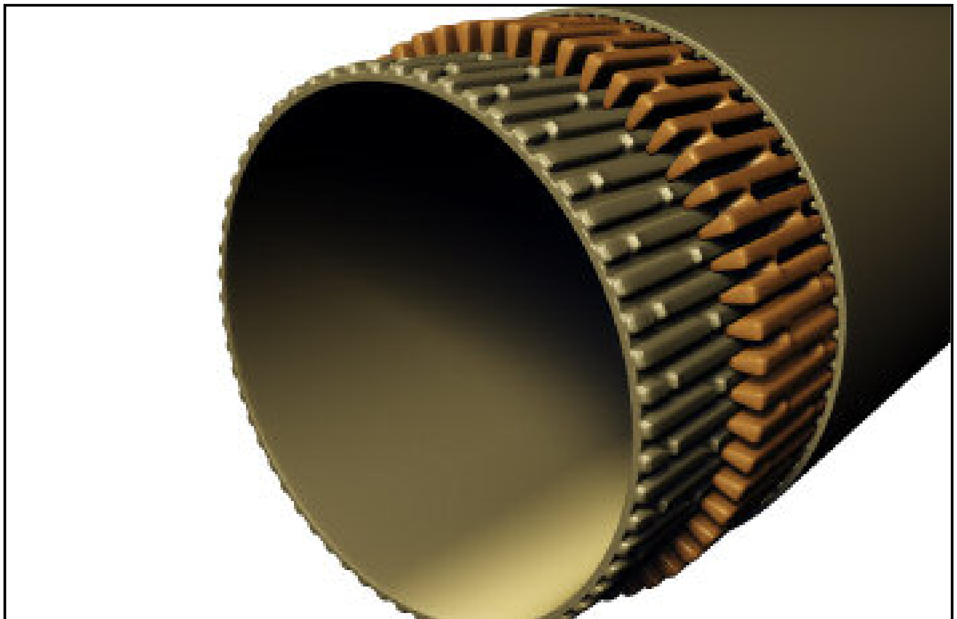
The goals are to prove technical, economic and manufacturing concepts for innovative, self-expanding casing technology for a monodiameter well and to conduct a field demonstration of the concept.

### Performers

*Confluent Filtration Systems*
*Houston, TX*

*AMET, Inc.*
*Rexburg, ID*

*Southwest Research Institute*
*San Antonio, TX*



Elastomer ridges in a self-expanding casing.

### Project Results

The project is expected to demonstrate a more efficient, mechanically robust, and economically feasible self-expanding well casing system for use in both microhole and conventional drilling.

### Benefits

The development of expandable casing for monobore wells promises to reduce drilling risks and improve economics throughout exploration and production. Self-expanding technology allows reduction of hole volume, increased inside diameter production tubing, shortened field schedules, and minimized drillsite footprint. The technology is well-suited for drilling and casing microholes with tight annular spaces.

### Background

Current expandable tubular technology relies on fluid pressure to plastically deform the tubular. A fundamental problem with deforming steel is that the process requires shrinkage along its other dimensions. Irregularities in tubular chemistry and wall-thickness—coupled with more-irregular borehole conditions, including excess bend severity, diameter restrictions, and non-concentricity—further reduce current tubular expansion reliability.

Current expandable tubular technology is not feasible for microhole coiled tubing drilling because the pressures required to expand the tubulars are too great.

This project is developing an expandable casing that consists of pre-stressed cells that eliminate shrinkage and don't require pressure for deployment.

### Project Summary

The expandable casing being developed in this project consists of volumetrically adjustable cells (honeycomb structures) that are compressed to reduce the outside diameter. The reduced size is held in place by temporary metallurgical bonds established between various interior "cell-spring" surfaces. Once inserted into the wellbore, those stabilizing bonds are removed by specific chemical or mechanical activity, and the casing recovers to near its original dimensions.

Tasks of the project include the following:

- Concept development, which includes the development of user definitions and performance measures, basic research of specifications, and detailed qualitative evaluation of prospective design concepts.
- Design optimization, which involves the use of computer analytical methods, design by analysis routines, finite-element analysis, and 3-D geometry export for computer-aided machining.
- Prototype construction, which will include construction of a variety of prototypes to be used in physical tests and field demonstrations.
- Physical testing, which entails conventional laboratory evaluation of mechanical performance against theoretical properties.
- Manufacturing study, which will include research, evaluation, and conceptual development of various methods of joining and forming materials
- Field demonstration, which calls for deployment of a prototype section in a test well.

### Current Status (August 2005)

Two optimal casing geometries have been devised that can be expanded by 200%. Interest in the new technology has been expressed by private investors and major oil companies with an eye towards rejuvenating maturing fields. The next step is to conduct a detailed analysis of the prototypes through testing.

**Project Start / End:** 2-2-05 / 8-31-07
**DOE / Performer Cost:** $975,644 / $270,600
**Contact Information:**
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*Confluent Filtration* – Jeffery Spray (jaspray@earthlink.net or 281-597-8784)

## *Self-Expanding Sandscreen Technology*

### DE-FC26-05NT15491

### Project Goal

The goals of this project are to prove technical concepts for an innovative self-expanding sand-control screen technology, determine manufacturing systems and economics, and successfully deploy a small section of the screen in a demonstration well.

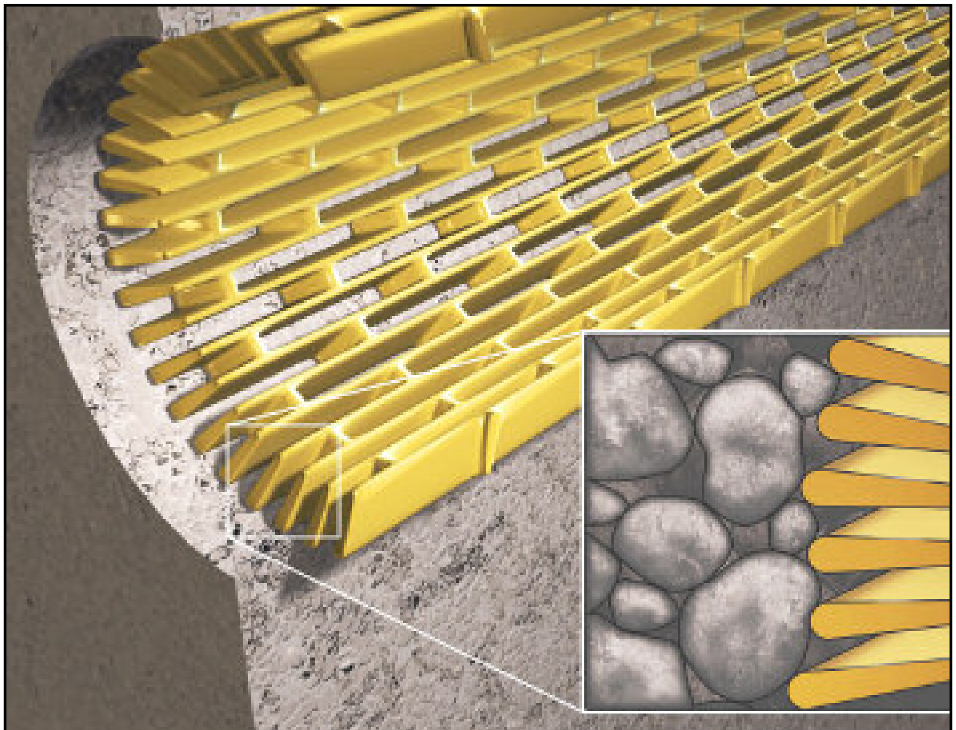
### Performers

*Confluent Filtration Systems*
*Houston, TX*

*AMET, Inc.*
*Rexburg, ID*

*Southwest Research Institute*
*San Antonio, TX*

*Stress Engineering Services*
*Houston, TX*



An artist's cutaway rendering of a self-expanding sandscreen.

### Project Results

The project is expected to result in the development of self-expanding screens that are capable of <150 micron particle retention, have improved hydraulic efficiencies that will allow increased production, and will work well in the tight annular clearances of microholes. The technology is expected to solve the problems of high flow-rate erosion and pressure loss inherent to microhole producing clearances.

### Benefits

Use of a high-flow, stand-alone sandscreen can result in faster well cleanup and reduced field time. Because the sandscreens are designed to be relatively plug-resistant, erosion-less and corrosion-less, fewer shutdowns and greater overall production should result from their use. The sandscreen is expected to weigh and cost one half that of conventional screens.

### Background

Small-diameter wellbores pose a unique set of completion and production problems. The fluid velocities inherent to microholes accelerate sand movement, which tends to plug, erode, and corrode sandscreens. The use of gravel packs in microhole operations is constrained by the limited annular volumes. Placing screen tubulars in microholes may create difficulties in allowing passage of other completion equipment, including pumps, sleeves, packers, geophysical tools, etc.

This project aims to develop a sandscreen technology that offers high flow rates and high hydraulic efficiencies, uses metal alloys resistant to erosion and corrosion, and is lighter and thinner-walled than conventional tubulars.

### Project Summary

The sandscreen technology being developed in this project is a highly supported, grid-type construction of close-tolerance structural panels that have been designed for high hydraulic efficiency. The grid elements are flush about the inside diameter, allowing smooth surfaces for downhole operations. The elements are optimally recessed on the outside diameter, creating a greater open area toward the formation. The tubular strength results from the large numbers of flexible cell bodies, which like wire rope, acquires strength from numbers of components acting collectively. The design of the tubular allows a lighter and thinner structure.

The project entails the following tasks:

- Design model development, which includes adaptation of industry specifications and modification according to self-expansion principles, optimization through computer analytical methods, finite element analysis, and 3-D geometry export for computer-aided machining.
- Prototype construction, which will include construction of a variety of prototypes to be used in corresponding physical tests and field demonstration efforts.
- Physical testing, which entails laboratory evaluation of mechanical performance against theoretical properties.
- Field demonstration, which calls for deployment of a prototype section in a test well.

### Current Status (August 2005)

Current activities are focused on modeling to meet or surpass industry specifications of high expansion ratio and particle retention range of 25µ – 250µ.

**Project Start / End:** 2-8-05 / 8-31-07
**DOE / Performer Cost:** $254,596 / $64,400
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*Confluent Filtration* – Jeffery Spray (jaspray@earthlink.net or 281-597-8784)

## *Friction Reduction for Microhole Coiled Tubing Drilling*

### DE-FC26-05NT15485

### Project Goal

The project goal is to create a robust, economical microhole coiled tubing drilling (CTD) friction reduction system that will enable the drilling of wellbores with 2,000 feet or more of horizontal displacement in a 3½-inch wellbore without the use of any other downhole coiled tubing friction mitigation device.

### Performer

*CTES*
*Conroe, TX*

### Project Results

The microhole CTD friction-reduction system to be developed under this project will utilize vibration energy applied at the surface to mitigate downhole friction when drilling long (>2,000 feet) horizontal or high-angle wellbores. The surface-applied vibration energy will be controlled such that the vibration energy naturally attenuates at some distance above the drillbit, eliminating any detrimental effects resulting from surface-induced bit vibration.

### Benefits

The primary benefits resulting from this project will include 1) drilling-cost reduction resulting from the use of less-expensive CTD for long, horizontal wellbores; and 2) the ability to develop additional hydrocarbon reserves in a more environmentally friendly manner due to the smaller footprint associated with a CTD rig.

### Background

A key barrier hindering increased utilization of CTD for inclined/horizontal wells is the cost of overcoming downhole friction when attempting to drill long (>2,000 feet) horizontal sections. When drilling these long laterals, the downhole friction forces reach such high levels that the drilling operation is stopped prematurely, or a costly downhole drilling tractor must be used to help pull the coiled tubing at the bottom of the well in order to continue drilling.

The current approach to reducing downhole friction involves the application of downhole vibrators or drilling tractors. Both of these technical approaches have significant limitations. Vibrating pipe to mitigate friction is a proven technology for conventional "jointed" drillpipe operations. However, CTD surface equipment is significantly different from that of a conventional drilling rig. This difference limits the ability to apply some of the existing types of vibration.

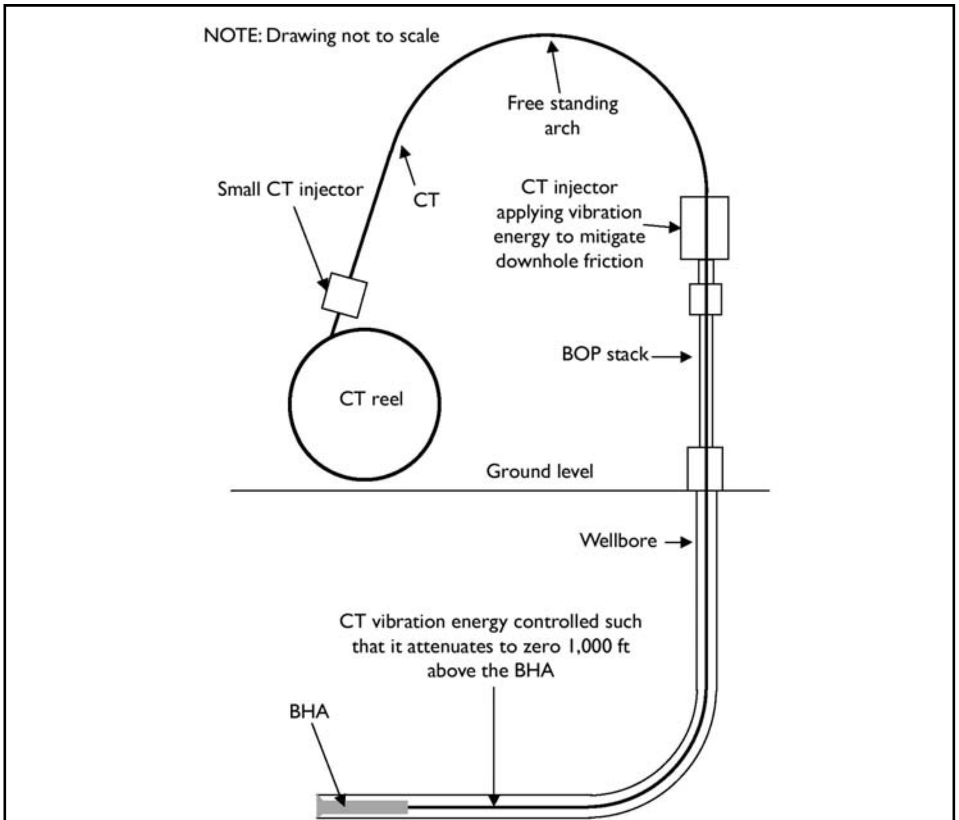
### Project Summary

The project consists of two 12-month phases, with a Go/No Go decision point at the conclusion of the initial phase. Phase 1 work contains five major tasks, including: development of a software model to predict downhole vibration attenuation versus depth; engineering and construction of a vibration test fixture; testing and validation of the vibration attenuation model in the vibration test fixture; and conceptual design and optimization of a full-scale friction-reduction system.

Phase 2 work also encompasses four tasks, including: finalize design of the friction-reduction surface equipment; fabricate surface equipment, component-test surface equipment, and field-test the complete friction-reduction system.

### Current Status (August 2005)

The numerical model for downhole vibration attenuation has been developed. The detailed design of the vibration test fixture is complete, and fabrication is underway. The next steps are to complete the vibration test fixture and initiate vibration testing for model validation.




Microhole coiled tubing drilling friction reduction system for horizontal wellbores.

**Project Start / End:** 4-1-05 / 3-31-07
**DOE / Performer Cost:** $756,570 / $189,140
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*CTES* – Edward Smalley (ed.smalley@ctes.com or 936-521-2222)

## *Development of a Through-Tubing (Microhole) Artificial Lift System*

### DE-PS26-03NT15472

### Project Goal

The project goal is to develop an economical method to lift water from natural gas wells in the more expensive operational areas such as the Gulf of Mexico.

### Performer

*Gas Production Specialists, LLC*
*Lafayette, LA*

### Project Results

A small (2⅛-inch outside diameter), through-tubing artificial-lift pump system that can remove water from oil and gas wells has been designed and is being manufactured. The technology is expected to improve gas recovery by removing bottomhole water from gas wells so that the reservoir energy has only to lift the gas column. This lift also could be used for oil wells under depletion drive. The technology allows operators to produce more oil and gas out of known reservoirs in areas that already have an existing infrastructure, as with many of the mature fields in the U.S.

### Benefits

The through-tubing artificial lift system has the potential to allow operators to reactivate wells that no longer can flow by natural reservoir pressure. By reactivating these wells, more production and thus more reserves recovery could be realized from currently idle assets. The technology focuses on extracting more oil and gas from known reservoirs in areas that already have an existing infrastructure.

Of the estimated 17,402 active wells in the Gulf of Mexico, over two thirds are currently shut-in. (OCS Report MMS 2003-050). Assuming that a very conservative 5% of this total are candidates for the through-tubing artificial lift technology, 870 wells potentially could benefit from the technology. Further assuming 1-2 billion cubic feet of gas per installation is being produced, a potential incremental reserves addition of ~1.3 trillion cubic feet (TCF) of gas is possible.

Another way to demonstrate the potential market of this technology is to look at the total reserves for the Gulf of Mexico. Proved reserves are estimated to be 167.3 TCF of gas. Assuming a conservative 1% incremental reserve increase resulting from the technology, an incremental reserve addition of ~1.7 TCF of gas is possible.

Slimhole electric submersible motor.

### Background

The Gulf of Mexico and mature onshore fields contain many gas wells rendered uneconomic because the depleted reservoir pressure cannot overcome the weight of fluid in the wellbore. In many cases these gas reservoirs have considerable remaining gas-in-place but lack cost-effective methods to produce them. The artificial lift system being developed in this project is expected to provide a low-cost way to dewater wells and increase gas production. Development of this technology will allow operators to extract more reserves out of depletion-drive reservoirs in the Gulf of Mexico and the continental U.S.

### Project Summary

This research and development project is aimed at developing a new through-tubing artificial lift pump system that is capable of removing small liquid volumes from gas wells. The advantage of this system is that it can be completely deployed and retrieved in a "rigless" fashion. In operating environments where costs are relatively high, such as offshore fields, this rigless deployment method can save the operating company hundreds of thousands of dollars.

This system is being made small enough to pass through the existing tubing string. The system pumps liquids up a small inner string and allows gas to flow in the newly formed annulus areas. The pump system consists of a small-diameter (2⅛-inch) electric submersible motor, gear reducer, thrust section, intake screen section, and a small-diameter liquid pump. Because it is a pumping system, all liquids can be pumped to the surface, allowing a gas well to be produced to its lowest abandonment pressure. Virtually no reservoir energy would be consumed moving liquids to the surface because the hydrostatic and friction pressure losses would be overcome by the pump.

### Current Status (May 2005)

The downhole electric submersible motor, gear reducer, intake screen section, and the pump have been designed and manufactured. The machining of the thrust section has been completed. After the thrust section is complete, additional machining will be necessary for the pump/screen connection as well as both connections of the thrust section. Upon completion of all machining, the components will be mated together for surface testing. Successful surface testing will be followed by downhole prototype testing. Business options are being evaluated to obtain partners to commercialize this technology.

**Project Start / End:** 6-21-04 / 9-30-06
**DOE / Performer Cost:** $80,000 / $130,000
**Contact Information:**
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*Gas Production Specialists* – Steven Bodden (sbodden@bellsouth.net or 337-839-0816)

# *Field Demonstration of Existing Microhole Coiled Tubing Rig*

## DE-PS26-04NT15482

### Project Goal

The project goal is to field-test a state-of-the-art microhole coiled tubing drilling (CTD) rig and to conduct technology-transfer efforts to generate interest in and gain acceptance of the technology. Utilization of this technology will enable development of marginal oil and gas wells while minimizing environmental impact.

### Performers

*Gas Technology Institute*
*Des Plaines, IL*

*Rosewood Resources*
*Dallas, TX*

### Project Results

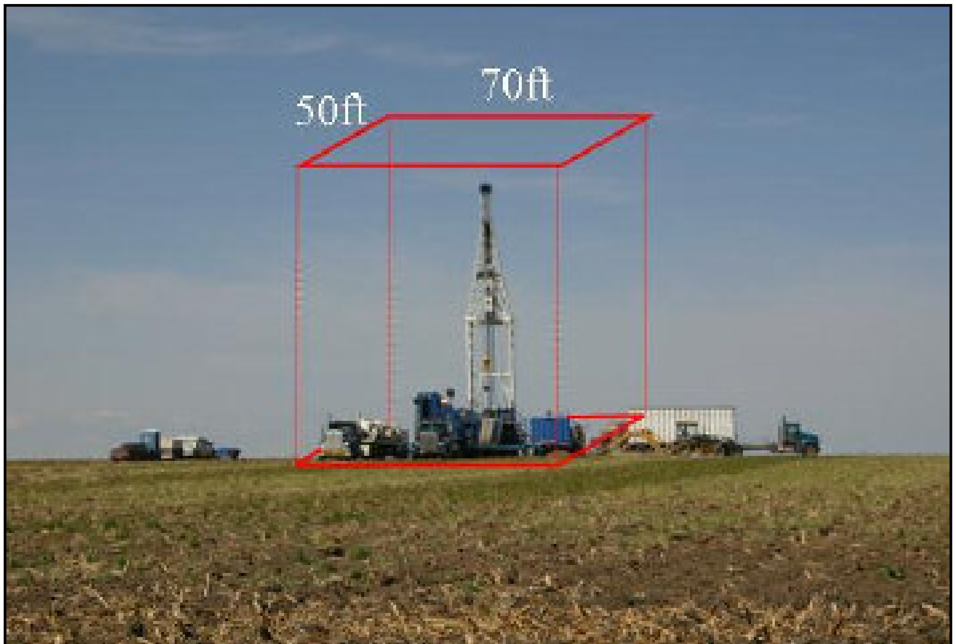
This project will demonstrate the advantages of microhole coiled tubing drilling and document the economic benefits when compared with conventional drilling. Dissemination of these results through publications and presentations will facilitate expanded use of this technique.

### Benefits

Based on Coiled Tubing Solutions' (CTS) drilling experience with coiled tubing rigs in Kansas, Montana, Texas, and Canada, microhole technology can cut the drilling cost of wells by up to 38%. The reduced cost translates to $55,000 cost savings per 1,200-foot well. The CTS rig design provides technical advances over existing drilling systems in seven areas: reduced drilling cost, low mobilization/demobilization times, improved pipe-handling, increased safety, measurement-while-drilling, reduced environmental impact, and increased wellbore transmissivity.

### Background

Currently, about 800 wells are drilled per year using coiled tubing in the U.S., with the potential for a much larger number if CTD becomes a proven tool. In addition, the cost savings and rig design with CTD are likely to facilitate additional production through the development of resources that are uneconomic at current drilling costs. The most significant economic impact will be the additional oil and gas resources that will be made available to U.S. consumers.



Field demonstration of a microhole coiled tubing rig showing the small footprint.

### Project Summary

In this project a next-generation microhole CTD rig is being field tested. The rig being used is CTS's MOXIE experimental rig that has been fabricated by CTS specifically for microhole CTD to depths of up to 5,000 feet.

Sites in Kansas and Colorado that have known gas resources at 1,200 to 3,500 feet in depth are being drilled and cased with the microhole CTD rig. The rig is being evaluated in six areas: mobilization and rigup time, drilling surface and production holes, running surface casing and cementing, logging and evaluation, running production casing and cementing, and rigging down and moving the equipment from the drillsite. Measurements are being made of time, equipment weight, penetration rates, rpm, torque, drag, pumping pressures, mud properties, solids control, and other measures of rig performance.

During the early field testing and monitoring of the microhole CT rig, the percentage of time for each operation was calculated. Operations considered included rigup time, 9%; pick-up of bottomhole assembly (BHA), 9%; drilling, 26%; laydown of the BHA, 9%; logging, 17%; and casing/cementing, 30%. The relatively low drilling time (26%) illustrates the advantage of using coiled tubing where the drillpipe connection is eliminated when compared with conventional drilling. The average rate of penetration for the initial eight wells drilled is 204 feet per hr.

### Current Status (July 2005)

Eight wells have been drilled and evaluated. The wells were drilled in Sherman County, KS. The data have been gathered and analyzed; results and conclusions are being prepared.

In a separate effort, the rig being used in this project drilled 124 gas wells in 7 months, totaling 300,000 feet of borehole.

**Project Start / End:** 2-7-05 / 5-1-06
**DOE / Performer Cost:** $999,794 / $1,000,000
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*Gas Technology Institute* – Kent Perry (kent.perry@gastechnology.org or 847-768-0961.

# Counter-Rotating Tandem Motor Drilling System

## DE-FC26-05NT15489

### Project Goal
The project objective is to develop a novel coiled tubing drilling (CTD) system, specifically designed to drill at high rates of penetration (ROP) with low weight on bit (WOB) and low reactive torque. The Counter-Rotating Tandem Motor Drilling System (CRTMDS) will aid in achieving higher ROP with a CTD system.

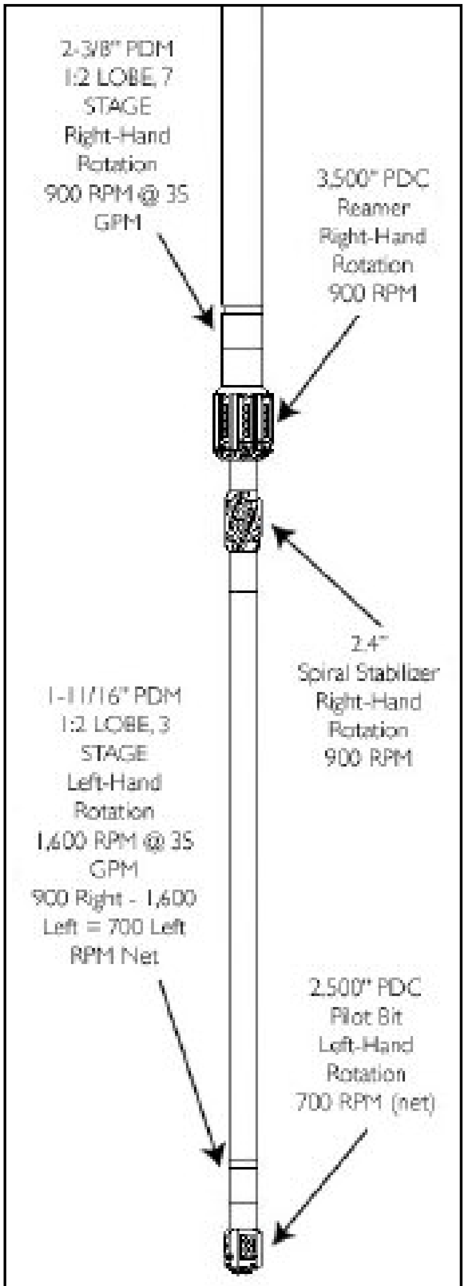
### Performer
*Gas Technology Institute*
*Des Plaines, IL*

### Project Results
The drilling system developed in this project is expected to allow high ROP while drilling with coiled tubing. The counter-acting torques from a left-hand pilot and a right-hand reamer will result in a net of near-zero reactive torque transmitted to the coiled tubing. The small-diameter left-hand pilot bit will drill with higher ROP and less WOB than a conventional bit.

The CRTMDS will enable use of higher-torque positive displacement motors (PDM), which improves ROP while maintaining the torque limitations of the coiled tubing, improving tool life, and reducing the frequency of bit changes.

### Benefits
Drilling costs will be lowered through the development of an improved drilling system suitable for coiled tubing drilling. Current CTD systems are able to drill at relatively low cost and with improved environmental characteristics as compared with conventional drilling rigs. However, coiled tubing drilling would have a much greater impact on oil and gas development if the rate of penetration could be increased by 25-60%, while decreasing the drilling cost by up to 40%.

### Background
Overall drilling costs can be lowered by drilling a well as quickly as possible. For this reason, a high ROP is desired. In general, high ROP can be achieved by increasing the WOB, the amount of torque on the bit, and the rotary speed of the bit. Two important limitations commonly associated with coiled tubing systems are the inability to apply high WOB to the bottomhole assembly and the torque-handling capacity of the coiled tubing. These two limitations work against the goal of high ROP.




The Counter-Rotating Tandem Motor Drilling System bit assembly.

### Project Summary
The CRTMDS developed in this project will combine a counter-rotating pilot bit and reamer to drill with low WOB and reduce reactive torque transmitted to the coiled tubing. The system uses a small-diameter, left-hand polycrystalline diamond compact (PDC) pilot bit driven by a left-hand turning PDM to drill a small pilot hole. A 3½-inch PDC reamer with an integrated stabilizer is run in tandem with and powered by a right-hand turning PDM. The bit contains premium PDC cutting inserts manufactured with advanced microwave-sintered carbide substrates.

A detailed design for a CRTMDS is being developed and evaluated. After evaluation of the design, a decision will be made as to whether to proceed with the fabrication and testing of a prototype system. If a prototype system is developed, it will undergo an extensive testing program to evaluate its performance and reliability. By the end of the program, a system suitable for use in commercial wells is expected to be available.

### Current Status (August 2005)
The design calculations have been developed for components of the 3½-inch CRTMDS and preliminary designs for a 2½-inch pilot bit and 3½-inch reamer has been completed. A small prototype of a similar tool was built for Los Alamos National Laboratory and tested at the Rocky Mountain Oilfield Testing Center in August 2005. Results from this test are being used in the final design of the CRTMD tool.

**Project Start / End:** 2-1-05 / 1-31-07
**DOE / Performer Cost:** $654,953 / $163,743
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*Gas Technology Institute* – Kent Perry (kent.perry@gastechnology.org or 847-768-0961.

# *Demonstration of the Use of Composite Coiled Tubing To Drill Low-Cost Deepwater Wells*

## DE-FC26-05NT15481

### Project Goal

The objective of this project is to demonstrate that it is possible to drill simple deepwater exploration wells at a significantly lower cost (perhaps 60%) than drilling with today's conventional methods. The demonstration will be achieved by using a composite coiled tubing drilling (CTD) system and an innovative seabed anchor to drill a slim well in the Gulf of Mexico. A series of three incrementally more difficult wells will demonstrate the system's effectiveness.

### Performer

*Geoprober Drilling Inc.*
*Houston, TX*

### Project Results

This project is expected to result in a low-cost method of drilling microholes for exploration in the Gulf of Mexico. A new type of seabed support system will be developed that incorporates a subsea shut-off system and a surface blowout preventer. The use of composite coiled tubing for drilling will be tested in a demonstration well.

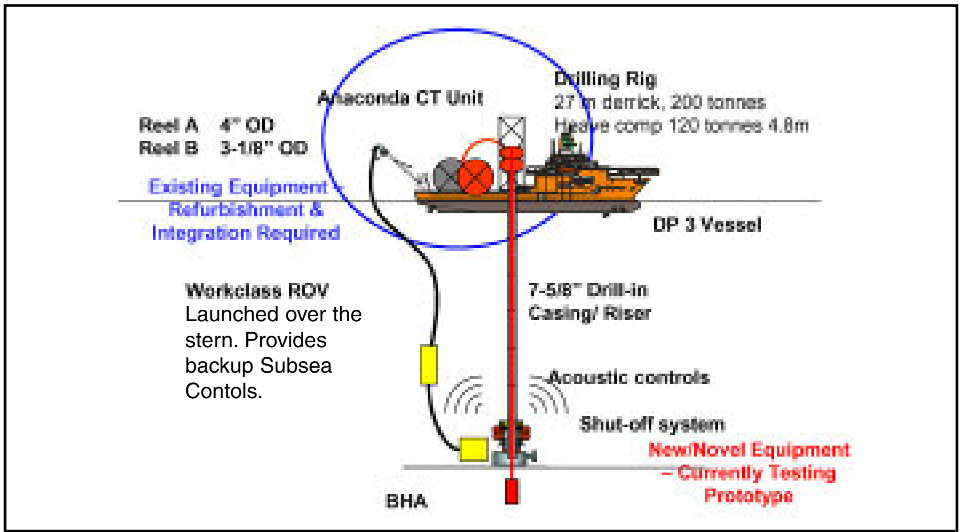
### Benefits

The costs of performing deepwater exploration can be significantly reduced with microhole technology by over 50%.

By eliminating the need to run and retrieve a large (21-inch) riser for a conventional deepwater well and thus allow the use of a much smaller drilling vessel, a microhole "finder" well would cost a projected $5.7 million compared with the $13.9 million that would be expended for drilling the well conventionally.

Procuring a conventional deepwater drilling rig has become very difficult. The approach to be demonstrated will provide a means to introduce new equipment at greatly reduced capital cost.

In addition to the cost benefits, there would be improvements in data collection due to the use of composite coil.




Geoprober microhole drilling system conceptual layout.

### Background

The "conventional" approach to deepwater drilling has been to utilize a drilling rig that can drill any type of deepwater well. In practice some wells are very challenging; for example, some deepwater Gulf of Mexico wells require 9-10 casing strings. As a result it is necessary to use large equipment and a large drilling rig to run this equipment.

However, there are many other wells that are far simpler, requiring only one or two casing strings. Rather than use the "one-size-fits-all" equipment to drill these wells, this project utilizes a completely new approach that uses a much smaller drilling rig, resulting in significant cost savings.

### Project Summary

This project calls for drilling three wells with an innovative composite-coil CTD system and a 3⅛-inch diameter bottomhole assembly. The aim is to develop the capability to drill low-cost, shallow microhole exploration wells in water depths ranging to 10,000 feet.

The three demonstration wells will be 1) a land well for the purpose of integrating the drilling and logging tool assemblies, 2) a test of the "anchor" portion of the drilling system in shallow water, and 3) an offshore well that will combine the achievements of the first two wells but will stop short of drilling into hydrocarbons.

A new type of seabed support system has been developed that incorporates a subsea shut-off system and a surface blowout preventer. This system enables microholes to be established in deep water with drilled-in casing.

The system includes an interface at the bottom of the smart composite-coil tubing, the voltage supervisory sub, to which other logging tools can be attached. In addition to the high baud-rate data-transmission capability, the smart composite coil offers power and control signals for activating and controlling downhole tools.

Halliburton will provide its Anaconda smart pipe/CTD system, minus its downhole tractor. That feature will be replaced by Geoprober's proprietary shut-off device—a "ballgrab" gripping device that is activated to hang off the casing, allowing the casing annulus to be sealed with a dual seal.

### Current Status (August 2005)

Drilling work on the project has not yet started. Related work is ongoing, including testing of a prototype of the "anchor" portion of the equipment and an assessment of the current state of the Anaconda equipment.

**Project Start / End:** 2-7-06 / 2-6-07
**DOE / Performer Cost:** $1,000,000 / $4,260,000
**Contact Information:**
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*Geoprober* – Colin Leach (colin.leach@geoprober.com or 281-920-6383)

## *Advanced Ultra-High-Speed Motor for Drilling*

### DE-FC26-04NT15502

### Project Goal

The project goal is to design ultra-high-speed (10,000 rpm) electric inverted configured motors in two sizes for drilling microholes.

### Performers

*Impact Technologies LLC*
*Tulsa, OK*

*University of Texas-Arlington*
*Arlington, TX*

### Project Results

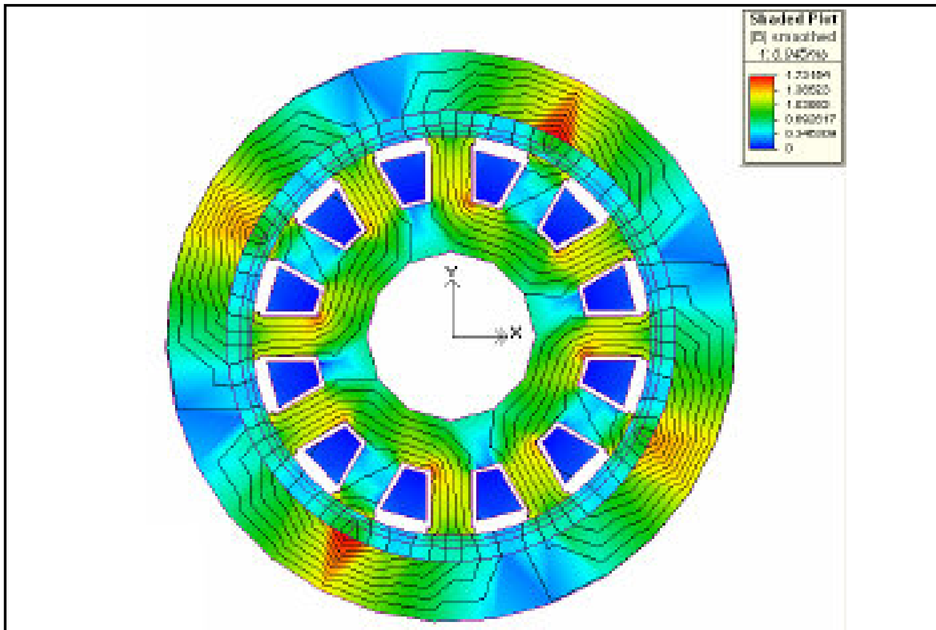
Researchers have developed electromagnetic designs for radial and axial motors in 2 outer diameters (OD) for speeds up to 10,000 rpm. Magnetic saturation and power/torque estimations have been made at various speed and loading conditions. Bearing and seal materials have been studied, but their final design must wait until the electromagnetic motor design has been finalized.

### Benefits

A new motor and drilling process combination will benefit oil and gas exploration and production by finding new reserves as a result of lower finding costs and increased production from existing wells with horizontal drilling applications. The drilling method is applicable to extremely hard or deep reservoirs that are difficult to drill with current technology. The gas storage industry can benefit from horizontal drilling in storage fields, which allows enhanced deliverability. Significant benefits are expected for the trenchless utility (telephone, fiber-optics, communications, water, sewer, etc.) and pipeline installations across roads and rivers.

### Background

Drilling boreholes at ultra-high speeds (>10,000 rpm) has been shown to penetrate faster than at lower speeds. Using abrasive and/or acidic fluids at high pressures also has been shown to increase drill rate. Employing an electric motor in the new "inverted" configuration allows the combination of these two mechanisms (ultra-high speed and high-pressure fluids) to be used for even faster and more efficient drilling.




Magnetic field distribution in a small, ultra-high-speed electric motor.

### Project Summary

This project initially focused on drillbits that are to be used in ultra-high-speed drilling applications. This was important to determine the required load, torque, horsepower, and sizes. From this study, it was found that few cutter elements and bits can withstand the generated heat, abrasiveness, and shock of this environment, although current work in this area is encouraging.

Based on this work, the motor requirements were set as a first pass for the electromagnetic design. Two sizes planned for initial design were 1.69 inches and 3 inches OD, with the lengths variable and motor power sections stackable. The chief benefit of an "inverted motor" configuration vs. an electrical motor is that the internal high-pressure fluids are not in contact with the electrical components. The weaker permanent magnets are lined inside the outer rotating housing and thus are supported from the extreme centrifugal forces generated by such high speeds. The internal and external flows can efficiently cool the electrical/magnetic-induced heat load. Air gap clearances and magnetic-strength saturation are ongoing concerns.

Radial designs have been finished. The more complicated axial design is ongoing and looks favorable relative to the radial design. Seals and bearing design will come out of the final electrical-magnetic design selected. Polycrystalline diamond, diamond, and other coatings are being considered for bearing surfaces. Ultra-high-speed seal materials will be selected last, based on the heat and pressure ranges required by the final design.

### Current Status (August 2005)

Researchers are finalizing the electromagnetic design of the motor. The current focus is on electric-magnetic axial design of a 3-inch OD motor for microhole drilling and on bearing materials and design. The next steps are to mate final electromagnetic mechanical designs with appropriate bearings and seals perform heat-transfer analysis of final designs, and prepare final machine drawings for prototyping.

**Project Start / End:** 10-1-04 / 3-31-06
**DOE / Performer Cost:** $165,882 / $55,441
**Contact Information:**
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*Impact Technologies* – Ken Oglesby (oakk@aol.com or 918-627-8035)

## *The Application and Use of Microholes for Vertical Seismic Profiling*

### FWP ESD04-006

### Project Goal

The project goal is to evaluate and develop vertical seismic profiling (VSP) technology for microholes to be used to enhance image resolution and depth penetration beyond current technology in a low-cost fashion.

### Performers

*Lawrence Berkeley National Laboratory*
*Berkeley, CA*

*Los Alamos National Laboratory*
*Los Alamos, NM*

*Rocky Mountain Oilfield Testing Center*
*Casper, WY*

### Project Results

A low-cost vertical seismic instrumentation system that can be deployed in a low-cost manner was developed for use in microholes. VSP surveys were completed in the Rocky Mountain Oilfield Testing Center (RMOTC) using a 20-level hydrophone string and a 20-level geophone string. Performing the surveys demonstrated that VSP data can be collected without using expensive rigs and extensive manpower. This work will serve as baseline study in preparation of a future $CO_2$ injection monitoring program.

### Benefits

The low-cost and easily deployed seismic system developed in this project will make VSP surveys more available to small operators with limited resources.

The increased resolution afforded by VSP can more accurately image subsurface reservoir rock and fluids and is particularly useful in understanding fractured and compartmentalized reservoirs.

Reduced amounts of equipment needed to run VSP surveys saves time, makes the system easily transportable through rough terrain and fragile environments, and reduces operational footprint.

### Background

While VSP is not a new technology, the routine, low-cost application of VSP at the same scale of surface seismic has not occurred. As oil and gas resources become harder to find and produce in the U.S., there is a critical need to enhance seismic resolution of the subsurface. While VSP offers such an increase in resolution, it has been held back by the use of expensive holes and large-scale deployments. Microhole technology offers a means to deploy VSP at lower cost and denser sampling than "conventional" VSP surveys.

The complete system used to acquire the VSP data. The simplicity of the system allowed for hand deployment, a rental vehicle for the "doghouse," and a small vibrator for the source. Note the small tripod used to support the sensor string; normally, a workover rig and many more personnel are needed.

### Project Summary

The project achievements include:

- A low-cost, easily deployed system for conducting VSP surveys was developed and tested.
- The use of hydrophone (fluid-coupled) and geophone (directly clamped) sensor strings were compared. The test showed that geophones were the most effective type of sensor for the situation investigated.
- A new "vacuum-assisted" geophone clamping mechanism was developed and used to minimize the overall size of the sensor package such that it will fit into microholes.
- Initial VSP surveys have been completed and processed from 800-foot microholes testing the systems developed.

This project is an integrated program of modeling, instrumentation evaluation and testing, and data acquisition and processing. The effort is tightly coupled with the microdrilling program being conducted by Los Alamos National Laboratory at RMOTC in Teapot Dome, WY. The focus of the project is to model, design, carry out, and process multiple shallow VSP surveys (500 to 700 feet deep) in microdrilled holes in an area that is well-characterized. The VSP results will be compared with surface seismic and other information such as well logs, existing models, and core analyses. The results are being used to further microhole technology development

### Current Status (July 2005)

A comprehensive VSP program is being carried out at RMOTC in a set of 4 holes at depths up to 1,500 feet. A string of 48-level geophones deployable in a total time of less than 1 hour are being used to gather data over a potential $CO_2$ injection pilot area to serve as a "background" data set.

**Project Start / End:** 3-12-04 / 3-11-06
**DOE / Performer Cost:** $400,000 / $0
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*LBNL* – Ernest L. Majer (elmajer@lbl.gov or 510-486-6709)

# *Technology Development and Demonstration of Microhole Oil Production at the Rocky Mountain Oilfield Test Center*

## FEW03FE06-04

### Project Goal

The primary goal is to show that microholes provide downhole access at significantly lower cost than conventional wells and provide superior acoustic performance when compared with the use of temporarily converted production or injection wells. A secondary goal of the project is to evaluate new prototypes of commercial drilling equipment. The Los Alamos National Laboratory microdrilling rig serves as a platform to evaluate commercial technology that is suitable for microdrilling and completion service.

### Performers

*Los Alamos National Laboratory (LANL) Los Alamos, NM*

*Lawrence Berkeley National Laboratory (LBNL) Berkeley, CA*

*Rocky Mountain Oilfield Testing Center (RMOTC), Casper, WY*

### Project Results

Microdrilling to 820 feet in an oil field has been demonstrated successfully, and microholes have been completed to provide access for retrievable acoustic sensor arrays.

### Benefits

Micro-instrumentation holes potentially could cost as little as a quarter to a tenth that of conventional boreholes. Successful demonstration of a nonmetallic casing such as PVC line pipe may reduce acoustic noise and improve the performance of micro-instrumentation holes dedicated to reservoir-monitoring service. Successful demonstration of prototype drilling and completion equipment on a microdrilling system may accelerate commercialization of new products.

### Background

Providers of geophysical data to the oil and gas industries seek low-cost access to the subsurface for the emplacement of seismic instrumentation for a variety of purposes. LANL's experience with seismic data acquisition in oil fields indicates that low-cost, dedicated microholes for deployment of seismic sensors are needed to enhance acoustic data monitoring of the subsurface. Dedicated data aqusition holes provide reduced natural surface and cultural noise, reduced or eliminated seismic-signal travel paths through highly attenuating surface layers, and a greatly improved signal-to-noise ratio.

Accordingly, microholes promise a low-cost alternative to conventional wells; they can be placed in the desired location and designed for optimal acquisition of seismic data.

LANL microdrilling at the RMOTC-operated Teapot Dome Field at NPR No. 3. The microdrilling rig includes the coiled tubing drilling unit on the right, mud cleaning system on the left, and the RMOTC drilling-water truck in the center.

### Project Summary

The LANL project is demonstrating the technical and economic feasibility of developing a highly mobile, self-contained, microhole drilling system for seismic data acquisition and other applications. Researchers also are evaluating commercial equipment that has the potential to enhance the performance of microdrilling. The project has completed the design of a high-pressure mud system that will support drilling mud circulation pressures up to 5,000 psi compared with the present 2,000 psi capability. High-pressure drilling will be used to evaluate a high-performance drilling assembly and increase the depth capability of the LANL coiled tubing unit from 820 feet to 1,500 feet.

Four deep micro-instrumentation wells have been drilled in Rocky Mountain Oilfield Testing Center (RMOTC) Teapot Dome field at NPR No. 3 in central Wyoming.

Quality Tubing Inc.'s QT16Cr80 stainless steel coiled tubing was used successfully as a drill stem for microdrilling.

Micro-instrumentation wells with both PVC and steel casing cemented to the surface are being evaluated by LBNL as acoustic observation wells.

### Current Status (August 2005)

The LANL drilling team has completed 4 micro-instrumentation access wells. The fourth well has been drilled to a depth of 1,310 feet. LANL's coiled tubing unit will be upgraded with a new coiled tubing reel, a 1,600-foot long string of stainless steel coiled tubing, and high-pressure piping needed for evaluating drilling assembly and deeper drilling operations. A drilling permit for a 5th well is being obtained.

**Project Start / End:** 5-04 / 4-06
**DOE / Performer Cost:** $1,300,000 / $0
**Contact Information:**
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*LANL* – Donald Dressen (dreesen@lanl.gov or 505-667-1913)

## *A Built-for-Purpose Coiled Tubing Rig*

## DE-PS26-03NT15474

### Project Goal

The project goal is to develop a Microhole coiled tubing drilling (CTD) rig capable of drilling a 3½-inch open hole to 6,000 ft total measured depth with a 1,000-foot lateral section. The rig will be capable of rotary and coiled tubing drilling and be able to drill efficiently, safely, cost-effectively, and with minimal environmental impact.

### Performer

*Schlumberger Well Services*
*Sugar Land, TX*

### Project Results

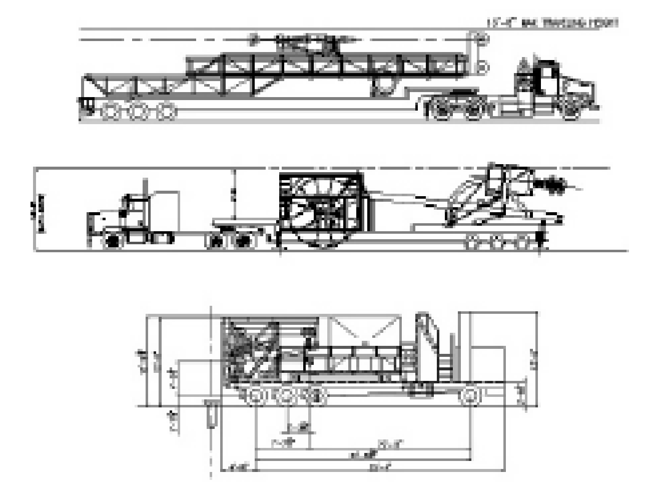
The project started with the review of current CTD rigs, with a plan to modify an existing rig for use as a microhole CTD rig. Research showed that the majority of built-for-purpose CTD rigs were very large and could prove difficult to move about on small lease roads. This led to a plan to reduce the overall size of the units, without hindering any of the efficiency factors that current purpose-built units have.

### Benefits

Microhole technology offers an alternative to conventional rotary drilling techniques. Rotary drilling typically has larger completion sizes due to limitations imposed by jointed pipe. These larger completions account for higher costs for drilling, completion, and disposal cost. The CTD rig's part in microhole technology is to keep the operating cost to a minimum so all of the economic benefits of drilling a microhole can be realized.

Cost savings to the operator could be as much as $1,071,144 per year. The estimated cost savings was based primarily on increases in efficiency compared with conventional units and the reduction of accidents. Based on economic calculation, the microhole CTD rig could perform an additional 50 days of drilling, or nearly $1,100,000 worth of billable drilling, each year.

A day rate of $20,000 for basic overbalanced drilling was used in the estimate. Higher day rates would be expected for more-complex operations and underbalanced drilling.



Transportation concepts for a purpose-built microhole coiled tubing drilling rig.

### Background

Coiled tubing drilling of oil and gas wells has been practiced since the early 1990s. Primary drivers for the development of coiled tubing services have been the ability to perform through-tubing re-entry work and to drill underbalanced. To date, a variety of purpose-built CTD rigs exist in various locations around the world. None of them is specifically designed to access the shallow oil and gas reservoirs in the U.S. in a cost-effective way.

### Project Summary

This project is focused on developing and building a microhole CTD rig that is aimed specifically at U.S. shallow oil and gas reservoirs. The rig is being designed to perform over- and underbalanced drilling work for both new and existing wells. It is being designed to improve the economics of shallow-well drilling by using small and purposed-built equipment that is easy to move and fast to mobilize, yet versatile in its application.

Among the project's achievements:

• Market analysis for the microhole CTD rig has been completed. The key information from the market analysis is a recognition of the need to make the rig scalable so that it can perform slimhole as well as microhole work. This will ensure that utilization is kept high, which will keep the unit's day rate as low as possible.

• Operational analysis showed that it is feasible to drill a microhole with coiled tubing. However, with smaller coiled tubing, artificial means of obtaining weight on bit may be necessary.

• Operating scenarios were developed to evaluate various microhole CTD rig concepts with regard to rig-up efficiency and the ability to perform the necessary tasks associated with drilling a microhole.

• The final concept was developed and is currently in the detailed design process.

Modifications planned are to enable the rig to perform more-complex work, such as underbalanced coiled tubing drilling and to optimize the safety and operational efficiency.

### Current Status (August 2005)

The market analysis, an operational study, and the conceptual design have been completed. A detailed design of the rig is being developed.

**Project Start / End:** 3-31-05 / 9-30-06
**DOE / Performer Cost:** $1,200,000 / $636,423
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*Schlumberger Well Services* – Warren Zemlak (warrenz@sugar-land.oilfield.slb.com or 281-285-7068)

## *Development of Radar Navigation and Radio Data Transmission for Microhole Coiled Tubing Bottomhole Assemblies*

### DE-PS26-03NT15477

### Project Goal

The overall goals of this project are to design, manufacture, and test two advanced technologies for the oil and gas industry: 1) real-time measurement-while-drilling (MWD) for guidance and navigation of coiled tubing drilling in hydrocarbon reservoirs and 2) two-way inductive radio data transmission on coiled tubing or via an insulated slickline fed inside the coiled tubing.

### Performer

*Stolar Research*
*Raton, NM*

### Project Results

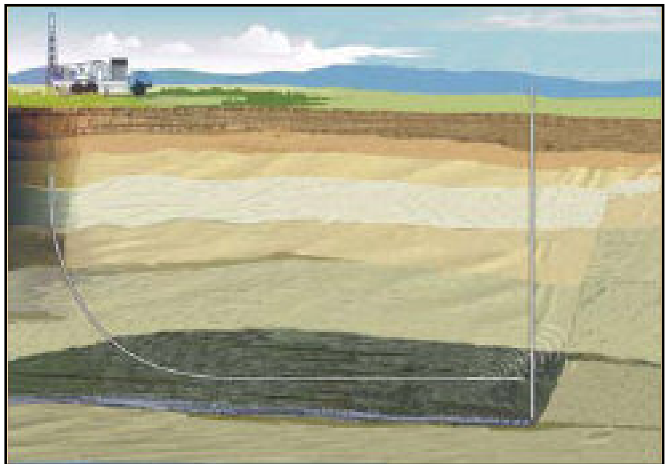
A data transmission system has been developed that is small enough to fit inside a 1 11/16-inch diameter housing. The system uses the outer surface of the drillpipe to propagate signals. A borehole test with this communications system was successfully performed over 500 feet of drillpipe in Deer Creek, UT. For the MWD guidance and navigation of coiled tubing, a prototype digital signal processing (DSP)-based radar system capable of coherent detection of radio waves has been designed and fabricated.

### Benefits

The technologies developed in this project allow real-time navigation and imaging during exploration with minimum land disturbance and fewer drillholes. The proposed technologies improve the recovery efficiency of shallow production wells. Through real-time navigation, the operator can eliminate the expensive practice of sidetracking in horizontal drilling.

### Background

The information from the MWD sensors in the bottomhole assembly must quickly be brought up to the surface to the drill operator for real-time navigation of the drillbit. Two methods are currently employed. One common method of transmitting downhole sensor data to the surface is by sending extremely low-frequency (e.g., 40 Hz) signals though the layers of the earth to reach a receiver antenna located on the surface, typically away from the drill rod. This method provides a slow communications channel due to its low frequency of operation. The other method uses wire lines (or fiber optics) embedded in the drill pipe to provide high-speed communications with the topside receiver. This is generally an expensive and irreversible process. Stolar's data communications system is a cost-effective alternative to these methods of MWD communication.



Radar measurements while drilling for horizontal directional drilling, navigating, and structure detection.

Currently, the location of the drillbit in the hydrocarbon reservoir is determined from the gamma ray, neutron, and resistivity sensors. There is no tool available to let the horizontal drilling operator know the distance between the drillbit and the bounding walls of the reservoir. The radar navigation tool eliminates this deficiency.

### Project Summary

The project to date has achieved these milestones:

- A data communications system has been designed and fabricated that is suitable for MWD applications and has a data transmission rate of 2,400 bits/second.
- The data communications system has been successfully tested in a borehole by transmitting the orientation of the drilling pipe over 500 feet.
- A prototype DSP-based radar system has been designed and fabricated that is capable of detecting and mapping the boundary rocks of a hydrocarbon reservoir.

The data transmission system is based on the frequency-shift keying (FSK) modulation of 91.5-kHz signals. This system, with a downhole navigation package, was successfully tested over 500 feet of pipe inside a water-filled test hole in the Deer Creek Coal Mine in Utah. The data transmission system did not require any added wires to the drilling pipe. The radio waves were inductively coupled to the rest of the drilling pipe by a loop antenna. The signal-to-noise ratio at the receiver for the one-way communications test was better than 30 dB.

The DSP radar system is able to change the modulation scheme on the fly. The different modulation schemes required for the various target depths are under investigation. The radar system is based on the coherent detection of reflected, continuous-wave signals below 160 MHz. The operating frequency and the dynamic range of the radar system depend on the electrical properties of the host rock. In a coal seam, higher frequencies of operation can be compared with an oil reservoir. This is due to the high resistivity of coal. An algorithm for processing the data from a stepped-frequency radar system has been developed that reduces the clutter effects.

### Current Status (August 2005)

The project is nearing completion.

**Project Start / End:** 7-26-04 / 9-25-06
**DOE / Performer Cost:** $737,000 / $184,875
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## *High-Power Turbodrill and Drillbit for Drilling with Coiled Tubing*

### DE-FC26-05NT15486

### Project Goal

The project entails developing and testing an effective downhole drive mechanism and a novel drillbit for drilling small-diameter vertical and horizontal wellbores with coiled tubing.

### Performers

*Technology International, Inc. (TII)*
*Houston, TX*

*Smith International, Inc. (SII)*
*Houston, TX*

### Project Results

Baseline testing of an existing 2⅞-inch diameter turbodrill with polycrystalline diamond compact (PDC) and impregnated diamond drillbits has been successfully performed at Gas Technology Institute's Catoosa, OK field test site. The hydraulic efficiency of the baseline MK2 turbine blades has been increased so far by 13%. A thermal model is being developed by TII to predict cutter temperatures while drilling hard and abrasive rock at high rpm. Being able to estimate cutter tip temperatures will aid in the development of a more durable drillbit employing high-temperature cutters.

### Benefits

Benefits to the industry from successful development of a microhole coiled tubing turbodrill and high-speed drillbit include:

- Delivery of more power to the bit than with positive displacement motors.
- Lower reactive torque for improved directional control.
- Longer drillbit life.
- Less vibration.
- Steady dynamics at the bit.
- Smaller cuttings that are easier to clean from the hole.
- Drilling at a higher rate of penetration (ROP) with less weight on bit (higher rotary speeds to 2,200 rpm provide higher ROP and lower cost per foot drilled).

The PDC and impregnated diamond drillbit being developed in this project.

- Operation at high downhole temperatures.
- Operation in two-phase muds at higher rotary speeds and for underbalanced drilling applications.
- Improved hole quality.
- High reliability.

### Background

Dr. Steve Holditch, 2002 president of the Society of Petroleum Engineers, said, "To economically recover gas, we need to learn how to drill smaller boreholes more rapidly and less expensively." But drilling today does not necessarily mean using a conventional drilling rig. Coiled tubing units increasingly are being used to drill for oil and natural gas deposits at lower costs and with a much smaller environmental footprint. Coiled tubing drilling is a cost-effective alternative for drilling highly deviated wells or drilling new hole sections in existing wells. The use of a relatively high-speed turbodrill and high-temperature drillbit will reduce the cost per foot drilled.

### Project Summary

The prototype coiled tubing turbine motor and drillbit being developed in this project are designed to:

- Drill a vertical hole to a depth of 5,000 feet.
- Drill laterals to 1,000 feet.
- Demonstrate the economic advantages of the coiled tubing drilling operation when compared with conventional drillpipe-conveyed downhole assemblies.

The performance of the turbodrill and bit system will lead to an advance in the design of components that ultimately will lead to a higher-power turbine section.

The next step in the project is to incorporate the design improvements into a new downhole drilling assembly for a microhole drilling system. Tools will be made available to microhole project partners for independent field applications in re-entry wells and workover operations using commercial coiled tubing rigs.

A thermal model is being developed by TII to predict cutter temperatures while drilling hard and abrasive rock at high rpm. Being able to estimate cutter tip temperatures will aid in the development of a more durable drillbit employing high-temperature cutters.

### Current Status (August 2005)

Initial tests of prototype hardware were conducted at drilling research centers to expedite the testing process and to ensure maintenance of carefully controlled operating conditions. Baseline turbodrill and drillbit testing was completed in March 2005. A turbine blade hydraulic design model was used to redesign the turbine blades, and successful dynamometer testing was completed in June 2005. Further turbodrill hydraulic modeling is currently under way, as well as thermal modeling of the drillbit cutters.

**Project Start / End:** 4-1-05 / 8-1-06
**DOE / Performer Cost:** $759,668 / $200,000
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*Technology Int'l.* – Robert Radtke (radtke@kingwoodcable.com or 281-359-8520

## *Small, Mechanically Assisted High-Pressure Waterjet Drilling Tools*

### DE-FC26-05NT15484

#### Project Goal

The goal of this project is to produce a high-pressure jet-drilling system that will dramatically reduce the torque and thrust required for drilling, thereby increasing reliability, drilling rate of penetration (ROP), and lateral reach.

#### Performer

*Tempress Technologies, Inc.*
*Kent, WA*

#### Project Results

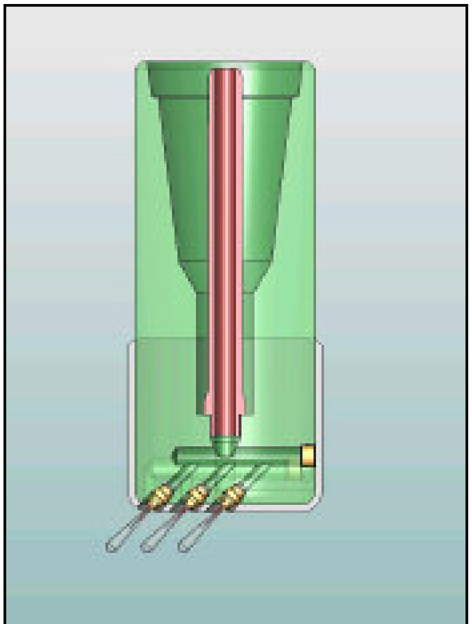
This project will result in the development of a downhole intensifier and associated tools for jet drilling of microholes with coiled tubing. The tools developed in this project also can be used for ultra-short radius re-entry of producing formations with a compact jet drill.

#### Benefits

The economic benefits of the high-pressure waterjet microhole coiled tubing drilling (CTD) system are derived from both increased capabilities and reduced drilling costs. This drilling system will be able to drill deeper and farther in deviated wells than current coiled tubing technology because of 1) increased downhole power, 2) the ability to drill underbalanced, 3) improved cuttings transport, 4) reduced tendency to stick in the hole, and 5) increased drilling efficiency in pressure-sensitive shales. Other economic benefits result from the decreased hole size. When the volume of a 3½-inch diameter hole is compared with that of a conventional 8½-inch diameter hole, 83% less fluid is required to fill and circulate the microhole.

#### Background

Small downhole positive-displacement motors (PDM) have limited power output and are prone to stall when run with aggressive polycrystalline diamond compact bits. PDMs are designed to operate at a limited pressure differential on single-phase water-based mud. Also, as lateral reach increases, the thrust available for mechanical drilling drops due to coiled tubing friction and helical buckling in the borehole. Drilling with high-pressure fluid jets makes more efficient use of available downhole power and has proven effective in most rock formations. High-pressure jet-drilling dramatically reduces the torque and thrust required for drilling, thus increasing ROP and lateral reach.



Conceptual model of a 3½-inch mechanically assisted jet bit powered by a positive-displacement drilling motor

#### Project Summary

This project involves the development of a downhole intensifier (DHI) to boost the hydraulic pressure available in conventional CTD to the level required for high-pressure jet erosion of rock. The first phase of the project consists of three major tasks:

- Analyze the CTD system to define operating parameters for the drilling assembly (completed).
- Design the downhole intensifier, jet drill, PDM motor modifications, and drillbit.
- Fabricate and test components in a test facility.

A review of high-pressure jet-drilling and mechanically assisted jet-drilling was carried out to define the bottomhole assembly (BHA) configuration and DHI performance specifications for CTD applications. Two BHA configurations were evaluated: mechanically assisted high-pressure jet drilling with the DHI deployed below a PDM drill motor and high-pressure jet-drilling with the DHI deployed upstream of a rotary jet drill.

The analysis showed that high-pressure jet-drilling with a high-pressure drill motor and DHI should allow drilling at 3-5 times conventional drilling rates.

The project will provide both a mechanically assisted, high-pressure jet-drilling tool and a pure high-pressure rotary jet-drilling tool. Both tools will utilize a common DHI. The downhole intensifier and high-pressure rotary jet drill designs represent modifications of existing tools designed for coiled tubing scale milling. Researchers will work with PDM, seal, and bearing suppliers to provide high-load bearings and seals to maximize the pressure capacity of conventional motors and with a bit supplier to provide a custom dual-passage drillbit to provide both high-pressure jetting and mechanical cutting capabilities. The tools then will be assembled for functional testing. Endurance testing on two-phase flow will be carried out in a pressure-test facility with full power water and nitrogen pumpers.

The jet-drilling system is expected to provide sustained drilling rates of 80 feet per hour or more with a microhole CTD system, while providing over 100 hours of reliable motor operation.

#### Current Status (August 2005)

Initial work has focused on integration of the downhole intensifier with existing CTD systems. This effort has determined the hydraulic power, tool size, BHA assembly, drillbits and associated components. A detailed design of the DHI is complete.

**Project Start / End:** 7-26-04 / 9-25-06
**DOE / Performer Cost:** $737,000 / $184,875
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*Tempress* – Jack Kolle (jkolle@tempresstech.com or 425-251-8120)

# *Microhole Coiled Tubing Bottomhole Assemblies*

## DE-FC26-05NT15487

### Project Goal

The project goal is to combine existing technologies for measurement-while-drilling (MWD) and logging-while-drilling (LWD) into an integrated measurement system to facilitate low-cost drilling of small (3½-inch diameter), shallow (<5,000 foot depth) boreholes using coiled tubing drilling (CTD) technology. The project will deliver two prototypes ready for field testing.

### Performer

*Ultima Labs*
*Houston, TX*

### Project Results

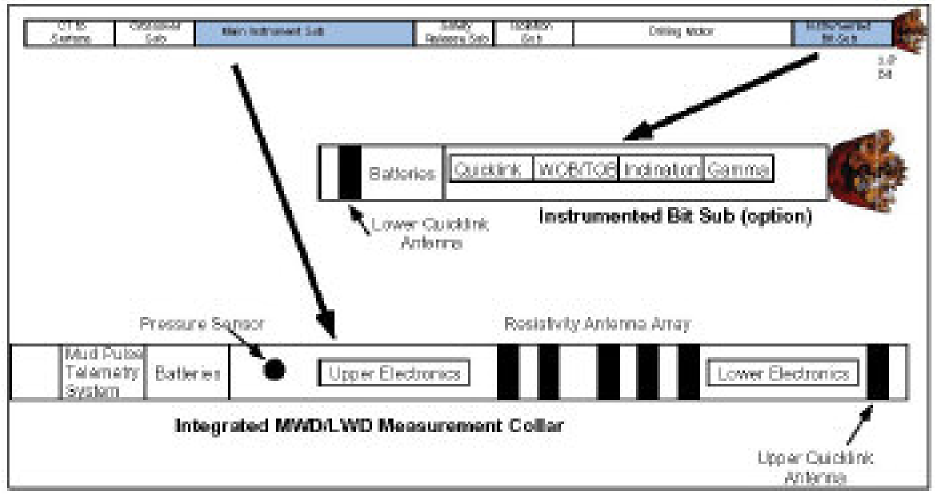
The first prototypes are scheduled for field testing in 2007. The measurement system will provide critical enabling measurements for efficient CTD and formation evaluation.

### Benefits

The project will combine existing, proven technologies for MWD and LWD into an integrated, cost-effective downhole measurement system. Drillers will use the MWD measurements to optimize drilling performance. Geologists will use the LWD measurements to optimize wellbore placement and completion for maximum production and to estimate resources in place.

Widespread adoption of microhole technology will enable low-risk infill development that could potentially tap billions of barrels of bypassed hydrocarbons at shallow depths in mature fields. Exploration efforts in search of new reserves will benefit from the anticipated cost and environmental benefits. DOE estimates remaining U.S. shallow resources at 218 billion barrels. Recovery of just 10% of the targeted resource would yield a volume equivalent to 10 years of OPEC imports at current rates.

Mature producing areas worldwide also will benefit from the technology. Development of technology that expands global sources of hydrocarbons ensures a diversity of supplies and maintains the U.S. as the leading global supplier of oilfield technology.




Ultima Labs' integrated LWD/MWD measurement system in coiled tubing drilling bottomhole assembly.

### Background

As the technology to drill microhole wells develops, the tools to conduct downhole measurements in the smaller holes will be needed as well. This project is developing an integrated tool to improve drilling efficiency and reduce cost. In addition, the increased information about the downhole rocks and environment will allow more accurate reserves estimates and development planning.

### Project Summary

The early phase of the project will establish design requirements and generate a conceptual design that meets these requirements. Following review and approval of the conceptual design by the project team, detailed design will begin on the mechanical and electronic subassemblies and sensors. Individual subassemblies will be tested and incorporated into the prototypes during prototype assembly. The completed prototypes will be tested in the lab and in a flow loop to verify pulser operation prior to the first field test.

The MWD measurements include inclination and azimuth for directional control and weight on bit, torque, and bore and annular pressure for drilling optimization. LWD measurements include natural gamma ray and propagation resistivity.

The integrated collar being developed is battery powered and includes a mud pulse telemetry system. The power and telemetry combination allows the tool to be run on simple coiled tubing without a wireline for power and communication.

Manufacturing cost savings will be realized by designing the integrated collar for the lower temperatures and pressures experienced in shallow boreholes. Maximum tool temperature rating is 125º C and the pressure rating is 5,000 psi.

### Current Status (August 2005)

The project was launched in April 2005. A detailed design with specifications has been completed, and two prototypes are ready for field testing. The next steps are to design resistivity and shorthop antennas, directional gamma sensors, electronics, and detailed mechanical drawings.

**Project Start / End:** 2-1-05 / 1-31-07
**DOE / Performer Cost:** $795,515 / $189,879
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## *Microhole Downhole Drilling Tractor*

### DE-PS26-03NT15475

### Project Goal

The project goal is to design, manufacture, and demonstrate a reliable and economical hydraulically powered coiled tubing (CT) tractor that will transport the drillbit and bottomhole assembly into long (>3,000 ft) horizontal well sections.

### Performer

*Western Well Tool, Inc.*
*Anaheim, CA*

### Project Results

Researchers have developed a design for a drilling tractor that operates within the tight geometric constraints of small-diameter holes. The baseline design for the microhole tractor has been completed, and testing has verified that some of the critical components are compatible with expected low-solids drilling mud.

### Benefits

The microhole drilling tractor (MDT) will allow drilling of horizontal holes up to 2,000 feet beyond conventional CT drilling.

Using CT and the MDT can be 25-50% less expensive than rotary rigs in some applications, especially in environments where set-up time is costly.

Controls are simple and direct using the injector and pump pressure, thus eliminating need for expensive electrical controls.

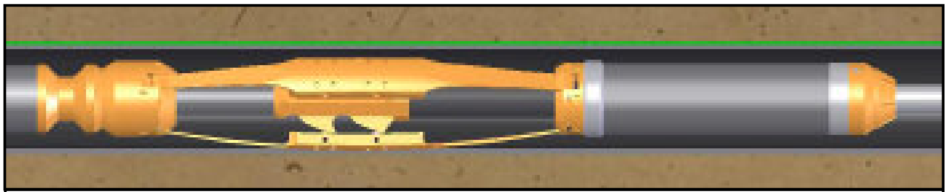
The MDT is capable of high loads (3,500+ lbs) through dog-legs up to 15 degrees per 100 feet.

Grippers for tractor movement are highly reliable, have a long life (>175,000 feet traveled before maintenance), are highly debris- and fluid-tolerant, can efficiently traverse washed-out hole sections, do not damage casing, and are proven to operate in both very soft and hard formations.

Using a simple principle of operation, power is provided by differential pressure of the drilling mud at the tool.

### Background

Although there are many advantages of CT drilling, one area of needed technology development is a method to exert enough weight on the bit to drill through rock. Coiled tubing easily buckles, which makes it difficult to impart drillbit weight. One technology that has been recently developed to overcome this problem is a downhole tractor that thrusts the drillbit into the formation while pulling the coiled tubing along behind.



Profile of microhole drilling tractor gripper expanded against hole.

### Project Summary

The MDT to be designed and manufactured is a drilling fluid-powered unidirectional downhole CT tool. The tractor outside diameter will be 3⅜ inches to accommodate 3⅝-inch holes, and the tractor will be able to drill >3,000 ft horizontal well sections.

The MDT builds on previously developed Western Well Tool Tractor technology that has demonstrated the capability to operate downhole with a variety of drilling muds, operating parameters, and drilling equipment. The tractor consists of a central control assembly that directs the mud flow and provides the pull and thrust of the tractor and a forward and aft shaft assembly with patented grippers that operate successfully in soft and hard formations.

The microhole tractor walking process consists of several steps. A forward roller-toe gripper is expanded (inflated) against the walls of the hole, thrusting the bit forward and pulling the coiled tubing as the tractor progresses. The forward roller-toe gripper deflates while the aft roller-toe gripper expands against the hole wall, pushing the bit forward and pulling the drillstring into the new position. This process repeats, allowing the tractor to "walk" down the hole while drilling in front of the tractor and pulling the drillstring behind it.

In the first phase of the project, a drilling tractor will be designed that is reliable, economical, field-ready, and can drill horizontal well sections of 3,000 feet or more. In the second phase of the project, a prototype drilling tractor will be built and field-tested to demonstrate its performance with a CT rig by drilling multiple inclined and horizontal holes.

### Current Status (July 2005)

The tool is being redesigned to accomodate a tool size change from 3¼ inches outside diameter to 3⅜ inches.

The commercial value of the MDT is underscored by a current 3 well contract with a major oil company using a similar tractor.

**Project Start / End:** 2-1-05 / 1-31-07
**DOE / Performer Cost:** $795,515 / $189,879
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