Sec. 999 Unconventional Resources Detailed Project Info

Research Area: Gas Shales

Project Title: **Novel Concepts for Unconventional Gas Development in Shales, Tight Sands and Coalbeds**
Performer: *Carter Technology*

EXECUTIVE SUMMARY
Carter Technologies Co of Sugar Land, Texas is a technology developer in the field of underground engineering and modification of subterranean formations for environmental and energy applications. The project director and principal investigator for this work is Ernest Carter, a Texas Professional Engineer.

Objective: The project objective is to prepare a preliminary study of novel methods of formation stimulation to increase the production of large amounts of gas in shale, coal, and tight sandstone formations. This is a preliminary study of novel concepts for the development of unconventional gas resources that differ significantly from the traditional drilling and stimulation methodologies.

Methods of mechanically or hydraulically cutting large infiltration galleries connected to the well bore will be evaluated and numerically modeled. These slots are similar to steerable fractures only larger. The best concepts will be integrated with advanced fracture propagation and propping concepts for form a hybrid stimulation technique. Concept and design drawings will be prepared and cost estimates developed.

The project will perform new creative design work based on the principal investigator's work in cutting underground pathways and modifying formation permeability. The work will utilize patented and public domain concepts as well as novel methods developed by the principal investigator. Microsoft Excel computer modeling tools will be used to evaluate mechanical and hydraulic slot cutting friction loads and economic size in various formations. The project covers early-stage conceptual studies and does do not involve field or laboratory work in the current phase.

The proposed methods do not rely on detailed knowledge of the natural fracture systems and therefore may be applicable to formations with limited data. If successful, this project will allow more efficient drainage fields with higher recovery rates.

Collaborative associates for the project include M-I LLC, a Smith/Schlumberger Company, and professors from the University of Oklahoma and the University of Houston.

Project Title: **New Albany Shale Gas**
Performer**:** *Gas Technology Institute (GTI)*

EXECTUTIVE SUMMARY

Objectives of the project: This project serves the RPSEA objective in Area of Interest 1: Gas Shale. The target resource is New Albany shale with up to 160 Tcf on in-place gas, the production from which awaits the development of effective drilling and completion technologies. The principal objective of this project is to develop techniques and methodologies for increasing the success ratio and productivity of New Albany shale gas wells to a level at which the otherwise noncommercial wells become commercial producers. The goal of the proposed research is to convert this considerable resource into producible gas reserves.

Description of project/methods to be employed: The proposal is for a field-based industry cooperative project with producer involvement and high co-funding that combines scientific and technical analyses with field data acquisition, testing, and field validation. A comprehensive integrated project plan for geologic, geochemical, reservoir engineering, and production stimulation studies and a detailed field data acquisition and testing plan addressing all major issues have been prepared.

Impact and benefits of the project: The average estimate of producible gas present in New Albany shale is 10.5 Tcf (1.9 to 19.2 tcf.) However, substantial production from this resource requires the development of technologies for reducing the production cost and financial risks that is achievable only through comprehensive research and development work as proposed for this project. Successful completion of the proposed work has the potential of initiating commercial production from New Albany shale resulting in the addition of 10 tcf of gas to the US natural gas supply amounting to about 40% of the annual demand.

Major participants:
Industry Participants: Aurora Oil and Gas Corporation, CNXGas, Diversified Operating Corp., Noble Energy, Rex Energy, Southwestern Energy, and Trendwell Energy Corp. These industry partners are contributing $800,000 dollars of co-funding to the project.

Research Participants: Texas A&M University, Bureau of Economic Geology (University of Texas), West Virginia University, Amherst College, University of Massachusetts, Pinnacle Technologies, and ResTech. Research participants are also contributing a total $530,000 to the project.

Project Title: **Geological Foundation for Production of Natural Gas from Diverse Shale Formations**

Performer: *Geological Survey of Alabama*

EXECUTIVE SUMMARY

To assist the development of emerging gas shale plays in Alabama, the Geological Survey of Alabama proposes to conduct a three-year study called "Geological Foundation for Production of Natural Gas from Diverse Shale Formations." Dr. Jack C. Pashin, who is director of the Energy Investigations Program at the Geological Survey of Alabama, will serve as project director/principal investigator.

The Black Warrior Basin and Appalachian Thrust Belt of Alabama contain a diversity of emerging gas shale plays in Cambrian (Conasauga Formation), Devonian (Chattanooga Shale and unnamed shale units), and Mississippian strata (Floyd Shale). Development of these reservoirs has been slowed by a series of technical challenges, including uncertainty about best practices for exploration, drilling, and well completion. This uncertainty stems largely from inadequate characterization of the geologic framework of the targeted shale formations and is compounded by major differences of composition, thickness, geometry, and fracture architecture that exist between these formations and proven gas shale reservoirs in other regions.

Unconventional gas plays require an integrated, multidisciplinary approach to exploration and development, yet broadly applicable geologic models of resource distribution and producibility have yet to be developed for gas shale formations. The proposed study will employ a spectrum of field and laboratory techniques to characterize the stratigraphy, sedimentology, geologic structure, hydrodynamics, geothermics, petrology, geochemistry, and resource/reserve base of the gas shale reservoirs in the Black Warrior Basin and the Appalachian Thrust Belt of Alabama. This study is designed to increase knowledge of the mechanisms of gas storage and the sources of permeability in shale formations with diverse composition and geology. This integrated approach will reduce risks associated with exploration and development and will provide for an accurate assessment of resources and reserves. This study will further assist industry in the formulation of exploration and development strategies that are optimized for each gas shale play and will derive basic scientific concepts and models that can be applied to emerging and frontier gas shale plays throughout North America.

Project Title: **Petrophysical Studies Of Unconventional Gas Reservoirs Using High-Resolution Rock Imaging**

Performer: *Lawrence Berkeley National Laboratory, Earth Sciences Division*

EXECUTIVE SUMMARY

The main objective of this work is to determine (a) the physical mechanisms that limit gas recovery from tight rock formations, and (b) the means of extending this recovery as far into the future as possible. Because the mechanisms that block gas flow in the formation and near the wellbore are not fully understood, we propose to use the sophisticated petrophysical imaging tools and theoretical calculation methods at our disposal to elucidate them. Once we better understand the key factors that influence the rate and ultimate level of gas recovery, we will investigate methods of changing the formation properties volumetrically to optimize production in space and in time. The usual approach of highly discounting the future recovery may no longer be applicable in a world in which real energy prices will be growing faster than the local (e.g., state) economies.

We propose to acquire high-resolution images of gas-bearing shale rocks using Advanced Light Source (ALS) facility and Focused Ion Beam (FIB) technology at Lawrence Berkeley National Laboratory (LBNL), and analyze these images using Maximal Inscribed Spheres-type methods in order to estimate gas shale and tight sand flow properties at different, including in situ, conditions. These approaches have been developed at LBNL and University of California at Berkeley (UCB) and have been successfully applied to studies of chalk, diatomite, and sandstone. We will investigate the impact of pore-space geometry in different rock formations on flow properties, including absolute and relative permeabilities, capillary pressure, and Klinkenberg coefficient. We will use the 3D images of the rocks acquired in this project to develop depositional models and to link the petrophysical properties of the rock to the geology and geological history of the reservoir.

A thorough and comprehensive study of existing unconventional gas-bearing formations will create a knowledge base for the development of emerging and frontier developments. The proposed study is fundamental, and acquired knowledge will be equally applicable in short- and long-term technology developments.

Project Title: **A Self-Teaching Expert System for the Analysis, Design and Prediction of Gas Production from Unconventional Gas Resources**
Performer: *Lawrence Berkeley National Laboratory (LBNL)*

EXECUTIVE SUMMARY

OBJECTIVES: Using a multi-disciplinary approach, to develop a self-teaching expert system that (a) can incorporate evolving geological, geophysical, fracturing, reservoir and production data obtained from an continuously expanding database of installed wells in unconventional tight gas reservoirs (i.e., tight sands, shale or coalbeds), (b) continuously update the built-in database and refine the underlining decision-making metrics and process, (c) can make recommendations about formation fracturing and well stimulation, in addition to well location, orientation, design and operation using the most recently updated metrics and processes, (d) offer predictions of the performance of proposed wells (and quantitative estimates of the corresponding uncertainty) in the stimulated formations, and (e) permit the analysis of data from installed wells for parameter estimation and continuous expansion of the data base of the expert system.

DELIVERABLE: The deliverable of this project is a self-teaching expert system that can be a vital tool in the attempt to increase reserves and successfully produce gas from shale formations, and to increase production from already producing systems. The final product is not just the development of an abstract approach or methodology, but a computer program that is easily installed and executed on a wide variety of computational platforms. To fully realize the benefits of the self-teaching expert system, a promising approach is its storage at a central location and access through a Web-based application. Note that the data that are entered into the database are treated as confidential, with the user not knowing their origin without the explicit consent of the data owners. Although the geographical location associated with the data may be disclosed, the data provenance and ownership will not. Thus, the user benefits from the data availability to design more productive production systems without compromising confidential information belonging to the entities that provided the data.

POTENTIAL IMPACT: Successful development of the proposed self-teaching expert system is expected to result in a significant (possibly quantum) increase in both reserves and production by providing a technology that will significantly reduce the uncertainties associated with such systems, thus bringing previously inaccessible energy resource to production.

MAJOR PARTICIPANTS: Lawrence Berkeley National Laboratory, Texas A&M University, University of Houston, Anadarko, Halliburton, BGI.

Project Title: **Optimizing Development Strategies to Increase Reserves in Unconventional Gas Reservoirs**

Performer: *Texas Engineering Experiment Station*

EXECUTIVE SUMMARY

Objective:

The goal of the proposed project is to develop integrated reservoir and decision models to help operators in unconventional gas reservoirs increase reserves and accelerate production, while protecting the environment, by determining the optimal well spacing and completion strategy as quickly as possible. This goal requires explicit modeling of subsurface uncertainty and advanced decision tools that take this uncertainty into account to optimally manage risk. These tools and methods will be developed within the context of existing and emerging gas shale and tight gas reservoirs.

Project Description

According to the National Petroleum Council, North America has over 5000 trillion cubic feet (TCF) of natural gas resources in shale or tight sand formations. While this resource base is large, developing it in an economic and environmentally sensitive manner is challenging. For example, in the lower 48 United States, around 300 TCF of the shale gas and tight gas is estimated to be recoverable using existing technology. In specific development areas such as the Barnett Shale, current recovery per well averages just 7% of gas in place --- far below the 20% that many believe is achievable. In addition to low recovery rates, operators in unconventional reservoirs must invest large amounts of capital and face significant risks.

To address this challenge, the Texas Engineering Experiment Station (PI's Duane A.McVay and J. Eric Bickel) proposes to develop new technologies and methods for determining optimal development and testing programs, including well spacing and completion practices, in gas shale and tight sand reservoirs. The core of this technology will be an integrated reservoir and decision model that fully incorporates uncertainty. The reservoir model will be based on moving window and reservoir simulation techniques, while the decision model will employ dynamic programming to determine the optimal development and testing program.

Impact and Benefits:

This research will increase the Nation's gas reserve base and accelerate production by enabling operators to determine optimal development plans sooner, rather than over 20-30 years as has happened historically. In addition, optimal development will minimize the number of wells required, with attendant environmental benefits. This is particularly important since some large unconventional gas reserves lay under densely populated urban areas.

Major Participants:

Drs. McVay and Bickel will pursue this research in collaboration with Unconventional Gas Resources (UGR) and Pioneer Natural Resources Company (Pioneer). Both of these companies have extensive experience in the development of America's unconventional gas reservoirs. The technology and tools developed will be applied in Pioneer's Barnett Shale asset and UGR's tight gas assets in the Berland River Area, Alberta.

Project Title: **Novel Fluids for Gas Productivity Enhancement in Tight Formations**

Performer: *University of Tulsa*

EXECUTIVE SUMMARY

Objective:

Develop novel fluids for remediation and fracturing by better understanding the impact of fluid properties on the performance of flowback of gas in tight gas wells.

Project Description

Natural gas is increasingly becoming the fuel of choice due to its cleaner burning properties. In the continental United States and many parts of the world large volumes of natural gas are available in very difficult to produce formations such as shales, tight sands, coalbeds and hydrates.

Our research program aims to address key issues to enable recovery from these resources through improved completions and stimulation fluids. Due to the low permeability of the unconventional formations fracture stimulation is most commonly used to recover more gas. Fracture treatments are frequently performed with polymeric fluids and the impact of the invasion of these fluids is to depress the productivity of the gas well. Invasion of aqueous fracturing fluids during stimulation operations can reduce the relative permeability to gas resulting in a “block”. The invaded fracturing fluid establishes a region of high saturation in the rock formation near the fracture, and can significantly reduce the relative permeability and hence the productivity of the well. We propose to develop novel fluids for remediation and fracturing by better understanding the impact of fluid properties on the performance of flowback of gas in tight gas wells.

Impact and Benefits:

The results of this study will enable better selection of treatment fluids to remediate non-performing tight gas wells and also strategies for fluid additives selection in fracturing fluids for future applications.

Project Title: Improvement of Fracturing for Gas Shales
Performer: *University of Houston*

EXECUTIVE SUMMARY

Objective:

Develop non-damaging fracturing fluids (and proppants) for gas shale reservoirs that also minimize water use and disposal fluids and demonstrate their performance by field tests.

Project Description:

As the global demand for energy (and thus carbon emission) rises and the discovery of new hydrocarbon resources drops, the recovery from unconventional gas resources become increasingly important. Gas shales, tight gas, and coal-bed methane are important natural gas resources (≈ 300 Tcf reserve) for United States. The key issue slowing down the development gas shales is the connectivity between the pore space and the well bore. Hydraulic fracturing if successful provides this connectivity and has improved the economic viability of many wells in the Barnett Shale in the Fort Worth Basin, but the reliability of the fracturing needs to be improved. Damage caused by the fracturing fluid and limited fracture length has limited the productivity of fractured wells. The need for large quantities of water and disposal of fracture fluids has adverse environmental effect. The goal of this proposal is to develop non-damaging fracturing fluids (and proppants) for gas shale reservoirs that also minimize water use and disposal fluids and demonstrate their performance by field tests.

Use of light weight proppants will be combined with foams to maximize fracture length, minimize formation damage, minimize use of water in fracturing and minimize disposal of fluids. There will be two phases: fluid development and field demonstration. The first phase would include five tasks. The first phase would include determination of physical / mechanical properties of ultra-low density proppant developed by BJ services at different closure stress and temperature environments, development of conventional as well as foam fracturing fluids with emphasis on low liquid content, environmental sensitivity and reduced use of polymers, and engineering methodology for fracture treatments in Barnett Shale gas fields. The second phase would include field demonstration of fracture treatments and post-fracture treatment evaluation. Development of non-damaging fracture treatment for gas shale reservoirs would open up hundreds of TCF of natural gas for production.

Major Participants:

Major participants of this study would be BJ Services (innovative fracturing fluids and ultra-light weight proppants), Daneshy Consultants (the experience of fracture design) and University of Houston (formation damage and enhanced recovery).

Project Title: **Improved Reservoir Access Through Refracture Treatments in Tight Gas Sands and Gas Shales**

Performer: *University of Texas, Austin*

EXECUTIVE SUMMARY

Project Description:

The primary challenge facing gas producers in unconventional gas plays is the rapid depletion rate of new wells and their relatively high cost. Rapid decline rates require that many new wells be drilled just to maintain production. To address these concerns, this proposal aims at developing methods for improving reservoir access through existing wellbores so as to minimize drilling and completion costs. This can be accomplished by reducing the number of wellbores drilled by suitably fracturing and re-fracturing both vertical and horizontal wells.

Re-fracture treatments are widely applied in gas shales and tight gas sands but with highly variable success rates. Current methods for candidate well selection are primarily based on statistical data available from past treatments in the play. Re-fracture designs do not take into account changes due to near-wellbore and reservoir stresses and pre-existing proppant packs which can have a big influence on the design of re-fracture treatments. This proposal aims at developing a systematic methodology for providing an operator the following key deliverables:

A well defined methodology for candidate well selection based on poro-elastic models and analysis of field data.

Recommendations and charts for the time window most suitable for re-fracturing, for a range of reservoir types, reservoir properties and production profiles.

Application of re-fracture treatments in horizontal and deviated wellbores

Re-fracture treatment designs utilizing novel fluids, proppants and injection strategies

This will be accomplished through field application of newly developed geo-mechanical models, proppant placement strategies, and better re-fracture designs based on novel fluids and proppants.

Project Title: **Paleozoic Shale-Gas Resources of the Colorado Plateau and Eastern Great Basin, Utah: Multiple Frontier Exploration Opportunities**

Performer: *Utah Geological Survey*

EXECUTIVE SUMMARY

Objectives:

The overall objectives of this study are to (1) identify and map the major trends for target shale intervals and identify areas with the greatest gas potential, (2) characterize the geologic, geochemical, and petrophysical rock properties of those reservoirs, (3) reduce exploration costs and drilling risk especially in environmentally sensitive areas; and (4) recommend the best practices to complete and stimulate these frontier gas shales to reduce development costs and maximize gas recovery. All project maps, data reports, and results will be publicly available and presented to the petroleum industry (both small and large operators) through a proven technology transfer plan. The project will therefore, develop techniques and methods for exploration and production for emerging frontier basins where these operations typically encounter technical, economic, and environmental challenges.

Project Description:

Shale gas reservoirs in Utah have tremendous untapped frontier potential. Paleozoic shales in the Colorado Plateau and eastern Basin and Range Provinces have long been known for their potential as source rocks for hydrocarbons that have migrated into other formations but have not been considered as in-situ gas reservoirs. These include the Mississippian Manning Canyon and Delle Phosphatic shales and the Pennsylvanian Paradox Formation of north-central, western, and southeastern Utah, respectively. Shale beds within these formations are widespread, thick, buried deep enough to generate dry gas, and contain sufficient organic material and fractures to hold significant recoverable gas reserves. Exploratory efforts are just beginning to target these frontier gas shales; many in environmentally sensitive areas. The Manning Canyon Shale is mainly claystone with interbeds of limestone, sandstone, siltstone, and mudstone, and has a maximum thickness of 2000 ft. Total organic carbon (TOC) varies from 1% to more than 8%. In north-central Utah, the Manning Canyon was deeply buried by sediments in the Pennsylvanian-Permian-aged Oquirrh basin and is likely very thermally mature. The Delle Phosphatic Shale is a member of the Chainman Shale, Deseret Limestone and Little Flat Formation. The Delle Phosphatic Shale Member is composed of interbedded organic-rich phosphatic shale, siltstone and limestone deposited in a starved basin at the foot of the Paleozoic carbonate ramp. The member is typically 100 to 200 ft thick. Cyclic shale units in the Paradox Formation consist of thinly interbedded, black, organic-rich marine shale; dolomitic siltstone; dolomite; and anhydrite. Individual shale units generally range in thickness between 25 and 50 ft; the cumulative shale thickness is typically 100 to 200 ft. These units contain TOC as high as 15%, are naturally fractured (usually on the crest of anticlinal closures), and are often overpressured.

Although the organic content of some of these shales is partially known, the reservoir quality and the basic rock mechanic data so important to successful completions are virtually unknown. In addition, the distribution and thickness of these rocks are poorly mapped and the vertical succession and regional correlation of the Manning Canyon and Delle Phosphatic has not been interpreted in a sequence stratigraphic framework. The burial history of the Manning Canyon and Delle Phosphatic appears complex and probably varies widely from deep burial in the Permian Oquirrh basin (>10,000 ft of overlying Pennsylvanian and Permian strata) to shallower burial along the Paleozoic shelf of central Utah. There are no published studies of the best completion practices for the Manning Canyon, Delle Phosphatic, and Paradox shales.

The proposed **tasks** include data compilation from existing wells and publications; detailed description and petrophysical, geochemical, and rock mechanical analysis of cores and cuttings from our collection; outcrop examination and sampling; regional mapping including structure, thickness, thermal maturity, and deposition facies maps of key shale gas reservoirs; and design, description, and recommendation of the best completion practices for these frontier Utah shale gas reservoirs based on various parameters defined by our study.

Research Area: Water Management - Coalbed Methane and Shales

Project Title: **An Integrated Framework for the Treatment and Management of Produced Water**

Performer: *Colorado School of Mines*

EXECUTIVE SUMMARY

The Colorado School of Mines (CSM) in collaboration with the Argonne National Laboratory (ANL) and Kennedy/Jenks (K/J) Consultants is proposing a research study in response to RPSEA's Request for Proposals 2007UN001 in the interest area of water management associated with coalbed methane and gas shale production. The proposal is entitled *"An Integrated Framework for Treatment and Management of Produced Water"*. The project will be directed by Professor Jörg Drewes (CSM) with the following principal investigators: Professors Tzahi Cath and Pei Xu (CSM), John Veil and Dr. Seth Snyder (ANL), and Jim Graydon, (K/J Consultants). The project team will be supported by senior key personnel, Dr. Jean Debroux and Dr. Larry Leong, K/J Consultants, Dr. Bob Raucher, Stratus Consulting, Dr. Dean Heil as well as graduate students at CSM, Dr. Wayne Buschman with Eltron Research and Development, and two technical advisors, Dr. Jeff Cline, Cline Energy Consultants and Dr. Dave Stewart, Stewart Environmental. The project team will work closely with an Industry Advisory Council (IAC) and a Stakeholder Advisory Committee (SAC). The IAC, designed to review and guide this research, is comprised of industry professionals representing major gas producers (Anadarko, Chevron, Pioneer, Marathon, Petroglyph, Pinnacle, Triangle).

This study will focus on one of three primary areas of interest in this solicitation, - water management in coalbed methane and gas shales. It will bring together both producers and potential end-users to address the key issues associated with the management and treatment of produced water for beneficial use. The objectives of this study are fourfold:

(a) Collect data on the quality (composition) and quantities of produced water associated with unconventional gas production (CBM, gas shale) in the Western U.S. This assessment is essential for subsequent investigations regarding its suitability for beneficial use and will guide the research team and future users in selecting appropriate processes for water treatment and beneficial use applications.

(b) Explore the most appropriate and cost-efficient technologies for treatment of typical produced waters that will allow beneficial reuse of the treated water. Potential combinations of treatment processes will be selected from both well-established conventional processes that can be deployed in the field today and emerging technologies that show great merit for this application but which are not fully developed yet.

(c) Assess requirements to minimize environmental impacts and reduce institutional barriers to beneficial use of produced water.

(d) Compile the findings of the study into an integrative decision analysis framework for management of produced water leading to beneficial use.

The proposed research will develop an Integrated Decision Framework to manage and treat

produced water that has the potential to substantially reduce the overall costs and enhance gas recovery and economic viability (and longevity) of CBM and gas shale fields while minimizing potential environmental impacts. The results of this study will provide a technically sound, objective integrated framework to identify, quantify, evaluate and communicate both the extraordinary challenges and opportunities posed by the management of produced water in the arid west. The techniques and methods developed during this study will provide needed guidance to the industry in selecting the most cost-efficient management and treatment strategies for handling produced water by considering the site-specific conditions of CBM and gas shale operations.

Through cost-benefit analyses, this approach will help to promote more cost-efficient treatment technologies resulting in smaller brine volumes, aid in developing strategies to manage and dispose brine streams, and highlight beneficial use scenarios.

Project Title: **Comprehensive Investigation of the Biogeochemical Factors Enhancing Microbially Generated Methane in Coal Beds**

Performer: Colorado School of Mines, University of Wyoming, Laramie WY, U.S. Geologic Survey

EXECUTIVE SUMMARY

Research has shown that microorganisms are capable of converting coal to methane, though at widely different rates under controlled laboratory conditions. The methane is produced by methanogenesis, a process in which microorganisms (methanogenic archaea) convert substrates such as acetate or CO2 and hydrogen into methane. The overall objective of the proposed research is to systematically investigate processes involved in methanogenesis from coal to better understand how the process can be enhanced and accelerated. Project activities will include characterizing the following factors that may lead to enhanced methanogenesis: (1) specific chemical constituents of coal, analyzed by methods such as gas chromatography and mass spectrometry, (2) specific microorganisms identified via phospholipid and DNA analyses, (3) culture growth amendments and conditions such as pH, temperature, nutrient and salt levels evaluated by microcosm CH4 production, and (4) chemical pre-treatment of the coal with acids, bases, oxidants, solvents, and/or enzymes to release soluble organic matter that may subsequently stimulate the native methanogens. Additionally, the chemical pathways of methanogenesis from coal, the rate limiting steps and the interactions between microbial communities will be characterized and these dynamics will be captured in a computer model. All of these inquiries will provide a broader understanding of microbial methane production from coal, as a critical first step to ultimately stimulating methanogenesis *in situ*. These questions will be answered by a diverse and well qualified research team consisting of scientists from the Colorado School of Mines, University of Wyoming, and the United States Geological Survey, as listed above, as well as a private firm, Ciris Energy. Industry partners include Coleman Oil and Gas, Pinnacle Gas Resources and Pioneer Natural Resources.

Laboratory experiments have shown that the methane associated with coal can be increased from typical values of 60 SCF/ton to over 300 SCF/ton. As an example of the potential of enhanced methanogenesis, if 1% of the coal in the Powder River Basin could be converted to methane by adding inexpensive nutrients to stimulate existing microorganisms in the coal beds, approximately 30 TCF of gas would be produced, dramatically increasing reserves and profitability. In addition, if sufficient methane could be produced to exceed the solubility of methane in water, the gas could be produced without dewatering the coals, thus avoiding the costly dewatering step and its associated political and environmental complications.

Project Title: **Enhancing Appalachian Coalbed Methane Extraction by Microwave-Induced Fractures**

Performer: *The Pennsylvania State University*

EXECUTIVE SUMMARY

Project Description

This research (Enhancing Appalachian Coalbed Methane Extraction by Microwave-Induced Fractures) will evaluate if it is possible to generate new fractures and enhance existing cleats (aperture or length) by exposing coal to short exposures (seconds duration) of microwave energy under *in situ* stress conditions of coalbeds. It is known that microwaves can, in the absence of confining pressure, fracture coal. The approach has been used to reduce the energy required for pulverization. Our aim is to determine if microwave-induced fractures can be generated when the coal is under stress and if they will significantly enhance permeability. The existing and induced fractures will be evaluated at high resolution in 3 dimensions with an industrial X-ray facility. The cleats aperture will be calibrated with optical microscopy and the cleat surfaces (roughness) by optical profile techniques. By creating new cleats/fractures, lengthening or widening existing cleats, the permeability and hence methane gas flow will increase. The permeability increase to methane will be evaluated on an Appalachian bituminous coal core.

Impact and Benefits:

Better coalbed or coalmine methane drainage technologies could save lives, enhance domestic coalbed methane production, and reduce coalbed methane emissions that contribute to climate change. Such an approach may also prove favorable to increasing the rate of CO_2 injection for enhanced coalbed methane extraction.

Major Participants:

The research will be performed at The Energy Institute at the Pennsylvania State University under the direction of Drs. Jonathan Mathews and Phillip Halleck with research contributions from Nottingham University, England.

Research Area: Tight Sands

Project 1 Title: **Novel Concepts for Unconventional Gas Development in Shales, Tight Sands and Coalbeds**

Performer: *Carter Technology*

EXECUTIVE SUMMARY

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Objective: The project objective is to prepare a preliminary study of novel methods of formation stimulation to increase the production of large amounts of gas in shale, coal, and tight sandstone formations. This is a preliminary study of novel concepts for the development of unconventional gas resources that differ significantly from the traditional drilling and stimulation methodologies.

Methods of mechanically or hydraulically cutting large infiltration galleries connected to the well bore will be evaluated and numerically modeled. These slots are similar to steerable fractures only larger. The best concepts will be integrated with advanced fracture propagation and propping concepts for form a hybrid stimulation technique. Concept and design drawings will be prepared and cost estimates developed.

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The proposed methods do not rely on detailed knowledge of the natural fracture systems and therefore may be applicable to formations with limited data. If successful, this project will allow more efficient drainage fields with higher recovery rates.

Collaborative associates for the project include M-I LLC, a Smith/Schlumberger Company, and professors from the University of Oklahoma and the University of Houston.

Project Title: **Application Of Natural Gas Composition To Modeling Communication Within And Filling Of Large Tight-Gas-Sand Reservoirs, Rocky Mountains**

Performer: *Colorado School of Mines*

EXECUTIVE SUMMARY

The following proposal is offered by Colorado School of Mines. The Project Manager / Principal Investigator is Dr. Nicholas B. Harris, Research Associate Professor, Department of Geology and Geological Engineering.

The project title is "Application of Natural Gas Composition to Modeling Communication Within and Filling of Large Tight-Gas-Sand Reservoirs, Rocky Mountains."

The large tight-gas-sand reservoirs of the Rocky Mountains comprise a major natural gas resource in the United States. While it is clear that these reservoirs fill from the bottom up, not from a top seal downward as do conventional reservoirs, the process(es) by which gas migrates into these reservoirs is unknown. Possible mechanisms are that: (a) gas diffuses upward through a series of moderately permeable seals, (b) gas forces its way upward by fracturing intermediate seals, or (c) gas migrates up conduits such as faults or fracture systems and then diffuses laterally.

Each model has implications for predicting the top of gas within fields and the distribution of fields within a sedimentary basin and for estimating the scale of the natural gas resource with sedimentary basins. We also do not know the extent to which gas can circulate within a field or the extent to which circulation is restricted by stratigraphic or structural barriers.

We propose to use the composition of natural gas samples from several major tight-gas fields in Wyoming, Colorado and Utah, to test possible mechanisms for gas migration into the tight-gas sand reservoirs and communication within such reservoirs. We will integrate data on bulk hydrocarbon composition, the isotopic composition of hydrocarbon gases and CO_2 and the noble and radiogenic gases from these gas fields with experiments to determine the composition of gas entering the reservoir from source rocks and gas migration computer models. If this research is successful, we will have identified new tools and models that can be used by natural gas resource companies to enhance their development of these fields and to discover new fields. This research may also lay the groundwork for geophysical approaches to the direct detection of natural gas tight-gas-sand reservoirs.

Project Title: **Reservoir Connectivity and Stimulated Gas Flow in Tight Sands**
Performer: *The Colorado School of Mines*

EXECUTIVE SUMMARY
Production of natural gas from tight sandstone reservoirs is a complex interplay of flow from rock matrix to natural fractures, flow within complex networks of natural fractures, and flow within different complex networks of hydraulic fractures. In cases of such high complexity, no single technology or scientific discipline can alone tell the story. Instead, only an integrated workflow combining the clues from the various disciplines: seismic, rock mechanics, petrophysics, geology, and production, can stand a chance of realistically capturing the complexity of flow in fractured tight gas systems. For that reason, we have assembled a team covering all these disciplines and with experiences ranging from theory, through lab experiments to practical oil and gas field applications. Today's common approach is to identify a gas-bearing zone and then – after the fact – find "sweet spots" where production wells hit the right combination of charge, permeability and accessible gas volume. Tomorrow's "sweet spots" should be 'engineered', based on knowledge of what fracture patterns will result from a particular process, under conditions of known stress fields, in sand bodies with predictable connectivities, and with reservoir parameter distributions consistent with a well-documented rock body architecture.

The project will include the development of static reservoir models based on all available subsurface data at the Mamm Creek field, calibrated by LiDAR and other outcrop data from equivalent reservoir rocks on the adjacent outcrops at the Grand Hogback. These models will provide the 'boundary conditions' for geomechanical predictions of fracture propagation and the analysis of dynamic performance through multi-phase fluid-flow simulations. Rock mechanical modeling is included to try to predict fracture behavior in these specific rocks, and a complete suite of seismic data will also be used to document what the fractures actually do in nature. These include multi-component 3D, vertical seismic profiles, azimuthal AVO, and microseismic and electric (self potential) tools to monitor fracture propagation. Finally, in order to allow extrapolation of the findings at and around the Mamm Creek field to targets elsewhere in the Piceance basin, one project team will map the regional stratigraphic, structural and depositional systems trends to help identify conditions likely to be associated with "sweet spots".

The project team consist of engineers, geophysicists and stratigraphers from the Colorado School of Mines, the University of Colorado – Boulder, Mesa State University and iReservoir.com.

Project Title: **Petrophysical Studies Of Unconventional Gas Reservoirs Using High-Resolution Rock Imaging**

Performer: *Lawrence Berkeley National Laboratory*

EXECUTIVE SUMMARY

The main objective of this work is to determine (a) the physical mechanisms that limit gas recovery from tight rock formations, and (b) the means of extending this recovery as far into the future as possible. Because the mechanisms that block gas flow in the formation and near the wellbore are not fully understood, we propose to use the sophisticated petrophysical imaging tools and theoretical calculation methods at our disposal to elucidate them. Once we better understand the key factors that influence the rate and ultimate level of gas recovery, we will investigate methods of changing the formation properties volumetrically to optimize production in space and in time. The usual approach of highly discounting the future recovery may no longer be applicable in a world in which real energy prices will be growing faster than the local (e.g., state) economies.

We propose to acquire high-resolution images of gas-bearing shale rocks using Advanced Light Source (ALS) facility and Focused Ion Beam (FIB) technology at Lawrence Berkeley National Laboratory (LBNL), and analyze these images using Maximal Inscribed Spheres-type methods in order to estimate gas shale and tight sand flow properties at different, including in situ, conditions. These approaches have been developed at LBNL and University of California at Berkeley (UCB) and have been successfully applied to studies of chalk, diatomite, and sandstone. We will investigate the impact of pore-space geometry in different rock formations on flow properties, including absolute and relative permeabilities, capillary pressure, and Klinkenberg coefficient. We will use the 3D images of the rocks acquired in this project to develop depositional models and to link the petrophysical properties of the rock to the geology and geological history of the reservoir.

A thorough and comprehensive study of existing unconventional gas-bearing formations will create a knowledge base for the development of emerging and frontier developments. The proposed study is fundamental, and acquired knowledge will be equally applicable in short- and long-term technology developments.

Project Title: **Gas-Condensate Productivity in Tight Gas Sands**
Performer: *Stanford University / Department of Energy Resources*

EXECUTIVE SUMMARY

Objectives:

The objective of the project is to develop methodology to increase the productivity of gas-condensate fluids from tight gas reservoirs in the US.

Description of the Project.

Presently, gas-condensate reservoirs experience reductions in productivity by as much as a factor of 10 due to the dropout of liquid close to the wellbore. The reduction is worse in low permeability formations that make up tight gas reservoirs. The liquid dropout blocks the flow of gas to the well and lowers the overall energy output by a very substantial degree (90% if the productivity is reduced by 10). The combination of condensate phase behavior and rock relative permeability results in a change of composition of the reservoir fluid, as heavier components separate into the dropped-out liquid while the flowing gas phase becomes lighter in composition. This effect has been sparsely recognized in the literature, although there is clear evidence of it in field observations. The project will quantify the effect, develop a scientific understanding of the phenomena, and use the results to investigate ways to enhance the productivity by controlling the liquid composition that drops out close to the well. By optimizing the producing pressure strategy, it should be possible to cause a lighter liquid to be condensed in the reservoir, after which the productivity loss would be more easily remedied. The research will make use of experimental measurements of gas-condensate flow, as well as compositional numerical simulations.

Impact and Benefits

The potential impact of the project will be to develop a production strategy (based on the control of well producing pressure) to limit the loss of productivity in gas condensate wells in tight gas sands. More gas will be produced to the consumer.

Title: **Advanced Hydraulic Fracturing Technology for Unconventional Tight Gas Reservoirs**

Performer: *Texas A&M University*

EXECUTIVE SUMMARY

Objective:

The central role of hydraulic fracturing in enabling economic production from unconventional gas reservoirs makes it clear that advances in the economic application of hydraulic fracturing will add substantial unconventional gas reserves to the nation's future gas supply. The objectives of this proposed research are to develop new methods for creating extensive, conductive hydraulic fractures in unconventional tight gas reservoirs by statistically assessing the productivity achieved in hundreds of field treatments with a variety of current fracturing practices ranging from "water fracs" to conventional gel fracture treatments; by laboratory measurements of the conductivity created with high rate proppant fracturing using an entirely new conductivity test – the "dynamic fracture conductivity test"; and by developing design models to implement the optimal fracture treatments determined from the field assessment and the laboratory measurements.

Description of Project:

First, we will conduct a thorough data-driven study of current field practices in hydraulic fracturing of tight gas reservoirs. We will develop an advisory system based on the database to guide optimal fracture design. Second, we will develop new fracture conductivity testing procedures to more closely simulate the process occurring in high-rate, low proppant concentration fracturing. In these dynamic fracture conductivity tests, we will inject proppant/frac fluid slurries under realistic field conditions, and then shut-in the conductivity cell to simulate the way conductivity is actually created. By applying a fresh approach to determining the manner in which proppant is placed and fracture conductivity created in low-permeability gas well fracturing, we aim to develop novel, systematic treatment design procedures to develop the next generation of hydraulic fracturing technology for these reservoirs. We expect this new understanding to lead to improved designs of hydraulic fracturing treatments, with changes possible in the proppant loading and schedule, proppant type and size, and fluid type and polymer loading. Finally, we will implement the findings of the field treatment analysis and the laboratory studies to design optimized hydraulic fracture treatments.

Impact and Benefits:

Success in improving tight gas hydraulic fracturing technology from the research proposed will increase recoverable gas reserves in virtually every tight gas basin in the United States.

Project Title: **Optimizing Development Strategies to Increase Reserves in Unconventional Gas Reservoirs**

Performer: *Texas Engineering Experiment Station*

EXECUTIVE SUMMARY

Objective:

The goal of the proposed project is to develop integrated reservoir and decision models to help operators in unconventional gas reservoirs increase reserves and accelerate production, while protecting the environment, by determining the optimal well spacing and completion strategy as quickly as possible. This goal requires explicit modeling of subsurface uncertainty and advanced decision tools that take this uncertainty into account to optimally manage risk. These tools and methods will be developed within the context of existing and emerging gas shale and tight gas reservoirs.

Project Description

According to the National Petroleum Council, North America has over 5000 trillion cubic feet (TCF) of natural gas resources in shale or tight sand formations. While this resource base is large, developing it in an economic and environmentally sensitive manner is challenging. For example, in the lower 48 United States, around 300 TCF of the shale gas and tight gas is estimated to be recoverable using existing technology. In specific development areas such as the Barnett Shale, current recovery per well averages just 7% of gas in place --- far below the 20% that many believe is achievable. In addition to low recovery rates, operators in unconventional reservoirs must invest large amounts of capital and face significant risks.

To address this challenge, the Texas Engineering Experiment Station (PI's Duane A.McVay and J. Eric Bickel) proposes to develop new technologies and methods for determining optimal development and testing programs, including well spacing and completion practices, in gas shale and tight sand reservoirs. The core of this technology will be an integrated reservoir and decision model that fully incorporates uncertainty. The reservoir model will be based on moving window and reservoir simulation techniques, while the decision model will employ dynamic programming to determine the optimal development and testing program.

Impact and Benefits:

This research will increase the Nation's gas reserve base and accelerate production by enabling operators to determine optimal development plans sooner, rather than over 20-30 years as has happened historically. In addition, optimal development will minimize the number of wells required, with attendant environmental benefits. This is particularly important since some large unconventional gas reserves lay under densely populated urban areas.

Major Participants:

Drs. McVay and Bickel will pursue this research in collaboration with Unconventional Gas Resources (UGR) and Pioneer Natural Resources Company (Pioneer). Both of these companies have extensive experience in the development of America's unconventional gas reservoirs. The technology and tools developed will be applied in Pioneer's Barnett Shale asset and UGR's tight gas assets in the Berland River Area, Alberta.

Project Title: **Novel Fluids for Gas Productivity Enhancement in Tight Formations**

Performer: *University of Tulsa*

EXECUTIVE SUMMARY

Objective:

Develop novel fluids for remediation and fracturing by better understanding the impact of fluid properties on the performance of flowback of gas in tight gas wells.

Project Description

Natural gas is increasingly becoming the fuel of choice due to its cleaner burning properties. In the continental United States and many parts of the world large volumes of natural gas are available in very difficult to produce formations such as shales, tight sands, coalbeds and hydrates.

Our research program aims to address key issues to enable recovery from these resources through improved completions and stimulation fluids. Due to the low permeability of the unconventional formations fracture stimulation is most commonly used to recover more gas. Fracture treatments are frequently performed with polymeric fluids and the impact of the invasion of these fluids is to depress the productivity of the gas well. Invasion of aqueous fracturing fluids during stimulation operations can reduce the relative permeability to gas resulting in a “block”. The invaded fracturing fluid establishes a region of high saturation in the rock formation near the fracture, and can significantly reduce the relative permeability and hence the productivity of the well. We propose to develop novel fluids for remediation and fracturing by better understanding the impact of fluid properties on the performance of flowback of gas in tight gas wells.

Impact and Benefits:

The results of this study will enable better selection of treatment fluids to remediate non-performing tight gas wells and also strategies for fluid additives selection in fracturing fluids for future applications.

Title: **Improved Reservoir Access Through Refracture Treatments in Tight Gas Sands and Gas Shales**

Performer: *University of Texas, Austin*

EXECUTIVE SUMMARY

Project Description:

The primary challenge facing gas producers in unconventional gas plays is the rapid depletion rate of new wells and their relatively high cost. Rapid decline rates require that many new wells be drilled just to maintain production. To address these concerns, this proposal aims at developing methods for improving reservoir access through existing wellbores so as to minimize drilling and completion costs. This can be accomplished by reducing the number of wellbores drilled by suitably fracturing and re-fracturing both vertical and horizontal wells.

Re-fracture treatments are widely applied in gas shales and tight gas sands but with highly variable success rates. Current methods for candidate well selection are primarily based on statistical data available from past treatments in the play. Re-fracture designs do not take into account changes due to near-wellbore and reservoir stresses and pre-existing proppant packs which can have a big influence on the design of re-fracture treatments. This proposal aims at developing a systematic methodology for providing an operator the following key deliverables:

A well defined methodology for candidate well selection based on poro-elastic models and analysis of field data.

Recommendations and charts for the time window most suitable for re-fracturing, for a range of reservoir types, reservoir properties and production profiles.

Application of re-fracture treatments in horizontal and deviated wellbores

Re-fracture treatment designs utilizing novel fluids, proppants and injection strategies.

This will be accomplished through field application of newly developed geo-mechanical models, proppant placement strategies, and better re-fracture designs based on novel fluids and proppants.

Project Title: **Optimization of Infill Well Locations in Wamsutter Field**

Performer: *University of Tulsa*

EXECUTIVE SUMMARY

Project Description:

One of the most important challenges the operators of tight gas reservoirs face is optimizing infill well locations. Unlike conventional reservoirs, optimization of infill well locations in tight gas reservoirs is significantly difficult for the following reasons:

The tight gas reservoirs show significant variation in reservoir properties and lack of spatial continuity. It is difficult to determine the contributions from a new well due to acceleration of production and incremental addition due to connection of new drainage volumes.

These sands, on a gross basis, tend to be quite thick. During the up-scaling of fine-scale models for simulation purposes, the sands will create appearance of connectivity which does not exist in the finescale model.

The distinction between static and dynamic connectivities needs to be recognized. Sands which appear continuous may not help production due to very low permeability and convoluted flow patterns resulting in lack of dynamic continuity.

The orientation of hydraulic fractures can make a difference in optimizing well spacing.

The proposed project, Optimization of Infill Well Locations in Wamsutter Field, addresses specific issues in the Wamsutter gas field, one of the largest gas fields in the Rocky Mountain region. The solutions proposed here can be used in other similar tight gas reservoirs.

We use a combination of streamline simulation and modified flow simulation methods to properly account for the dynamic connectivity in the reservoir. After generating the reservoir descriptions, through the use of streamline (time of flight) concept, we will determine the connected volume to a single well. We will ensure consistency between the time of flight and the EUR. We will then remove the unconnected volume during the flow simulation, and "add" new connected volume as new wells are drilled. History matching of the earlier production data will be based on fracture orientation and its conductivity. Using the proposed approach, we will be able to address the following:

Contribution to well performance due to acceleration and incremental production due to connected volumes.

"Sweet spots" within the representative areas of the Wamsutter field where infill drilling on 40-acre spacing is economically justified.

Effect of fracture orientation on the optimal well spacing.

Major Participants:

The project will involve The University of Tulsa (Offeror), Texas A & M University and Devon Energy Corporation. The principal investigator is Dr. Mohan Kelkar of The University of Tulsa. Dr. Akhil Datta-Gupta will lead the effort at Texas A & M University. The project will be substantially cost leveraged by Devon Energy, paying for more than 80% of the total cost of the project.

Project Title: **Gas Production Forecasting from Tight Gas Reservoirs: Integrating Natural Fracture Networks and Hydraulic Fractures**

Performer: *University of Utah*

EXECUTIVE SUMMARY

Objectives:

The following objectives have been set forth to address these significant tight gas production issues.

1. Existing and new geologic data will be used to create fracture network maps.
2. Propagation of hydraulic fractures given the natural fracture system and the existing stress condition in the system will be examined.
3. Gas production from these systems will be studied by combining the natural and hydraulic fractures into multiphase discrete fracture network reservoir models.

Project Description:

The Uinta Basin in eastern Utah is a significant producer of "unconventional" gas in the United States. Tight gas reservoirs in the Basin, spread across several prolific formations span thousands of vertical feet and may contain as much as 14 TCF of natural gas. Because the very low permeability of the matrix rock, understanding the geometry and properties of natural fractures is critical to the development of effective ways of finding and producing the gas. It is also important to create hydraulic fractures to take maximum advantage of the existing natural fractures. The multiphase flow of gas and water toward the production wells depends on the interplay between the characteristics of fractures (natural/hydraulic), and prevailing relative permeabilities, and capillary pressures in the reservoir.

Even though the initial focus of the project team will be the Mesaverde formation, deeper Dakota, and other formations will also be studied. Outcrop, log and other data will be used to create static fracture models, which will be evolved into dynamic models by considering well tests. State of the art geomechanical tools will be used to obtain hydraulic fracture geometries, given the fracture/stress state of the reservoir. These geometries will be represented explicitly in the University of Utah discrete-fracture network reservoir simulators to obtain realistic assessments of gas production from tight gas reservoirs. The project team will develop a protocol for creating field-wide natural fracture networks, given static and dynamic reservoir information. Tools will be developed to determine more realistic hydraulic fracture geometries in vertical and horizontal wells. This will provide better understanding of designing hydraulic fractures to intersect existing natural fractures. Reservoir simulation of these realistic features will help optimize drainage and minimize costs.

Major Participants:

The team to accomplish these tasks includes reservoir simulation and hydraulic fracturing experts at the University of Utah, fracture specialists at Utah State University, Uinta Basin specialist geologists at Utah Geological Survey, FRACMAN (fracture generation software) creators Golder and Associates and UDEC (Universal Distinct Element Code, hydraulic fracture creation software) developers ITASCA. Gas producers in the Basin, Anadarko and Windriver Energy will participate in the project.