PUBLIC EXECUTIVE SUMMARY

Gas Well Pressure Drop Prediction under Foam Flow Conditions

The University of Tulsa (Offeror)

Mohan Kelkar, Principle Investigator

One of the most important challenges the operators of tight gas reservoirs face is maintaining sustained production from these wells. One of the characteristics of tight gas wells is the significant drop in production rate over a short period of time. Since most of these wells produce some water, without some type of artificial lift method, it is difficult to sustain production from these wells. One of the most common techniques used for lifting the water is foam lift; this involves injecting surfactant in the well so that in-situ foam between gas and water is created, and the foam is produced to the surface which includes water and gas. For deep gas wells with small amounts of water production, foam lift is the most economical method. Unfortunately, no correlation exists to calculate the pressure drop under foam flow. Therefore, operators are unable to correctly predict the performance of the well under foam flow conditions. In addition, since we cannot predict the time of abandonment, we cannot determine the reserves for the wells which are on foam lift.

The proposed project addresses the issue of pressure drop calculation under foam flow condition. By using available data from vendors and field measurements, as well as collecting data from new experimental facility, we will develop suitable correlations to calculate the pressure drop in vertical gas wells.

We will use a combination of both experimental data and theoretical modeling to develop this correlation. We will produce and characterize the foam, determine bubble rise velocity, and collect pressure drop data in both 2” and 3” tubings, using different surfactants employed in the field. We will validate our correlation by comparing the results with the field data. Using the proposed approach, we will be able to address the following:

- Predict the pressure drop in tubing under foam flow conditions; and hence the rate at which the well can be produced and optimized
- Predict the future performance as well as the time of abandonment of the well as the reservoir is depleted

The project will involve The University of Tulsa (Offeror), Marathon and Chevron. The principal investigator is Dr. Mohan Kelkar of The University of Tulsa. The cost share will be provided by Marathon, Chevron and The University of Tulsa.

PUBLIC EXECUTIVE SUMMARY

RFP number: 2009UN001

Offered by Higgs-Palmer Technologies

Project director: Ian Palmer

Project title: Characterizing Stimulation Domains, for Improved Well Completions in Gas Shales.

Objectives of the project: (1) Develop a method and a prototype screening software tool to characterize how flow properties change within the domain of a well stimulation, both during and after the stimulation. (2) Develop two permeability-based diagnostics of the domain stimulation, and relate these to fracture treatment parameters. (3) Use the results as a guide to improvements in well stimulations, leading to accelerated gas production and recovery. (4) Demonstrate the prototype tool by application to field data. The prototype tool will be designed so that it can be used systematically by an operator to diagnose well stimulations, and point to improvements.

Description of the project, including methods: The objectives will be achieved by combining our in-house programs for predicting shear failure (geomechanics basis) and for rate-transient analysis (RTA). The seamless software will require serious development to include post-transient flow, pressure-dependent permeability, and guidelines for proppant design in fracture networks. The screening software will be designed to quantify both injection permeability (by predicting shear failure and matching a microseismic pattern), and production permeability (by using RTA to match gas rate), and to compare them with virgin permeability. The next step is to program into the software tool two different permeability-based diagnostics (production permeability and loss of injection permeability), and to relate these to fracture treatment parameters (such as poor fracture fluid cleanup, damage by chemicals in the frac fluid, and inadequate proppant design), for the purpose of improving well stimulations. The next objective is to mitigate the injection perm loss by creative design of proppant injection to prop open the natural/induced fractures before they close (ie, to re-invent proppant design applicable to a fracture network). This will be achieved by a simplified, practical theoretical study of the transport of different proppants through a network of fractures. How to get proppant into a network of fractures, with good coverage, is a critical aspect. The results will be summarized in the software tool so that an operator can be guided to choose a proppant design to improve the domain stimulation. The prototype software tool will be demonstrated by application to field data (microseismic, gas rates, and stimulation parameters) in 6 horizontal wells.

Key deliverables: The overall deliverable is a user-friendly software tool, which can be used by operators to fully characterize flow properties of stimulation domains, and provide guidance to improve well stimulations. A second deliverable is a summary of the damaging effects of fracture treatments on natural/induced fractures. A third deliverable is a simplified but practical theoretical analysis and report of proppant transport in a fracture network, including access to fractures, penetration into fractures, and resulting fracture conductivity. The final deliverable is a demonstration of the tool using data from 6 wells in the Fayetteville shale, a proven shale play where there are over 1,000 horizontal multi-stage fracture-stimulated wells for comparison.

Potential impact: This is an R&D project, and the potential is attractive. The key is diagnosing and improving well stimulations, with a direct impact on gas production and recovery. The new perm-based diagnoses should be insightful in regard to improving well stimulations. The correlations with fracture treatment parameters should lead to significant improvements. For example, if by changing proppant design to retain more of the injection permeability we could boost gas rates by up to a factor of two, this would be an enormous benefit to gas shales (this scenario appears possible). The potential impact, on production and reserves, of the field demonstration will be insightful at the least, and could be revolutionary at best. The learnings should have a high degree of application to other shales.

Other participants involved in the work:

Aetman Engineering of Houston, PCM Technical of Tulsa, Southwestern Energy Company of Houston.

Organizations providing cost-share:

Higgs-Palmer Technologies, PCM Technical, and Southwestern Energy Company

09122-03

RFP Number: **RFP2009UN001 (Unconventional Onshore Program)**

Project Title: **Advanced Flow Management Strategy for Unconventional Gas Evaluation and Production**

Date: December 4, 2009

Offeror: **Stratamagnetic Software, LLC**
5830 Doliver Dr., Suite 53
Houston, Texas 77057
DUNS # 13-921-0343

Cost Share: Stratamagnetic Software, LLC (20%)

Technical and Contractual Contact: **Wilson C. Chin, Ph.D., MIT**
President, Project Director and Principal Investigator
Houston Cell: 832-483-6899
Email: **wilsonchin@aol.com**

Public Executive Summary

The Unconventional Resources program seeks to maximize domestic natural gas production by optimizing efficiencies in exploration and production while improving safety and minimizing environmental impact. Two needs are highlighted, gas shales and tight sands. We address both given these similarities: permeabilities are very low, hydraulic fracturing is used to increase flow, and formation properties change with production. We emphasize that our methods also apply to oil in conventional reservoirs. We address the complete business cycle by integrating three key areas: improved formation evaluation, enhanced production, and dynamic reservoir description for effective gas field management.

For improved formation evaluation, our preferred well logging instrument is the formation tester, which collects in-situ samples for laboratory evaluation. Flowline transients obtained while pumping, interpreted using Darcy flow models, provide direct permeabilities and anisotropies key to forecasting cash flow and production. Unlike traditional, time-consuming, steady-state methods that increase the likelihood of stuck or lost tools, an environmentally unacceptable consequence, two new fast approaches, i.e., “pulse interaction” and “phase delay,” using early time data are developed. Our models for HPHT gas flow apply at all dip angles but especially focus on horizontal wells. These work best in very low permeability media, maximizing efficiency and increasing resolution while improving safety.

For enhanced production, we develop new reservoir simulators for liquid and gas flow modeling from systems of general 3D multilateral wells containing horizontals that snake and bend arbitrarily. These wells host finite planar, nonplanar, parallel or obliquely intersecting fractures. Liquid capabilities help fracture design, while gas options facilitate production. The objective is a strategic planning tool offering the possibility of fewer wells utilizing fewer but more efficiently deployed fractures. Drilling and stimulation costs are reduced and environmental benefits are significant. Fewer wells means minimal surface footprint associated with rig operations – reduced fracture numbers imply lower water costs, less subsurface contamination and diminished chance of fracture propagation into water tables and aquifers.

For dynamic reservoir description, we develop coupled reservoir flow and geomechanics models that adjust rock properties as formations are produced and stimulated, focusing on coupling mechanisms associated with complicated horizontal and multilateral well systems that host multiple fractures. This reservoir management tool supports improved characterization as production data becomes available, providing updated permeability, porosity and dynamically changing flowpath information needed for infill drilling and other development strategies. Math models for surface gas are similar to those for soil mechanics and subsea oil production in subsidence, compaction and wellbore stability studies. We will efficiently draw upon available R&D and develop integrated flow and geomechanics methods for complicated three-dimensional well systems. Our work addresses the entire business cycle from formation evaluation to production to subsequent flow enhancement. Not only will our methods target gas flows in tight consolidated rock and naturally fractured media, but they apply to oil production from conventional reservoirs and thus improve our overall technology base.

Public Executive Summary

Name of Offeror: Gas Technology Institute (GTI)
Principal Investigator: Mr. Iraj Salehi
Project Title: Marcellus Gas Shale Project
Solicitation Number: RFP2009UN001

The **Marcellus Gas Shale** is an emerging resource that covers an area of 54,000 square miles across four states with estimates of 63 tcf of producible gas. The **Objective** of this research is to develop technologies to overcome the technical and environmental challenges preventing the expansion of Marcellus production through a field based project. ***The project serves the RPSEA objective of enhanced shale gas production from the Appalachian region.***

Gas Technology Institute has formed a team of prominent experts from Pennsylvania State University, Bureau of Economic Geology, West Virginia University, Pinnacle Technologies, and ResTech.

The proposed project also coordinates with ongoing RPSEA research. Related research at Stanford University, Lawrence Berkeley National Laboratory, and Texas A&M is being integrated to avoid research duplication and leverage research dollars.

Industry participation includes the leading developers of the Marcellus (Range Resources), providing detailed field data and testing utilizing wells of opportunity provided by Range Resources. **The value of the data and wells provided by Range Resources, and cost sharing by the Research Team exceeds $1,650,000.** In addition, GTI will include the Marcellus Shale Committee (MSC - consisting of 33 producing members.) The MSC membership provides an effective technology transfer venue where results of the project will be reviewed on a regular basis. Duration of the project will be 18 months and the following technical issues will be addressed. These include: Basin-level Resource Characterization, Formation Evaluation, Fracture Modeling and Diagnostics, Reservoir Engineering, Field Data Acquisition; and Data Analysis, Coordination, and Technology Dissemination.

Project Deliverables include: 1) Geological database of results integrated with all project data, 2) Report describing the geological conditions for promising production potential, 3) Techniques for optimized fracture stimulation of Marcellus horizontal wells, 4) Assessment of reservoir production characteristics including conductivity and influence of natural fractures, and effective stimulated reservoir volume. The **Technology Transfer Plan** includes open industry workshops, presentations at MSC meetings, other industry conferences as well as web based reporting. Benefits of the research effort will accrue through a better characterization of the resource, enhanced fracture stimulation, and reliable reservoir assessment. **The project has a goal of leading the way to convert the immense technically recoverable Marcellus gas into an economically recoverable reserve.**

PUBLIC EXECUTIVE SUMMARY–Performance Verification of Proppants Derived from Indigenous Raw Materials for Use in Gas Recovery from Shale Deposits. Dr. John Hellmann, PI

Objective: This project shall verify the performance of proppants manufactured from alternative raw materials in hydrofracturing and stimulation of gas shales in the Marcellus play.

Description: The availability of Ottawa and Brady sands as well as high grade bauxites and kaolins currently used in state of the art proppants for oil and gas extraction are experiencing depletion at a significant rate and are therefore becoming increasingly more expensive. Furthermore, with the development of new gas and oil reserves, such as the Marcellus play, transportation costs to deliver the proppant to the site of use is a large portion of the cost of hydrofracturing. Research at Penn State over the last decade has demonstrated the ability to manufacture proppants from indigenous raw materials which exhibit properties and performance exceeding that of sands, and rivaling the best state-of-the-art sintered bauxite and kaolin-based materials. The advantages of this approach include a cheaper and readily available source of raw materials, which are nearby their site of application, thereby significantly lowering their cost in the hydrofracturing process. The research on and development of proppants from indigenous raw materials (such as mixed glass cullet and basalt-, rhyolite-, and andesite-based glass ceramics) is nearing completion, and the next step in their deployment as alternatives to current state of the art proppants is the verification of their performance in an experimental test well.

Key deliverables: Deliverables are the development of new, significantly less expensive and more readily available proppant materials and the related hydrofracturing technology to permit their use in emerging gas plays in the Appalachian Basin and elsewhere.

Potential Impact: The use of indigenous raw materials and local manufacturing infrastructure will significantly moderate the cost and enhance the availability of proppants used in domestic hydrofracturing operations. The project integrates materials research and development with the raw materials supply chain, large scale industrial manufacturing, and gas well hydrofracturing and service industries to ensure the deployment of a new technology which offers significant cost savings to the oil and gas industry.

Other Participants: Dr. Barry Scheetz, Professor of Materials and Civil Engineering and David L. Shelleman, Senior Research Associate, Department of Materials Science and Engineering, Penn State

Cost share: Cost share is provided in the form of graduate student stipend/tuition, as well as financial and in-kind participation from industrial collaborators in providing raw materials (ISP, PA Recycling Markets Center, MO-SCI Corp., and Vogel Disposal Services Inc.), processing expertise and manufacturing capability (ISP, Ajax Electric Co., MO-SCI Corp., Sinew, Inc., and Potters Inc.), and gas well development and services (Kroff Inc. and Superior Well Services Inc.)

09122-06

PUBLIC EXECUTIVE SUMMARY

Offeror: West Virginia University Research Corporation

PI: Dr. Yueming Cheng; Co-PI: Prof. Samuel Ameri

Project Title: Prediction of Fault Reactivation in Hydraulic Fracturing of Horizontal Wells in Shale Gas Reservoirs

Objectives: In this proposal, the PI's goal is to develop an advanced method to predict fault reactivation and improve effectiveness of hydraulic fracturing stimulation of horizontal gas shale wells. The proposed project will target at the Marcellus shale in Appalachian Basin. Four specific objectives are proposed: (1) to assess the reactivation potentials of faults by identifying the in-situ stress conditions of faults nearby fracture treatment wells; (2) develop a propagation model for multiple fractures simultaneously created; (3) to extend current 2D stress model to characterize the stress state changes of a fault and near-fault zones, and predict fault slippage due to hydraulic fracturing; (4) to optimize fracture design avoiding reactivation of faults.

Description: Gas shale represents ultra-low permeability reservoirs and requires multi-stage hydraulic fracturing treatments to be economically viable. Hydraulic fracturing itself is featured with complex fracture propagation and geometries. In the Marcellus shale, the reservoir structure is complicated by large fault networks. Faults nearby wells may be reactivated by hydraulic fracturing. The reactivated fault can cause early aborting or failure of fracturing treatment and fluid leakage along the fault. To identify the potential of fault reactivation caused by hydraulic fracturing, we will use boundary element method to develop a multi-fracture propagation model coupled with stress variation model to describe the interaction of stress field and fracture geometry. With these models, the stress state at any point of interest in the reservoir can be determined during the process of fracturing stimulation and hence the fault reactivation can be quantitatively evaluated based on geomechanic principle and criteria. The results of the proposed research will improve the understanding of physical phenomena related to successful stimulation and recovery of gas shales, and lead to advances in hydraulic fracturing technology applied to Marcellus shale in Appalachian Basin.

Key deliverables: The proposed project will deliver a new technology and associated software application to provide a rapid and cost-efficient assessment of the feasibility and effectiveness of a hydraulic fracturing, and an effective fracturing design avoiding hazard situations of reactivating of faults. While we believe the software will have commercialization potential, the objective of this project is development of the technology, not commercialization of software.

Potential impact: The research described in this proposal is novel and transformative because, if successful, ineffective fracturing treatment will not be initiated and risks of reactivating faults can be mitigated so that we can reduce treatment cost and gas leakage impact on environment. The outcome of this research can be used to guide hydraulic fracturing design by optimizing fracture spacing and fracture length while avoiding reactivation of faults. Ultimately, the proposed research will enhance the economic and energy security of the U.S. by improving the efficiency of energy resource exploration and the supply of domestic natural gas.

Other participant: Range Resources – Appalachian LLC

Organization providing cost-share: West Virginia University College of Engineering and Mineral Resources and the Department of Petroleum and Natural Gas Engineering.

EXECUTIVE SUMMARY

Offeror: Utah Geological Survey, Salt Lake City, Utah

Project Director/Principal Investigator: Craig D. Morgan
Major Participants (Partners):
University of Utah
Halliburton Energy Services

Cretaceous Mancos Shale Uinta Basin, Utah: Resource Potential and Best Practices for an Emerging Shale Gas Play

Existing gas production in the Uinta Basin could be greatly enhanced by the addition of gas reserves in the Cretaceous Mancos Shale. The Mancos Shale is an emerging shale gas play, but both the geologic and engineering insights are immature, presenting the industry with poorly constrained exploration and development risks. As with many emerging shale gas resources, the resource has not been fully characterized, reliable estimates of gas in place are not available, and production potential is poorly constrained. Specifically, among the thousands of feet of strata the optimum intervals and best exploitation strategies are unknown. To quantify the plays' financial risks, accurate geologic and geophysical characterization must be integrated with reservoir specific engineering practices. To accomplish this, the proposed project will:

1. Characterize the geology (sedimentology, stratigraphy, organic, stable isotope, and inorganic geochemistry, natural fracture analysis, and geophysical and 3-D seismic analysis) of the Mancos Shale in the Uinta Basin in order to identify premium target zones, and determine the resource potential.
2. Define the geologic parameters that determine various geomechanical properties (i.e. brittleness, "fracability"). These relationships are currently poorly understood. Use defined relevant geologic parameters to predict regions of brittleness ("fracability") and Mancos shale gas prospectivity, from an engineering perspective.
3. Establish best drilling, completion, and production techniques for specific targeted intervals based on their rock properties.

Geologic and engineering evaluation will use public and proprietary datasets; well logs, core, well cuttings, geochemical data, 3-D seismic information and production data. This project will produce a GIS-based integrated geologic characterization of the Mancos Shale along with drilling, completion, and stimulation method recommendations. The proposed investigation will quantify and potentially lower the

economic risk of exploration and development in the Mancos Shale Gas play, encouraging larger-scale, commercial production.

To provide integration of geologic and engineering disciplines, the project team includes sedimentary geology, geochemistry, geomechanics, production engineering, petrophysical log evaluation, seismic evaluation, reservoir simulation, and hydraulic fracturing specialists. Project team members have been assembled from the Utah Geological Survey, the University of Utah's Energy & Geoscience Institute, Geology and Geophysics Department, Chemical Engineering Department, and Halliburton Energy Services. Questar Exploration & Production, Gasco Energy, Wind River Resources and Pioneer Natural Resources, will participate in the project, by donating data. Many other Uinta Basin gas producers will participate as Advisory Board members, many of whom may contribute data as the project progresses but are unable to commit assets to the project at this time.

Public 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 and experienced down hole oil well tool designer. The project is titled: “Stimulation of Gas Shale Without Hydro-Fracturing”. The project objective is to develop an alternative method to stimulate and produce natural gas from shale without injecting the enormous quantities of water required for hydro-fracturing.

Gas production from shale depends on stimulating a well by hydraulic fracturing. Massive hydraulic fracturing in shale has dramatically increased estimates of recoverable natural gas. However, fracturing technology injects enormous volumes of chemically treated water. Environmental groups, water resource interests, and some legislative bodies think this could be an environmental problem and some states are considering stringent regulations that could restrict fracturing by fluid injection.

This proposal will further develop and test an innovative new drilling and completion method to stimulate production in gas shale and other soft formations without water injection. Initial computer modeling indicates that a cable saw based tool can cut an extended groove, or “slot” longitudinally along the wellbore extending 100 feet or more into the rock all along a 2500 foot long horizontal lateral borehole that can be oriented horizontally or vertically. The slot has a tremendous surface area and provides a low restriction connection from the wellbore to natural fractures scattered throughout the formation. After cutting, the slot may optionally be enhanced with explosive gas tuned pulses to help open more natural fractures. Preliminary modeling work by Peter Valko indicated that the method will be as good as hydro-fracturing. The proposed work will conduct additional computer modeling and physical tests at increasing scales culminating in tests with a commercial size drill rig. The project will produce computer models on the mechanical process as well as gas fracture generation and model the production improvement expected from the method. The cuts are precisely steered so they allow more precise geometric targeting of production zones so that resource blocks are fully utilized without waste. The wide slots provide essentially infinite conductivity and will significantly extend the life of the wells. Significant cost savings are expected from the method which will be compounded by the environmental benefits of eliminating the water resource and disposal requirements.

The novel method is applied using traditional drilling rigs and drilling fluids. When fully applied it is estimated to produce a net cost savings of 45 to 55 percent over fracturing for the same initial production and extend the producing life of the well by 65 to 90 percent. It re-uses the well drilling fluids used in drilling the well so there is an immediate and substantial savings compared to procuring and disposing the fluids needed to stimulate a well by hydro fracture. The method is estimated to use only 1% of the water required for hydraulic fracturing and water use may be reduced further by operating with air in water sensitive shale. The slot connects the wellbore to natural fractures within the formation in a geometrically predictable manner minimizing the problem of accidently breaking into adjacent water bearing layers.

Other participants involved in the scope of work include David Reynolds Gas Technology Institute: Scott Randolph, Randolph Services: Dr. James Rector of BGI Resources, Dr. John D. McLennan, University of Utah: Richard Green, Explosive Technologies (INL Retired): Dr. Yonane Abousleiman, University of Oklahoma: Dr. Peter Valko, Professor Texas A&M University: Dr. Hisham A. Nasr-El-Din Professor Texas A& M University, Dr Craig Cooper, Idaho National Laboratory: Dr. George J. Moridis and Dr, Matthew T. Reagan, Lawrence Berkley National Laboratory. Participants providing cost share include BGI Resources, University of Utah, Carter Technologies Co, and Gas Technologies Institute.

Public Executive Summary
Name of Offeror: Illinois State Geological Survey, University of Illinois
Project Title: New Albany Shale Emerging Gas Play Analysis in Illinois
Solicitation Number: RFP2009UN001
Unconventional Onshore (Emerging Gas Shale) Program

Objectives: to develop an integrated program that will expand the New Albany Shale gas play into Illinois by documenting play types and distribution of three New Albany Shale sub-plays (thermogenic gas, biogenic gas, and mixed thermogenic-biogenic gas regions), identified in the eastern portion of the Illinois Basin in Indiana and Kentucky (Martini, Walter and McIntosh, 2008), to the western basin in Illinois. The New Albany is a thick, organically-rich shale over much of Illinois, and gas shows are common on mud logs and drilling reports, yet a gas play has not been demonstrated, and exploration is sparse in Illinois. This study will focus on the central and western part of the basin that has not yet been critically examined, but where similar processes, such as infiltration of meteoric waters into the fractured shale and stimulation of microbial methane generation, are likely, and thermally-mature organic-rich shales are present. This proposed study will complement the earlier RPSEA-funded studies that have focused largely on the New Albany Shale of Indiana and Kentucky.

Methodology and Benefits: The proposed work will be conducted by: 1) sampling, chemical and isotopic analysis and mapping of brines and gas from produced fluids, gases, and well rock samples from the New Albany Shale and from immediately overlying and underlying oil and gas reservoirs, to look for evidence of microbial versus thermogenic gas; 2) sampling, analysis and mapping of environmental conditions that may be prohibit or favor microbial methane generation (e.g. chloride and sulfate concentrations, and shale thermal maturity); 3) analyzing and mapping the gas source parameters of the New Albany Shale in Illinois, such as the lateral and vertical distribution of organic richness, geochemical rock properties, and maturity indicators; and 4) analyzing and mapping available fracture and structural indicators important in production of in-situ gas. Using a Geographic Information Systems (GIS) approach to analyze data on maps, charts and cross sections, high quality areas and the type of gas play will be identified in order to enable increased recovery of some of the remaining technically recoverable 3.792 tcf of gas estimated to lie in the Illinois Basin (Swezey et al, 2007).

Major participants: Dr. David G. Morse, Principal Investigator, and Joan E. Crockett, Co-Principal Investigator, at the Illinois State Geological Survey (ISGS) which is a division of the Institute of Natural Resource Sustainability at the University of Illinois at Urbana-Champaign, and Dr. Jennifer C. McIntosh, Co-Principal Investigator, at the University of Arizona, Tucson. Industrial participants include: Continental Resources, Deep Rock, Howard Energy, O'Brien Energy, Shakespeare Oil, Stewart Producers, Podolsky Oil, Bethel Energy, and Energy Producers, Inc. Cost-share is provided by the above Universities ($329,543). Industry participants will provide brine and hydrocarbon samples, access to

wellbores for sampling and logging, and other proprietary geochemical, drilling, exploration and production information.

Key Deliverables: New Albany Shale data and interpretations will be made available to the public. Technology transfer will be provided through hosted workshops, publications in industry journals and ISGS publications, presentations at professional meetings, and the posting of data, maps and interpretations on the ISGS website.

09122-10

Public Executive Summary

Project title: **Optimizing Shale Gas Production by Geochemical and Geophysical Compartment Characterization**

Name of Offeror: Wright State University
Principle investigators: Doyle Watts and Ernest Hauser (Wright State University)
Other Participants: Marathon Oil Corporation, BJ Services Company, Power Environmental Energy Research Institute, GeoIsoChem Inc.

This proposal answers RPSEA 2009 Unconventional Onshore Program Solicitation asking for concepts for shale gas production that could "develop reliable methods to forecast future production from shale resources based on data available early in the development cycle", and "develop methods for determining the stimulated volume associated with a particular treatment approach and the properties associated with that stimulated volume". Our main objective for the proposed research and development program is to establish a systematic model for shale gas compartments analysis, in order to predict, monitor and optimize shale gas production.

The project will integrate geological, geochemical and geophysical diagnostic tools to obtain a better understanding the heterogeneity of connectivity, porosity and permeability, and hydrocarbon generation history in a compartment. Existence of sealing compartments in shale gas "sweet spots" is indicated by the coexistence of overpressure and abnormal "rollover" feature of ethane isotope found recently. It implies sealing compartment, which plays a crucial role to understand the generation-migration-accumulation of conventional petroleum, also help to provide complete view of shale gas formation, accumulation, and even production. Since shale gas is formed indigenously, the conventional compartment analysis method is not appropriate to apply. The project will develop a compartment analysis method to optimize shale gas production.

Key deliverables associated with the project include:

- A well established model using natural gas geochemistry, rock physical property, well log and seismic data to analyze compartments and to optimize shale gas production, including to predict sealing condition of a shale gas compartment, retained gas amount in the play, production rates, decline rates and recovery factor, and to determining intervals to frac or drill horizontals.

- A software package for systematic analysis of compartments to optimize shale gas production

The potential impact of the project includes remarkable and rapid increase of gas production and decrease of cost in drilling and stimulation.

Our industrial partners include Marathon Oil Corporation, BJ Services Company, and GeoIsoChem Inc., while Marathon and BJ Services will contribute 20% of industrial cost shares to this project (Marathon 10%, BJ Services 10%).

Public Executive Summary

Prime Contractor: Board of Regents of the University of Oklahoma

Simulation of Shale Gas Reservoirs Incorporating Appropriate Pore Geometry and the Correct Physics of Capillarity and Fluid Transport

Faruk Civan, Deepak Devegowda and Richard Sigal (PI), Mewbourne College of Earth and Energy, University of Oklahoma

A valid reservoir simulator is a key technology to plan, model and predict the results of production operations. A proper simulator must provide for the appropriate pore geometry complexity, and model the processes with valid physical assumptions. Shale gas reservoir models require both high complexity and modified physics. Production of such a simulator is the prime **objective** of this project.

In the last couple of years as shale reservoir rocks have been imaged using ion-milled samples and SEMs with nano-meter resolution, it has become clear that some portion of the pore geometry is contained in the organic material. This material is hydrophobic, gas wetting and probably never contained brine. The organics also store gas by adsorption. The shale also contains brine filled pores that are most likely water wet, and gas may also be present in non-organic pores of undetermined wettability. This complex matrix porosity is overlain by a natural fracture system, probably water wet, and the complex fracture system created by the simulation, which may be fractionally wet. There is as yet no clear understanding on how these pore systems are connected. The reported observations that many shale gas reservoir rocks imbibe oil-based mud, and also that some do not imbibe water-based mud speaks to the complex wettability and pore geometry structure of the system. NMR measurements show strong surface relaxation for both oil and water implying a heterogeneous wettability system. Any valid reservoir model must be able to accommodate the four porosity elements potentially present and provide for the ability to have arbitrary connectivity between them.

Because of their very low permeability and potentially large capillary forces, standard commercial simulators make approximations that are inappropriate for porous media with very small pore sizes such as shale gas reservoir rocks. The most serious approximations are: 1) the assumption of instantaneous capillary equilibrium, 2) that transport can be completely defined by viscous flow (Darcy's law), and 3) that relative permeability is not flow rate dependent. These assumptions result in simulators that: do not correctly predict the amount of produced water; do not properly handle the changes in gas transport rates with time, so probably can not correctly model gas production; and do not correctly predict the deposition of stimulation water especially during re-stimulation. The last has serious implications on predicting the possible development of

water blocks. The project **deliverable** will be a simulator with the correct physics and possible pore geometries so that modeling and history matching provide valid information about the reservoir geometry its production rates and its ultimate recovery that are not corrupted by the approximations implemented in the simulator. It will further provide an essential component to any coupled stimulation simulation modeling system, and a starting point for simulators that can model wet gas shale reservoirs.

This project will first develop the algorithms necessary to implement the correct physical principles and pore geometry in a simulator. These formulations will then be tested on simple problems using a prototype simulator that is currently being developed for this purpose. After this testing stage the new algorithms will be implemented as modules in selected commercial simulators and tested on simple cases. The final stage of the project will be performing simulations on producing reservoirs using the modified simulators and the original commercial simulators to determine the practical effects of using a simulator that incorporates the better physical approximations and pore geometry.

Cost share mainly will be provided by **BP, Chesapeake, EXCO, Newfield, and Total**, who have partnered with us on this project. The University of Oklahoma will wave some of the graduate students tuition. Additional cost share will be provided by the waving of the user fees at the OU Super Computing Center, and using without fee commercial simulators from Schlumberger and CMG. Also **CMG** has agreed to provide expert help in implementing the new algorithms on their simulator.

09122-12

Public Executive Summary

Integrated Experimental and Modeling Approaches to Studying the Fracture-Matrix Interaction in Gas Recovery from Barnett Shale

Prime contractor: Qinhong (Max) Hu, University of Texas at Arlington (UTA)

Subcontractor: Robert P. Ewing, Iowa State University (ISU)

The Barnett Shale is a profitable gas field, but the current gas recovery rate is only 10-15% of the estimated gas in place. Recovery in this extremely tight formation is limited by diffusive gas transport from the matrix storage to the stimulated fracture network. Unfortunately, there are no systematic studies on pore connectivity of the Barnett Shale and its effect on gas diffusion. Chemical diffusion in sparsely-connected pore spaces will not be described by classical Fickian behavior; anomalous behavior is suggested from percolation theory and confirmed in our previous results on different types of rock. The objectives of the proposed work are to evaluate the implications of low porespace connectivity in the fracture-matrix interaction in fractured shale, through the following complementary and innovative experimental and modeling approaches:

- Collect shale samples from the Barnett Formation and characterize the geological, hydrological, and geochemical properties (e.g., porosity, permeability, pore-size distribution, water retention curve, mineralogy, TOC, surface area).
- Using imbibition as a diffusion analog, test rock samples of different height:diameter ratios to probe pore connectivity in shale.
- Examine the edge-accessible porosity and pore connectivity by vacuum-saturating rock samples with a liquid tracer, then using laser ablation coupled with ICP-MS to map tracer distribution.
- Inject Wood's metal into shale samples and image the distribution of the solidified metal in connected pore geometry using electron microscopy.
- Evaluate natural gas (methane) interactions with crushed shale using column transport experiments under both unsaturated and saturated conditions.
- Investigate methane transport influenced by fracture-matrix interaction in fractured shale and interpret the results based on hydrogeochemical parameters obtained from previous tasks.
- Perform pore network modeling using random walks on 3-D lattices with different pore connectivity, to interpret experimental results involving diffusion, advection, sorption, and fracture-matrix interaction (this task will be performed by the subcontractor at Iowa State University).

The outcomes of this proposal will bridge the knowledge gaps in the pore connectivity effect on diffusive gas transport and gas recovery in fractured shale system, which leads to approached to improved gas recovery and associated economic benefits.

Gas Recovery from Shales Stimulated by Supercritical CO_2

Derek Elsworth (Project Director), Chris Marone (co-PI), Demian Saffer (co-PI) and John Hellmann (co-PI), Penn State University (Prime Contractor)

Jishan Liu (co-PI), University of Western Australia

Public Executive Summary

Objective: This project will explore the potential use of CO_2 as a fracturing fluid in developing high surface area interconnected fracture networks of low flow impedance, to increase the volume and recovery rate of gas from tight gas shales.

Description: Oscillating injection pressures of the supercritical fluid injectate close to the gas-liquid transition offers the potential to drive unstable meso-scale fractures with the low viscosity high-compressibility energetic fluid. Additionally, corrosive interactions at the interface between injected CO_2 and interstitial brines offer the potential to develop micro-fracturing by stress corrosion cracking, by free-face etching, and by differential stressing from replacement sorption of CH_4 for CO_2 in organic mineral components. Together, these physical and chemical effects offer the potential to generate connected fracture porosity at a variety of scales, thereby accessing both free- and bound-gas locked within the matrix of tight gas shales. This project will explore these behaviors through an integrated program of laboratory experimentation and analysis.

Key deliverables are a robust understanding of fundamental physiochemical interactions of CO_2 with gas shales which contribute to the evolution of new porosity and the accelerated desorption of free- and bound gas. This improved understanding will contribute to new stimulation methods for improved and accelerated recovery of the gas reserve.

Potential Impact: The fundamental motivation of this study is that supercritical CO_2 offers these superior characteristics in generating connected porosity to drain natural gas. However, the beneficial use of a plentiful energy by-product (CO_2) as a surrogate for copious quantities of a scarce natural resource (potable water as a fracing fluid) provides an intrinsic natural and economic benefit.

Other Participants: None other than those noted in the cost share.

Cost share is supplied by Shell Development Australia via the University of Western Australia and CSIRO. The PI of this project, Jishan Liu will participate in this study. Additional linkage will be with ExxonMobil URC with whom we are currently collaborating and negotiating an award to examine the mechanics of hydro-fracturing in shales.

Public Executive Summary

Title: Stress-Sensitivity and Multi-Phase Fluid Production Issues in Mesaverde Group, Piceance Basin Tight Sands

Offeror: University of Utah, Salt Lake City, Utah; Co-Principal Investigators: John McLennan, Milind Deo and Lauren Birgenheier

This proposal addresses restricted tight sandstone reservoir productivity that is due to low absolute and relative permeability to gas and water, elevated capillarity and a propensity for water block in the matrix and in fractures. There are extensive data to suggest that the *mobility* of both the water and the gas phases are very low over a wide saturation range, causing a phenomenon often colloquially referred to as a "permeability jail." There is also field evidence to suggest that permeability is governed by the amount of hydraulic fracturing treatment fluid (load) that is not recovered, potentially forming a water block. The proposed study will assist in:

- Predicting and avoiding disappointingly small drainage volumes
- Developing methods for determining fluid storage and flow properties
- Developing methods for determining how relevant reservoir properties change with depletion-related stress and saturation changes.
- Developing methods for determining the stimulated volume from the perspective of post-treatment fluid retention – and inferring how this volume will evolve with time and production.

A natural and necessary extension to the on-going large-scale basin characterization and mapping studies in the Piceance basin is fundamental characterization of the multi-phase mechanisms restricting production and correlation with the specifics of the geologic regime.

The proposed program is based on three principles. The first is the practical necessity of integrating geologic and engineering disciplines to solve production problems. Next is the recognition that reservoir behavior is best addressed by multi-scale investigations – ranging from seismic to microscopic. The final consideration is that relative permeability related to discontinuities – natural and hydraulic fractures – are as important as matrix characteristics.

The main objective of this project is to address several **reservoir production issues** in tight gas sandstone reservoirs of the Mesaverde Group of the Piceance Basin. A pre-requisite is delineating **the relationship between low permeability and geologic controls or textures.** Issues such as relative permeability hysteresis following water imbibition due to loading up or hydraulic fracturing will be addressed and preferred methods for flowback after stimulation as well as precautions to be taken when shutting in and planning artificial lift will be suggested.

The program will use samples and field scale information from fields producing from the Mesaverde Group in the Piceance Basin. Specific goals include:

1) Clarify situations for the existence of relative permeability impairment and capillary blocks.

2) Measure relative permeabilities, and visualize saturations at the pore/grain scale. New generation testing equipment is available to do this at a scale that will help clarify the role of rock fabric in low permeability sandstones. Concentrate on fracture flow and hysteresis– to supplement existing matrix measurements.
3) Perform experiments at different stress conditions to establish the relationship the evolving stress regime has with the petrophysical and rock-fluid properties. Potentially logging-based calculations could be used to infer compressibility-related permeability reduction.
4) Conduct studies of fracture systems to connect the behavior in the matrix to that in the fractures – at varying effective stress levels, and ideally under representative reservoir conditions.

The project team from the University of Utah includes engineers, focusing on geomechanics, stimulation/completion, production, reservoir simulation and reservoir management; geologists, focusing on lithologic and mineralogic variabilities; and geophysicists that will tie production to 3-D seismic characteristics. Halliburton Energy Services will provide in-kind services and expertise in stimulation/completion and production management. Bill Barrett Corporation and Anadarko Petroleum Corporation will provide in-kind datasets, including core, wireline log suites, cased hole drill stem tests, in-situ stress data, and 3-D seismic. The University of Utah will provide the necessary cost share in the form of equipment and graduate student support.

PUBLIC EXECUTIVE SUMMARY
Improved Shale Gas Recovery by Wettability Alteration via Frac-fluids

Correlations Company, located in Socorro, NM, proposes to conduct research to better understand the relationship between water-frac fluids and the gas-producing rate from shale reservoirs. **Bill Weiss will serve as the principal investigator**. The project is an outgrowth of previous work on the surfactant stimulation of oil-wet reservoirs and similar work in water-wet gas storage reservoirs to increase deliverability. The wettability and hence the capillary pressure (Pc) of shale reservoirs are relatively unknown. It is generally thought that the greater the fraction of load water returned during production (lower Pc), the higher the gas flow rate. We propose to develop Pc curves using shale core material from the Barnett in the Ft. Worth basin, the Marcellus in the Appalachian basin, the Haynesville in north Louisiana, and the Woodford in the Arkoma basin.

The objective of the proposed work is to determine if wettability alteration will increase the gas flow rate from shale following hydraulic fracturing completions. Description and methods: We will measure the effect of frac-fluid additives on shale Pc curves and correlate completion variables with production. We propose to use the **vapor adsorption method** to develop a series of Pc curves for the reservoir rocks (shale) before and after surfactant treatment. The wetting properties of the rocks will be altered with surfactants. Prior to the Pc tests, we will screen the surfactants by measuring contact angles on reservoir cores and fluid rise in capillary tubes. Multivariate correlations including the geology characterized by petrophysical logs will be developed from historical completion data to determine that the volume of returned fluids correlates with the gas production rate. This information will be useful in selecting surfactants that increase or decrease wettability.

Key deliverables will be sets of Pc curves for various shale plays and the effect of completion fluids on them. The correlation between geology as defined by petrophysical measurements, completion fluid data, and the resulting gas producing rate will also be generated. Shale gas is increasing the U.S. gas supply, whereas conventional gas rates are declining. **These two deliverables could enhance the shale gas production rate by 10%.**

Correlations Company has formed a team of leading shale gas players: Chesapeake Energy Corporation, Continental Resources, Inc., Frac Tech Services, Halliburton, Newfield Exploration, Shell, Universal Well Services and CESI Chemical, a leading frac-fluid chemical vendor with microemulsion expertise. **Various team members will support the project with in-kind funding.**

Public Executive Summary

Title: The Use of Production-Induced Microseismic Activity to Measure the Reservoir Drainage Volume of Gas Shale Wells

Name of Offeror: MicroSeismic, Inc.
Project Director: Chris Neale (cneale@microseismic.com)
Principal Investigator: Leo Eisner (leisner@microseismic.com)
Additional Participants: Marathon Oil Company, The Pennsylvania State University

Solicitation Number: RFP2009UN001

Project Objectives:
Commercially viable development of shale reservoirs usually requires hydraulic fracture stimulation to connect existing fracture networks with induced fracture while placing adequate proppant to develop reasonable conductivity. Microseismic monitoring is used extensively to optimize completions efficiency by providing a map of the volumetric distribution of microseismic events during stimulation and assuming most of the volume will contribute to fluid flow over a reasonable time frame. This assumption has not been adequately field tested to date. Historic methods for microseismic data acquisition do not provide a commercially viable means for the long term monitoring of stimulated wells once the wells are put on production.

This Project will utilize recently commercialized microseismic acquisition and processing technology to monitor several Marcellus gas wells during the first 6 to 12 months of production. Production induced microseismic activity will be confined almost exclusively to the contributing fracture network, and so will directly map the drainage volumes associated with these wells. The microseismic monitoring results will be integrated with supplemental data such as core, 3-D seismic, logs, and event source mechanisms to identify the true reservoir stimulated (and drainage) volume on a well by well basis. Additionally, the production related microseismic volumes will be compared to the volumes mapped during hydraulic stimulation to improve on the use of microseismic monitoring during stimulation to describe the effective stimulated volume of the treatment. Work will also be performed to describe the interaction of natural and induced fractures as gas is produced from the contributing fracture network.

Project Description:
MicroSeismic, Inc. will utilize an existing, permanently installed buried geophone array owned by Marathon Oil Company to detect and locate microseismic activity associated with production from at least five Marcellus wells in Fayette County, PA. Passive data will be recorded for 12 months across an array of 120 geophones installed to perform high resolution hydraulic stimulation monitoring over a 20 square mile area.

The recorded data will be processed using proprietary “beam-forming” algorithms to accurately locate microseismic activity associated with production from the individual wells monitored. Source

mechanisms for a subset of the detected events will be determined to assist in the evaluation of the reservoir mechanisms creating the microseismic activity.

The processed data will be analyzed by geological, geophysical, and engineering personnel to identify the production induced microseismic activity, calculate effective stimulated volumes, describe the reservoir mechanisms causing the microseismic activity, and correlate the reservoir stimulated volume mapped during stimulation with the effective stimulated volume determined from this Project.

KEY DELIVERABLES:

The Project will provide: a) maps of effective stimulated volume on a well by well basis; b) determination of the effectiveness of using microseismic monitoring during hydraulic stimulation to calculate effective stimulated volumes; c) description of the interaction between natural and induced fractures during fluid production; d) suggestions on how to improve stimulation modeling by "history matching" with the mapped effective stimulated volume

EXPECTED IMPACTS AND BENEFITS:

This Project will potentially improve reserves recovery from gas shale resources by providing a tool to intelligently guide the placement, density, azimuth, and length of individual wells, allowing greater contact with undepleted gas in place and unconnected fracture networks. Relating the effective stimulated volume back to individual stage frac designs will allow for more efficient stimulation procedures and significant long term cost savings over the development cycle.

This Project will provide valuable information on which of the several natural fracture networks present in the Marcellus shale are effectively stimulated and contributing to gas production, and so assisting in stimulation objectives for future Marcellus development.

PARTICIPANTS:

MicroSeismic, Inc., Marathon Oil Company and The Pennsylvania State University will work together to deliver the Project objectives. Each entity will participate in the cost-sharing of the overall project cost.

PUBLIC EXECUTIVE SUMMARY

Offeror: Colorado School of Mines

PI: Dr. Yu-Shu Wu; Co-PI's: Dr. Jennifer L. Miskimins, Colorado School of Mines (CSM);
Dr. Timothy J. Kneafsey, Lawrence Berkeley National Laboratory (LBNL)

The objective of the project is to study, test and develop an innovative technology for enhanced gas recovery (EGR) from low-permeability tight gas reservoirs. In particular, the proposed research is focused on developing a novel cryogenic fracturing technology for significant reduction of flow resistance near wells and increase mobile gas volume in tight gas reservoirs.

The proposed research project consists of the following three tasks: (1) experimental study of a cryogenic fracturing technology; (2) investigation of tight-rock cryogenic fracturing processes and conditions; and (3) assessment of applicability to permeability-improvement in field application, if the technology is proven to work. We will fulfill the project objectives and complete the tasks during a three-year effort.

The novel approach of cryogenic fracturing stimulation, once proven and completed, will make significant contributions in an environmentally sound manner to commercial gas production and ultimately improve recovery from tight and shale gas reservoirs. In particular, the proposed development will potentially revolutionize unconventional gas production from low-permeability reservoirs by applying **non-contaminating** cryogenic fracturing technology. This research is strategically important to our future energy needs and our nation's economy. In addition, the technology developed from this research can be applied not only to shale and tight sandstone gas formations, but also to oil production in various reservoirs as well as other subsurface resource and environmental projects.

The CSM will make contributions to share the project cost. In addition, an industry service company, CARBO Ceramics will provide additional support to the project.

Spatial Energy, LLC
1035 Pearl Street, Suite 334
Boulder, CO 80302
303-625-1048-Telephone
www.spatialenergy.com

Spatial Energy, LLC

Project Title: SmartGas Suite Solution to Unconventional Onshore Program RFP 2009UN001

Public Executive Summary

Spatial Energy, LLC (primary contractor) proposes to develop and commercialize the SmartGas Suite, a water data warehouse and analytical tool which will improve the economic viability and lower the environmental impact of unconventional gas exploration and production in the U.S. The SmartGas Suite is a new, innovative and integrated approach to maximizing water resources, minimizing environmental impact and costs while improving the economics of recovering gas from unconventional reservoirs.

The objectives for the SmartGas Suite include a comprehensive, easy to access water data website and analytical tools for minimizing environmental impact and costs. In addition, the SmartGas Suite will include automated methods for measuring the impact on the environment of surface disturbances.

The key deliverables of the SmartGas Suite will include: a commercially accessible water data warehouse for initial use in the Piceance, New Albany, Barnett, Haynesville, Marcellus and Eagleford basins and a commercially marketed and supported GIS based software solution, SmartGas Suite, to optimize unconventional gas reservoirs. These deliverable solutions will be extended to include a localized water warehouse for all key U.S. gas basins, along with commercial enhancements to the SmartGas Suite software to extend the capabilities as the market demands.

An important aspect of this proposal will enhance existing RPSEA funded projects. These projects include: 2008 Gas Technology Institute's Barnett and Appalachian Shale Water Management and Reuse Technologies, 2008 GE Global Research's Pretreatment & Water

Management for Frac Water Reuse, 2007 Colorado School of Mine's Water Management and 2007 Lawrence Livermore's Self-Teaching Software. We envision working with these teams to incorporate their research, to the extent possible, into the SmartGas Suite. This will maximize their efforts and immediately put their research into a commercially supported software package available widely throughout the oil and gas operators in the specified basins.

The benefits to RPSEA, both present and future, include: an unconventional gas industry standard data and software solution, a proven commercial partner with dedicated commercialization resources, multiple basin applicability, an open and extendable commercial application through the use of current industry standard platform (ESRI) and interfaces to existing software tools that allow ongoing feature extensions by multiple organizations, lowering the cost and minimizing the environmental impact of unconventional gas recovery and maximizing water resources in key unconventional gas basins.

The Spatial Energy management team is comprised of experts from Spatial Energy, Earth Analytic, Inc. and GeoSpatial Partners, LLC, all of whom are contributing cost share. Industry participation in the project will include Anadarko, Apache, Chesapeake and Pioneer. Our partners anticipate using internal resources and data to pilot the SmartGas Suite in several key unconventional gas basins, as well as contributing time, material, proprietary data, travel and satellite data for testing and commercialization.

09122-19

Novel Artificial Lift Methods to Increase Reserves in Tight Sand and Shale Gas Reservoirs

Principal Investigators: Dr. Ding Zhu and Dr. A. D. Hill
Department of Petroleum Engineering, Texas A&M University
3116 TAMU – Richardson Building, College Station, Texas 77843-3116
Email: dingzhu@tamu.edu; danhill@tamu.edu

Industry collaborators: EOG Resources
Sponsoring Organization: RPSEA

The inability to efficiently lift water from unconventional gas wells is a major constraint on the ultimate recovery from shale gas and tight sand gas wells. When it becomes impossible to lift the water from such a well, the well must be abandoned, even though there may be considerable remaining gas reserves in place. As production from unconventional gas resources matures, this problem will grow in scope. Declining reservoir pressures make efficient lifting of liquids critical to continued production from such reservoirs.

The objectives of the proposed research are to develop novel approaches to artificial lift of vertical, horizontal and inclined wells in tight sand and shale gas reservoirs. The study will investigate the suitability of artificial lift methods available in the industry to most efficiently unload liquids from unconventional gas wells, will integrate the lift methods with well structure design for vertical, horizontal and inclined wells, will develop models that considering the complex flow conditions in typical shale gas and tight sand producing wells, and will develop novel approaches for artificial lift design in such wells that can efficiently and economically produce gas from unconventional resources. Specific objectives are to model the two-phase flow in the build section of horizontal gas shale producers, to study the effect of horizontal well trajectory on the ease of lifting liquid from gas shale wells, to develop methods to find the optimal depth for setting a pump in a gas shale well, to model the countercurrent gas-liquid flow in a tight gas well with the tubing tail below multiple producing zones, and to couple reservoir inflow performance models with the complex wellbore flow models developed to examine the effect of wellbore condition on reservoir recovery. The models developed will be implemented in software packages that will allow convenient analysis of artificial lift methods for these types of wells.

The deliverables of this project will be a theoretical model for artificial lift design and well performance for horizontal wells in shale gas reservoirs; a theoretical model for well structure design, artificial lift design and well performance of multiple-layer vertical gas wells with hydraulic fractures; a software package integrating the models developed in this project for unconventional gas well production for optimal recoverable reserves l; and guidelines for field applications of the findings from the project.

The size of the potential reserves addition from the improved artificial lift methods to be developed in this project is very significant. Conservative estimates from knowledgeable operators in the Barnett shale are that efficient artificial lift in Barnett shale wells could extent the economic life of these wells by up to ten years, adding about 10% to the gas recovery per well. With current reserves per well averaging 1.75 Bscf, and the expectation of about 10,000 wells being completed in the Barnett, this 10% increase in reserves is about 1.8 Tcf in the Barnett shale alone. Similar additions to reserves can be expected from artificial lift improvements for tight gas sand wells and other shale gas plays.

This project will be conducted primarily by the principal investigators, Dr. Ding Zhu and Dr. A. Daniel Hill, and a team of graduate students. A key collaborator will be Mr. Steven Coleman, Production Advisor for EOG Resources. In addition to providing actual pressure profile data from EOG Resources wells in the Barnett shale, Mr. Coleman will serve as an advisor about industry artificial lift practices in unconventional gas wells. We will also receive guidance and feedback of the conduct of the project through regular meetings with the 13 companies sponsoring the Crisman Institute in the Petroleum Engineering Department at Texas A&M University. The cost-sharing for the project will be provided by EOG Resources and Texas A&M University.

09122-20

RFP Number 2009UN001, Unconventional Onshore Program

Improved Drilling Efficiencies and Reservoir Characterization using Drilling Data

Executive Summary

The Colorado School of Mines, through the Unconventional Natural Gas Institute, is pleased to submit the following proposal, *Improved Drilling Efficiencies and Reservoir Characterization using Drilling Data*. The Principal Investigator is Dr. Alfred Eustes with co-PI's from the Colorado School of Mines. Participants supplying data include Whiting Petroleum Corporation and Brigham Oil and Gas Company. TDE Data Solutions will provide data base expertise and software in the analysis procedures.

Many of the gas plays in the US are tight and require many wells to produce. Operators drilling in the same geographic and geologic areas are developing a significant database from real time drilling operational recording. We propose to analyze this data treasure for useful information for improved drilling operations and potential reservoir characterization.

Correlated to petrophysical logs and drilling records, this data will be used to determine optimal operating parameters. Unscheduled events will be analyzed for precursor events that could identify impending problems in real time. Comparing the drilling operational parameters to the known reservoir properties could show correlations for real time analysis of reservoirs while drilling.

By reducing time on location, the environmental impacts of drilling such as visibility, air quality degradation, audible pollution, and habitat disruption are reduced. Improved efficiencies means longer bit runs, faster penetration rates, and less unscheduled events disrupting time lines reducing drilling costs. And lower costs mean reducing the economic limit which increases the reserve volume. Improved reservoir analysis means more reserves.

The proposed research project is anticipated to be a two-and-one-half year project. The first year is devoted to collecting the rig data stream for analysis, correlating the data streams, and developing algorithms for optimization and characterization routines. The last year and a half is devoted to data analysis, field assessment, and technology transfer. The deliverables would be various optimized drilling parameters, potential precursor events to anticipate unscheduled events, and a set of reservoir characteristics based on drilling operational data in the database analysis region.

09122-21

OPTIMIZING LIMITED ENTRY PERFORATING FOR CREATING MULTIPLE HYDRAULIC FRACTURES IN MULTI-ZONE TIGHT GAS SANDS

Principal Investigators: Dr. A. D. Hill, Dr. Ding Zhu and Dr. Eduardo Gildin
Department of Petroleum Engineering, Texas A&M University
3116 TAMU – Richardson Building, College Station, Texas 77843-3116
Email: danhill@tamu.edu

Industry collaborators: NSI Technologies, ConocoPhillips, and Anadarko
Sponsoring Organization: RPSEA

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 research in this project proposes to develop a new approach for tight gas well completion and fracturing to improve the current limited entry perforating methods for simultaneously creating multiple hydraulic fractures in stacked, multizone tight gas reservoirs such as those occurring in the Mesa Verde formation in the Piceance basin. The objectives of this project are to evaluate the current limited entry perforating practice for hydraulically fracturing multiple-zone tight gas sands, to develop new methods and models of the perforation/nearwell fracture pressure behavior based on extensive finite element simulations of flow in this region, to implement the new perforation model in a modern fracturing simulator, and to use this tool to generate practical guidelines for more efficiently applying limited entry perforating to fracture stimulating of multiple-zone tight gas sands. The ultimate goal is to develop novel multi-zone completion and stimulation methods applicable to tight sand reservoirs that extend the maximum connection between the wellbore and the reservoir, and therefore enhance reserve recovery in such formations

Because of several critical limitations in current models of perforation design for fracturing, multi-stage fracturing by limited entry through perforations has low efficiency, leaving significant portions of payzone unfractured and not connected to the wellbore for production. To improve the practice, we will develop new methods and models, conduct extensive finite element simulations of the perforation/near-well fracture system by using the new models, considering the complex patterns of fracture initiation at perforations that are known to occur, such as annular fractures around the casing, or fractures propagating from the base of perforations. Based on these simulations, we will develop a new correlation relating the pressure drop in the perforation/near well fracture region to the injection rate though the perforation. The new perforation pressure behavior model will then be used in a modern fracture model to develop improved design procedures for limited entry hydraulic fracturing treatments. Expected outcomes of the study include recommended perforating practices to improve the reliability of the limited entry fracturing process, and guidelines for how many fractures can be created with this technique when the perforating is done in an optimal fashion. We anticipate that new recommendations about perforation orientation and/or perforation phasing will result from this study. Because current limited entry fracturing application routinely leaves some of the targeted gas zones unfractured, the improvements in this process anticipated to result from the proposed work should add significantly to recoverable gas reserves in stacked, multizone tight gas sands.

NSI Technologies, a company that provides state of the art hydraulic fracture design software to the industry will participate in this study by providing their software for use in some of the research. They will also add the newly developed models of perforation pressure drop behavior to their model. Operating companies, including Anadarko and ConocoPhillips, will also advise the researchers on the project, particularly regarding the current practice of limited entry fracture stimulation. The cost-sharing for the project will be provided by NSI Technologies and Texas A&M University.

09122-22

RPSEA

UNCONVENTIONAL ONSHORE PROGRAM

RFP No. 2009UN001

ADVANCED DIAGNOSTICS AND IMAGING - DRILL BIT SEISMIC WHILE DRILLING - WIRELINE RVSP

AREAS OF INTEREST

CATEGORY: EXISTING – ACTIVE DEVELOPMENT DRILLING AND PRODUCTION

NEAR TERM OBJECTIVES 1 & 3

Technical Contact: Robert Radtke, Program Manager

David Glowka, Principal Investigator

Contractual Contact: Sheila Underreiner

Technology International, Inc.

2103 River Falls Drive

Kingwood, TX 77339

(281) 359-8520 (281) 957-5248 (fax)

bradtke@technologyinternationalinc.com

Halliburton Energy Services

Ron Dirkson

eSeis Corporation

Roger Young

AOA Survey

Finn Michelsen

Public Executive Summary

The objective of this project is to commercialize a recently developed seismic source that can be deployed in deep (up to 35,000 + feet) high temperature and high-pressure (HTHP) wells to perform advanced Drill Bit Seismic While Drilling (SWD) with "look ahead" capability to 3000 feet, and wireline Reverse Velocity Seismic Profiling (RVSP) services with greater ranging capability than is currently commercially available. A key element that has been needed for decades is a seismic source that can be located at the drill bit or on the wireline to create and transmit an adjustable frequency, long ranging, and optimized resolution signal to the surface. This new system will enable integration of (1) acoustically enhanced PDC drill bits, (2) conventional wireline truck for reverse verticle seismic profiling (RVSP), and (3) seismic monitoring for verification of pre-drill seismic models while drilling, higher resolution to detect zones at depth, whcih currently have limited surface seismic resolution, and real-time data analysis and diagnostics for more complete reservoir model characterization while drilling.

Over the past 20 years seismic sources have been investigated without achieving/maintaining commercial success -- (1) the roller bit (TOMEX) having been replaced by the faster drilling PDC bit, (2) piezoelectric sources by Marconi, Halliburton, and Baker Hughes, and (3) hydraulic pulsation downhole sources by Texaco (Andreson Tool) and Tempress Technologies. After 6 years of scientific research sponsored by DOE NETL, Technology International, Inc. (TII) has discovered patent pending SeismicPULSER™ technology that meets the needs for an adjustable frequency downhole seismic source. The technical path to discover the method to generate fundamental frequencies of 1Hz to 1 kHz with 4 harmonics began with testing of a sparker source in the TII Seismic Borehole Rock Simulator and Flow Loop, and then, field trials at the University of Texas Devine and DOE RMOTC wireline and drilling field test sites, respectively. The technology is graded a 5 on the API Technical Readiness Scale. Technology to be demonstrated by this project includes the ability to operate in a relatively quiet rig site environment by first storing electrical energy in the drill string capacitors, and firing the sparker with the pumps turned-off.

Limited subsurface imaging technology impacts operators's efforts at finding and producing gas in unconventional reservoirs. From the geomechanics viewpoint, it is like "drilling blind and hoping the right zone is found." (Ref. Ron Dirkson, Halliburton MWD Manager). To the driller, it was said by Mike

Tweedy, Chevron Oil Company, "The time is coming when we will not drill without looking ahead of the bit any more than we would drive at night without headlights—occasionally shining a lamp to see what we hit." A breakthrough in Drill Bit Seismic While Drilling that provides real-time imaging ahead of the bit would significantly lower drilling and completion costs and direct the bit to desirable zones.

Technology International, Inc. (TII) developed patent pending SeismicPULSER^{TM} technologies capable of generating adjustable fundamental frequencies with an otherwise high frequency sparker. It is proposed that the new technology be applied to Drill Bit Seismic While Drilling to determine accurate drill bit trajectories needed to reach desirable tight gas sands in the Pieance Basin in NW Colorado, and to interrogate existing cased holes to locate additional reserves.

The work will be perform a consoreium consisting of TII, the prime contractor, with significant cost sharnig by Halliburton Energy Services, who will design and fabricate 6-3/4" and 8" diameter Drill Bit SWD tools. TII will also design and fabricate 4" and 3" wireline tools. Eseis Corporation and AOA Survey will provide diagnostic and seismic survey services. Field tests will initially be performed at the DOE RMOTC field test site, and then in the Pieance Basin with the cost sharing support of BP.

TII respectfully submits this proposal to RPSEA to field test the SeismicPULSER^{TM} source for Drill Bit SWD and wireline RVSP services in the Pieance Basin supporting the Category for Existing – Active Development Drilling and Production, and near term Objectives 1 and 3 of this solicitation

09122-23

RFP2009UN001

Executive Summary

Offeror: The Colorado School of Mines, Golden, CO
Project Director: Dag Nummedal, Director, Colorado Energy Research Institute
Project Title: Piceance Basin 2: Integrated Geology, Reservoir Engineering and Geophysics for Improved Discovery and Production of Tight Natural Gas

The project has two primary objectives: One is to develop a comprehensive scientific understanding of the distribution of natural gas in the Cretaceous sedimentary section of the Piceance basin, Colorado. The other is to help develop the technologies that optimize the production of this gas.

To achieve these objectives, the Colorado School of Mines and its partners at five affiliated institutions have put together one of the most comprehensive teams ever to ensure that all relevant skills and knowledge is included. To ensure open, frequent and accurate communication among the team members we will engage a web-based communications and data exchange tool, "iProject", provided as a cost-share by one of the project partners (iReservoir). Geological, geophysical and engineering tasks are also closely linked, to the point of having project members performing data analysis and interpretation jointly with team members of different disciplinary backgrounds.

The technical tasks include identification of the major geological controls on "sweet spots" in tight gas sandstones, the role of stratigraphy and diagenesis in forming gas compartments with different degrees of connectivity, and the influence of geologic structures on basin-scale distribution of facies and fracture networks. This is the first attempt at understanding the physical containment of gas on such scales.

The project will also break new ground in terms of its approach to multi-scale geological input into reservoir modeling. In part the input will come from a genetic, gamma-log-based classification of sand bodies based on cores and outcrops, in part it will come from an approach to modeling based on discrete fracture network calibrated against image logs and cores. Based on this advanced static reservoir model, we will then perform a dynamic flow simulation on the dual porosity model (matrix and fractures). New work on advanced algorithms for anisotropy mapping will further help identify fracture patterns, and make the reservoirs-scale static models even more reliable.

Issues of great interest in the Rocky Mountain gas community include the controls of the top of the gas column and the abnormal pressure. We are adding two new ways of examining the issue: one geochemical and the other based on ionic diffusion and streaming potentials which might govern the migration of fluids in basin-centered gas accumulations.

Although the project is strongly focused on tight (sandstone) gas, we are also examining the potential for shale gas production from the deep basin Mancos Shale. We will also integrate all our emerging knowledge about both the Mancos and the overlying Mesaverde Group into a first-ever basin-wide petroleum systems model for the gas in the Piceance basin. This latter (and last) task will be the ultimate validation for the value of the many other tasks. In the end, although the research is specific to the Piceance basin, the main purpose of this large project is to help advance our understanding of the fundamentals behind unconventional gas migration, trapping and production.

Public Executive Summary

Title: Optimization of Frac-Fluid Composition to Enhance Productivity from Gas Shales

Offerer/Cost Share: University of Southern California (USC)

Principal Investigator/Project Director: K. Jessen (USC)

Co-Principal Investigators: D. Hammond, M. Sahimi, T. Tsotsis and D. Zhang (USC)

Project Goal and Objectives: The significant domestic natural-gas potential of gas shales will play an important role in supplying the U.S. gas market throughout the next decades. Efficient and cost-effective operational procedures for releasing the natural gas from these low-permeability shale formations are continuously being developed and refined. In addition to the operational challenges, environmental aspects of shale-gas production must also be included in the planning/expansion of these operations.

The goal and objective of this project is to improve the understanding of the interactions that occur between the shale matrix and the water-based fracturing fluids that are commonly used to stimulate production wells in order to enhance initial productivity and maintain economical gas rates. An improved understanding of these interactions is instrumental to progress in the design and optimization of frac-fluid compositions that will enhance the short-term as well as the ultimate recovery from shale-gas formations in an environmentally benign manner. The goal of the project will be pursued through a combination of experimental work and modeling efforts at multiple length scales performed by a team of Chemical/Petroleum Engineers, Hydrologists and Geologists. The efforts will leverage on our existing experience with characterization of shale materials, geochemistry, and our close collaboration with the shale-gas producing company, the Energy Corporation of America (ECA).

Methodology: A unique and consistent collection of core samples will form the basis of our experimental work towards a better understanding of interactions between the shale matrix and fracturing fluids. Our experimental program will focus on the consequences of exposing a shale fracture face to various fracturing fluids in terms of mass-transfer characteristics and rock-fluid interactions. Careful geochemical analysis of shale and flowback water samples will allow us to investigate the principal interactions and will guide us in the design of more effective frac-fluid compositions. Lab-scale experiments will be performed in order to investigate the invasion characteristics of fracturing fluids into the micro fractures and the shale matrix itself, including the consequences of using recycled water. Modeling efforts based on the observed fracture networks and geochemical reactions will be performed in order to delineate the related longer-term impact on the gas production rates. The observations at the lab-scale will be translated to field-scale settings *via* gamma ray and spectral logs and the interpretation of the flowback-phase composition after hydraulic frac-jobs. The study is expected to generate important new guidelines for the field application of water-based frac fluids that will aid producers in tailoring frac-fluid compositions to a specific asset and in minimizing the use of fresh water.

Public Executive Summary

Name of Offerer: Groundwater & Environmental Services, Inc.

Title: An Integrated Approach to Reducing Risk in Water Management for Gas Shale Development and Production

Project Director/Principal Investigator: Charles Whisman, PE

Solicitation Number: RFP2009UN001

Groundwater & Environmental Services, Inc. (GES) is proposing a research and development project in response to RPSEA's Request for Proposals 2009UN001 in the interest area of Gas Shales. Other project participants are SCE Environmental Group, Inc. (SCE), the Energy Systems and Engineering Institute of Lehigh University (Lehigh) and the Environmental Institute of Lackawanna College. Professor Andrew J. Coleman, Ph.D., P.G. (Lehigh) and Charles E. Blanchard, P.E. (GES) will serve as principal investigators.

This project will focus on the near-term objective of developing tools, techniques and methods that substantially decrease the environmental impact of produced and used water associated with gas shale development. The objectives are fourfold:

(1) Establish a produced water constituents of concern (COC) database to simplify the design of water treatment systems and facilitate water re-use and/or disposal in an environmentally friendly manner. The design of a water treatment technology that can be used at a wide variety of sites requires knowledge of the COC concentrations, as these concentrations vary depending on region and the nature of the water. Development of a water treatment system is relatively straightforward if the COC concentrations are known for a particular site and water source (fracturing fluid, flow back water, etc.).

(2) Evaluate and develop water treatment technologies through bench and pilot-scale testing of a water pretreatment system that can remove the COCs as a compact, manageable sludge. Currently, produced water is treated by a desalinization process prior to discharge; other options, such as road salt use, require that elements such as those that constitute naturally-occurring radioactive materials (NORM) and barium are removed. Removal and stabilization of these COCs would minimize the amount of hazardous waste that is managed and facilitate the disposal of the hazardous components in cost effective manner. Many of these key analytes are precipitated by sulfate ions, and a ready source of sulfate ions in Pennsylvania is acid mine drainage. The use of acid mine drainage as the sulfate ion source will be evaluated as part of the bench and pilot-scale testing. The use of acid mine drainage, where available, could help to eliminate this problematic waste and provides a source of relatively clean water that could be used as part of a fracturing fluid water makeup.

(3) Develop a fracturing fluid that is non-hazardous or reactive with the environment, facilitates subsequent water treatment, incorporates recycled produced water, and has the same functionality as the common formulations. The data obtained as part of the database development above will assist in the development of a "green" fracturing fluid and well conditioning materials.

(4) Perform analytical models that will be utilized to evaluate long-term fate and transport analyses on the COCs of interest which may be introduced into the subsurface from fracturing or well maintenance and conditioning activities.

The research, testing, design and modeling to be performed as part of this project will lead to the development of an integrated approach to reducing the risks associated with water treatment and management practices involved in gas shale development and production. The results of this study will provide a technically-sound approach to identify, evaluate and communicate both opportunities and challenges currently posed by the management of water as part of gas shale development and production.

Public Executive Summary

Researchers at Louisiana Geological Survey (LGS) and Department of Civil and Environmental Engineering (DCEE) at Louisiana State University (LSU) propose to perform for the Research Partnership to Secure Energy for America (RPSEA) the work associated with the proposal entitled "Integrated Water Management Tool to Improve the Conjunctive use of Fresh and Marginal Groundwater Resources, and the Reuse of Backflow-Water for the Haynesville Shale Play." The PI and CoPIs in collaboration with the Louisiana Oil and Gas Association (LOGA) and Chesapeake Energy Corp. (Chesapeake) propose to develop for RPSEA a methodology to provide a long-term sustainable water supply for industry to explore and produce the Haynesville Play, while minimizing environmental issues.

The proposed project seeks to provide RPSEA with an environmentally sound transferable methodology to assess the conjunctive beneficial use of fresh and marginal groundwater resources, and the reuse of backflow in gas shale plays for drilling and hydraulic fracture stimulation (HFS). The methodology will be comprehensive and include: (1) assessing fresh and marginally-saline groundwater resources; (2) developing a groundwater management model as a decision making tool to conjunctly use fresh and marginal groundwater; (3) incorporating a numerical groundwater flow and saltwater transport models to analyze and identify current fresh and alternate sources of marginal groundwater resources; (4) statistically determining the optimal water supply well spacing; and (5) assessing the reuse of produced backflow water. It is important to note that while this project will provide valuable quantitative water supply and quality data for the Haynesville Play, it will also provide a framework to conduct similar groundwater management projects at other unconventional plays which require large amounts of water for the hydraulic fracture stimulation of rock formations in order to release energy resources.

The work will be performed at LGS under the leadership of Prof. Van Biersel and Prof. John, Director of LGS and State Geologist. More specifically, the main objectives would be performed by LGS's Water and Environment Section staff as follows: Prof. Carlson would be in-charge of the groundwater flow model effort; Mr. Milner of the saltwater distribution mapping and geologic characterization; and Prof. Van Biersel of the contaminant transport model and cost-based water treatment analysis. Additional assistance will be provided by Prof. Tsai and Prof. Willson from DCEE, and undergraduate and graduate student assistants from LSU. Chesapeake and LOGA and its members would provide industry experience during the model developments and feedback during the methodology testing at current/proposed drilling sites. In addition, guidance and information from RPSEA and its industry collaborators, and the public sector (e.g. state and local agencies, Sparta Groundwater Commission, etc.) and other would be sought.

The proposed information that LGS is able to provide is critical to both the oil and gas industry, and local officials for the management of water resources in a sustainable manner for future generations.

The deliverables for this project would include a comprehensive report, presentations at regional or national professional venues, and executable programs with guidebook presented at workshops. The cost share portion of this project will be provided in the form of partial salaries for the PI and CoPIs.

09122-27

Public Executive Summary

SEE – Sensing for Economical Extraction of US natural gas: A new technology to better understand and boost the production from specific resources such as New Albany Shale

Offeror: Symyx Technologies, Inc., Sunnyvale, California 94085

Principal Investigator: Miroslav Petro

Additional Participants:

- Madden Systems, a subsidiary of Smith International, Inc., Odessa, Texas
- Crane Wireless Monitoring Systems, Dallas, Texas
- North Dakota State University, Fargo, North Dakota

Objectives

The objective of this program is to develop a commercializable prototype of a new downhole fluid measurement capability – the SEE sensor.

The SEE sensor will be the first system that can provide sufficient recognition and understanding of chemical interactions between fluids and rock formations deep downhole. Sensor arrays packaged into downhole tools will communicate with the surface logging systems via a high-speed telemetry, thereby providing the necessary real-time information regarding the downhole environment.

Description

The basis of a new technology has been discovered that can drastically increase what is recoverable from current fields and revolutionize the well remediation in the oil and gas industry. Recently we have laboratory validated novel sensing devices capable of real-time detection of chemistry and complex interactions of underground fluids directly in harsh downhole environments. At the heart of this breakthrough is a class of novel materials discovered using the Symyx high-throughput combinatorial approach. Enabling oil & gas industry to dynamically analyze and model petroleum reservoirs with respect to geological features, this technology provides a basis for the intelligent design of well remediation and development of new extractions. Packaged into miniaturized assemblies, sensor arrays will be assembled into complete downhole systems, which can communicate on realities down-hole with surface control centers. This new tool will provide unique real time chemical and physical information on the downhole environment, enabling producers to instantly tailor the processes performed underground in a number of critical oilfield applications. Based on responses from a variety of oilfield experts received so far, we strongly believe that the Sensing for Economical Extraction (SEE) technology can revolutionize the industry and transformationally redefine what's recoverable.

As the first target, this technology intends to address pressing issues in the existing and emerging gas fields, such as the New Albany Shale. Specifically, in-situ profiling of wellbore multiphase fluid composition and flow paths along the depth will enable producers to locate entry points of water and other influxes. Additionally, complex information on the fluid-fluid and fluid-rock interactions, as well as determination of the nature, source and motions of the downhole fluids in relation to other wells, can be obtained from this technology to provide superior knowledge for decision makers who are trying to optimize gas production. These findings are expected to contribute to, and correlate well with, the results of the previous RPSEA anchor projects such as the evaluation of shale gas origin (biogenic vs. thermogenic) based on salinity / alkalinity ratio of the aqueous phase and the maturity of the gas source based on content of larger hydrocarbon molecules relative to methane in the gas phase. Such an understanding coupled with the ability to measure a specific downhole situation, will provide unprecedented information to decision-makers, enabling them to navigate drilling to richer resources and optimize production to fuller recoveries.

Our plan within the scope of this proposal includes development of the miniaturized assemblies containing the sensor arrays, optimization the individual sensors to fine-tune the array response for the immediate application target, hardening all of the sensor array components, and interfacing the sensor module with a string of existing downhole instruments that can collect additional data and communicate with surface control centers in real time. Integrating the new sensor technology into an existing infrastructure minimizes the execution risk, time and cost of commercializing this technology. Subsequent to this initial and enabling project our cross-functional team will be positioned to progress very quickly from development to oilfield trials. Further, the direct participation of oilfield partners provides rapid access to critically important realistic downhole environments and test wells.

Key deliverables associated with the project

The specific deliverables of the proposed project are:

1. A library of sensor materials, with their performances evaluated.
2. A functional sensor array module, with communication interface.

Organizations providing the required cost share

Symyx Technologies, Crane Wireless Monitoring Systems, and Madden Systems will each provide portions of the required cost share.

09122-28

PUBLIC EXECUTIVE SUMMARY

PROJECT TITLE: Development of an Air Monitoring and Pollution Mitigation System for Oil and Gas Activities in the Barnett Shale

TOTAL RPSEA FUNDING REQUESTED: $1,999,481 **DURATION:** 36 months

OFFEROR: Houston Advanced Research Center

PRINCIPAL INVESTIGATOR (PI): Dr. Eduardo P. Olaguer **CO-PI:** Dr. Richard Haut

OBJECTIVES, DESCRIPTION, AND IMPACT:

The main objective of the project is to develop an air monitoring and pollution mitigation system that can be used by the oil and gas industry in the Barnett Shale and other basins to minimize its contribution to ozone exceedances, as well as reduce its emissions of hazardous air pollutants (HAPs) and greenhouse gases (GHGs). This system will include:

- A local remote sensing network based on multi-axis (MAX-) and imaging (I-) Differential Optical Absorption Spectroscopy (DOAS) that will directly quantify area-wide and specific process emissions (wells, drilling equipment, compressor engines, pipelines, storage tanks, etc.) of NO_2, SO_2, HONO, and HCHO from an oil and gas field;
- Fast (1s time resolution) in-situ monitors for a variety of ozone precursors, HAPs, and GHGs;
- Meteorological instrumentation;
- An inverse plume modeling system to derive emissions of species monitored by in-situ devices, and to attribute these emissions to specific oil and gas field activities; and
- A software system to facilitate analysis of monitoring, activity, and inverse modeling data.

A field campaign applying the monitoring system to oil and gas field emissions will be conducted in the Town of DISH, Texas and other areas of the Barnett Shale.

A second project objective is to establish an outreach and technology transfer program to help local producers: 1) obtain external funding from the Texas Emissions Reduction Plan and the USEPA to implement retrofit technology for compressor and other engines used in oil and gas operations; 2) document the emission reductions achieved through engine retrofits or other controls, such as vapor recovery, green well completions, and reduction of truck traffic due to hydro-fracture water remediation; and 3) contribute to the further development and widespread adoption of the monitoring technology.

OTHER PARTICIPANTS PERFORMING SCOPE OF WORK: UCLA, Aerodyne Research, Inc.

ORGANIZATIONS PROVIDING COST SHARE: Town of DISH, Texas

OTHER COLLABORATORS: North Central Texas Council of Governments, Chesapeake Energy

09122-29

PROJECT EXCUTIVE SUMMARY

Project Title: Using Single-molecule Imaging System Combined with Nano-fluidic Chip to Understand Fluid Flow in Tight and Shale Gas Formation

Offeror: Missouri University of Science and Technology (MS&T, Formerly UMR)

Principle Investigators: Dr. Baojun Bai, Co-PI: Dr. Yinfa Ma

Offeror's subcontractor: Colorado School of Mines, Dr. Xiaolong Yin, Dr. Keith Neeves

Industry Sponsors: BJ Services, Hess Cooperation

The project targets on improving the understanding of the flow behavior of natural gas and introduced fluids (water, surfactant solutions and polymers) in nano-darcy range of tight gas and shale formations by using advanced single-molecule imaging system combined with nano-fluidic chips and pore-scale numerical simulation techniques. Specifically, we will examine the flow behavior of gas and introduced fluids in the nano-scale pores and cracks in tight formations and study the effect of introduced fluids on natural gas transportation properties, such as capillary pressure, absolute permeability, relative permeability, non-Darcy flow. The difference of fluid flow in shale and tight sand formations will be also identified. The fundamental research will result in novel methods to determine the fluid flow properties in tight formation.

The proposed project has seven tasks. The first three tasks meet initial RPSEA requirements. The fourth task is to use novel nanofabrication techniques capable of defining geometric features down to 10 nm to fabricate nano-fluidic chips that mimic the pore geometry of tight formations. The fifth task is to carry out imbibition and core flooding tests to understand the interaction between fluid and fluid and the interaction between fluid and rock in macroscale core samples. The sixth tasks is to visualize the natural gas, water, surfactant solution and polymer solution flow behavior in the nano-scale pore and cracks using single molecule detection system. The flow behavior from macroscale and nanoscale results will be compared and correlated. The seventh task is to characterize fracturing fluids injection into tight formations with nanoscale pores and the subsequent flowback using pore scale numerical simulation. The properties that will be characterized include relative permeabilities, residue saturation of gas during invasion, residue saturation of liquid after flowback, effect of pore microstructure. Comparison with nano-fluidic chip and core flooding experiment results will be made to verify and adjust the mathematical models.

This project lasts three years. The acquired knowledge from this fundamental research will be of major importance to short- and long-term tight sand and shale technology development. The total cost share provided by MS&T, CSM, BJ Services and Hess is 29% of the total budget.

PUBLIC EXECUTIVE SUMMARY

Title: Improving Reservoir Contact for Increased Production and Recovery of Gas Shale Reservoirs (Achieving management of fracture complexity)

Offerer: Innovation Center / TerraTek, A Schlumberger company

Principal Investigator: Dr. Roberto Suarez-Rivera

Understanding the geologic conditions controlling reservoir potential, and controlling fracture surface area generation and preservation, are essential for successful unconventional shale gas resource exploitation. These conditions, in turn, depend on reservoir properties and production mechanisms, as well as on hydraulic fracturing network mechanics. The latter is predominantly affected by localized heterogeneities (e.g., the presence and distribution of interfaces, mineralized fractures or other planes of weakness), that define a broader-scale reservoir fabric, and are fundamental sources for fracture complexity[1]. These are factors that we may understand but cannot be controlled. However, field experience suggests that other operational conditions (e.g., pumping rate, fluid viscosity, proppant) may also play a significant role in the development of fracture complexity[2]. If so, understanding these conditions will help us exercise some control on fracture complexity and will result in a significant opportunity for developing enhanced fracturing methodologies, leading to higher production and higher ultimate recovery.

The main objective of this theoretical and experimental project is to understand the operational drivers of fracture complexity (pumping rate, fluid viscosity, and proppant) and provide guidance for maximizing this opportunity. Other objectives of this project are to study the equivalency between pumping rate and viscosity (proppant effectively adds viscosity among other things) for controlling fracture complexity, and to define scaling relationships for relating laboratory-scale experiments to field-scale hydraulic fracturing treatments. The end product deliverable would be a methodology for control and management of fracture complexity such that this can be maximized on desirable locations and minimized in undesirable locations, with the objective of maximizing gas production and recovery. The problem is difficult, but the potential for greatly improved production is real.

The project tasks include selection of optimal outcrop sites, collection of adequate samples, characterization of these samples and their interfaces, and a considerable number of tests on large-scale blocks (1 ft x 1 ft x 1.5 ft) for evaluation of fracture complexity under multiple conditions of stress, orientation of the planes of weakness, and for changing conditions of pumping rates and fluid viscosity. The project is expected to include measurements on outcrop rocks from the Marcellus, the Barnett, and the Mancos shales and/or other gas shales, tight sandstones and coal.

The project team includes the Schlumberger Innovation Center (Principal Investigator), TerraTek a Schlumberger Company (for laboratory testing), the Schlumberger Unconventional Gas Regional Technology Center (located at TerraTek and Dallas), and an external Advisory Board including representatives of producers with important portfolios of gas shale plays. These participant groups bring critical, essential technology, unique laboratory and field experience, access to outcrop sites, and completions information (including possibly micro-seismic measurements and well production). The management of the project will be led by Dr. Suarez-Rivera, Schlumberger Scientific Advisor and Head of the Innovation Center and located at TerraTek in Salt Lake City. Other team members encompass geologists and engineers, and most importantly, technical advice from supporting producer companies. This is a strong team.

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[1] **Suarez-Rivera et.al, 2006 ARMA/USRMS 06-1130.**

[2] **George King, SPE Completions Workshop, Horizontal Well Stimulation, Pittsburgh 2009.**

Lumedyne Technologies Incorporated
9275 Sky Park Ct.
Suite 100
San Diego, CA 92123

Executive Summary

Ultra-Low Noise MEMS Accelerometers for Unconventional Seismic Imaging

Lumedyne Technologies Incorporated

Principle Investigator: Dr. Richard Waters

The seismic imaging industry has a problem: its sensor technology has been unable to keep up with industry needs. With the increasing scarcity and complexity of extracting today's unconventional domestic oil resources, high resolution seismic images are critical to increase extraction percentages and to enable today's strategic drilling techniques.

Seismic imaging has proven itself an invaluable tool for oil exploration. It reduces the number of dry wells, identifies new deposits, and increases oil extraction percentages by providing a means to know what exists beneath the surface. The more complex the resource, the greater the role techniques like seismic imaging play. Lumedyne Technologies (LTI) proposes to improve image resolution by developing a new accelerometer capable of measuring signals just above the background noise of the earth. The sensor would provide a flat response over a broad frequency range (0-2000 Hz) and a noise floor of 1ng/√Hz, orders of magnitude better than the current state-of-the-art technology. Such an advance in sensor technology would provide a step-function improvement for seismic imaging and provide better images for improved access to unconventional domestic resources. These improved images would result in improved understanding of unconventional resources and, therefore, benefit virtually every other area of research in this area as well as improved recovery through 'more intelligent drilling'.

The objective of this effort will be to develop and build prototype accelerometers with the 1ng/√Hz utilizing LTI's proprietary new accelerometer technology. LTI's technology was developed by the US Navy for navigation purposes and has now been exclusively licensed to LTI for commercialization. The technology boasts World Record performance and was named one of the "Most Promising" Energy Technologies of 2007 by Rice Alliance. LTI is fully committed to the development and commercialization of its accelerometer for seismic imaging and will provide its own project cost share.

Participants: Lumedyne Technologies **Cost Share Providers:** Lumedyne Technologies

09122-32

Public Executive Summary

Offeror: The Pennsylvania State University **Principal Investigator**: Prof. Terry Engelder

Project Title: A geomechanical model for gas shales based on the integration of stress measurements and petrophysical data from the greater Marcellus gas system

Objectives of the Project: When an unconventional (i.e. gas shale) reservoir with a permeability < 1 μd is made economic by fracture stimulation, rock stress dictates fracture growth in terms of crack orientation, vertical and lateral dimension, breakdown pressure, closure pressure, aperture, and other characteristics. Because the greater Marcellus gas system hosts several prospective gas reservoirs, the engineering design of an efficient and economic fracture stimulation will account for stress-related issues including, for example: 1. the reservoir-by-reservoir stress contrasts that may act to contain vertical growth in some situations and allow for further vertical growth in other situations, 2. the regional variation in breakdown pressures which are meaningful when identifying pump requirements, and 3. the orientation of the local stress when trying to misalign horizontal laterals to promote higher production through generation of a complex network of interconnected fractures near the wellbore. To this end, the objective of this project is generate a geomechanical model for the Marcellus gas system through the integration of rock stress and petrophysical properties. **Description of the Project:** The heart of this project is a series of micro-frac stress tests in three vertical wells strategically placed in the two sweet spots of the Marcellus fairway. The data for this model come from the Schlumberger MDT tool plus ancillary geophysical logs and petrophysical analyses of core. Four potential locations for the stress tests are from low stress environment to high: Marshall, Greene, Bradford, and Lycoming Counties. The goal is to develop an integrated, predictive geomechanical model for the Marcellus gas system that can be generalized for application in other shale plays. **Key deliverables:** A technology transfer by reports and papers in requisite journals that will document local and regional geomechanical characteristics of the Marcellus gas system. **Potential Impact of the Project:** Organization of industry in an open collaboration to understand one of the most important parameters, rock stress, in engineering the stimulation of horizontal wells for greater productivity. An open collaboration between industry and academia of this type is a real breakthrough for an industry that generally tends to be tight with sensitive data. **Industrial Participants**: Range Resources, Chesapeake, and Schlumberger. The cost share > $2MM. **Research Participants:** Terry Engelder & graduate student (Penn State), Bill Zagorski & Joe Frantz (Range Resources), Rick Svor & Jeff Miller (Chesapeake) plus Dick Plumb & George Waters (Schlumberger). This team is a collaboration of top notch engineers and geologists.

Public Executive Summary

Project Title: **Enhancement of Natural Gas Production from Existing Gas Shale Formations**

Objectives: (1) Develop a novel stimulation technique applicable to established gas shale; (2) Establish a model for determining the fluid storage and flow properties in low permeability shale. The ultimate objective is to substantially increase commercial production and ultimate recovery from gas shale in an environmentally friendly manner.

Project Description: Gas shales production grew to more than 8 bcfd from 2 bcfd during the past five years, which makes gas shales an increasingly important source of natural gas production. However, it is estimated that up to 90% of gas in place remains unrecoverable by existing stimulation methods. There is a great need for new stimulation methods. Meanwhile, the process of gas release and production from shale formations is poorly understood because neither conventional Darcy flow nor mathematical modeling of gas flow considers the differences in transport mechanisms in nanopore networks in gas shales. In addition, it is difficult to predict shale gas storage.

To address these dilemmas, New Mexico Institute of Mining and Technology (NMT) proposes to develop new technologies and methods for increasing production and understanding the fluid flow and storage in shales through two major efforts. The first effort is to implement a novel stimulation method to increase permeability and gas production in an environmentally friendly way. This novel method differs significantly from the traditional hydraulic fracturing application. Testing will examine both technology applicability and cost effectiveness. The second effort is to establish microstructure-based models by molecular and reservoir simulations to determine the critical factors controlling fluid flow and estimate gas storage in gas shale. The proposed project is a R&D project.

Impact and benefits: This research will address the problem of extremely low permeability, which is the biggest bottleneck for gas production from gas shales, by implementing a novel stimulation method. The research will also determine the factors controlling rock-fluid interaction, gas desorption, and gas flow in gas shales by molecular simulations and reservoir modeling. The successful research will increase commercial production and ultimate recovery in an environmentally friendly way as well as contribute to the estimation of the total gas storage in shales.

Major participants: This project will be conducted by New Mexico Institute of Mining and Technology. The Project Manager is Dr. Reid B. Grigg. Co-PIs are Dr. Chongwei Xiao and Dr. Luzheng Zhang. Industry partner Noble Energy Inc. will be providing support to this project. Another possible partner would be Halliburton. In addition, we will be cooperating with the New Mexico Bureau of Geology and Mineral Resources in this effort.

PUBLIC EXECUTIVE SUMMARY

RPSEA RFP2009UN001 – Unconventional Onshore Program
Fountain Quail Water Management: Anti-Fouling Coating for Enhanced Gas Shale Water Recycling

Offeror: Fountain Quail Water Management Project Director: Patrick Horner

Additional companies and organizations participating in this project are Devon Energy, Dupont, Sandia National Laboratory, and the Gas Technology Institute. The project cost share will be provided by FQWM and Devon Energy.

The overall objective of this proposal is to improve the recovery, efficiency, utilization factor, and cost effectiveness of MVR Evaporation for gas shale wastewater recycling through the application of a new fouling resistant coating. These benefits will ultimately enhance gas shale production through improving the supply of water sources for hydraulic fracturing and improve overall water recycling economics.

Treatment of flowback and produced waters associated with shale gas development is problematic due to high volumes, high contaminant loading, and high fouling potential. Conventional wastewater treatment equipment has not been able to effectively recycle the flowback. Fountain Quail's NOMAD 2000, Mechanical Vapor Recompression (MVR) Evaporator, is a highly energy efficient process for producing distilled water from wastewaters contaminated with high levels of dissolved salts. Evaporative treatment involves the boiling of a solution such that contaminants remain in the liquid phase, while pure water vapor evaporates, which can be condensed to distilled water for re-use of environmental discharge.

The overall objective of the proposed effort is to evaluate the costs and benefits for the utilization of a fouling resistant coating on Fountain Quail's NOMAD MVR Evaporator Heat Exchanger Plates in a gas shale wastewater recycling application. Reducing the fouling of gas shale wastewater equipment via the application of fouling resistant coatings could accelerate exploration and reduce the costs of production, while improving safety and minimizing environmental impacts by making water recycling more cost effective, efficient, and reliable. In making the recovery of and beneficial use of a portion of the brackish produced water from these shales more efficient, an environmental liability is turned into an asset. For this project, the extent to which new fouling resistant coatings can improve water recovery, energy efficiency, and utilization factors will be evaluated in field demonstrations. If

successful, the coatings will be applied in the design of future systems developed for gas shale and other water treatment applications.

Impact and benefits of the project:

1. Reduces industry demand for freshwater in shale gas developments.
2. Eases water availability constraints for well development and completion.
3. Decreases environmental impacts from water transportation including air impacts, fugitive dust, traffic, carbon emissions and carbon footprint.
4. Technology and know-how developed can be extended to other shale gas basins.

PUBLIC EXECUTIVE SUMMARY

Increasing Natural Gas Production from Tight Gas Sands with High Sw from Marginal or Abandoned Wells in Multiple Gulf Coast Region States

UNIVERSAL GEOPOWER LLC, HOUSTON TX

Chris Luchini, Project Manager

Universal GeoPower LLC will lead a team to develop and apply technologies that can enable and sustain trillions of standard cubic feet (SCF) of natural gas production from existing Unconventional Onshore Producer, tight gas sand marginal or abandoned wells in the Gulf Coast Region states. The specific objective of this project is to develop and apply technologies that re-establish and increase natural gas production from two existing abandoned Wilcox wells in Goliad County, TX, while augmenting the site profitability from the sale of renewable electricity produced from geothermally-heated brine. The wells will be re-entered, perforated, fracture-stimulated, and recompleted to promote and enhance the flow rates of natural gas and brine. Existing gas handling and processing equipment will be refurbished and a geothermal powerplant, based on Pratt & Whitney Power Systems PureCycle® Model 280 modules driven by the hot brine, will be designed, installed, and connected to the grid to deliver renewable electricity. The expected annual well outputs are 470 million SCF of natural gas and 21,000 MWh (2.5 MWe) of electricity, with a production lifetime of over 20 years. In achieving these metrics, the project will define the technology pathway for 4,900 marginally productive Unconventional Onshore Producer tight gas wells in Gulf Coast Region states that could deliver 1 Trillion SCF of natural gas and 54 million MWh (6,100 MWe) of renewable electricity to US consumers every year. The Universal GeoPower team includes HTK Consultants Inc to perform the well rework, CH2M HILL to design and install the powerplant, and Southern Methodist University to lead the technology transfer of the project results to the Unconventional Onshore Producer community. Universal GeoPower will provide all cost share.

EXECUTIVE SUMMARY

Stress Dependant Pore System Characterization, Stimulation, And Horizontal Well Completion Optimization In Unconventional Gas Reservoirs Through A Multi-Discipline Approach

Offeror: William K. Miller, NSI Fracturing, LLC
PI: Larry K. Britt NSI Fracturing LLC and Britt Rock Mechanics Laboratory, LLC
Co-PI: Dr. Baojun Bai MS&T, Dr. J. Jones, Dr. M. Dubois IHR, and Robert E. Barba IES

Unconventional gas resources are characterized by very steep production declines and low base production level. In addition, they require significant capital to maintain production often making the economics of the plays marginal at best. Successful unconventional gas projects require a quality resource as well as a quality completion and fracture stimulation(s). One without the other is just another marginal to uneconomic well. As a result, this project focuses on each of these objectives through a multi-disciplinary approach.

The first project objective is to characterize the stress dependant pore system for unconventional gas reservoirs utilizing logs, core, and analysis of well performance data. Core from the Haynesville, Woodford, and Hugoton Embayment will be evaluated. Tests designed to characterize the primary and secondary pore systems of these rocks as a function of stress will be conducted.

Secondly, the laboratory results will be used to aid in optimizing the fracture stimulations in the unconventional gas resource(s). Each of the unconventional gas formations will be reviewed and the implications of mineralogy, rock mechanics, and geomechanics on fracture design assessed. In addition, the implication of these disciplines on fracture materials (fluid and proppant) utilization will be evaluated. There should be little doubt that mineralogy plays a role in determining the best fluid type for fracture stimulations. Similarly, the rock mechanics and geomechanical effects on fluid and proppant types and volumes will be investigated.

Finally, a new multiple fractured horizontal completion and stimulation technique utilizing degradeable polymers for wellbore and fracture diversion is to be developed. This objective seeks a product/method that allows the creation of more fractures either initiated at the wellbore or from within an existing fracture while limiting the number of completions and packers required. This final objective focuses on maximizing the well performance while minimizing the completion and stimulation risk and cost.

EXECUTIVE SUMMARY

New Simulation Technology for Hydraulically Fractured Shale Gas Reservoirs

Dr. John Yilin Wang and Dr. Turgay Ertekin – The Pennsylvania State University

The overall objectives of this project are: (1) to develop a new, fit-for-purpose numerical simulation model for accurate simulation of the hydraulic fracturing propagation, fluid cleanup process, and long-term gas recovery in shale gas reservoirs; (2) to develop type curves for shale gas production data analyses based on our new model developed in step one; (3) to develop new stimulation and completion methods enabling less amount of fracture fluids injected but resulting in improved productivity and ultimate recovery in shale gas wells; (4) to create spreadsheet models, tables and figures for optimal selection of proppant, fracture fluids, additives, pumping schedule, field operations for shale gas wells in US.

The new model will incorporate geological information, well data, reservoir data, rock properties, natural/hydraulic fracture parameters, stimulation treatment data, and interaction of reservoir fluids, fracture fluids and rocks. New methods and models of formation evaluation will be developed to provide inputs for our model. Laboratory experiments will be carried out to provide critical rock and fracture data. The model will be a single-well numerical simulator, capable of characterizing the changes of reservoir/fluid/fracture parameters over time. One of the emphases will be the fracture fluid cleanup process.

Major participants of this project are The Pennsylvania State University and Sklar Exploration Company. Cost sharing will be provided by both members. The study will focus on Haynesville shale gas in Louisiana and Marcellus shale gas in Pennsylvania. Our new models and stimulation technologies will be tested on shale gas wells in both plays. The new knowledge and technologies will be distributed through SPE conferences, workshops at the Pennsylvania State University, publications, theses/dissertations, technical reports, software packages, and website.

The new research will lead to better reserve assessment, less fracture fluids required, faster fracture fluid cleanup, improved productivity and increased recovery in shale gas reservoirs. Otherwise, up to 90% of the shale gas in place remains as unrecoverable (RPSEA 2009).

Public Executive Summary

IMPROVED PERFORMANCE PREDICTION OF SHALE GAS RESERVOIRS

Production and reserves of all unconventional gas reservoir types have increased in the past decade. Specifically, shale gas production and reserves are growing rapidly. In 2007, eight of the top ten U.S. gas plays were producing from unconventional reservoirs with the Barnett Shale being the 2nd highest gas producer. That same year, unconventional gas reservoirs accounted for 47% of the U.S. dry gas production and 62% of the booked reserves (EIA 2009). Moreover, by 2007, shale gas reserves had grown to 21.5 Tcf and accounted for more than 9% of the total U.S. dry gas reserves (225.2 Tcf) (EIA 2009). With declining conventional gas reservoirs, unconventional gas reservoirs, led by shale gas, are expected to provide the majority of the U.S. gas supply growth in coming decades (EIA AEO 2009). Despite the growing importance of shale gas, the basic mechanisms underlying production of gas from shale are partially understood at best, and uncertainty limits the industry's ability to optimize completion and production strategies and to estimate future production and reserves.

This proposal will focus upon an improved mechanistic understanding of shale gas recovery, and associated uncertainty, from U.S. gas shale reservoirs. The project should provide improved access to significant gas shale resources which are currently marginal or uneconomic. The "natural laboratory" will be the Haynesville shale gas formation where a local operator (Matador Resources Company) will provide us with core, logs and production data. Haynesville is a more difficult formation than the Barnett, being a deep, high pressure-high temperature shale of which only an estimated 20% of the formation can be developed with existing technology. The work on Haynesville will be placed in a larger context through a review of US gas shale resources and a probabilistic decline curve analysis for improved reserve estimates, with uncertainty. The proposal includes the measurement of permeability and porosity as a function of compaction using a new laboratory apparatus provided by Schlumberger, followed by near well and multi-well coupled simulation and stress modeling using a pre-commercial version of Eclipse-VISAGE developed specifically for gas shale reservoirs. The static model upon which this simulation model will be based will utilize

electrofacies characterization and non-parametric regression techniques to construct a detailed geostatistical model, followed by the application of specialized upscaling approaches for tight gas reservoirs extended to gas shales, for flow simulation. These models will be calibrated to field response using streamline-based history matching technology. Optimal well stimulation design will be developed using formal optimization techniques and the calibrated mechanistic models. Finally, Phase II of this project, starting in Year 2, provides a field test which consists of a Haynesville high angle well monitored using micro-seismic measurements from a dedicated vertical monitoring well.

Key project deliverables include:

- Laboratory measurements at reservoir conditions of the impact of compaction on permeability and porosity of shale samples.
- A major review of U.S. gas shale reserves, with associated uncertainties in these estimates.
- Integrated mechanistic geologic / simulation / geomechanical models calibrated to laboratory data and field performance.
- Design of optimal well stimulation treatments.
- In Phase II, a field test of a well stimulation treatment with microseismic monitoring of the fracture propagation

The project will be managed through the Texas Engineering Experiment Station / Texas A&M University. The PI for the project will be Dr. Michael King, with project work provided by Dr. John Lee, Dr. Akhil Datta-Gupta, Dr. Duane McVay, Dr. Walt Ayers, Dr. Eduardo Gildin and their graduate students, all in the Petroleum Engineering Department. Other major project participants are Brad Robinson and Baljit Sehbi at Matador Resources Company (MTC) and Dr. Marc Thiercelin at Schlumberger. MTC and Schlumberger will be providing significant in-kind cost sharing.

09122-39

RPSEA - RFP2009UNC001 - Unconventional Onshore Program

Offeror: ConocoPhillips

Project Directors/Principal Investigators: David Beardmore – ConocoPhillips
Don Whitfill – Halliburton

Project Title: "Large Scale Lab Study of Wellbore Strengthening"

Public Executive Summary:

An industry group is proposing to study the fundamentals of Wellbore Strengthening at the large-scale facility at Terra-Tek Geomechanics Laboratory. Wellbore Strengthening is any treatment that increases the wellbore breakdown pressure to above the breakdown pressure under normal conditions. Wellbore Strengthening has the potential to drastically reduce Lost Circulation, and to reduce the number of casing strings required in Unconventional Resources (UR) wells, thus significantly reducing drilling costs. The objectives of the study (key deliverables) would be to develop new and improved methods and materials to conduct Wellbore Strengthening reliably, and also to prevent and correct Lost Circulation.

The genesis of this proposed project comes from the very successful joint industry project that was conducted in the mid-1980's, DEA-13 Oil Mud Lost Circulation (Phases I and II). This project produced a fundamental understanding of the difference between Lost Circulation in Oil-Based Muds and Water-Based Muds, and led to the discovery of the mechanism of Wellbore Strengthening. Eighteen different companies funded this work, demonstrating its importance.

Wellbore Strengthening has been conducted in the field by some operators, but the success rate is well below 100%. However, the confidence to make Wellbore Strengthening a part of a field development design is lacking due to an incomplete understanding of the mechanisms of the method. One of the project goals would be to give the industry confidence to reduce the number of casing strings by Wellbore Strengthening in a UR development. Reducing the number of casing strings by one in a multi-well development could save 5+% of Drilling Costs.

Also, despite a significant understanding of Lost Circulation mechanisms, methods and materials for correcting losses in the field have continued to be only partially successful. The results of this project would make a step change in the success rate of corrective methods and materials for losses in the UR arena. UR in the US onshore often have LC difficulties, as so much of the US has been drilled and produced, there are numerous severely depleted zones

that must be drilled through to access the UR formations. Additionally, the UR pay zones and their overlying strata are often naturally fractured, leading to losses.

The combination of less casing strings and reduced LC stands to reduce UR Drilling Costs by about 10%. Also, current Wellbore Strengthening treatments are environmentally benign.

Note that the results of the proposed project would benefit all types of UR (shales, coal seam, and tight gas) and all development categories (Existing, Emerging, and Frontier Area). Also, an important benefit of the results of this project is that they would be applicable to all wells drilled in the US, whether in Unconventional Onshore, ultra-deepwater, in the shallower GOM, or conventional resource wells on land. The results would apply directly to benefit the Ultra-Deepwater and Small Producers Programs managed by RPSEA.

The importance of the topic is underscored by the fact that 10 of the largest public oil companies, and the 4 of the largest oilfield service companies have indicated strong interest. Ten companies supporting the project at $75,000 each would provide $750,000. A RPSEA support of 80% would make total project funding $3.75MM. A 3-phase approach to testing would mean that $1MM would be expended per year over 3 years. In the current economic conditions of the industry, without the 80% support by RPSEA, this project would not go forward relying solely on industry funds.

The lab work would be conducted at Terra Tek in Salt Lake City, the same facility that conducted the important testing in DEA-13. Terra Tek has a unique capability in their large scale, big-block test frame. Only tests on large (30” x 30” x 30”) rock samples can allow study of fracture propagation over a significant timeframe, which is required to understand fundamental mechanisms of Lost Circulation and Wellbore Strengthening. The main output a test is the pressure – time plot that indicates how hard it is to propagate a fracture with mud under specified conditions with certain mud additives. A funding level of $3.75MM would fund about 30 large-scale tests – which would allow for the project goals to be met. Less expensive ($35,000 each), smaller-scale tests may be used in a screening function to allow the project to reduce the large-scale block tests.

GPRI would serve at the contract administrator. They have extensive experience administering industry research projects. An administrative fee of 10% would apply.

Development of a 1,000 level Drill Pipe Deployed Fiber Optic 3C Receiver Array for Boreholes

Björn N.P. Paulsson, Ph.D., Paulsson, Inc.

Executive Summary

In the US, very large unconventional gas resources are found in geologic formations with low matrix permeability. According to the latest estimate by the National Petroleum Council (NPC 2003) the volume of technically recoverable gas from gas shales, coal seams, and tight sands in the lower 48 states is in excess of 293 trillion cubic feet (TCF). These resources however can only be recovered by applying advanced mapping, monitoring and extraction technologies.

Statement of how the problem is being addressed.

It has been shown that borehole seismology is technically able to map fractures and fracture systems and monitoring fracturing processes using 3C borehole seismic data in 3D. Currently borehole seismic techniques are however limited in their use for mapping and monitoring gas reservoirs by the limited number of receivers deployable in a well, the receivers limited vector fidelity and their limited ability to operate at high temperatures and high pressures in corrosive environments. We are proposing to develop a novel borehole seismic instrumentation system that will address the detailed mapping and monitoring needs prior to and during extracting gas from gas shale reservoirs and tight sands.

To meet the objectives of high resolution imaging and monitoring of gas shale reservoirs required to yield economic production we are proposing to design a 1,000 level drill pipe deployed borehole seismic receiver array system using fiber optic sensor technology and build a 200 level demonstration system. This system will then be used for two demonstration surveys under this program with operators of gas shale and tight sand reservoirs in the US. The fiber optic sensor technology was developed by the US Navy for its submarine fleet and it has been shown that the fiber optic sensors are more sensitive, have a lower noise floor and are more robust than electronic equivalents such as hydrophones, geophones and MEMS sensors making them excellent candidates for the demanding borehole environment. The drill pipe design allows the receiver array to be deployed in both vertical and horizontal wells which is an operational requirement since many of the newly drilled wells in gas shales are horizontal. The all metal clamping system using drill pipe hydraulics as a power source and fiber optic receivers operated using light only manufactured using high temperature fibers will allow the design and manufacturing of receiver arrays that can operate to temperatures to 300ºC (572ºF) at pressures of up to 30,000 psi since no electronics or electric power will be used in either the hydraulic clamping system or fiber optic geophones. Since no electronics or electric equipment is part of the borehole component of the borehole seismic imaging system the system will be extremely robust and can thus be used for long term monitoring such as permanent installations in boreholes as well as for redeployable borehole seismic systems.

Key Deliverables.

A borehole seismic system available to the gas shale and tight sand industry that can operate in both vertical and horizontal wells at pressures up to 30,000 psi and at temperatures up to 300ºC (572ºF). Data and images from two borehole seismic demonstration surveys that can be used to assess the value of the new borehole seismic imaging system and be used to plan for surveys in gas shale and tight sand fields.

Commercial Applications and Other Benefits from the Proposed Project.

High resolution 3D images derived from high frequency high fidelity borehole seismic P and S wave data will be critical to understand the geometry and dynamics of gas shale reservoirs in general and the fractures in the gas shale reservoirs in particular. These images lower the risk of misplacing new wells and re-drilling of existing wells into the reservoirs and will together lead to a greatly improved recovery of the gas resources. Improved understanding and delineation of reservoirs lowers the economic risk, allowing for the operation of smaller, more complex and normally marginal gas shale and tight sand fields. It will also allow for the identification and production of previously unknown gas resources in larger fields such as fractured zones and blocks isolated by faulting. In all producing reservoirs, an improved description is critical to manage production effectively.

Partners and Subcontractors.

The following five companies will participate in the manufacturing of the downhole seismic system and the processing of the generated data. US Sensor Systems, Inc. will build the fiber optic geophones. Optiphase, Inc. will build the interrogator of the fiber optic geophones which will allow unprecedented seismic data volumes to be transmitted from the borehole to the surface. Kemlon Products will build the pressure housings and the connectors and Premier Drill Pipe, Ltd. will build the drill pipe and deployment system components which is the strength backbone of the deployment system. Norsar will process the borehole seismic data and generate models and image the micro seismic data. All the components from the four manufacturing partners and subcontractors will be built using designs and specifications from Paulsson, Inc. Norsar will process the micro seismic data from the demonstration survey guided by Paulsson using their newly developed state of the art software for micro seismic monitoring and imaging. Software for processing 3D VSP data is today a commercial product and commercial software will be used to process the 3D VSP data to obtain and 3D velocity volume and a 3D seismic image volume.

Organizations providing the required cost share

The following organizations will provide cost share contributions: Paulsson, Inc., US Sensor Systems, Inc., Optiphase and Norsar.

Executive Summary

IMPROVED DRILLING AND FRACTURING FLUIDS FOR SHALE GAS RESERVOIRS

The University of Texas at Austin

Principal Investigators:

Mukul M. Sharma (Petroleum and Geosystems Engineering)

Martin E. Chenevert (Petroleum and Geosystems Engineering)

The development of shale gas plays is largely dependent on the cost of drilling and fracturing horizontal wells. Rapid decline rates require that new wells be drilled just to maintain production. A reduction in the cost and environmental footprint of drilling and fracturing will lead to a significant expansion of shale gas development. This proposal aims at developing materials and methods for substantially reducing drilling and completion costs and maximizing gas well productivities in shale gas reservoirs. We propose to accomplish this in two ways:

(1) Develop nanoparticle based water-based drilling fluids that are compatible with reactive gas shales and cost a lot less than the oil-based fluids being used today, and

(2) Minimize the amount of frac-fluid trapped in the shale by capillary forces by using fluorocarbon surfactants and energized fluids.

Gas shales often have a high clay content that can cause wellbore stability problems that necessitate the use of oil-based fluids for drilling. This significantly increases drilling costs and the environmental footprint. Recent work conducted in the PI's lab shows that the addition of nanoparticles (in the size range of the pore throats of the shale) to the drilling fluid results in a dramatic reduction in the reactivity of the shale with the drilling fluid. The use of such fluids provides a significant cost savings when drilling water-sensitive shales with water-based fluids without the danger of wellbore collapse.

Fracturing fluids used in gas shales often reduce the permeability of the shale to gas because of trapping of the water in the pore space. This water remains trapped by capillary forces because the pore size in the shale is so small and the capillary pressures are so high. We propose to use fluorochemical surfactants in fracturing fluids that adsorb on the shale surface and render the pore surfaces neutrally wet. This significantly reduces the capillary pressure holding the water in the pore space and allows the gas to flow back more easily. The effect of water-blocking on shale gas well productivity is, therefore, minimized resulting in a 2 to 5 fold increase in well productivity.

Finally, in gas shales that contain water sensitive clays, it may be desirable to minimize or eliminate contact with a water based fluid. Energized fracturing fluids, such as CO_2 foams, provide a way to accomplish this. The interaction of energized frac fluids with shales will be measured and the potential benefits quantified.

In summary, this proposal aims at developing novel drilling and fracturing fluids that will provide an operator the following key deliverables:

- Novel, water-based drilling fluids for water sensitive shales that will significantly reduce the cost of drilling horizontal wells in shale gas reservoirs.
- Fluorocarbon additives and energized fracturing fluids to help minimize the impact of water blocking in gas shales during flowback.
- Data and recommendations on the use of these novel drilling and fracturing fluids in gas shales.

PUBLIC EXECUTIVE SUMMARY

Name of Offeror: IEC, Inc.
Project Director/Principal Investigator: Dr. Killian C. Ikwuakor
Title: Development of predictive petrophysical models for multi-component characterization of tight gas reservoirs
Solicitation Number: RFP2009UN001

The Piceance basin in northwest Colorado is a hub of exploration and production of natural gas from tight gas sandstones as well as a laboratory for the study of tight gas reservoirs. However, significant portions of the gas-in-place remain unproduced because of lack of better understanding of the petrophysical characteristics of tight sand reservoirs and lack of effective strategies that would improve reservoir delineation and recovery. The above factors combine to make new technology requirements a key component in the future production of natural gas from tight sands. The project will perform preliminary studies of novel concepts and methods for development of tight gas resources, and for the estimation of potential reserves of tight sand resources based on an evolving technology.

The project will develop novel interpretation and analysis techniques that differ significantly from traditional practices, based on the principal investigator's work in combined and simultaneous interpretations of compressional wave (P-wave) and shear wave (S-wave) data. Combined use of P-wave and S-wave data can improve subsurface images and estimates of reservoir and fluid properties because P-waves and S-waves respond differently to solids and liquids. However, technical development of multi-component applications is currently limited because the effectiveness of the techniques cannot be fully tested. With clear and predictive interpretive models, multi-component technologies will find rapid and widespread application in determining tight gas reservoir characteristics and solving the nation's increasing demand for natural gas.

Development of predictive petrophysical models will be based on a family of linear equations relating P-wave velocity (Vp), S-wave velocity (Vs), porosity and effective stress. Measurements of Vp, Vs and porosity will be made at high levels of effective stress on cores collected from tight fractured gas reservoirs in the Piceance basin. Coefficients extracted from the crossplots of these measurements will serve to develop reservoir models and quantify reservoir and fluid properties. The project will deliver a final report that contains the results of the proposed study, including the data from all the tasks performed, along with crossplots, tabulations of results, analyses and conclusions based on these data.

Successful research will lead to: 1) improved techniques for S-wave seismic modeling and subsurface imaging, 2) new knowledge base and systematic technical development and understanding of applications of multi-component data, 3) new and accurate log interpretation techniques for quantitative determination of mobile fluid saturations and gas-in-place, and 4) a predictive capability to locate natural fractures prior to drilling, and predict pay zones prior to completion. To the nation, successful research will secure that future demands of natural gas will be met.

09122-43

RFP Number:

RFP2009UN001 (UNCONVENTIONAL ONSHORE PROGRAM)

Title of Project:

Key Factors Affecting Petrophysical and Geomechanical Properties of Gas Shale and Their Effects on Fluid Flow: Implications for Frac-Fluid Considerations

Name of Offeror (Prime contractor):

The Bureau of Economic Geology
The University of Texas at Austin
University Station, Box X
Austin, TX 78713-8924

Names of Offeror's subcontractors and other participants:

Dr. Jack Ward, PetroEdge Energy Inc., Houston, TX
Mr. Robert Archer, Knowledge Reservoir, LLC, Houston, TX

Prime contractor's technical point of contact name, phone number, and email:

Dr. Fred Wang
512-471-7358
fred.wang@beg.utexas.edu

Dr. Ursula Hammes
(512) 471-1891
ursula.hammes@beg.utexas.edu

Prime contractor's contractual point of contact name, phone number, and email

Courtney Frazier Swaney, Assistant Director
(512) 471.6424
osp@austin.utexas.edu

Area of interest: Gas shales
Topic Area: Reservoir description and management

Public Executive Summary

With the rapid development of Barnett, Haynesville, Eagleford, Fayetteville, Caney and Woodford shale-gas plays, southwest states, including Texas, Louisiana, Oklahoma and Arkansas, have become the most productive and important shale-gas-producing province in the United States. In addition to the Barnett Shale, **Haynesville** Shale in Louisiana and East Texas, and **Eagleford** Shale in South Texas are two new high-quality and high-rate shale-gas plays. In North America alone, more than 70 shale-gas plays have been identified and among them the **Marcellus Shale** is the largest one. With this rapid increase in emerging shale-gas plays and shale–gas production, gas-shale systems have presented many new challenges to production technology and the environment, as well as basic understanding of pore networks, petrophysical, geological, geomechanical and engineering properties and their impacts on fluid flow in shale-gas reservoirs.

Success of shale-gas production can be attributed to internal and external factors. Internal factors related to gas-shale quality include gas content, thickness and size, brittleness, pore network and reservoir quality whereas external factors include evolution of production technology and market conditions. Cores from Barnett, Haynesville, Eagleford, and Marcellus Shales available to the Bureau of Economic Geology provide a rare opportunity to address effects of key rock and fluid properties on fluid flow in gas shales, and economically viable and environmentally-sound technologies needed for all shale and tight-gas developments in the U.S. and around the world. This proposed project will (1) measure key geologic, petrophysical and engineering properties; (2) study effects of burial history and tectonic setting on petrophysical and geomechanical properties; (3) develop novel theories on pore network, low connate water saturation, frac-fluid and gas flows, and brittleness, as well as state-of-the-art modeling technologies and screening criteria for shale-gas systems; and (4) screen new frac fluids that have less impacts on the environment and can enhance production.

The project addresses economically viable and environmentally-friendlier technologies needed for all shale-gas and tight-gas communities in the U.S. and around the world. These methods will have potential to increase shale-gas reserve, to save billions of U.S. dollars in full-cycle fracing costs, to increase environmental protection, and to profit even more from production enhancement.