FORT UNION DEEP

Topical Report

By
Lyle A. Johnson Jr.

March 2002

Work Performed Under Cooperative Agreement
DE-FC26-98FT40323 Task 18

For
Timberline Energy, Inc.
Franktown, Colorado

And
U.S. Department of Energy
National Energy Technology Laboratory
Morgantown, West Virginia

By
Western Research Institute
Laramie, Wyoming

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ABSTRACT

Coalbed methane (CBM) is currently the hottest area of energy development in the Rocky Mountain area. The Powder River Basin (PRB) is the largest CBM area in Wyoming and has attracted the majority of the attention because of its high permeability and relatively shallow depth. Other Wyoming coal regions are also being targeted for development, but most of these areas have lower permeability and deeper coal seams.

This project consists of the development of a CBM stimulation system for deep coal resources and involves three work areas: (1) Well Placement, (2) Well Stimulation, and (3) Production Monitoring and Evaluation. The focus of this project is the Washakie Basin. Timberline Energy, Inc., the cosponsor, has a project area in southern Carbon County, Wyoming, and northern Moffat County, Colorado.

The target coal is found near the top of the lower Fort Union formation. The well for this project, Evans #1, was drilled to a depth of 2,700 ft. Three coal seams were encountered with sandstone and some interbedded shale between seams. Well logs indicated that the coal seams and the sandstone contained gas. For the testing, the upper seam at 2,000 ft was selected.

The well, drilled and completed for this project, produced very little water and only occasional burps of methane. To enhance the well, a mild severity fracture was conducted to fracture the coal seam and not the adjacent sandstone. Fracturing data indicated a fracture half-length of 34 ft, a coal permeability of 0.2226 md, and permeability of 15.3 md. Following fracturing, the gas production rate stabilized at 10 Mscf/day within water production of 18 bpd.

The Western Research Institute (WRI) CBM model was used to design a 14-day stimulation cycle followed by a 30-day production period. A maximum injection pressure of 1,200 psig to remain well below the fracture pressure was selected. Model predictions were 20 Mscf/day of air injection for 14 days, a one-day shut-in, then flowback. The predicted flowback was a fourfold increase over the prestimulation rate with production essentially returning to prestimulation rates after 30 days.

The physical stimulation was conducted over a 14-day period. Problems with the stimulation injection resulted in a coal bed fire that was quickly quenched when production was resumed. The poststimulation, stabilized production was three to four times the prestimulation rate. The methane content was approximately 45% after one day and increased to 65% at the end of 30 days. The gas production rate was still two and one-half times the prestimulation rate at the end of the 30-day test period. The field results were a good match to the numerical simulator predictions. The physical stimulation did increase the production, but did not produce a commercial rate.

To attempt to increase the production rate, an attempt was made to lower a water pump in the well, but was unsuccessful. Analysis of the problem indicated that the well casing had become damaged by the coal seam fire. Plans to use a reamer or mill bit to correct the buckled casing have been proposed. The cosponsor will evaluate the lower two seams and the sandstone between the coal seams to determine if a commercial gas well can be completed.

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EXECUTIVE SUMMARY

Coalbed methane (CBM) is currently the hottest area of energy development in the Rocky Mountain area. The Powder River Basin (PRB) is the largest CBM area in Wyoming, and to date has attracted the majority of the attention because of its high permeability and relatively shallow depth. Other areas, such as the Hanna, Washakie, Green River, and Denver Basins of southern Wyoming, are also being targeted for development. Most of these areas have lower permeability and deeper coal seams than the Powder River Basin.

This project consists of the development of a CBM stimulation system for deep coal resources and involves three work areas: (1) Well Placement, (2) Well Stimulation, and (3) Production Monitoring and Evaluation. The focus of this project is the Washakie Basin. Timberline Energy, Inc., the cosponsor, has a project area in southern Carbon County, Wyoming, and northern Moffat County, Colorado. The area is approximately eight miles west of the town of Baggs, Wyoming. Surface and mineral ownership is a mixture of fee, Bureau of Land Management (BLM), and state.

The target coal is found near the top of the lower Fort Union formation in a zone referred to as the "Baggs coal zone." The Fort Union is Paleocene in age and the coals are generally subbituminous B and C in rank. The well for this project, Evans #1, was drilled to a depth of 2,700 ft. Three coal seams were encountered, at 2,000, 2,150, and 2,450 ft. The interval from the top to the bottom coal seam was composed of sandstone with some interbedded shale. Well logs indicated that the coal seams and the sandstone contained gas. For the testing, the upper seam was selected.

The well was completed with a rod pump and was produced for several days immediately after completion. During that time, very little water was produced and only occasional burps of methane. To stimulate the well, a mild severity fracture was conducted to limit the fracture to the coal seam and not the adjacent sandstone. Based on the fracturing data, the fracture gradient was 0.95 psi/ft and a fracture half-length of 34 ft was apparent. The permeability of the coal seam, estimated from fracturing data, was 0.2226 md. The permeability of the fracture was estimated to be 15.3 md. Following fracturing, the gas production rate stabilized at 10 Mscf/day within water production of 18 bpd.

The WRI CBM model was used to design a 14-day stimulation cycle followed by a 30-day production period. A maximum injection pressure of 1,200 psig to remain well below the fracture pressure was selected. Model predictions were 20 Mscf/day of air injection for 14 days, a one-day shut-in, then flowback. The predicted flowback was a fourfold increase over the prestimulation rate with production essentially returning to prestimulation rates after 30 days.

The specifications for the physical stimulation were a maximum rate of 25 Mscf and 1,200 psig over a 14-day period. In actuality, because of a problem with the control system on the contractor's injection compressor, discovered after the test, the injection rate was 8 to10 times the specified rate. After the well was shut-in for one day, it was placed on production. The water and gas that initially

flowed from the well were hot. The initial gas analyses indicated the presence of hydrogen and carbon monoxide, both indications that the coal seam had been ignited. The hot conditions, the hydrogen, and the carbon monoxide lasted approximately two days, which indicated that the coal fire had been extinguished by the influxing water. The ignition of the coal was produced by injection of hot (~300 °F) air, because the compressor inter-coolers could not handle the high flow rates.

The poststimulation, stabilized production was three to four times the prestimulation rate. The methane content was approximately 45% after one day and increased to 65% at the end of 30 days. The gas production rate was still two and one-half times the prestimulation rate at the end of the 30-day test period. The field results were a good match to the numerical simulator predictions. The physical stimulation did increase the production, but did not produce a commercial rate.

To attempt to increase the production rate, an attempt was made to lower a water pump in the well, but was unsuccessful. Analysis of the problem indicated that the well casing had become damaged by the coal seam fire. Plans were developed to correct the problem. The plan is to use a reamer or mill bit to remove the casing that has buckled, and therefore restore the well to operable conditions. The cosponsor will then evaluate the lower two seams and the sandstone between the coal seams to determine if a commercial gas well can be completed.

INTRODUCTION

Coalbed methane (CBM) is currently the hottest area of energy development in the Rocky Mountain area. Wyoming has several areas where CBM is or will be developed. The Powder River Basin (PRB) is the largest of these areas, and to date has attracted the majority of the attention because of its high permeability and relatively shallow depth. Other areas, such as the Hanna, Washakie, Green River, and Denver Basins of southern Wyoming, are also being targeted for development. Most of these areas have lower permeability and deeper coal seams than the Powder River Basin.

The coal in these other areas is deeper and less permeable than the PRB coals. To enhance the CBM production, it will be necessary to stimulate the permeability by either pneumatic or hydraulic fracturing to provide a greater drainage area. As in most CBM areas, dewatering of the coal seam will be required prior to establishing significant flow of the desorbed methane. Water disposal in these areas, as in other areas, has the potential to be an increasing problem, and therefore the reduction in water production is becoming an issue.

Resource

The focus of this project will be the Washakie Basin. Timberline Energy, Inc. has a project area in southern Carbon County, approximately eight miles west of the town of Baggs, Wyoming. Surface and mineral ownership is a combination of fee, Bureau of Land Management (BLM), and state. Timberline is the operator of leases under producing wells. An existing infrastructure of gas gathering lines and treatment facilities is in place. Year-round access is provided by a network of field roads.

Conventional natural gas is produced in this area from the Wasatch, Fort Union, Lance, Lewis, and Mesaverde formations at depths of 800 to 7,000 ft in the Baggs South, West Side Canal, Smith Ranch, and State Line fields. These fields lie on the eastern portion of Cherokee Ridge that separates the Washakie Basin, Wyoming, from the Sand Wash Basin, Colorado. The Sierra Madre uplift is to the northeast.

The target coal is found near the top of the lower Fort Union formation in most wells throughout T12N, R92 & 93W, Colorado and Wyoming, and is referred to as the "Baggs coal zone" (Honey and Robinson Roberts, 1989). The Fort Union is Paleocene in age, and the coals are generally subbituminous B and C in rank with Btu values of 8,500 to 10,000 Btu/lb. Gas contents are estimated to be 100 to 200 cuft/ton. Drilling depths range from 4,000 ft on the west edge of T12N, R93W to 1,200 ft on the east edge of T12N, R92W (McCord, 1984 and Schwochow, 1991). The "Baggs coal zone" outcrops along the Little Snake drainage about nine miles farther east. Several good geologic studies have been conducted in this area, including Hettinger, 1979, and three studies by Dames and Moore in 1979.

Honey and Robinson Roberts, 1989, produced a cross-section east of this project area that indicates 45 to 50 ft of coal trending onto Timberline's acreage. From this cross-section and other wells in the project area, the "Baggs coal zone" appears to be continuous across the project area. The coal zone is about 30 ft thick at a depth of 2,100 to 2,200 ft. Additional wells east and west of the project site show the "Baggs coal zone" to be 20 to 28 ft thick at depths of 1,000 to 2,000 ft and 27 to 33 ft thick at depths of 3,000 to 4,000 ft, respectively.

For estimating gas content per well, many assumptions are required. The "Baggs coal zone" has an average thickness of 30 ft under Timberline's project area. Using 1.3 gm/cc and 150 Mcf/ton in a spreadsheet for volumetric gas calculations yields 267 Mcf/ac-ft of coal (Ayers, 1994 and Fassett, 1988). Cleat spacing and fracture densities are unknown. If 40-acre drainage is reasonable, there is 320 MMcfg in place. A 75% recovery factor would allocate 240 MMcfg per well.

To verify these predictions, Barrett Resource Corporation's Four Mile Sheep Company Unit #3 well, east of the project area, was recompleted into the Fort Union in 1998 by perforations at 1,227 through 1,232 ft. The initial production rate was 260 Mcf/day, with an undisclosed amount of water. The well is listed as a CBM well, even though the perforations are actually in a sandstone bracketed by a 14-ft coal seam above and a 2-ft thick coal seam below. The coals correlate to the "Baggs coal zone." Cumulative production through March 1999 was 80 MMcf of gas and 7,500 BW. The average gas and water production during March 1999 was 105 Mcf/day and 35 BW/day, respectively.

Timberline's project area offers a significant opportunity to evaluate CBM production and stimulation techniques for CBM below 2,000 ft. Existing boreholes in the area provide excellent geologic and geophysical data necessary for control. The "Baggs coal zone" has adequate thickness, continuity, and gas content to be a commercial target. Testing advanced technology could improve economic results at this site and allow for widespread technology transfer to similar settings throughout the Rockies.

Process Simulation

Western Research Institute (WRI) has both a numerical simulator capable of predicting CBM production and a patent-pending process for stimulating CBM production while decreasing the total amount of water produced. Both of these technologies will be applied and verified in this project. Following is a description of both techniques.

Model Description

Reservoir models are invaluable for predicting recovery as a function of time and operating conditions. Models can aid in reservoir design since the effects of different well spacing and

production pressures can be tested before being implemented in the field. Models are also useful for determining the total reserves in place and for estimating the economic life of a field.

The production of methane from coal beds presents different problems than encountered in conventional sandstone reservoirs. In coal beds, the pressure must first be reduced before methane is released from the coal. The methane is subsequently produced along cleats within the coal bed, where it is drained by production wells. Often, water is present in the coal bed's cleat system, and this water must be produced before methane is recovered. The rate at which water is produced and the ability to reduce the pressure within the coal bed so that methane can be produced are important considerations that determine the economics of CBM production.

WRI has developed a numerical simulator (WRICBM) to model the production of methane from coal beds. WRICBM is a full-featured simulator with capabilities that are useful in predicting recovery from coal beds in Wyoming. WRICBM is capable of modeling the production of multicomponent gases. This feature is useful when the coal bed produces other gases, such as nitrogen and carbon dioxide. WRICBM can also simulate the effects of water influx, such as from an active aquifer. WRICBM can also predict recovery from reservoirs that are composed of both sandstone and coal. A brief description of WRICBM's formulation follows.

WRICBM models a dual-porosity formation in which a non-porous, non-permeable, stationary matrix communicates with a porous, permeable matrix. The stationary matrix represents the coal. The permeable matrix represents the coal bed's cleat system. Water and gases only flow within the permeable matrix. Gases exchange between the stationary and permeable matrix elements. This feature simulates gas desorption/sorption between the coal bed's coal and cleat systems. The movement of multicomponent gases and water phases within the permeable matrix is described by the multiphase modification of Darcy flow. Therefore, the transport of fluids is dependent on pressure gradients for each phase, fluid viscosity, and permeability of gas and water phases. The rate and quantity of gas desorption/sorption can optionally be determined by equilibrium, pseudo-unsteady state, and fully unsteady-state controlled-transport mechanisms. Equilibrium transport assumes that the pressure in the coal is the same as the pressure in the local cleat system with no time delay for desorption. The pseudo-unsteady state transport assumes an average concentration of gas sorbed within the coal and diffusion-limited transport of sorbed gas within the coal. Fully unsteady-state transport assumes a concentration gradient of sorbed gas within a coal element with diffusion-limited transport of sorbed gas within the coal. The unsteady-state methods assume the sorbed gas concentrations at the surfaces of each coal element are functions of the local partial pressures of the permeable matrix. Individual partial pressures are calculated as the product of the reservoir pressure in the cleats and the individual mole fraction of each gas species present. The multicomponent, extended Langmuir relationship relates the quantity of individual gas component sorbed to respective gas partial pressure.

Material balance equations for water and for each gas component present are solved simultaneously by the model for each differential element of the coal bed. Darcy flow describes the transport in the cleats. Source terms represent the quantity of gas desorbed/sorbed for each component in the individual gas balance equations. WRICBM calculates the flow of water at the wells in the standard way. The calculation uses viscosity of the phases, differential pressure between the coal bed's cleat pressure and the wellbore, and a productivity index that accounts for the radial nature of the well's drainage. Source terms couple the well equations to the individual material balance equations.
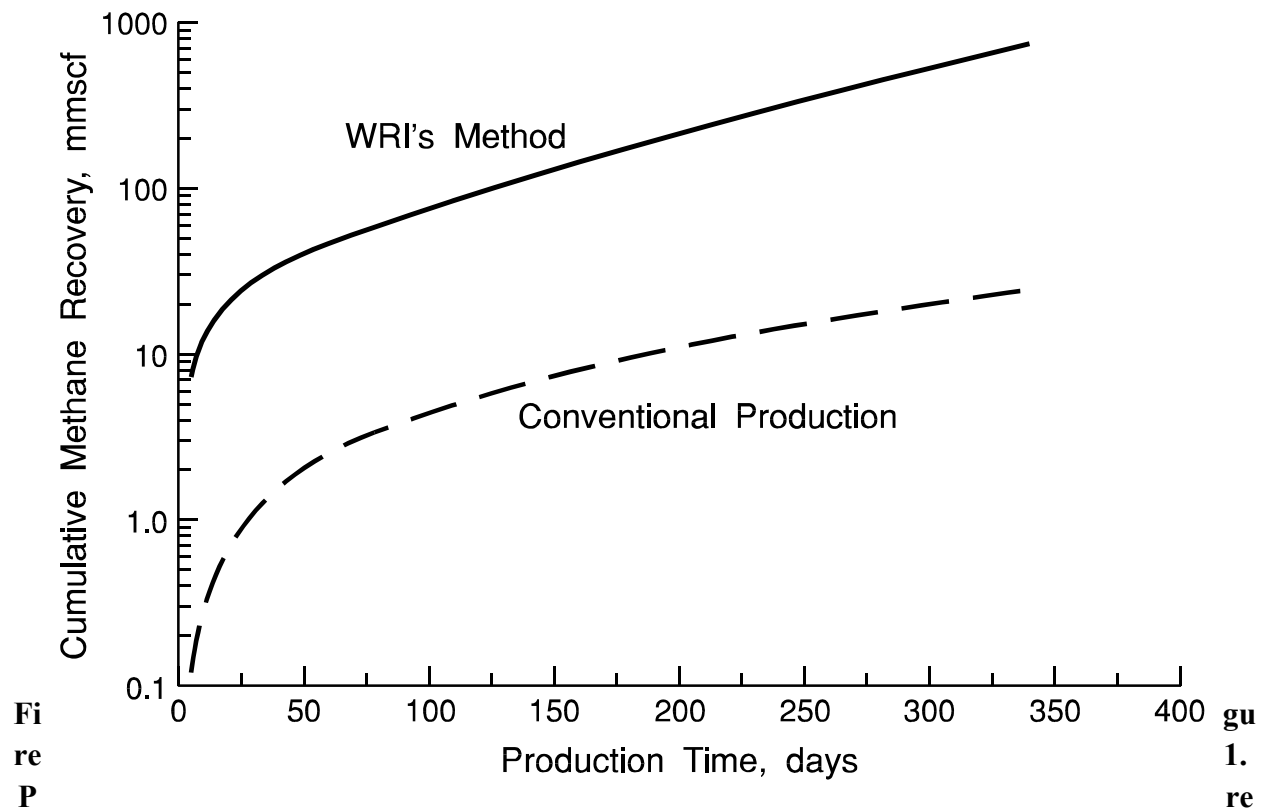
The model has been validated against Amoco's CBM model and has been used to history match and predict CBM processes in the San Juan CBM area of New Mexico.

WRI's Stimulation Method

The production of methane from coal beds involves the reduction of pressure within the coal so that methane can be released and subsequently produced to the surface. If water is initially present in the coal, the reduction of pressure will also result in the production of large quantities of water before significant production of methane begins. Water handling costs and the length of time necessary to initiate gas production by reducing the pressure in the coal bed often determine the economics of CBM recovery.

WRI has developed a method for partially dewatering and stimulating methane production from CBM wells. This method is unique in that an initial dewatering phase is not required prior to producing large quantities of methane. The coalbed operator benefits in that water handling costs are reduced and there is no time delay before methane production commences. WRI implemented the method of stimulation in a computer model. The predicted cumulative recoveries from both a stimulated and conventionally operated well are shown in the following figure. After one year's production, the stimulated producer recovers 30 times more methane than the conventionally operated well.

The proposed project will consist of the development of a CBM stimulation system for deep coal resources. WRI's CBM simulator will be used to design the process. Well stimulation will consist of increasing the coal bed permeability through either pneumatic or hydraulic fracturing to provide access to a greater portion of the resource. Following the fracturing, WRI's CBM stimulation process will be applied to offset the dewatering period that is necessary in CBM production to allow desorption of the methane. Data from adjacent CBM wells, which the cosponsor will be installing during the test period, will be used for comparison with wells that have no stimulation or have only fracture stimulation.

Predicted Coalbed Methane Recovery from a Typical Powder River Basin Coal

OBJECTIVE

The objective of this task is to demonstrate the viability of stimulation techniques for production of CBM from deep resources. In meeting this objective, the validity of the WRICBM will be tested, as will the effectiveness of WRI's stimulation techniques for CBM production.

EXPERIMENTAL TASKS

This project consists of the development of a CBM stimulation system for deep coal resources. The stimulation consists of increasing coal bed permeability through either pneumatic or hydraulic fracturing to provide access to a greater portion of the resource. Following fracturing, WRI's CBM stimulation process is applied to offset the dewatering period that is necessary in CBM production to allow desorption of the methane. Three tasks pertaining to the objectives described will be undertaken. Following is a description and progress of each task.

Well Placement

This task involved the selection of the well location and the drilling and completion of the well to be used for the stimulations. Included in this task was the connection of the well to the gas gathering system and installation of metering equipment.

Well Stimulation

The well stimulation involved three areas. First, the process was simulated with WRICBM to predict well response for three scenarios: (1) without any stimulations, (2) with only fracture stimulation, and (3) with both fracturing and WRI's stimulation process. The second area was the selection and conduct of the physical fracturing. Finally, the well was stimulated with WRI's stimulation process.

Production Monitoring and Evaluation

Following stimulation, the production from the stimulated well was to be monitored for several months. Data would be used to validate WRICBM through history matching.

RESULTS

The target coal was located in the top of the Fort Union formation in the Washakie Basin of southern Wyoming and northern Colorado. The test area is eight miles southwest of Baggs, Wyoming, in northern Moffat County, Colorado. The well, Evans #1, was drilled to a depth of 2,700 ft. Three coal seams were encountered, at 2,000, 2,150, and 2,450 ft. The interval from the top to the bottom coal seam was composed of sandstone with some interbedded shale. Well logs indicated that the coal seams and the sandstone contained gas. For the testing, the upper seam was selected.

The well was completed with a rod pumping unit and produced for several days. During that time, very little water was produced and there was occasional burps of methane. Therefore, to stimulate the well a mild severity fracture was conducted. The mild severity was used to limit the fracture to the coal seam and not the adjacent sandstone. The fracturing of the coal consisted of injecting 466 gal of water with an initial shut-in pressure of 1,916 psig. Based on the fracturing data, the fracture gradient was 0.95 psi/ft and a fracture half-length of 34 ft was apparent. Two methods were used to analyze the fracture data to produce an estimate of the permeability of the coal seam. A modified Mayerhofer method produced a permeability of 0.2226 md with the Cartesian pseudoradial flow graph producing an upper limit of 0.3786 md. There was good agreement between the two methods. The permeability of the fracture was estimated to be 15.3 md.

Following stimulation, the well was placed on production with the gas rate stabilizing at 10 Mscf/day within a 14-day window. The water production was 18 bpd during this period.

Based on the data from the fracturing test, a numerical simulation was performed to predict the enhancement that could be expected from the use of WRI's stimulation method. The modeling predicted that because of the low permeability of the coal, there would be limited penetration of the injected material. Even with the limited penetration of the injectant, the decision was made to proceed with the stimulation to verify the model's ability to predict the gas injection and flowback.

The model was used to design a 14-day stimulation cycle followed by a 30-day production period. The gas content used for the prediction was 150 scf/ton with a maximum injection pressure of 1,200 psig. The pressure was selected to remain well below the fracture pressure. Model predictions were 20 Mscf/day of air for 14 days followed by a one-day shut-in. The predicted flowback was a fourfold increase over the prestimulation rate and a methane content of 55% after one day of flowing. Production essentially returned to prestimulation rates after 30 days.

The specifications for the stimulation were a maximum rate of 25 Mscf and 1,200 psig over a 14-day period. In actuality, because of a problem with the injection compressor's control system, not discovered until after the test, the injection rate was 8 to 10 times the specified rate. After air injection, the well was shut-in for one day and then placed on production. The water and gas that initially flowed from the well were hot. The initial gas analyses indicated the presence of hydrogen and carbon monoxide. Both of these facts indicated that the excessively high air-injection process had ignited the coal seam. The hot conditions and the presence of hydrogen and carbon monoxide lasted approximately two days, which indicated that the coal fire had been extinguished by the influxing water. The ignition of the coal was produced by injection of hot (~300 °F) air, because the compressor inter-coolers could not handle the high flow rates. Because the high temperatures had made the downhole section of the rod pump inoperable, the pump was replaced after two days of flowback to increase water removal, and therefore gas production.

The poststimulation, stabilized production was three to four times the prestimulation rate. The methane content was approximately 45% after one day and increased to 65% at the end of 30 days. The gas production rate was still two and one-half times the prestimulation rate at the end of the 30-day test period.

To attempt to increase the production rate, an attempt was made to lower a water pump in the well, but was unsuccessful. The pump was removed and the bridge plug that had been set below the first coal seam and above the second seam was attempted to be removed. The bridge plug would not pass the first coal seam area. The plug was run to the bottom of the hole and uncoupled so that the tubing could be removed. Further attempts to get pumps and tools past the first coal seam indicated that the well casing had become damaged by the coal seam fire.

Plans were developed to correct the problem. The plan is to use a reamer or mill bit to remove the casing that has buckled, and therefore restore the well to operable conditions. The cosponsor will

then evaluate the lower two seams and the sandstone between the coal seams to determine if a commercial gas well can be completed.

CONCLUSIONS AND FUTURE PLANS

WRI's CBM numerical simulator accurately predicted the stimulation process that was used to stimulate the methane production from the Fort Union coal seam. WRI's physical stimulation process did produce an increase in the methane production from the tight coal seam, but the production from the single seam alone would not make a commercial well.

The lessons learned during this project are that the stimulation process has the potential to increase methane production, but the use of air as the stimulant will require strict supervision so that only cool air is injected. The realistic stimulant to put operators at ease would be nitrogen. This would prevent any possibility of accidental ignition of the coal.

The future plans for this project are to correct the damage to the well so that the cosponsor can evaluate the lower seams as to their potential.

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