Analysis of the Impact of Methane Farming on Federal Coal in the Powder River Basin, Wyoming

by JEREMY FUGLEBERG Star-Tribune energy reporter | Posted: Tuesday, February 22, 2011 2:46 pm

This confidential analysis, produced by the Bureau of Land Management on March 11, 2010, expresses concern about lost revenue due to the methane farming process used by Colorodo-based Luca Technologies. The company uses a process in which nutrients are pumped to microbes who consume coal and produce methane gas. The analysis was obtained through a Freedom of Information Act request by the Powder River Basin Resource Council, which passed on the report to the Star-Tribune.

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Summary and Conclusions

Methane Farming is generation and production of methane in real time by stimulating naturally occurring in-situ **microbial activity** which converts coal to methane. Methane farming **reduces the quality** (BTU value) **of** the **coal by consuming coal** to generate methane. The available data suggest coal **BTU** values **may be reduced** by **as much as one percent**. This effectively **transfers value** from the **coal estate to** the **oil and gas estate** unless there is a separation of the mineral estates. **Luca** Technologies **plans to start** methane **farming on a commercial scale** in the eastern Powder River Basin, Wyoming. Luca operates approximately **589** coalbed gas **wells** in the eastern Powder River Basin. **Two-thirds of Luca's wells are on U.S. coal only land** (only the coal is Federal). **Lost Federal coal royalty** due to coal degradation is estimated to be (b) (4)(b) (4) (b) (4)(b) (4) per year. **Royalty on methane** produced by farming would be approximately **three times** as much as the **lost coal royalty** due to coal degradation. The **most crucial royalty issue** in methane farming concerns **U.S. coal only lands**. Luca will probably not use all its wells for methane farming. Luca's wells are as close as three miles from existing coal leases. **Methane farming may continue for 50 years**, possibly longer. There is a strong **possibility** of **conflicts between methane farming and coal mining**. It would be beneficial to U.S. if these conflicts were avoided. Existing data suggest methane farming activities probably will not significantly concentrate or mobilize trace or major elements within the coal, but should be monitored. **Primary issues** to be considered include:

- **Mineral Development Conflict Mitigation**
- **Separation of Mineral Estates**
- **Conveyance of Mineral Rights**
- **Calculation of Royalty**

Introduction

Methane Farming is generation and production of methane in real time by stimulating naturally occurring in-situ microbial activity which converts coal to methane. Methanogenesis producing microbial activity approximately doubles with a 10° C (18° F) increase in temperature. Subsurface temperature increases about 10° C when depth increases 1,000 feet. Approximately 35° to 37° C (95° to 98° F) is optimal for methane production (DeBruyn, 2010, personal communication).

Luca Technologies, an applied research company headquartered in Golden, Colorado, has spent approximately $40 million developing a method to farm methane. Through its operating arm, Patriot Energy Inc., Luca is using depleted coal bed natural gas (CBNG) wells to apply nutrients (restorations) to naturally occurring methane producing bacteria which reside in the coal. The bacteria break down coal and generate methane. This process decreases the energy value of coal. It literally consumes coal. Luca has field tested the technology and "... is now poised for large-scale commercial implementation in the PRB." (Ulrich and DeBruyn, 2009, p. 1). Toward this end, Luca has acquired approximately 589 wells in the eastern Powder River Basin. The wells are located approximately three to four miles west of currently leased coal in the Eagle Butte, Rawhide, and Buckskin mines, and about nine miles west of the Caballo and Belle Ayr mines.

The Wyoming State Office requested that the Reservoir Management Group review Luca's proposed methane farming activities and provide a written report on the potential impacts to Federal lands. Of particular interest were impacts on coal quality (BTU value), potential conflicts between methane farm wells and coal mine expansion, and possible concentration of trace elements in the coal.

Procedure

A list of wells operated by Patriot Energy was compiled. A map showing mineral ownership in the portion of the Powder River Basin where there is current or potential coalbed gas development was constructed (Figure 1). A map showing Patriot Energy wells and current coal leases was also constructed.

Luca was asked to provide estimates of impacts to coal quality on a BTU basis. As part of these calculations Luca estimated the amount of methane generated by each restoration and an efficiency rate based on the amount of methane recovered compared to the energy consumed from the coal. This estimate assumed conservation of energy. In other words, it assumed energy was neither generated nor destroyed during the process and all the energy required to

generate methane was taken from the coal. This includes the energy used by methanogens for sustenance.

A multiple approach was used to obtain a range of reasonable estimates for lost value of the coal caused by methane farming. Three different estimates were calculated.

1. Because methane farming converts coal to gas, the most recent BLM guidance (IM WY-85-14) was used to calculate royalty.[1] IM WY-85-14 addressed coal gasification on a Federal coal lease (see footnote 1), a vaguely similar process to methane farming. Luca's estimated flow rate (26 MCFPD) and gas conversion efficiency (85 percent) were used.
2. The decrease in coal value caused by loss of BTU content (BTUs per pound of coal) was calculated using Luca's (October 2009) estimated impacts.
3. A royalty value for the gas generated by methane farming was calculated based on Luca's estimate of gas recovered per restoration.

In addition, Luca was asked to review possible mobilization and concentration of trace elements within the coal and to consider research done by Drever and others (1977). This research identified concentrations of trace elements near the coal-overburden interface.

Results and Discussion

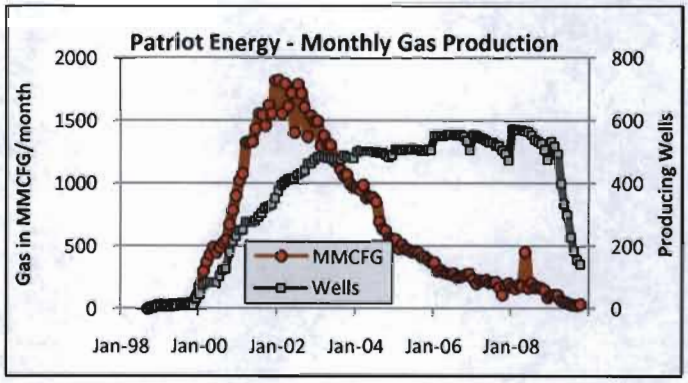
The coalbed gas development area in the Powder River Basin, Wyoming is interspersed Federal, nonfederal, and partial Federal mineral ownership (U.S. coal only). Approximately half the area is Federal minerals. Approximately one-third is U.S. coal only with all other minerals being nonfederal. Luca has acquired operating rights to approximately 589 coalbed gas wells in central Campbell County, Wyoming (Figure 1). The wells are mostly depleted (figures 2a and 2b). IHS Energy Inc. (2009) data indicated only 145 wells were actively producing gas or water in October 2009, the most recent month with recorded production. As shown in figures 2a and 2b, gas and water production, the number of producing wells, and well efficiency (as measured by the water to gas ratio), have all decreased 75 to 98 percent from their peaks. The water to gas ratio measures the amount of water that must be lifted for each MCFG produced. Note that Figure 2b shows that ratio increasing from less than one barrel of water per MCFG during 2002 to 2005 to six to ten barrels of water per MCFG in 2009.

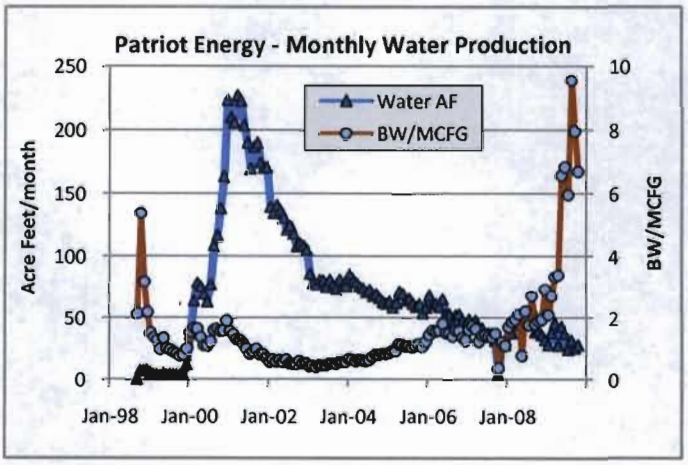
[1] Federal coal leases are issued by BLM. A Federal coal lease requires a $100 per acre minimum bid and three dollars per acre annual rental. In addition, all costs incurred by BLM to issue the coal lease are subject to cost recovery.

Mineral ownership in the Luca wells is dominated by U.S. coal only land. Two-thirds of the wells are on U.S. coal only land and most of the remaining third are on all U.S. minerals (Figure 3). This mineral ownership pattern underscores the compelling issue of U.S. coal only land.

Luca plans to gravity feed produced water, after enriching it with microbe nutrients, into the coal. Each application, called a restoration, is designed to stimulate methanogenesis within the microbial community. These anaerobic bacteria naturally inhabit the coal. Luca estimates that each restoration will generate approximately 32.5 MMCF of methane which will take approximately 4 ½ years to recover.

After methane is generated by bacteria it will rise via buoyancy to the upper part of the coal seam. The methane will then move through coal fractures to the well bore. Water will be pumped from recovery wells to assist methane recovery. Produced water will be recycled back into the coal. Luca estimates an average of ten restorations can be applied to a volume of coal. The effectiveness of each restoration will depend on how effectively it contacts the coal (DeBruyn, 2010). Coal thickness as a parameter is not critical. Field tests showed the same results from a 17 foot thick Tongue River coal as from a 70 foot thick Wyodak coal. Water levels in the coal and the amount of coal contacted by the nutrients are more critical than coal thickness (DeBruyn, 2010). Harris and Stricker, 2010, are not aware of any scientific evidence that indicates more than one or two restorations, if applied to the same coal, would produce significant quantities of methane.





Figures 2a and 2b. Monthly gas and water production from coalbed gas wells operated by Patriot Energy (Luca Technologies). Note the decline in gas and water production, and the number of producing wells. Data are from IHS Energy Inc. production database.

Methane production by microbes consumes energy from the coal. If conservation of energy is assumed, the energy used from the coal is at least as great as the amount of methane produced by microbial activity. Luca used 15 percent as the amount of energy used by the microbes for sustenance and therefore unrecoverable (Luca Technologies, 2009). Fifteen percent is considered a reasonable number by Harris and Stricker, 2010, personal communication.

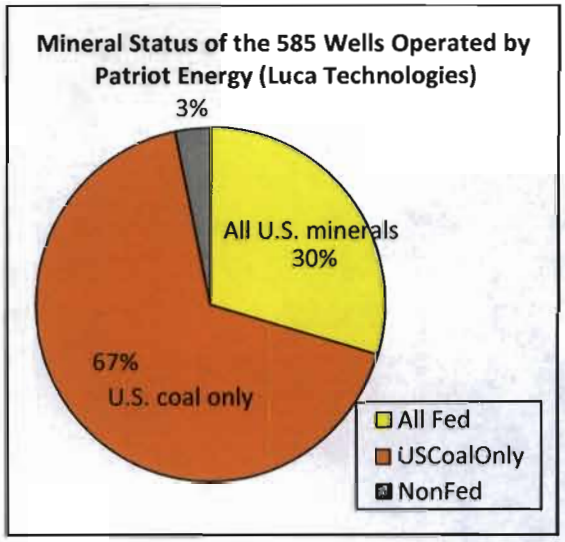


Figure 3. This pie diagram shows the proportion of potential methane farming wells on fee oil and gas with Federal coal (U.S. coal only). Data are from IHS Energy Inc. and BLM files.

Luca calculated potential lost BTU value from the coal and presented its calculations via Power Point to the BLM during a conference call on October 20, 2009. Luca calculated individual lost royalty estimates for Anderson, Big George, Canyon, and Middle/Lower Wyodak coals using chemistry and coal thickness data from Stricker (2007). Luca used data from a cored well located about 20 miles west of the southern-most Patriot Energy wells. A summary of Luca's results is shown in Table 1. The calculations shown in Table 1 are based on as received basis coal analyses. An efficiency factor of 85 percent was built into the calculations used by Luca and incorporated into Table 1. Table 1 indicates a decrease of 0.05 percent to 0.5 percent in coal quality for coals between (b) (4) (b) (4)(b) (4)(b) (4) Based on IHS Energy data, a significant percent of Luca's wells have completion intervals of less than 30 feet. For wells with completion intervals of 15 feet in the Anderson coal, approximately one percent of the BTU value of the coal would be consumed, assuming the generated methane volume is the same as for thicker coals. This is not an unreasonable scenario considering Luca's results from its pilot in Sheridan County (DeBruyn, 2010, personal communication).

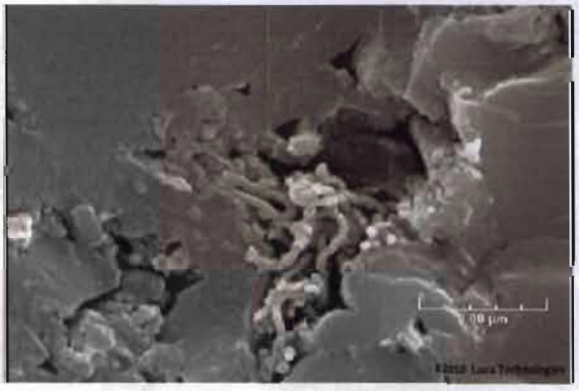


Figure 4. Photograph of Monarch coal fracture face macro porosity with in-situ microbes. Source: Luca Technologies website, 2010.

Luca's Power Point slides and calculations were reviewed by Dr. Gary Stricker in consultation with Dr. Steve Harris, a microbiologist. Both are with the U.S. Geological Survey in Denver. Dr. Stricker's

written summary (2009) indicates Luca used maximum coal thickness reported for a particular coal, the thicker the coal the lower the overall coal degradation on a percentage basis. However, Stricker generally concurs with Luca's estimates shown in Table 1. Coal thicknesses listed in Luca's estimates (2009) appear to be as much as twice as large as coal thicknesses calculated from IHS Energy Inc. data from the Patriot Energy wells. It must be conceded however that coal thicknesses calculated from IHS Energy data may be somewhat problematic. However, the royalty estimates listed in this report are based on energy values and are not affected by what may be a thickness discrepancy.

Name of Coal	Thickness	Tons/AF	BTU/lb	1 Restoration	10 Restorations
Anderson	(b) (4)	(b) (4)	(b) (4)	(b) (4)	(b) (4)	(b) (4)
Big George	(b) (4)	(b) (4)	(b) (4)	(b) (4)	(b) (4)	(b) (4)
Canyon	(b) (4)	(b) (4)	(b) (4)	(b) (4)	(b) (4)	(b) (4)
Mid/Lwr Wyodak	(b) (4)	(b) (4)	(b) (4)	(b) (4)	(b) (4)	(b) (4)

Table 1. Summary of the estimated reduction in coal heating value caused by methane farming. Each restoration was estimated to generate 32,500 MCF of methane which has a heating value of 1,009.7 BTU/scf. Data compiled and calculated from Luca Technologies October 20, 2009, confidential written communication.

The IHS Energy well database lists the coals in Table 2 as completion zones in the Patriot Energy wells. They are generally the same coals listed in Table 1. Coals listed as others in Table 2 are mostly below the Wyodak-Anderson zone but include ten Felix coal wells which are shallower than the Wyodak-Anderson coal zone. The coals listed in Table 2 indicate that Luca's estimates of coal degradation provided on October 20, 2009 should be, for the most part, valid for coals completed in the Patriot Energy wells.

Coals	Wells
Anderson	120
Canyon	95
Fort Union	64
Smith	70
Wyodak	202
others	30

Table 2. Producing coals listed in the IHS Energy well database.

BLM issued guidance on coal gasification (IM WY-85-77) contains the following equation to calculate royalty (Hageman, 2010, written communication):

Royalty ($/mo) = cents/MMBTU (coal) X dollars/cent X MMCFGPD X BTU/scf X day /mo X 0.125 (royalty rate).

This calculation is based on extraction of syngas from a Federal coal lease (see footnote one). The calculation requires technical data, the most important being the quantity and quality (BTU/scf) of gas produced and a value for the coal converted to gas. The equation assumes 100 percent efficiency. The above equation was used to calculate royalty payments for coal valued (b) (4)(b) (4)(b) (4)(b) (4)(b) (4)(b) (4)(b) (4)(b) (4)(b) (4)(b) (4)(b) (4)(b) (4)(b) (4)(b) (4)

Annual royalty estimates are listed in Table 3. Estimates for 100 percent and 85 percent efficiency (conversion of coal to methane) are listed. A higher royalty estimate is required for

the 85 percent efficiency case because 15 percent of the coal consumed is being used to support microbial activity with the remainder converted to methane.

If royalty was paid on the estimated volume and quality of gas produced it would be (b) (4)(b) (4)(b) (4)(b) (4) (b) (4)(b) (4)(b) (4)(b) (4) (b) (4)(b) (4)(b) (4)(b) (4) (b) (4)(b) (4)(b) (4)(b) (4) (b) (4)(b) (4)(b) (4)(b) (4) (b) (4)(b) (4)(b) (4)(b) (4) (b) (4)(b) (4)(b) (4)(b) (4) the coal consumed to generate the methane. Inputs used to calculate these estimates are listed in Table 4. (b) (4)(b) (4) (b) (4)(b) (4)(b) (4)(b) (4)(b) (4) (b) (4)(b) (4)(b) (4)(b) (4)(b) (4) (b) (4)(b) (4)(b) (4)(b) (4)(b) (4)

Underground coal gasification formula, 9,000 BTU/lb (from Hageman written communication, 2010)		
Factor	100% Efficiency	85% Efficiency
Cents/million BTU ($10/ton)	(b) (4)(b) (4)(b) (4)	
Dollars/cent	(b) (4)(b) (4)(b) (4)	
CH_4 in MMCF/year (26MCFPD)	(b) (4)(b) (4)(b) (4)	
BTU(gas)/cubic foot	(b) (4)(b) (4)(b) (4)	
Royalty rate	(b) (4)(b) (4)(b) (4)	
Process efficiency	(b) (4)(b) (4)(b) (4)	
Royalty in dollars/year	(b) (4)(b) (4)(b) (4)	

Table 3. This table lists the estimated lost royalty per year for coal consumed by methane farming operations. A process efficiency factor was not included in original equation. A flow rate of 26 MCFPD equates to 9.49 MMCF/year. Data sources: Steve Hageman, written communication, and Stricker and others, 2007.

Three methane farming situations considered in this analysis are:

1. all minerals (oil, gas, and coal) are owned by the U.S.,
2. only the coal is owned by the U.S. (referred to as U.S. coal only), and
3. no minerals are owned by the U.S.

Clearly the most crucial royalty issue in methane farming concerns U.S. coal only lands. Our analysis shows that royalty on produced methane will almost always be greater than the royalty value of the coal. If none of the minerals are owned by the U.S., then coal degradation is moot. The situation on U.S. coal only land is much different however. The nonfederal oil and gas mineral owner will almost certainly want a royalty on the farmed methane even though it will be generated from U.S. coal. Basin wide, farmed methane would be generated from Federal coal in approximately 84 percent of the cases.

Input Parameter	Value
Gas production rate	(b) (4)(b) (4)(b) (4)
BTU value of gas	(b) (4)(b) (4)(b) (4)
Efficiency factor	(b) (4)(b) (4)(b) (4)
Gas royalty	(b) (4)(b) (4)(b) (4)
Gas price	(b) (4)(b) (4)(b) (4)
Coal quality	(b) (4)(b) (4)(b) (4)
Coal density	(b) (4)(b) (4)(b) (4)
Coal value	(b) (4)(b) (4)(b) (4)
Coal royalty	(b) (4)(b) (4)(b) (4)
Well spacing	(b) (4)(b) (4)(b) (4)

Table 4. Input values to calculate methane and lost coal royalties for methane farming. A coal thickness value is not required. Data sources include Luca, 2009 and DeBruyn, 2010.

This would involve a transfer of value from the Federal coal estate to the private oil and gas estate in 32 percent of the cases. On Luca's acreage, methane farming would involve a transfer of value from the Federal coal estate to the private oil and gas estate in 67 percent of the cases (see Figure 3). Methane farming on U.S. coal only land requires that a mechanism be derived to protect the public interest.

Potential Mineral Development Conflicts

Coalbed gas development began on the eastern side of the Powder River Basin. Wells on the eastern side of the basin, nearest the coal mines, will reach their economic limit first, then become potential methane farm wells. These wells are nearest the active coal mines. Powder River Basin coal mines produce 38 percent of our nation's annual coal consumption. Figure 5 shows the location of coalbed gas wells and coal mines. Note the close proximity. Surface coal mine development is expected to move westward about one to two miles per decade during the next 50 years. Methane farming is potentially a long term activity (50 years).

Without mitigation, there is a very real potential for severe mineral development conflicts between gas farming and surface coal mining. These potential conflicts are at least as severe as those experienced during the late 1990s and early 2000s when hydrocarbon production from low volume oil and gas wells and from coalbed gas wells conflicted with coal mining on Federal leases. Clearly there cannot be methane farming and coal mining operations on the same acreage at the same time. Federal revenue from coal mining operations would dwarf revenue from methane farming.

Mobilization and Concentration of Trace Elements During Methane Farming

Luca was questioned about mobilization and concentration of trace elements by microbial activity. Research by Drever and others (1977) was mentioned to Luca. This research indicates that trace elements have apparently been mobilized and deposited near the coal seam margins in the Powder River Basin. Luca responded with a written report by Ulrich and DeBruyn (2009). Luca's report concludes that "...it is unlikely that trace metals will be released from the coals or become more concentrated in coals as a result of Luca enhancing methanogenesis." Luca requested the report remain confidential due to the sensitive nature of some of the information presented.

Luca's report indicates that solubility of some metals can be affected by microbial activity. Concentrations of copper, iron, and manganese are well above the maximum contaminate limit

in water samples from coalbed gas wells in the Powder River Basin (Rice and others, 2000) and from at least one of Luca's wells. Luca's laboratory data indicate there does not seem to be significantly higher concentrations of trace metals after methanogenesis. Luca suggests analysis of post treatment water samples to confirm no increase in dissolved metals. Luca's report is somewhat inconclusive. Continued monitoring of post treatment water samples is justified.

SIGNED 3-11-2010

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Glossary

AF	Acre feet
BTU	British thermal unit of heat
IM	Instruction memorandum
lbs	Pounds
MCF	Thousand cubic feet at standard conditions, 68°F and one atmosphere pressure
MMBTU	Million British thermal units
scf	Standard cubic foot (68°F and one atmosphere)
syngas	A mixture of gasses, mostly hydrogen and carbon monoxide, generated by high temperature, subsurface gasification of coal
U.S. coal only	Patented land where coal was the only mineral right reserved to the United States
USGS	United States Geological Survey
WOGCC	Wyoming Oil and Gas Conservation Commission, a state agency which regulates oil and gas development

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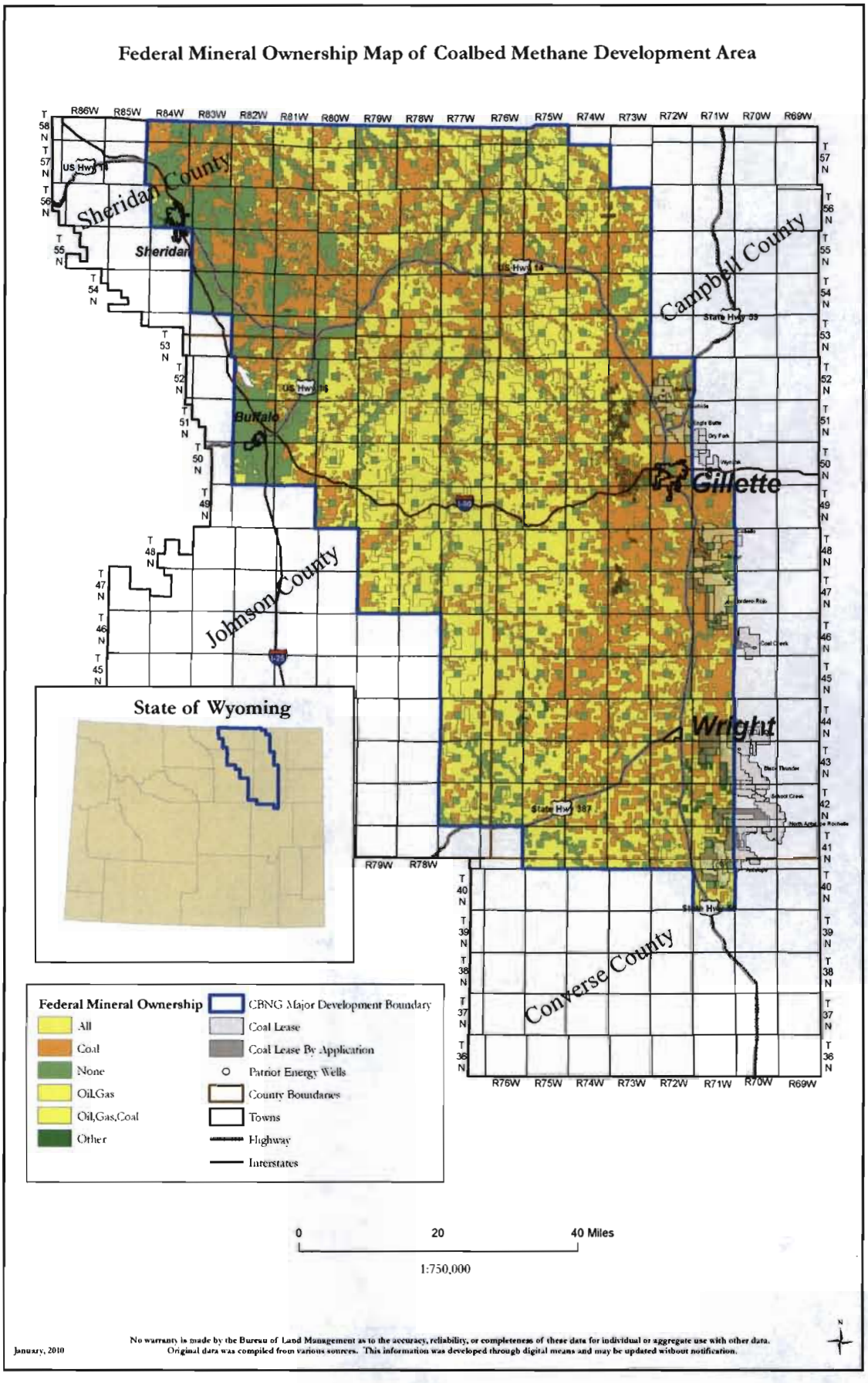

Figure 1. Map of mineral ownership within the main coalbed gas development area in Wyoming. The location of Luca's wells is shown. Data are from BLM files and IHS Energy Inc. production database.

Producing Coal Bed Methane (CBM) Wells, Coal Leases, Lease By Applications (LBA), Coal Mined Out Areas, Total Conflict Administration Zones (CAZ) as of December 2009

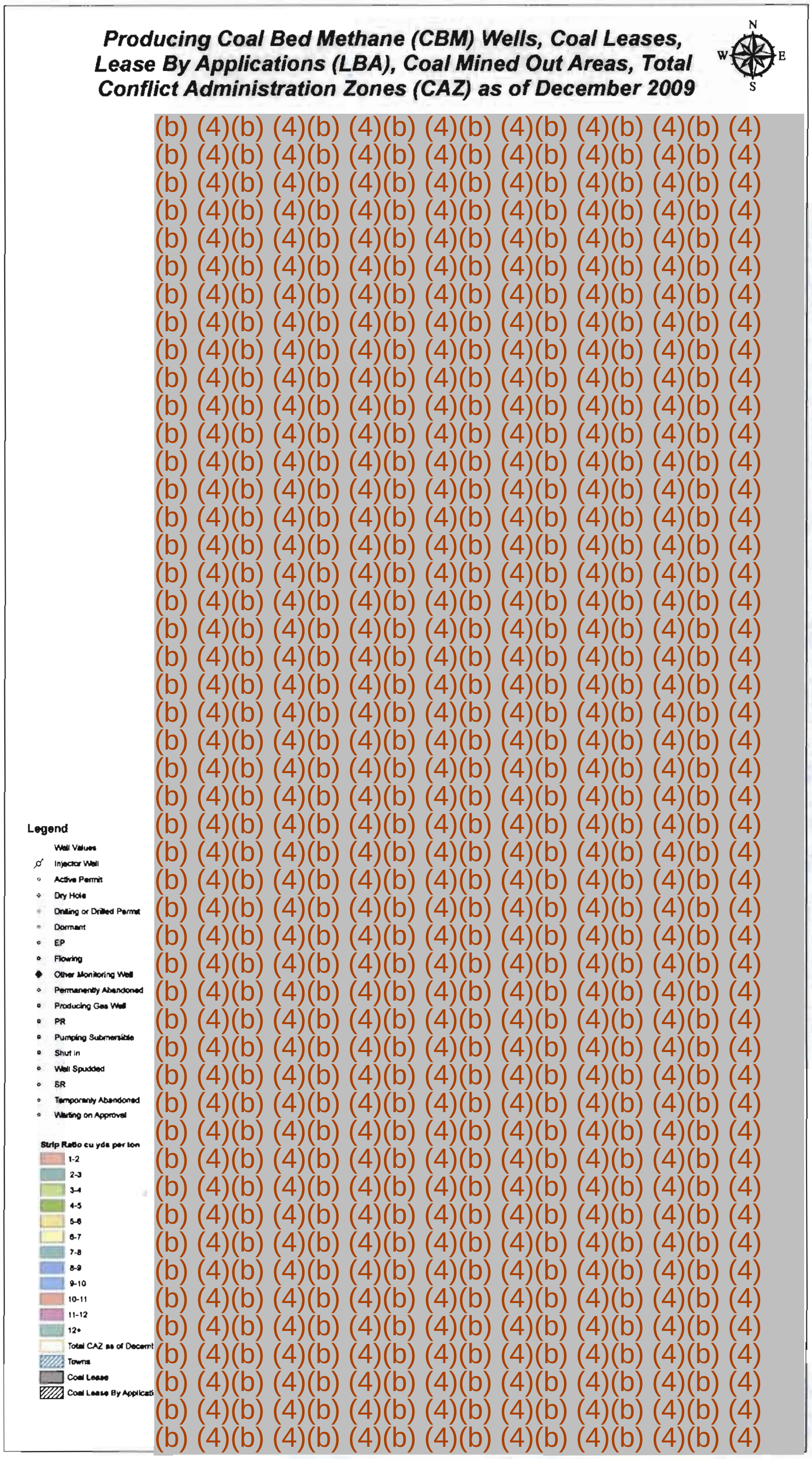

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Figure 5. [redacted]

Additional questions for Roly DeBruyn 1-28-10

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Notes from meeting with Roly DeBruyn. Started at 1400 and ended at 1555 on 1-28-10. It was held at BLM office in Casper. Steve Wright, Fred Crockett, and Mike Karbs (very briefly) represented the BLM. These notes were taken by FC 1-28-10.