Coalbed Natural Gas Resources and Produced Water Management

by Dan Arthur and
Bruce Langhus
ALL Consulting
and
Viola Rawn-Schatzinger,
RMC Consultants

As coalbed methane becomes a primary objective for natural gas drillers, concerns about produced water are coming to the forefront. ***First of three-part series.***

Private and government emphasis in recent years has stressed the growing importance of natural gas as a prime source of energy for industrial power and residential heating needs in the United States. Natural gas was a top priority at a June 2003 meeting of the National Petroleum Council in Washington, D.C. The chairman of the Independent Petroleum Association of America, Diemer True, spoke of development of coalbed natural gas supplies in the western United States.

"The Inter-Mountain West holds a vast promise for America's future natural gas supply," True said.

Western coalbeds with softer bituminous coals contain abundant coalbed natural gas but produce large quantities of water during extraction processes. The U.S. Department of Energy (DOE), in cooperation with the Bureau of Land Management (BLM) and the Ground Water Protection Research Foundation, sponsored a comprehensive guide to coalbed natural gas-produced water. Data from the United States Geological Survey (USGS) displays in map form the coal producing basins in the Rocky Mountain region showing the complex federal and state land ownership, which affects mineral leases, coalbed natural gas production, and environmental regulations for produced water (Figure 1).

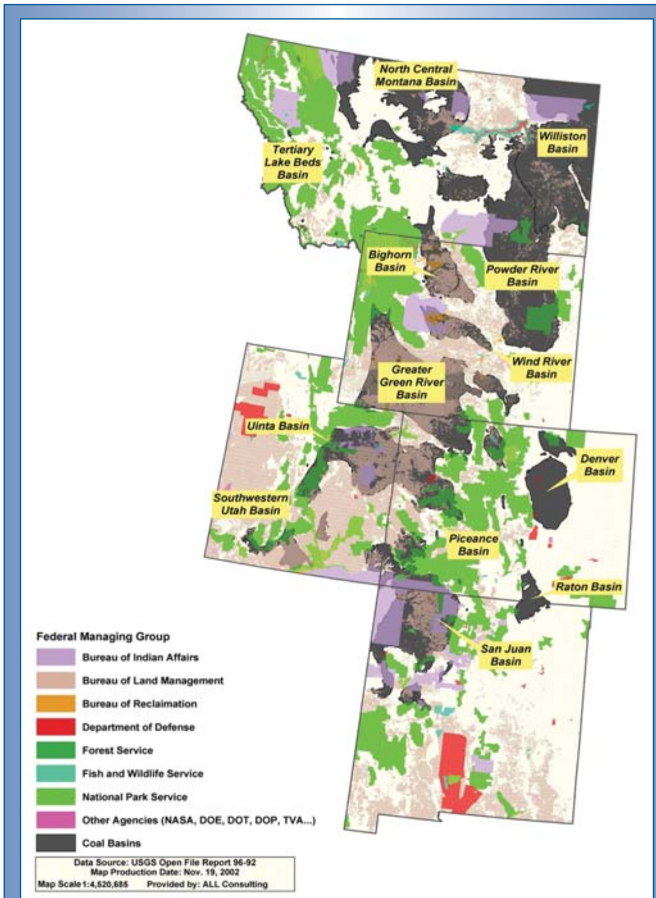

Figure 1. This map shows coal basins within the study area as well as land ownership distribution. (Source: USGS Open File Report No. 96-92; produced by ALL Consulting)

Introduction

The purpose of the guide *Handbook on CoalBed Methane Produced Water: Management and Beneficial Use Alternatives,* prepared by ALL Consulting of Tulsa, Okla., is to summarize existing knowledge on the geological and environmental constraints of producing coalbed natural gas and to explore alternative treatments and beneficial uses for the large quantities of produced water. Formerly termed coalbed methane and still commonly referred to as CBM, the governmental terminology is coalbed natural gas. The USGS, the BLM and the various state geological surveys provided volumes of produced water and CBM production estimates of coalbed natural gas recoverable reserves. Extensive documentation is included in the handbook, soon to be available from the DOE in Tulsa.

This article is the first in a three-part series summarizing the CBM Handbook to appear in future issues of *GasTIPS*. Water problems related to coalbed natural gas production include withdrawal of groundwater from the coal seams, the potential of wasting high-quality water and environmental concerns on disposal of the produced water. The guidebook addresses these concerns, beginning with an overview of coalbed natural gas production scenarios and including a basin-by-basin assessment of CBM resources across the United States, water rights, produced water treatment methods and beneficial uses. Emphasis is on the beneficial uses for the produced water in the Rocky Mountains, with special attention to the Powder River and San Juan basins. The San Juan Basin is the oldest coalbed natural gas region in the U.S. and along with the Powder River Basin has reached a mature stage in CBM development.

Coalbed natural gas is produced in the Illinois Basin, the Appalachian region, the Black Warrior Basin in Alabama, the Gulf Coast and

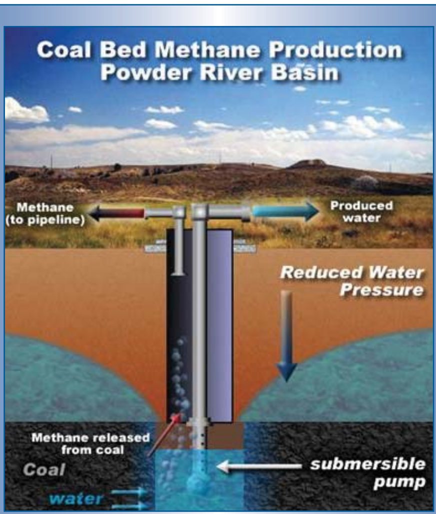

Figure 2. The hydrostatic pressure drops by producing water from a coalbed methane well.

the mid-continent (Kansas, Oklahoma, Arkansas) region; however, produced waters from these areas have higher concentrations of chlorides and dissolved solids than produced water from most western basins, which preclude them from most beneficial uses of CBM produced water.

Coalbed natural gas management and resources

To produce coalbed natural gas from coal seams, a series of wells are drilled to pump groundwater to the surface to reduce the hydrostatic pressure in the coalbeds. Figure 2 shows a simplified schematic of the production process. Once the fluid pressure in the coalbed is released, natural gas or methane is released. The produced water is in high volume early in CBM development, but the volume of water is reduced dramatically during the life of the well. Produced water quality varies from meeting federal drinking water standards up to concentrations of 180,000 ppm total dissolved solids (TDS).

Coalbed natural gas contains nearly 100% methane (CH_4) and is typically produced from coal seam reservoirs at shallow depths. The coal deposits underlie 13% of the United States. Coals are ranked by hardness, with most of the hard coals found in eastern basins. Eastern hard coals have less water, which is normally of low quality and unsuitable for drinking or agricultural use. In addition, many eastern coals do not have enough water to be removed from the coals to initiate methane or natural gas production. Coals in the western United States are younger in age and typically softer, producing significantly more water of higher quality. Coal seams in the western United States are often the aquifers for drinking water. Coal basins in the western United States are generally in dry to very arid climates, and water availability for CBM development and produced water disposal are more critical concerns than in the temperate eastern United States.

A number of factors control coalbed natural gas production and the associated produced water, including permeability, fractures, gas migration, coal maturation, coal distribution, geologic structure and basin tectonics. Natural fracturing is primarily related to geologic structure and coal maturation or ranking. Maturation of coals from soft plant and woody debris is a lengthy geologic process caused by heat and pressure from the overlying rock layers. Older coals are typically in the harder anthracite and semi-anthracite range. Younger, soft coals range through several levels of bituminous coal to lignite and peat (Figure 3).

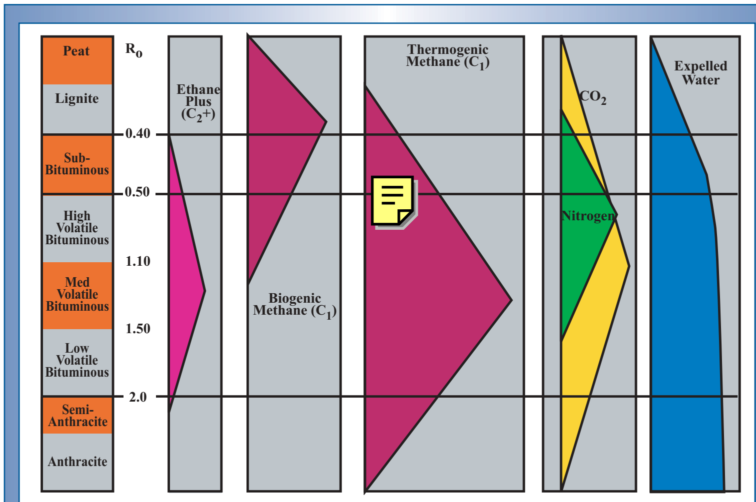

Figure 3. Maturation of coals from soft plant and woody debris is a lengthy geologic process caused by heat and pressure from the overlying rock layers. Older coals are typically in the harder anthracite and semi-anthracite range, while younger, soft coals range through several levels of bituminous coal to lignite and peat.

As a rock, coal has low permeability, so that fluids produced from coal seams migrate through secondary permeability such as fractures. In mining and coalbed natural gas production the network of natural fractures is termed cleat. The cleat provides the surface area and the pathway for coalbed natural gas desorbsion from the coal. Cleat formation, orientation and spacing result from variations in regional stresses, bed thickness, coal rank, vegetative content and ash content. As water is produced through the wellbore, the hydrostatic pressure within the coal seam decreases, and gas is desorbed and flows into the cleat network migrating toward the production well. As coal matures to anthracite, less methane/natural gas is generated, and little porosity or water remains in the matrix. Coalbed natural gas from most western states is produced from sub-bituminous and bituminous coals. The softer western coals with more abundant water have the potential to produce vast quantities of coalbed natural gas, but produced water volumes also are significant.

Coalbed natural gas/methane completion methods

Because sub-bituminous coals are softer and less competent, they are typically completed using vertical wellbores. The wellbore and coal face are completed using formation water to flush the cleat or natural fractures. Submersible pumps are commonly used to pump the water from the coal seams in order to desorb or release the natural gas. If the cleat is not fully developed, the coal may be artificially fractured using low-pressure stimulation techniques. Both water flushes and

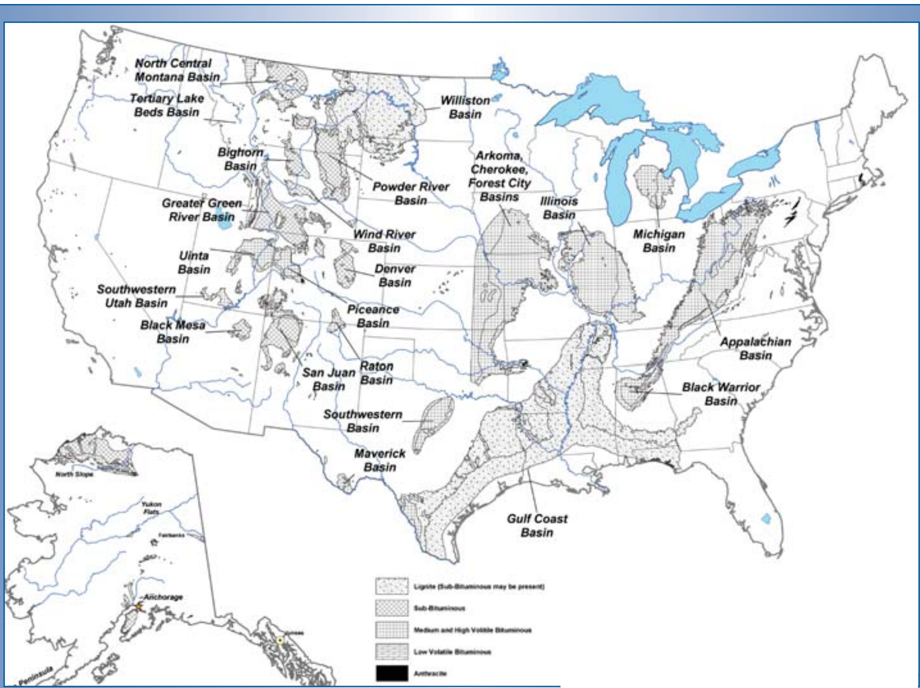

Figure 4. The coal ranking is an indication of coalbed natural gas potential.

stimulation require large volumes of water to produce the coalbed natural gas, and as a consequence large volumes of produced water are brought to the surface.

Eastern hard coals, which contain less water, are often developed using multiple horizontal drains from a single borehole. Horizontal wells have a drawback for CBM production in most western states in that they work best when limited to a single coal seam per well, which would make horizontal drilling prohibitively expensive. Attempts at multi-laterals into more than one reservoir [illegible] fail because it is not possible to lower the water level in individual coals independent of each other. However, horizontal wellbores have been successfully used to produce coalbed natural gas from bituminous coal seams in the San Juan Basin of New Mexico. Eastern coals tend to require more fracturing to produce coalbed natural gas than the more highly naturally fractured western coals.

CBM development and Resources by region

Water problems associated with coalbed natural gas production are significantly higher in the western United States than in the east. The necessary water to pump out of CBM wells to desorb the natural gas involves water right issues, which will be addressed in the second article of the series. The potential for wasting usable groundwater and the disposal costs of produced water are serious environmental concerns in western states. In the arid West, usable water must be conserved for beneficial uses. In general, groundwater quality in the West is higher than in eastern basins. Produced water from the Appalachians, Gulf Coast and central United States typically contains more than 10,000 ppm TDS and is not suitable for beneficial uses. In the West, coalbed natural gas production raises two concerns – depleting ground water and lowering local water tables, which could cause residential and agricultural wells to go dry. Figure 4 is a map of coal distribution across the United States showing the coal ranking, which is an indication of coalbed natural gas potential.

CBM developers are expected to manage ground water production, find beneficial uses for produced water, and at the same time minimize or remediate any negative impacts produced water may have on the environment. To understand the potential effects and uses of coalbed natural gas produced water, it is essential to review the resources of CBM producing areas, both for historical production and future potential.

Alaska—Alaska is new to coalbed natural gas production (first well in 1994) but has potential for development, and production would benefit remote rural communities as well as larger cities and towns. Reserve estimates for Alaska are as high as 1 quadrillion cf of coalbed natural gas. Coals identified in 13 basins in Alaska are in the bituminous to lignite range with abundant water. Three of the basins – the western North Slope, the Alaskan Peninsula (southwest Alaska) and the Yukon Flats basin in central Alaska – contain the highest resources. Water supply is not a problem in Alaska because of high annual precipitation; however, produced water disposal is a concern. Surface discharge is not a viable means because during the winter streams experience low flow rates. Water quality data from Alaska is limited, so studies would be required in most basins prior to CBM development.

Black Warrior Basin—The Black Warrior Basin in Alabama is one of the oldest CBM plays in the United States. Coal degasification projects in the early 1980s led to a rapid expansion of coalbed natural gas production. CBM reserves are estimated at 20 Tcf with about 20% considered recoverable. As of 2002, there were 3,250 active CBM wells in the Black Warrior Basin. Because of the type of hard coals and the number of years water has been withdrawn from the coal reservoirs, the volume of produced water is low, averaging 58 b/d per well. Produced water quality is typically low, with TDSs in excess of 30,000 ppm in portions [illegible]e basin. Produced water is discharged into surface water such as the Black Warrior River, which has a very large surface flow and a large assimilative capacity to dilute CBM water.

Gulf Coast—The large Gulf Coast region extending west from the Mississippi Embayment across Alabama, Mississippi, Louisiana, Arkansas and Texas into northern Mexico contains a number of coal-bearing formations. Coals are mainly Eocene- and Cretaceous-age sediments. The USGS estimates CBM reserves from the Gulf Coast at 4 Tcf to 8 Tcf. Groundwater quality across this area is highly variable. In south Texas, the water is brackish with high TDS content. Although test wells have been drilled in Louisiana and Texas, CBM production in the region is minimal at this time.

Illinois Basin—The Illinois Basin contains the largest deposits of coal in the United States, primarily of Pennsylvanian age. Coal beds are shallow, most at less the 650ft deep. Test wells have been drilled in Illinois, Indiana and Kentucky, but commercial coalbed natural gas production is limited. Groundwater in the Illinois Basin is low quality, and a significant portion is contaminated because of previous coal mining activities. The TDS content is high, particularly the chlorides, making produced water unsuitable for beneficial uses.

The neighboring Michigan Basin, although similar to the Illinois Basin in many aspects of petroleum production, does not contain sufficient coal reserves to be considered for coalbed natural gas development.

Appalachian Basin—The extensive coal deposits of the Appalachian Basin range across Pennsylvania, West Virginia, Ohio, Kentucky, Maryland, Tennessee, Virginia and the Black Warrior Basin of Alabama. The coals of Pennsylvanian and Permian age have coalbed natural gas potential at depths of 500ft to 1,200ft. Coalbed natural gas is heavily commercialized in Virginia and Alabama and moderately developed in Pennsylvania, West Virginia and Kentucky. Reserve estimates for the Appalachian Basin range from 60 Tcf to 76 Tcf. The water conditions in the Appalachian Basin are highly variable, but typically produced water contains above 10,000 ppm TDS, high in metals, sulfur and arsenic. The low volumes of water are not suitable for human or livestock consumption and must be disposed of primarily through reinjection.

Arkoma-Cherokee Basins—The Cherokee Platform covers parts of southeast Kansas, southwest Missouri and northeast Oklahoma, while the Arkoma Basin extends from central Arkansas into central Oklahoma. Because of changes in the Tax Credit laws, coalbed in this region of Pennsylvanian age have been developed for coalbed natural gas production extensively during the past decade. In Kansas, CBM wells have increased from 230 in 1992 to nearly 800 by 2002. By late 2001, there were more than 550 CBM wells in the Oklahoma portion of the Arkoma Basin, with most of the wells producing less than 20 bbl of water per day. The produced water in the region is high in TDS, up to 90,000 ppm, and is normally injected into the underlying Arbuckle formation.

Figure 5. A coalbed natural gas well is shown being drilled in the Powder River Basin of Wyoming.

Powder River Basin—The Powder River Basin of Wyoming and Montana (Figure 5) has become the hottest coalbed natural gas/CBM play of the past decade, and its large volumes of produced water have caused considerable public concern and controversy. The Tertiary-age bituminous coals in the Powder River Basin produce CBM from three to five widespread coal seams in the Wyodak Anderson zone of the Tongue River member of the Fort Union formation. By early 2002, more than 9,000 CBM wells were operating in the Wyoming portion of the basin, a more than ten-fold increase in only 3 years. Production in 2002 averaged more than 25 MMcf/d in Wyoming. In the Montana part of the basin, only one field has been developed, with 200 wells by 2001. Reserves are estimated at 90 Tcf for the Montana portion of the Powder River Basin, and further development is anticipated once the BLM completes the Environmental Impact Statements (EIS). The BLM estimates that more than 60,000 CBM wells will be drilled in the Powder River Basin during the next 10 years to 20 years. One of the key factors for CBM development in the Powder River Basin is the economic management of produced water. A number of factors will be discussed in the second and third articles of this series.

The BLM estimates that coalbed natural gas wells in the Powder River Basin produce as much as 20 gpm during initial CBM production. Water rates decline as CBM production continues, with average rates of 2.5 gpm to 4 gpm estimated during the life of each well. On the margins of the Powder River Basin, produced water quality is high because of fresh water recharge into the coal seams. Produced water from the marginal areas can be used for human and livestock consumption, as well as crop irrigation. This water is in high demand from ranchers and other residents. Toward the north end of the basin, TDS rises so that water can not be used for human consumption but can still be used for livestock. The high saline content with TDS more than 3,000 mg/L and high sodium content makes the produced water from the north end of the basin unsuitable for irrigation without proper management to prevent potential damage to some local soils. Livestock are able to adapt to the saline/sodium levels. Produced water from the Powder River Basin suggests a variety of treatment and beneficial use options.

San Juan Basin—The San Juan Basin of New Mexico and Colorado is one of the oldest CBM producing regions in the United States. Cretaceous-age Fruitland and Menefee formations contain thick coal deposits. The Fruitland coalbeds are wider, ranging on average 10ft thick, and are found at depths of 4,000ft. The deeper Menefee (6,500ft) coals are thinner and more discontinuous across the San Juan Basin. Coals in the basin are bituminous and sub-bituminous. Methane gas has been an economic resource in the San Juan Basin for 100 years. Coalbed natural gas development began in the 1940s and 1950s and became extensive in the 1980s following passage of the Crude Oil Windfall Profits Tax (1980). Annual production of CBM averages 0.9 Tcf from more than 3,100 wells.

The BLM estimates that in the San Juan Basin more than 1,000 CBM wells will be drilled in Colorado and 3,000 in New Mexico in the near future. These wells produce an average of 25 bbl water per day per well. Currently deepwater injection is the most common means of disposal. Treatments and beneficial use options need to be expanded to meet environmental requirements for the arid San Juan Basin.

Uinta Basin and Central Utah—The coals from Utah mainly fall into the Ferron Coalbed Fairway, an 80-mile corridor of basins crossing east-central Utah. The Fairway averages 6 miles to 10 miles wide, and the BLM estimates it contains 4 Tcf to 9 Tcf of recoverable reserves. Coalbed natural gas production is primarily from the Blackhawk and Ferron formations in the Uinta Basin and the Cretaceous-age Mesaverde Group and Mancos shale further south on the western portion of the Colorado Plateau. CBM exploration began in Utah in the 1980s and expanded significantly in the mid-to-late 1990s. The Utah Geological Survey data shows that CBM production provides 28% of all Utah's natural gas. Development is expected to increase when new EISs are completed by the BLM. Coalbed natural gas resources are estimated at 10 Tcf for the state of Utah. Water production from CBM operations in Utah averages 215 bbl water per day per well, a significant volume of water for disposal or beneficial use. TDS content ranges from 6,000 mg/L to 43,000 mg/L. In the Uinta Basin, 98% of all water used is from surface runoff from the Wasatch Mountains. The arid basin dewaters the river system during dry summers, and new water sources would be highly beneficial. Proper management of CBM produced water could favorably impact the agriculture of the region.

Colorado Plateau Basins—The Colorado Plateau contains a number of basins in Wyoming and Colorado resulting from Laramide tectonics and deposition in the Cretaceous Western Interior Seaway. The best known basins are the Wind River, Green River, Hanna, Denver, Raton and Big Horn basins. The Western Interior Seaway and the Laramide Orogeny also formed the Powder River Basin.

Coalbed natural gas reserves for the Wind River Basin in west-central Wyoming are estimated at 2.2 Tcf to 6 Tcf. The five sub-basins making up the Green River Basin in south-central Wyoming and north-central Colorado have more than 200 exploratory CBM wells into bituminous coal seams. The BLM estimates an additional 4,000 CBM well will be drilled in the Wyoming portion of the basin in the future. The Hanna and Denver basins have been extensively exploited for surface and shallow coals for decades, but little coalbed natural gas has been developed. CBM development of the Raton Basin of southeast Colorado and northeast New Mexico has increased in the late 1990s to several hundred wells. Water appropriation for CBM operations is a major consideration in the Raton Basin. No CBM development has occurred in the Bighorn Basin of northern Wyoming because of insufficient laterally extensive coalbeds.

Western Washington—coalbed natural gas development in Washington has been tested in three basins west of the Cascade Mountains. Coalbed natural gas potential from Washington is estimated at 24 Tcf (recoverable percent unestimated). Three Washington basins resulting from volcanism and glaciation provide the best opportunity for CBM development – Bellingham Basin, Western Cascade Mountains and Southern Puget Lowlands. Limited testing but no commercial CBM development has occurred in these areas. Groundwater provides 65% of Washington's drinking water, and 25% of all commercial, industrial and agricultural water, so water management for coalbed natural gas development will be a prime concern.

Williston Basin—The Williston Basin of northeast Montana, North and South Dakota, and Saskatchewan and Manitoba, Canada, is one of the newest regions for coalbed natural gas evaluation and development. The coals of the Williston Basin are similar in age and deposition to those of the Powder River Basin to the southwest. However, surveys for CBM potential by the North Dakota Geological Survey indicate the Williston Basin does not have the same potential as the Powder River Basin. There is no CBM development in the Williston Basin, although some potential is seen in lignite plays in the southern part of the basin. Almost 95% of North Dakota's communities depend on groundwater. Water quality from shallow aquifers is high, but water from deeper formations has higher saline content and would require proper water management if produced.

Conclusions

Coalbed natural gas will supply a significant portion of natural gas from the western United States in the next 20 years. Expansion and continued development will depend on planning and proper water management to meet the requirements set out in EISs. Several states are waiting for the new EIS being prepared by the BLM. New technologies to treat produced water and new evaluations for beneficial uses will form an important part of the development of coalbed natural gas in the future. The DOE, the BLM, the Ground Water Protection Council, and various state geological surveys and universities are actively involved in solving the problems of produced water so coalbed natural gas development can continue to supply valuable natural gas to the U.S. economy while maintaining the environmental quality of the land. ✧

Future articles

Water Appropriation and Treatment Methods for Produced Water.

Beneficial Uses for CBM Produced Water.