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**An Overview of CBM Exploration and Production**

Steve de Albuquerque

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I’ll give you a little background of what coalbed methane really is from a geologic perspective. I’ll give you a little bit of developmental history on the coalbed methane basins, specifically in the U.S., that are currently being developed today. I want to take you through a life cycle of a coalbed methane project, and then talk a little bit about development issues that we’ve all heard so much about in the last three or four years. I’ll talk a little bit about produced water management, since that has some controversy surrounding it. Then coalbed methane water characterization, and then talk about water resource values as it’s related to fresh water resources in the development of coalbed methane. And then I’m going to talk a little bit, to close, on focusing on what’s going on in the basin today.

What is coalbed methane? Simply put, it’s a CH₄ for natural gas. It’s formed within coal seams as a result of the coalification process. What’s the coalification process? Think about a big landfill in natural decay or a compost pile. You have natural plant material deposited in there that’s been buried within the earth, and as things get buried within the earth, you increase temperature and pressure. It’s kind of like a pressure cooker. And as you increase that temperature and pressure, the organic material begins to decay. So, in a cartoon sense, let’s look at this real quick. About 78 million years ago, you had organic heat deposits laid down with sediments deposited over the top. There are different environments for CBM throughout the West. Through geologic time, the stuff gets buried.

Again, pressure and temperature increase, you begin to get bichromial activity in a very simplistic sense of methane in coal formed in the substrips. What did that look like in the Powder River Basin back in the Paleocene? If you think about the Atlantic Coast plain in the Carolinas today, that would go back in geologic time to when the coal deposits were beginning to form.

How does coalbed methane work? Before I go through this slide, let me just give you a very simplistic explanation. Keep in mind that this is quite simplistic. You have a bottle of club soda that you can buy at any grocery store. Club soda is sodium bicarbonate water. That’s exactly what coalbed methane water is, pretty much, sodium bicarbonate water. When you open that bottle of club soda, what happens? You see the bubbles come out very quickly. Well, in a sense, that’s how coalbed methane is developed and brought to the surface. You have a well that we put into the ground. We begin to pump the well. We pump water out of the well. We have a hydrostatic head on the aquifer, which lowers the pressure on the aquifer. As you lower the pressure in the aquifer, the gas begins to rise. This goes into the coal face and then into the fracture and cleat system, and hopefully goes into your well. In a very simplistic sense, that’s how it works, just think of a bottle of club soda.
Think of a gas well. I’m going into a sandstone reservoir, and hopefully we get gas immediately. But as you go through time, gas begins to play off in a conventional well. The difference is that the gas that has migrated into that sandstone reservoir was not sourced in the reservoir; whereas in coalbed methane the gas that is sourced is part of the coal. In the cleat system and the fracture, initially you get a lot of water. That’s the blue line on the bottom. As you begin to lower the pressure in the coal aquifer, you begin to get gas, and then it will mirror a conventional well and play out as the gas content drops in the coal.

Typically, people vented methane gas from coal mines as a safety measure. Natural gas is an explosion hazard, it can be a health risk, and even today, people vent enormous amounts of methane gas from coal mines simply as a safety measure. It’s kind of interesting that coal companies oftentimes have no right to that gas, and the only outlet they have for that gas is to vent it through the atmosphere. In the post-1974 energy crisis, people began to investigate producing coalbed methane as part of this coal mine. But at the time, gas prices precluded technology development. It just didn’t happen. In the early 1980s, we saw spiking gas prices. Technology had advanced and development pursued in Tuscalusa, Alabama to the north and to the eastern side of Tuscalusa. We see the first commercial gas sale in about 1980. That’s the Black Warrior Basin, in the Alabama portion of the Warrior Basin. There is potential, and people are beginning to explore now in the northern and central regions of the Appalachian Basin, and we have people looking quite hard at the Illinois Basin.

Actually, that’s three different basins that I’ve depicted as one around northeastern Oklahoma and southern Kansas. Western Washington basin, south of Seattle, actually has a plain up there. They’re beginning to produce some water. There’s the Greater Green River Basin and the Uinta Basin in here. And then you have the granddaddy of them all, in terms of oil and gas content, which is the San Juan Basin, to date; and they probably will for a while. On the western edge of the basin, you’re beginning to see a little bit of activity. We have a field outside the San Juan. It’s been probably one of the most prolific coal plays in the U.S. And, of course, the Powder River Basin, which is where all the activity is today. And then, the Raton. The Raton has been active for a few years with quite good success. And then the final basin that I have up here is the Wind River Basin.

Let’s talk about the lifecycle of a coalbed methane project. There are three main phases in the lifecycle.
project. The reason I’m telling you this is because it is quite different. You start off with identifying and evaluating and acquiring acreage. You go in and you actually drill a couple of core holes. And you get—you send some of that data to the lab, and they do what’s called absorption/desorption testing on the coal. Basically, you come up with the gas content and a rate of absorption so that you get coal permeability. How permeable is the coal and at what depth does the coal exist; and that would give you an indication of the release gas. The rule of thumb is if the coal’s less than 5,000 feet, the way technology exists today, you can drill. If coal is deeper than 5,000 feet, and I know people are pushing this theory as we speak, but I suspect through time you will see people begin to look at deeper coals. Well, if the core data looks good, we take it to pilot phase. Let’s install a few wells. And you see if you can depress to get the gas to desorb from the coal. And in the final phase, that’s when you really know you have a project. And then you can begin expanding the wells out from the central dewatering point.

Let’s talk about coalbed methane concerns and issues. The main one I see in the West today is a split estate with federal versus mineral. That creates a lot of inherent conflicts initially, right off the bat. If you could go back in time and fix something, it would probably change a lot of conflicts that we see today. You have a lot of genuine concerns. Your concern for wilderness, scenic areas, wildlife, and habitat out there. Most of the perspective coalbed methane areas are in the western U.S. today, and these are full of scenic areas of, areas of wilderness potential, and several types of species. You have, where existing coalbed methane method operations occur, you have legitimate complaints. Unfortunately, my opinion is that there’s a minority few people who actually have tarnished an industry. You know, my opinion is that the sky is not falling with coalbed methane, quite frankly, and I do feel that there are some bad actors out there and legitimate complaints associated with bad actors that, in a sense, have tarnished the industry.

Simply put, you have people that just don’t want this kind of thing in their backyard. It’s very scenic, and they’re very concerned about coalbed methane development in their area. Then you have your standard nuisance issues. Noise; people who live in a rural area are used to hearing the wind, and now they hear a hum from an engine or a compressor, and they’re not used to that, and they don’t like it. You also have traffic, increased traffic. This creates road dust and is a nuisance issue for landowners in the area. The main concern that I’ll probably spend most of my time talking about today is produced water quality. What is the water quality from the coal seams and how do we manage it?

There are three things about coalbed methane that are very similar to gas: They produce gas, you drill a well, and they produce water. Outside of all that, CBM is fairly unique compared to conventional oil and gas. The only thing they really have in common are purely those three things. Then you have some issues that I don’t think are founded as legitimate complaints. You hear people saying things about land subsidence. That’s just—this hasn’t happened. Underground coal fires. I hear about this all the time, and that’s just not true. Doesn’t happen. It hasn’t happened.

There are concerns about groundwater contamination and about CBM development and the stigmas associated with it. The Powder River Basin is actually quite good. There are some issues that you need to watch, and I’ll talk about this in a minute. But quite frankly it recharges the aquifer system in the alluvial, and if you
look at the water quality, if you look at the facts, the detailed water quality, the coal versus the..., you’ll very quickly come to the decision that the water quality is recharging and improves the water quality. So when I hear about surface discharges, it just blows me away, because the fact is that it is a valuable resource, it’s a good resource, and we should tap it as a valuable resource and treat it as such. Well, let’s talk about mitigation and gas development. You build roads, we disturb the surface. There’s no way around that. Oil and gas companies and mineral owners have a valid and existing right to produce that resource. But before you do that, you need to step back to look at where you’re working, and you need to understand and respect existing land uses. And projects will fit in the contention of existing land uses and how to respect what’s going on out there and do it in a way that’s going to be low impact and operate in a manner that allows both existing land uses to continue and your operation to continue without controversy.

Like I said, oil and gas is development. There is land disturbance. We do build roads. We do build pipelines. What you want to do is try to maximize well spacing. To do this, you have to have a pretty good understanding of what the coal influences from a given well are going to be. That way, you have to drill less wells, and it’s more cost effective to the company. It’s less land disturbance. You want to try to minimize the size and number of well pads. Real wells disturb a lot of ground. I sit and I work with my drilling guys day in and day out to try to get them to shift the paradigm through so I can move my trucks around. The fact is that those guys can operate in a smaller area, and we tend to work out the details and make it work.

So what I try to do with my drilling group is work on a paradigm-thinking shift, as we did 20, 30 years ago. We just need to minimize size and numbers. And then that follows right into minimize the number of roads, pipelines, and the infrastructure that we have. And this is a big one—minimize impact to wildlife and habitat. I don’t think there’s any doubt that when you drill, you do have habitat impact and you do impact the wildlife. That has a long-term negative effect on the species of habitat; big game, mule, deer, and elk in the Rockies and Alberta and then Canada. So we’re very interested in wildlife interaction with oil and gas and what the impacts are. But again, it goes back to minimizing your footprints, in a sense, and understanding what species are in your area.

Before we go in and do any development at Phillips, we send a surveyor in to consider where raptor nests are and things like that. We know where the sensitive areas are. But we can plan, like I said, we plan and execute our development around these areas. Quite frankly, we operate in Utah, and it’s the second largest concentration of North American... outside of Idaho, the birds of prey area. We’ve studied in detail the oil and gas impacts on raptor nesting, specifically, for about ten years now and have a pretty good data set. We’ve probably had to shy away from about 600 wells because of raptor issues, but the raptor population has increased. We tend to think that the cycle really driving them is based on what we’re seeing today.

Visual impacts. People don’t like to look at pumping units. People in the West, when they build their retirement homes and look out over the vista, they don’t want to see that. Technology has advanced now, and there are low-profile pumps that you wouldn’t know what you were looking at if you drove by. A lot of people I can take to the Powder on tours and I’ll drive down and say, let me know when you see the first well, and we’ll pass 300 wells before they even know what they’re looking at. The fact is, it’s very low-profile. They’re small boxes blended into the landscape. Noise is a big one, too. Again, I mentioned noise earlier as a nuisance. The fact is, people don’t like to hear noise in rural environments, and you need to be sensitive to that. You can, through interior design and control, design something that makes less noise than they did a few years ago.

Whatever you do on a CBM project, you really want to consider water seriously and how you manage that water. Well, what is the issue with produced water management? The fact of the matter is we have to produce ground water. That’s the whole physical component to get the gas out. The question becomes: Now that I have this water, what do I do? And there’s not going to be one answer that solves all the water problems. You’re going to have an integrated approach, and this is true across the United States, quite frankly. Well, what is the water management approach? You need to figure out how much water you’ll use when you do the pilot phase of the project.

Quality, and this is the driving force right here, water quality will define water management. If you don’t take anything else away from here, take this away. Water
quality will define your options. You have to ask this question, once you determine what you’re going to do with that water, whether surface discharge, or livestock use? You have to ask the question, where is that water going? And I’m thinking surface discharge right now; is it okay to be there? Because the last thing that you want to do is create some unintended consequence for a landowner downstream. So you really need to understand your quality, what’s downstream of you, and you need to look at the project’s economics.

Let me give you a quick little overview here. I could take the produced water from Utah, it’s fairly salty. So if I took that produced water and put it in the Powder River Basin today, it’s greater than 1,000 TDS, they probably never would have drilled one well in the Powder River Basin. So the economics of water management work into your economics of your project development to make a real project. And then resource values. Again, this is a proven true resource. Let’s look at surface discharge considerations, because that is such a controversial issue in a lot of places.

You look at two things. First thing is water volume; how much water are you going to have. You also have to regulate the volume of discharge. They only regulate as it affects water quality. But you still need to think about the water you’re discharging. Are you going to cause erosion or unintended consequences? Are you going to cause downstream flooding? Are you going to do something that follows you? Are you going to make impacts in a negative way or positive way? What about stream channel morphology? And have you considered stream channel conveyance laws? And what do I mean by that? If you just discharge water on the surface, three or four things are going to happen. A little bit is going to evaporate or you’re going to have infiltration into the subsurface, generally speaking. Evaporation, on the other hand, sends the water up into the atmosphere, but it concentrates the salt. And then you have the uptake of water by plants and streams along the channels. So you need to think about what’s happening along that conveyance and discharge.

Water quality. Water quality is mostly regulated by the states. States have their own water quality standards, and they have two types of standards: the numerical standards that you won’t discharge more than X parts; and then they have the narrative standards which really deal with agricultural uses. Are you going to have fish populations, for example, in the water that you discharge? So you need think about that.

You need to think about downstream water use as it pertains to your water quality. And you define that water quality by characterizing the coal seam of water. Well, what do we do when we characterize water? If you recall discharge considerations, because that is such a controversial issue in a lot of places.

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**SURFACE DISCHARGE CONSIDERATIONS**

- Water volume:
  - Erosion
  - Flooding
  - Stream channel morphology
  - Stream channel conveyance loss
- Water quality:
  - State water quality standards
  - Downstream water use
  - Coal seam water characterization

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**CBM PRODUCED WATER CHARACTERIZATION**

- Major characteristics:
  - pH, temperature, electrical conductivity
  - Salinity (TDS), TSS, hardness, alkalinity
  - Sodium Adsorption Ratio (SAR)
  - Stream channel conveyance loss
- Inorganics:
  - Major cations and anions
  - Metals
  - Radionuclides
- Organics:
  - Volatiles and semivolatiles

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characteristics of the water, salinity is an early indicator. SAR is only a clay soil issue.

So the thing you really want to understand is what your ratio is. We look at inorganics, major cations and anions of the water. We look at metals; have they presented a problem for receptors in the stream or people
downstream? Then we look at radionuclides, because we don’t want to do thing without understanding the consequences of what we do. The third thing we look at is organics. Volatiles and semivolatiles, like things you find in petroleum gasoline. You typically don’t see these in coalbed waters. Exceptions vary that do produce minimal amounts of crude oil because of the geological setting. But those are more the exception to the rule. But you still want to scrub your water.

What we hear most about in the Powder is irrigation water quality. And irrigation water quality is defined using two parameters. The first one is salinity, how salty is the water. The second one is sodicity. And that’s the amount of sodium in a water relative to calcium and magnesium. What’s the problem with sodicity? Sodicity, basically, is made up of solids which dissolve in the water. Total salts equals salinity, which equal TDS. Just for your information, seawater is about 30,000 TDS. Conventional oil wells can produce all the way up to 100,000 parts. Heavy water from a conventional well will range anywhere from 500 up to 20–30,000, depending on where you are geologically. I’m not going to go through all those. And we measure this in the field or lab using it as a gross indicator of salinity.

This is what we use in the Powder. What’s the problem with salinity? You know, you spill water from a conventional well and the plants die. And my operations guys come to me and say, you know, we killed the grass because we had a water spill. And they say, you know, that salt must have been toxic to the plants. The fact of the matter is that, no, it wasn’t toxic to the plants. The plants can’t get the water. Plants take up water using osmosis, osmotic potential. It’s a pull on water by the salts. What happens is that the salts in the soil compete with the plants for the water. There’s water there, but the plants can’t get it because there’s so many ions and cations in there that it won’t release the water. What happens is you have drought stress in salty soil. There’s plants there that just can’t get the water.

The second issue: What’s the problem with sodium? Well, excess sodium can destroy clay soil structure. Soils can be sand, clay, or somewhere in between. They’re not all the same. Sodium will cause soil dispersion. In a good soil, it’s a well-aggregated, clumpy-type dirt that floats past that dirt, that subsurface, and into the roots. When you have excess sodium, that tends to repel the plays and the negatively charged sites on the edges of the clay and cause dispersion, and inhibit soil drainage and infiltration. And again, it’s a relative proportion of the sodium, that’s how we measure it, to calcium and/or magnesium and bring down the SAR. So there are things you can do to juggle the water quality to make it less of an impact to a clay soil. Well, based on that water quality, you will decide to do one of probably five or six things with your water. You can inject it into a Class II conventional salt water disposal well as part of an oil and gas product, but you would never get that resource back. So you need to look at your water quality, and if it’s fresh enough, you really need to think about where it’s going to be lost.

**SODIUM AND SODICITY**

- **Na⁺**
  - Excess sodium can destroy clayey soil structure
  - Causes soil dispersion
  - Inhibits soil drainage
  - Inhibits infiltration

- **Sodicity**
  - Relative proportion of Na⁺ to Ca²⁺ and Mg²⁺

- Sodicity measured by:
  - Sodium adsorption ratio (SAR)

**SALTS AND SALINITY**

- Solids forming ions when dissolved
- Total salts = Salinity = TDS
- Na⁺, K⁺, Mg²⁺, Ca²⁺, CO₃²⁻, HCO₃⁻, SO₄²⁻, Cl⁻, NO₃⁻
- Measured by electrical conductivity (EC)
The second thing you could do is freshwater aquifer restoration, where you go into a zone that’s fresh enough or with good enough water quality to dispose of it. The problem with that is that it’s not able to take that much water. And in the Powder, we have formations in the shallow zones, and it just can’t handle the amount of water that we would produce in the Powder. We can discharge water on the surface if, in fact, the water quality is good enough to do that. But you need think about downstream. We can evaporate the water. In Utah, we have seven injection wells and one really big evaporation pond. I don’t really like evaporation because you have to manage it, but that is one thing you can do with it.

We can treat it by reverse osmosis or chemical amendment. Even if that costs the oil company less than ten cents a barrel to treat, it’s not going to happen because remember I talked about project economics. That cuts into the lifting cost of the gas and makes it less cost effective to produce that gas. Or we can find a beneficial use for that water. And I know there’s probably going to be a lot of discussion about this in the next couple days. But, you know, water in the West is actually a precious resource. It may be more valuable to the Westerners than natural gas is to a gas company. We need to capture this resource. I really think we need to do that. And yes, in fact, irrigation can occur with some of these coalbed waters. Municipal water supply. Penno was recharging a certain zone in the City of Gillette’s drinking water, and they were able to do that from that zone for a long time. So you can possibly look at that. You can use it for industrial supply, or you can use it for wildlife enhancement or restoration.

You know, Phillips is on the board of directors of . . . which is a wildlife habitat restoration enhancement organization that looks at habitats from the Cascades to the Rockies in the various states. We deal with the one thing they look at, most of is water, freshwater. It’s hard for me to imagine that freshwater on the ground is not a benefit to wildlife. I see that in the Powder every day.

The fact is, it is a life blood of wildlife and if we can capture it again, the value of that water, we want to do that. And then there’s things out there that we simply haven’t looked at yet or nobody’s come up with yet.

Let me give you a range of salinities for you to keep in mind. This is based on Phillip’s experience. Produced water is about 1,000. Remember, I said seawater is 30,000. You can see the minimum and the maximum there, so there’s quite a range. It’s actually getting quite fresh; fresh enough to service. So my low number there is probably not low enough. In the Black Warrior, it’s 700 to 37,000, which is right there at seawater.

<table>
<thead>
<tr>
<th>CBM PRODUCED WATER SALINITY</th>
<th>ave</th>
<th>min - max</th>
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<tbody>
<tr>
<td>San Juan</td>
<td>15,600</td>
<td>(7,000–20,000)</td>
</tr>
<tr>
<td>Black Warrior</td>
<td>12,500</td>
<td>(700–37,400)</td>
</tr>
<tr>
<td>Western Uinta</td>
<td>11,00</td>
<td>(6,400–19,600)</td>
</tr>
<tr>
<td>W. Powder River</td>
<td>1,500</td>
<td>(1,000–2,500)</td>
</tr>
<tr>
<td>E. Powder River</td>
<td>1,000</td>
<td>(800–2,000)</td>
</tr>
<tr>
<td>NW Colorado</td>
<td>2,000</td>
<td>(650–5,200)</td>
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I’ll talk a little bit about how we manage surface discharge. Keep in mind that we’re going into something about the size of the Mississippi River. So there is surface discharge at that point. In the Western Uinta Basin, we’re about 11,000. The Powder on the western side of
the basin is a little bit poorer quality. Then the east, which is shown here at the bottom, is okay. With all of these salinities, we have salinities that are about 450, and we’re able to surface discharge that. There are a few permits that people are working on at the fringe of the basin now. In the San Juan Basin, there’s almost 100 percent Class II injection. In the West Uinta, there’s 97 percent Class II injection, and we evaporate about 3 percent. Powder River, almost 100 percent of it is surface discharge. Black Warrior Basin is 100 percent surface discharge. Tuscaloosa and the Raton, in the Colorado side, about 70 percent of it is surface discharged and the other amounts of that is injected in a Class II well, a salt water well. On the New Mexico side, on Ted Turner’s ranch—he has coalbed methane on his ranch—100 percent of it is injected. In the Sand Wash, about half is surface discharge and the other half is injected.

### CBM PRODUCED WATER MANAGEMENT

<table>
<thead>
<tr>
<th>Basin</th>
<th>Discharge Method</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>San Juan</td>
<td>Class II injection</td>
<td>99.9%</td>
</tr>
<tr>
<td>Western Uinta</td>
<td>Class II injection</td>
<td>97%</td>
</tr>
<tr>
<td>Powder River</td>
<td>Surface discharge</td>
<td>99.9%</td>
</tr>
<tr>
<td>Black Warrior</td>
<td>Surface discharge</td>
<td>100%</td>
</tr>
<tr>
<td>Raton CO</td>
<td>Surface discharge</td>
<td>72%</td>
</tr>
<tr>
<td>Raton NM</td>
<td>Class II injection</td>
<td>28%</td>
</tr>
<tr>
<td>Raton NM</td>
<td>Class II injection</td>
<td>100%</td>
</tr>
<tr>
<td>Sand Wash</td>
<td>Class II injection</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>Surface discharge</td>
<td>50%</td>
</tr>
</tbody>
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Let’s look at the Powder. Here you have northeastern Wyoming outlined in red, and I’ll give you a quick overview of what’s going on permit-wise. This is the northwest part of the basin. There is a high quality irrigation river in that portion of Wyoming. Up in Montana, there is really good quality water. Let’s go to the Powder River itself. There are no SAR limits, but there’s an agreement with Montana to monitor at the state line. This may limit coalbed methane production. Then Wyoming will have to implement requirements upstream.

Look at the Belle Fourche and the Cheyenne River. Let me just talk quickly in closing here about these northeastern Wyoming rivers. In the Belle Fourche River, there are probably 100s plus, maybe thousands of coalbed wells discharged. If you look at the blue line and you look at the stream gauge, they correlate quite well with precipitation.
In fact, if you look at 1993 to 1999, you see the stream flow. This is at the same time we’re seeing hundreds of coalbed wells coming online. Well, they organized sending the water to South Dakota and Montana. But look at the hydrographs. The hydrographs don’t lie. Where is the water? The water is infiltrating, and it is, in fact, not leaving the state of Wyoming. I’m sure there’s some of that that does get through to the Belle Fourche River in northeastern Wyoming from coalbed methane. Okay. If you look Caballo Creek and Highway 59, that’s where the core areas are, and that’s U.S. Geological Survey gaming station and there might be that much water crossing that.

This is a picture of the Belle Fourche down at Moorcroft. I could jump across the Belle Fourche here. Hundreds of coalbed methane wells contribute to coal mines that are discharging to the Cheyenne River. In fact, you see the same kind of trend. Wildhorse Creek in Arvada, Wyoming has 32,000 barrels a day. They’re discharging somewhere upstream at this location. Where’s the water? It’s not there.

In summary, I want you to take away from this that all CBM projects are not alike. Your water quality will define your approach, and your water management economics may determine if you have a coalbed methane project or not. And if there is a value net water resource, by all means you have to capture it. Water’s too precious in the West not to. And it’s not going to be a one size fits all. It’s going to be an integrated approach on your operation.

Thank you.

COALBED METHANE IN THE ROCKY MOUNTAIN REGION: YESTERDAY, TODAY AND TOMORROW
MATTHEW R. SILVERMAN, Consulting Petroleum Geologist

Coalbed methane (CBM) resources are important in a number of different places in the Rockies. This paper is intended to provide a broad, geographic background on where those resources are and where they may be in the future.

Just a dangerous waste product a few decades ago, CBM now represents about seven percent of the natural gas production in the United States. Most of the country’s gas, of course, comes from conventional gas production, but that seven percent is very important. It represents about 1.3 trillion cubic feet (TCF) of gas per annum, coming from about 15,000 coalbed methane wells. Most of those CBM wells are in the Rockies.

Today, those CBM resources are focused in four basins (Figure 1). The most important area in terms of production is the San Juan Basin of New Mexico and Colorado.