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Coalbed Natural Gas Produced Water Issue

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This Edition of Eye on Environment features

Treatment and Beneficial Use of Coalbed Natural Gas Produced Water

Department of Energy-funded research is targeting efforts to sustain America's fastest-growing new source of natural gas supply while simultaneously seeking to resolve another critical issue in Western states—chronic water shortages—in an environmentally friendly way.

DOE's Oil and Gas Environmental Program places major emphasis on developing new technologies to clean produced water for beneficial use. This issue of Eye on Environment focuses on DOE-funded research under way at Montana State University to clean coalbed natural gas (CBNG) produced water for beneficial uses.

In recent years, CBNG development has been the hottest natural gas play in the U.S. Domestic production of CBNG grew more than tenfold during 2000-2003, to a total of 1.6 trillion cubic feet (TCF) in 2003. Estimates vary, but at least 15,000 CBNG wells have been drilled just in the Powder River Basin of Wyoming and Montana, site of the most frenetic CBNG drilling activity.

Producing natural gas from Western coalbeds also generates huge volumes of water (**Figure 1**). Each CBNG well in the Powder River basin may produce 20-50 gallons of water per minute, sometimes discharging water for several years. According to U.S. Geological Survey estimates, Powder River Basin CBNG water production has jumped almost thirtyfold since 1997, reaching about 3.8 million barrels per day in 2004.

While such large volumes of water might otherwise be welcome in the arid West, concerns remain over producers' options for handling and disposing of this water and its byproducts. Expensive treatment and disposal measures could render many CBNG development projects uneconomic. Conversely, providing a new source of water suitable for crop irrigation, livestock

Figure 1. *CBNG produced water discharged into holding pond.*

watering, and other uses in the often drought-stricken Western states would prove a genuine boon to the region.

RESEARCH OVERVIEW

Montana State's Extension Water Quality (EWQ) program, housed in MSU's Department of Land Resources and Environmental Sciences, has conducted extensive research on water quality and soil science as they relate to Montana's agricultural issues. In recent years much emphasis has been placed on issues surrounding the disposal and/or beneficial use of CBNG produced water. A specific focus is on how produced water with a characteristic saline-sodic fingerprint will interact with soil and water resources in CBNG production areas of Montana and Wyoming.

MSU's EWQ program, under the direction of water quality specialist and soil scientist Jim Bauder, has extensive experience with cropping systems and irrigation management issues in arid and semi-arid regions of southeastern Montana and northeastern Wyoming. Additionally, some of EWQ's existing research focus includes plant and soil salinity and sodicity issues, irrigation water management, and beneficial water use.

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The years of experience with agriculture issues associated with southeastern Montana, combined with the program's objectives to serve the water resource research and educational needs of the state, inspired EWQ to investigate and design research projects focused on gaining a better understanding of the CBNG product water chemistry and the relationships between CBNG produced water and, land surface, soil, and water resources.

In September 2001, DOE awarded a research grant to MSU to conduct research to evaluate phytoremediation of Powder River Basin CBNG produced water. The research is designed to:

- Characterize the chemistry and chemical behavior of CBNG produced water under confined and non-confined conditions and surface exposure.

- Assess the potential impacts of CBNG produced water dispersals to land surfaces, agricultural crops, and native plant species.

- Investigate environmentally sustainable methods of dispersal or land spreading of CBNG produced water.

- Use wetland plants in the phytoremediation of saline-sodic water.

- Investigate potential beneficial use of CBNG produced water to enhance native range, wildlife habitat, and livestock forage production.

- Engineer on-site CBNG produced water treatment facilities.

MSU maintains Montanta's only state-of-the-art, environmentally controlled research facilities, the Plant Growth Center (PGC), capable of meeting EWQ program research needs (**Figure 2**). Significant project efforts were housed at the MSU PGC facilities and at university farm plots located adjacent the campus. Additionally, research field sites located on both the Powder and Tongue rivers support large-scale plots that enable MSU researchers to work in areas and environments that mirror conditions seen in CBNG developed regions.

FIELD RESEARCH PROJECTS

On the following pages are summaries of bench-top and field projects housed at MSU research facilities and at cooperating ranches in the Powder River Basin of Montana. These efforts formed the basis of the DOE-funded research project.

Figure 2. *Montana State University Plant Growth Center and Horticulture Research Farm.*

Soil Behavior upon Repeated Wetting with Saline-Sodic Water

The purpose of this project was to determine:

- Compatibility between CBNG produced water and potentially irrigable soils.

- Effects produced water may have on soil physical properties when applied to the irrigable soils of southeastern Montana.

Soil samples representing four soil textures (fine sandy loam, silt loam, silty clay loam, and silty clay) were collected from sites within the Powder River Basin in Montana. Soil sampling locations were selected on the basis of their representativeness of potential or actual irrigated acreage in the proposed development area of Montana (**Figure 3**). CBNG and Powder River waters were synthesized and applied to the soil samples. Changes in soil chemical and physical properties were monitored throughout a variety of water application scenarios.

Extensive soil sampling, treatment, and chemical characterization validates that the previously reported Exchangeable Sodium Percentage-Sodium Adsorption Rate (ESP-SAR) relationship holds, even when native soils and/or those soil materials were irrigated with CBNG signature water (see box on p. 4 for definitions of terms). Single wetting events with either Powder River water or CBNG signature produced water resulted in elevation of both ESP and SAR levels. However, the resultant levels did not appear to pose a risk of significant dispersion or salt stress to commonly grown crops. Repeated wetting and drying with CBNG signature water, such as in the case of sprinkler irrigation or routine flooding, resulted in significant elevation of electricial conductivity (EC), SAR, and ESP levels, with about 50% of the resultant values exceeding the previously reported thresholds for salt injury to commonly grown crops of the area and the thresholds for dispersion. Subsequent leaching with simulated rainfall reduced EC measurably, had little or no effect on SAR, and reduced ESP by about 3%.

Figure 3. *Greenhouse study examining soil physical properties in response to irrigating with saline-sodic and nonsaline-sodic water (upper photos). Characteristic "shrink-swell" of Montmorillonite soil found in CBNG development regions (lower photo).*

Role of Plants in Phytoremediation

In this project, it was hypothesized that specific halophytic, salt-tolerant species of plants can

function to uptake excess salts and remediate the saline-sodic conditions associated with CBNG discharge water. These species have the potential to accumulate high levels of sodium and other salts within their aboveground tissue and, in some cases, excrete these salts onto leaf surfaces. It is also hypothesized that these halophytic species have the ability to provide substantial volumes of high-quality forage.

Definitions

Electrical conductivity (EC) is a measure of salinity. The U.S. Department of Agriculture defines water with an EC value greater than 4.0dS/m as saline.

Sodic water is high in sodium concentration relative to calcium and magnesium. The sodicity of water is expressed as the sodium adsorption ratio (SAR). Sodic water is defined as having an SAR greater than 12.

Exchangeable sodium percentage (ESP) is a measure of specific sodium concentration with a threshold of 15%.

Column experiments were conducted using maritime barley, Wytana saltbush, and big saltbush to determine soil water and shallow groundwater response over a 32-week period with no column drainage (**Figure 4**). Species' abilities to uptake and remove salt from the soil profile were assessed. Species were exposed to one of two water chemistries and one of three water table positions.

Aboveground biomass was harvested a total of four times and analyzed for total biomass production, nutrient content, and salt concentrations. Results indicate that there is potential for significant biomass production and salt uptake by these species. Based on experimental data, selected plant species are well-adapted to CBNG-quality water and appear to perform best in the presence of a shallow water table.

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Water Use Potential and Salt Tolerance of Riparian Species in Saline-Sodic Environments

The objective of this study was to assess the potential of halophytic riparian species used in constructed wetlands as a new management tool for CBNG produced water management. To accom-

Figure 4. *Plant column fitted with irrigation system, Montana State University Plant Growth Center.*

plish this, riparian species native to Montana and Wyoming and classified as halophytes were selected for experimental treatments (**Figure 5**). Species chosen were subjected to saline-sodic conditions designed to mimic CBNG produced water for a 24-week period and harvested once every 8 weeks. Water use rates, water chemistry, biomass production, forage value, and salinity tolerance of each species were monitored throughout the experimental period.

Figure 5. *Experimental design utilizing columns for growth of wetland species and evaporation bucket to estimate evapotranspiration rates.*

Biomass production of traditional wetland species declined following defoliation and under increasing salinity. Grass species increased biomass production following defoliation and under elevated salinity in the third growth period. Crude protein (CP) also decreased with progressive harvests for wetland species but increased in the third period for grass species. Based on percent acid detergent fiber and CP, forage value of most species was determined to be equal to or greater than average grass hay forage value.

All perennial forage species were able to produce biomass, crude proteins, and uptake salt over a 32-week period of irrigation. The project found that use of selected species in combination with a well-defined water management strategy could provide a cost-effective approach to dealing with high volumes of excessively saline-sodic irrigation water.

Results suggest that wetlands constructed of species analyzed will thrive in saline-sodic conditions and will outperform or perform similarly to evaporation ponds for CBNG produced water disposal while providing a forage resource and beneficial wildlife habitat.

Essentially all qualities of CBNG produced water found within the Powder River Basin present opportunities for either enhanced livestock forage production, enhanced wildlife habitat along ephemeral streams and in managed upland locations, enhanced wildlife habitat and carbon sequestration within the vicinity of impoundments, and sustained flow augmentation during low flow periods.

Assessing Constructed Wetlands for Beneficial Use of Saline-Sodic Water

This study also focused on the potential of constructed wetlands as a tool for CBNG produced water management (**Figure 6**)—but this time by assessing seasonal water use, biomass production, and water use efficiencies (WUEs) of three native, salt-tolerant plant communities.

Native species establish hydrologically distinct communities in formerly ephemeral channels now running with CBNG produced water, and nine species known to propagate in CBNG channels were selected and segregated into three communities. Closed-system wetland cells were constructed, and each community was assigned to four of these cells, or lysimeters. Chemistry of the supply water

Figure 6. *Constructed wetland research site located at Montana State University's Horticulture Farm.*

was sodic and moderately saline (EC ~ 3.4 dS/m, SAR >25), typical of northern portions of the Powder River Basin, where low to moderate ECs (2-3 dS/m) and high SARs (>20) are common.

All three communities had similar total water use, but WUEs differed significantly among the communities. Evaporation from a Class A evaporation pan was observed to be higher than evapotranspiration from the planted lysimeters (**Figure 7**). Species survival and colonization were very good for seven of the nine species selected.

Results of this study indicate that constructed wetlands planted with native, salt-tolerant species have potential to utilize substantial volumes of CBNG produced water while remaining robust and viable. Although results suggest evaporation from open water surfaces such as evaporation or infiltration pits may be greater than evapotranspiration from a constructed wetland, constructed wetlands have the added benefits of providing wildlife habitat, recreation, and property enhancement.

Assessment of CBNG Produced Water Intervention on Water Parameters of Significance

The goal of this study was to determine if trend analyses could identify or quantify significant changes in salinity (specific conductance), sodium concentration, or SAR of flow in the Little Powder River and which of those changes might be coincident with CBNG produced water reaching the main channel of the Little Powder River. Various parametric and nonparametric statistical analyses were conducted on a time series of existing USGS data for the Little Powder River above Dry Creek near Weston, WY.

Using CBNG Wastewater for Enhanced Biomass Production and Carbon Sequestration in Arid and Semi-Arid Regions of Montana and Wyoming

The project goal here was to examine the potential beneficial use of CBNG produced water to enhance plant growth and biomass production, thus facilitating carbon sequestration in soils. The overall objective is to explore a mechanism that helps reduce carbon dioxide levels in the atmosphere and provide a beneficial use of CBNG wastewater.

Figure 7. ***Lysimiter set up for simulated wetland system.***

The focus of the research is to monitor biomass production and carbon accumulation in soils and convert findings into predictions of carbon sequestration potential in the Powder River Basin (**Figure 8**). The effects of saline water on carbon sequestration and biomass production have not been determined. However, the research is investigating CBNG produced water as potential means of supplemental water supply for the region.

SUBCONTRACTED RESEARCH

The research highlighted in this section represents projects designed and implemented by MSU's EWQ program.

Collaborative arrangements with other programs in MSU's Department of Land Resources and Environmental Sciences have added to the diversity of CBNG-related research at MSU.

Figure 8. ***Research site along the Powder River in Montana.***

DOE funding was leveraged through MSU subcontracts, including CBNG-related research projects on the potential reclamation of disturbed drillsite parcels, soil physical impairment studies, and forage quality studies. Additionally, most of the cited projects have been associated with Master's theses at MSU.

MSU research also has supported advances in CBNG treatment technologies. A subcontract between MSU and Drake Engineering Inc. resulted in a CBNG on-site water treatment system, currently in field tests with Marathon Oil Co. Outside of Sheridan, WY, a full-scale, 250 gallon per minute commercial unit is slated to be online in early June 2005. This unit has 95% recovery of produced water at salinity and sodicity levels that meet permitted instream standards. Drake Engineering is now investigating commercial production and sale of the brined byproduct of this system (**Figure 9**).

The MSU EWQ program will continue to expand its research focus in the area of saline-sodic water management in CBNG developed areas of Montana and Wyoming. Cooperative opportunities continue to be harvested with the University of Wyoming and Colorado State University, as well as with local producers throughout the region.

Through the support of the DOE program, MSU will continue to build research initiatives that investigate the potential for beneficial utilization of CBNG produced water to enhance the landscape and productivity of agricultural lands in the Powder River Basin of Montana and Wyoming.■

Figure 9. *Drake Engineering Process Unit test site in Johnson Co., WY (top photo), and Process Unit prototype vessels at Marathon Oil site near Helena, MT (bottom photo), in April 2005 . Photos courtesy of Drake Engineering.*

Upcoming Events/Meetings

June 12-14, Western Governors' Association,
Western Leadership in the Global Economy,
Breckenridge, CO
Contact: **www.westgov.org**

June 15-17, IPAA, *2005 Midyear Meeting,*
San Francisco, CA
Contact: **www.ipaa.org**

June 30, RMAG, *5th CBM Symposium,*
Denver, CO
Contact: **www.rmag.org**

August 1-3, Colorado Oil & Gas Association
Rocky Mountain Natural Gas Strategy Conference & Investment Forum, Denver, CO
Contact: **www.coga.org**

September 18-20, IOGCC, *2005 Annual Meeting,*
Jackson Hole, WY
Contact: **www.iogcc.state.ok.us**

October 24-26, IPAA, *2005 Annual Meeting,*
Houston, TX
Contact: **www.ipaa.org**

November 8-11, International Petroleum Environmental Conference (IPEC), Houston, TX
Contact: **http://ipec.utulsa.edu**

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