Coalbed Methane (CBM) Resource Summary of Findings with Produced Water Technologies Review

INTRODUCTION

A two-part effort was undertaken to support an upcoming Environmental Protection Agency (EPA) CBM Survey by addressing the following two points:

#1 – Determine what Produced Water (PW) technologies exist other than those addressed in the Arthur Langus Lange (ALL) Consulting PW reports of 2003 and 2006, and identify any other PW research going on. PW research or technologies not included in the ALL work were to be identified.

#2 – Identify data sources, outside the two usual sources (USGS and EIA), for CBM resource amounts and for locations where CBM might be developed in the future that would supplement the available data.

Questions for consideration included:

- How old is the USGS and EIA data, and what, if any, are the limitations of this data?
- What is the total amount of U.S. CBM resource?
- Where is the CBM, and where might it be developed in the future?
- Are there any PW assessments out there other than the ALL work?
- If found, do these additional PW assessments reveal any deeper PW knowledge than has been captured by either the NETL office or by ALL?
- Have recent NETL PW research/technologies been captured by the ALL reports?

The following data was collected and is presented in two segments:

(A) CBM Gas-in-Place Resources Summary and
(B) CBM Produced Water Treatment Technologies.

(A) CBM Gas-in-Place Resources: Summary of Findings

For the entire U.S., there is an estimated total of 1,817 Trillion cubic feet (Tcf) of Coalbed Methane (CBM) gas-in-place resources, includes 10 Tcf for Raton Basin and 21 Tcf for Illinois Basin.[1] The 1,817 Tcf gas-in-place resource estimate for the entire U.S. includes an estimate of 1,037 Tcf for all of Alaska.[2] Thus, the Lower-48 CBM gas-in-place resource estimate is 780 Tcf, which is 31 Tcf larger than the 749 Tcf shown at http://www.pe.tamu.edu/gpri-new/home/BrineDesal/Images/ProdWaterFig1.jpg

[1] *Total gas-in-place resource includes:*
A) Known technically and economically recoverable resources, i.e. – all past production and current proved reserves
B) Known technically recoverable resource that is not yet economically recoverable, and some may never become economically recoverable
C) Known resource that is not yet technically recoverable, and some may never become technically recoverable
D) Undiscovered resources (amounts can be either technically recoverable or not technically recoverable)
E) Estimates for future reserves growth or "appreciation" (amount of the total resources that in the future are expected to become both technically and economically recoverable; generally listed as an additive element under technically recoverable resource, i.e. - prior to becoming economically recoverable proved reserves) and
F) Gas-in-place resource that will never be recoverable under any circumstances.

[2] *Higher resource estimates of 21 Tcf for the Raton Basin and 25 Tcf for the Illinois Basin were found in the literature which is referenced in the attached table, but these were not used to arrive at the 1,817 Tcf because the two lower estimates were found far more often in the literature. Two of the regional Alaska estimates added up to 1,050 Tcf for all of Alaska, a value that also was not used to arrive at the 1,817 Tcf.*

As of the end of 2005, U.S. cumulative CBM production was almost 18 Tcf, and U.S. proved reserves of CBM was almost 20 Tcf – all in the Lower-48 states.[3] This information can be found in the EIA 2005 Annual Reserves Report (November 2006).[4]

[3] *EIA's data does not show anything for Alaska (no CBM produced or proved in AK), and in my opinion, it appears that this Alaska CBM resource will probably remain unproved/unproduced in the foreseeable future. Recent attempts to gain approval to produce some of the substantial CBM resource in the Cook Inlet, to "save" the Agrium fertilizer plant and reduce the very-dicey employment situation in that same area, were stifled. Also, due to rising construction and capital costs, government delays/changes, etc., the likelihoods of getting an Alaska gas pipeline or a Canadian MacKenzie Delta gas pipeline or both or even an "over-the-top" gas pipeline to serve both Alaska and Canada now appear much smaller than in the past few years.*

[4] *See http://tonto.eia.doe.gov/FTPROOT/petroleum/021605.pdf and the EIA worksheet of the attached Excel file.*

Thus, if we subtract the 38 Tcf (the 18 + the 20) of Lower-48 produced and proved CBM resource from the Lower-48 total of 780 Tcf of CBM gas-in-place resource, we get an estimate of 742 Tcf of Lower-48 CBM gas-in-place resource that remains to be "found", proved and/or produced. If we subtract out the USGS estimates for undiscovered technically recoverable CBM resource on the North Slope of Alaska, the USGS is only showing Lower-48 undiscovered technically recoverable CBM resource of:

95% probable estimate: 46.07 Tcf (53.14 minus 7.07) or about 6.2% of the 742 Tcf
Mean estimate: 67.32 Tcf (85.38 minus 18.06) or about 9.1% of the 742 Tcf
5% probable estimate: 96.60 Tcf (132.68 minus 36.08) or about 13% of the 742 Tcf[5]

[5] *These percentages are much lower if Alaskan CBM gas-in-place resource is included (1817 minus 38 gives 1779 Tcf); results in about 3%, 4.8% and 7.5% respectively.*

The listed Lower-48 unconventional CBM resource percentages, i.e. – for undiscovered technically recoverable resource vs. total remaining gas-in-place resource, are quite small compared to the similar percentages for conventional oil and gas resources (i.e. – total technically recoverable resources vs. total remaining gas-in-place resources).[6]

[6] *EIA "total" technically recoverable estimates for conventional oil and gas resources- see Table 4.1 of EIA's Annual Energy Review, usually include estimates for reservoir appreciation (or reserves growth) in addition to the estimates for undiscovered. However, even if the conventional reservoir appreciation estimates were excluded to arrive at "exactly alike" conventional percentages, the above Lower-48 unconventional CBM percentages are still "comparatively-speaking" quite small. Also please note, such low percentages are not the situation for some of the individual listed USGS basins where the USGS undiscovered technically recoverable data is available, especially some of the more active CBM producing basins such as San Juan, Powder River, and Black Warrior where the CBM percentages are considerably higher, i.e. – in this case, the percentages compare basin-level estimates for undiscovered technically recoverable resource to even larger basin-level estimates for total gas-in-place resource (rather than to smaller estimates for total remaining gas-in-place resource as is done above).*

There are some large basin-level data discrepancies in the attached file, i.e. – when comparing some of the USGS data for undiscovered technically recoverable CBM resources to the data found in the literature for total CBM gas-in-place resource. As just one example, the USGS undiscovered technically recoverable estimates for the Uinta-Piceance basins range between 1-4 Tcf vs. the total CBM gas-in-place resource for these basins of 109 Tcf.

There are at least 3 possibilities to explain such large discrepancies. Perhaps the USGS has:
A) Already assigned a large portion of the total CBM gas-in-place resource to "already found" technically recoverable resource, i.e. – while using the total CBM gas-in-place resource data that was found in the literature

B) Already assigned a large portion of the total CBM gas-in-place resource to "already found" resource" categories, i.e. - to both the technical– recoverable resource category and the not technically recoverable resource category, *and the possibility exists here that the USGS believes much of the resource is "found" but not technically recoverable in the areas where the discrepancies are large*

C) Already assigned large portions of the total CBM gas-in-place resource to expected CBM "reserves growth", but no USGS data was found for "reserves growth" estimates for CBM.

In fact, no additional USGS information or data was found to actually support any of the above 3 assumptions or "possibilities". Thus, these large discrepancies still leave this reviewer wondering why the data differences are so large!

Also please note, such large data discrepancies are not the situation for some of the other USGS basins where the USGS undiscovered technically recoverable data is available, especially some of the more active CBM producing basins such as San Juan, Powder River, and Black Warrior.

(B) CBM Produced Water Treatment Technologies

The ALL Consulting report "A Guide to Practical Management of Produced Water from Onshore Oil and Gas Operations in the United States" (October 2006) covered the main treatment technologies and management strategies for Coalbed natural gas produced water. The report examined the techniques in use and made references to specific companies developing and testing the technologies. DOE has sponsored a number of projects in the recent years concerned with treatment technologies for CBM produced water. However, most of these technologies are new and not commercially available at the present time. Several of the projects are directed at produced water from oil fields, but may also be applicable to CBM produced water treatment and management. Not all of the DOE sponsored projects and technologies which address produced water treatment were covered in the ALL report.

DOE funding is directed at research to develop new technologies or management practices; or to improve existing technologies and practices. Because of DOE's research objectives to fund innovative new technologies, most of the projects are in the testing stage and are not commercial. Some of the projects have produced promising technologies and practices, which CBM operators should be aware of for future use. Technologies being addressed by DOE projects fall into several categories dealing with identification of contaminants, treatments for CBM or oilfield produced water, improved membrane separation, and waste minimization.

Links to DOE WebPages for individual projects provide up-to-date information on the progress and status of produced water treatment technologies which were not discussed in the ALL report due to the recent nature of the research.

Innovative technologies:

University of Texas at Austin: DCE-FC26-04NT15547. Researchers are working on developing new, fouling-reducing membrane coatings for use with commercially available reverse osmosis (RO), ultrafiltration (UF) and nanofiltration (NF) membranes to reduce membrane fouling and markedly improve membrane lifetime for produced-water purification. Initial work on coating materials focused on making and characterizing poly-ethylene glycol films. Copolymers were then synthesized by incorporating acrylic acid with the films. Pre-polymerization mixtures were applied to the commercial membranes using a slide coater, and then UV-polymerization was used to create the coated membranes. Progress in achieving defect-free coatings has been made, and coated samples were successfully prepared, characterized, and subjected to an oil/water emulsion under cross-flow conditions. Spin coating has been explored as a possible means of creating thinner, more uniform coatings. Another means of surface modification being explored is direct chemical surface modification of commercial membranes by grafting hydrophilic molecules. The ALL report mentioned ultrafiltration and nanofiltration, but did not go into detail on how such membrane function; and did not have available the innovative work under development at UT Austin on membrane coatings and their effect on membrane efficiency. (DE-FC26-04NT15547)

New Mexico Institute of Mining and Technology: (DE-FC26-04NT15548), University of Texas at Austin: (DE-FC26-04NT15546), and Los Alamos National Laboratory: (FEW 02FE20, FEW 04FE10-5, FEW 15546). A project to develop a surfactant-modified zeolite (SMZ)/vapor-phase Bioreactor system for treatment of produced water is the combined effort of the universities and the LANL. The bioreactor is being tested at the McGrath salt water disposal facility at Farmington, New Mexico. The process involves use of SMZ to remove BTEX (benzene, toluene, ethylbenzene and xylene) and other organic contaminants from oil and gas field produced water. SMZ is an innovative, cost-effective filtration/sorption medium made from naturally occurring zeolites and commercially available surfactants. The project has demonstrated that SMZ can be regenerated over a number of cycles of use without loss of sorption capacity for BTEX. The vapor phase bioreactor system can rapidly recover from downtime, and pilot texts indicate that the system can be scaled up to handle commercial oil and gas streams. Following additional testing at a field site in Wyoming, the surfactant-modified zeolite vapor-phase bioreactor system will be ready for commercial application. (DE-FC26-04NT15546, DE-FC26-0415548, FEW 02FE20, FEW 04FE10-5, and FEW 15546)

Texas Engineering Experiment Station (TEES), Texas A&M University: DE-FC26-03NT15427 and DE-FC26-04NT15543. Researchers at TEES have developed a Mobile Desalination Unit and water filtration system than can process over 10,000 gallons of brine or produced water per day. The goal is to provide a cost-effective way to convert oil and gas field waste water into clean by-product water that can be used for irrigation, watering livestock, and municipal water needs in remote, rural parts of Texas where lack of water is often a limiting factor for both agricultural and urban development. The filtration system is designed to improve and restore micro-filter membrane performance in the reverse osmosis (RO) process. The mobile filtration/RO unit has been field tested in the Barnett Shale play in North Texas, where it was found that with treatment produced water could be used to hydraulic-fracture new gas wells saving an average of $8,000 per completion. Barnett shale drilling operations use about 10,000 to 15,000 barrels of fresh water per frac job. The savings for one operating company, which cooperated in the pilot project, was estimated at $250,000 per month. Additional field tests of the mobile desalination unit have taken place in south Texas where produced water has been treated for agricultural use. (DE-FC26-03NT15427, and DE-FC26-04NT15543)

AERA Energy, Bakersfield, CA: DE-FC26-02NT15463. AERA has built a pilot water treatment plant for oilfield produced water to remove boron and ammonia using ion exchange and high pH reversed osmosis processes. During phase II of the pilot project, produced water from the San Ardo formation at Placerita field was treated to remove minerals and provided a stream of treated water that met water quality criteria for agriculture and industrial use. The goal of the project was to reduce the costs of treating and managing produced water by creating beneficial by-product water for irrigation of crops or wildlife habitat. The ALL report described the combination of filtration, reversed

osmosis and ion exchange technologies used to remove boron and ammonia, but the plant operator, AERA Energy was not mentioned. (DE-FC26-02NT15463)

Colorado School of Mines: DE-FC26-04NT15549. The Colorado School of Mines has undertaken a complex study of coalbed natural gas produced water in the Rocky Mountains. The project has ten subcontracts with universities, Argonne National Laboratory and industry to analyze the volumes of CBM produced water and its effects on streams, soil, vegetation, and animal life; and to determine technologies to reduce both the volume and impact of the produced water through various treatment technologies and management practices. The waste water volume minimization subcontract is being conducted by the University of Wyoming with assistance from Argonne National Laboratory and Gas Technology Institute. The method would use an underground membrane system. The membrane uses a composite of microporous materials, which operate by size exclusion (filtration) and hydrophobicity (gas transfer), and nonporous materials that allow molecular diffusion through a solid wall. Methane gas could pass through the composite membrane filter, and water would be retained. Laboratory research indicates that waterless CBM production is possible using downhole filtration techniques.

Waste water volume minimization relies on the use of economic, rugged membrane filters to retain the water below the surface. This method of subsurface separation of CBM and waste water could significantly reduce operating costs. Retaining the waste water in the subsurface would eliminate many of the concerns of land owners about CBM produced water harming the soil and streams with higher salt and mineral content. The public benefits from waste water volume minimization and from the reduction of concern over pollution related to surface discharge and the degradation of streams and aquifers. Waste water volume minimization holds the potential for waterless production (zero discharge) of coalbed natural gas. The ALL report did not mention the waste minimization or zero discharge research conducted by the Colorado School of Mines and University of Wyoming, but the potential of the technologies once they are field tested and proven should be considered. (DE-FC26-05NT15549)

BC Technologies, Ltd: DE-FC26-05NT15551. BC Technologies, Oak Ridge National Laboratory, and the Integrated Petroleum Environmental Consortium are investigating coalbed natural gas produced water in the Greater Green River Basin of Wyoming. The team plans to develop and demonstrate a unique and synergistic process for wellhead produced-water treatment, using gas hydrate technology, to bring brines to a level where beneficial use is possible. The overall goals are to develop a technically feasible, environmentally benign, and cost-effective process for produced-water treatment at the wellhead and to transfer it to the energy industry expeditiously. The ALL report discusses previous work on freeze thaw technologies developed by BC Technologies, but did not discuss their advances into gas hydrates for use in treating produced water, as this research is still in initial development and testing stages. (DE-FC26-05NT15551)

Attachments:

Table of USGS and Other Non-USGS CBM Resource Estimated
Map of U.S. Coal Reserves/Basins
Map of U.S. Coalbed Gas