CBM REVIEW
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Using CO_2 for enhanced coalbed methane recovery and storage

John Litynski, National Energy Technology Laboratory, US, and Derek Vikara, Michael Tennyson and Malcolm Webster, KeyLogic Systems Inc., US, investigate the potential commercial use of CO_2 for enhanced coalbed methane recovery and storage.

Concern that the buildup of CO_2 in the atmosphere is contributing to global climate change has led to efforts to reduce CO_2 emissions from the combustion of fossil fuels. One approach receiving considerable attention is carbon capture and storage (CCS) in geological formations.[1] In CCS, CO_2 is captured at a large point source, such as a coal-fired power plant, transported to a storage site, and injected into a geological formation, such as depleted oil and gas reservoirs, deep saline aquifers and unmineable coal seams.

The Carbon Storage Program, implemented by the US Department of Energy's (DOE) Office of Fossil Energy and managed by the National Energy Technology Laboratory (NETL), is helping to develop technologies that capture, separate and store CO_2 to reduce greenhouse gas (GHG) emissions without adversely influencing energy use or hindering economic growth. NETL envisions a portfolio of technologies that are safe, cost-effective and deployable on a commercial scale.[2] One promising CCS option with enormous near-term deployment potential is geological storage of CO_2 in unmineable coal seams. These types of geological formations have been extensively evaluated in the past: the geology is well understood and other data is already available. The injection of CO_2 into unmineable coal seams can lead to enhanced coalbed methane (ECBM) recovery, in which revenue from produced hydrocarbons can help offset the cost of capture and storage. It may also be possible to use existing wells and other infrastructure to further reduce project costs. This carbon utilisation technology offers significant potential for reducing CO_2 emissions and mitigating global climate change, and could potentially provide an economic incentive through hydrocarbon production.

STORAGE POTENTIAL

The potential capacity for CO_2 storage in unmineable coal seams in the US is significant, representing at least 15 years of emissions from large stationary sources (currently about 3780 million tpa of CO_2).[3] Although not all unmineable coal deposits have been examined, NETL's Regional Carbon Sequestration Partnerships (RCSPs) have documented (at the geological basin level) the location of 60 – 117 billion t of CO_2 storage potential in unmineable coal seams distributed over 29 states and one Canadian province (Figure 1).[4] The RCSP's estimates include only those coal seams that cannot be mined economically with current technology. In addition, coal seams with potentially potable water (<10,000 ppm total dissolved solids [TDS]) were excluded as storage options.

Storage capacities are estimated based on coal seam geometry (area, thickness), sorption data (Langmuir isotherms obtained from powders),[5,6] and an efficiency factor reflecting seam variability and the inability to access all parts of a formation. These estimates are believed to be conservative. More accurate estimates will require determination of sorption phenomena at coal seam conditions, detailed assessment of coal seams and additional field experience injecting CO_2 into a variety of coal types and structures. NETL is conducting in-house R&D using information on coal cores and fragments to assess the magnitude of storage capacity uncertainty, as well

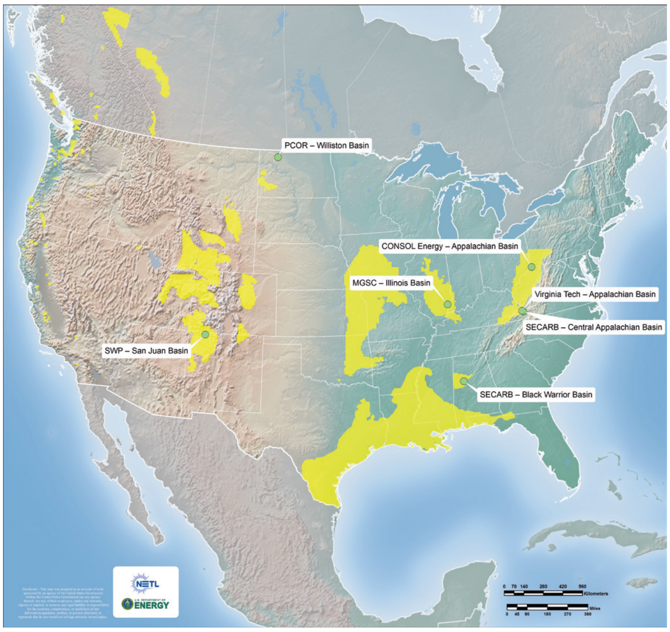

Figure 1. Assessed unmineable coal seams (yellow) by NETL's Regional Carbon Sequestration Partnerships that could serve as potential CO_2 storage locations, and the location of NETL-supported field tests researching CO_2 injection and storage into unmineable coal seams.

as isotherm data from powders to understand CO_2 sorption to coal structure (maceral type).[7] NETL is working with Advanced Resources International through the Coal SEQ III project to develop and field-test three advanced geochemical and geomechanical modules to appreciably increase the accuracy of simulating the behaviour of geologically sequestered CO_2 in coal and shale.

MAJOR ISSUES TO OVERCOME

Results from laboratory investigations, small-scale field tests and numerical modelling indicate the feasibility of CO_2 injection into coal, but also highlight the need for detailed understanding of both CO_2 sorption under reservoir conditions (to improve estimates of capacity) and the dynamic response of coal to CO_2 sorption (which may either enhance or degrade CO_2 injectivity). If these issues can be resolved, methane production could provide a strong incentive for the rapid commercial deployment of CO_2 storage in unmineable coal seams.

CO_2 SORPTION UNDER RESERVOIR CONDITIONS

CO_2 injection into coal seams (either as a gas or supercritical fluid) results in sorption of CO_2 on organic-rich surfaces within the coal. Some of the CO_2 dissolves into water already present in the coal (forming carbonic acid), and some exists as a discrete phase (gas or supercritical fluid, depending on pressure). CO_2 sorption in coal is a physical process, not a chemical reaction. Some residual partial pressure of CO_2 must be maintained or out-gassing from the coal seam will occur.[8] Injected CO_2 can displace adsorbed methane on coal surfaces, facilitating methane recovery at production wells. The binding energy of CO_2 relative to methane is significantly higher: laboratory and field measurements have indicated displacement factors of >2 (more than two molecules of CO_2 adsorbed per molecule of methane desorbed).

DYNAMIC RESPONSE OF COAL TO CO_2 SORPTION

Since up to 80% of coal in the US is unmineable, ECBM represents a significant opportunity for increasing domestic and, potentially, global gas production.[9] Conventional CBM represents 10% of current methane production and 10% of proven methane reserves. Although production of CBM is widely commercialised, ECBM in conjunction with CO_2 storage is not. A major technical hurdle for commercialisation of CO_2-ECBM is a detailed understanding of the dynamic response of coal to desorption of methane and adsorption of CO_2, which, depending on coal type and structure, can either increase or decrease permeability and affect overall injectivity. Coal swelling caused by adsorption of CO_2, with consequent loss of injectivity, is often cited as the major technical concern relative to CO_2 storage in coal seams and CO_2-ECBM production. However, this concern is based on very limited and often conflicting laboratory and field data.[10,11,12,13,14] This is, in part, related to complexities arising from the coupled processes of CO_2 sorption, methane desorption, dewatering[15] and to an incomplete understanding of the response of coal to CO_2 as a function of coal structure (rank, maceral type, mineral matter).[16] To address these issues, the DOE is conducting laboratory and field experiments and developing new reservoir simulation tools for improved prediction of system behaviour. Many of these field experiments involve the drilling and completion of test wells to inject CO_2 into target formations.

FIELD TESTS

NETL's RCSP programme and Carbon Storage Core R&D programme are supporting several US field tests to assess the impact of CO_2 injection on CO_2 injection rate in the context of ECBM (Figure 1). Five RCSP field tests and two Core R&D field tests have injected or will be injecting various volumes of CO_2 into unmineable coal seams of various seam thicknesses and adsorption values (Table 1).

The six tests in which CO_2 has been injected have demonstrated safe and effective CO_2 storage in coal seams; however, results in the Illinois Basin, Central Appalachian Basin and San Juan Basin indicate lower-than-expected or reduced CO_2 injection rates over time.[17] One possible explanation is the effect of the swelling coal matrix, which could reduce a formation's permeability. Laboratory investigations, small-scale field tests and numerical modelling results are encouraging, but current results indicate that swelling can compromise project performance and economics by limiting incremental methane recovery and long-term CO_2 injectivity.[18] These results highlight the need for additional research on CO_2 behaviour in deep coal seams to determine how to manage the effects of coal-swelling during long-term injection. The ability to use this storage type will provide an incentive for CO_2 injection into coal. The Consol Energy project continues gas recovery operations, though

Table 1. Summary of geologic conditions for injecting CO_2 into unmineable coal seams for selected NRLT-supported field tests

Geologic provinces	Injected volume (t of CO_2)	Storage formation (depth and thickness)	Average adsorption (ft^3/t)	Average injection rate (tpd)	Results
MGSC - Illinois Basin	91	Springfield coal seam Depth: 300 ft Thickness: 7 ft	1075 @ 390 psi	0.5 - 0.8	Injection increased then stabilised
PCOR - Williston Basin	90	Fort Union coal seam Depth: 900 ft Thickness: 10 ft	350 @ 350 psi	5.5	Increased injection rate by heating CO_2
SECARB - Black Warrior Basin	252	Black Creek, Mary Lee and Pratt coal seams Depth: 2000 ft Thickness: 1 - 6 ft each	600 - 900 @ 350 psi	80	Higher than expected injectivity
SECARB - Central Appalachian Basin	907	Pocahontas and Lee coal seams Depth: 1653 ft Thickness: 36 ft total	300 - 750 @ 350 psi	42	Injectivity decreased to 20 tpd
SWP - San Juan Basin	16,700	Fruitland coal seams Depth: 3012 ft Thickness: 60 ft total	809 @ 317 psi 776 @ 269 psi 1038 @ 372 psi	46	Lower injection rate than anticipated
Consol Energy - Appalachian Basin	2268	Upper Freeport and Pittsburgh coal seams Depth: 670 - 1260 ft Thickness: 1 - 10 ft each	1378 @ 920 psi*	6.35	Injection rate and gas recovery as expected
Virginia Tech - Appalachian Basin	20,000	Horsepen, Pocahontas, Seaboard and Sewell coal seams Depth: 857 ft - 2130 ft Thickness: 10 - 26 ft total	Injection not initiated	Injection not initiated	Injection not initiated

* Estimated from laboratory studies of CO_2-sorption on powdered Upper Freeport coal.

the injection operation system is currently offline. Consol Energy is implementing a new high-pressure injection system to optimise injection operations and investigate CO_2 injection at higher rates.

The NETL continues further research to understand CO_2 behaviour in coal seams by partnering with Virginia Tech for a new field test. Limited experience with injection into coal, tight sandstone and organic-rich shales in Central Appalachia makes commercial potential uncertain at this time. The Virginia Tech project aims to reduce this uncertainty by designing and implementing characterisation, injection and monitoring activities to test these stacked formations (listed in Table 1) and track the migration of CO_2 throughout the injection and post-injection phases. A detailed geological characterisation of the proposed injection site indicates that regional geological structures, coal permeability and reservoir seals are adequate for a 20,000 t injection test. The proposed research will provide needed information on other stacked storage options and provide an additional benefit of proven carbon storage potential in coal seams with ECBM and other stacked unconventional formations in Central Appalachia. Many of the CBM operations in the Central Appalachian Basin are approaching maturity, providing large reservoirs suitable for storing CO_2. CO_2 injection into coal seams could increase CBM reserves by 20 – 40%, while concurrently increasing the storage capacity for sequestration of large volumes of CO_2.

CONCLUSIONS

Current capacity estimates indicate that unmineable coal seams have the potential to store decades of CO_2 emissions from stationary-sources.[19] Understanding the dynamic response of coal to CO_2 flow – such as how swelling impacts permeability – remains a key scientific challenge and is the focus of several RCSP field tests and ongoing laboratory/theoretical efforts within DOE's Carbon Storage Program. DOE is the lead federal agency for the research, development, demonstration and deployment of carbon storage technologies, and has a robust programme to evaluate the potential of CCS projects involving CO_2 injection and storage into unmineable coal seams and associated ECBM production. These efforts will provide greater insight into the potential for safe and permanent storage of CO_2 in coal seams in the US and will refine the national assessment of CO_2 storage capacity in coal formations by furthering fundamental research on the interaction of CO_2 and coal.

NOTE

More information is available at NETL's Carbon Storage homepage: http://www.netl.doe.gov/technologies/carbon_seq/index.html

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