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Enhanced microbial coalbed methane generation: A review of research, commercial activity, and remaining challenges

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ABSTRACT

Coalbed methane (CBM) makes up a significant portion of the world's natural gas resources. The discovery that approximately 20% of natural gas is microbial in origin has led to interest in microbially enhanced CBM (MECoM), which involves stimulating microorganisms to produce additional CBM from existing production wells. This paper reviews current laboratory and field research on understanding processes and reservoir conditions which are essential for microbial CBM generation, the progress of efforts to stimulate microbial methane generation in coal beds, and key remaining knowledge gaps. Research has been primarily focused on identifying microbial communities present in areas of CBM generation and attempting to determine their function, in-situ reservoir conditions that are most favorable for microbial CBM generation, and geochemical indicators of metabolic pathways of methanogenesis (i.e., acetoclastic or hydrogenotrophic methanogenesis). Meanwhile, researchers at universities, government agencies, and companies have focused on four primary MECoM strategies: 1) microbial stimulation (i.e., addition of nutrients to stimulate native microbes); 2) microbial augmentation (i.e., addition of microbes not native to or abundant in the reservoir of interest); 3) physically increasing microbial access to coal and distribution of amendments; and 4) chemically increasing the bioavailability of coal organics. Most companies interested in MECoM have pursued microbial stimulation: Luca Technologies, Inc., successfully completed a pilot scale field test of their stimulation strategy, while two others, Ciris Energy and Next Fuel, Inc., have undertaken smaller scale field tests. Several key knowledge gaps remain that need to be addressed before MECoM strategies can be implemented commercially. Little is known about the bacterial community responsible for coal biodegradation and how these microorganisms may be stimulated to enhance microbial methanogenesis. In addition, research is needed to understand what fraction of coal is available for biodegradation, and methods need to be developed to determine the extent of in-situ coal biodegradation by MECoM processes for monitoring changes to coal quality. Questions also remain about how well field-scale pilot tests will scale to commercial production, how often amendments will need to be added to maintain new methane generation, and how well MECoM strategies transfer between coal basins with different formation water geochemistries and coal ranks. Addressing these knowledge gaps will be key in determining the feasibility and commercial viability of MECoM technology.

Contents

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1. Introduction

Coalbed methane (CBM) represents a significant portion of the world's natural gas reserves, and it has been suggested that up to 20% of the world's natural gas, including CBM, is microbial in origin (Rice and Claypool, 1981). However, drilling and maintaining microbial CBM is becoming less economical due to current, relatively low gas prices and competition from shale gas production, and due to the short life span of CBM production wells (10 years or less; Ayers, 2002; Stearns et al., 2005). Recent laboratory and field experiments have shown that not only has microbial CBM been generated in the geologic past and retained in the formation in commercial quantities, but that some sedimentary basins have active, on-going microbial methane generation (e.g., Cokar et al., 2013; Kirk et al., 2012; Martini et al., 2005; Strąpoć et al., 2007; Ulrich and Bower, 2008). Because methanogenesis is an active process, it may be possible to stimulate the microbial communities that have produced CBM to generate more methane from coal biodegradation on commercially relevant timescales (i.e., years). If microbial CBM generation could be enhanced, the productive lifespans of depleted microbial CBM wells could be extended and/or new microbial methane could be generated in areas without prior history of gas production. Because existing infrastructure would be used for stimulation projects, stimulating microbial CBM generation could also reduce the environmental impact of CBM production by reducing the need to drill new wells as old wells become depleted. Enhanced microbial CBM generation could also be used to convert deep or thin, potentially unmineable coal deposits into methane, and similar strategies could be used to produce methane in gas depleted shales and from coal waste materials. The process of stimulating microorganisms to produce more methane from existing production wells is known as enhanced CBM, or microbially enhanced CBM (MECoM).

Starting about 2000, rising natural gas prices led to a rapid expansion of CBM development (drilling and production) in the United States, primarily in the San Juan, Powder River, Illinois, Gulf Coast, Black Warrior, and Appalachian basins, which is demonstrated by the increase in active production wells in the Powder River Basin(Fig. 1; www.eia.gov). Coalbed methane in the Powder River Basin (PRB) is microbial in origin, while CBM in the San Juan, Illinois, Black Warrior, Appalachian, and Gulf Coast basins is a mixture of biogenic and thermogenic gas (Strąpoć et al., 2011). Development of CBM plays permitted greater access for researchers to coal formations to collect water and gas samples to study microbial CBM processes. In addition, as gas prices began to fall in summer 2008, commercial groups interested in MECoM were able to purchase wells for pilot field studies from companies that were divesting interest in CBM. Around this time, the advent and use of hydraulic fracturing technologies opened up new petroleum and hydrocarbon reservoirs and provided the market with substantial amounts of natural gas. This has resulted in sustained low gas prices that have made it difficult for MECoM groups to continue to develop commercial technology. Shale gas wells typically cost substantially more to drill than CBM wells (several million dollars versus around half a million dollars for CBM wells, depending on depth of wells and technology used), but also produce significantly more gas per well. This means that a single shale gas well generates significantly more revenue than a CBM well. However, the process of hydraulic fracturing increases the production rate, not the ultimate supply, of hydrocarbons, and peak hydrocarbon production from hydraulic fracturing is predicted to occur around 2030, and may occur much sooner (www.eia.gov; Patzek et al., 2013). In addition, the environmental hazards associated with hydraulic fracturing are still debatable and range from ecological, water quality, and induced seismicity (Burton et al., 2014; Hallo et al., 2014; Maguire-Boyle and Barron, 2014). Increased regulation of shale gas practices could make coalbed methane production more competitive with shale gas production. Regardless of current market conditions and resources, strategies, such as MECoM, can help to fully utilize domestic energy resources.

In this paper, we review the state of scientific knowledge and major advances that have been made towards sustainable commercial MECoM technology, including what is known about coal biodegradation and methanogenesis, from both the basic research and commercial sectors. We also identify key knowledge gaps that need to be addressed to further advance MECoM technology.

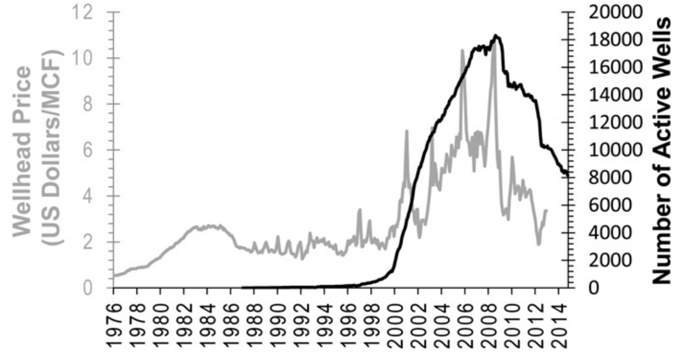

Fig. 1. U.S. wellhead price of natural gas (grey, no data since December 2012; Source: US EIA, 2015) and number of active coalbed methane wells in the Powder River Basin, Wyoming (black; Source: Wyoming Oil and Gas Conservation Commission). 1 MCF is ~28 m^3.