# Increasing the Rate and Extent of Microbial Coal to Methane Conversion through Optimization of Microbial Activity, Thermodynamics, and Reactive Transport

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a National Science Foundation Engineering Research Center in the MSU College of Engineering

## Introduction

**Study site: Powder River Basin (PRB) coal, Montana**

- Largest coal deposit in USA (40% of coal reserves)
- Most coal not economically accessible to conventional mining
- Stimulation of indigenous microbes with algae biomass
- Coal bioconversion into biogenic methane gas

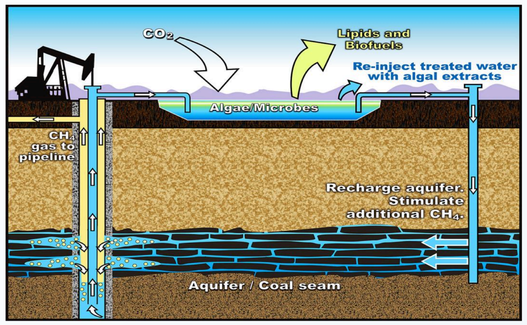



**Figure 1 . Stimulation of coal bioconversion via methanogenesis using microalgae biomass grown in CBM production water pond.**

## Overall Objectives

**Objective 1**: Determine the chemical and biological parameters limiting methane production from coal.

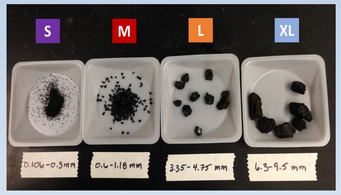
**Objective 2**: Develop strategies for the optimization of the MECBM (microbially-enhanced coal bed methane) technology based on thermodynamic and reactive transport considerations.

**Objective 3**: Scale up laboratory microcosms to optimize microbial coal-to-methane production in column flow reactors.

## *In situ* Incubations to Obtain Inoculum

**Figure 2**. All inocula for coal-dependent methanogenesis studies originate from subsurface coal incubations. The native coal is incubated in microbial samplers incubated down-well, and the coal slurry is immediately transferred to coal enrichments in the field.

## Surface Area/$O_2$ Effects



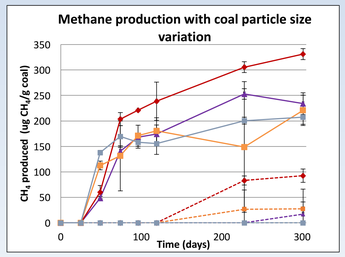




**Figure 3**. Coal particles of four different sizes were compared for differences in initial and sustained methanogenic rates. The tested size ranges were: 0.1 – 0.3 mm; 0.6 – 1.2 mm; 3.4 – 4.8 mm; and 6.3 – 9.5 mm. Under non-stimulated conditions, the 0.6 to 1.2 mm size had the most methane produced while the other three sizes were similar. For stimulated conditions, the 0.6 to 1.2 mm size produced the most methane, with the other three sizes similar again. Initial rates were faster for the two largest sizes, but the rate of methane production slowed considerably after 50 days when the two smallest sizes increased. We also attempted to characterize coal surface with electron microscopy and XPS, but results were inconclusive possibly due to oxidation and reactivity of coal surface once exposed to ambient atmosphere. These results suggest the possible effects of oxygen on surface properties, including bio-availability.

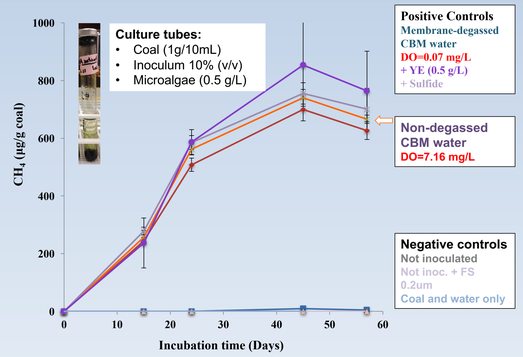
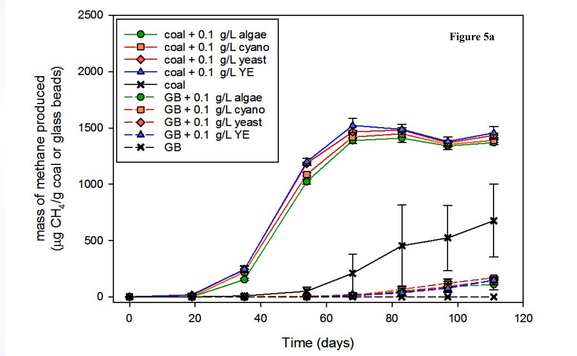



**Figure 4**. Initial experiments have been completed to determine DO-tolerance of CBM cultures. In the figure above, an active CBM enrichment with coal was used to detect coal-dependent methanogenesis. The purple line displays the culture under normal conditions in which CBM water was degassed to remove dissolved $O_2$ (DO) and stimulated with yeast extract. The gray line shows the same condition but further reduced with the sulfide. The orange and blue lines show the same conditions except the CBM was NOT degassed and sulfide was not added. The results indicate that the DO is consumed and methanogenesis then ensues. We are currently investigating the possible mechanisms of DO consumption (biotic vs. abiotic)> These results have ramifications for design plans for laboratory scale-up as well as potential field trails.

## Different Amendments



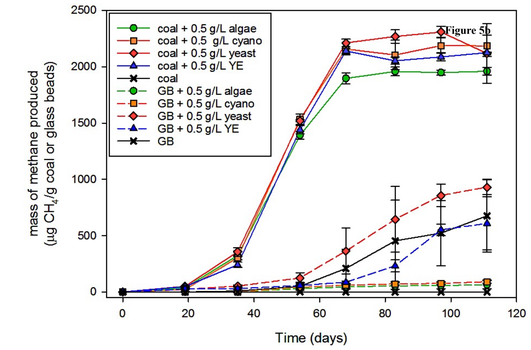
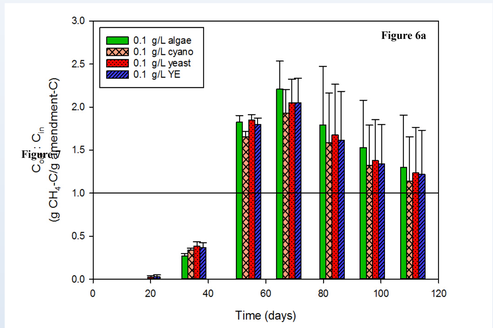




**Figure 5**. Time-series methane production data for (a) unamended and 0.1 g/L amended treatments and (b) unamended and 0.5 g/L amended treatments showing the cumulative methane produced at each sampling date. The methane produced is a sum of what is measured in the headspace and what can be assumed to be dissolved using Henry's law. This does not include methane that may be sorbed to the coal or glass beads. Error bars represent 1 standard deviation for triplicates of each treatment.



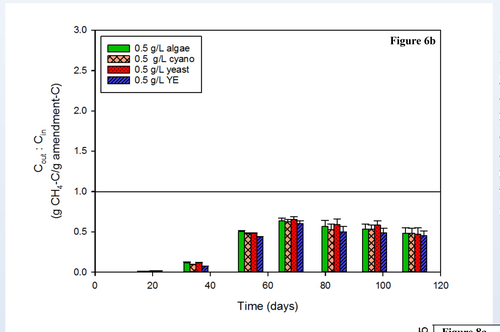




**Figure 6**. Comparison of 0.1 g/l (a) and 0.5 g/l (b) amendments with respect to ratio of C in generated methane and C content of added amendment. The shown methane levels are above what was detected with coal only incubations.

**Figure 7**. Principal component analysis of archaeal phylotype non-transformed relative abundances of the archaeal genera at day 111 for all treatments

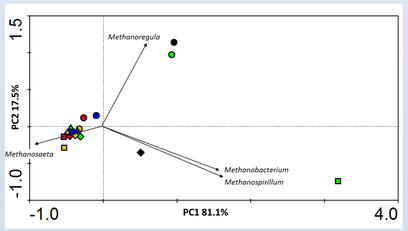
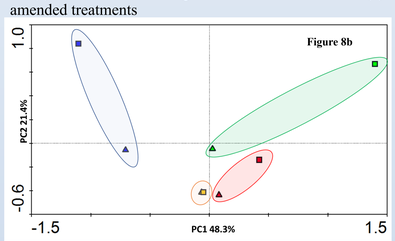
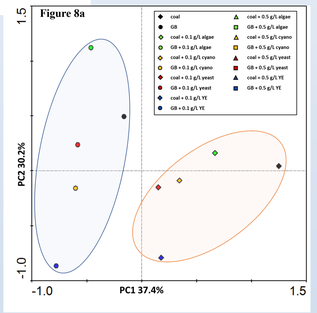



**Figure 8**. Principal component analysis of bacterial phyloptype non-transformed relative abundances of bacterial genera at day 111 for (a) unamended and 0.1 g/L amended treatments and (b) 0.5 g/L amended treatments




## Thermodynamic Predictions

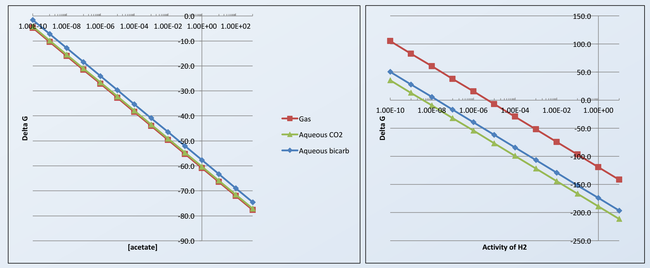
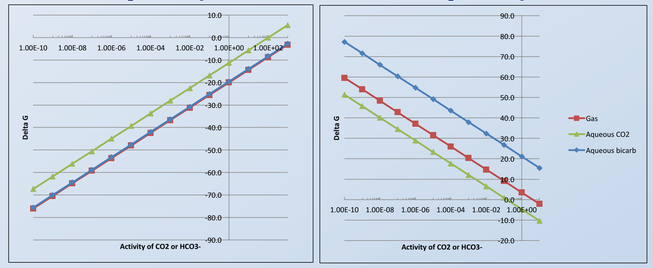


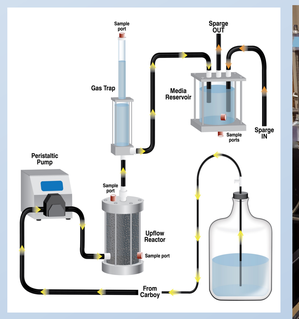

**Figure 9**. Thermodynamic predictions showing the relationship between ΔG and either $H_2$ concentration (in partial pressure) or acetate concentration. As suspected, increasing $H_2$ or acetate concentrations positively impact the thermodynamic favorability of methanogenesis. However, hydrogentrophic methanogenesis is impacted to a greater extent by aqueous $CO_2$/$HCO_3^-$ compared to gaseous. These predictions include general assumptions about the different types of methanogenesis included in the literature and actual $H_2$, $CO_2$, $HCO_3^-$, and acetate measurements from the field. In addition, the predictions are not for standard conditions, but have been modified to emulate conditions thought to represent field conditions.

ACETOCLASTIC
Product - $CO_2$ or $HCO_3^-$

HYDROGENOTROPHIC
Substrate - $CO_2$ or $HCO_3^-$




## Flow Columns for Coal-Dependent Methanogenesis




#1
9/14/16 – inoculated
11/14/16 – amended with $^{13}$C-algae
2/3/17 – first gas production

#3
9/14/16 – inoculated
NO GAS PRODUCTION TO DATE

#2
9/14/16 – inoculated and amended with $^{13}$C-algae
11/14/16 – amended with $^{13}$C-algae
10/11/16 – first gas production

#4
9/14/16 – inoculated and amended with $^{13}$C-algae
10/17/16 – first gas production