Producing methane from coal through biogasification - identifying suitable nutrient solutions for enhancing methane yield

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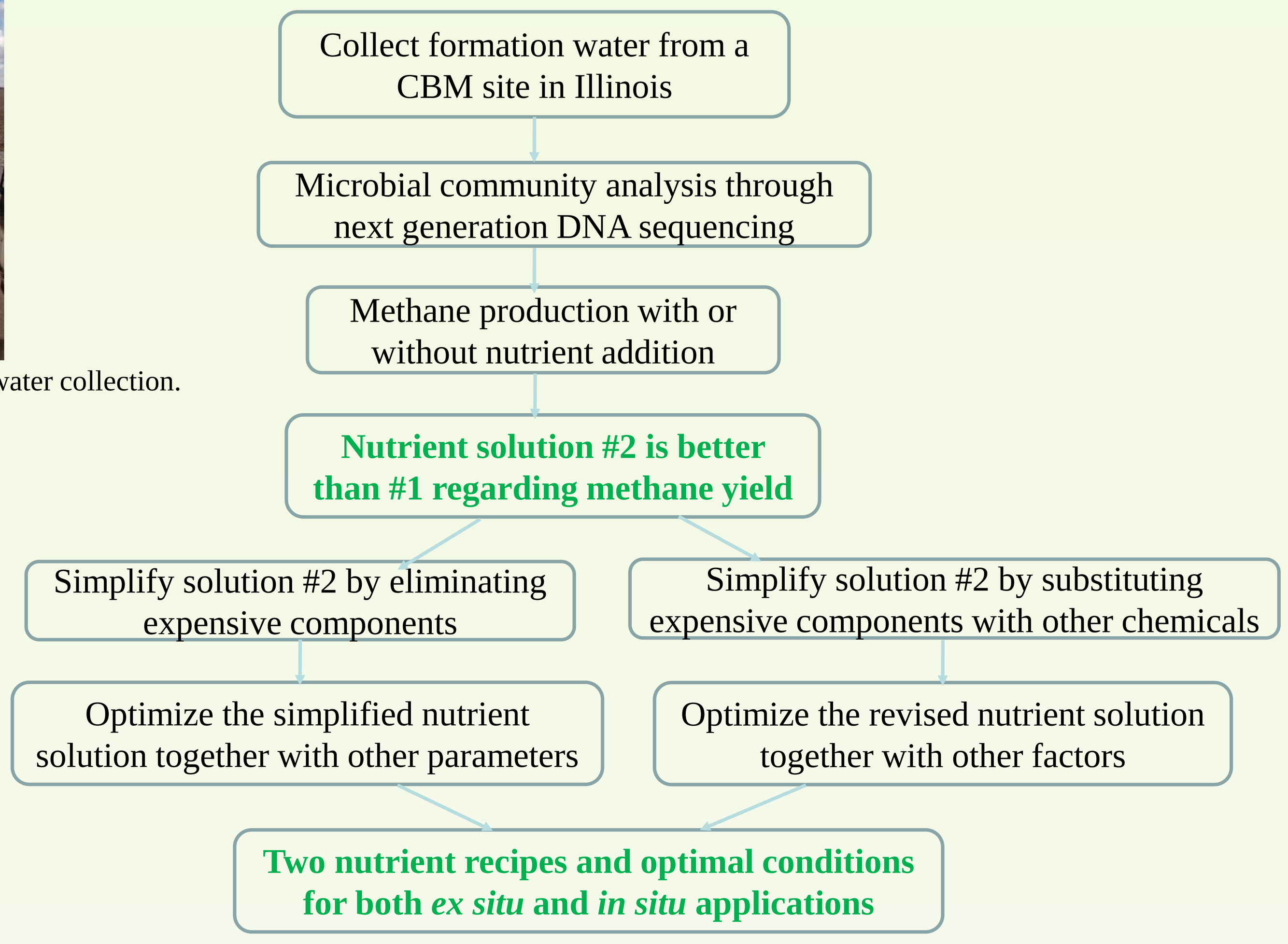
Abstract

As of 2011, Coalbed Methane (CBM) released through biogasification, contributes ~40% of the total CBM production in the US. This is largely owing to the significant production of biogenic CBM from low rank coal seams in western states of the US. Biogenic CBM in the Illinois basin which has the largest deposit of bituminous coal in the US, however, has not been explored extensively although biogenic methane has been observed at different locations. To enhance methane yield from higher ranked coals, we aimed to stimulate activities of indigenous microorganisms that can convert coal to methane in a collaborative and synergistic way. To achieve this goal, different nutrient solutions have been tested. The top two nutrient media which brought the highest methane production were then investigated on whether they can be simplified for decreasing the cost. In addition, effects from other parameters, such as coal loading, pH, temperature, coal particle size, shaking, inoculum loading, surfactants and solvents have been screened and evaluated. Important parameters were further studied to identify their optimal values. Results from this study can be applied to convert mined out coal and waste coal to methane. Additionally, the developed strategies can be used for enhancing methane production in unminable or abandoned coal seams.

Overall Methodology

Fig. 1: Site for formation water collection.



Microbial community analysis

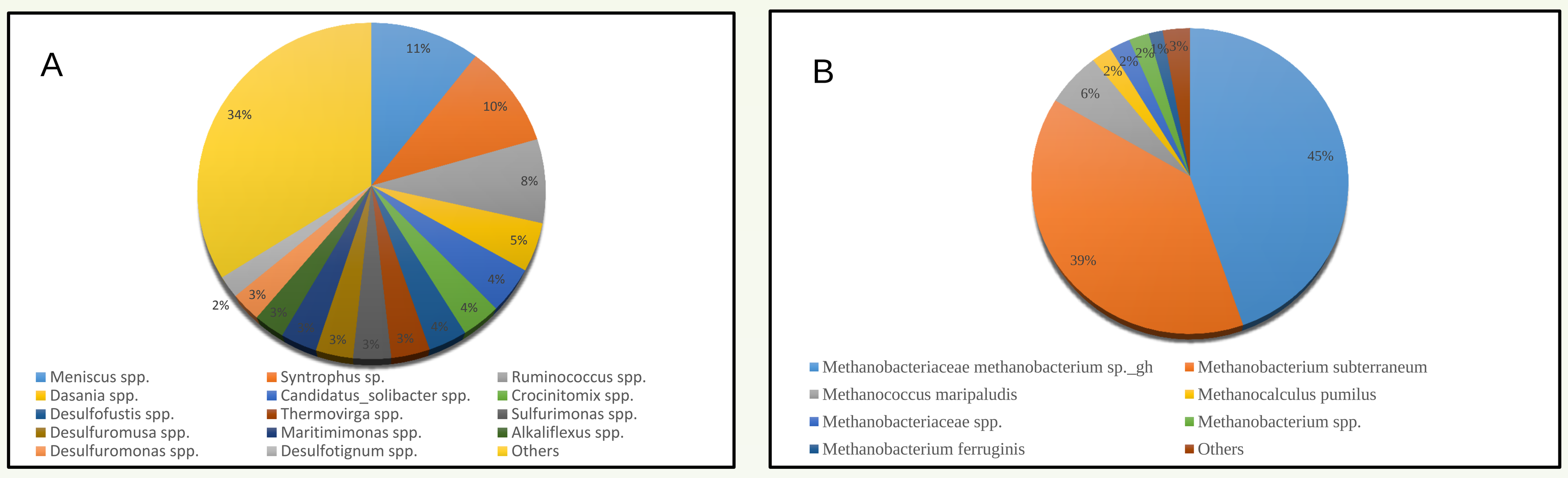


Fig. 2: Distribution of bacteria (A) and archaea (B) in the formation water.

Methane production with or without nutrient solutions

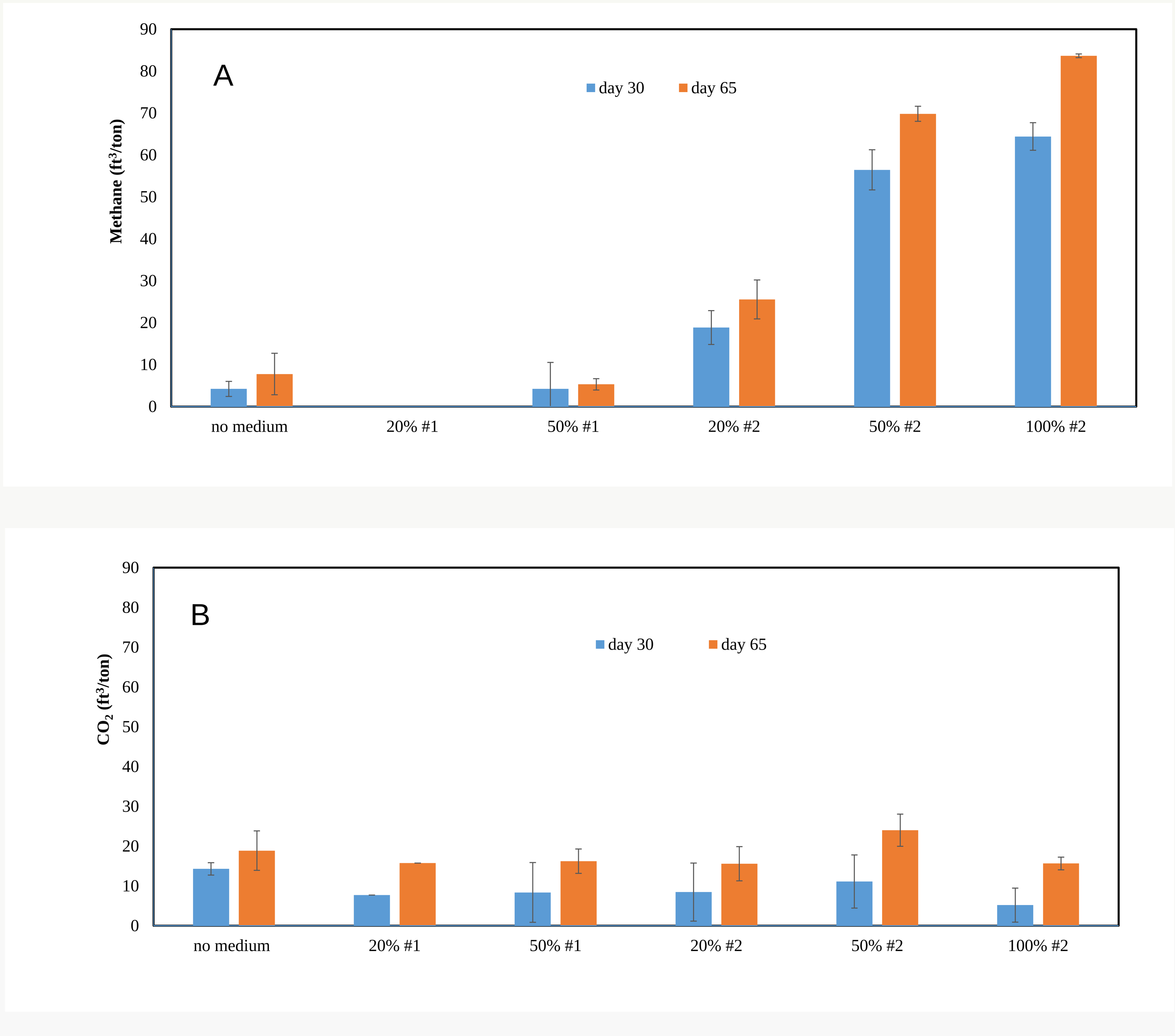


Fig. 3: Gas release from bituminous coal over time. A:methane, B: CO_2.

Simplify nutrient solution #2 by eliminating expensive components

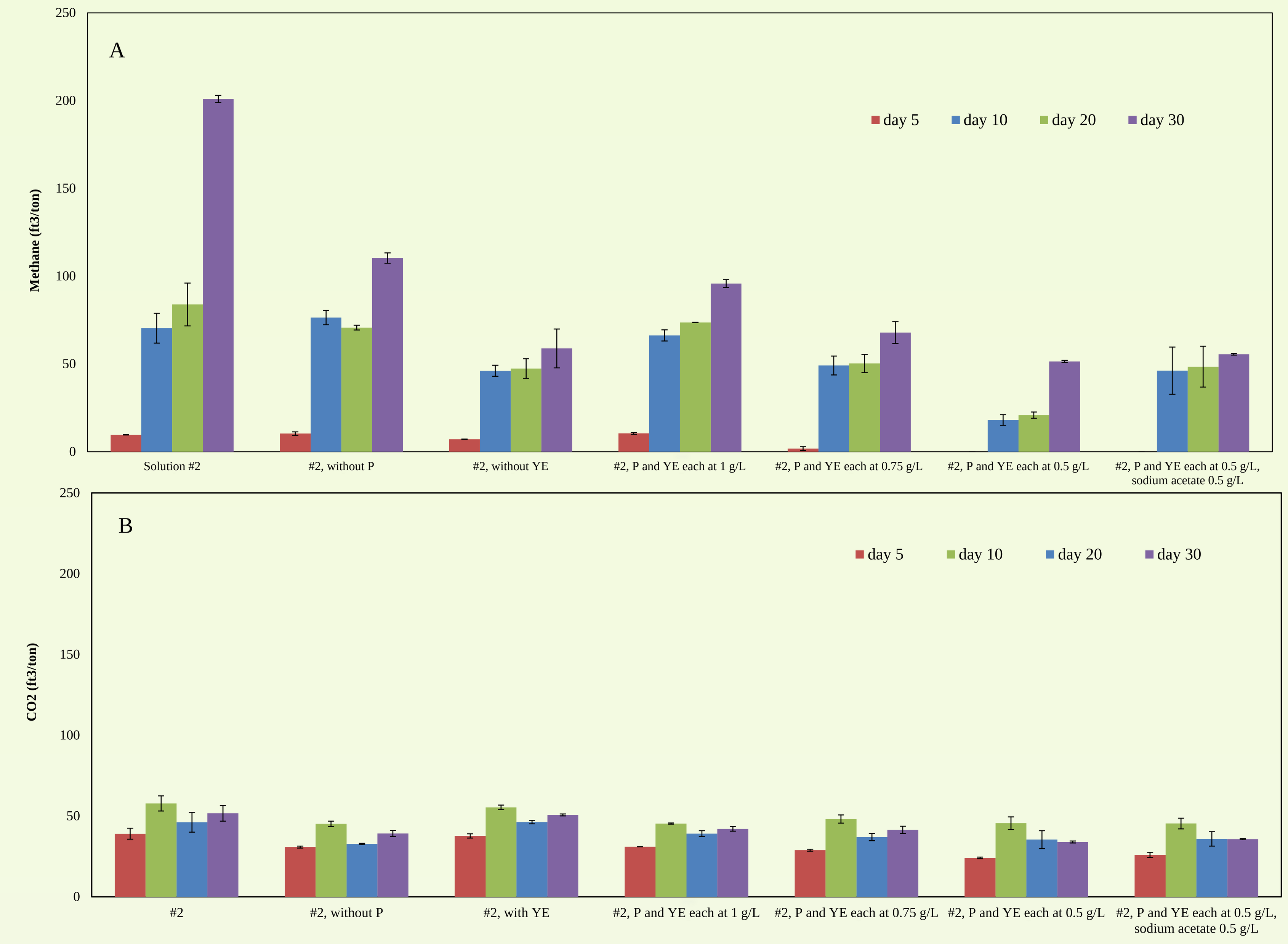


Fig. 4: Yield of gas on bituminous coal under different conditions. A: Methane, B: CO_2.

Screen significant factors for enhancing methane yield using solution #2

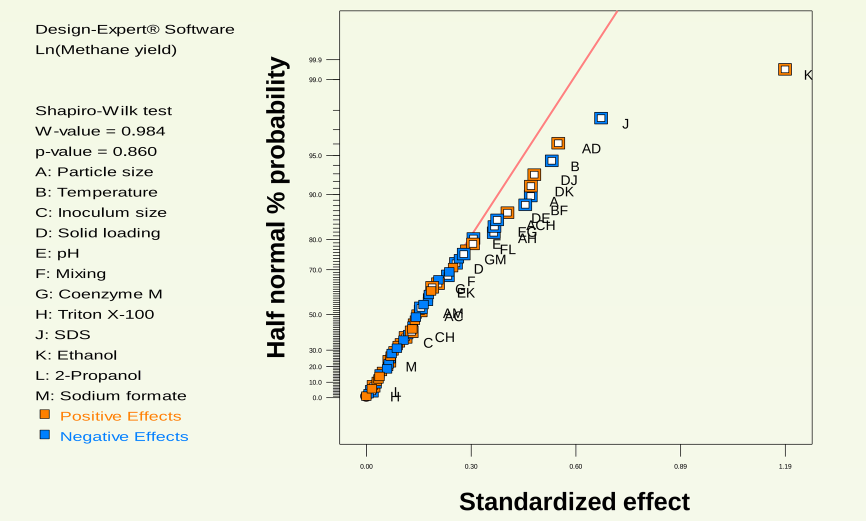


Fig. 5: Half normal probability plot indicating positive or negative effects on methane yield.

Table 1: ANOVA results reflecting significant parameters.

ANOVA for selected factorial model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	70.92	26	2.73	9.46	< 0.0001	significant
A-Particle size	3.52	1	3.52	12.2	0.0013	
B-Temperature	4.47	1	4.47	15.5	0.0004	
C-Inoculum size	0.2	1	0.2	0.7	0.4092	
D-Solid loading	1.05	1	1.05	3.63	0.0646	
E-pH	1.49	1	1.49	5.18	0.0287	
F-Mixing	0.87	1	0.87	3	0.0914	
G-Coenzyme M	0.67	1	0.67	2.32	0.1361	
H-Triton X-100	4.07E-03	1	4.07E-03	0.014	0.906	
J-SDS	7.16	1	7.16	24.84	< 0.0001	
K-Ethanol	22.77	1	22.77	79	< 0.0001	
L-2-Propanol	7.03E-03	1	7.03E-03	0.024	0.8767	
M-Sodium formate	0.07	1	0.07	0.24	0.6261	
AC	0.39	1	0.39	1.34	0.2549	
AD	4.79	1	4.79	16.61	0.0002	
AH	2.11	1	2.11	7.33	0.0102	
AM	0.39	1	0.39	1.35	0.2536	
BF	3.28	1	3.28	11.39	0.0017	
CH	0.27	1	0.27	0.93	0.3409	
DE	2.59	1	2.59	8.99	0.0048	
DJ	3.67	1	3.67	12.73	0.001	
DK	3.52	1	3.52	12.21	0.0013	
EG	2.13	1	2.13	7.4	0.0099	
EK	0.56	1	0.56	1.96	0.17	
FL	1.48	1	1.48	5.13	0.0294	
GM	1.23	1	1.23	4.28	0.0455	
ACH	2.23	1	2.23	7.73	0.0085	
Residual	10.67	37	0.29			
Cor Total	81.59	63				

The Model F-value of 9.46 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.

Replace expensive components in #2 solution with other chemicals

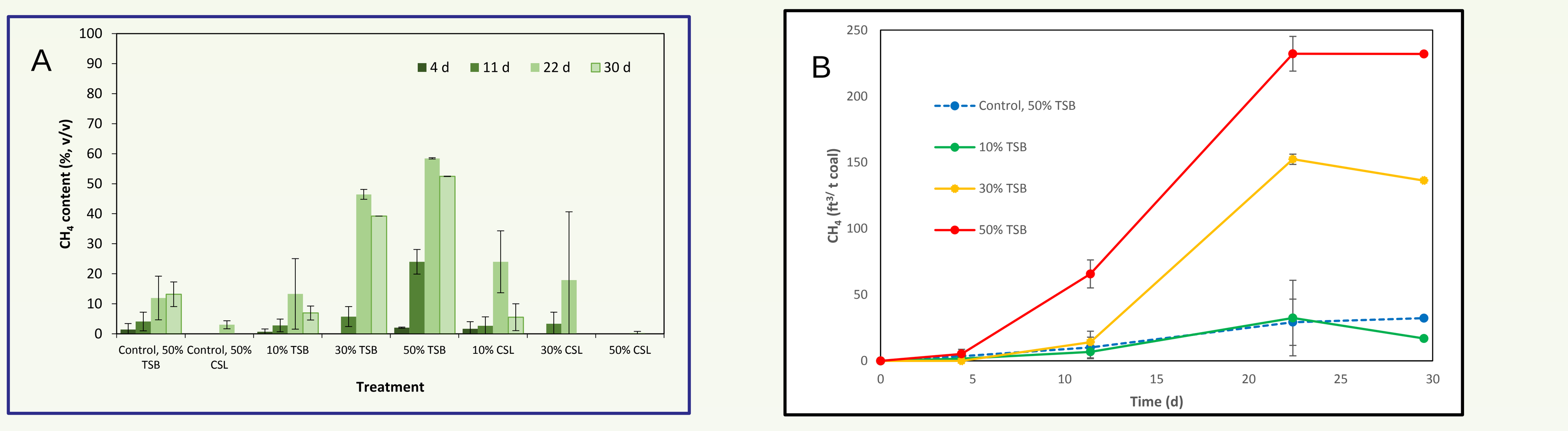


Fig. 6: Effects of corn steep liquor (CSL) and trypticase soy broth (TSB) on methane content (A). Methane yield from bituminous coal incubated with different strength of TSB (B).

Screen significant factors for enhancing methane yield using TSB

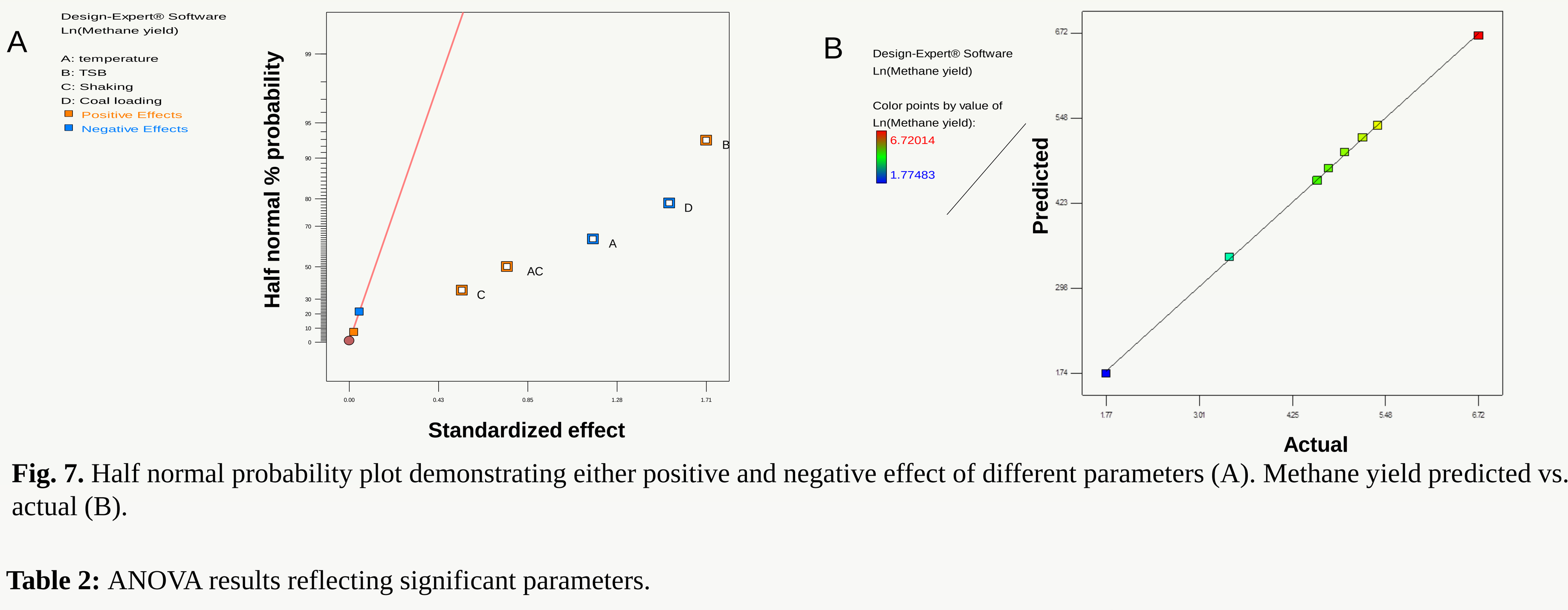


Fig. 7. Half normal probability plot demonstrating either positive and negative effect of different parameters (A). Methane yield predicted vs. actual (B).

Table 2: ANOVA results reflecting significant parameters.

ANOVA for selected factorial model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	14.97	5	2.99	1059.78	0.0009
significant					
A-temperature	*2.72*	*1*	*2.72*	*963.31*	*0.0010*
B-TSB	*5.83*	*1*	*5.83*	*2065.49*	*0.0005*
C-Shaking	*0.58*	*1*	*0.58*	*206.07*	*0.0048*
D-Coal loading	*4.69*	*1*	*4.69*	*1660.54*	*0.0006*
AC	*1.14*	*1*	*1.14*	*403.51*	*0.0025*
Residual	5.649E-003	2	2.825E-003		
Cor Total	14.97	7			

Table 3: Developed model for predicting methane yield on coal.

Final Equation in Terms of Actual Factors:

Ln(Methane yield)		=
+10.28805		
-0.16011	* temperature	
+0.037955	* TSB	
-0.037384	* Shaking	
-0.061257	* Coal loading	
+1.25820E-003	* temperature * Shaking	

Summary and Conclusions

1. Illinois bituminous coal can be converted to methane by a microbial community indigenous to a CBM production site.
2. Nutrient addition significantly enhances methane content and yield from coal.
3. Two nutrient solutions which have similar costs are developed for biogasifying bituminous coal.
4. Optimal parameters for improving coal biogasification are identified.
5. The highest methane production rate is between 27.6 and 32.6 ft^3/ton-day.

References

Zhang, J.*, **Liang, Y.-N.**, Yau, P.M., Pandey, R.*, Harpalani, S. 2015. A metaproteomic approach for identifying proteins in anaerobic bioreactors converting coal to methane. International Journal of Coal Geology. 146, 91–103.

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