# Biogasification Panel

2015 Gasification Systems and Coal &Coal-Biomass Workshop

Morgantown, WV

August 11th, 2015

U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

# Panelists

- Djuna Gulliver, Ph. D. (Moderator) – NETL-DOE
- Yael Tucker, Ph. D. – NETL-DOE
- Prof. Yanna Liang, Ph. D., P.E. – Southern Illinois University
- Prof. Matthew Fields, Ph. D. – Montana State University
- Prof. Taylor Sparks, Ph. D. – University of Utah

# Goal: Increase coal-to-methane production utilizing the microbial consortia

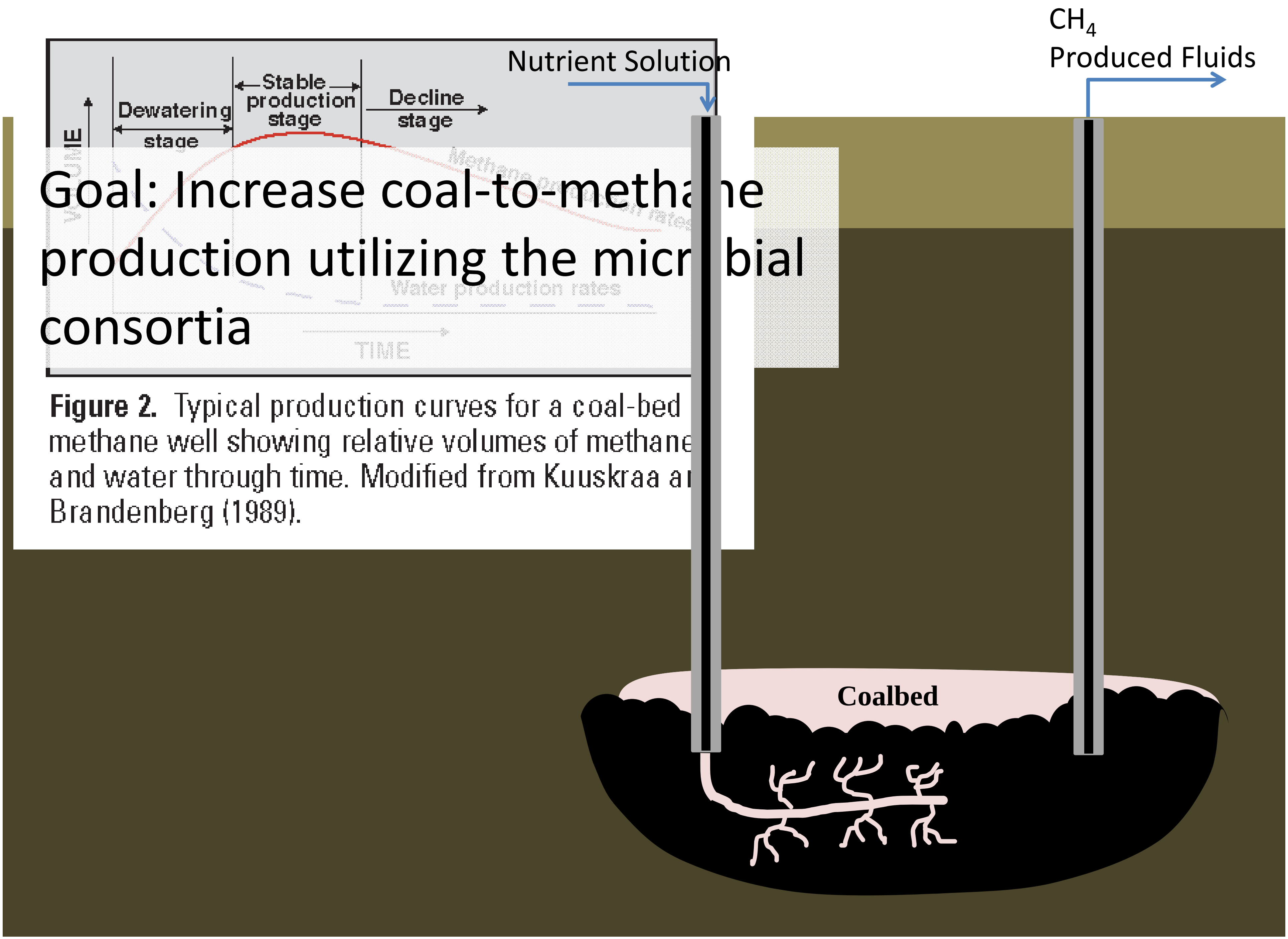
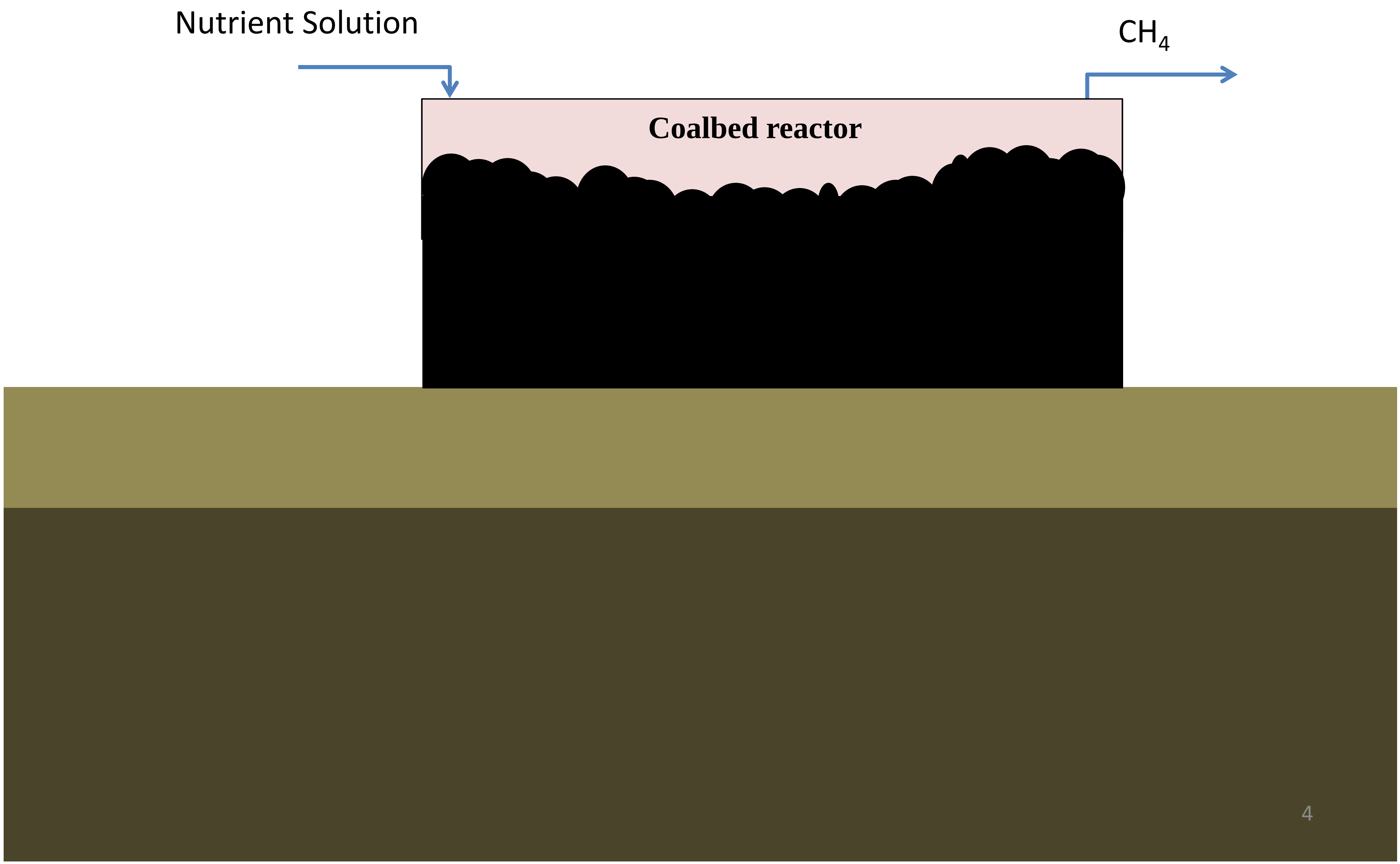
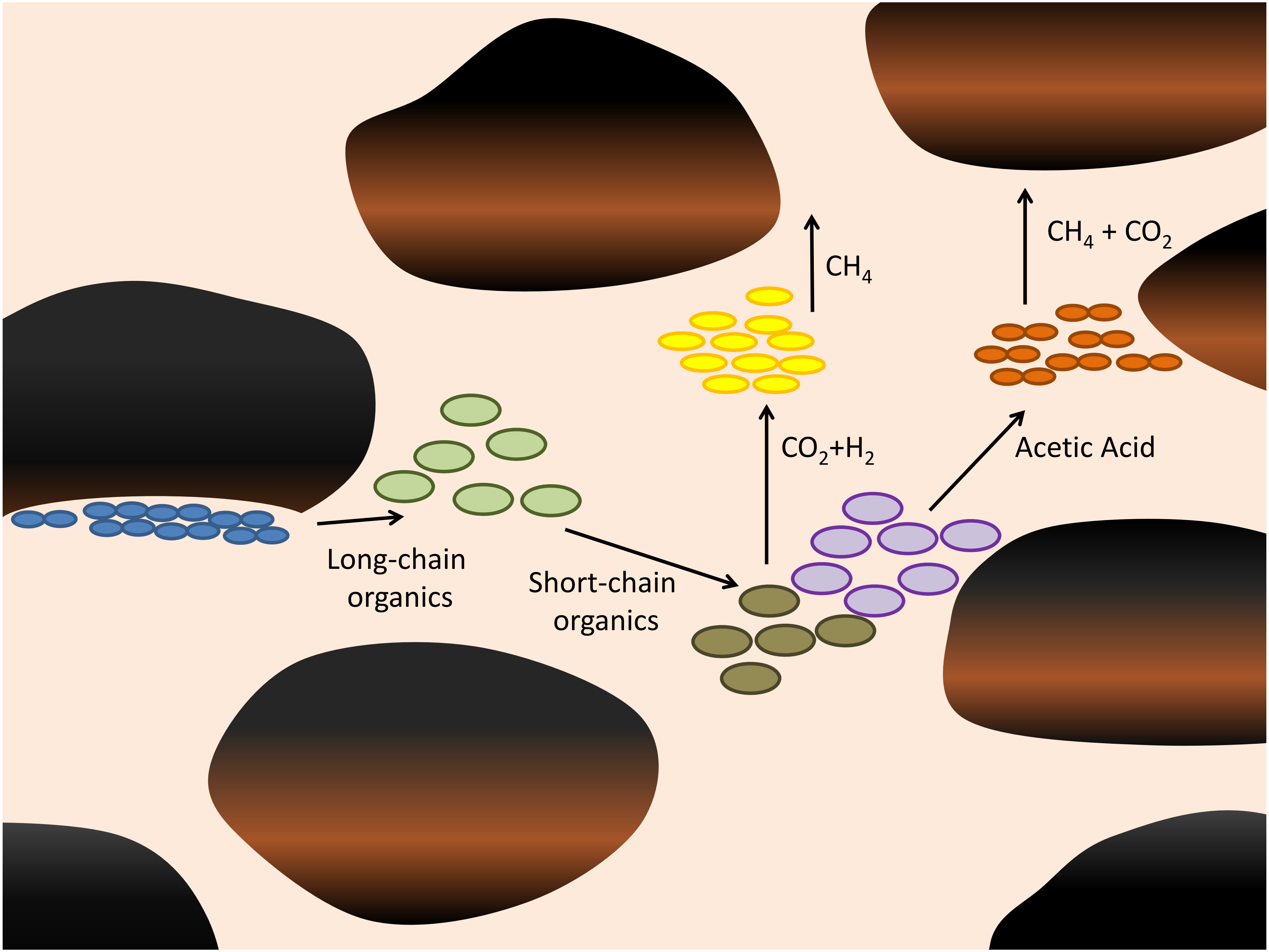



**Figure 2.** Typical production curves for a coal-bed methane well showing relative volumes of methane and water through time. Modified from Kuuskraa and Brandenberg (1989).


Nutrient Solution
$CH_4$
Coalbed reactor



Long-chain
organics
Short-chain
organics
$CO_2+H_2$
$CH_4$
Acetic Acid
$CH_4 + CO_2$

NETL

# Biogasification

Yael Tarlovsky Tucker – Genetics/ Microbiology

Djuna Gulliver – Environmental Engineering

Mark McKoy - Geology

Engineered Natural Systems Division

August 11, 2015

U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

*2015 Gasification Systems and Coal & Coal-Biomass to Liquids (C&CBTL) Workshop Lakeview Conference Center, Morgantown, WV August 10-11, 2015*

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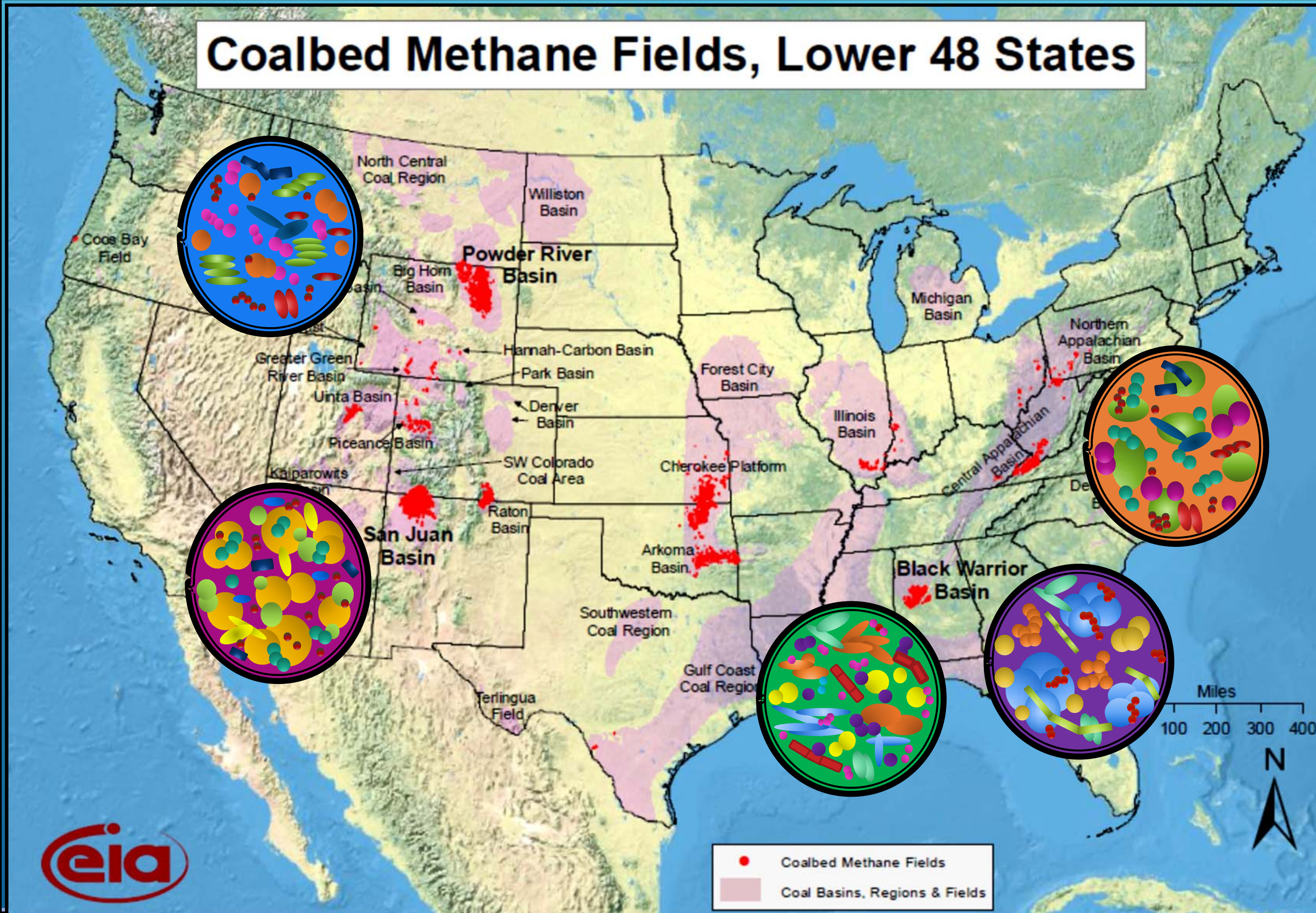
# GENETIC CHARACTERIZATION OF MICROBIAL COMMUNITIES IN “UN-MINEABLE” COALS

At NETL, our initial goal will be to characterize the native microbial communities across different basins in the United States in reference to chemical composition, and geologic characteristics of different reservoirs.




Source: Energy Information Administration based on data from USGS and various published studies
Updated: April 8, 2009

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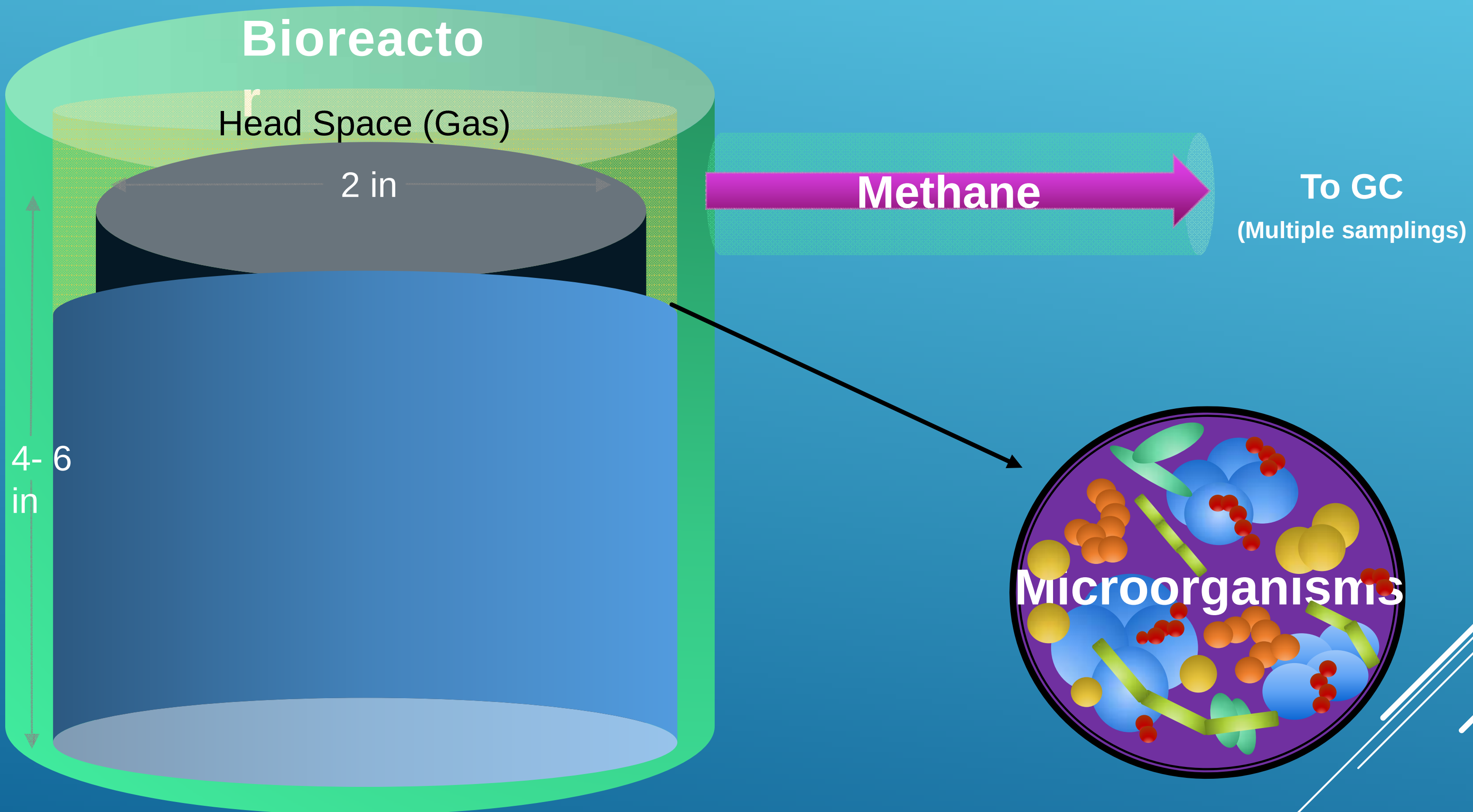
# ASSESSMENT OF NATURAL BIOGENIC GENERATION POTENTIAL

In combination to any production values acquired from any coals from coalbed methane reservoirs, natural methane potential will then be assessed using bench-top bioreactors. We will then compare this to the microbial, chemical, and geological characteristics and strive to understand their relationship.

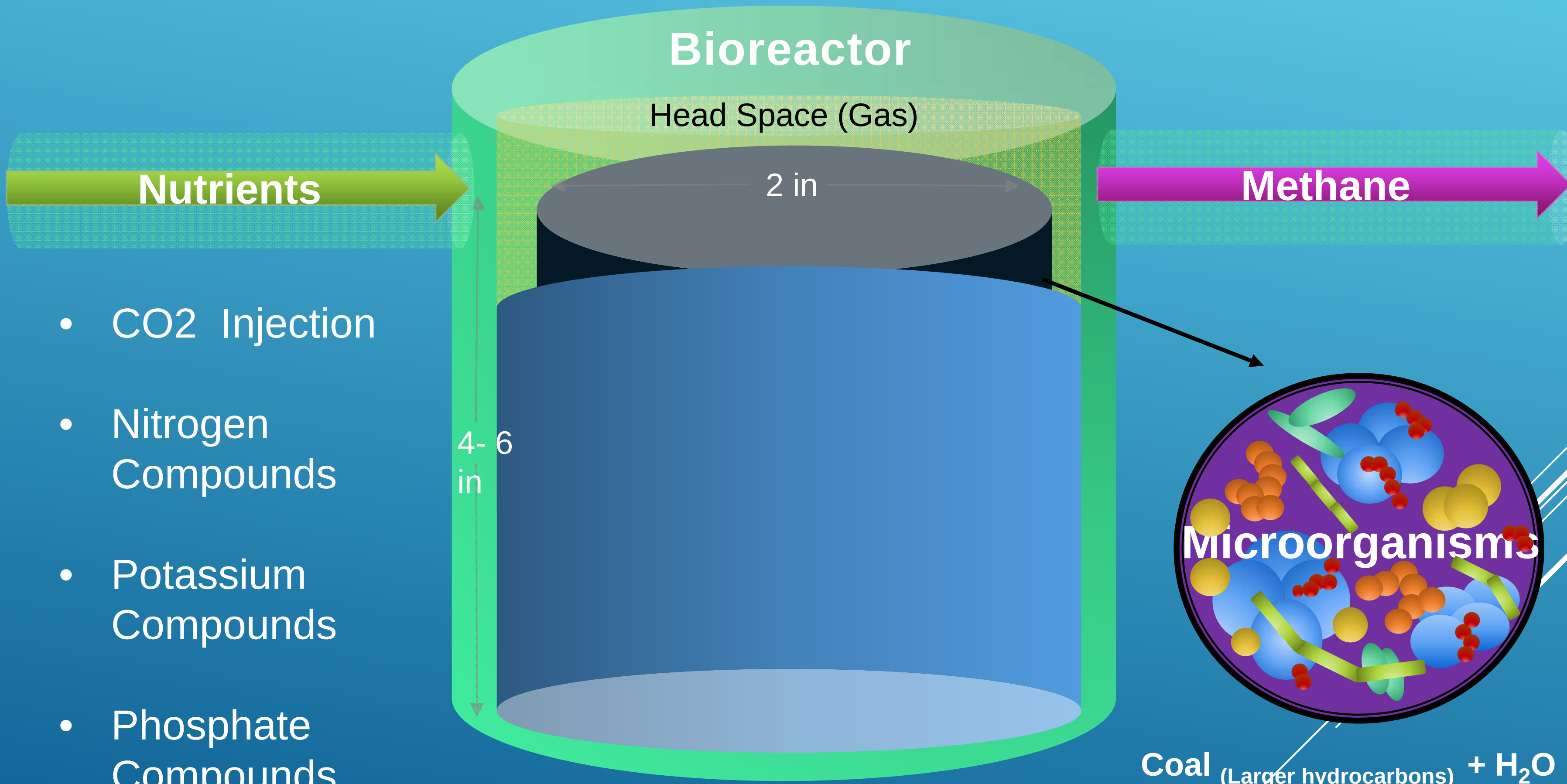



**Pressure Range: 0-1000 psi.**
**Temperature: 40-150 ºF**

**Coal** (Larger hydrocarbons) **+ $H_2O$ → $CH_4 + CO_2$**

# NUTRIENT ENHANCEMENT TESTS

This information will then be utilized to work with the natural consortia and complement their environment with inexpensive nutrients that may be limiting methane production in each reservoir. Together, these tests should help us find an inexpensive solution for enhancing the natural methane production potential several types of unmineable coals.



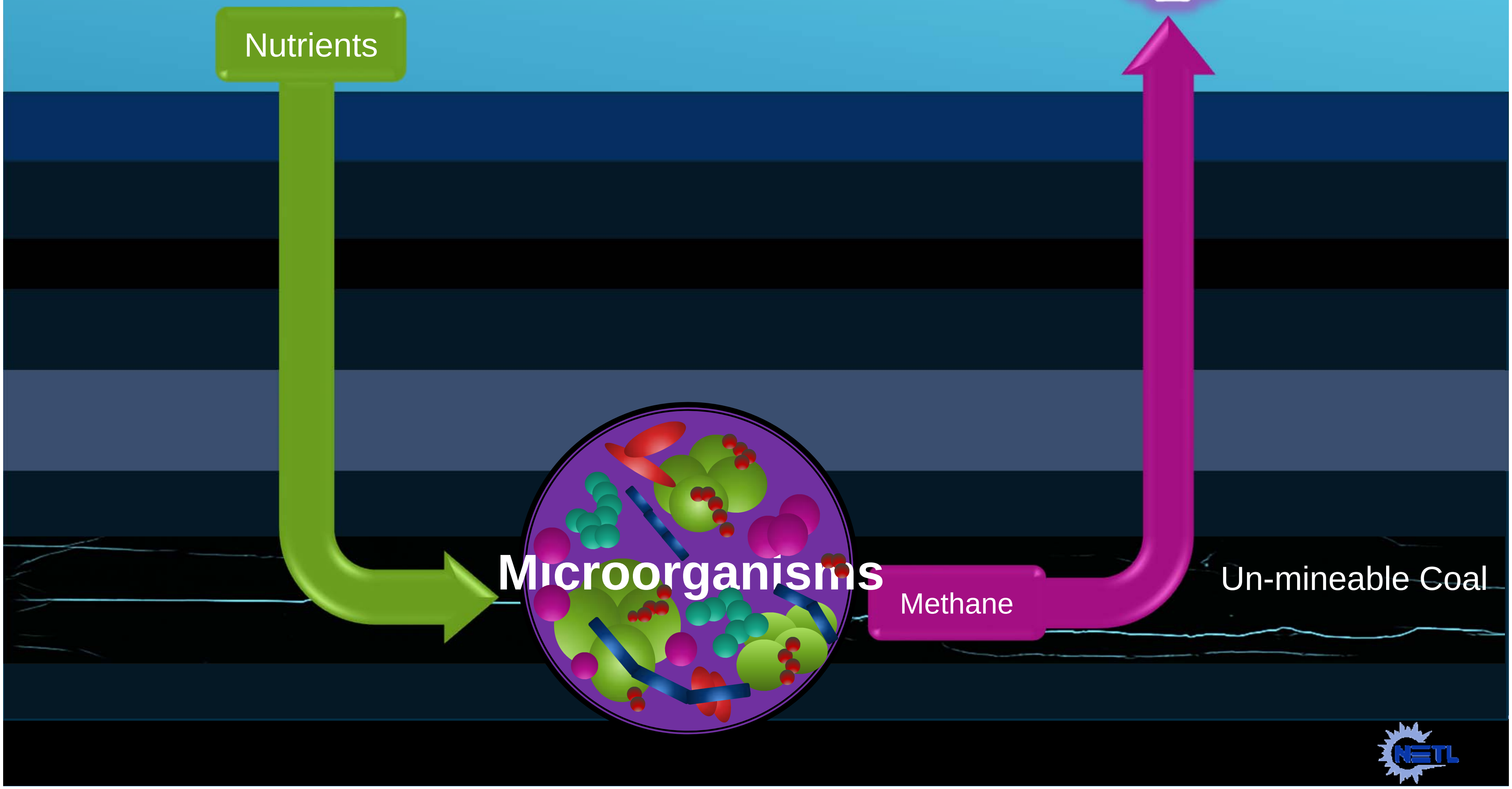

- CO2 Injection
- Nitrogen Compounds
- Potassium Compounds
- Phosphate Compounds

**Pressure Range: 0-1000 psi.**
**Temperature: 40-150 ºF**

**Coal** **(Larger hydrocarbons) + $H_2O$ → $CH_4 + CO_2$**

# FUTURE DIRECTIONS

Once we develop a series of nutrients that enhance methane production in our bioreactors, we will progress to a field demonstration where nutrients will be pumped into reservoirs. These test sites may include existing depleted coalbed methane wells or greenfield sites new to coalbed methane production.



# Optimized microbial conversion of bituminous coal to methane for *in situ* and *ex situ* applications

Yanna Liang, Ph.D., P.E.

08-11-2015

# Overall Objectives

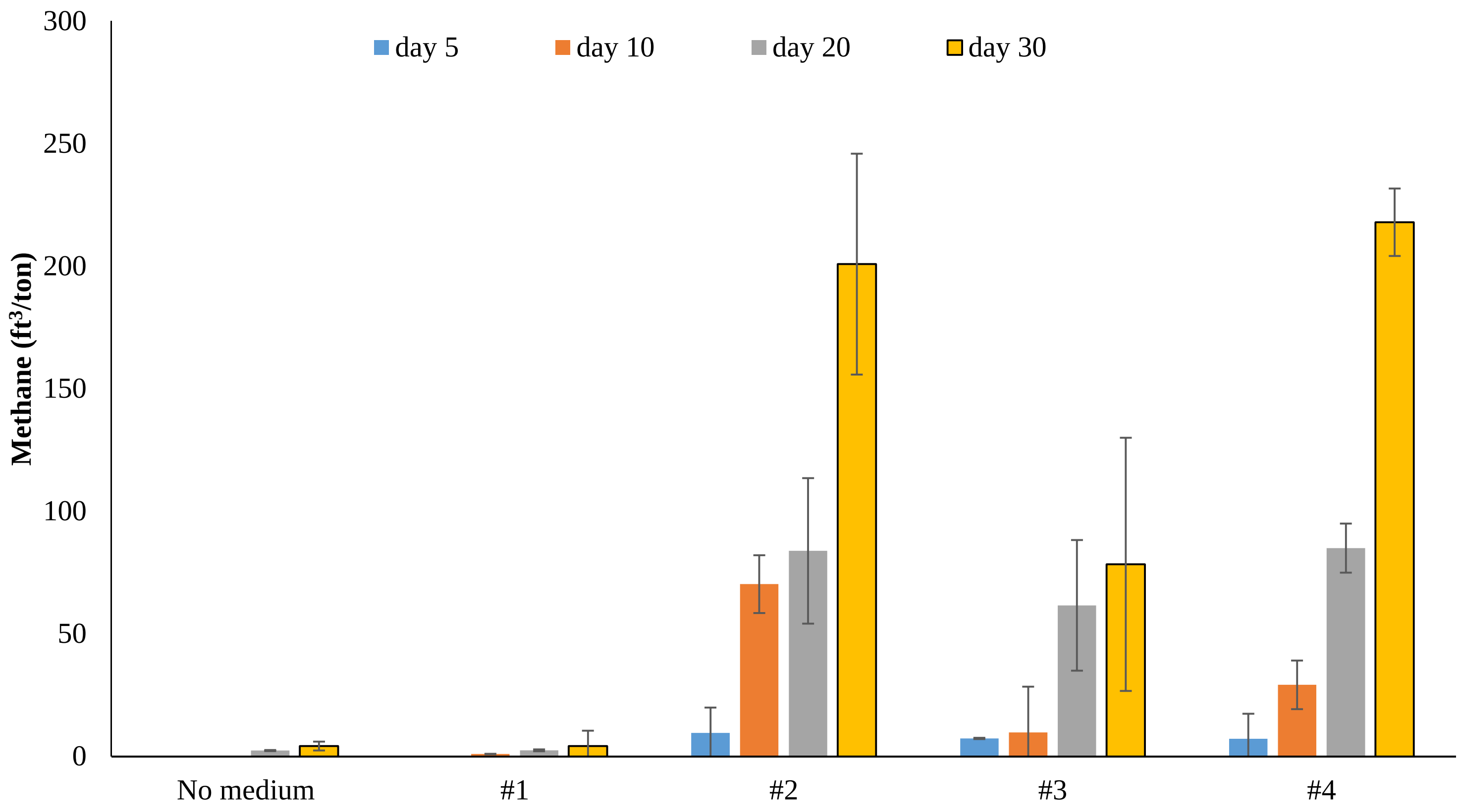
1) Optimize methane production from bituminous coal through biogasification

2) Demonstrate feasibility of the developed technology for *ex situ* and *in situ* applications

# Tasks

- Task 1.0 : Project Management, Planning and Reporting
- Task 2.0: Simplify the composition of the nutrient medium
- Task 3.0: Investigate individual and interactive effects from different parameters
- Task 4.0: Maximize methane productivity in a fed-batch system
- Task 5.0: Bioconversion under pressurized conditions
- Task 6.0: Ecological Considerations of the Proposed Process
- Task 7.0: Economic Analysis of the Proposed Process

# Comparison of nutrient solutions

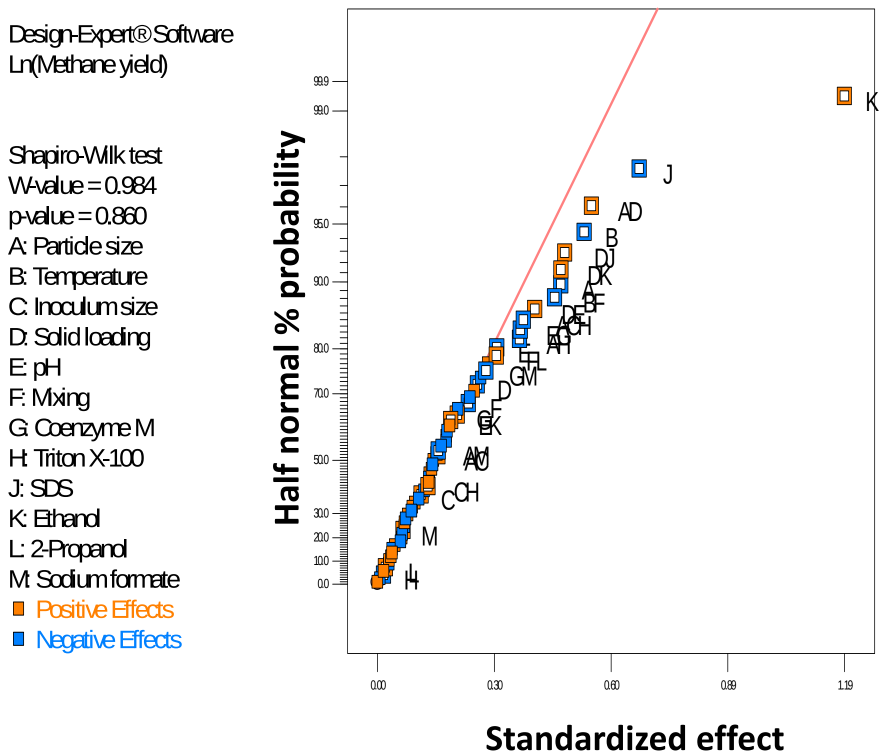



#1: General medium for anaerobic bacteria
#2: Medium for methane-producing methanogens
#3: Simplified medium based on #2
#4: Trypticase soy broth based medium

# Nutrient solution #2: screening significant parameters

| Number | Particle size (mm) | Temp. © | Inoculum size (mL) | Coal loading (g) | pH | Mixing (rpm) | CoM (mL) | Triton X (µL) | SDS (µL) | Ethanol (µL) | 2-Propanol (µL) | Sodium formate (g) | Methane Prod. ($ft^3/ton$) | Methane (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | <0.074 | 40 | 10 | 35 | 8 | 100 | 0 | 1.98 | 30 | 0 | 0 | 0.34 | 4.50 | 7.5 |
| 6 | <0.074 | 40 | 10 | 35 | 6 | 100 | 0 | 1.98 | 50 | 0 | 382.3 | 0 | 5.06 | 10 |
| 3 | 0.074-0.42 | 28 | 5 | 10 | 8 | 0 | 0.25 | 3.3 | 50 | 0 | 382.3 | 0.34 | 7.80 | 3 |
| 55 | 0.074-0.42 | 40 | 5 | 35 | 6 | 100 | 0 | 3.3 | 50 | 0 | 0 | 0.34 | 10.50 | 15.2 |
| 36 | <0.074 | 28 | 10 | 10 | 8 | 0 | 0.25 | 1.98 | 50 | 0 | 0 | 0 | 18.64 | 7 |
| 24 | 0.074-0.42 | 40 | 5 | 35 | 8 | 100 | 0 | 3.3 | 30 | 0 | 382.3 | 0 | 20.14 | 24 |
| 51 | <0.074 | 40 | 5 | 35 | 8 | 0 | 0.25 | 1.98 | 50 | 0 | 382.3 | 0.34 | 20.15 | 24 |
| 48 | 0.074-0.42 | 28 | 10 | 10 | 8 | 100 | 0 | 3.3 | 30 | 0 | 0 | 0.34 | 21.18 | 9.4 |
| 2 | 0.074-0.42 | 40 | 10 | 35 | 6 | 0 | 0.25 | 3.3 | 30 | 0 | 382.3 | 0.34 | 23.83 | 27 |
| 34 | <0.074 | 40 | 5 | 35 | 6 | 0 | 0.25 | 1.98 | 30 | 0 | 0 | 0 | 23.83 | 19 |
| 5 | <0.074 | 40 | 5 | 10 | 8 | 100 | 0.25 | 3.3 | 30 | 0 | 0 | 0.34 | 24.64 | 9.2 |
| 1 | 0.074-0.42 | 40 | 5 | 10 | 8 | 100 | 0 | 1.98 | 50 | 292 | 382.3 | 0.34 | 25.63 | 10.3 |
| 53 | 0.074-0.42 | 40 | 5 | 10 | 8 | 0 | 0 | 1.98 | 50 | 0 | 0 | 0 | 26.93 | 10.3 |
| 54 | 0.074-0.42 | 40 | 5 | 10 | 6 | 100 | 0 | 1.98 | 30 | 292 | 0 | 0 | 29.98 | 10 |
| 44 | <0.074 | 28 | 5 | 35 | 8 | 0 | 0 | 3.3 | 50 | 0 | 0 | 0 | 30.38 | 29 |
| 27 | 0.074-0.42 | 28 | 5 | 10 | 8 | 100 | 0.25 | 3.3 | 50 | 292 | 0 | 0 | 31.97 | 12.3 |
| 31 | 0.074-0.42 | 40 | 10 | 10 | 6 | 100 | 0.25 | 1.98 | 50 | 0 | 0 | 0.34 | 33.87 | 14 |
| 57 | 0.074-0.42 | 40 | 5 | 35 | 6 | 0 | 0 | 3.3 | 50 | 292 | 382.3 | 0 | 37.34 | 41 |
| 26 | 0.074-0.42 | 28 | 5 | 35 | 6 | 100 | 0.25 | 1.98 | 50 | 0 | 382.3 | 0 | 38.61 | 38 |
| 4 | 0.074-0.42 | 28 | 10 | 10 | 6 | 0 | 0 | 3.3 | 50 | 292 | 0 | 0.34 | 39.45 | 14 |
| 45 | 0.074-0.42 | 28 | 5 | 35 | 8 | 100 | 0.25 | 1.98 | 30 | 0 | 0 | 0.34 | 46.53 | 42 |
| 33 | 0.074-0.42 | 28 | 10 | 10 | 6 | 100 | 0 | 3.3 | 50 | 0 | 382.3 | 0 | 46.78 | 19 |
| 10 | 0.074-0.42 | 40 | 10 | 35 | 8 | 0 | 0.25 | 3.3 | 50 | 0 | 0 | 0 | 48.19 | 40 |
| 19 | 0.074-0.42 | 28 | 10 | 35 | 6 | 0 | 0 | 1.98 | 30 | 0 | 0 | 0 | 51.04 | 41 |
| 15 | 0.074-0.42 | 40 | 10 | 35 | 8 | 100 | 0.25 | 3.3 | 50 | 292 | 382.3 | 0.34 | 52.11 | 38 |
| 17 | 0.074-0.42 | 40 | 10 | 10 | 8 | 100 | 0.25 | 1.98 | 30 | 0 | 382.3 | 0 | 54.86 | 19.2 |
| 58 | <0.074 | 28 | 5 | 10 | 6 | 0 | 0 | 1.98 | 50 | 292 | 382.3 | 0 | 57.18 | 21 |
| 42 | <0.074 | 28 | 10 | 35 | 8 | 100 | 0.25 | 3.3 | 30 | 0 | 382.3 | 0 | 59.92 | 44 |
| 63 | <0.074 | 40 | 5 | 10 | 6 | 100 | 0.25 | 3.3 | 50 | 0 | 382.3 | 0 | 65.51 | 21 |
| 7 | <0.074 | 40 | 10 | 10 | 8 | 100 | 0 | 3.3 | 50 | 292 | 0 | 0 | 65.63 | 18 |
| 18 | 0.074-0.42 | 28 | 10 | 35 | 8 | 0 | 0 | 1.98 | 50 | 0 | 382.3 | 0.34 | 68.15 | 69 |
| 52 | 0.074-0.42 | 28 | 10 | 10 | 8 | 0 | 0 | 3.3 | 30 | 292 | 382.3 | 0 | 69.24 | 28 |
| 38 | <0.074 | 28 | 5 | 35 | 6 | 0 | 0 | 3.3 | 30 | 0 | 382.3 | 0.34 | 73.45 | 50 |
| 12 | 0.074-0.42 | 40 | 5 | 10 | 6 | 0 | 0 | 1.98 | 30 | 0 | 382.3 | 0.34 | 74.31 | 25 |
| 49 | <0.074 | 40 | 10 | 10 | 8 | 0 | 0 | 3.3 | 50 | 0 | 382.3 | 0.34 | 75.52 | 25 |
| 39 | <0.074 | 28 | 10 | 35 | 6 | 100 | 0.25 | 3.3 | 50 | 0 | 0 | 0.34 | 77.84 | 51 |
| 41 | <0.074 | 28 | 10 | 10 | 8 | 100 | 0.25 | 1.98 | 50 | 292 | 382.3 | 0.34 | 84.63 | 27 |
| 61 | <0.074 | 28 | 5 | 35 | 6 | 100 | 0 | 3.3 | 30 | 292 | 0 | 0 | 97.60 | 51 |
| 47 | <0.074 | 28 | 5 | 10 | 6 | 100 | 0 | 1.98 | 50 | 0 | 0 | 0.34 | 100.99 | 35 |
| 13 | 0.074-0.42 | 40 | 10 | 10 | 6 | 0 | 0.25 | 1.98 | 50 | 292 | 382.3 | 0 | 102.52 | 34 |
| 25 | <0.074 | 40 | 10 | 35 | 8 | 0 | 0 | 1.98 | 30 | 292 | 382.3 | 0 | 105.36 | 65 |
| 64 | 0.074-0.42 | 28 | 5 | 10 | 6 | 0 | 0.25 | 3.3 | 30 | 0 | 0 | 0 | 125.48 | 34 |
| 37 | 0.074-0.42 | 28 | 5 | 35 | 6 | 0 | 0.25 | 1.98 | 50 | 292 | 0 | 0.34 | 126.35 | 69 |
| 21 | <0.074 | 40 | 5 | 35 | 6 | 100 | 0.25 | 1.98 | 30 | 292 | 382.3 | 0.34 | 131.10 | 76 |
| 28 | <0.074 | 40 | 5 | 35 | 8 | 100 | 0.25 | 1.98 | 50 | 292 | 0 | 0 | 141.39 | 61 |
| 32 | 0.074-0.42 | 40 | 10 | 10 | 8 | 0 | 0.25 | 1.98 | 30 | 292 | 0 | 0.34 | 142.04 | 36 |
| 59 | <0.074 | 40 | 10 | 35 | 6 | 0 | 0 | 1.98 | 50 | 292 | 0 | 0.34 | 186.12 | 50 |
| 40 | 0.074-0.42 | 28 | 10 | 35 | 8 | 100 | 0 | 1.98 | 50 | 292 | 0 | 0 | 193.19 | 62 |
| 14 | <0.074 | 40 | 5 | 10 | 6 | 0 | 0.25 | 3.3 | 50 | 292 | 0 | 0.34 | 193.31 | 38 |
| 62 | 0.074-0.42 | 40 | 10 | 35 | 6 | 100 | 0.25 | 3.3 | 30 | 292 | 0 | 0 | 203.35 | 58 |
| 23 | 0.074-0.42 | 40 | 5 | 35 | 8 | 0 | 0 | 3.3 | 30 | 292 | 0 | 0.34 | 214.43 | 66 |
| 46 | <0.074 | 40 | 5 | 10 | 8 | 0 | 0.25 | 3.3 | 30 | 292 | 382.3 | 0 | 224.98 | 46 |
| 30 | <0.074 | 28 | 10 | 35 | 6 | 0 | 0.25 | 3.3 | 50 | 292 | 382.3 | 0 | 230.48 | 74 |
| 43 | 0.074-0.42 | 28 | 5 | 35 | 8 | 0 | 0.25 | 1.98 | 30 | 292 | 382.3 | 0 | 231.13 | 73 |
| 22 | <0.074 | 28 | 5 | 35 | 8 | 100 | 0 | 3.3 | 50 | 292 | 382.3 | 0.34 | 242.64 | 69 |
| 9 | <0.074 | 28 | 10 | 35 | 8 | 0 | 0.25 | 3.3 | 30 | 292 | 0 | 0.34 | 243.20 | 66 |
| 20 | <0.074 | 28 | 5 | 10 | 8 | 100 | 0 | 1.98 | 30 | 0 | 382.3 | 0 | 255.35 | 55 |
| 8 | <0.074 | 28 | 10 | 10 | 6 | 0 | 0.25 | 1.98 | 30 | 0 | 382.3 | 0.34 | 263.26 | 60 |
| 35 | 0.074-0.42 | 28 | 10 | 35 | 6 | 100 | 0 | 1.98 | 30 | 292 | 382.3 | 0.34 | 264.44 | 77 |
| 60 | <0.074 | 40 | 10 | 10 | 6 | 100 | 0 | 3.3 | 30 | 292 | 382.3 | 0.34 | 335.85 | 15 |
| 50 | <0.074 | 40 | 10 | 10 | 6 | 0 | 0 | 3.3 | 30 | 0 | 0 | 0 | 336.64 | 52 |
| 56 | 0.074-0.42 | 28 | 5 | 10 | 6 | 100 | 0.25 | 3.3 | 30 | 292 | 382.3 | 0.34 | 514.93 | 76 |
| 16 | <0.074 | 28 | 10 | 10 | 6 | 100 | 0.25 | 1.98 | 30 | 292 | 0 | 0 | 880.13 | 64 |
| 29 | <0.074 | 28 | 5 | 10 | 8 | 0 | 0 | 1.98 | 30 | 292 | 0 | 0.34 | 979.43 | 76 |

# Half normal probability plot for methane productivity ($ft^3$/ton)




# Effect from different parameters

| Term | Standardized Effect | Sum of squares | % Contribution |
|---|---|---|---|
| A-Particle size | -0.469 | 3.516 | 4.310 |
| B-Temperature | -0.529 | 4.469 | 5.478 |
| C-Inoculum size | 0.112 | 0.201 | 0.246 |
| D-Solid loading | -0.256 | 1.046 | 1.282 |
| E-pH | -0.305 | 1.493 | 1.830 |
| F-Mixing | -0.233 | 0.866 | 1.061 |
| G-Coenzyme M | 0.205 | 0.669 | 0.820 |
| H-Triton X-100 | -0.016 | 0.004 | 0.005 |
| J-SDS | -0.669 | 7.162 | 8.778 |
| K-Ethanol | 1.19305 | 22.774 | 27.913 |
| L-2-Propanol | 0.0209669 | 0.0070338 | 0.009 |
| M-Sodium formate | 0.0659437 | 0.0695771 | 0.085 |

# ANOVA test

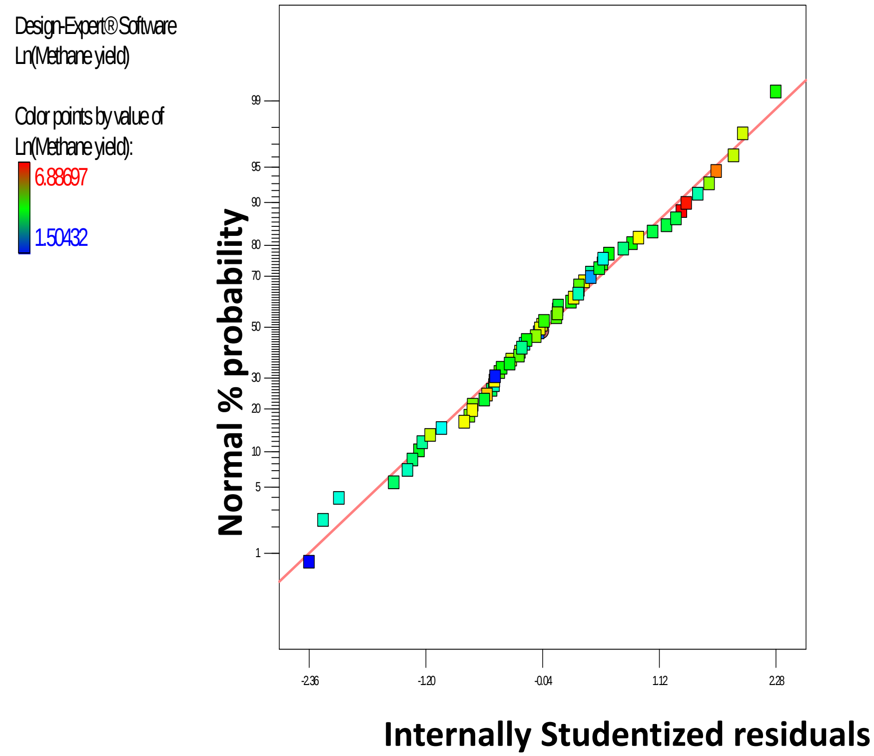
ANOVA for selected factorial model

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

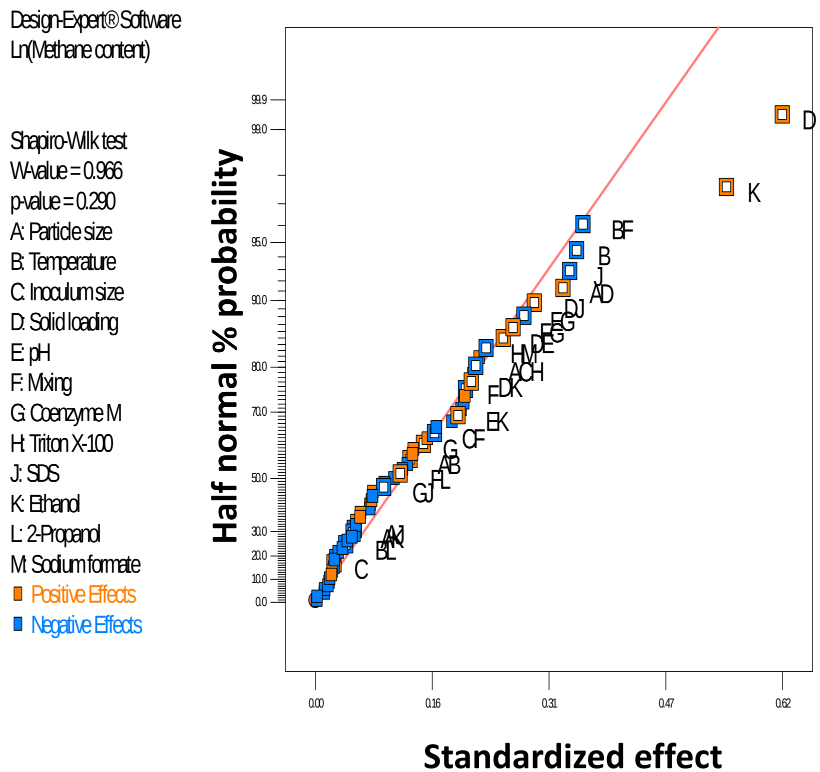
| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 70.92 | 26 | 2.73 | 9.46 | < 0.0001 | significant |
| A-Particle size | 3.52 | 1 | 3.52 | 12.2 | 0.0013 | |
| B-Temperature | 4.47 | 1 | 4.47 | 15.5 | 0.0004 | |
| C-Inoculum size | 0.2 | 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.

# Normal plot of residuals



# Half normal probability plot for methane content (%)



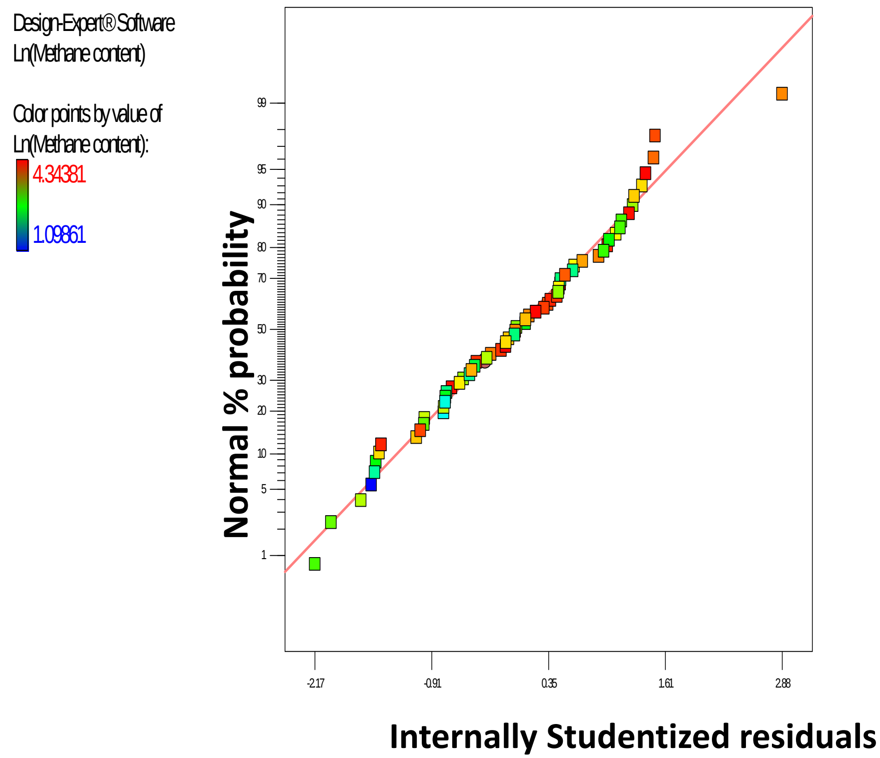

# Effect from different parameters

| Term | Standardized Effect | Sum of squares | % Contribution |
|---|---|---|---|
| A-Particle size | -0.195 | 0.608 | 1.726 |
| B-Temperature | -0.350 | 1.955 | 5.547 |
| C-Inoclum size | 0.025 | 0.010 | 0.029 |
| D-Solid loading | 0.625 | 6.240 | 17.703 |
| E-pH | -0.199 | 0.631 | 1.790 |
| F-Mixing | -0.201 | 0.647 | 1.834 |
| G-Coenzyme M | 0.145 | 0.335 | 0.951 |
| H-Triton X-100 | -0.073 | 0.086 | 0.244 |
| J-SDS | -0.340 | 1.853 | 5.257 |
| K-Ethanol | 0.550 | 4.841 | 13.733 |
| L-2-Propanol | 0.131 | 0.275 | 0.780 |
| M-Sodiium formate | - 0.0121663 | 0.0023 68 | 0.007 |

# ANOVA test

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 31.25 | 32 | 0.98 | 7.58 | < 0.0001 | significant |
| A-Particle size | 0.61 | 1 | 0.61 | 4.72 | 0.0376 | |
| B-Temperature | 1.96 | 1 | 1.96 | 15.17 | 0.0005 | |
| C-Inoculum size | 0.01 | 1 | 0.01 | 0.079 | 0.7803 | |
| D-Solid loading | 6.24 | 1 | 6.24 | 48.4 | < 0.0001 | |
| E-pH | 0.63 | 1 | 0.63 | 4.89 | 0.0345 | |
| F-Mixing | 0.65 | 1 | 0.65 | 5.02 | 0.0324 | |
| G-Coenzyme M | 0.34 | 1 | 0.34 | 2.6 | 0.117 | |
| H-Triton X-100 | 0.086 | 1 | 0.086 | 0.67 | 0.4198 | |
| J-SDS | 1.85 | 1 | 1.85 | 14.37 | 0.0007 | |
| K-Ethanol | 4.84 | 1 | 4.84 | 37.55 | < 0.0001 | |
| L-2-Propanol | 0.27 | 1 | 0.27 | 2.13 | 0.1544 | |
| M-Sodium formate | 2.37E-03 | 1 | 2.37E-03 | 0.018 | 0.8931 | |
| AB | 0.26 | 1 | 0.26 | 1.99 | 0.1679 | |
| AC | 0.64 | 1 | 0.64 | 4.98 | 0.0331 | |
| AD | 1.76 | 1 | 1.76 | 13.62 | 0.0009 | |
| AH | 0.54 | 1 | 0.54 | 4.15 | 0.0502 | |
| AJ | 0.044 | 1 | 0.044 | 0.34 | 0.5636 | |
| AK | 0.041 | 1 | 0.041 | 0.32 | 0.577 | |
| BF | 2.05 | 1 | 2.05 | 15.92 | 0.0004 | |
| BL | 0.027 | 1 | 0.027 | 0.21 | 0.6531 | |
| CF | 0.41 | 1 | 0.41 | 3.16 | 0.0853 | |
| CH | 0.059 | 1 | 0.059 | 0.46 | 0.5043 | |
| DE | 1.01 | 1 | 1.01 | 7.85 | 0.0087 | |
| DJ | 1.37 | 1 | 1.37 | 10.66 | 0.0027 | |
| DK | 0.7 | 1 | 0.7 | 5.41 | 0.0267 | |
| EG | 1.25 | 1 | 1.25 | 9.67 | 0.004 | |
| EK | 0.58 | 1 | 0.58 | 4.53 | 0.0414 | |
| FG | 1.12 | 1 | 1.12 | 8.69 | 0.006 | |
| FL | 0.21 | 1 | 0.21 | 1.6 | 0.215 | |
| GJ | 0.13 | 1 | 0.13 | 1.04 | 0.3158 | |
| HM | 0.84 | 1 | 0.84 | 6.48 | 0.0161 | |
| ACH | 0.74 | 1 | 0.74 | 5.72 | 0.023 | |
| Residual | 4 | 31 | 0.13 | | | |
| Cor Total | 35.25 | 63 | | | | |

# Normal plot of residuals

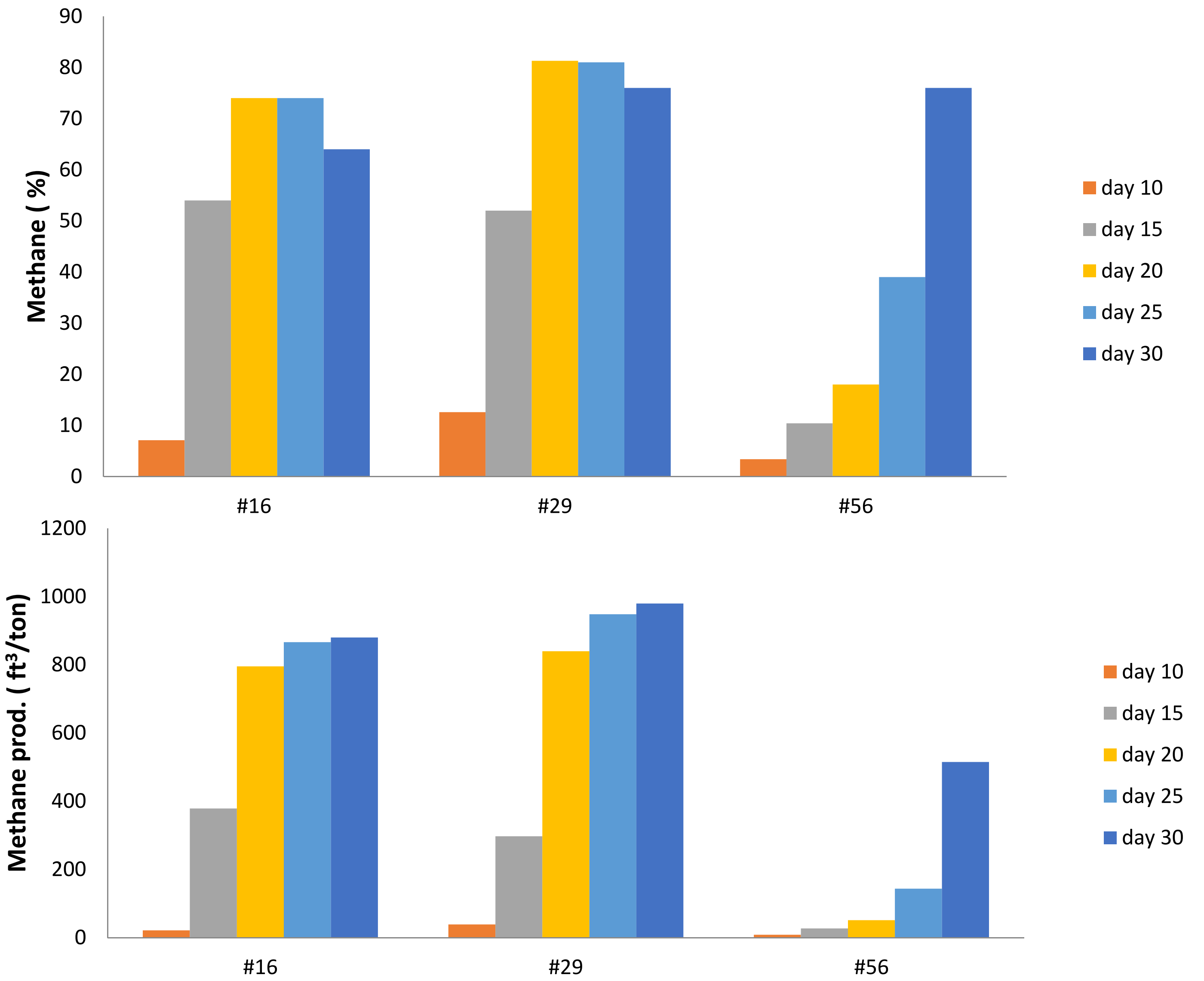


# Current status

An optimization experiment is underway.

1. Temperature range: 28-32$^{o}$C
2. Particle size: < 0.074 mm
3. Coal loading: < 700 g/L
4. Ethanol content: 100-300 mM

# Time series data



# Current challenges

*Ex situ*:

1. How to sustain methane release over time?
2. How to maximize coal conversion?

*In situ*:

1. How to deliver the nutrient solution?
2. How to determine the time interval for nutrient supplementation?

Acknowledgement

Department of Energy: DE-FE0024126

- Dr. Satya Harpalani
- Dr. Stephen Park
- Dr. Chunjie Xia
- Ji Zhang
- Rohit Pandey

# Optimization, Scale-up, and Design of Coal-Dependent Methanogenesis in Preparation for *in situ* Field Demonstration

Prof. Matthew W. Fields
Center for Biofilm Engineering
Energy Research Institute

Assit. Prof. A. Phillips
R. Hiebert
Prof. L. Spangler
Prof. A. Cunningham
Prof. R. Gerlach

Dr. W. Orem, USGS
Dr. B. Lomans, Shell Global

Morgantown, WV-August 2015

# Project Goal and Objectives

1 y project to mature *in situ* bio-gasification technologies for use in future field tests.

- Enhance traditional CBM production rates
- Shorten time needed to re-generate CBM fields
- Mitigate environmental impacts
- Increase longevity of existing infrastructure
- Provide essential data for resource estimations

Specific Objectives:

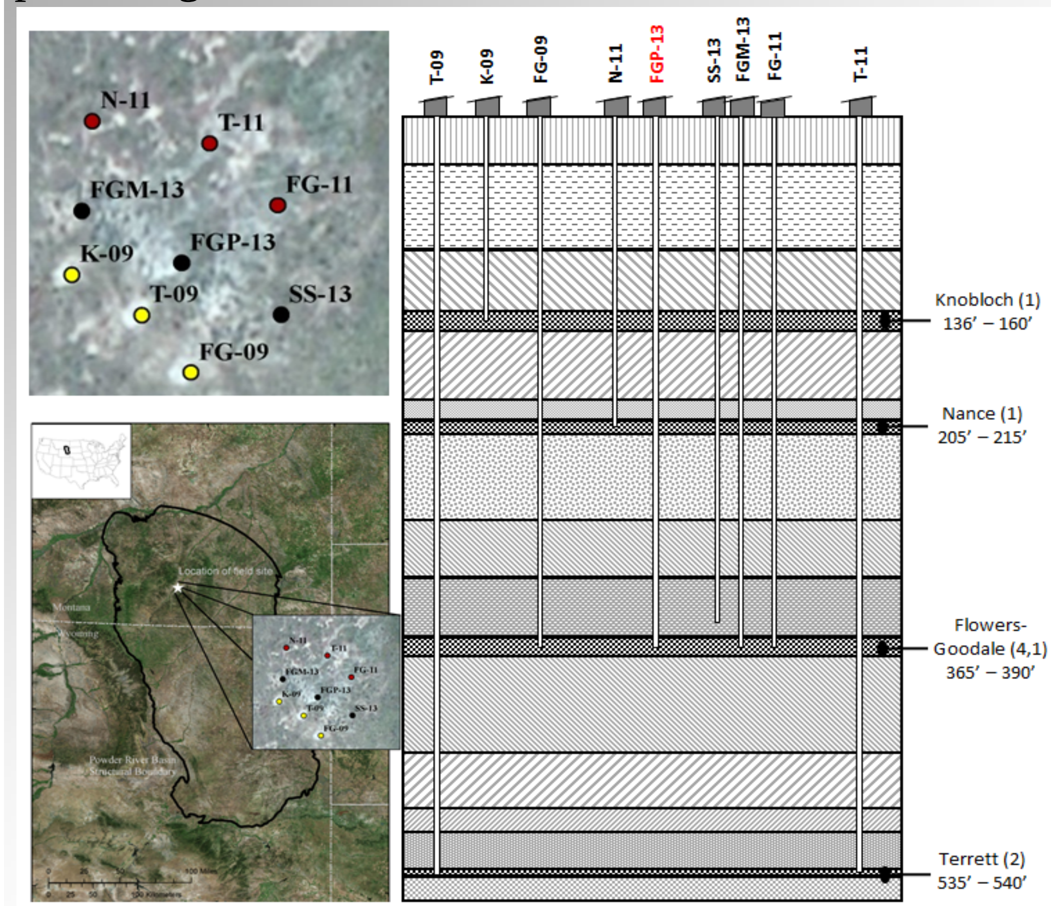
**Objective 1**. Evaluate time-delay to methane production post-stimulation during meso-scale injections

**Objective 2**. Complete site characterization

**Objective 3**. Evaluate and design potential field demonstration and economic analysis at the USGS Birney Test Site in the Powder River Basin

# Test Design Program with On-going Research & Collaboration

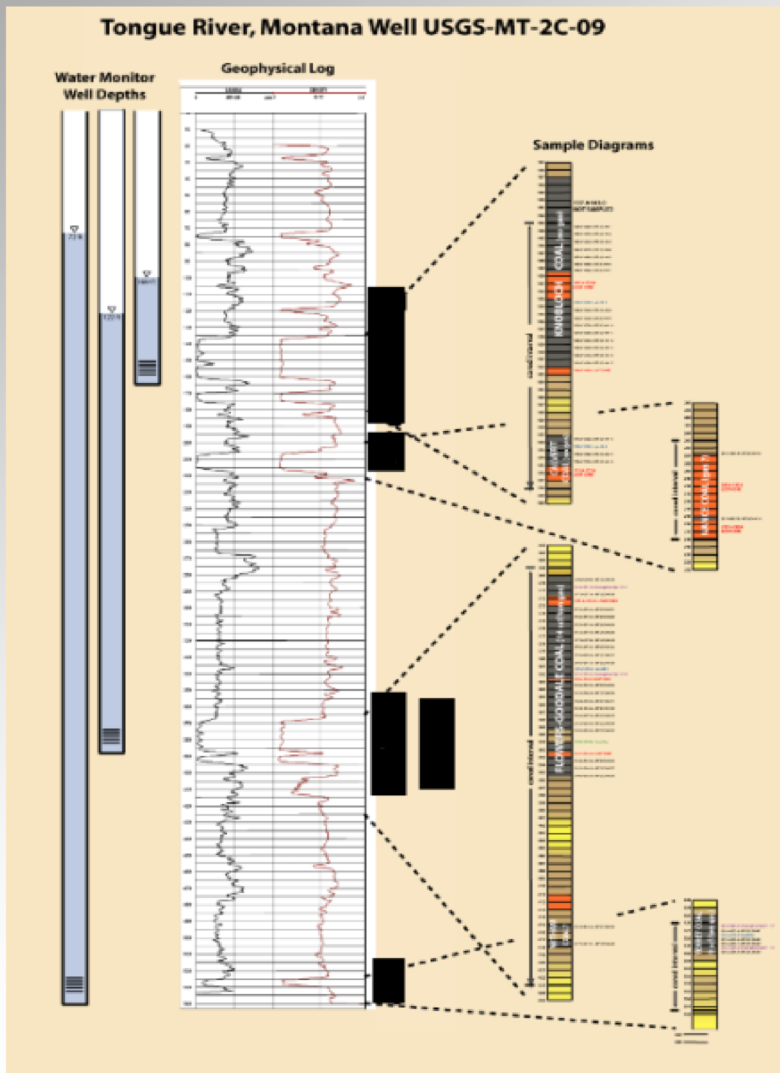
**Target field site** (USGS Birney Test Site) already under development by USGS in the PRB in collaboration with MSU. Drilling, logging, coring, and hydrologic tests have already taken place providing a data rich environment for the field test design.





Drilling, logging, coring, and hydrologic tests have already taken place providing a data rich environment for the field test design.

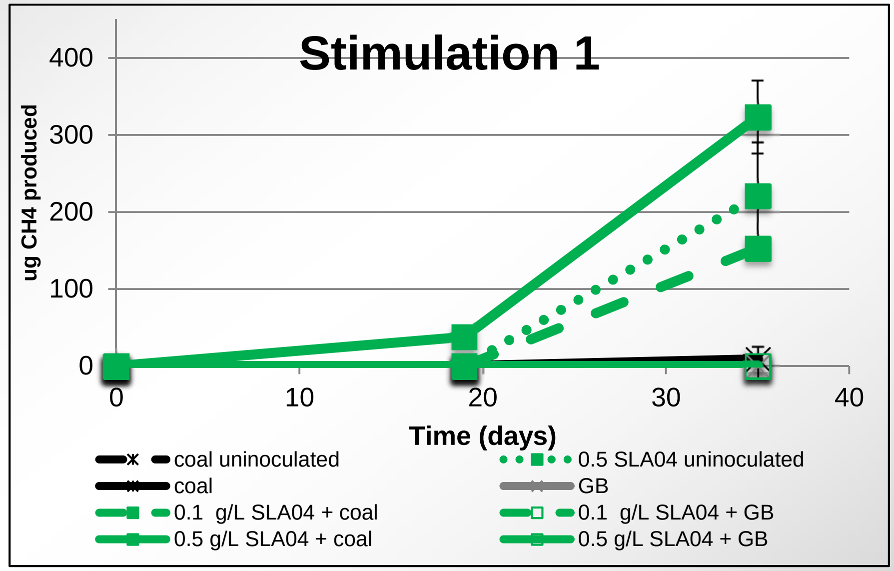
# Microbiology

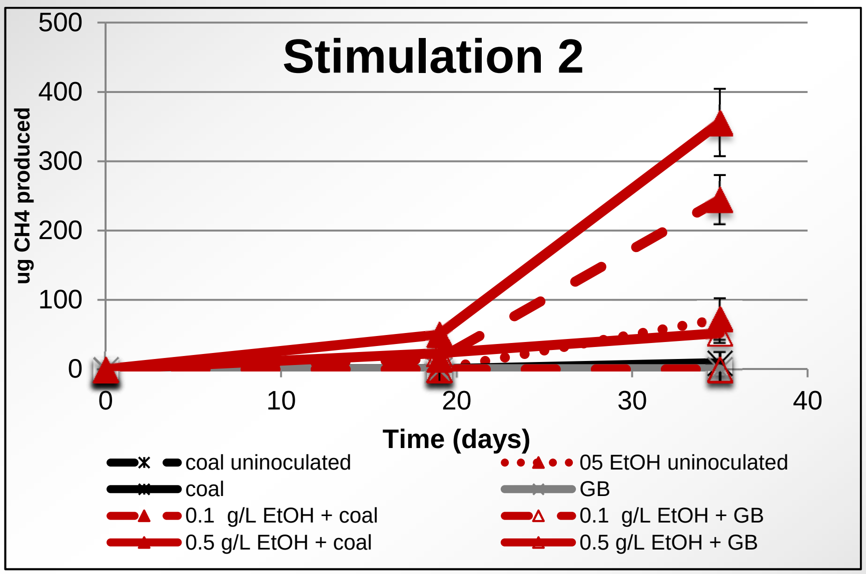


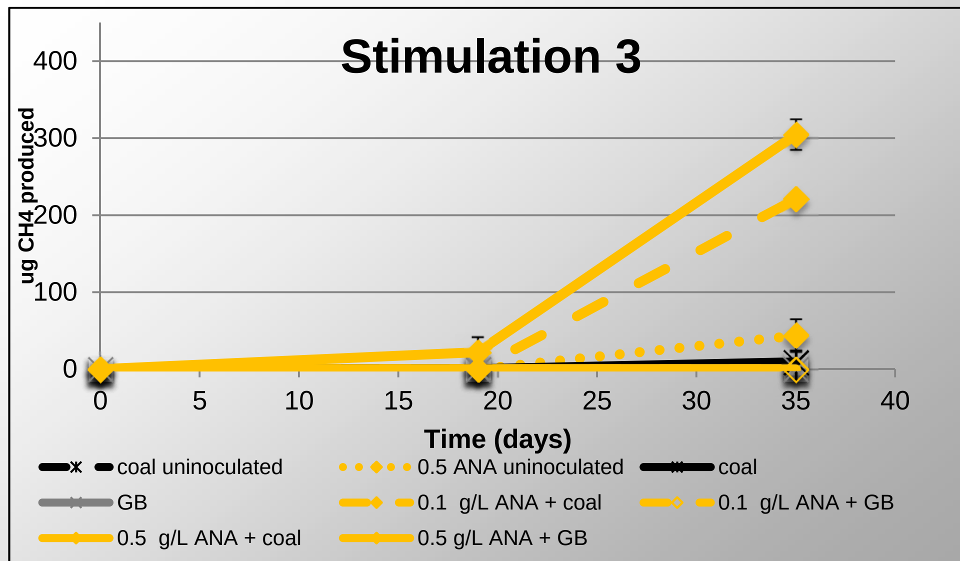

**Formation water, coal, and microbial communities extracted from coal surfaces from the target field site**


VWR
KIMTECH

# Long term bench-scale enrichments that display coal-dependent methanogenesis with various stimulants

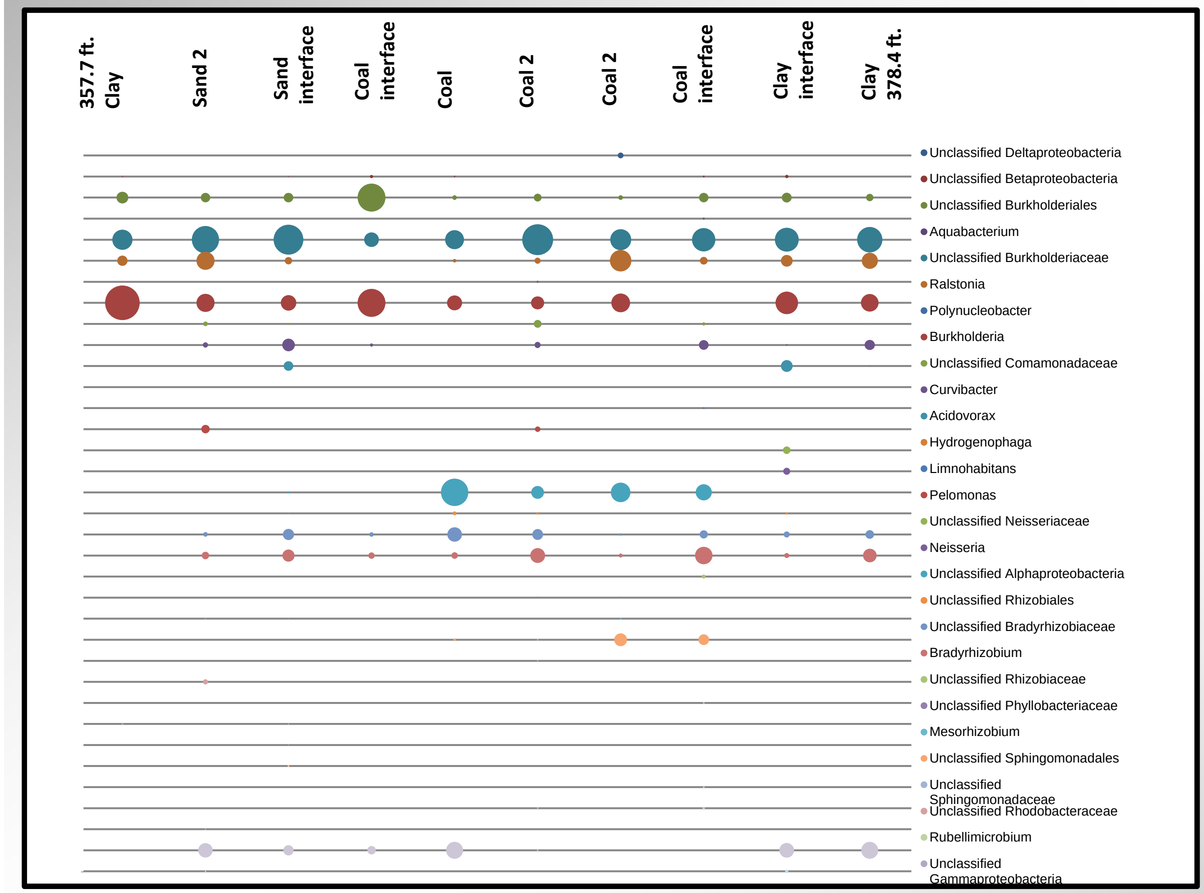



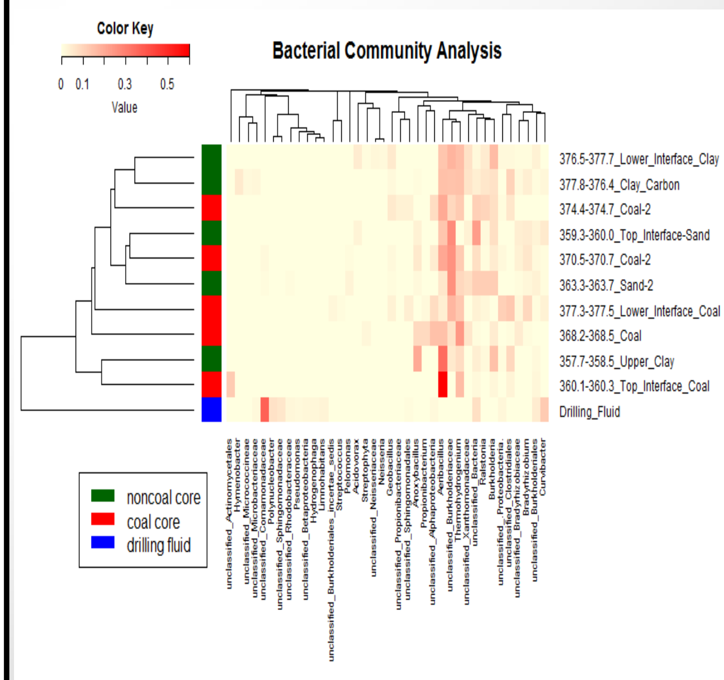



# Microbial Genomics

In addition to collaboration with the USGS, we are collaborating with Shell Global Solutions International BV. Shell will perform metagenomic sequencing on coal samples obtained from the USGS field site thereby providing extensive characterization of the microbial communities in the coal beds targeted for later field tests.



# Bench- and Meso-Scale Pressure Vessels

High pressure flow through test systems that allow for the study of cores at the 2.5 cm, 5 cm, and 75 cm diameter scales. The meso-scale high pressure vessel is equipped with a custom designed switchboard that allows for the sampling of fluids from the vessel while maintaining the pressure.

# Porous Media Reactor

We will use a porous media reactor constructed of a stainless steel top and bottom plate and a stainless steel mesh screen that surrounds the circumference of the reactor.

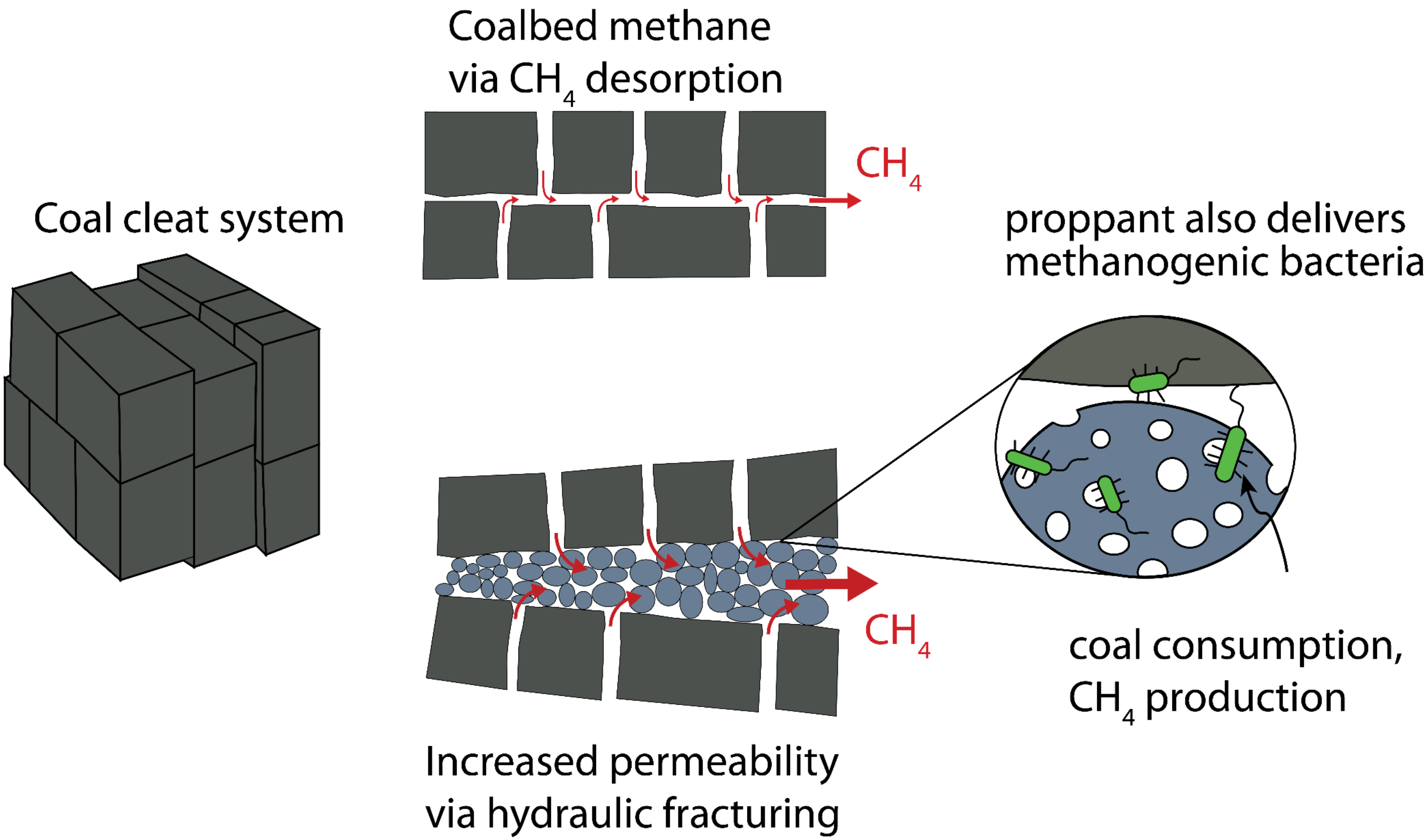
# Ceramic Proppant Design for In-Situ Microbially Enhanced Methane Recovery

*Award DE-FE0024088*

Taylor D. Sparks
Assistant Professor of Materials Science and Engineering
University of Utah

8/11/2015 DOE C&CBTL Workshop, Morgantown WV

# Microbes can be used to enhance coalbed methane recovery




Microbes can either

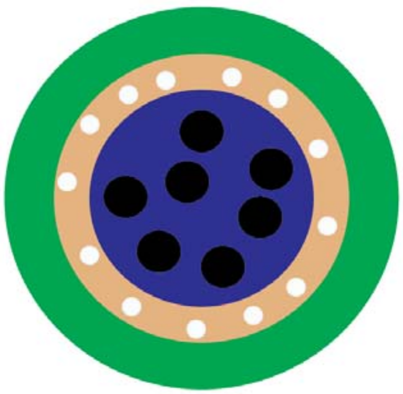
(1) consume coal reservoir to generate more methane, or

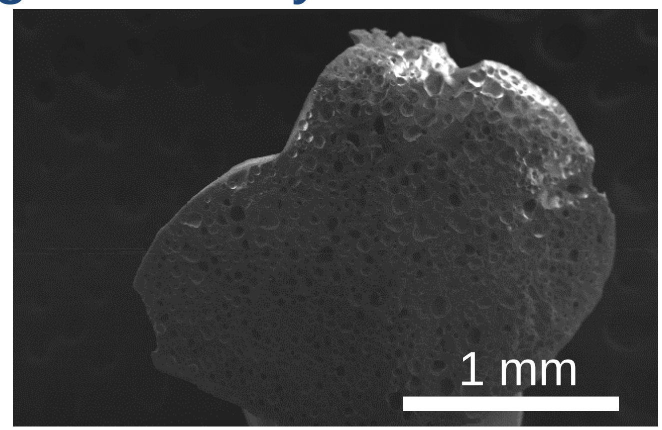
(2) remove coal fines in proppant bed to enhance conductivity

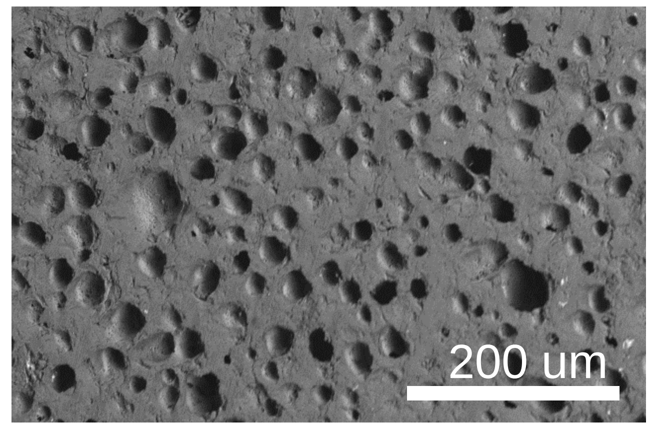
# Proppant must be redesigned for low density and microbial loading

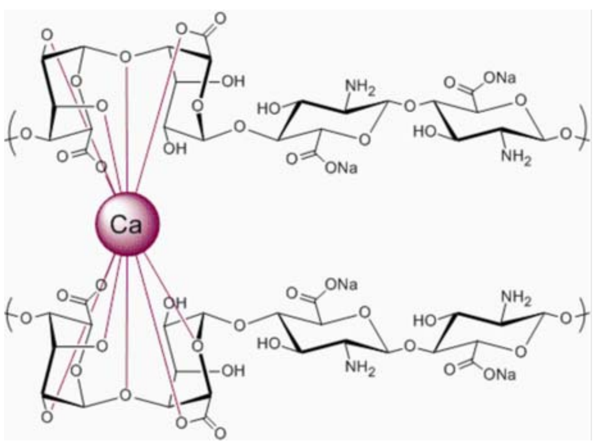
## Combined high temperature sinter / reduction step

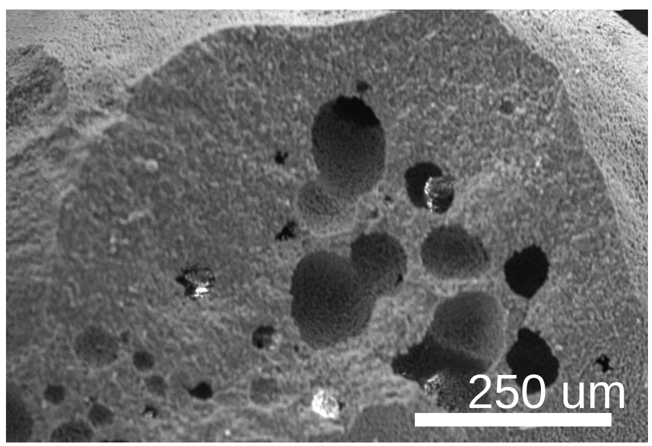
- 35-70  diameter inner pores
- 5-10  diameter outer pores
- Bulk density was 1.5 g/cm$^3$
- Strength testing underway

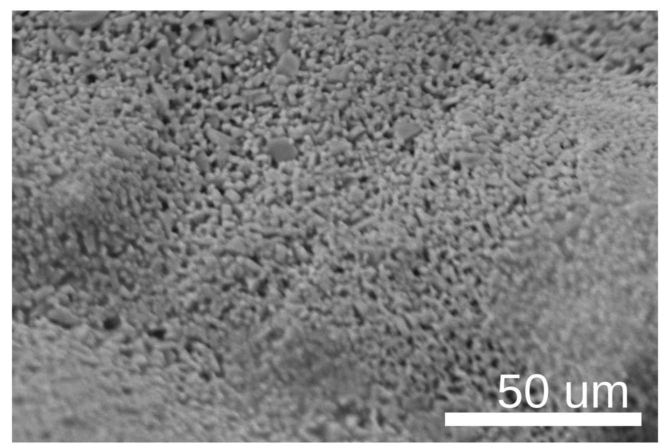




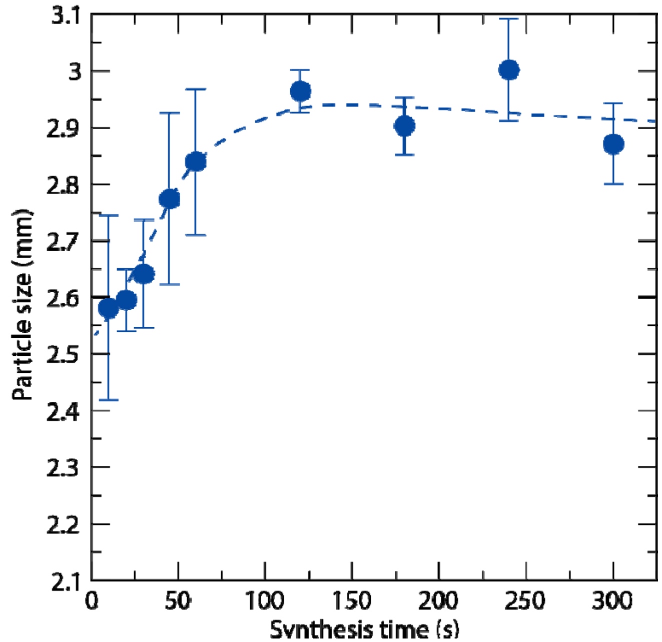



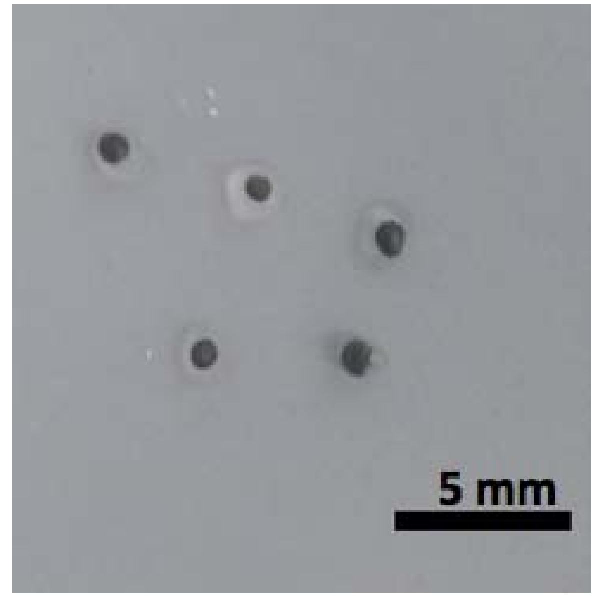



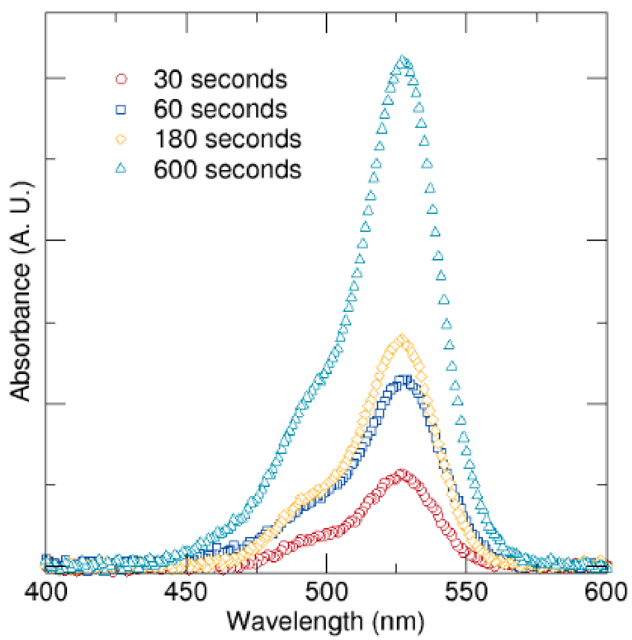



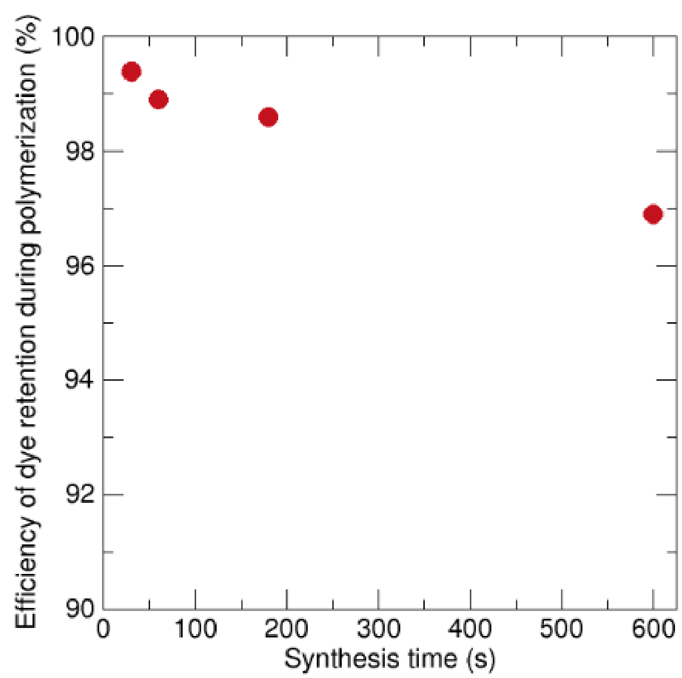



# Encapsulation process retains molecules impregnated into proppant

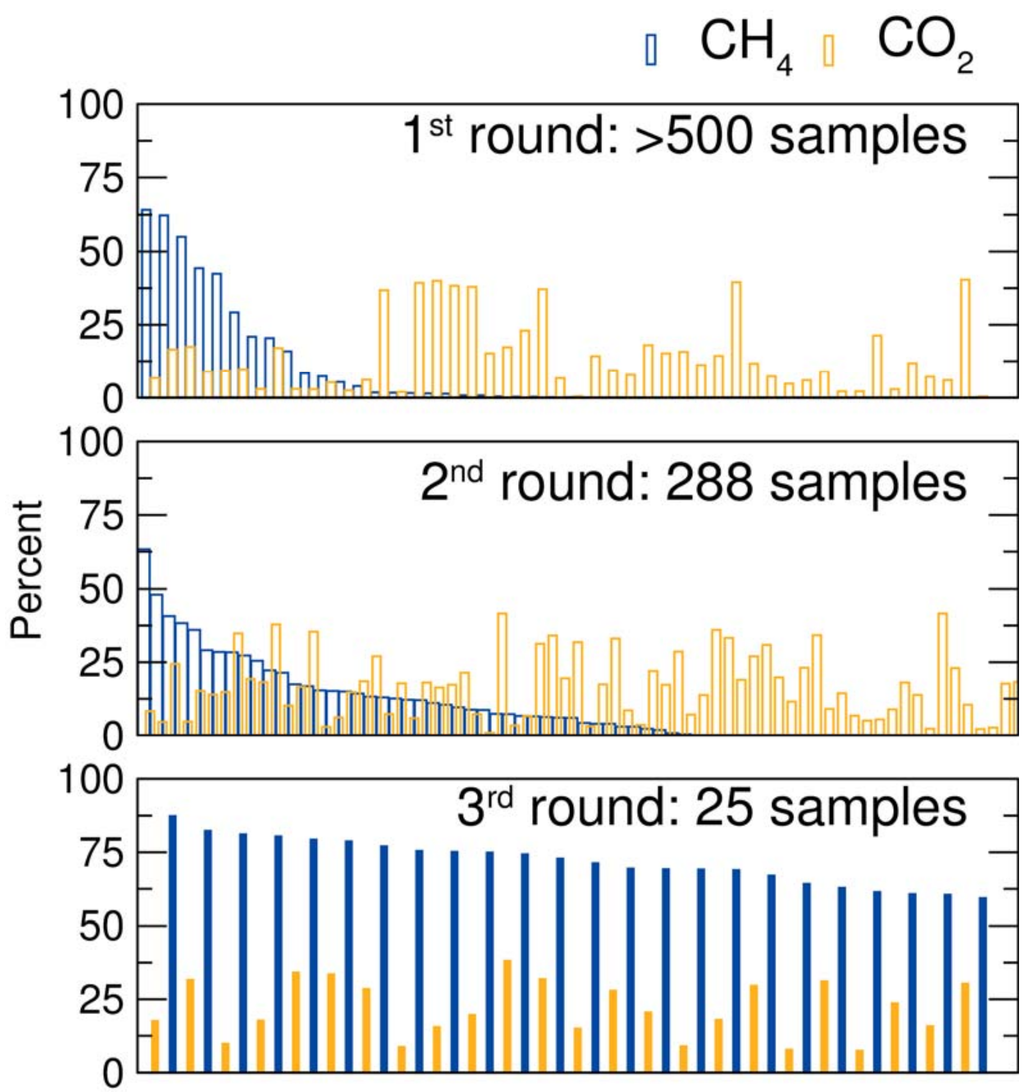


# Hundreds of microbial experiments performed to find optimum




Controlled variables:

- Bacteria source (14)
- Initial nutrients (6)
- Coal source (4)
- Growth conditions (3)

Statistical analysis applied to determine which variables had highest impact.

Best consortia have been isolated and cultured for proppant impregnation and reactor testing.

# Initial results suggest microbial approach is feasible

Synthesis of lightweight proppant with hierarchical porosity is possible with inexpensive materials and scalable process.

Polymer encapsulation was successful using inexpensive lactate alginate polymerization. Thickness and dye retention was calibrated.

Microbial consortia with high methane yield have been identified.

Optimal microbial nutrients, initial and final growth conditions identified for four common coal sources.

**To be done still…**
Strength and conductivity testing with proppant and encapsulated proppant.

Bacterial loading into proppant and time-dependent methanogenesis measurements.

Reactor level proof-of-concept demonstration.

NETL

# Questions?

# Biogasification – Field Site Deployment Goals and Challenges

August 11th, 3:00-5:00 pm
Ballroom 4

U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory