Development of a moving-bed carrier for stimulating direct interspecies electron transfer for improving anaerobic digestion

6th International Conference on

Sustainable Solid Waste Management

June 13 - 16, 2018

The Cultural Center former Ursuline School,

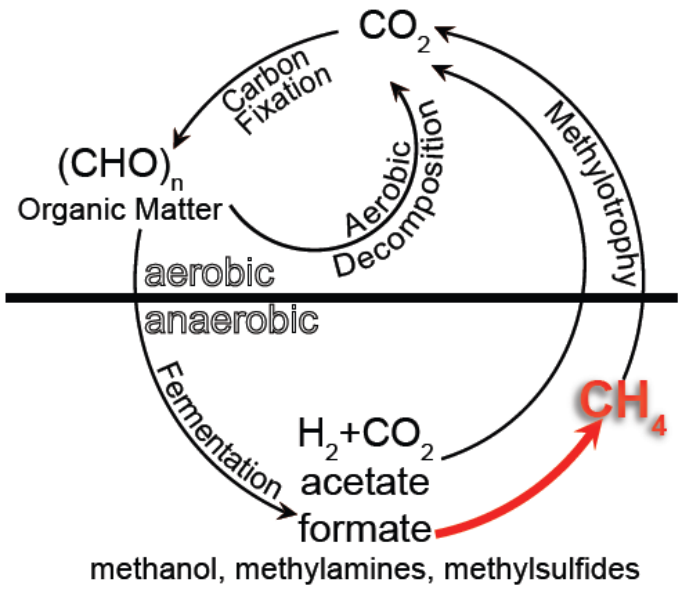
Naxos Island, Greece

HEE-DEUNG PARK

SCHOOL OF CIVIL, ENVIRONMENTAL AND ARCHITECTURAL ENGINEERING

KOREA UNIVERSITY

Importance of Methanogenesis

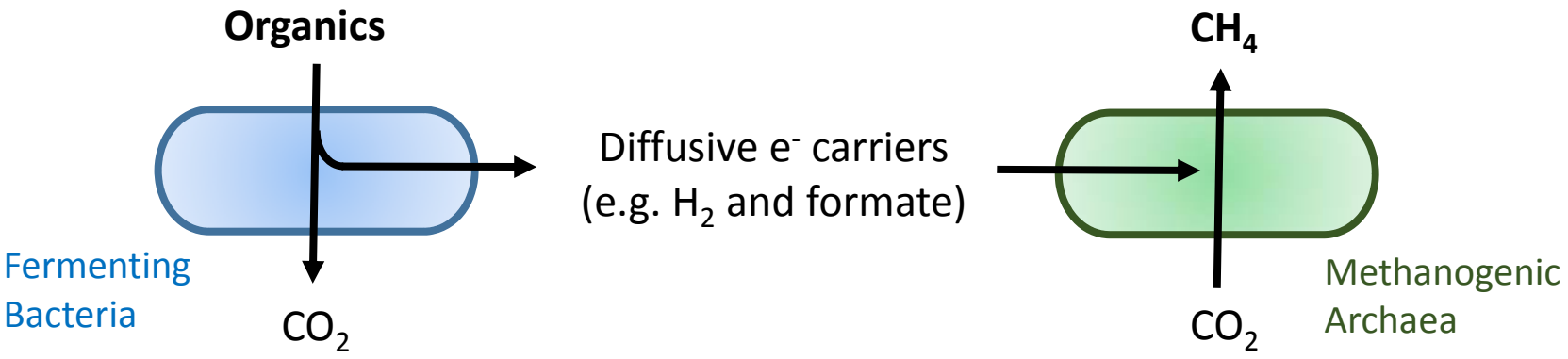


(Source: http://unlcms.unl.edu)

(Source: http://msutoday.msu.edu)

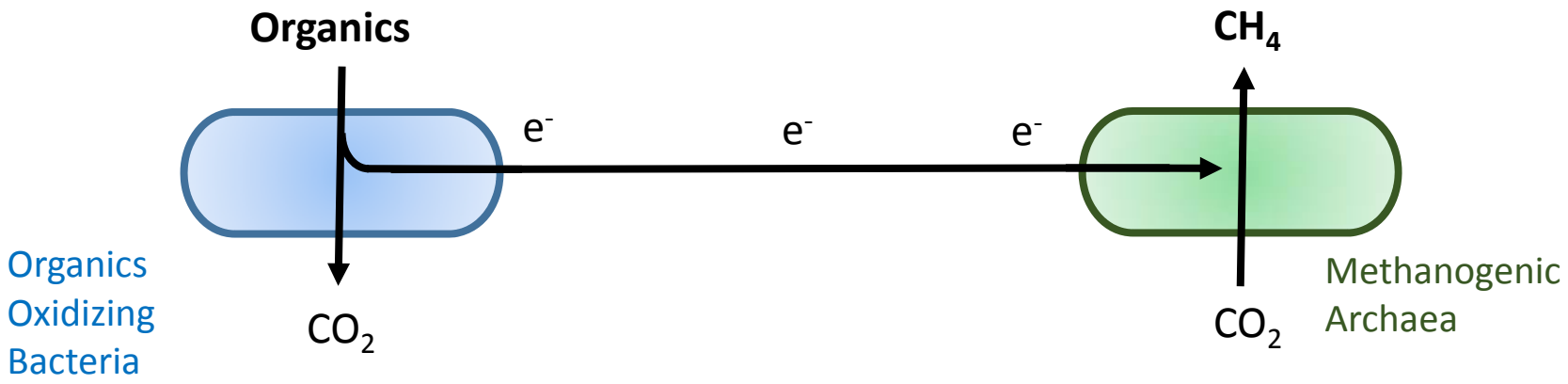
- Methanogenesis refers to methane formation by methanogenic archaea under anaerobic condition
- Methanogenesis plays roles in global carbon cycle and waste treatment (bioenergy production) by decomposing organic matters

Principles of Methanogenesis



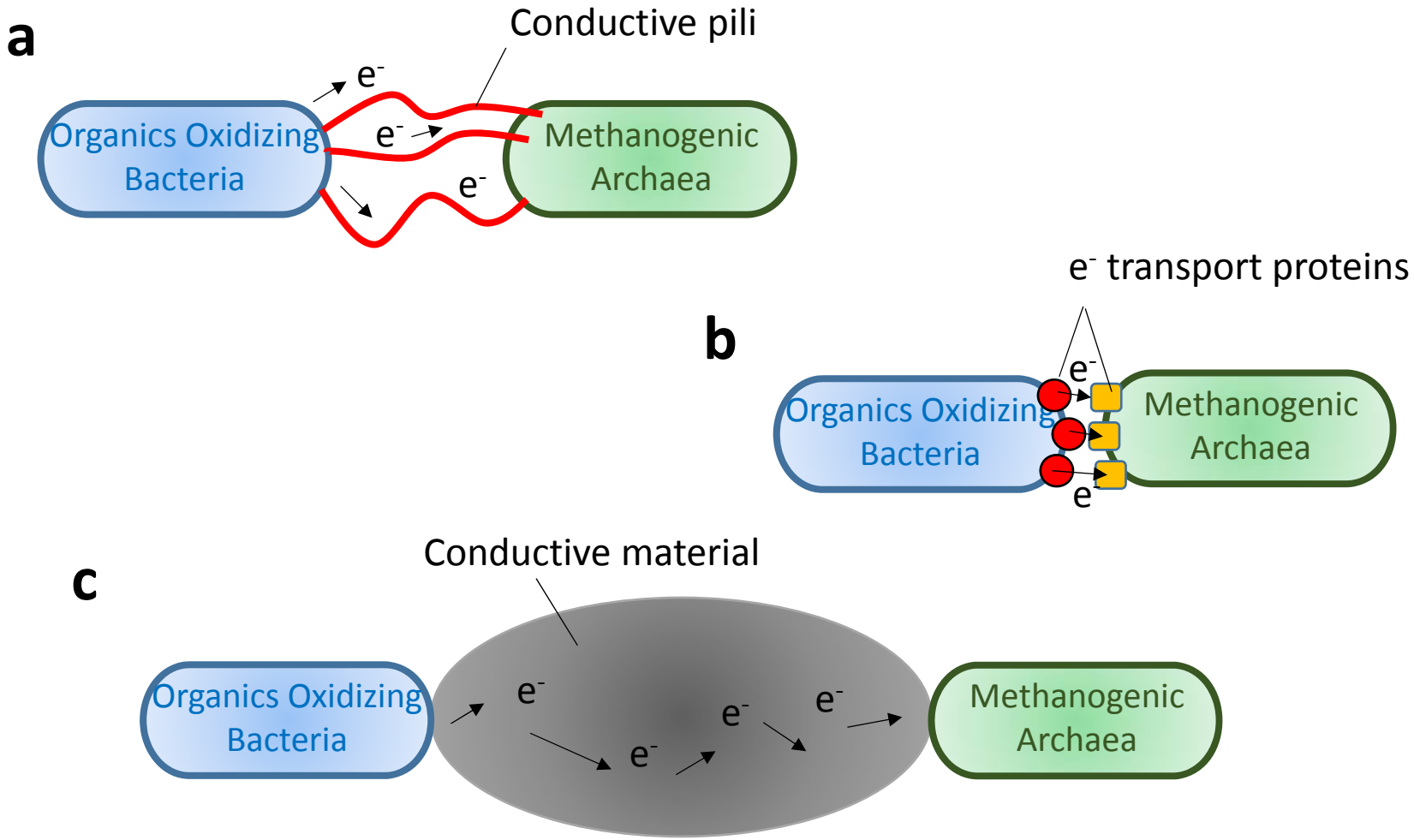
- Methanogenesis can be explained as electron transfer deposited in organics to methane by fermenting bacteria and methanogenic archaea (i.e. interspecies electron transfer, IET)
- IET occurs via diffusive electron carriers (e.g. H_2 and formate)

Direct Interspecies Electron Transfer (DIET) for Methanogenesis



- DIET removes some steps associated with hydrogen production and consumption, which lead to more energy efficient compared with IET via diffusive electron carrier (Lovley 2011, Energy Environ Sci 4)
- Electrical conductance is more efficient than molecular diffusion of electron carriers

How is DIET Possible?



Modification of Lovley 2017, Annual Rev. Microbiol.

Granular Activated Carbon can Facilitate DIET in Methanogenesis

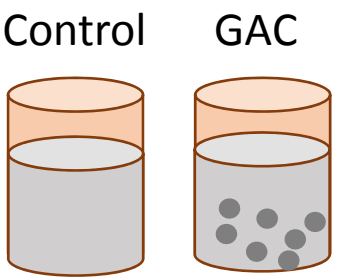
- Excellent adsorbent
- High surface area
- Good electricity conduit

- GAC supplementation improved stability and performance in anaerobic digestion due to adsorbing toxic chemicals and attaching microbes (Aktaş and Çeçen 2007, Int Biodet Biodeg 59; Liu et al. 2012, Energy Environ Sci 5)
- GAC facilitated DIET in methanogenesis (Kato et al., 2012, Environ Microbiol 14; Liu et al. 2012, Energy Environ Sci 5)

Research Questions

- Is it possible to generate a condition of DIET by supplementing GAC in anaerobic reactors for wastes treatments?
- What microbes can be enriched in the reactors?
- What are the potential benefits of DIET in anaerobic digestion?

Experimental Approach



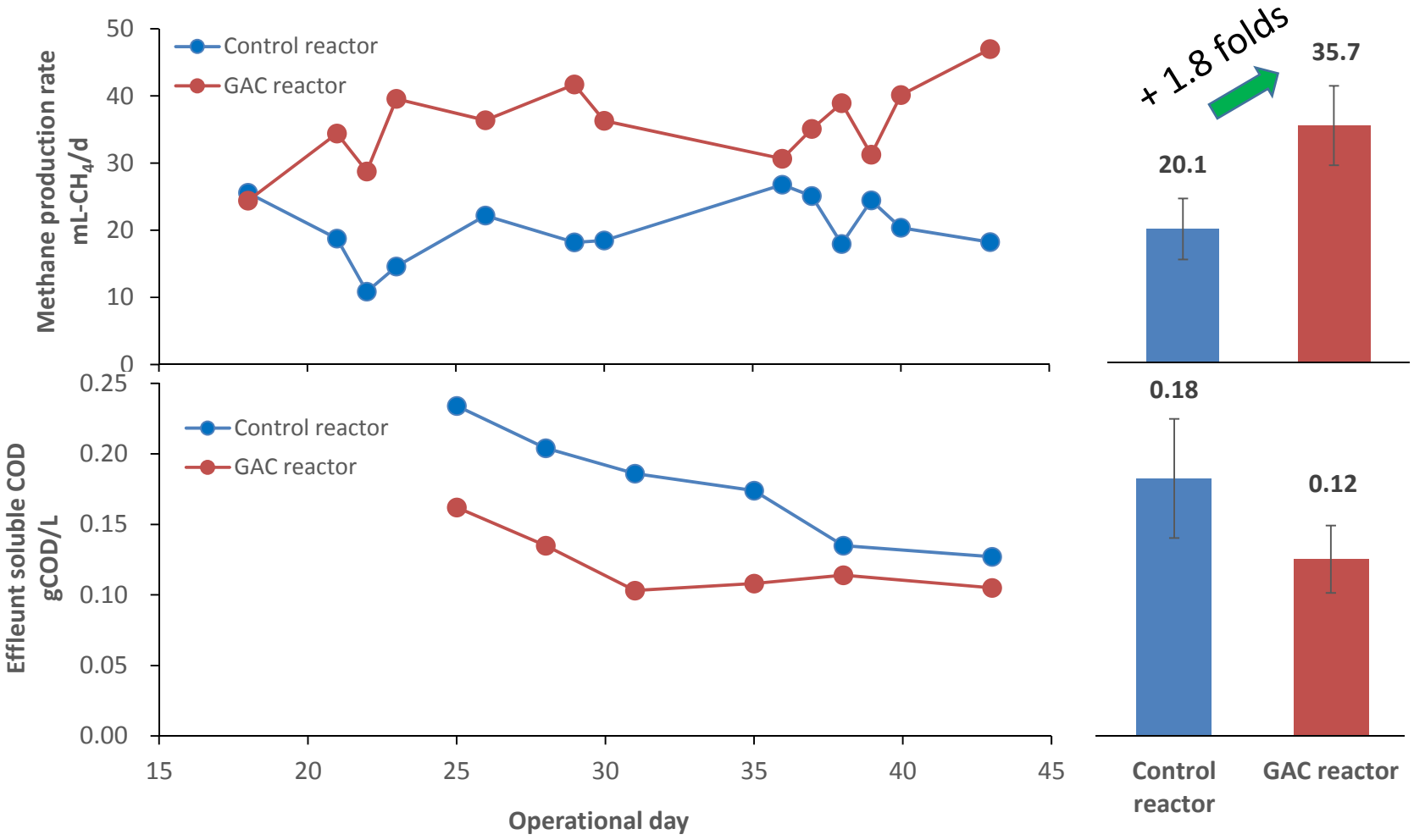
Continuous flow and batch
Reactors fed with acetate

Reactor performance (control vs. GAC reactors)
- COD reduction
- Methane production rates
- Relative contribution (suspended vs. GAC biomass)

Microbial community analyses (16S rRNA gene)
- Bacterial populations
- Archaeal populations
- Network analysis

Bioelectrochemical analyses
- Anodic current generation
- Cathodic current generation

GAC Supplementation Produced More Methane

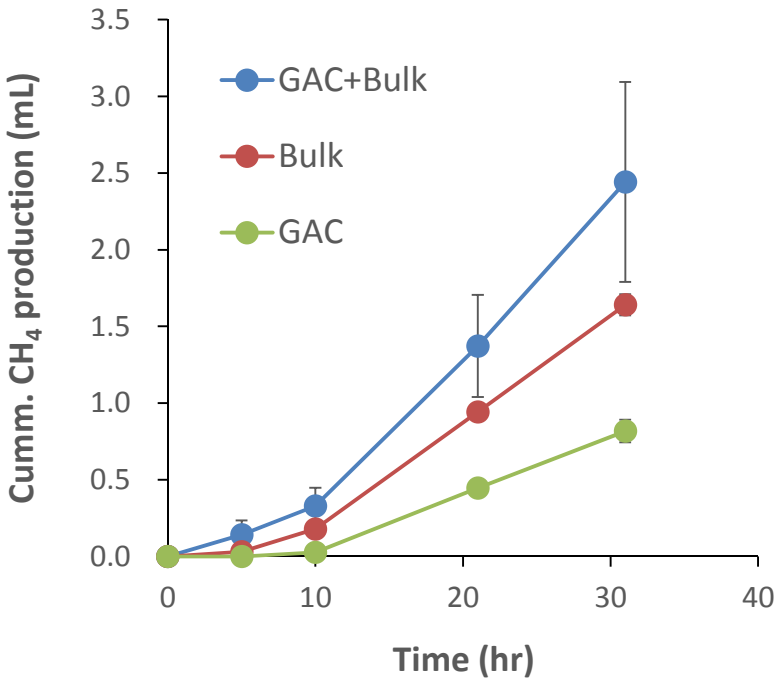


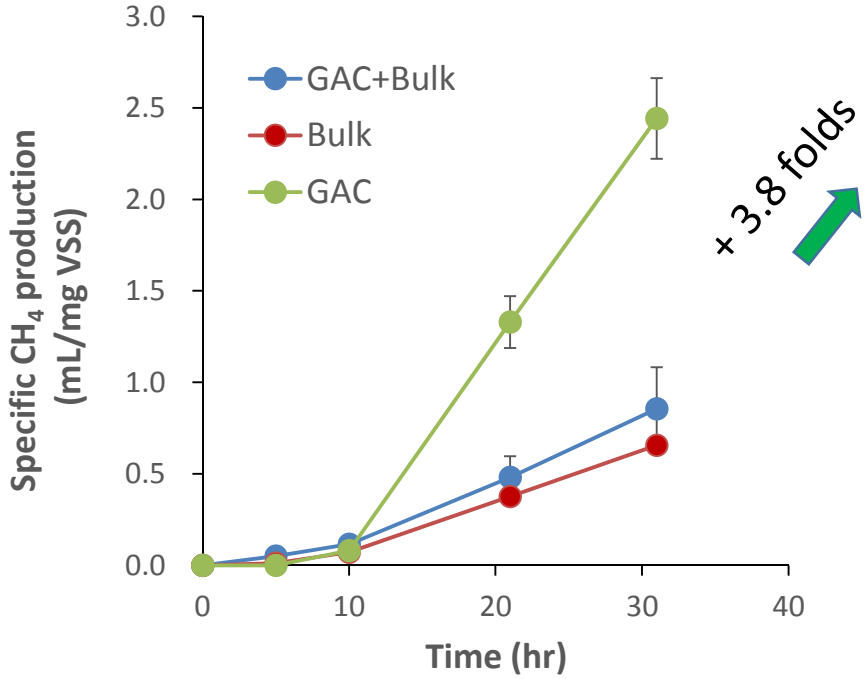
GAC Biomass Showed Higher Methane Production


GAC+Bulk

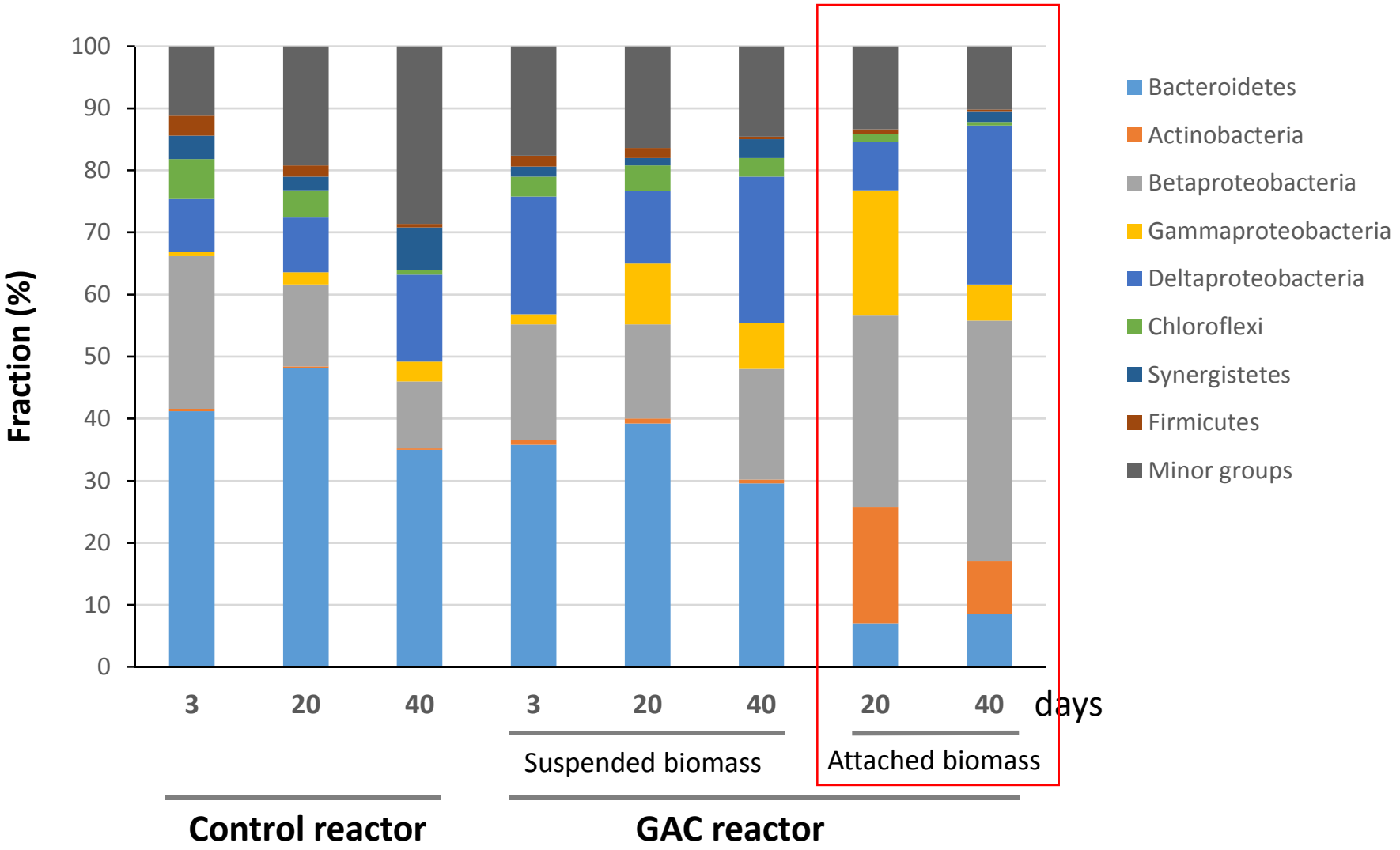

Bulk


GAC

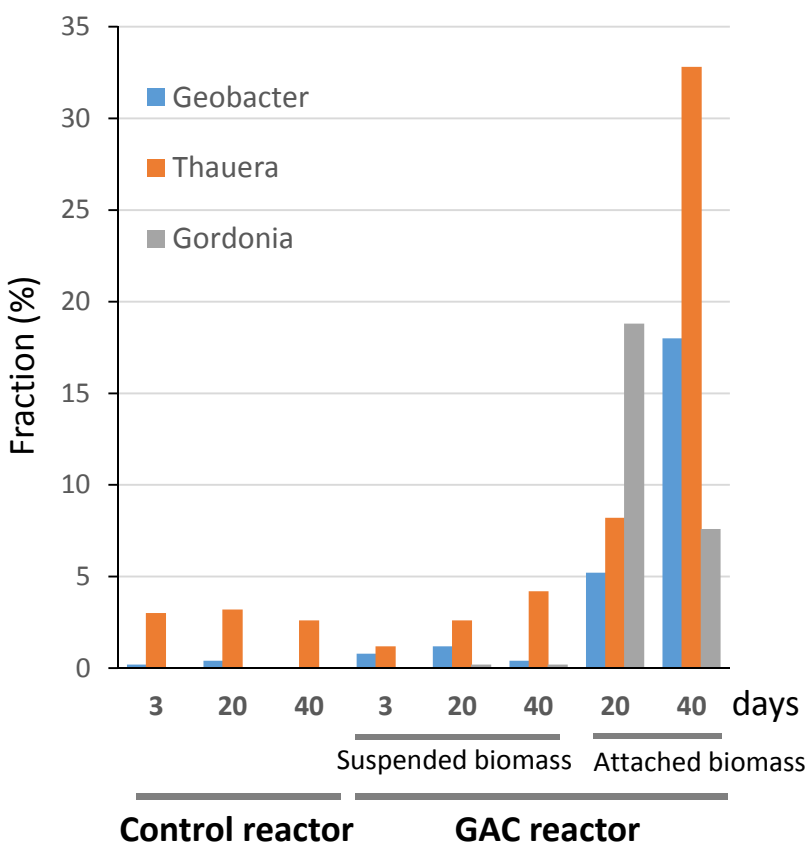


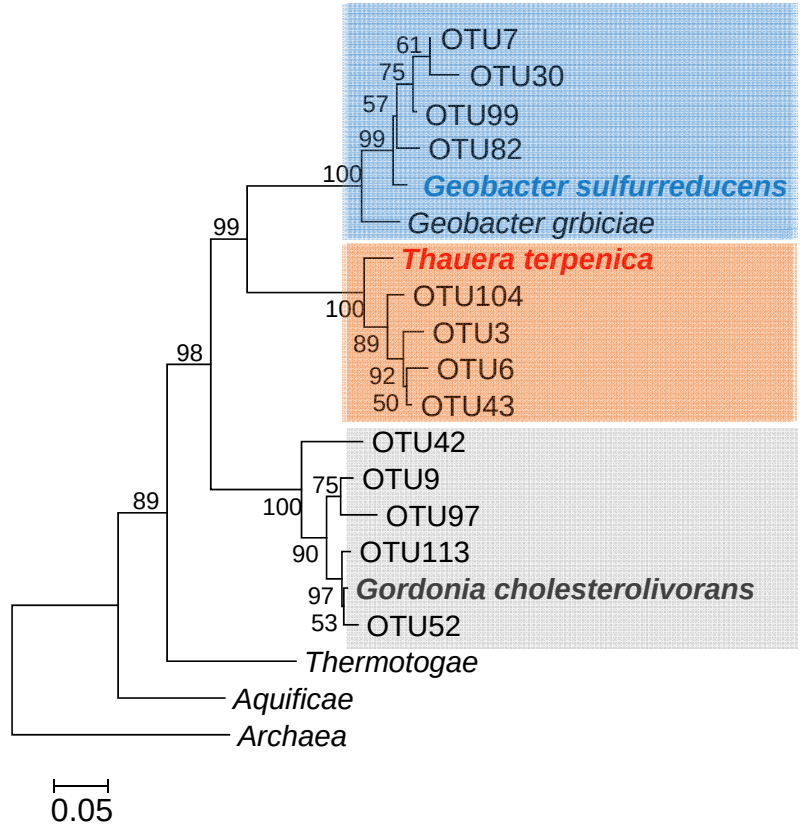


Bacterial Community Shift

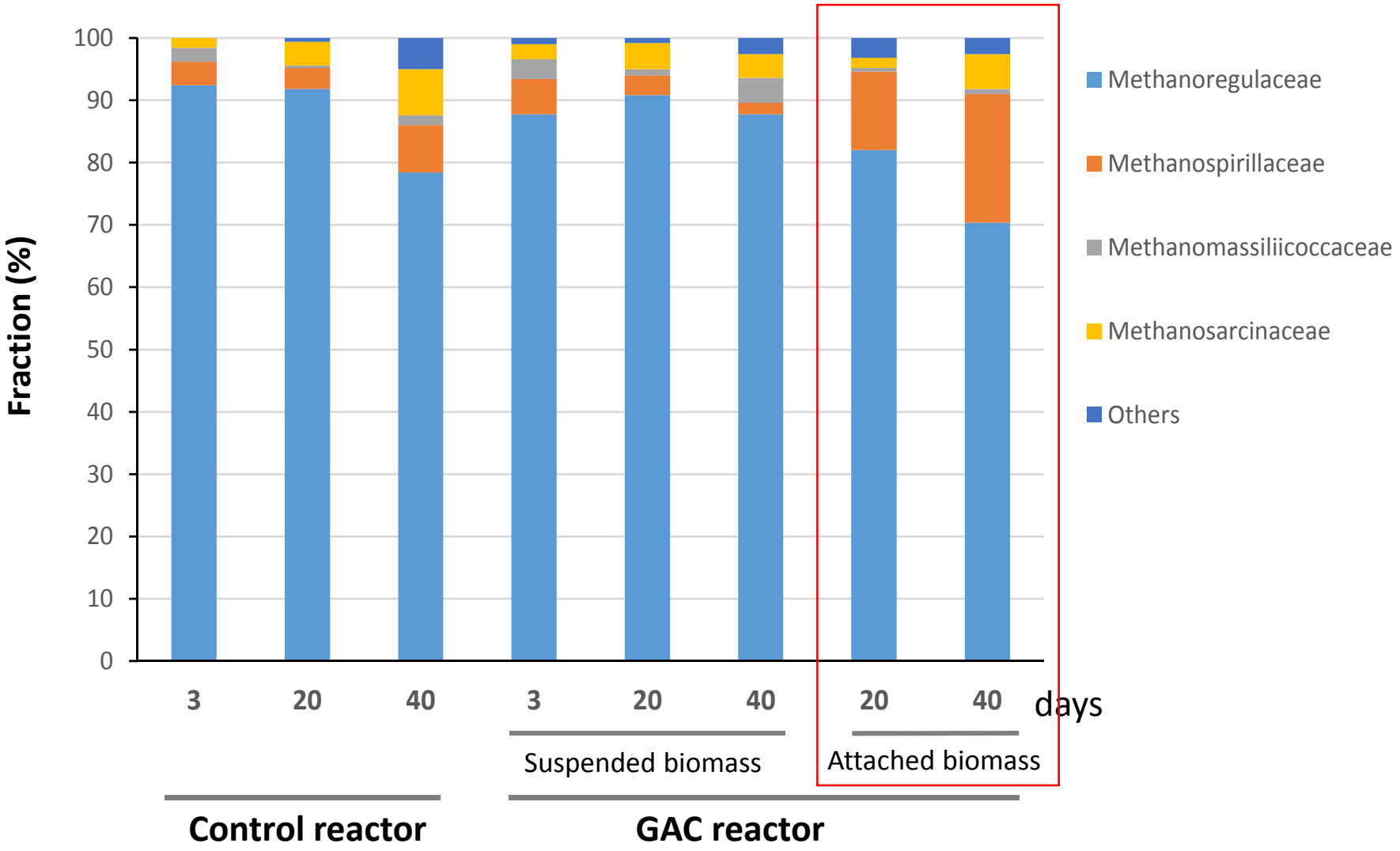


GAC Enriched Geobacter, Thauera, and Gordonia

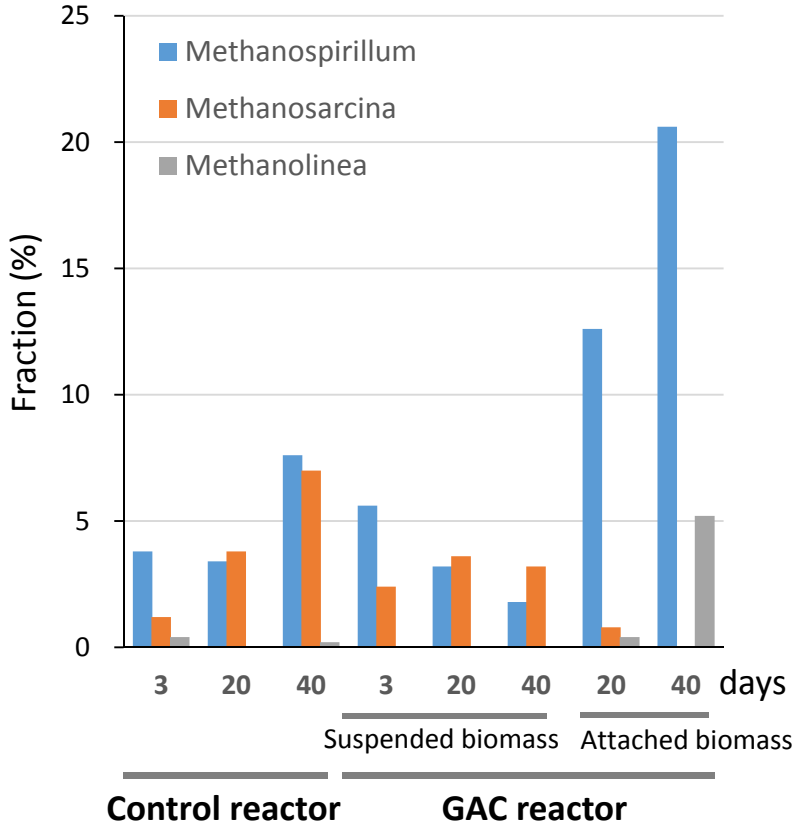


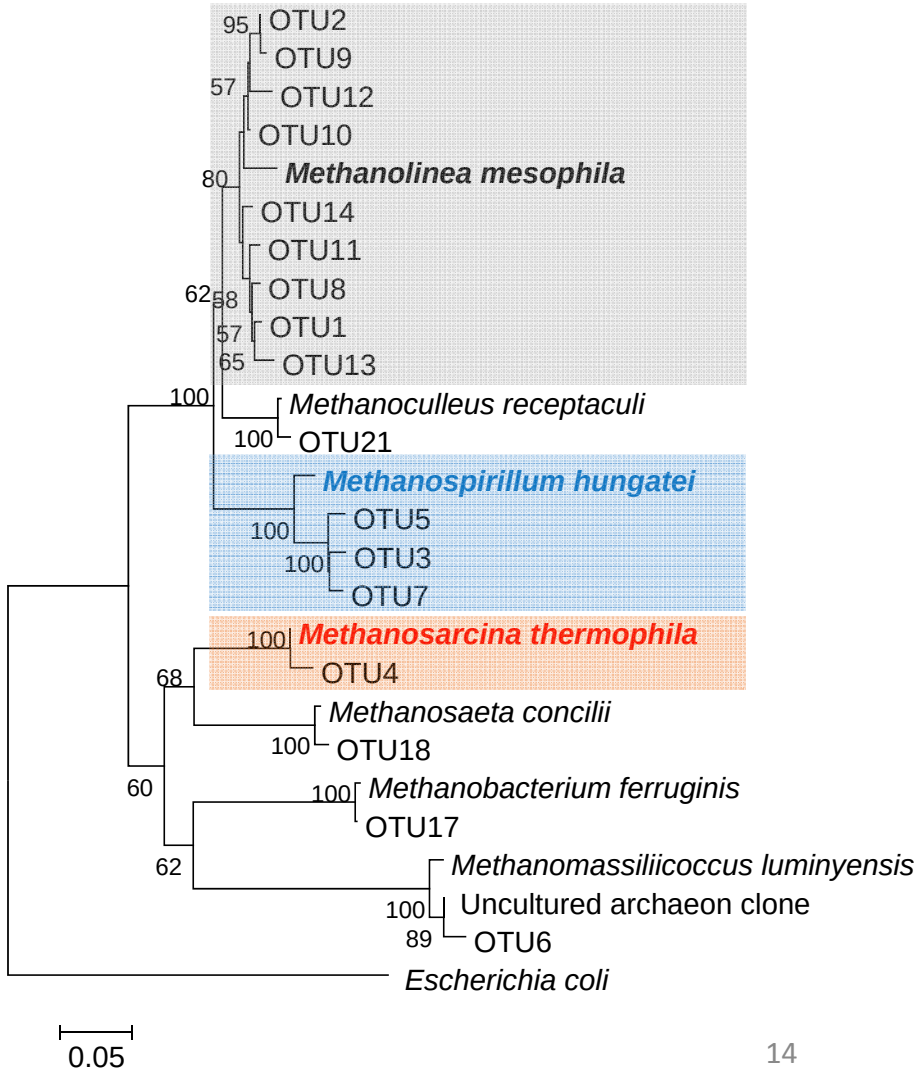


Archaeal Community Shift



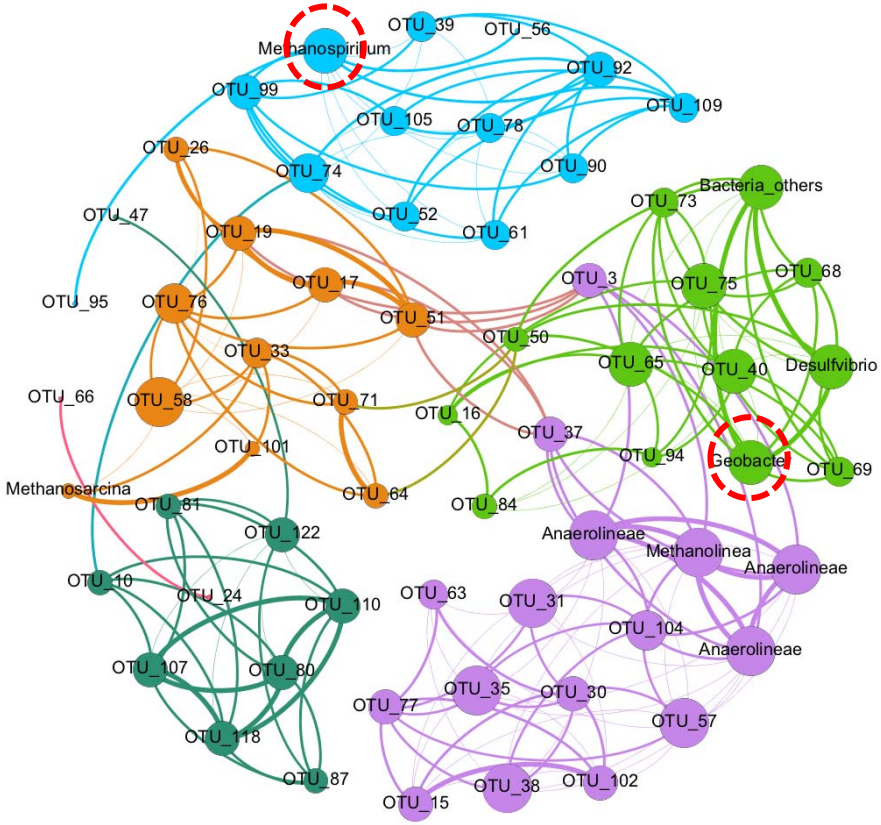
GAC Enriched Methanospirillum and Methanolinea



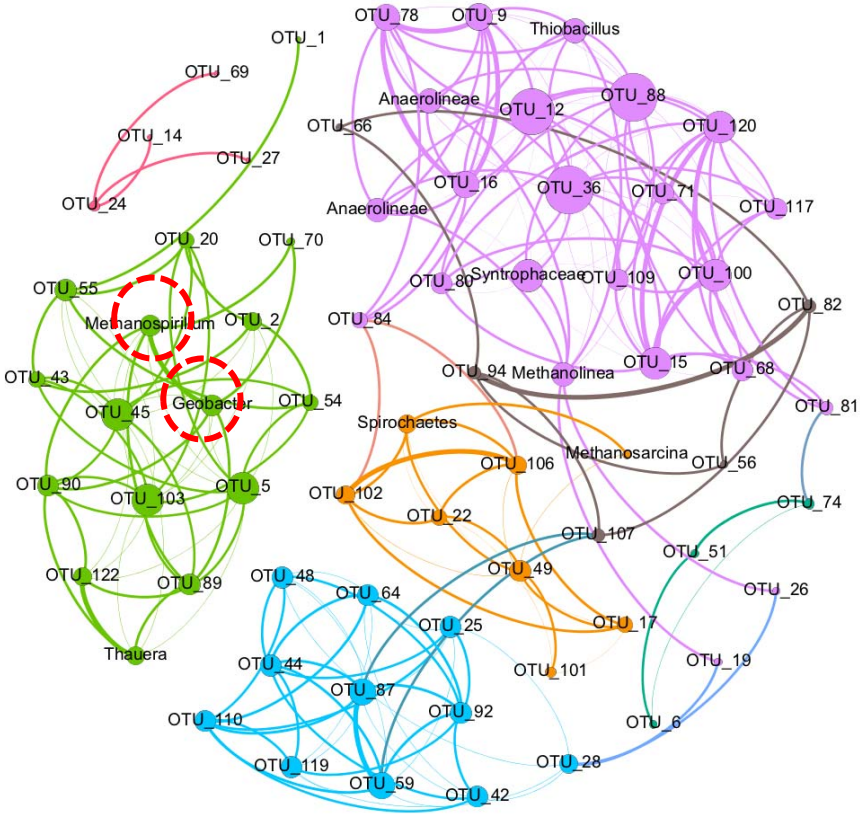


Network Analysis demonstrates a Non-random Co-occurrence

Control reactor

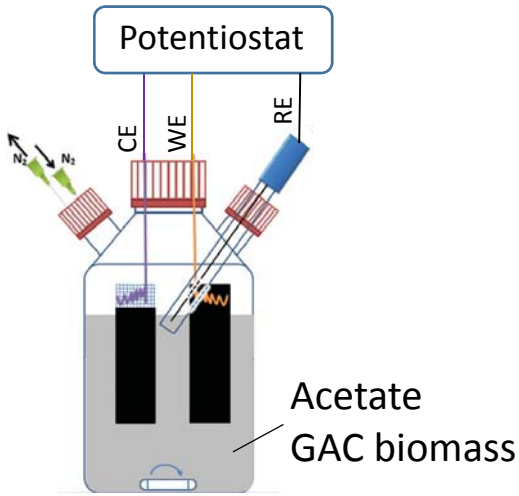


GAC reactor

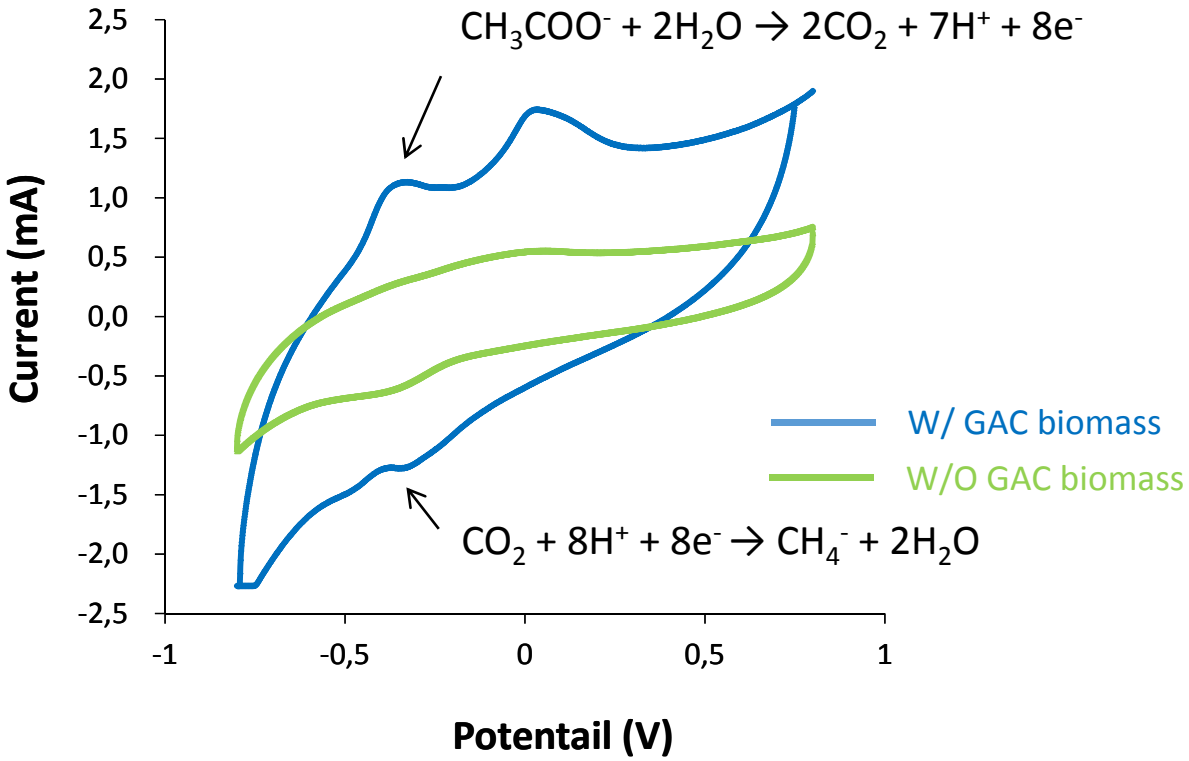


97% cutoff 122 OTUs
Rho > 0.6, P < 0.05

Cyclic Voltammogram Suggests DIET by GAC Biomass



three-electrode cell



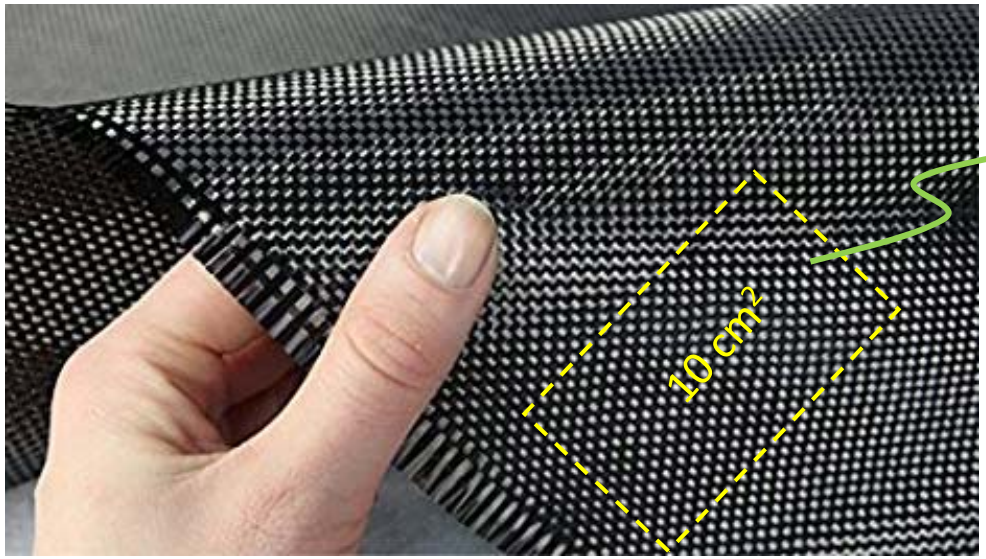
- GAC biomass generated anodic current at - 0.36 V and cathodic current at - 0.32 V, respectively

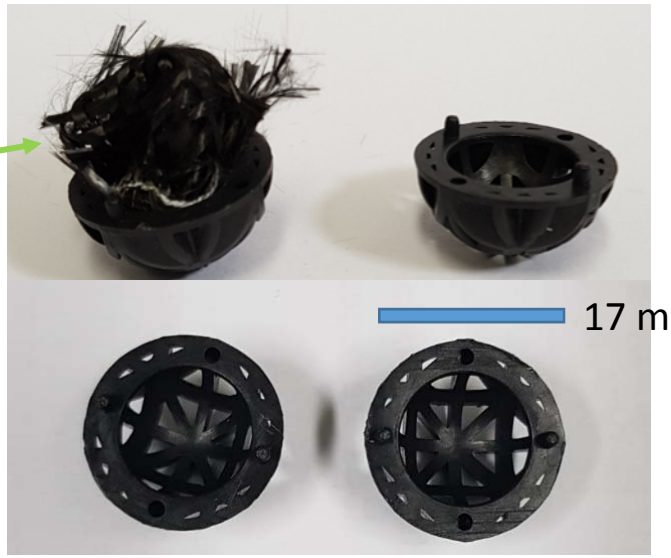
More Research Questions

- Can we hold conductive materials for DIET in a bioreactor without loss of them?

- Can substrates other than acetate also stimulate DIET?

Development of a Moving-Bed Carrier

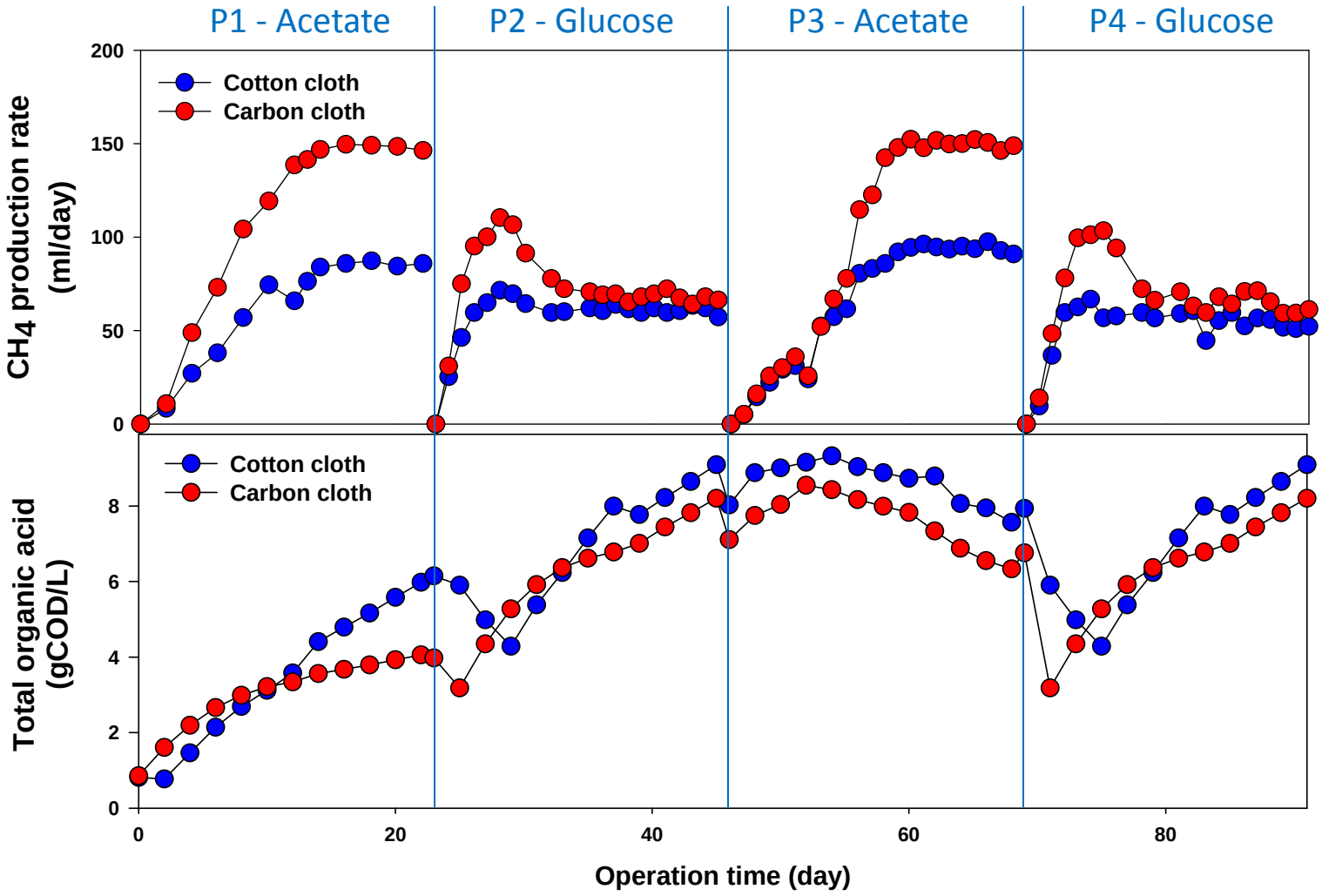




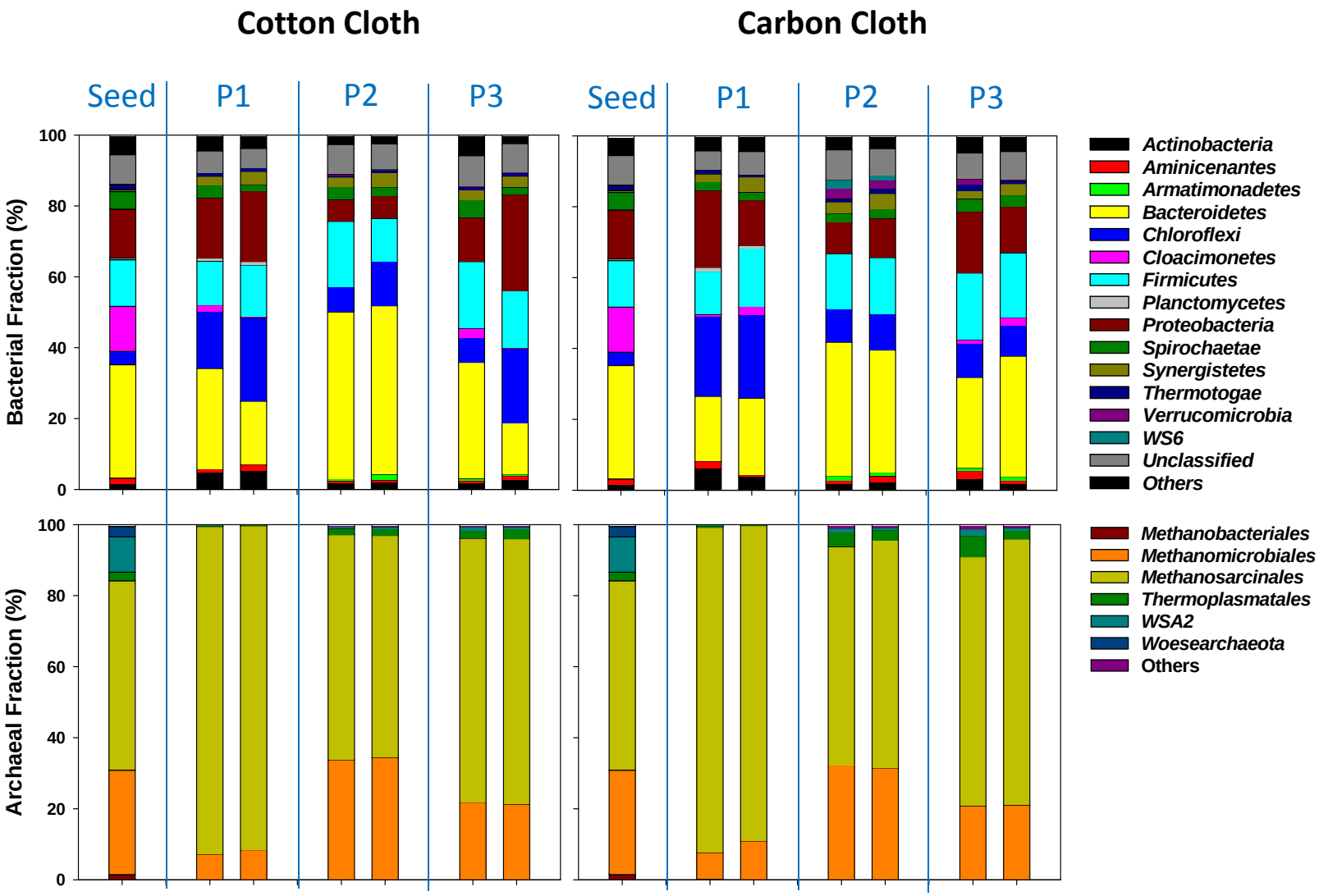
- Working Volume: 700 mL
- Carbon or cotton cloth: 10 cm^2 * 50EA
- Substrate: Acetate or Glucose (1 gCOD/L)
- Feeding rate: 35 mL/d
- Temperature: 35 ℃

- Phase 1 (3 weeks): Acetate
- Phase 2 (3 weeks): Glucose
- Phase 3 (3 weeks): Acetate
- Phase 4 (3 weeks): Glucose

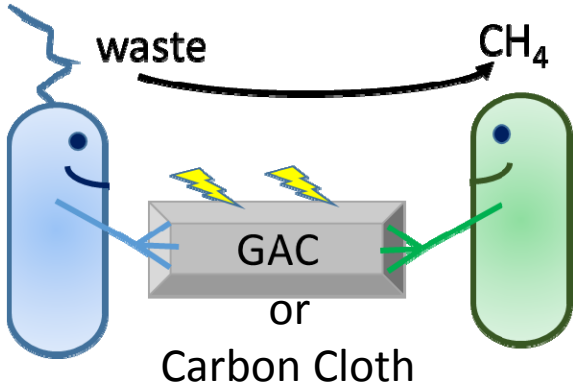
Carriers with Carbon Cloth Stimulated More Methane Production



Known DIET Microorganisms were not Identified



Summary and Significance



- Supplementation of GAC in anaerobic reactors enhanced methane production (1.8 folds), mostly due to the biomass attached on GAC
- GAC facilitated DIET between exoelctrogens (e.g. Geobacter) and methanogens (e.g. Methanospirillum)
- DIET via carbon cloth was effective only when acetate was provided as the substrate

Acknowledgements

Jung-Yeol Lee, Ph.D.
- Experimental design
- Reactor operation and analyses
- Bioelectrochemical analyses

Hyun-Jin Kang
- Design a moving-bed carrier
- Reactor operation

Sang-Hoon Lee, Ph.D.
- Microbial community analyses

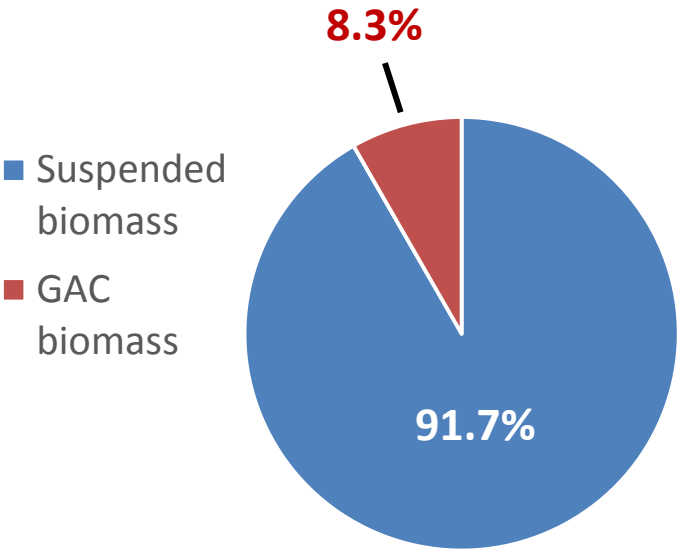
Jeong-Hoon Park, Ph.D.
- Microbial community analyses

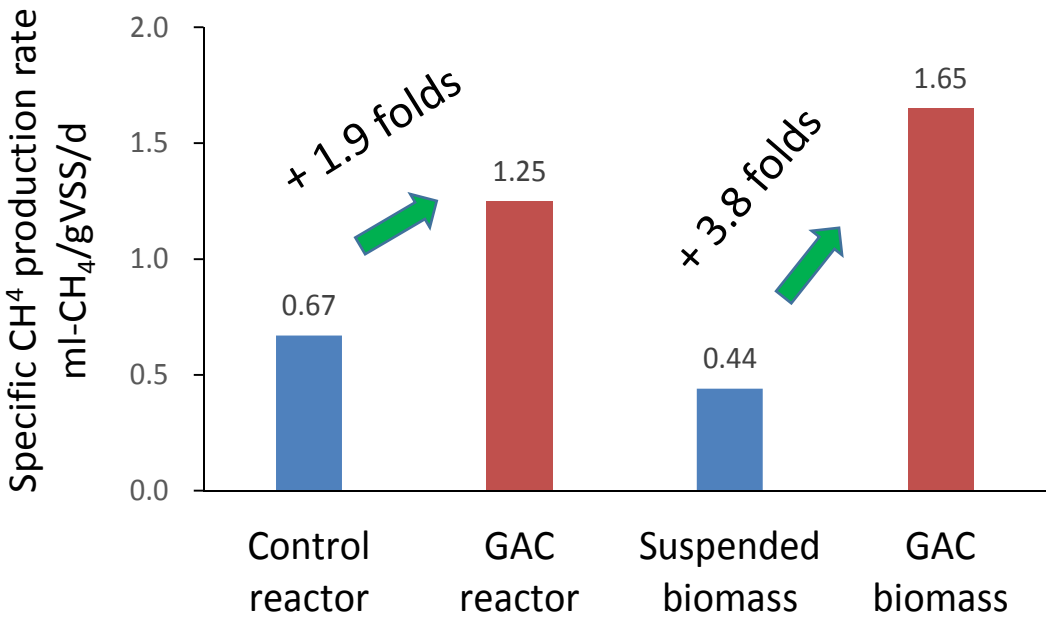
This work was financially supported by National Research Foundation of Korea (2018R1A2B2002110).

NRF 한국연구재단 National Research Foundation of Korea

KOREA UNIVERSITY 고려대학교 KOREA UNIVERSITY

GAC Biomass Comprised a Minor Fraction of Total Biomass





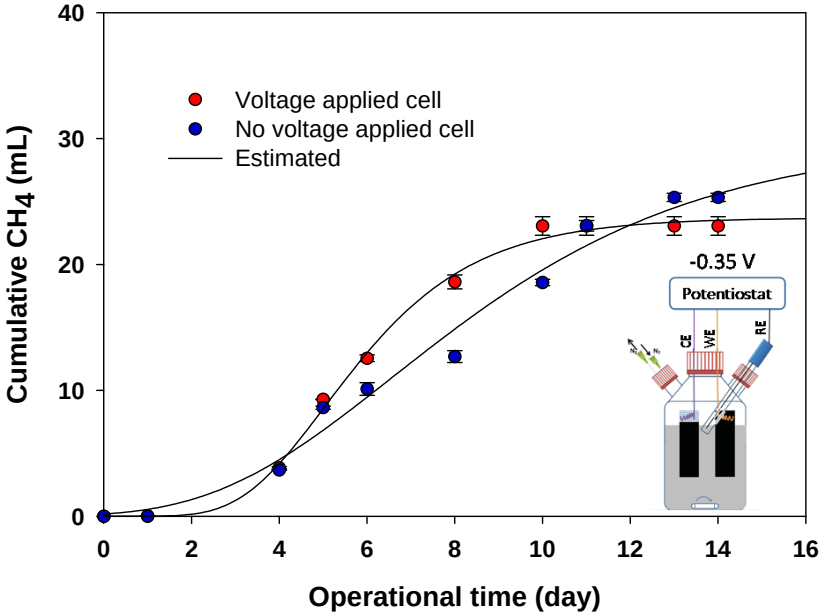
- GAC biomass was 3.8-fold higher than suspended biomass in terms of specific methane production rate

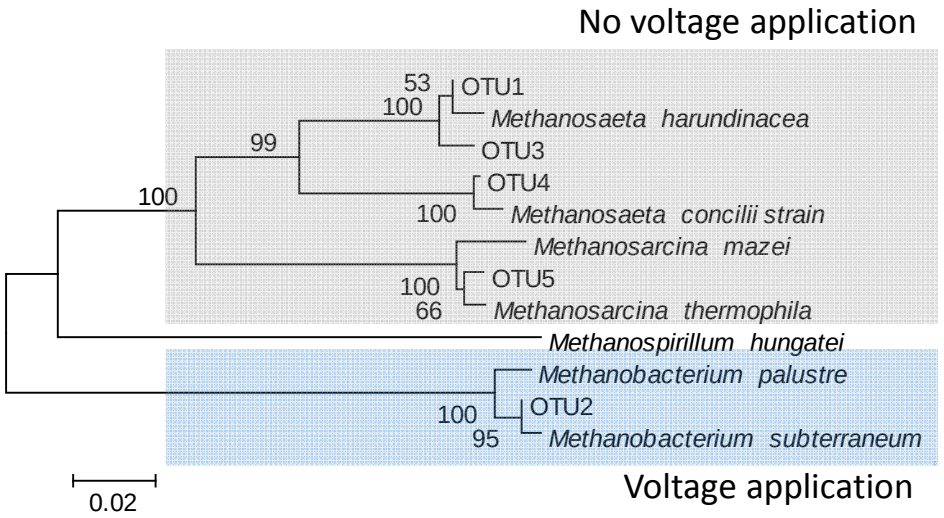
More Research Questions

- Does a voltage application to the conductive materials accelerate the DIET between two groups of microorganisms to produce methane?

- Is DIET via conductive materials also effective to mitigate sensitiveness to operational and environmental conditions in methanogenesis?

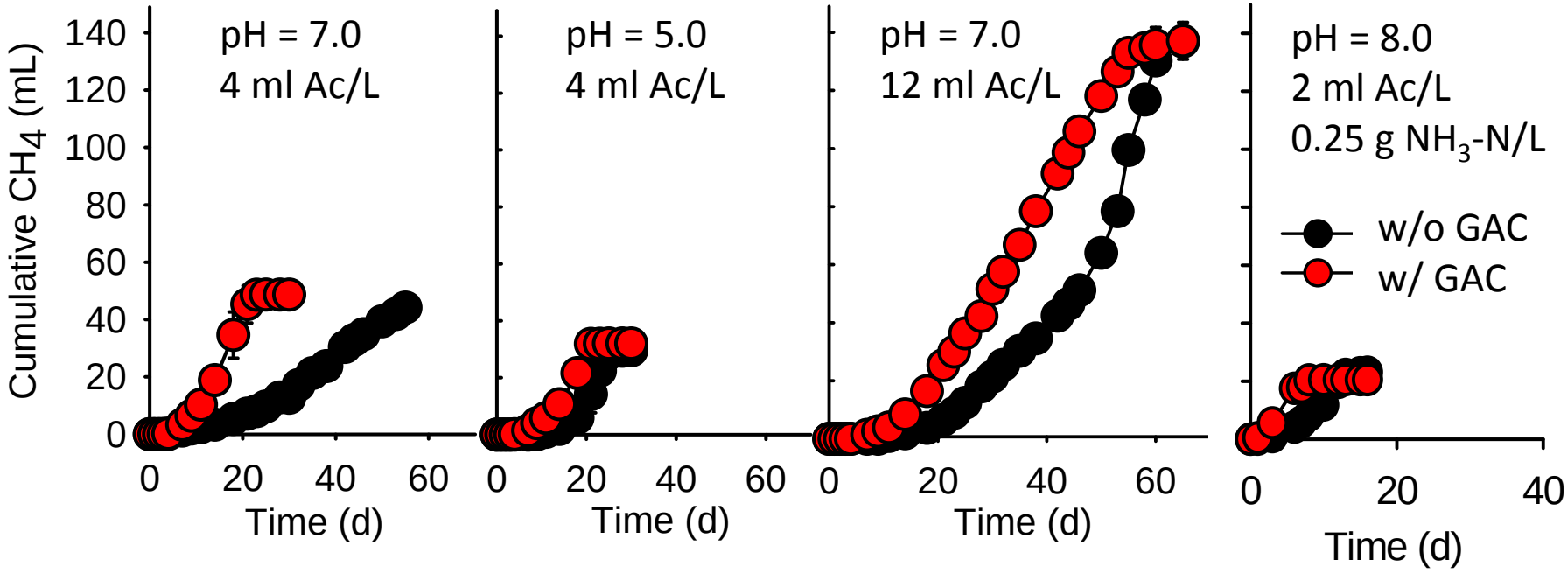
Voltage Application was not Helpful for DIET





- A voltage (0.35 V) applied cell showed a 168% higher methane production rate
- Methanogens generating DIET were observe only in the no voltage applied cell

DIET Moderated the Effects of Several Adverse Operational Conditions



- GAC supplementation moderated the harsh conditions, such as low pH (pH = 5.0), high organic loading (12 ml Ac/L), and high ammonia (0.25 g NH_3-N/L)