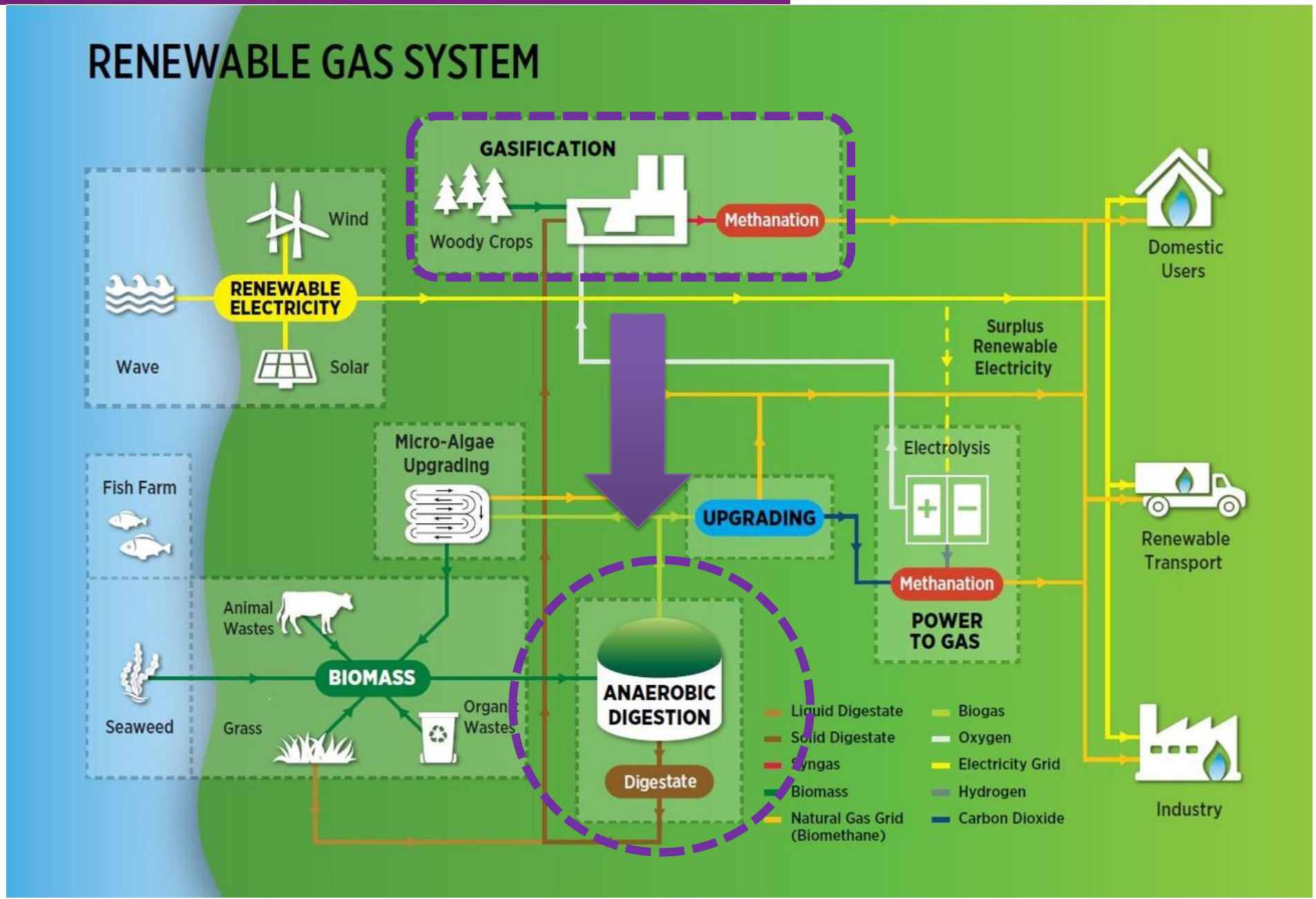
Microbial interspecies electron transfer in anaerobic digestion

Dr. Richen Lin

MaREI Centre, Environmental Research Institute

University College Cork, Ireland

Green gas production



Publications

Bioenergy

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Improved efficiency of anaerobic digestion through direct interspecies electron transfer at mesophilic and thermophilic temperature ranges

Richen Lin[a,b], Jun Cheng[c,*], Lingkan Ding[c], Jerry D. Murphy[a,b,d]

[a] MaREI Centre, Environmental Research Institute, University College Cork, Cork, Ireland
[b] School of Engineering, University College Cork, Cork, Ireland
[c] State Key Laboratory of Clean Energy Utilization, Zhejiang University, Hangzhou 310027, China
[d] International Energy Agency Bioenergy Task 37 "Energy from Biogas", Ireland

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

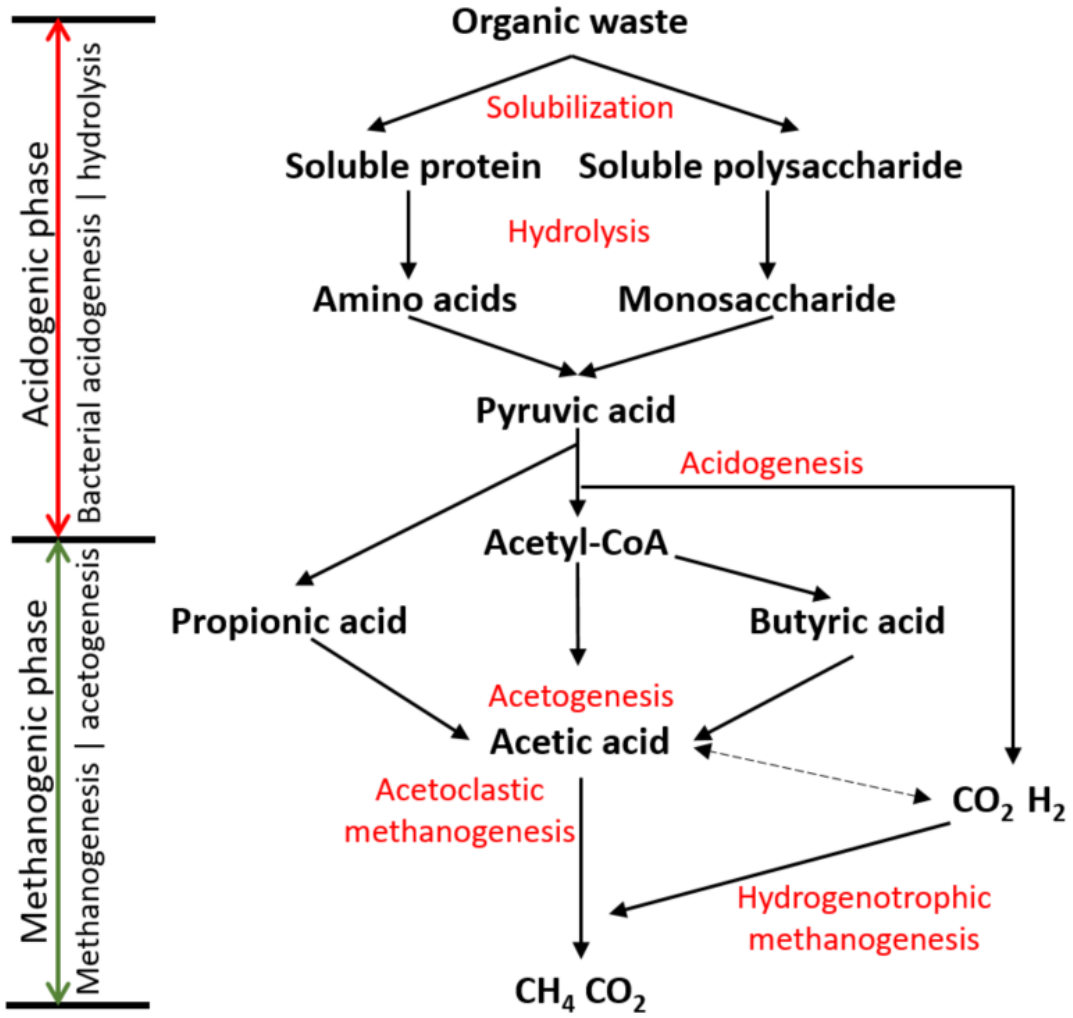
Boosting biomethane yield and production rate with graphene: The potential of direct interspecies electron transfer in anaerobic digestion

Richen Lin[a,b,c], Jun Cheng[a,*], Jiabei Zhang[a], Junhu Zhou[a], Kefa Cen[a], Jerry D. Murphy[b,c]

[a] State Key Laboratory of Clean Energy Utilization, Zhejiang University, Hangzhou 310027, China
[b] MaREI Centre, Environmental Research Institute, University College Cork, Cork, Ireland
[c] School of Engineering, University College Cork, Cork, Ireland

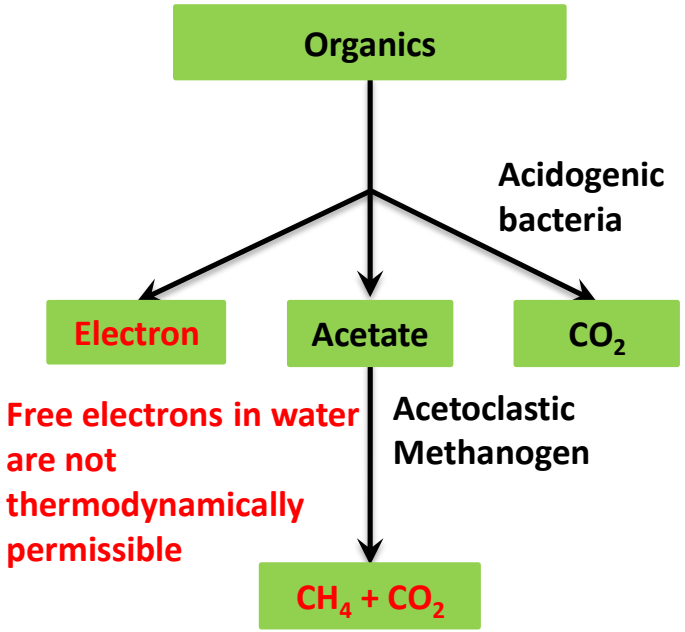
❖**Graphene could enhance biogas production rate in mesophilic and thermophilic anaerobic digestion by 30%.**

Interspecies electron transfer in anaerobic digestion



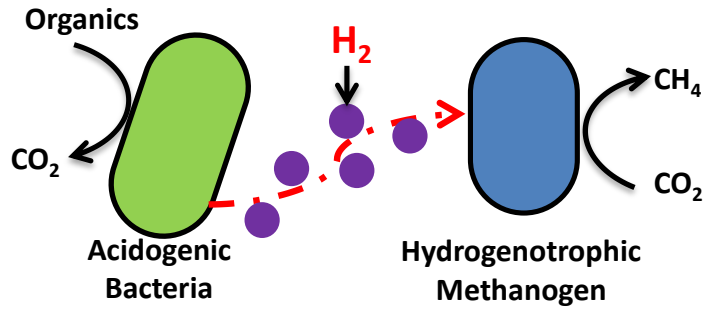
Four steps involved in anaerobic digestion.

- Hydrolysis
- Acidogenesis
- Acetogenesis
- Methanogenesis

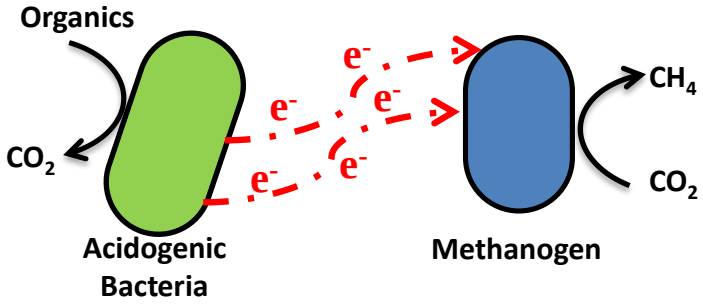


Simplified Model for Conversion of Organics to Methane

Two modes for electron transfer

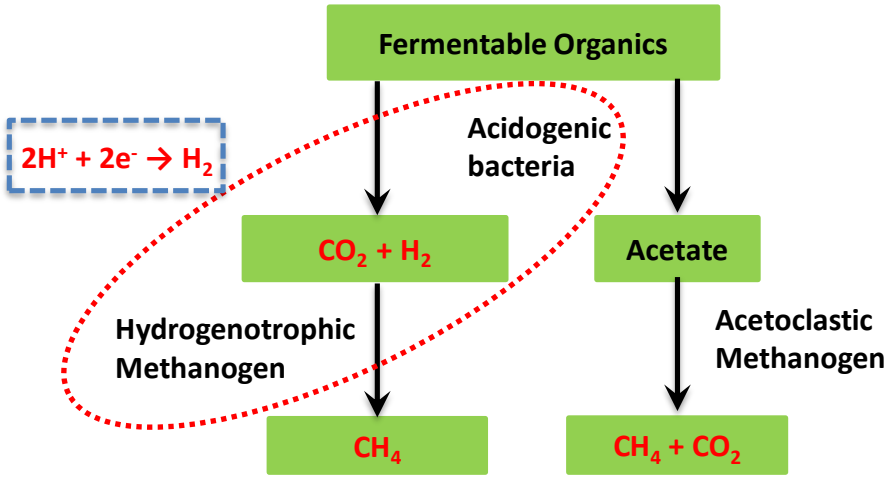


Mediated Interspecies Electron Transfer (MIET) between Acidogenic Bacteria and Hydrogenotrophic Methanogen

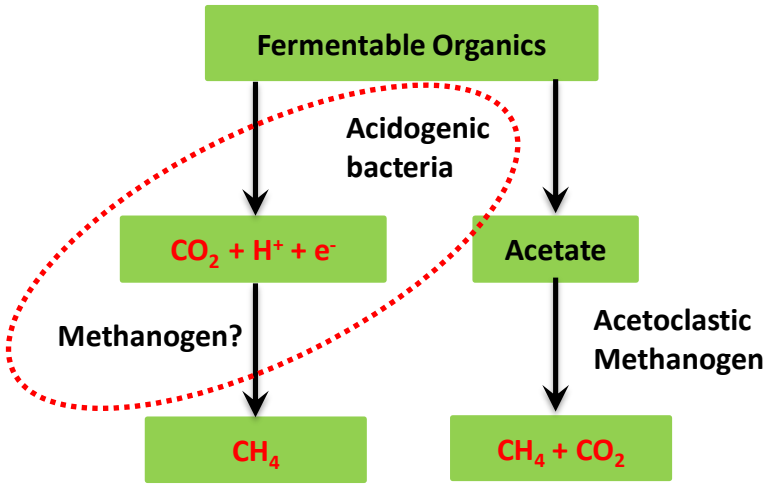


Direct Interspecies Electron Transfer (DIET) between Acidogenic Bacteria and Methanogen

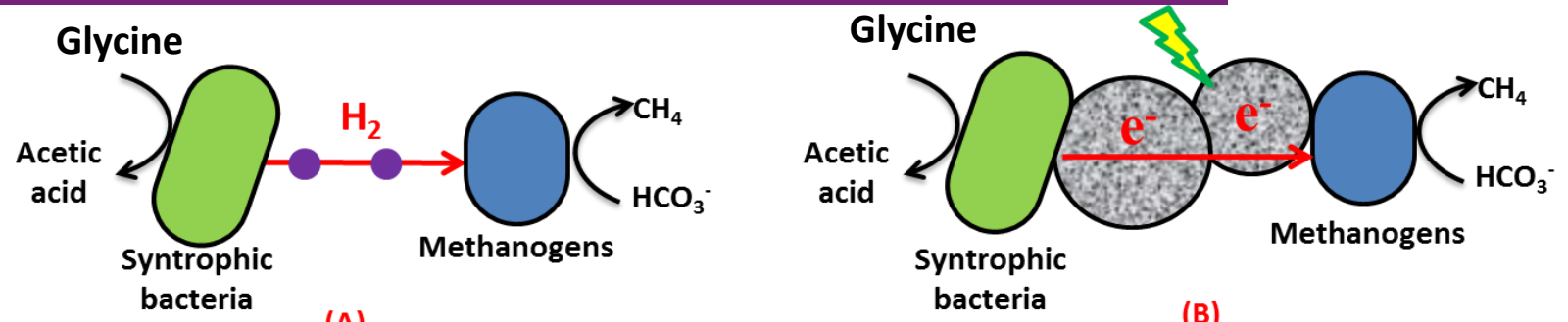
Mediated Interspecies Electron Transfer (MIET)



Direct Interspecies Electron Transfer (DIET)



Models: theoretical maximum electron transfer via MIET / DIET



(A)

$$i = D_f \cdot \frac{S_{cell}}{d} \cdot ([H_2]_{highest} - [H_2]_{lowest}) \cdot n \cdot F$$

(B)

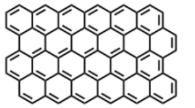
$$i = k \cdot \frac{S_{conduit}}{d} \cdot (E_{Met} - E_{syn})$$

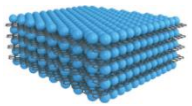
- **Table Gibbs free energy changes of DIET reactions under standard condition (pH = 7).**

Process	Reaction	$\Delta G_0'$ (kJ/mol)
1. Electron-producing reaction	MIET: $C_2H_5NO_2 + 2/3H_2O \rightarrow 2/3CH_3COO^- + 2/3H^+ + NH_3 + 2/3CO_2 + 1/3H_2$	-33.42
	DIET: $C_2H_5NO_2 + 2/3H_2O \rightarrow 2/3CH_3COO^- + 2/3H^+ + NH_3 + 2/3CO_2 + 2/3H^+ + 2/3e^-$	-59.97
2. Electron-consuming reaction	MIET: $1/3H_2 + 1/12CO_2 \rightarrow 1/12CH_4 + 1/6H_2O$	-10.89
	DIET: $2/3H^+ + 2/3e^- + 1/12CO_2 \rightarrow 1/12CH_4 + 1/6H_2O$	15.66
3. Acetate-consuming reaction	$2/3CH_3COO^- + 2/3H^+ \rightarrow 2/3CH_4 + 2/3CO_2$	-23.94
Overall	$C_2H_5NO_2 + 1/2H_2O \rightarrow 3/4CH_4 + NH_3 + 5/4CO_2$	-68.25

❖ **Graphene-based DIET sustains a much higher electron transfer flux (up to 6 orders of magnitude) than conventional hydrogen transfer.**

Hypothesis: conductive graphene can promote DIET

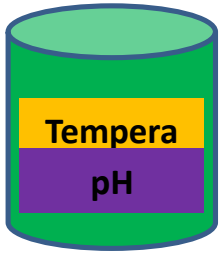




- High surface area
- Electrical conductivity
- Thermal conductivity

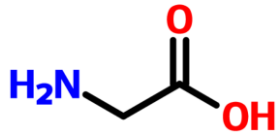
Graphene

Microbes



Mesophilic
AD (35 ° C)

$C_2H_5NO_2$



Amino acid (glycine): high content in seaweed

Batch Biomethane Potential System

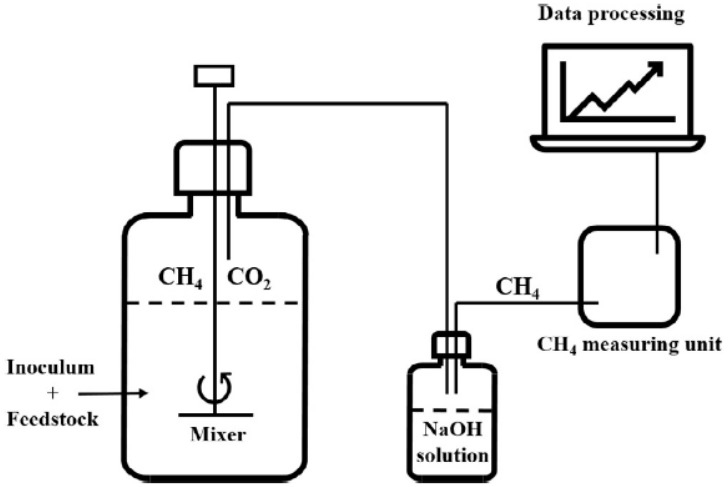
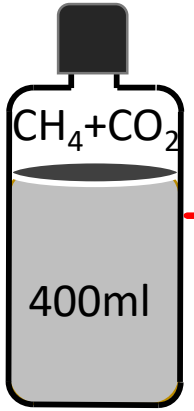


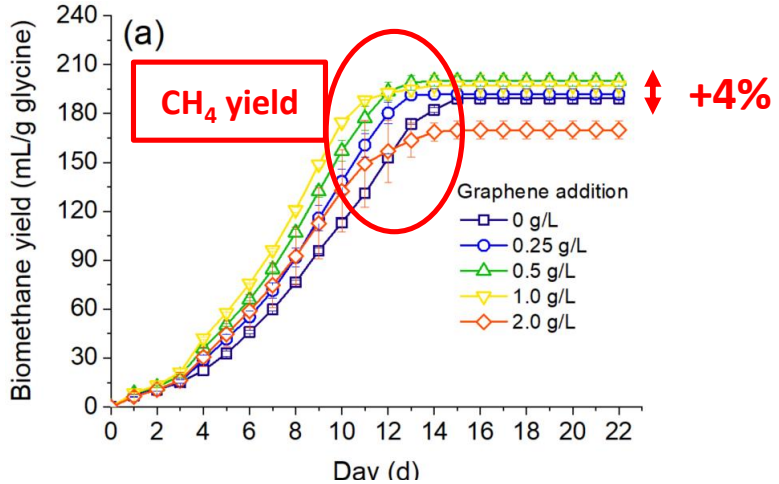
Fig. 1. Schematic diagram of the AMPTS II system for batch anaerobic digestion experiments.

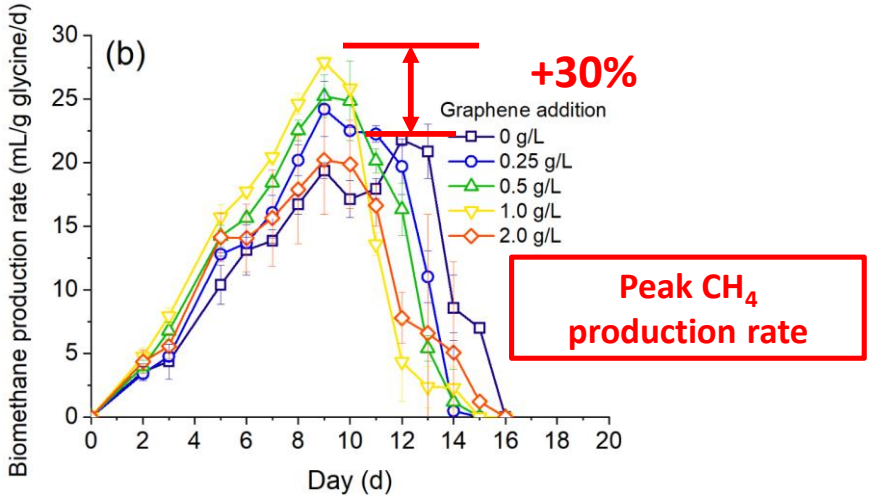


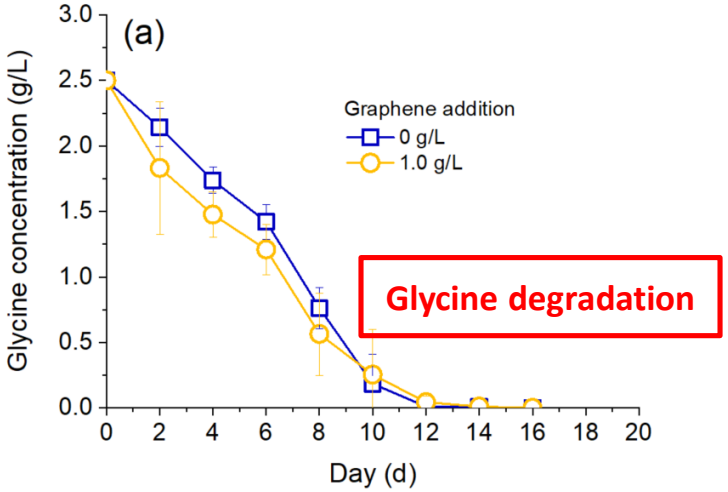
- Inoculum (5 g/L)
- Glycine (2.5 g/L)
- Graphene (different additions)

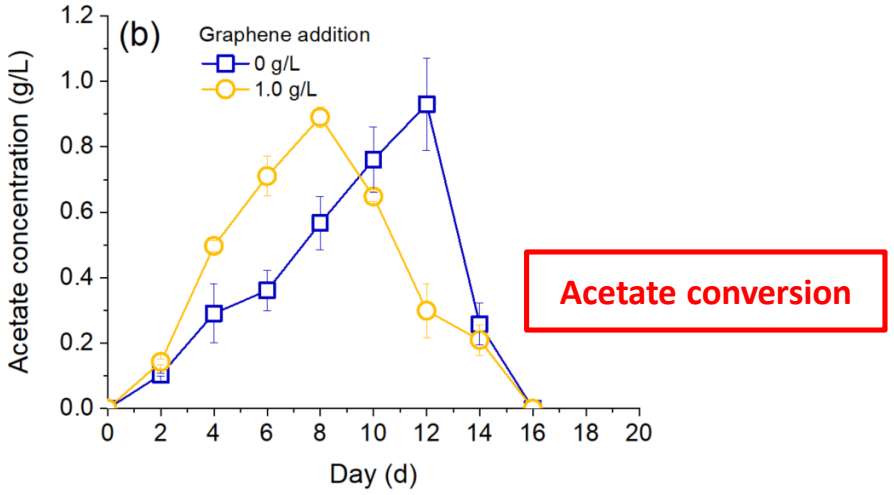
No.	Graphene addition (g/L)
1	0
2	0.25
3	0.5
4	1
5	2

Results: Anaerobic digestion performance





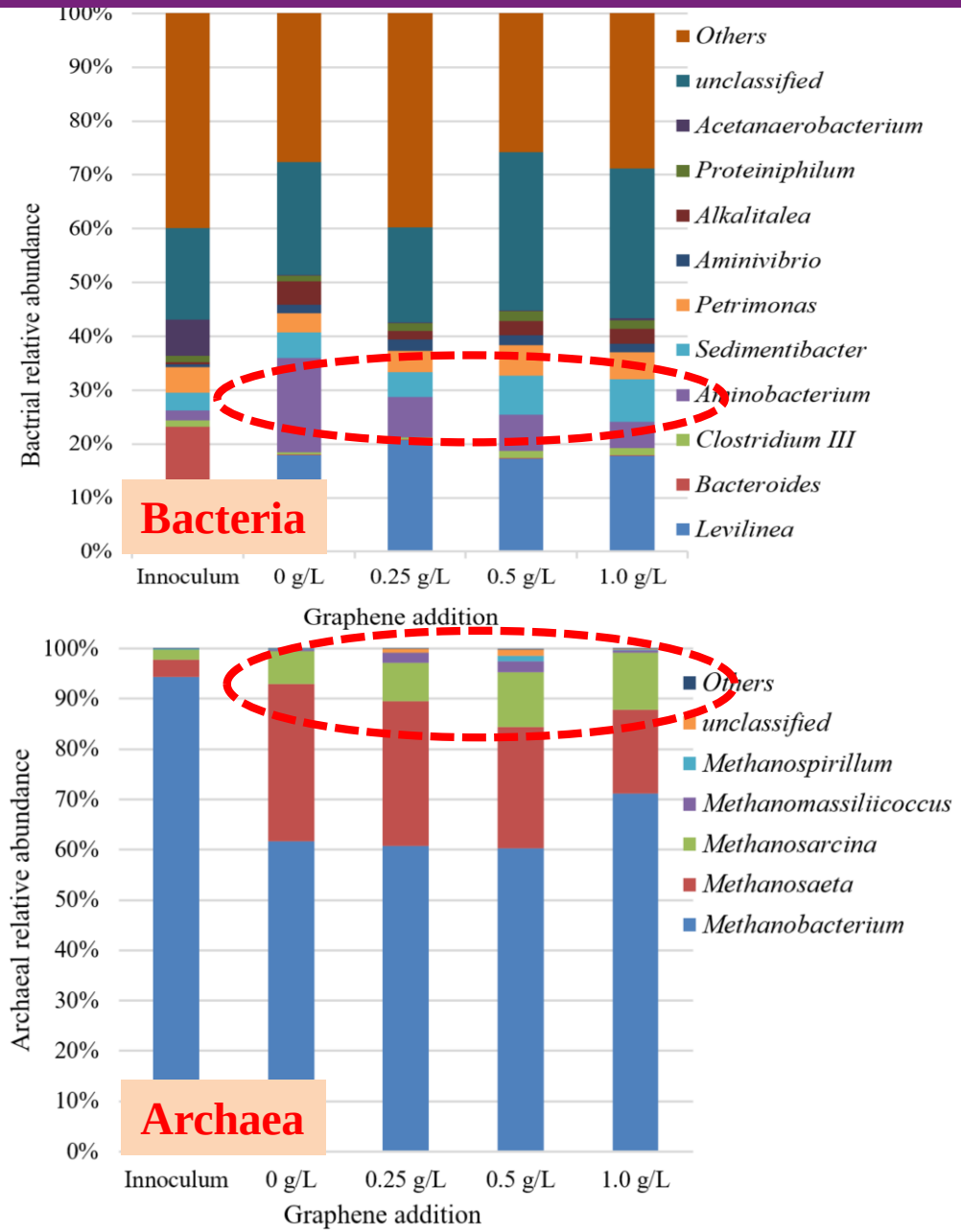




In the presence of 1 g/L graphene,

- Biomethane yield increased by 4.2%, peak production rate increased by 30.0%,
- Glycine consumption rate (at 8 d) reached 77.6% in comparison to 69.6% in control group.
- Acetate conversion was enhanced.

Results: Microbial communities



In the presence of graphene,

- The abundance of acidogen *Sedimentibacter* increased with increased graphene addition.

Temperature optimum (°C)	33–34
pH optimum	7.2–8.2
Requirement of yeast extract for growth	+
Decarboxylation of 4-OHB and 3,4-OHB	+
Fermentation of:	
Glycine	+
Purines	–
Pyruvate[c]	+ (A, B)
Carbohydrates	–
H_2 production	–

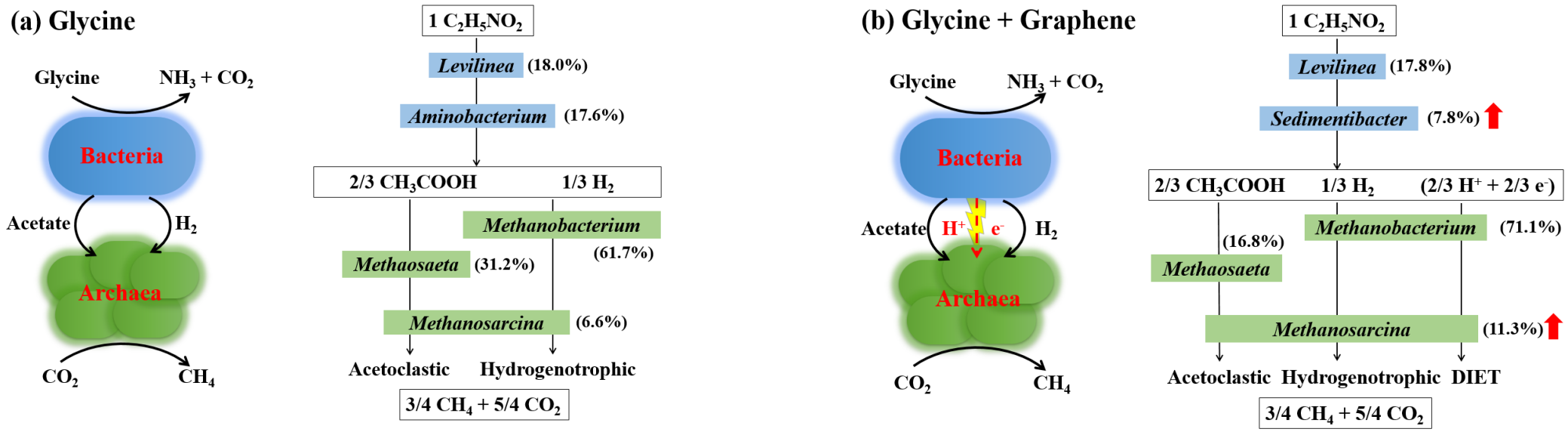
Sedimentibacter ferment glycine to acetic acid without production of H_2 (Lechner, U. 2015).

$C_2H_5NO_2 + 2/3H_2O \rightarrow 2/3CH_3COO^- + 2/3H^+ + NH_3 + 2/3CO_2 + 2/3H^+ + 2/3e^-$

In the presence of graphene,

- The abundance of *Methanosarcina* increased with increased graphene addition.

Results: Microbial networks



DIET pathway:

- $C_2H_5NO_2 + 2/3H_2O \rightarrow 2/3CH_3COO^- + 2/3H^+ + NH_3 + 2/3CO_2 + 2/3H^+ + 2/3e^-$
- $2/3H^+ + 2/3e^- + 1/12CO_2 \rightarrow 1/12CH_4 + 1/6H_2O$

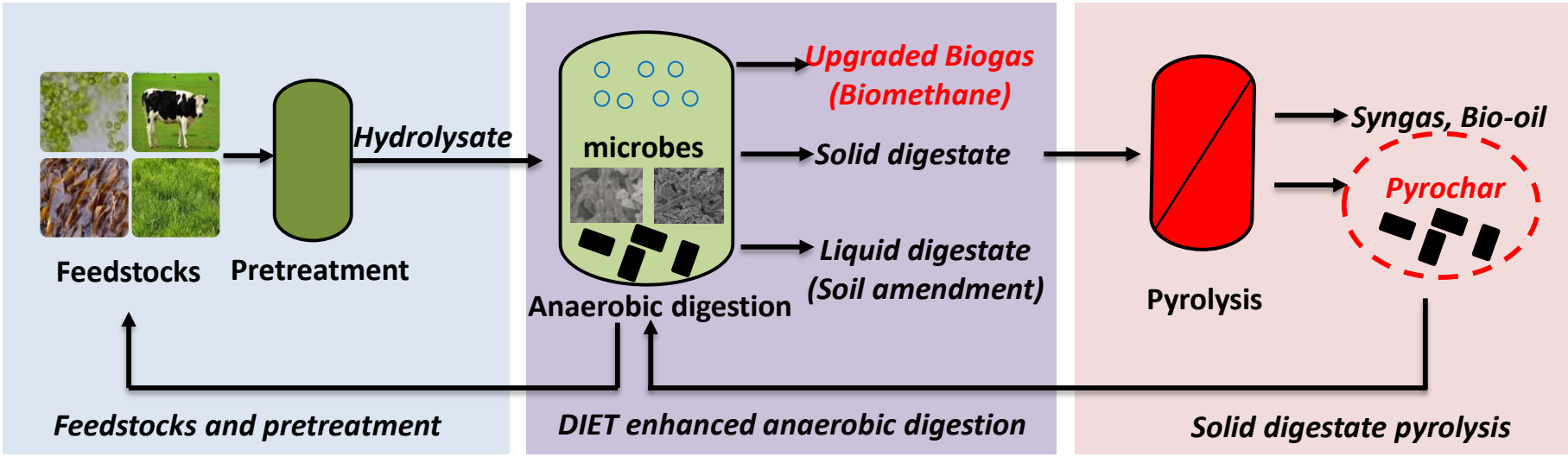
MIET pathway:

- MIET: $C_2H_5NO_2 + 2/3H_2O \rightarrow 2/3CH_3COO^- + 2/3H^+ + NH_3 + 2/3CO_2 + 1/3H_2$
- MIET: $1/3H_2 + 1/12CO_2 \rightarrow 1/12CH_4 + 1/6H_2O$

The connections between *Sedimentibacter and Methanosarcina* are likely responsible for DIET in glycine digestion.

Summary

- DIET is thermodynamically more favourable compared to MIET.
- The peak biomethane production rate, lag phase time, and peak time exhibited strong linear correlations with graphene concentration from 0 to 1.0 g/L.
- The connections between *Sedimentibacter and Methanosarcina* are likely responsible for DIET in glycine digestion.



Proposed advanced biofuel production in a circular bioenergy system

MaREI
Centre for Marine and Renewable Energy

WHO WE ARE ▾ | RESEARCH ▾ | INFRASTRUCTURE ▾ | INDUSTRY ▾ | DATA HUB ▾ | SOCIETAL IMPACT ▾
NEWS & MEDIA ▾

Marine Renewable Energy Technologies | Materials & Structures | Observation & Operations | Coastal & Marine Systems | Bioenergy | Energy Policy & Modelling | Energy Management

Thank you!

Science Foundation Ireland sfi For what's next

Gas Networks Ireland

MARIE CURIE ACTIONS

Marie Skłodowska-Curie Actions