



Dr. Archishman
Bose & Dr. Richard
O'Shea

Innovations in Biomethane: Insights from Recent Research Projects

Presenters: Dr Archishman Bose, Dr Richard O'Shea

The Biomethane Webinar
25th June 2025

HOST INSTITUTION



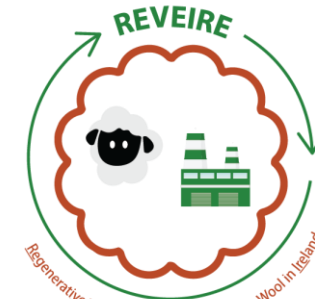
PARTNER INSTITUTIONS





Dr Richard O'Shea

- Lecturer in Sustainability in Enterprise, School of Engineering, UCC (2021- Present)
- PhD in Energy Engineering “Pathways to a biomethane industry in Ireland” (UCC, 2018)
- BE (Hons) in Energy Engineering (UCC, 2014)
- *Multiple Criteria Decision Analysis*
- *Decarbonization of industry, technoeconomic analysis*



ENTYRE
Mapping the Role of End-of-Life
Tyres for a Sustainable Circular
Economy in Ireland





Prof Jerry Murphy

Director: MaREI

Professor of Civil
Engineering



**Dr Archishman
Bose**

Bioenergy &
Biorefinery

Eli Lily Lecturer in
Process Engineering



Dr David Wall

Advanced Fuels &
Circular Economy

Senior Lecturer in
Transportation
Engineering



Dr Richard O Shea

Industrial Ecology

Lecturer in
Sustainability in
Enterprise



Dr Xue Ning



Dr Nathan Gray



Dr Deepa Sachan



Dr Soumitra Pati



Dr Yunfei Li



Dr Abdul Haq



Derek Casey



Rajas Shinde



Nikita Verma



M. Nabeel Haider



**Mohammadali
Babanejadi**



Asif Tanvir Bhuiya



Niloufar Hasanpour



Rohan Solanki



Hongkun Zhu



**Shaghayegh
Mojoodi**



Jun Ni



Matthew Carrol

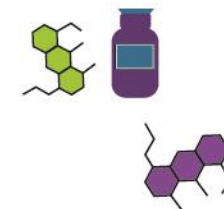


Dr Gaia Crestani

e-Fuels & e-Refineries



Refinery



Experimental Analysis

Carboxylic Acids
Carbon Dioxide

Waste Valorisation

Sustainable Technologies

Systems Modelling



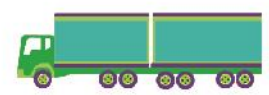
Circular Economy, Energy & Environmental Systems

Hydrogen

Methanol

Ammonia

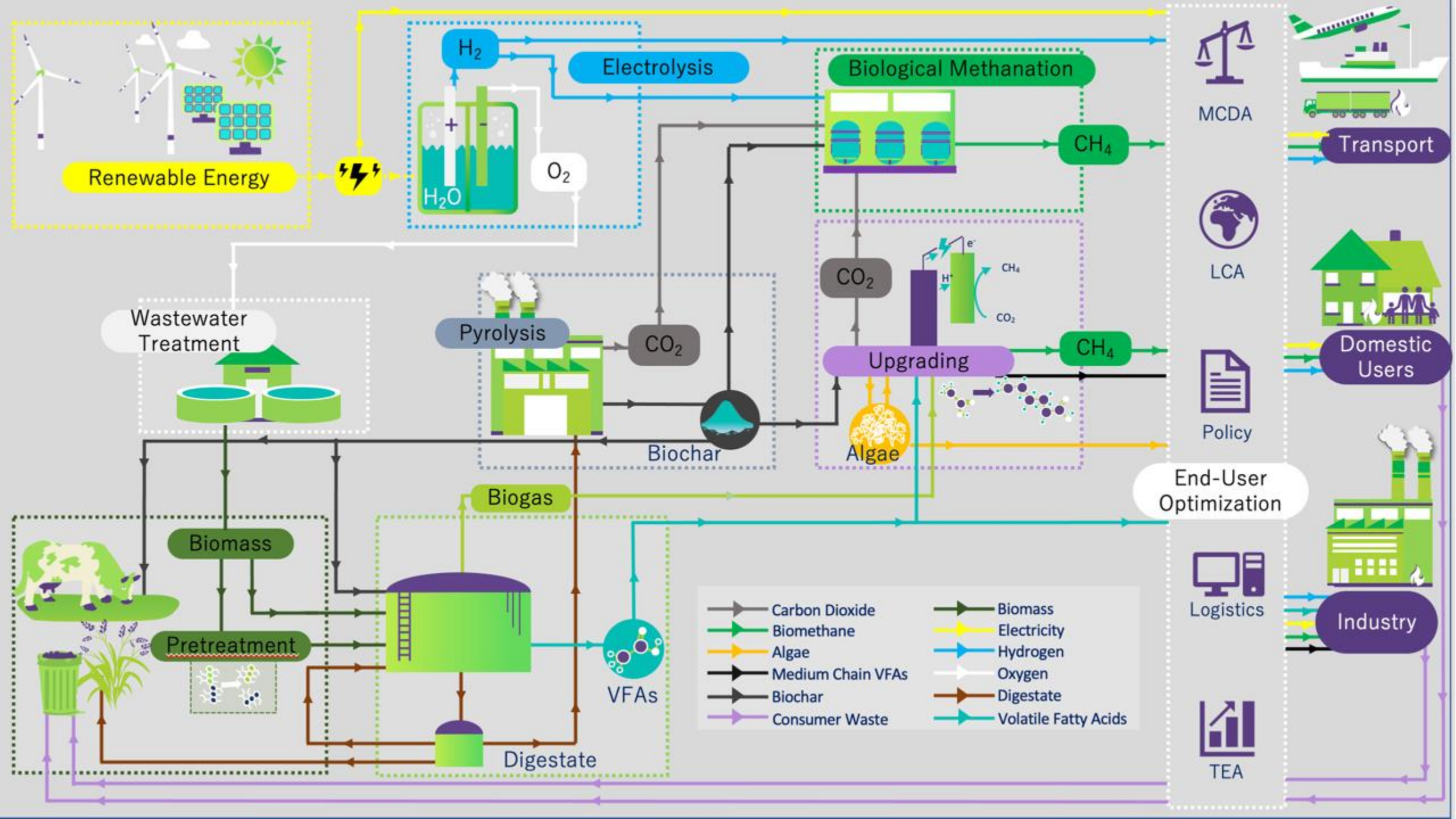
Methane



Fuels



Biofuels & Biorefineries





Prof Jerry Murphy



Dr David Wall



Dr Richen Lin



Dr Richard O Shea



Dr Xue Ning



Dr Donal O Ceileachair



Dr Jorge Diaz Huerta

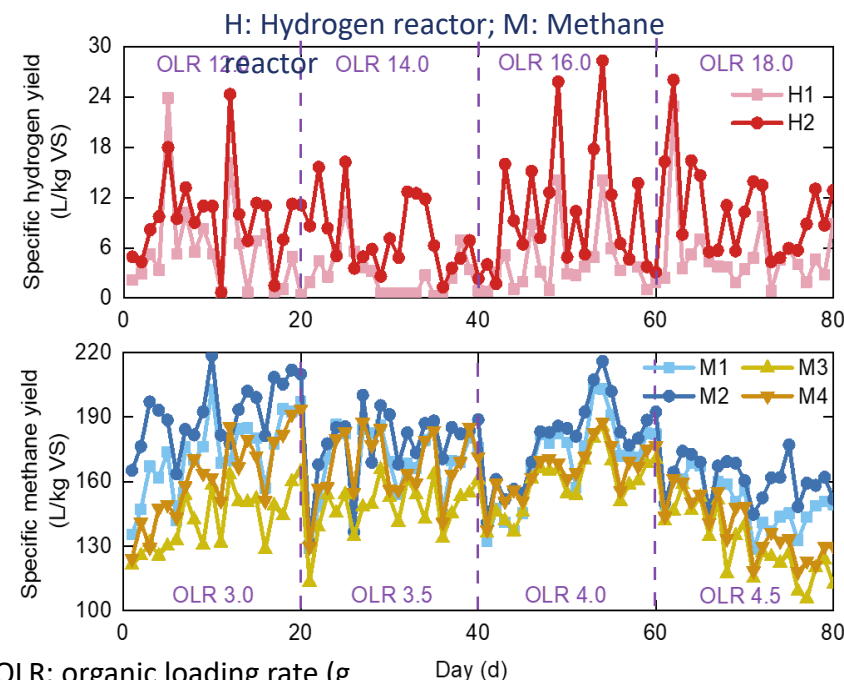
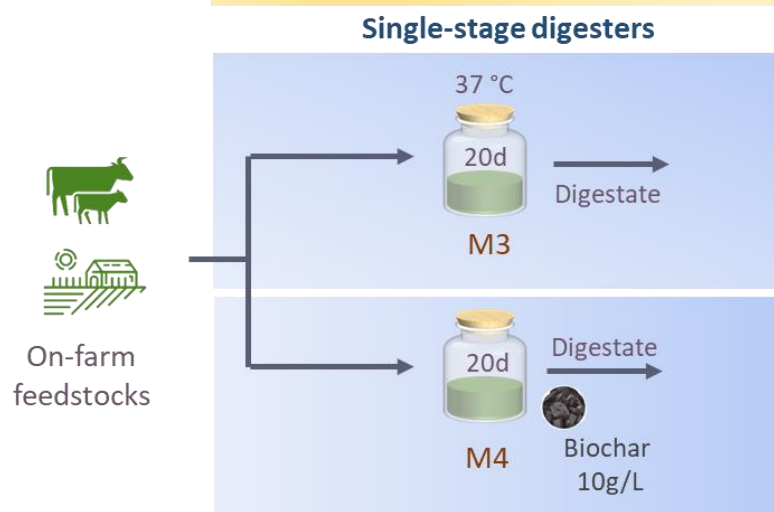
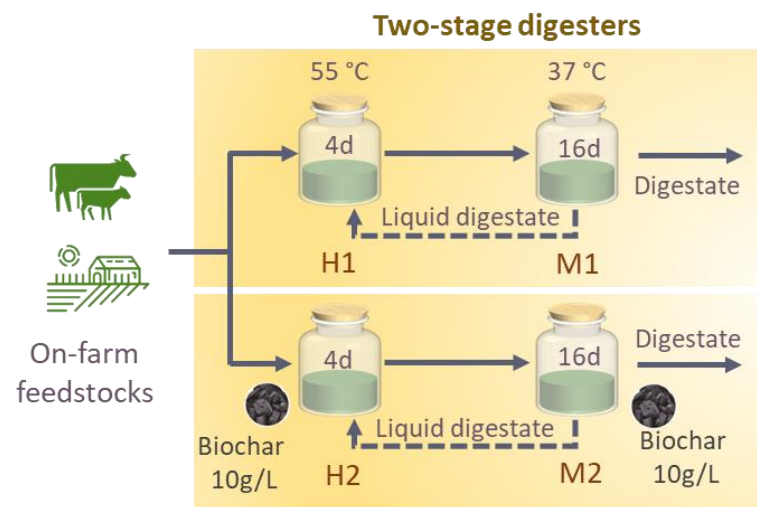
WP1: Enhance on-farm digestion efficiency through novel pre-treatments

WP2: Integration of electro-methanogenesis with anaerobic digestion to increase overall biomethane conversion

WP3: Optimising the logistics of on farm anaerobic digestion in Ireland

WP4: Techno-economic analysis of potential on-farm anaerobic digestion pathways

WP5: Management, communication, and dissemination



OLR: organic loading rate (g VS/L/day)

Biochar increased bio-hydrogen yield by 62% - 139% in two stage continuous digestion

Biochar increased biomethane yield by 3% in single stage continuous digestion, and 7% in two stage continuous digestion (OLR 4 kg VS/m³/day)



Improving biomethane production from biochar-supplemented two-stage anaerobic digestion of on-farm feedstocks

Xue Ning^{a,b}, Chen Deng^{a,b}, R. B. Daniel T. Hickey^{a,b}, Anna Hockley^{a,b}, Richard O'Shea^{a,b}, David M. Wall^{a,b}, Richen Lin^{a,b}, Jerry D. Murphy^{a,b}



Prof Jerry Murphy



Dr David Wall



Dr Richen Lin



Dr Richard O Shea



Dr Xue Ning



Dr Donal O Ceileachair



Dr Jorge Diaz Huerta

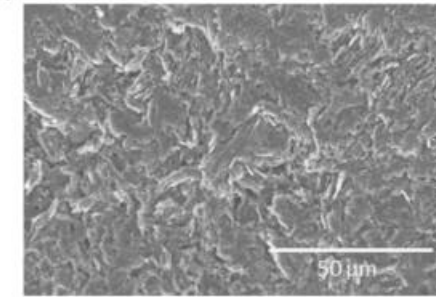
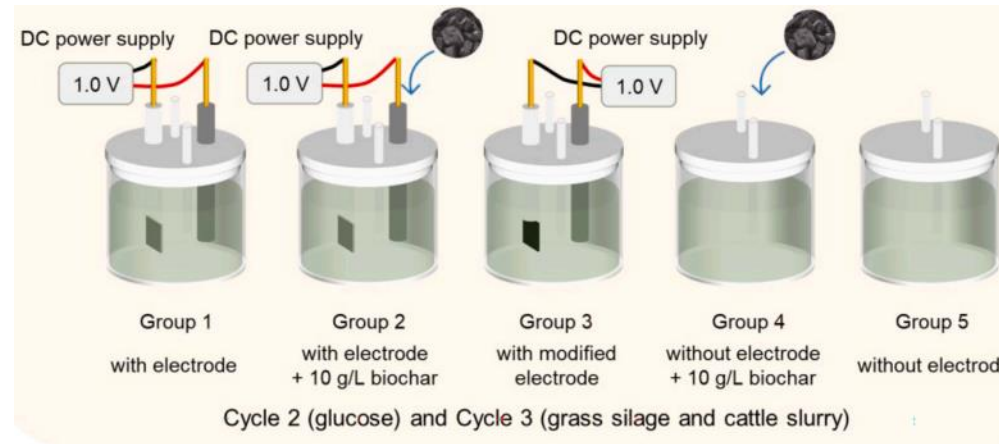
WP1: Enhance on-farm digestion efficiency through novel pre-treatments

WP2: Integration of electro-methanogenesis with anaerobic digestion to increase overall biomethane conversion

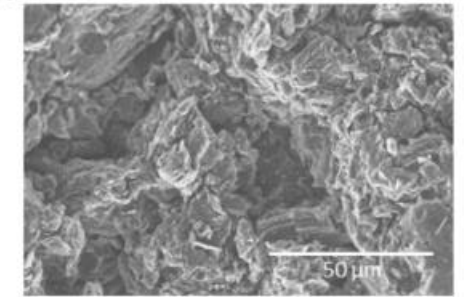
WP3: Optimising the logistics of on farm anaerobic digestion in Ireland

WP4: Techno-economic analysis of potential on-farm anaerobic digestion pathways

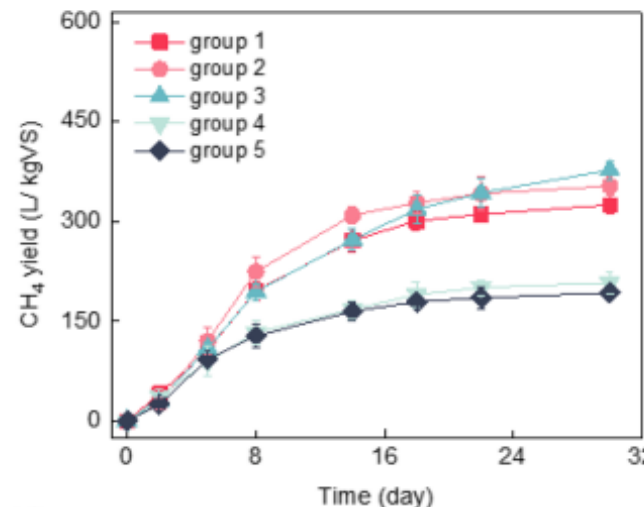
WP5: Management, communication, and dissemination



Pristine Electrode



Modified Electrode



Biochar increased biomethane yield by 7.9%

MEC-AD system increased methane yield by 96.8% and methane content by 32.5%

Proposed underlying cause: Increased VFA degradation on the anode and in-situ carbon conversion from CO_2 to CH_4 on the cathode

6.5 fold return on electrical energy input



Prof Jerry Murphy



Dr David Wall



Dr Richen Lin



Dr Richard O Shea



Dr Xue Ning



Dr Donal O Ceileachair



Dr Jorge Diaz Huerta

WP1: Enhance on-farm digestion efficiency through novel pre-treatments

WP2: Integration of electro-methanogenesis with anaerobic digestion to increase overall biomethane conversion

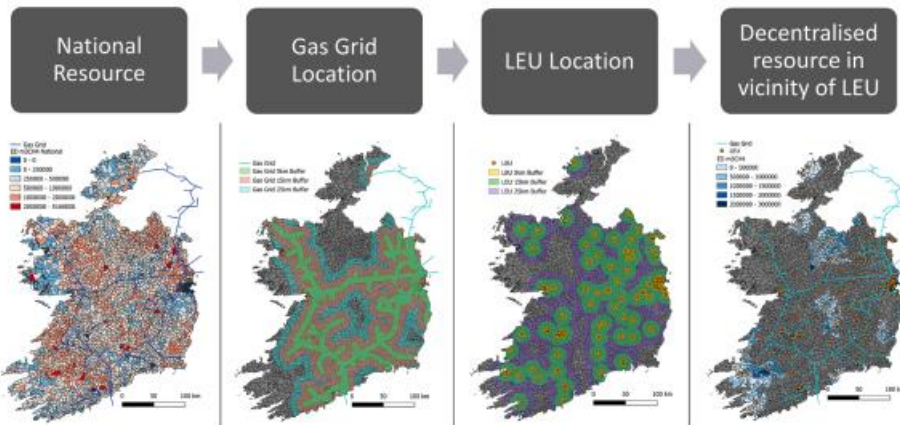
WP3: Optimising the logistics of on farm anaerobic digestion in Ireland

WP4: Techno-economic analysis of potential on-farm anaerobic digestion pathways

WP5: Management, communication, and dissemination



Alternative energy management strategies for large industry in non-gas-grid regions using on-farm biomethane

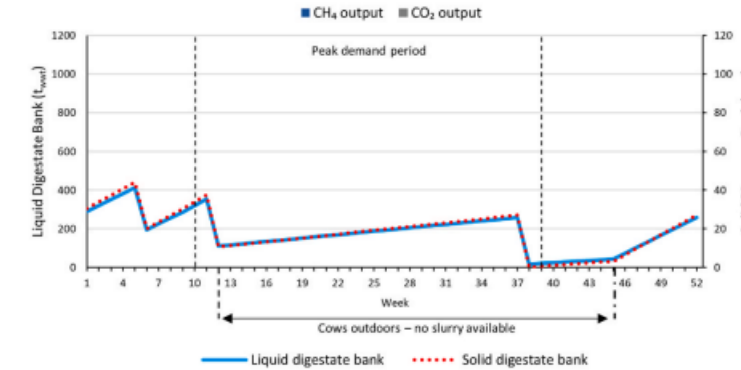
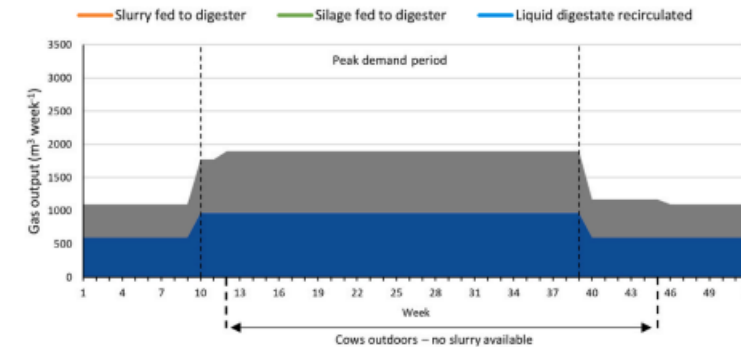
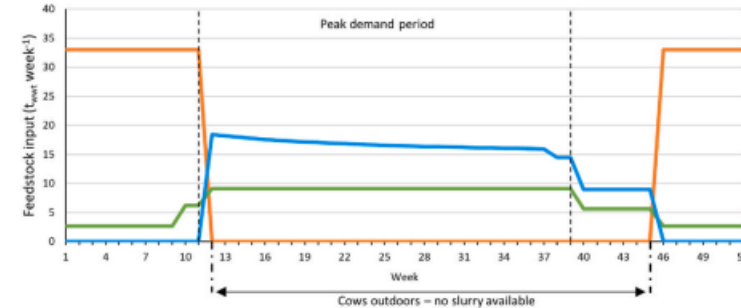


Total biomethane resource: ~67 PJ

Share of Total Resource (%)		Distance from Gas Grid (km)				
		5	10	15	20	25
Distance from Large Energy User (km)	25					11.19
	20				14.40	9.56
	15			17.31	12.28	7.87
	10		16.06	12.25	8.61	5.16
	5	9.72	7.42	5.69	3.91	2.42



The effect of seasonal biomass availability and energy demand on the operation of an on-farm biomethane plant



Supply: Zero-grazing, pasture based

Demand: Constant, Winter, Summer

- Seasonal manure availability may reduce output by 21%.
- Can reduce digester size by 6- 17%.
- If extra silage is used meeting the RED-III criteria becomes more difficult.
- Digestate recirculation is required if liquid manure is unavailable
- Seasonal gas demand may increase digester size by up to 30% compared to constant demand.



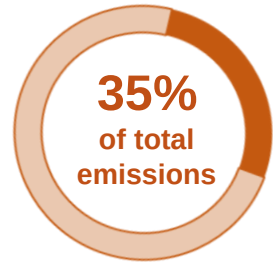
Dr David Wall



Dr Richard O Shea



Rajas Shinde



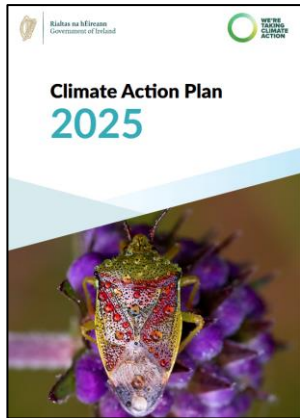
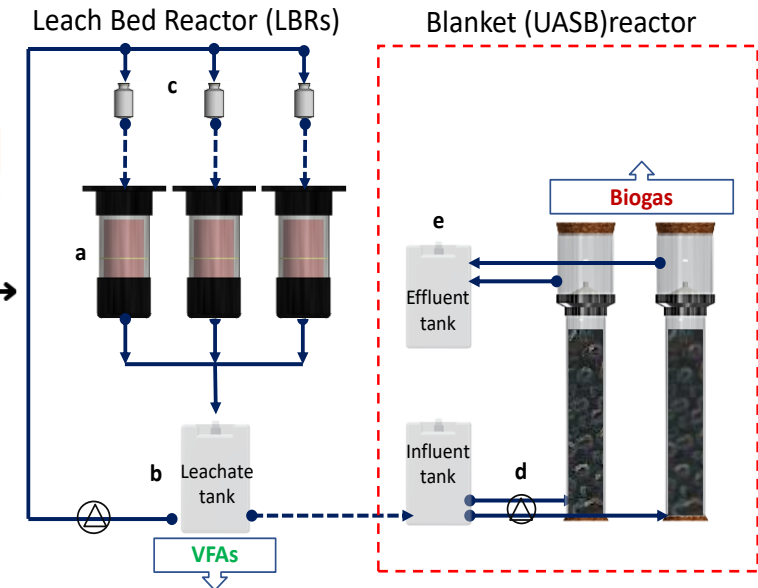
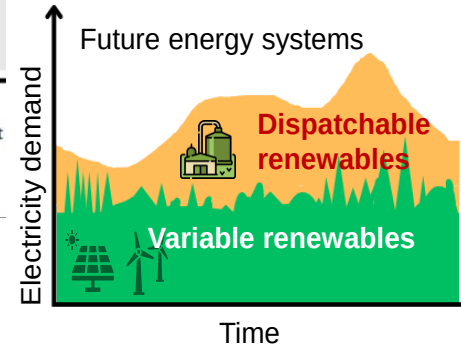
"A Dynamic Anaerobic Digestion-based Biorefinery Model to Enhance the Alternative Uses of Grass"



Demand-driven biogas production from Upflow Anaerobic Sludge Blanket (UASB) reactors to balance the power grid

Rajas Shinde^{a,b,c}, Anga Hackula^{a,b}, Richard O'Shea^{a,b}, Susanne Barth^c, Jerry D. Murphy^{a,b}, David M. Wall^{a,b,c}

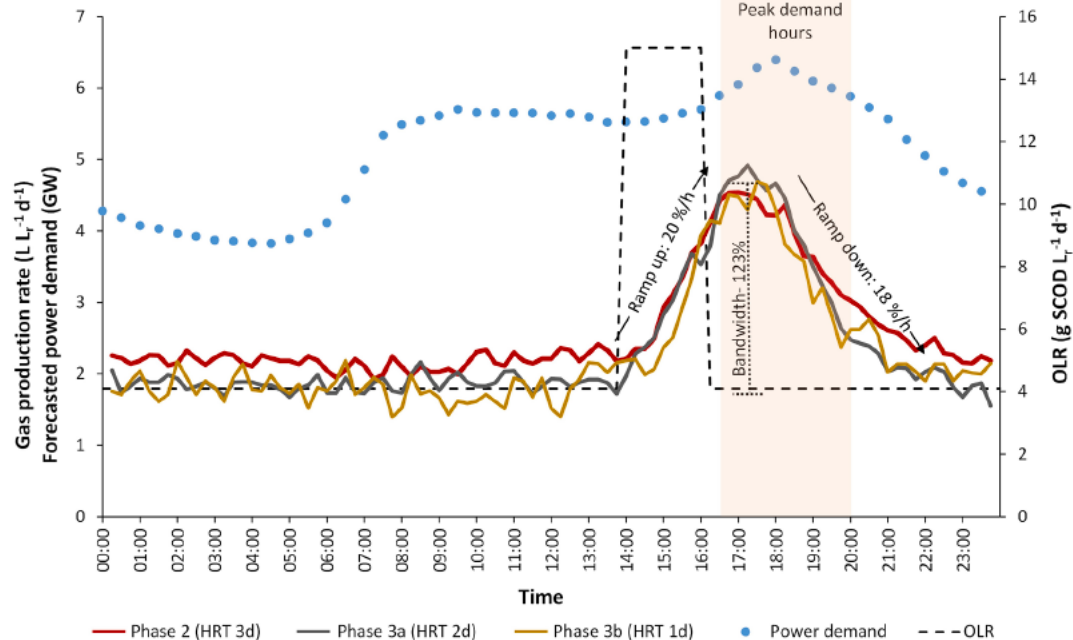
Peak OLR 2 hours before peak demand
20 %/hr ramp up
18 %/hr ramp down
123 %bandwidth
Biogas production aligned with peak electricity demand



25% reduction in agricultural emissions by 2030



5.7 TWh of biomethane by 2030





Prof Jerry Murphy



Dr David Wall

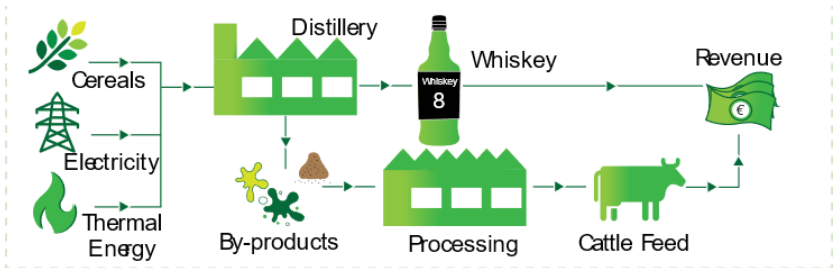


Dr Richard O Shea



Dr Anga Hackula

By-products: 10.3 kg per Original Litre Of Alcohol (OLA)



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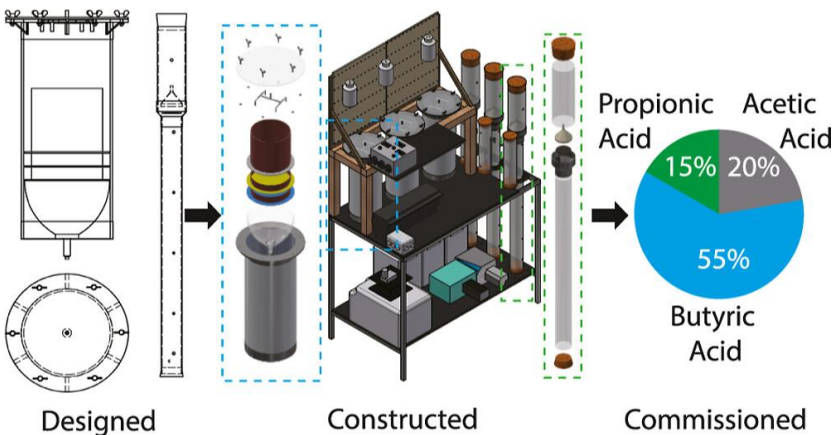
Article

Design, Construction, and Concept Validation of a Laboratory-Scale Two-phase Reactor to Valorize Whiskey Distillery By-products

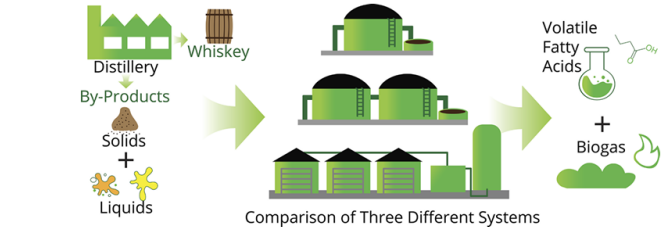
Anga Hackula, Richard O'Shea, Jerry D. Murphy, and David M. Wall*

Cite This: ACS Eng. Au 2023, 3, 224–234

Read Online



~60% of theoretical biogas output
~75% vol. methane content
~55% butyric acid
~20% acetic acid



Contents lists available at ScienceDirect
Bioresource Technology

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



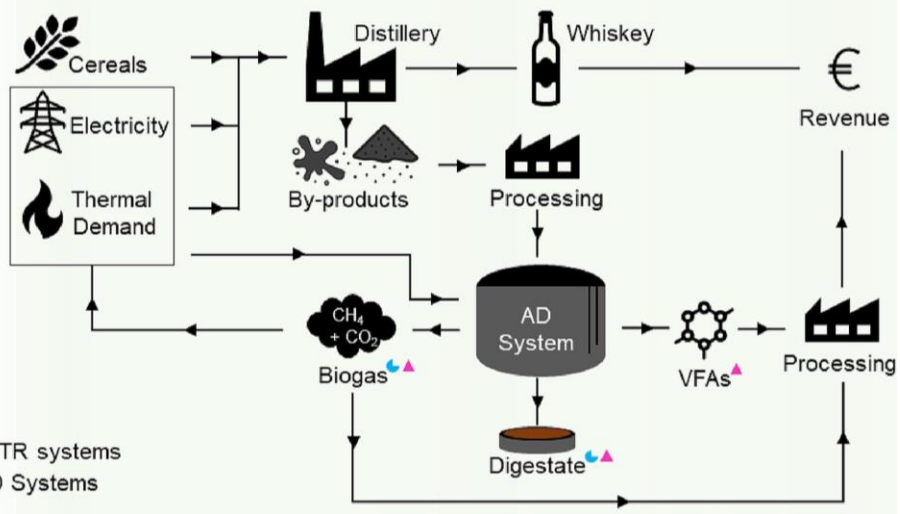
Two-phase anaerobic digestion for enhanced valorisation of whiskey distillery by-products

Anga Hackula^{a,b}, Rajas Shinde^{a,b,c}, Daniel Hickey^{a,b}, Richard O'Shea^{a,b}, Jerry D. Murphy^{a,b}, David M. Wall^{a,b,c}

Anaerobic
Digestion
Systems

Legend:

● : Traditional CSTR systems
▲ : Two-phase AD Systems



Similar methane yields between 3 systems assessed
Ability to replace 44% of distillery gas demand
Additional 0.14€/OLA



Prof Jerry Murphy



Dr Stephen Jackson



Dr Richard O Shea



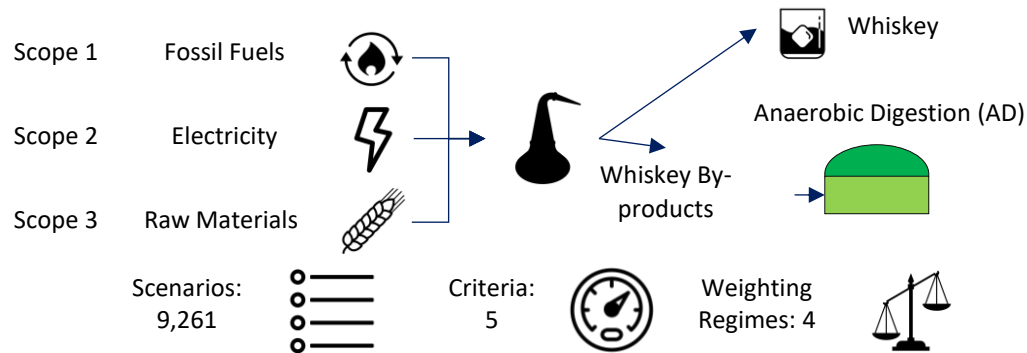
Dr Xihui Kang

Biofuel Research Journal 31 (2021) 1417-1432

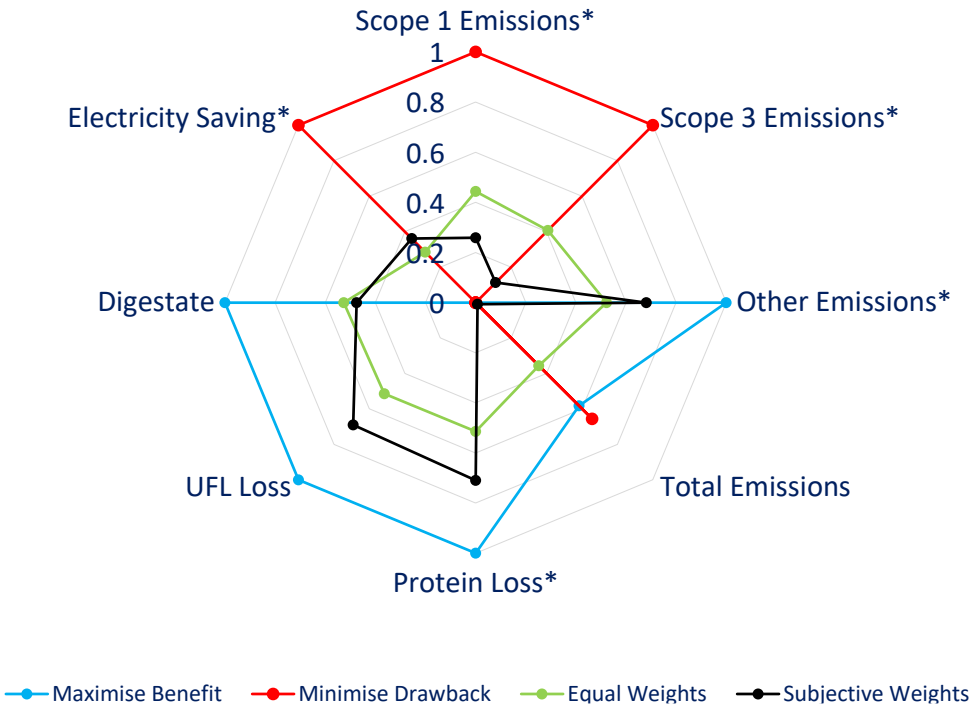


Original Research Paper

Distillery decarbonisation and anaerobic digestion: balancing benefits and drawbacks using a compromise programming approach



	Max benefit	Min drawback	Equal weights	Subjective weights
Draff (%)	100	0	50	100
Thick Stillage (%)	100	0	50	100
Thin Stillage (%)	100	0	55	0
Scope 1 Saving (%)	60	0	33	45
Scope 3 Saving (tCO₂eq)	11,389	0	6,748	10,105
Other emissions (ktCO₂eq)	38,641	0	20,165	26,315
Protein Loss (t)	13,554	0	6,974	9,618
Electricity Saving (MWh)	8,514	0	6,086	5,442



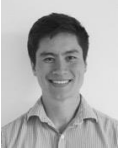
Decarbonizing whiskey production



Prof Jerry Murphy



Dr Stephen Jackson



Dr Richard O Shea



Dr Xihui Kang



Assessing decarbonisation pathways in the food and beverage sector: A multi-criteria decision analysis approach

Richard O'Shea^{a,b,*}, Richen Lin^c, David M. Wall^{a,b}, Jerry D. Murphy^{a,b}



Technologies:
5



Pathways:
21



Criteria:
5



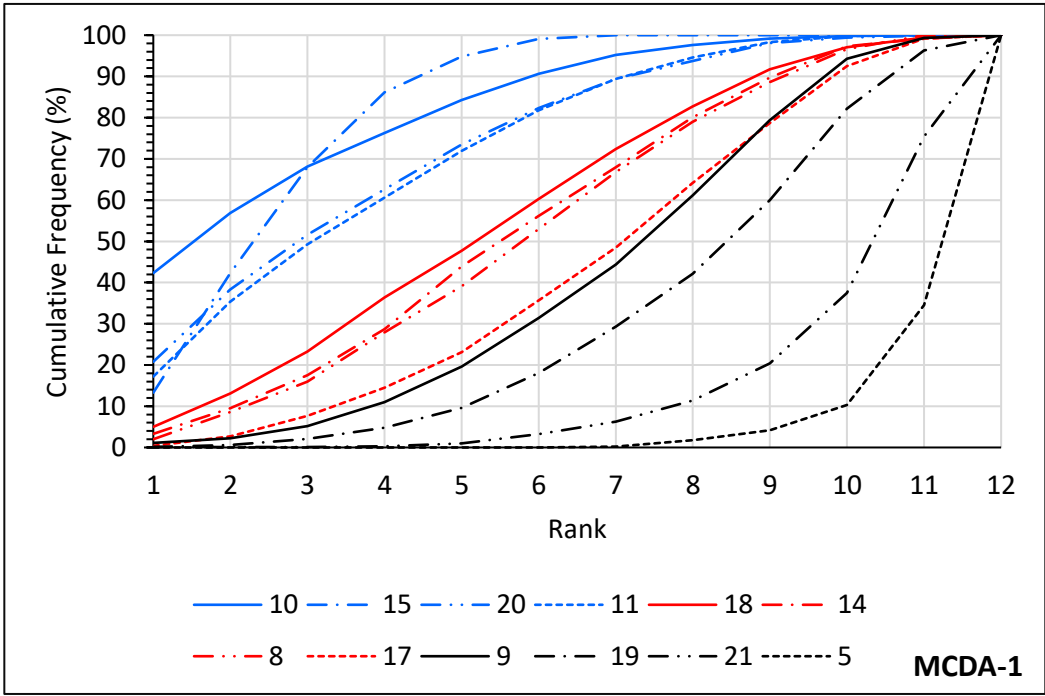
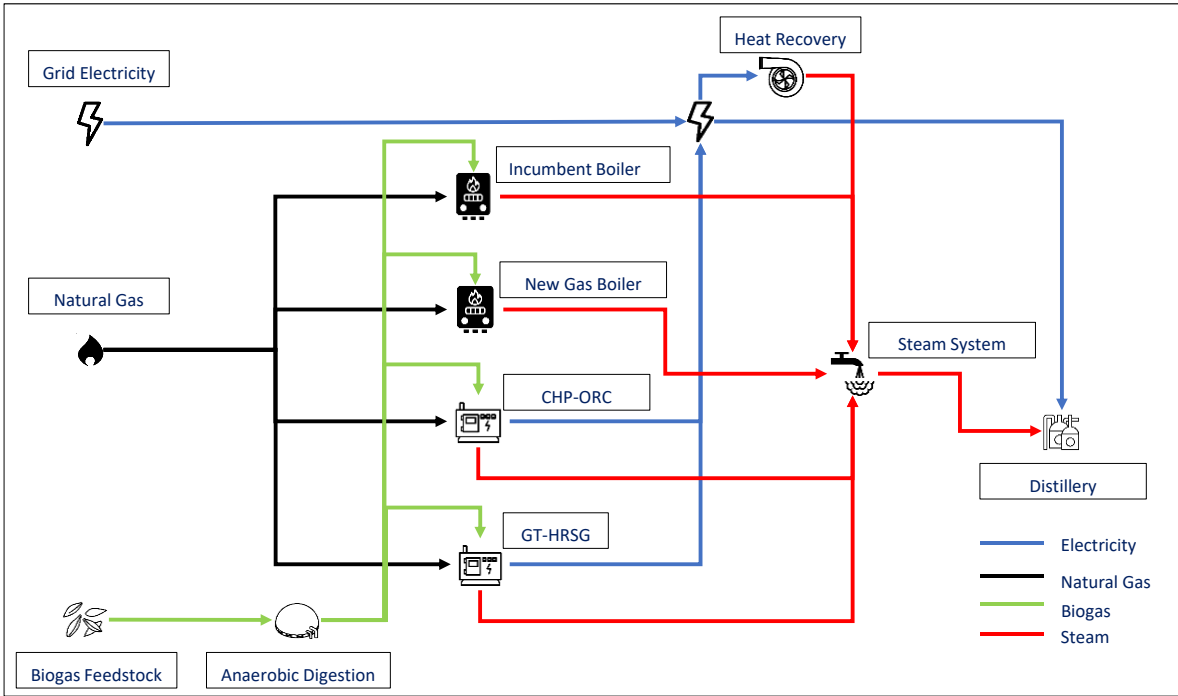
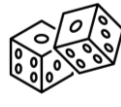
Weighting
Regimes:4



MCDAs Methods:
5



Monte Carlo
Simulations:
1,000

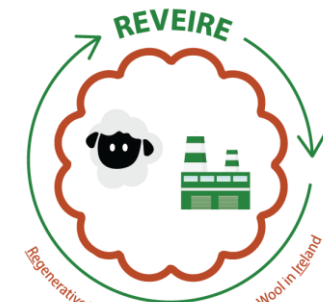


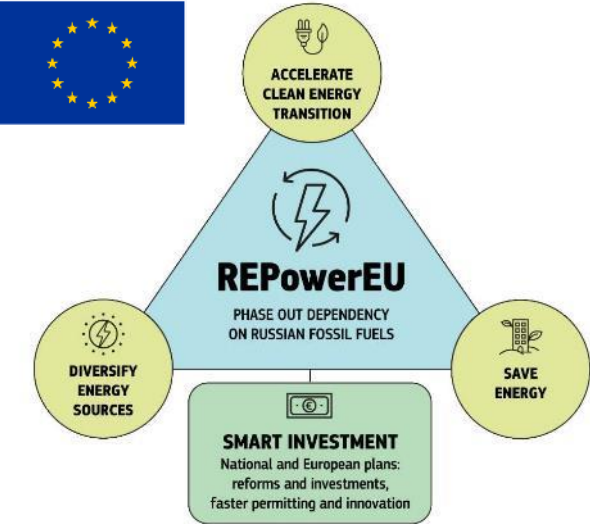
	Equal Weighting (MCDA-1)	Economic Only (MCDA-2)	Environment Only (MCDA-3)	Environment and Economy (MCDA-4)
Pathway	New Boiler & CHP-ORC & Heat Recovery	New Boiler & CHP-ORC & Heat Recovery	38kV & Heat Recovery & Biogas	New Boiler & CHP – ORC & Heat Recovery & Biogas
NPV (M€)	11.232	11.232	-15.398	-6.016
Project carbon saved (tCO ₂ eq)	342,383	342,383	780,365	765,188
LCOA (€/tCO ₂ eq)	-32.80	-32.80	19.73	7.86
Discounted payback (yr)	12.75	12.75	>20	>20
CAPEX/tCO ₂	1,524	1,524	480	932
Scope 1 emission reduction (%)	43	43	100	100



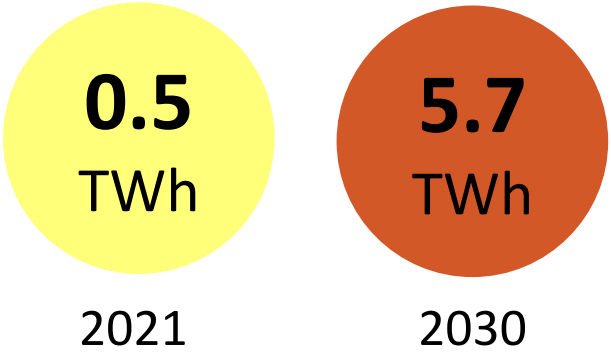
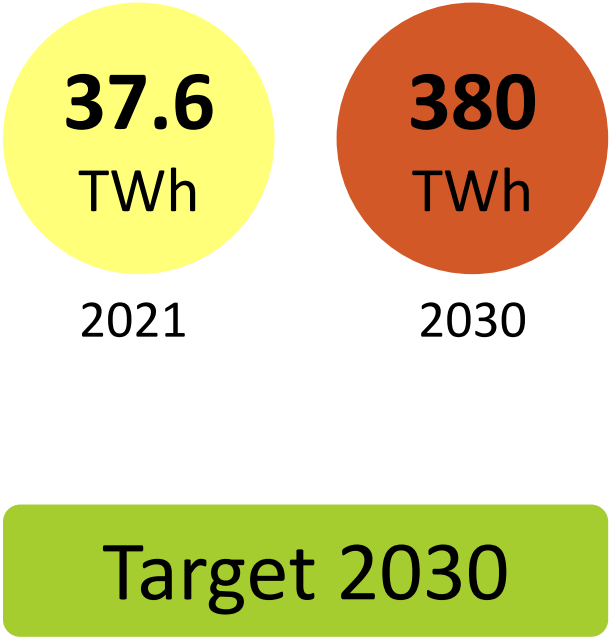
Dr Archishman Bose

- Eli Lilly Lecturer in Process and Chemical Engineering, UCC (2022)
- PhD in Engineering, focusing on Photosynthetic Biogas Upgrading, UCC (2022)
- MSc (Mechanical/Energy Engineering), KTH Royal Institute of Technology, Sweden and Politecnico di Torino, Italy (2018)
- BEng (Mechanical), Jadavpur University, Kolkata (2014)
- Program Director, MEngSc Pharmaceutical & Biopharmaceutical Engineering, UCC (2023)
- *Circular Bioeconomy and Industrial Symbiosis*
- *Process design and feasibility analyses* (technoeconomic analysis, life cycle assessment) with focus on biorefining





CLIMATE ACTION PLAN 2023
Changing Ireland for the Better



What is Sustainable Biomethane

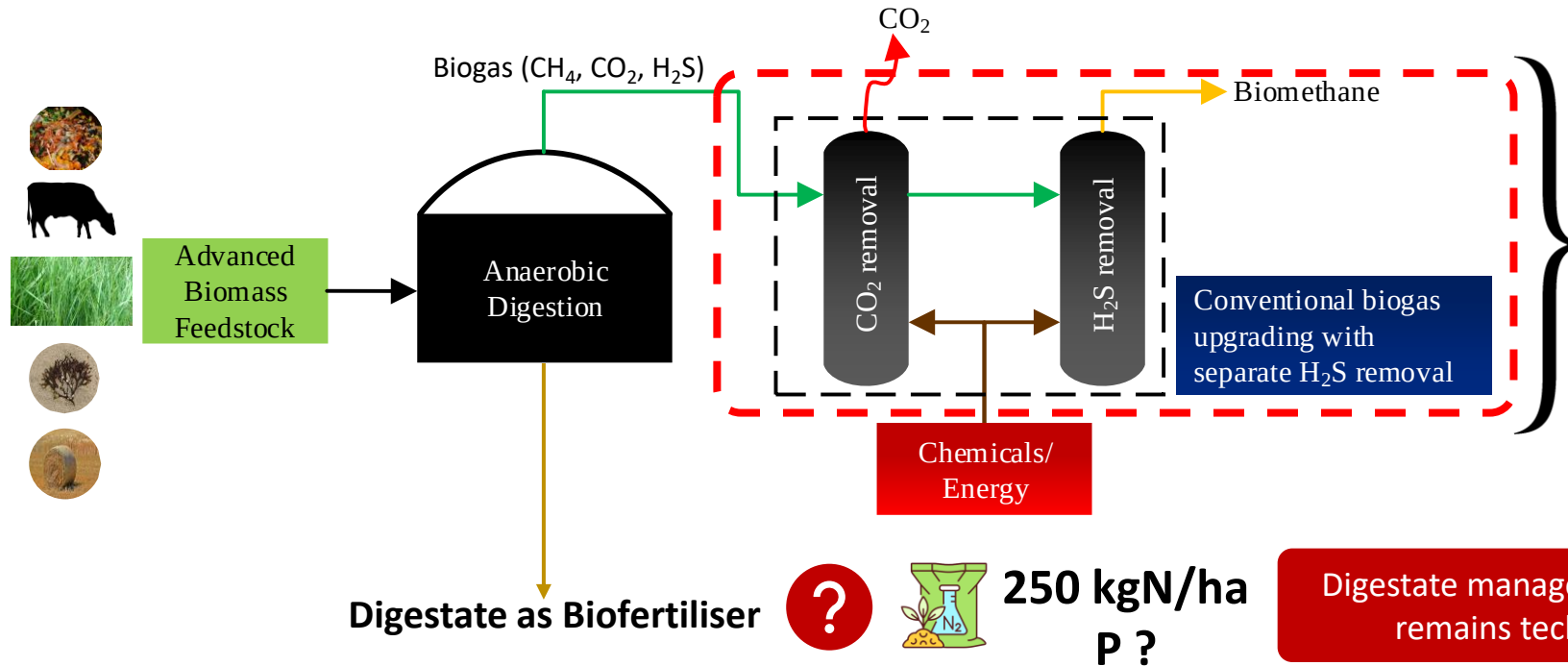


L 328/82 EN Official Journal of the European Union 21.12.2018

DIRECTIVES

DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 11 December 2018
on the promotion of the use of energy from renewable sources
(recast)
(Text with EEA relevance)

Advanced Anaerobic Digestion



Higher Cost & Energy

Problems of Scaling

Higher Marginal Abatement Costs

CO₂ released back into atmosphere

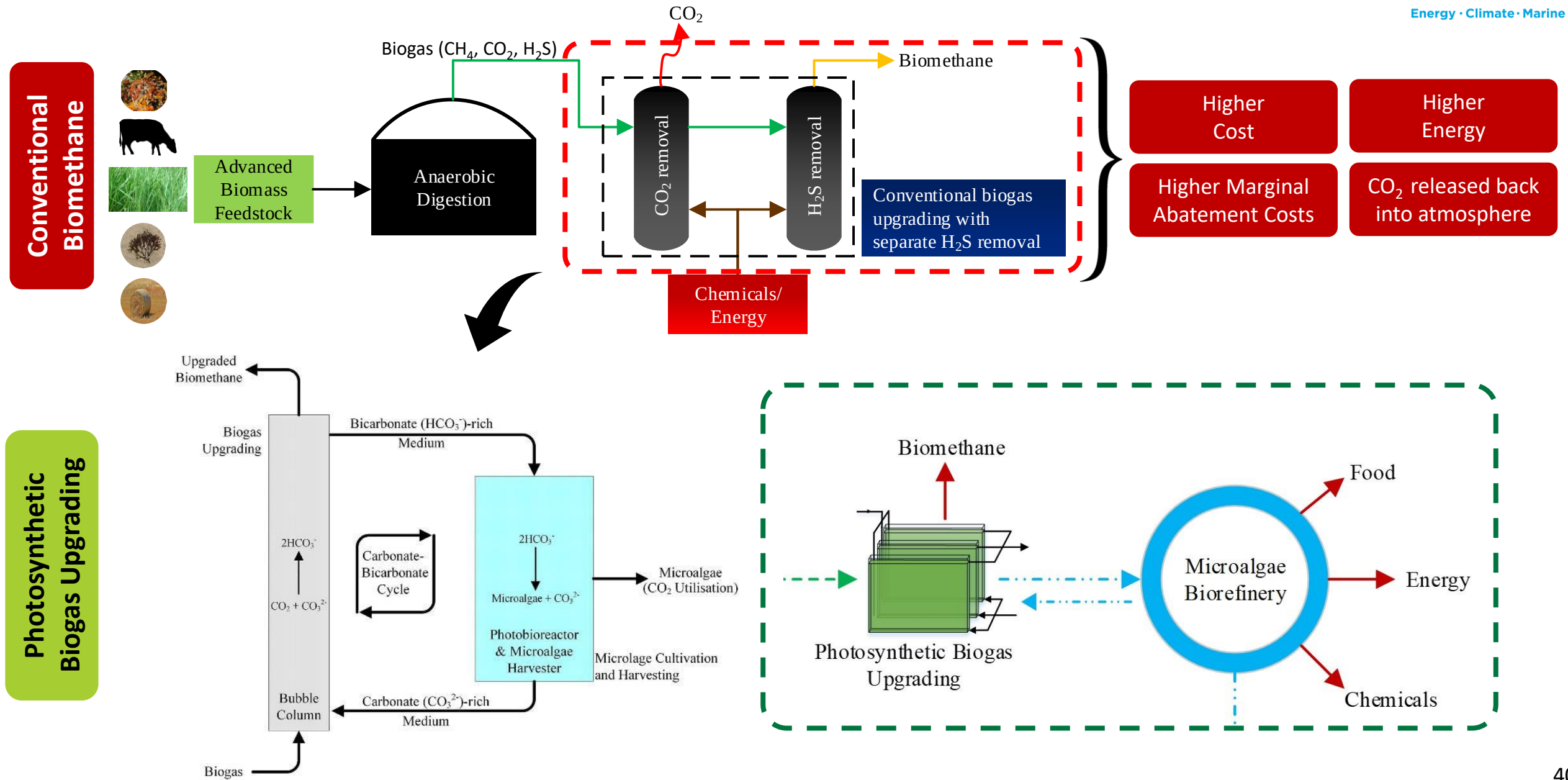
Digestate management and Land availability remains technological bottlenecks



Novel AD-Biorefineries

Need for more Sustainable Biogas Upgrading

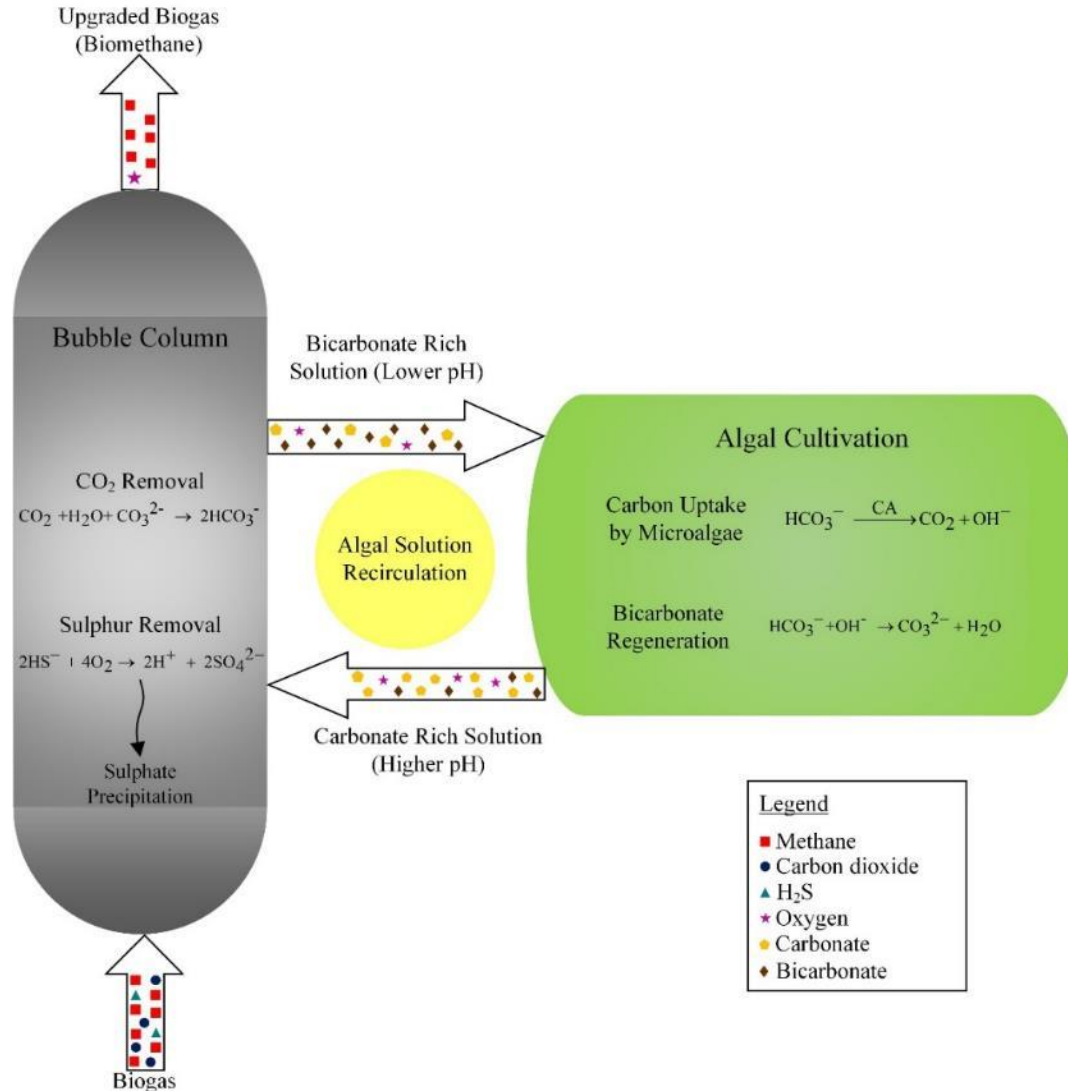
Need for alternative use of digestate



Novel Biogas Upgrading

Understanding the Process

Understanding the Process and its Opportunities



Biotechnology Advances 37 (2019) 107444



Contents lists available at ScienceDirect

Biotechnology Advances

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



Research review paper

How to optimise photosynthetic biogas upgrading: a perspective on system design and microalgae selection

Archishman Bose^{a,b}, Richen Lin^{a,b,c}, Karthik Rajendran^{c,e}, Richard O'Shea^{a,b}, Ao Xia^d, Jerry D. Murphy^{a,b,e}

^a Environmental Research Institute, MaREI Centre, University College Cork, Cork, T23 XE10, Ireland

^b School of Engineering, University College Cork, Cork, Ireland

^c Department of Environmental Science, SEM University-AP, Amaravati, Andhra Pradesh 522 502, India

^d Key Laboratory of Low-grade Energy Utilization Technologies and Systems, Chongqing University, Chongqing 400044, China



Bioresource Technology

Volume 304, May 2020, 123027



Review

A perspective on novel cascading algal biomethane biorefinery systems

Archishman Bose^{a,b}, Richard O'Shea^{a,b,c}, Richen Lin^{a,b}, Jerry D. Murphy^{a,b}

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<https://doi.org/10.1016/j.biortech.2020.123027>

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Chemical Engineering Journal

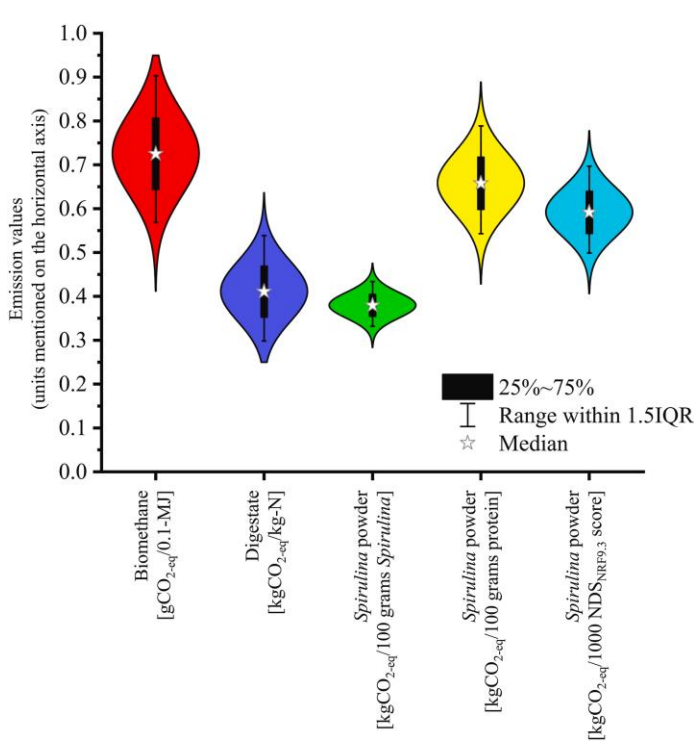
Volume 437, Part 1, 1 June 2022, 134988



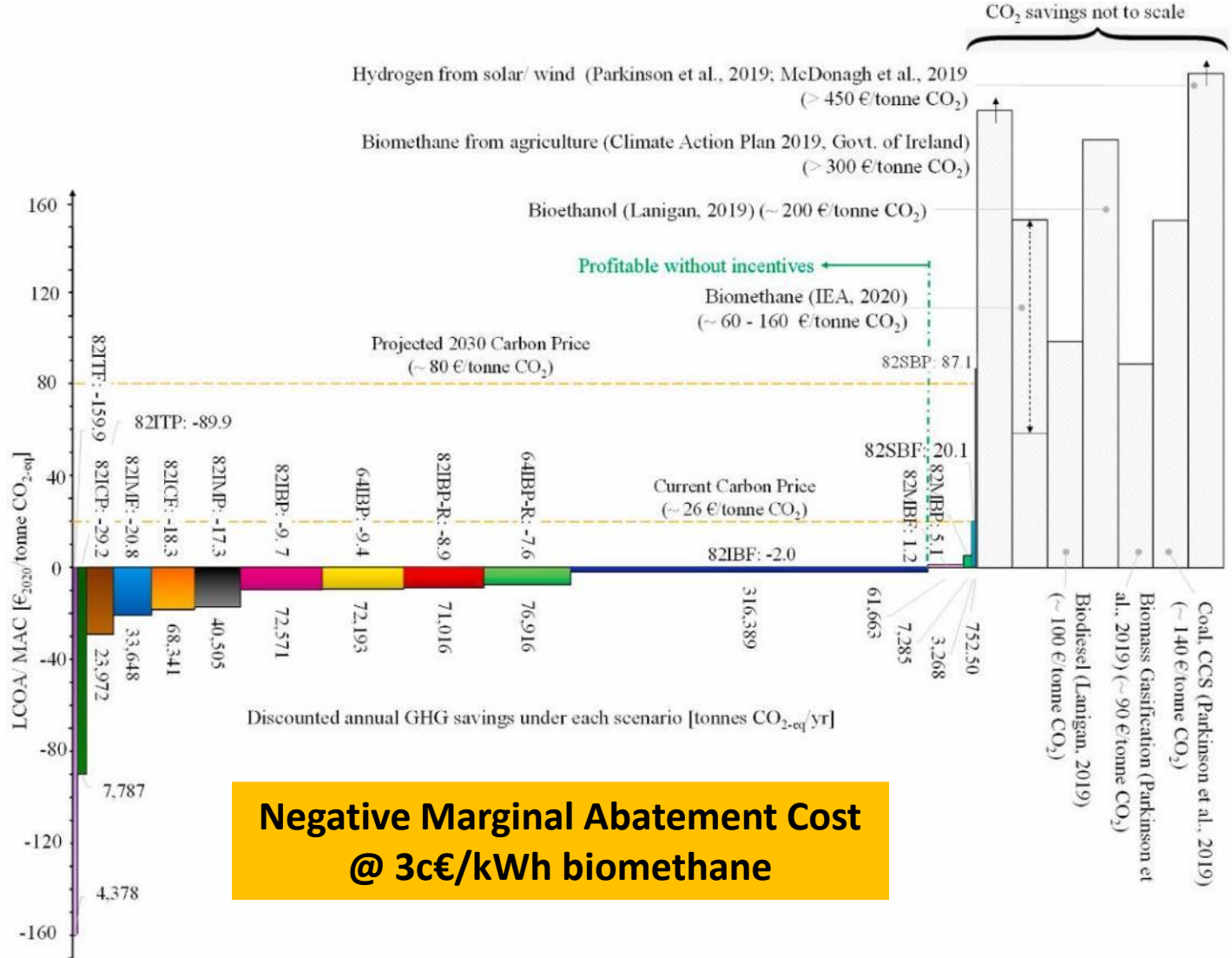
Optimisation and performance prediction of photosynthetic biogas upgrading using a bubble column

Archishman Bose^{a,b,c}, Richard O'Shea^{a,b,d}, Richen Lin^{a,b,d}, Jerry D. Murphy^{a,b,d}

Show more



**Biomethane @
< 10 gCO₂/MJ
(c. 90% emission reductio)**



**Negative Marginal Abatement Cost
@ 3c€/kWh biomethane**

4

Key Questions

?

How to optimise and scale-up the Bubble Column Reactor

?

Which local microalgae species is ideal in Ireland

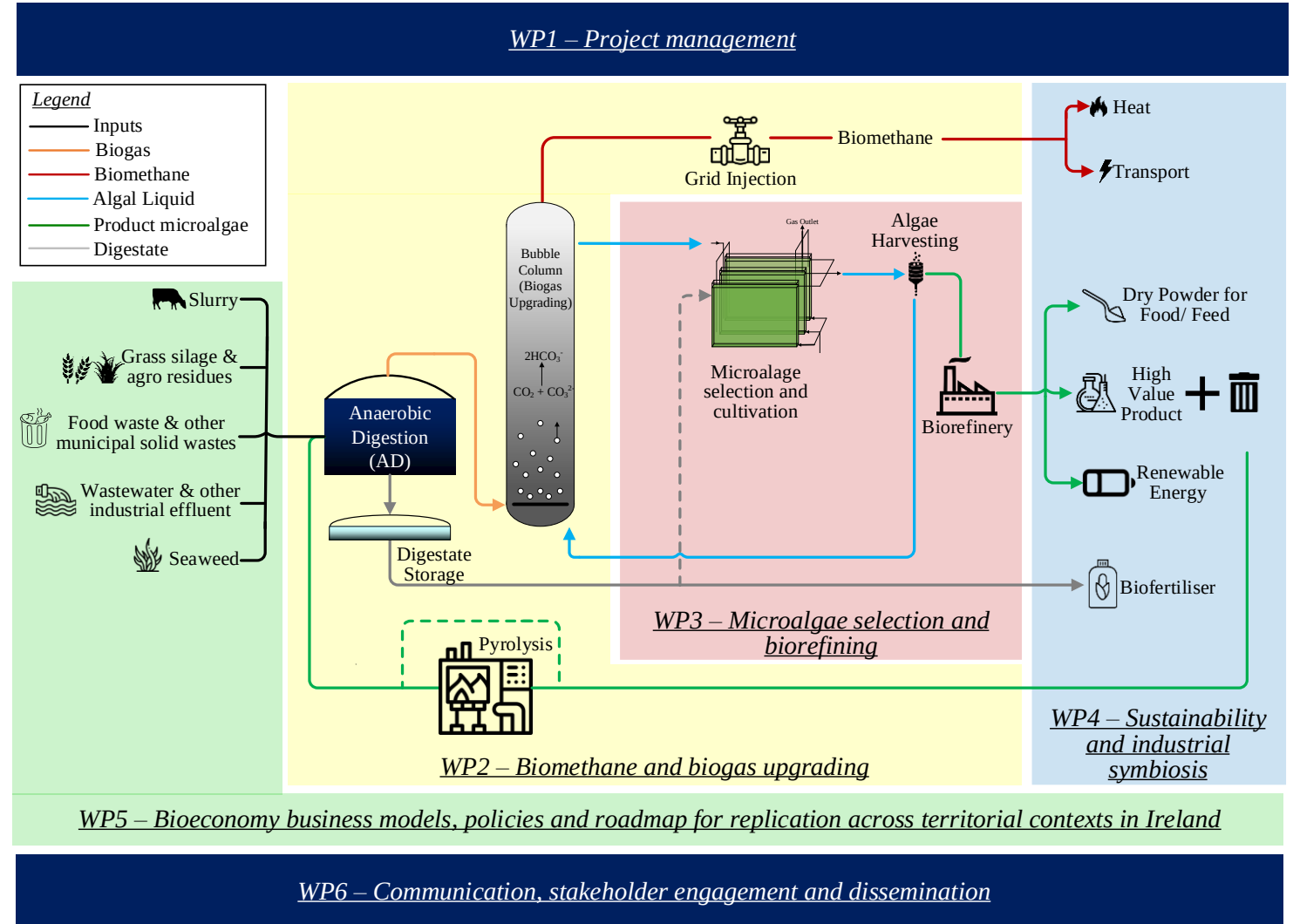
?

What product/ process configuration is optimal?

?

How to develop business models around this cascading process

Developing Cascading Biomethane Biochemicals and Biofertiliser Systems for a Circular Bioeconomy in Ireland (CABBBIE)



In practice (feasibility, acceptance, business models and scaleup)

Sustainability Assessments

NPV, IRR, E-ROI



Multi Criteria Decision Analyses



Business Model Development

Demand Analysis
Financing Model
Ownership Model

In the lab (deep science)

Scale-up via Piloting

Dissemination and Capacity Building

Policy and Roadmaps



Biotechnology Advances
Volume 82, September 2025, 108581

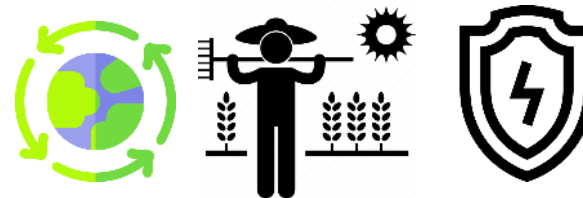
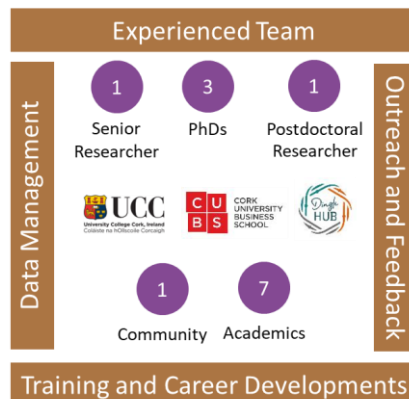


Microalgae species selection

Lab-scale optimisation

Selecting optimal algal strains for robust photosynthetic upgrading of biogas under temperate oceanic climates

Muhammad Nabeel Haider ^{a b}, Linda O'Higgins ^a, Richard O'Shea ^{a b}, Lorraine Archer ^c, David M. Wall ^{a b}, Nikita Verma ^{a b}, María del Rosario Rodero ^d, Muhammad Aamer Mehmood ^e, Jerry D. Murphy ^{a b}, Archishman Bose ^{a b} ✉



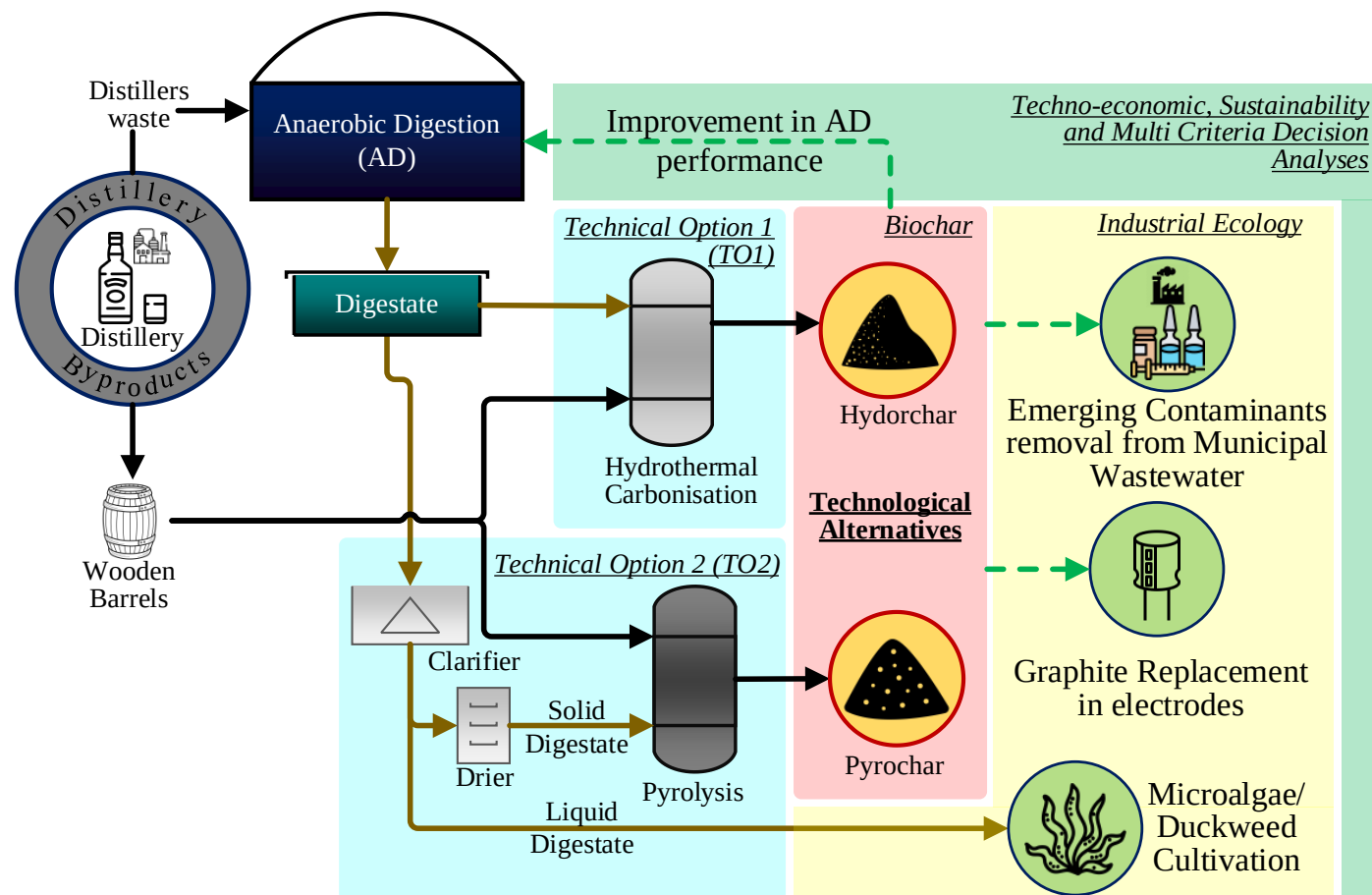


Digestate to Biochar



Engineered Organic Carbon-based
EMERGE
Functional Materials for Energy and Water

Engineered Organic Carbon-based Functional Materials for Energy and Water (EMERGE)



Distillery by-products
(consistent feedstock)



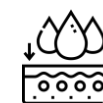
Anaerobic digestate ?



Biochar

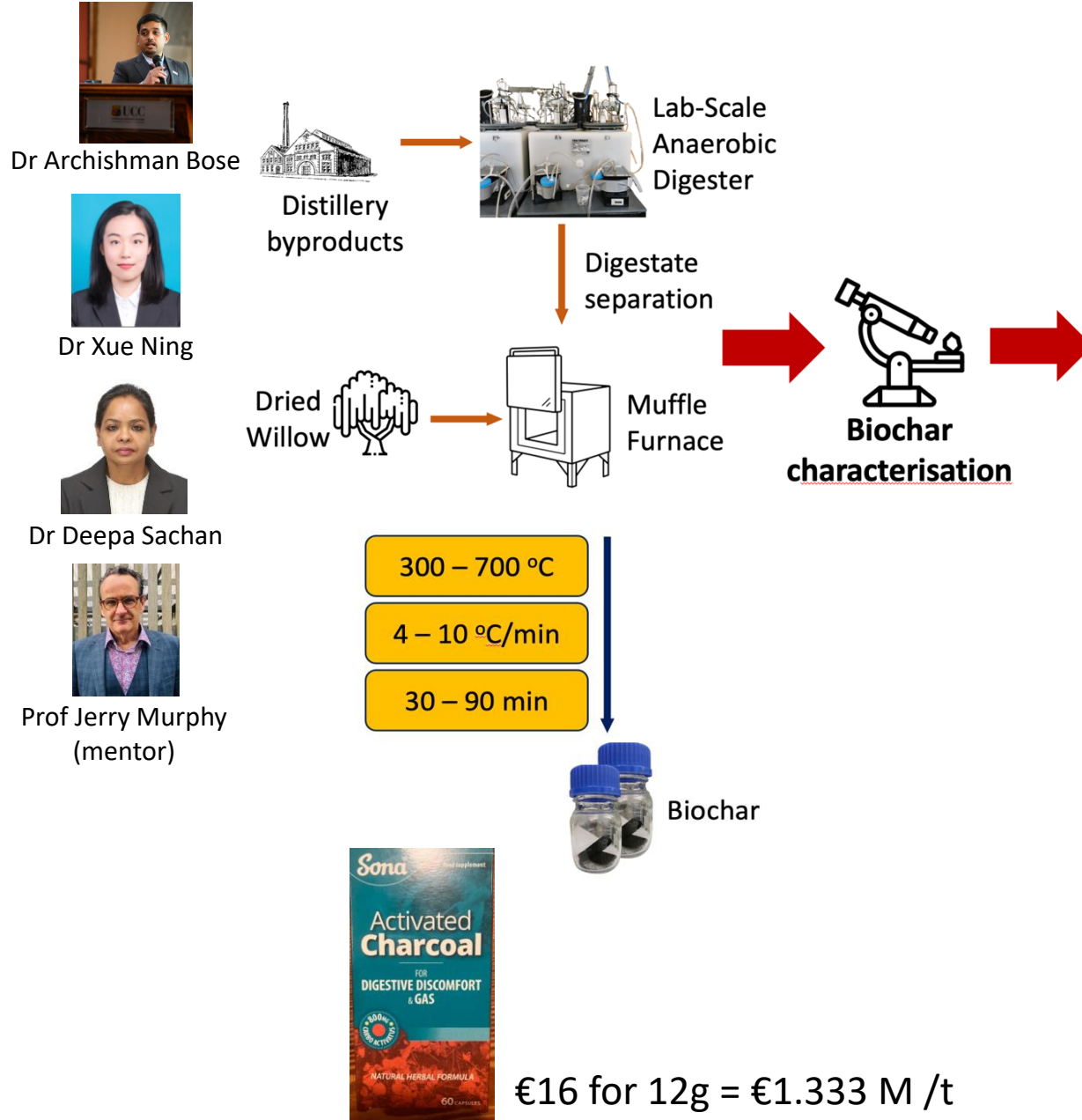


Novel Adsorbent

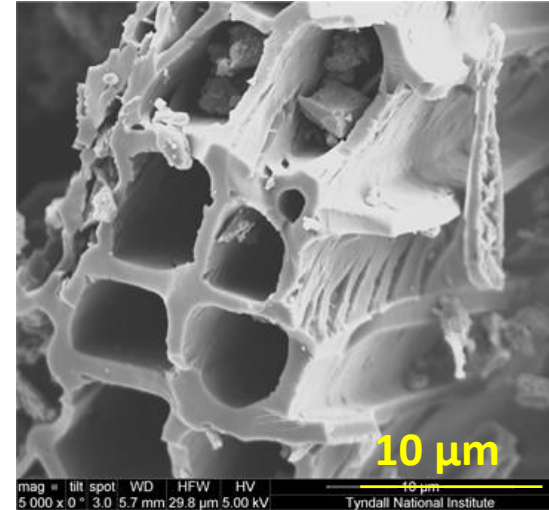


Graphite Replacement





Biochar at 700 °C, 90 mins



- ↑ BET surface area **54.4m²/g**
- ↑ High Conductivity **23.6 µS/cm**
- ↑ Surface Morphology & Functional Groups
- ! Large Variation within batches!

Acid-Treated Biochar

- ↗ BET Surface Area **391.5 m²/g (7-fold increase)**
- ↗ Conductivity **44.5 µS/cm g (2-fold increase)**
- ↗ Improved Consistency



Tube Furnace



Muffle Furnace



Microwave Digester



**Surface Area
Analyser**

Lab-scale
experiments

Characterisation of
biochar

Optimisation of
operations

Mapping Pathways
for Scale-up



**BET Surface Area and Pore
Volume Analyser**



FTIR



Scanning Electron Microscopy



X-ray Diffractometry

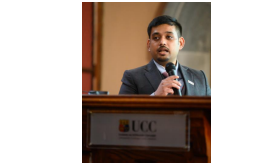


Raman Spectroscopy



**EDX (Energy-Dispersive X-
ray analysis)**

Can Biochar Remove Emerging Contaminants?



Dr Archishman Bose



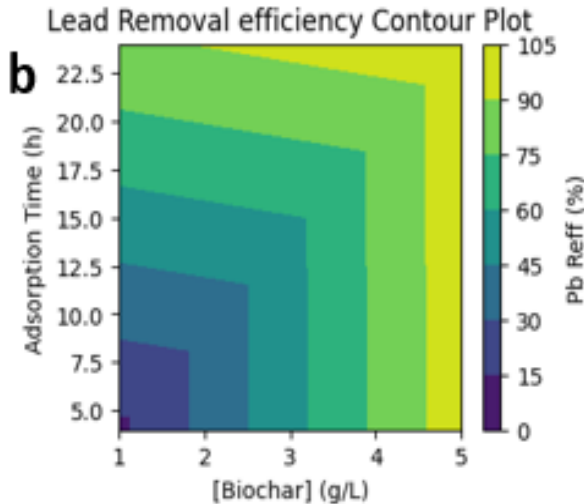
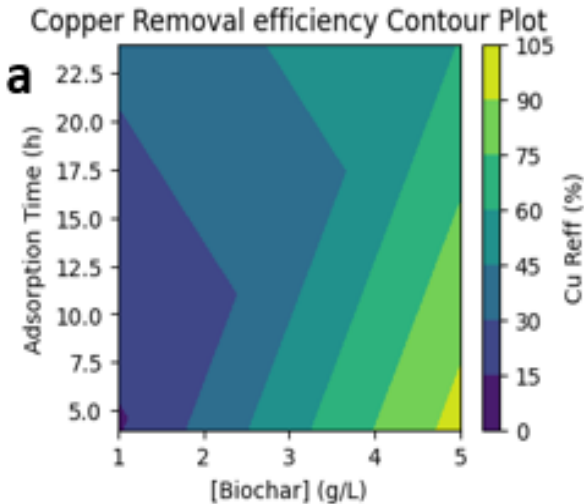
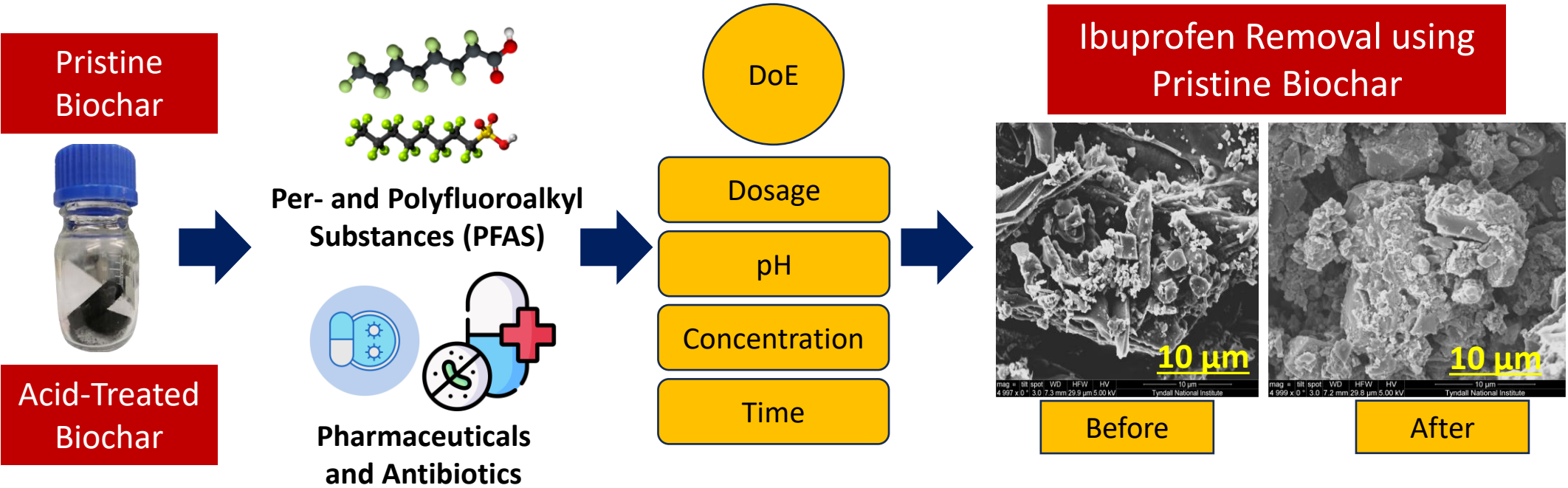
Dr Xue Ning



Dr Deepa Sachan

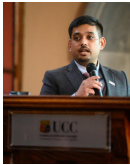


Prof Jerry Murphy
(mentor)





Dr Xue Ning



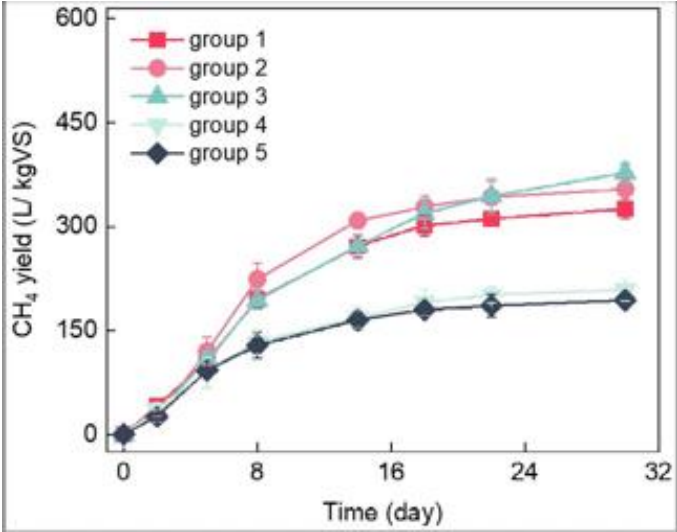
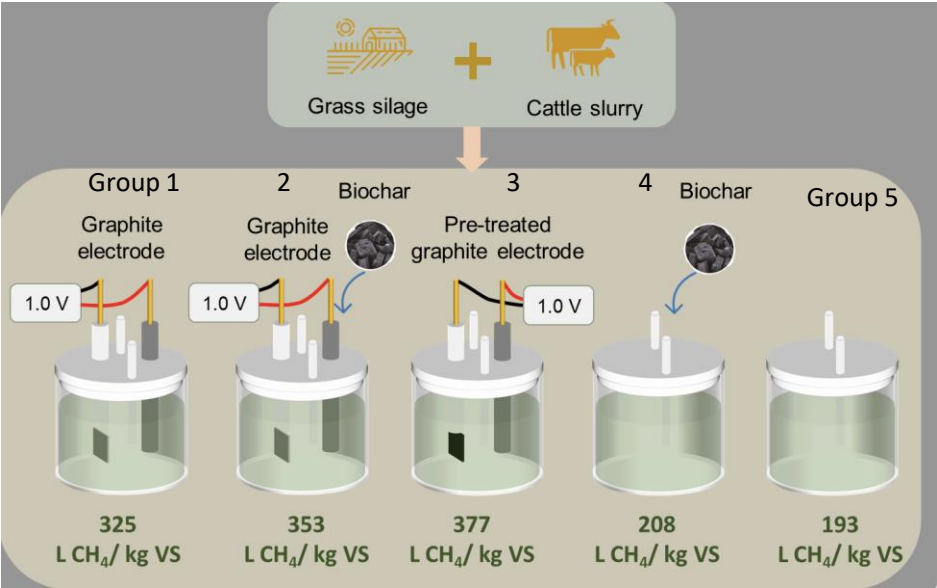
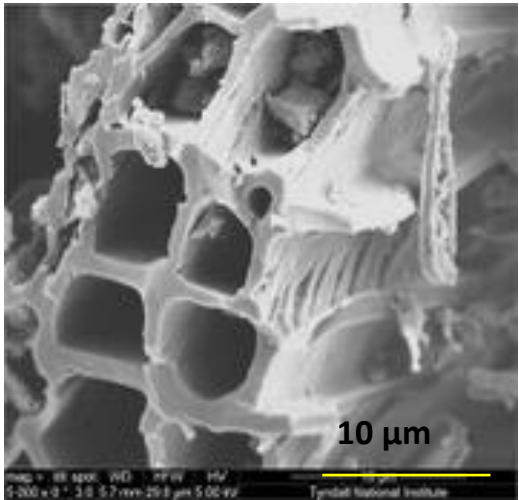
Dr Archishman Bose



Prof Jerry Murphy
(mentor)

Description: Minimising feedstocks to facilitate RePowerEU target of 35 bcm of biomethane by 2030

- (1) Two phase digestion with biochar electrodes to improve biomethane production.
- (2) Replacing graphite electrodes with biochar-based electrodes could improve sustainability of adding electrodes to AD.
- (3) The concept could be extended to microbial electrosynthesis for CO₂ valorisation



Improving biomethane production from biochar-supplemented two-stage anaerobic digestion of on-farm feedstocks

Xue Ning^{*,†}, Chen Deng^{*,†}, R. W. Daniel T. Hickey^{*,†}, Anna Hackula^{*,†}, Richard O'Shea^{*,†}, David M. Wall^{*,†}, Richan Lin^{*,†}, Jerry D. Murphy^{*,†}



Biochar facilitates biofuel production through batch single-stage and two-stage digestion of grass silage and cattle slurry

Xue Ning^{*,†}, Chen Deng^{*,†}, R. W. Daniel T. Hickey^{*,†}, Anna Hackula^{*,†}, Richard O'Shea^{*,†}, David M. Wall^{*,†}, Richan Lin^{*,†}, Jerry D. Murphy^{*,†}



Improving the efficiency of anaerobic digestion and optimising *in-situ* CO₂ bioconversion through the enhanced local electric field at the microbe-electrode interface

Xue Ning^{*,†}, Richan Lin^{*,†}, R. W. Daniel T. Hickey^{*,†}, Anna Hackula^{*,†}, Richard O'Shea^{*,†}, David M. Wall^{*,†}, Jerry D. Murphy^{*,†}

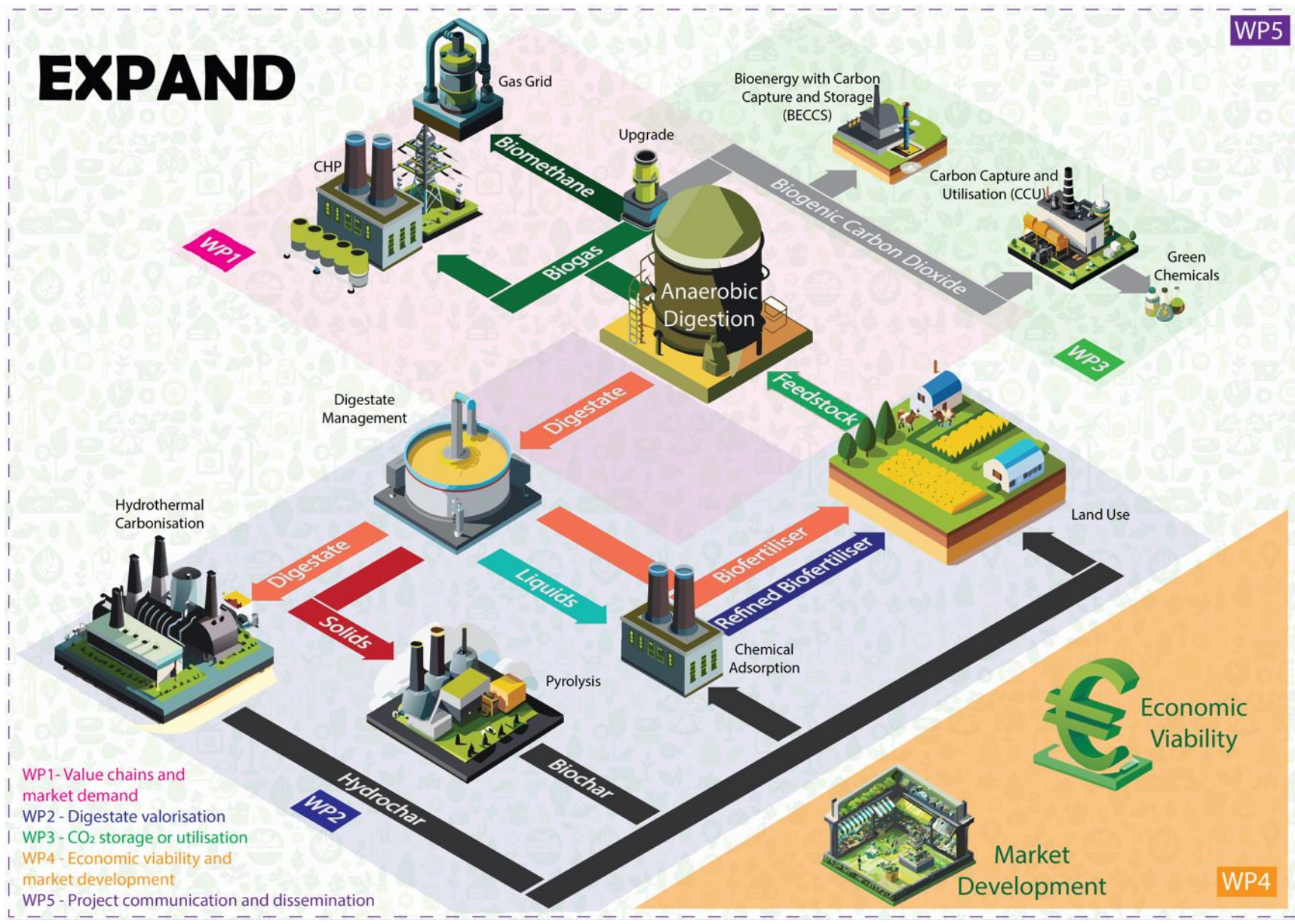
Cell Reports
Physical Science

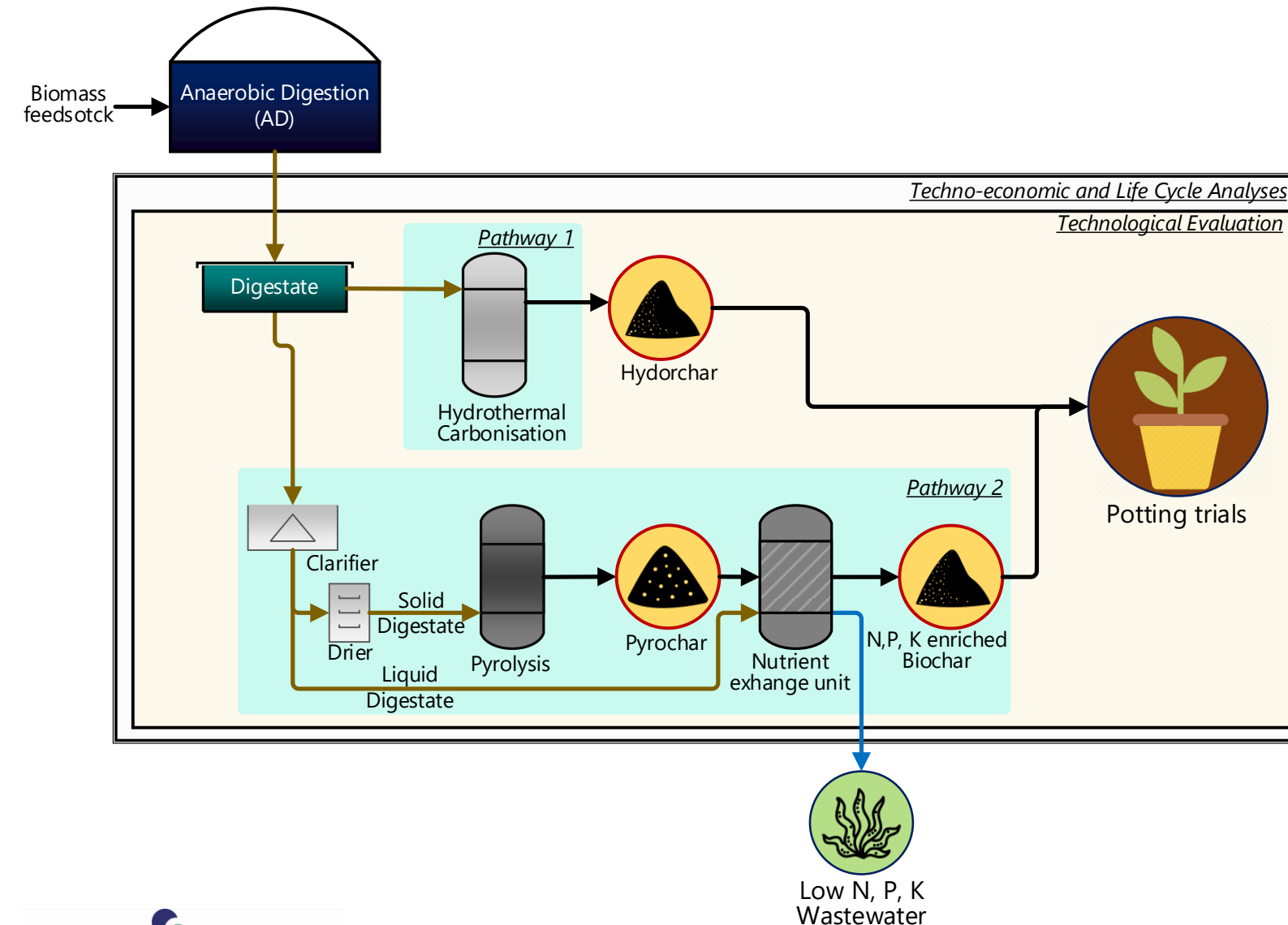


Article
Microbe-electrode interactions on biocathodes are facilitated through tip-enhanced electric fields during CO₂-fed microbial electrosynthesis



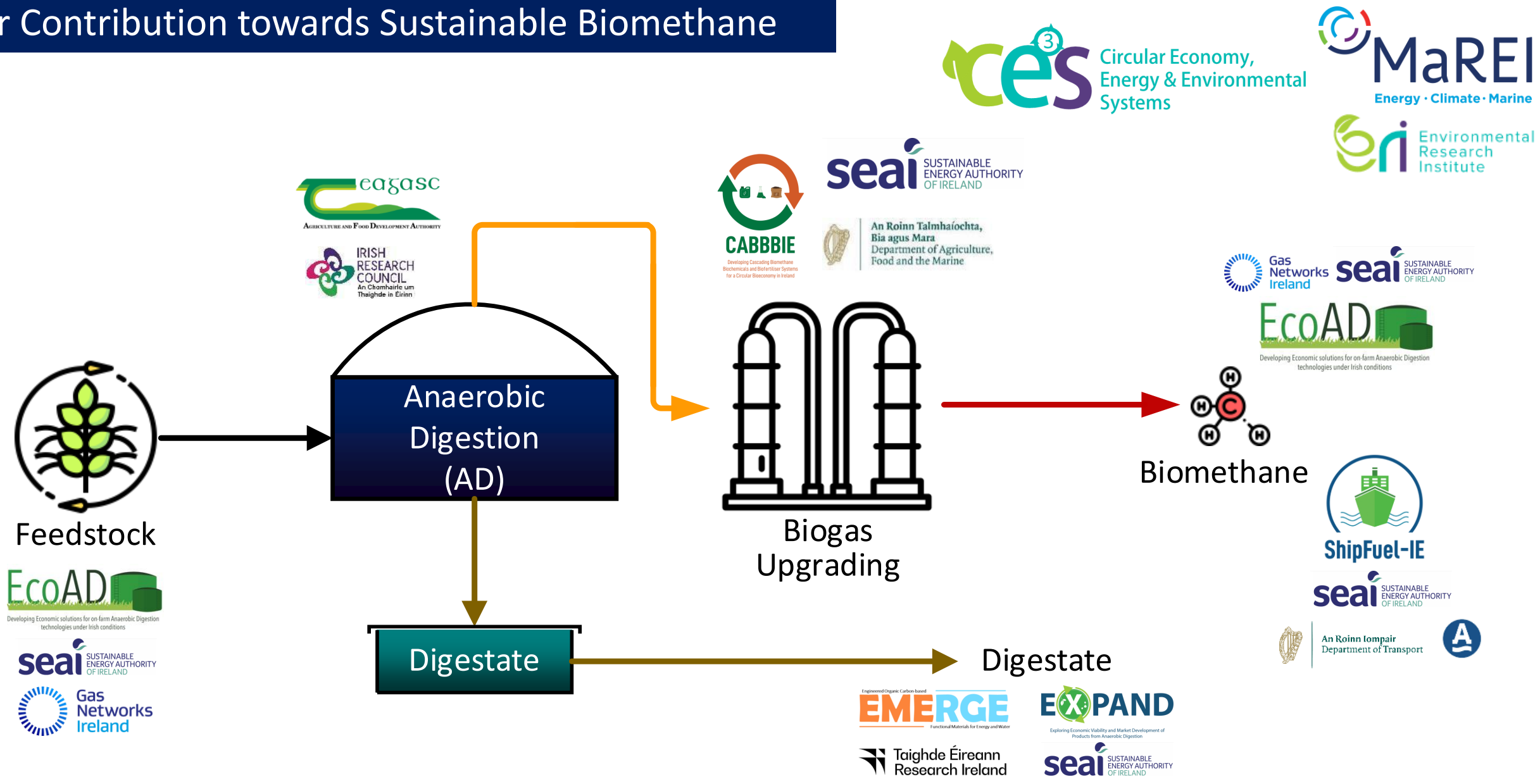
Exploring Economic Viability and Market Development of Products from Anaerobic Digestion





- 1 Assessment of **conventional digestate management options** focusing on digestate as a biofertiliser.
- 2 **Production of pyrochar and hydrochar** from digestate as a **soil amendment** and a **biofertiliser**.
- 3 **Nutrient adsorption capacity of pyrochar** from liquid digestate.
- 4 **Pot trials to assess grass growth yield** from different biochars.
- 5 **Techno-economic and lifecycle assessment** of biochar fertilisers v. direct land spreading of digestate

Our Contribution towards Sustainable Biomethane



Thank you

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