# Europe: Energy, Agriculture and Climate: current challenges & future outlooks

Prof Jerry d Murphy,

THINK NEGATIVE: CARBON NEGATIVE AGRICULTURE TO PRODUCE MORE CONSUMING LESS

**Rome Date:** March 13th, 2024

MaREI Energy · Climate · Marine

A World Leading SFI Research Centre

Science Foundation Ireland For what's next

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# Prof. Jerry D Murphy

Director MaREI centre (2015)

Professor of Civil Engineering, UCC (2017)

Engineers Ireland Excellence award (2015)

Biogas Task Leader IEA Bioenergy (2016 - 2021)

Marine Industry award for excellence (2017)

Adjunct Professor University of Southern Queensland (2018)

Fellow of the Irish Academy of Engineers (2019)

Advisory Board of German Bioenergy Research Centre (2020)

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**Prof Jerry Murphy**

*Director: MaREI*

Professor of Civil Engineering

**Dr Archishman Bose**

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Eli Lily Lecturer in Process Engineering

**Dr David Wall**

*Advanced Fuels & Circular Economy*

Lecturer in Transportation Engineering

**Dr Richard O Shea**

*Industrial Ecology*

Lecturer in Sustainability in Enterprise

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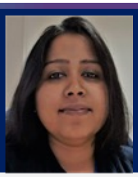
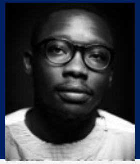
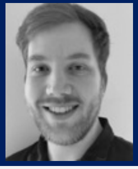

Dr Vaishali Thaore


Dr Richen Lin


Milena Marycz


Xue Ning


Kwame Donkor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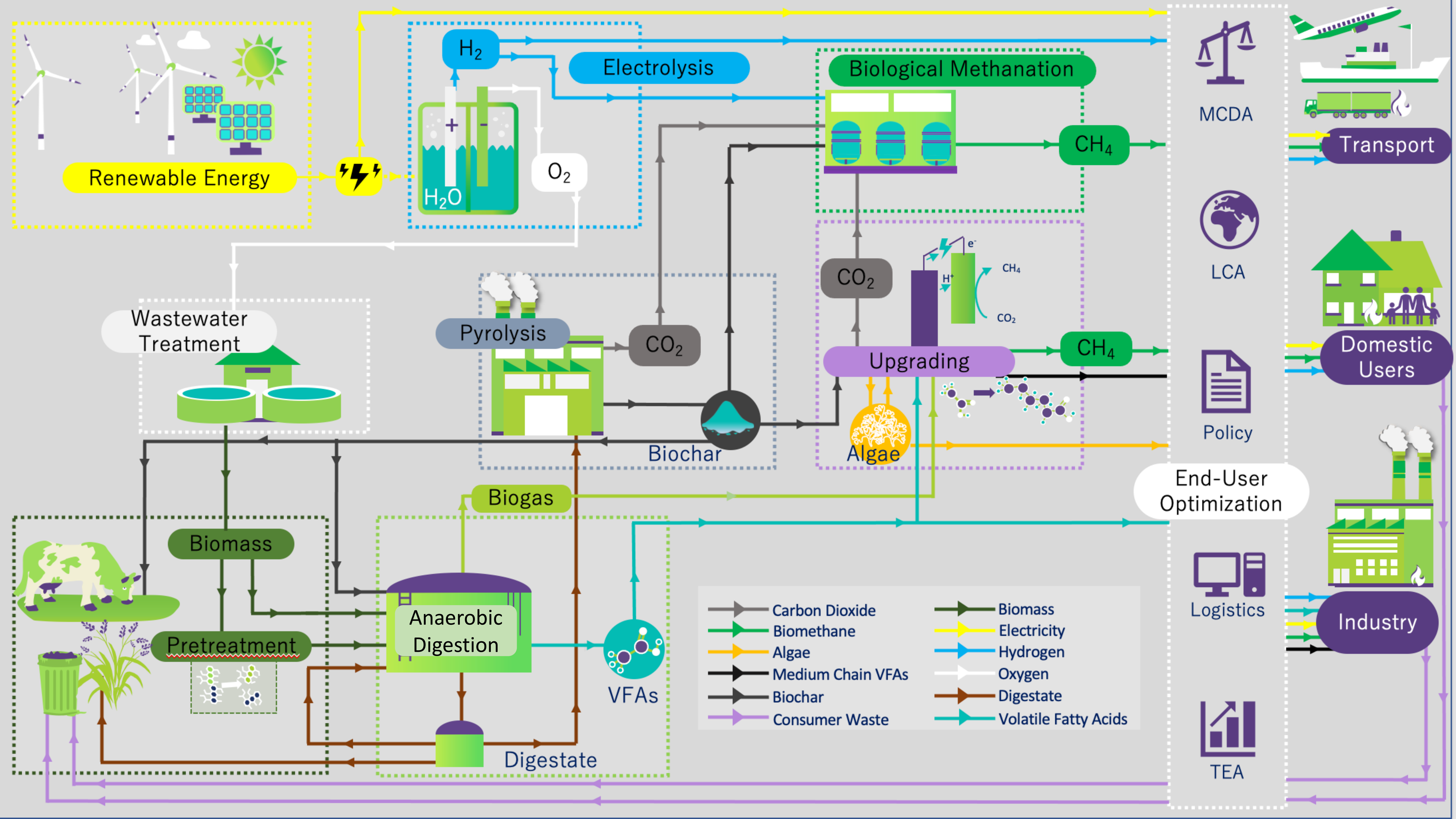
Anga Hackula


Rajas Shinde


Yunfei Li


Dr Kunwar Paritosh



Renewable Energy
$H_2$
Electrolysis
$H_2O$
$O_2$
Biological Methanation
$CH_4$
$CO_2$
Pyrolysis
Wastewater Treatment
Biochar
$CO_2$
$e^-$
$H^+$
$CH_4$
$CO_2$
Upgrading
$CH_4$
Algae
Biogas
Biomass
Pretreatment
Anaerobic Digestion
VFAs
Digestate
MCDA
LCA
Policy
End-User Optimization
Logistics
TEA
Transport
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Industry
Carbon Dioxide
Biomethane
Algae
Medium Chain VFAs
Biochar
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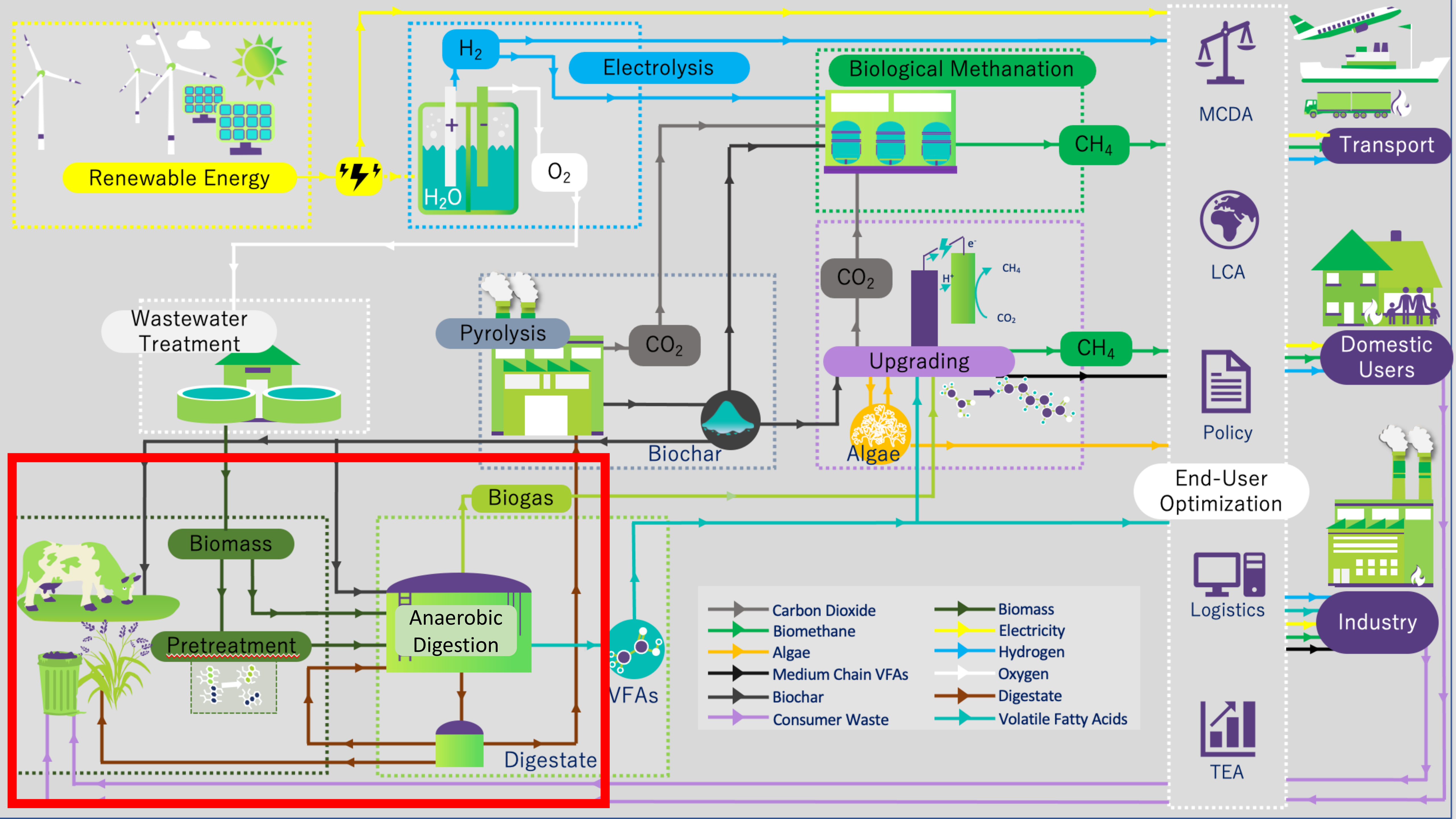
Biomass
Electricity
Hydrogen
Oxygen
Digestate
Volatile Fatty Acids



Renewable Energy
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H2O
O2
Electrolysis
Biological Methanation
CH4
MCDA
Transport
LCA
CO2
CH4
CO2
e-
H+
Wastewater Treatment
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CO2
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CH4
Domestic Users
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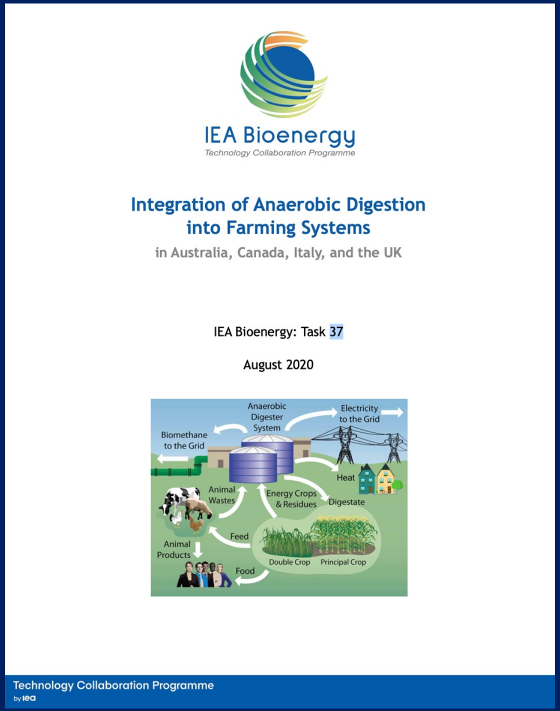
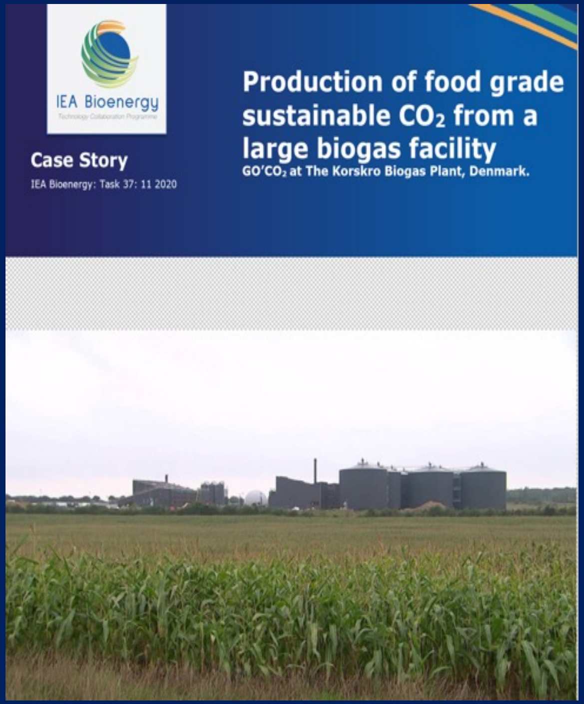
TEA

# INTERNATIONAL ENERGY AGENCY TCP in BIOENERGY: BIOGAS TASK






## Technical Reports

http://task37.ieabioenergy.com/technical-brochures.html

## Case Stories:

http://task37.ieabioenergy.com/case-stories.html

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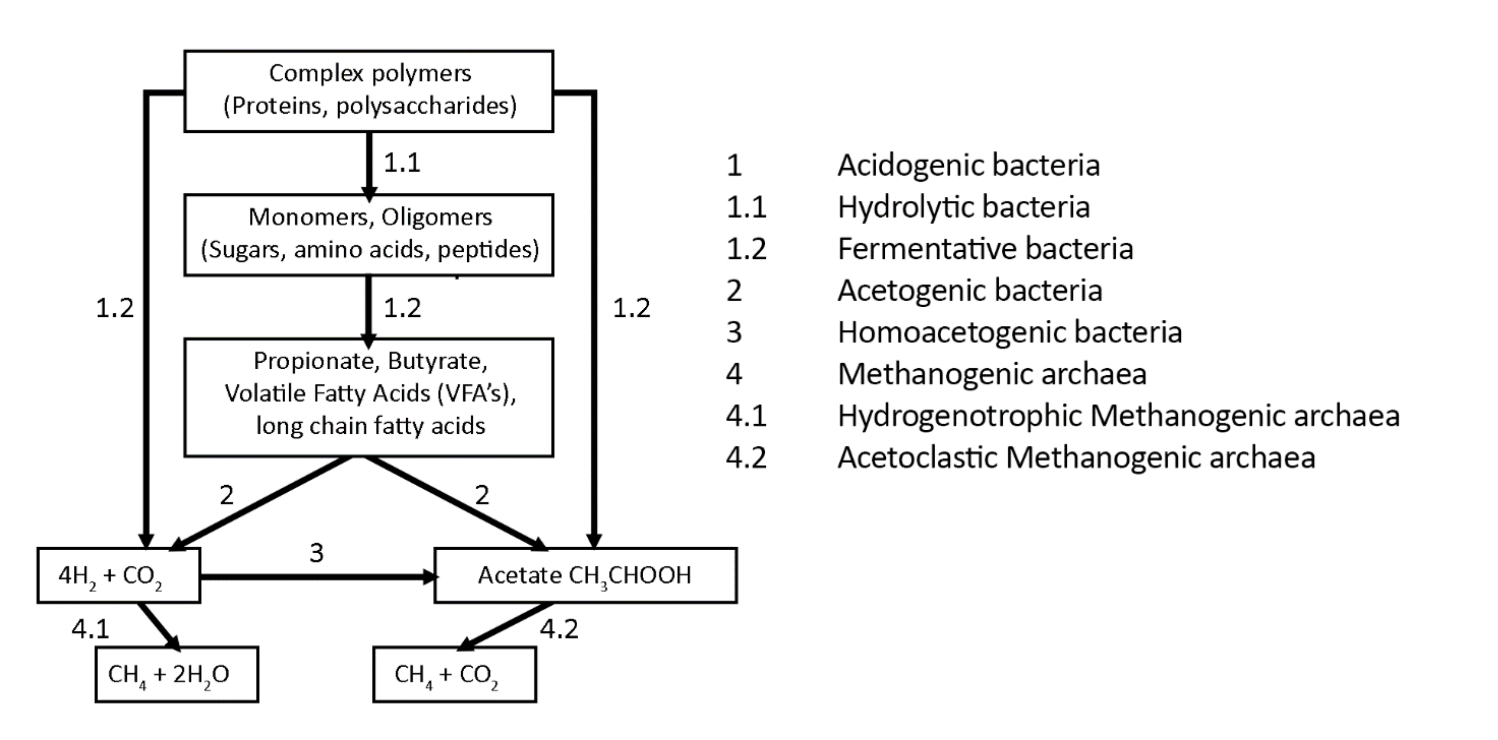
# WE NEED BIOGAS, RENEWABLE BIOMETHANE, RENEWABLE FERTILISER AND $CO_2$

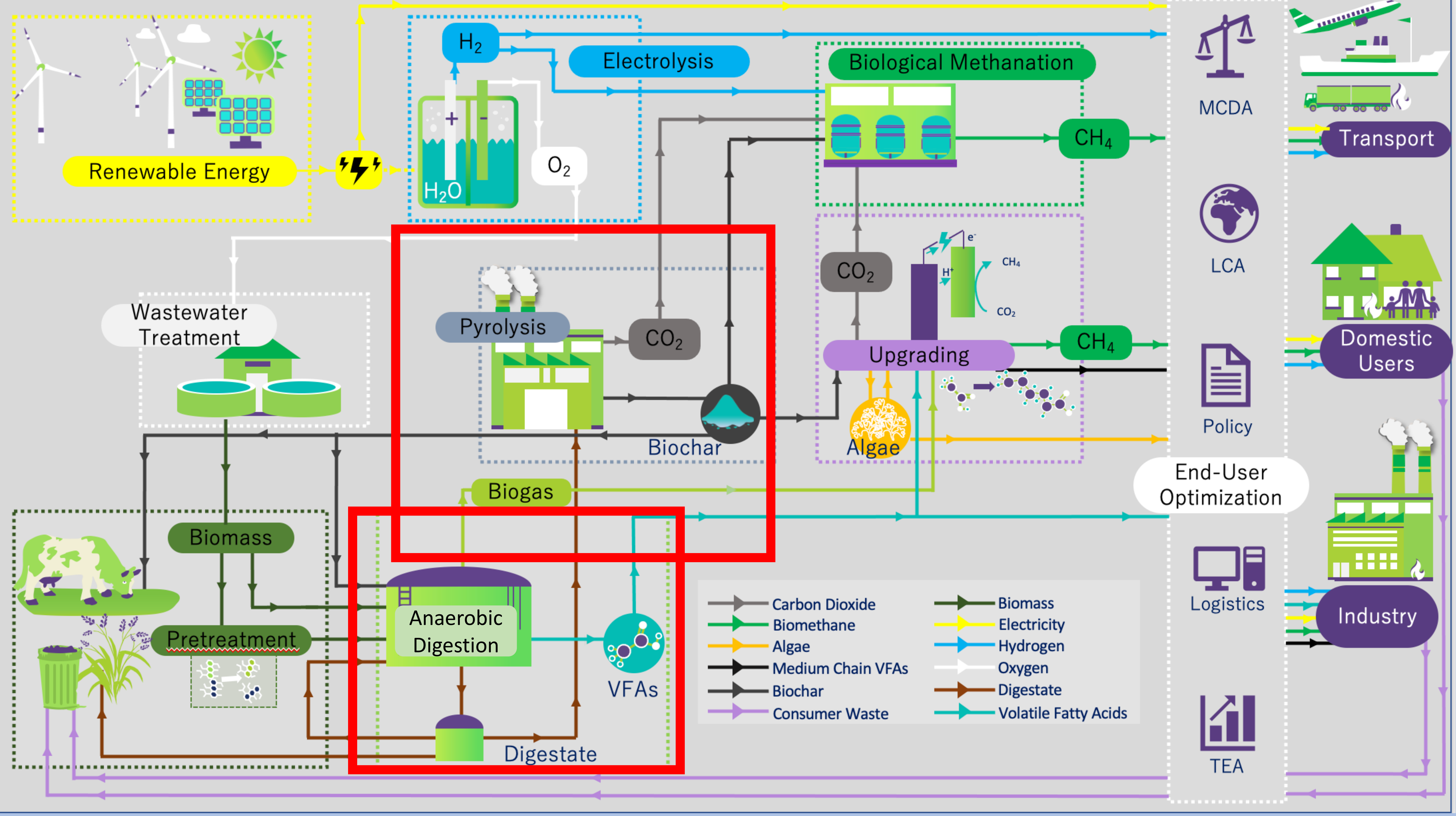



## REPowerEU

In 2020 production of biomethane in the EU was 3 billion cubic meters (bcm). REPowerEU set a target of 35 bcm for biomethane; a 10 fold increase.

## Climate Action Plan

5.7TWh of biomethane by 2030 in Ireland
Equivalent to 650MW of continuous production
Equivalent to 220 number 3MW facilities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# TWO-PHASE DIGESTION WITH BIOCHAR ADDITION

Journal of Cleaner Production 423 (2023) 138723

Contents lists available at ScienceDirect

Journal of Cleaner Production

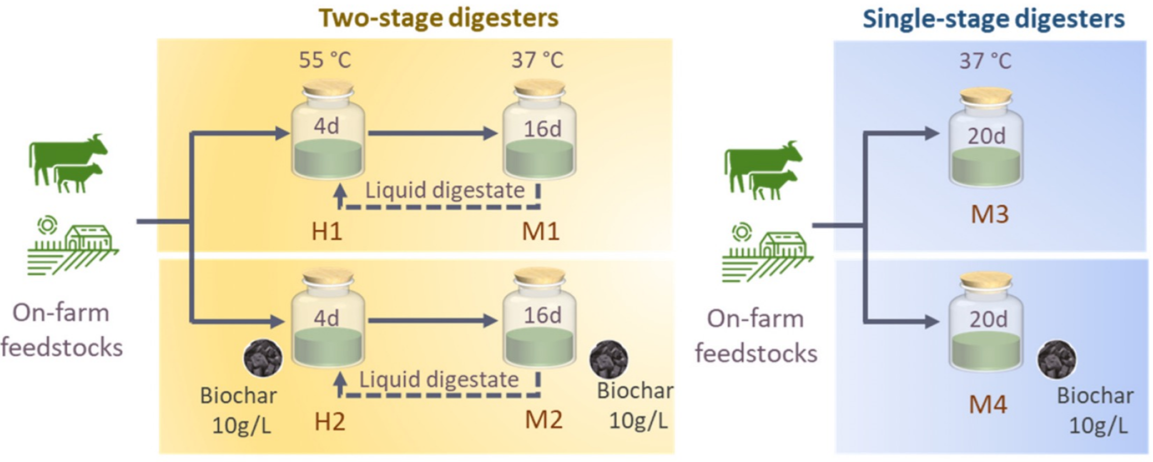
journal homepage: www.elsevier.com/locate/jclepro

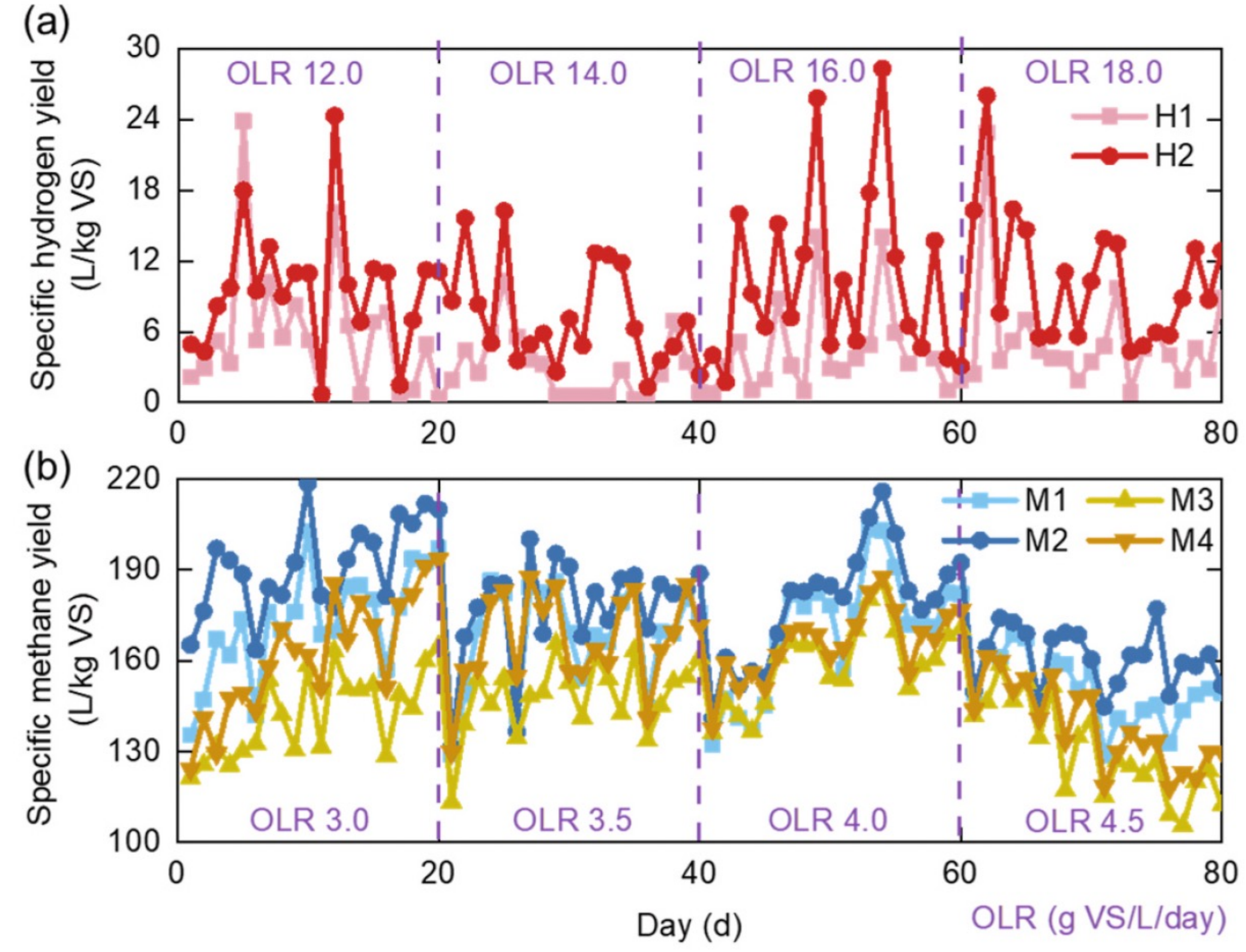
Improving biomethane production from biochar-supplemented two-stage anaerobic digestion of on-farm feedstocks

Xue Ning[a,b], Chen Deng[c,a,b,*], Daniel T. Hickey[a,b], Anga Hackula[a,b], Richard O'Shea[a,b], David M. Wall[a,b], Richen Lin[a,b,d], Jerry D. Murphy[a,b]

[a] SFI MaREI Centre for Energy, Climate and Marine, Environmental Research Institute, University College Cork, Cork, Ireland
[b] School of Engineering and Architecture, University College Cork, Cork, Ireland
[c] School of Chemistry and Chemical Engineering, Southeast University, Nanjing, 210096, China
[d] Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing, 210096, China

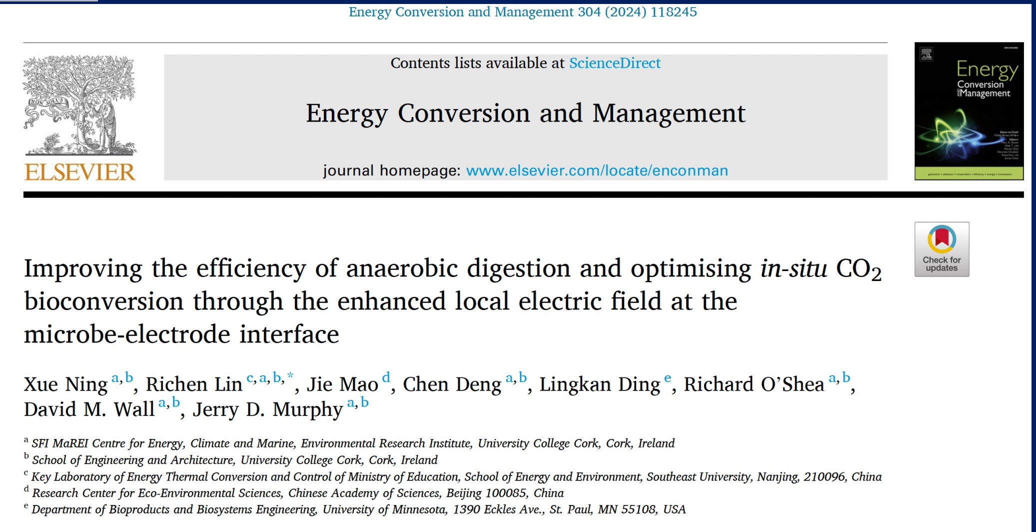
stable carbon-rich
electrically conductive
cost-effective




Biochar has a more significant effect on hydrolysis and acidogenisis

# HOW TO ENHANCE OUTPUT OF BIOMETHANE FROM EXISTING FEEDSTOCK



Energy Conversion and Management 304 (2024) 118245

Contents lists available at ScienceDirect

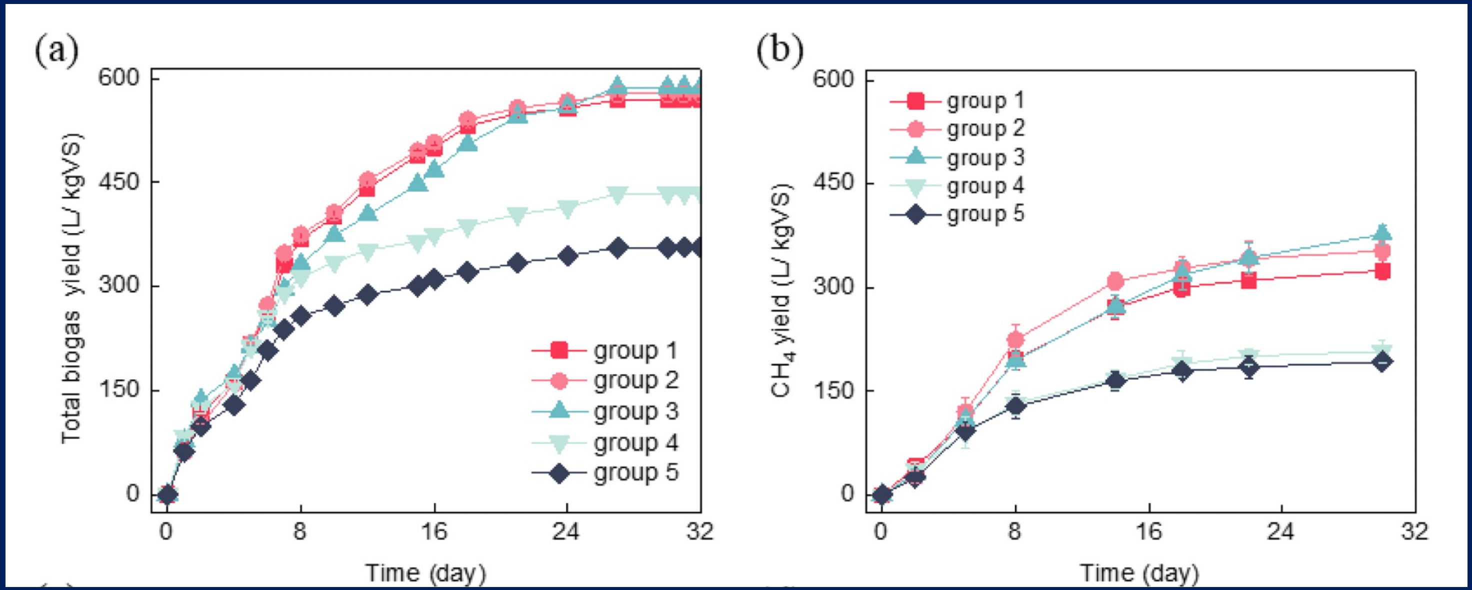
Energy Conversion and Management

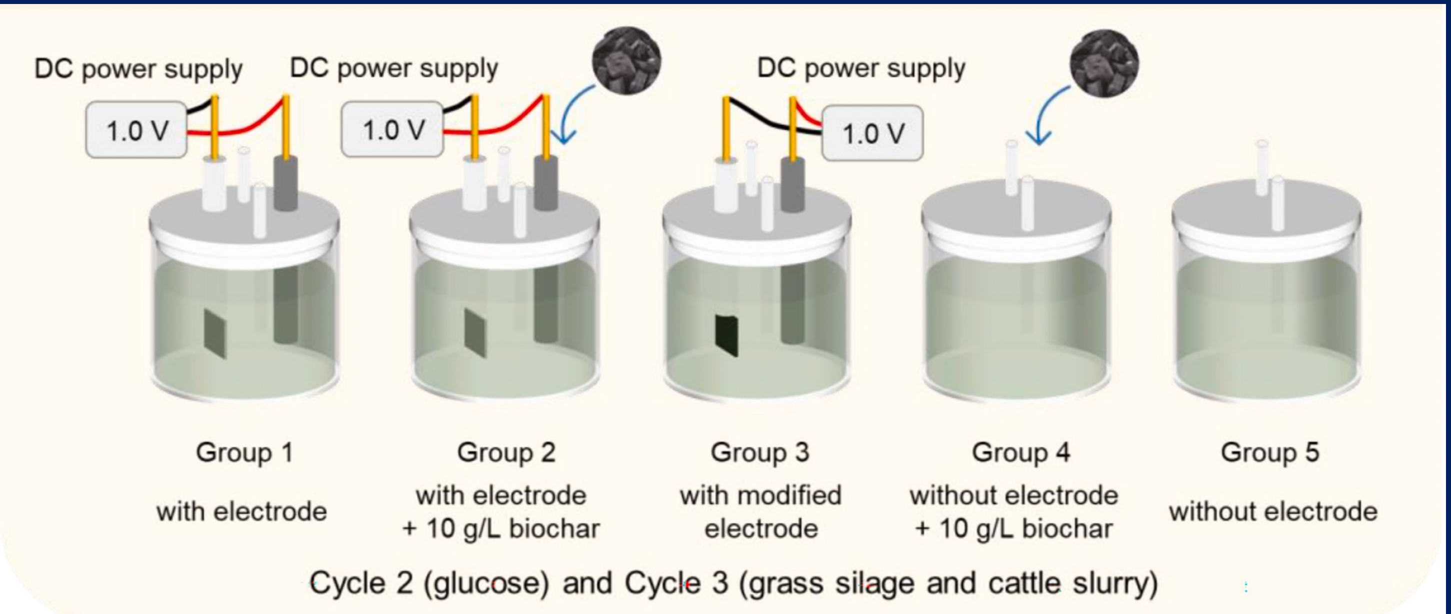
journal homepage: www.elsevier.com/locate/enconman

Improving the efficiency of anaerobic digestion and optimising *in-situ* $CO_2$ bioconversion through the enhanced local electric field at the microbe-electrode interface

Xue Ning[a,b], Richen Lin[c,a,b,*], Jie Mao[d], Chen Deng[a,b], Lingkan Ding[e], Richard O'Shea[a,b], David M. Wall[a,b], Jerry D. Murphy[a,b]

[a] SFI MaREI Centre for Energy, Climate and Marine, Environmental Research Institute, University College Cork, Cork, Ireland
[b] School of Engineering and Architecture, University College Cork, Cork, Ireland
[c] Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing, 210096, China
[d] Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
[e] Department of Bioproducts and Biosystems Engineering, University of Minnesota, 1390 Eckles Ave., St. Paul, MN 55108, USA




Biodegradability increases at anode

$CO_2$ reacts with electrons at cathode to produce $CH_4$

Catalytic role of electricity generated a 6-fold increase in electricity input

10g/L biochar and electrodes > electrodes

Modified cathode > cathode

We can double output from digester

Potential to halve feedstock required for RePowerEU

# VOLATILE FATTY ACID (VFA) PRODUCTION FROM DISILLERY BY-PRODUCTS

Energy Conversion and Management 301 (2024) 118064

Contents lists available at ScienceDirect

Energy Conversion and Management

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

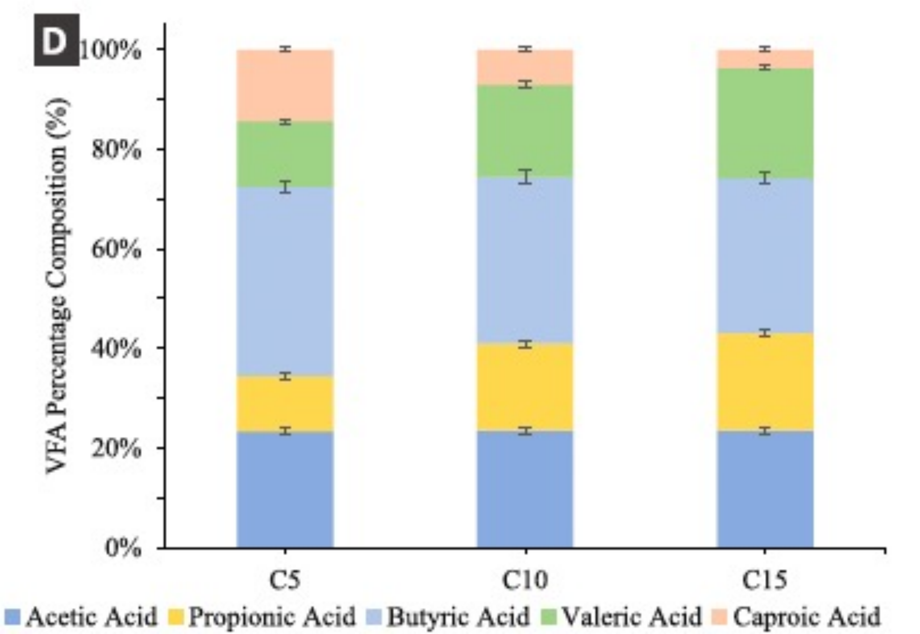
Developing distillery biorefineries through dark fermentation of whiskey production by-products: the effect of organic loading rate on decarbonisation pathways

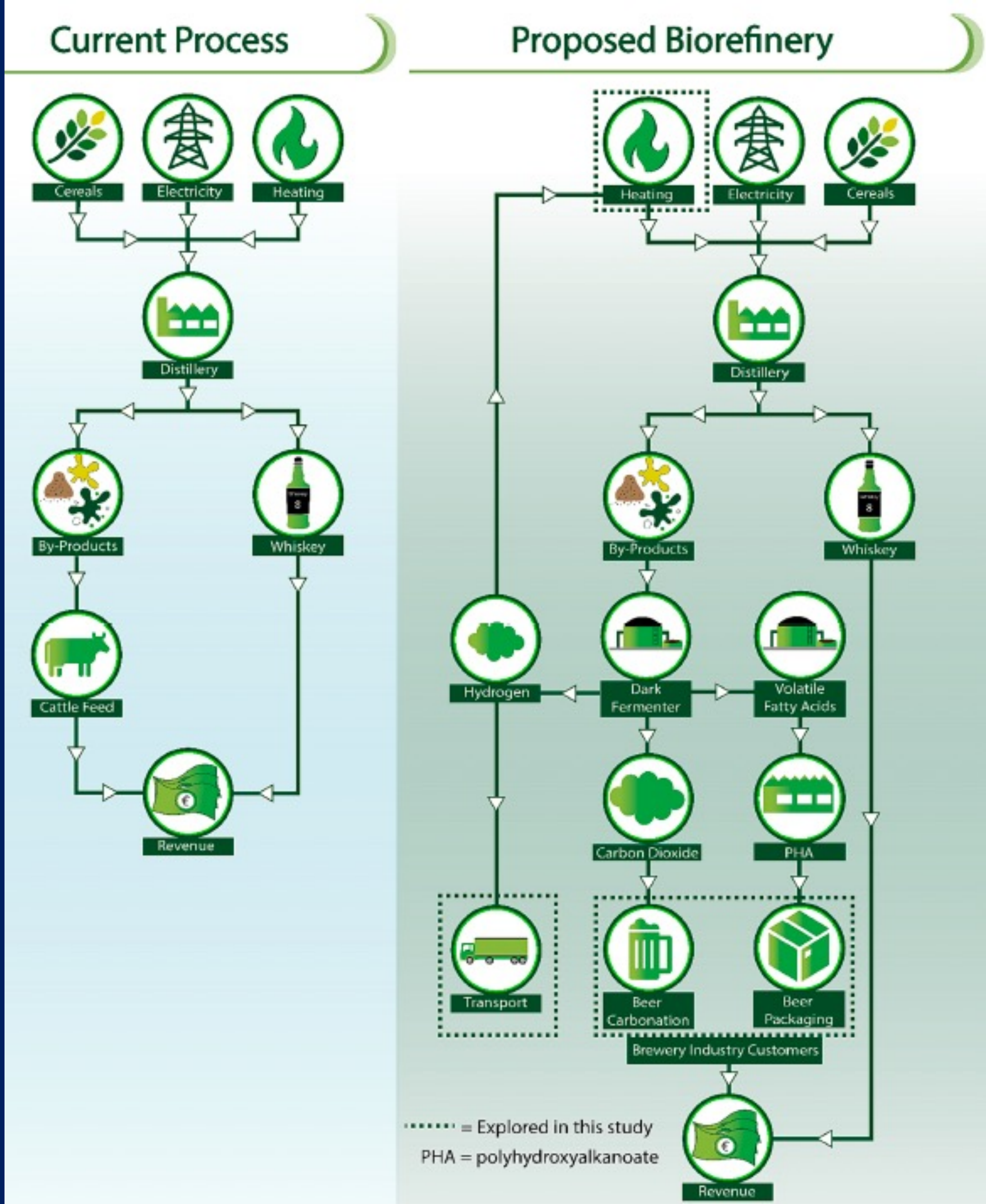
Anga Hackula, Richard O'Shea, Jerry D. Murphy, David M. Wall *

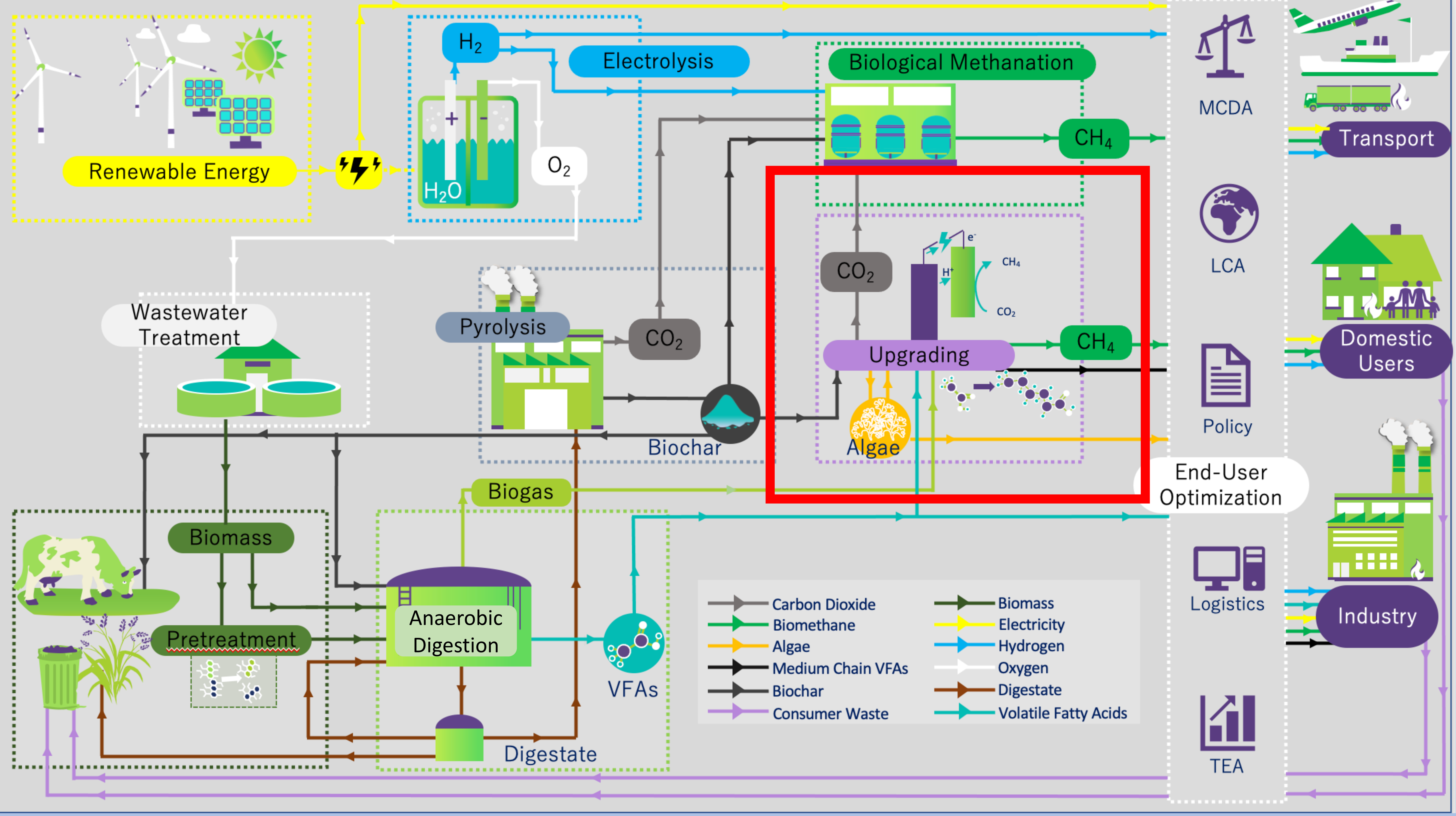
SFI MaREI Centre for Energy, Climate and Marine, Environmental Research Institute, University College Cork, Cork, Ireland
Civil, Structural and Environmental Engineering, School of Engineering and Architecture, University College Cork, Cork, Ireland

## Organic loading rates (OLR) impact VFA profile

- Higher OLR yields more valeric acid
- Lower OLR yields more caproic acid





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# POWER TO FOOD: MICROALGAE BIOREFINERY WITH BIOGAS UPGRADING

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,*], Karthik Rajendran[c,*], Richard O'Shea[a,b], Ao Xia[d], Jerry D. Murphy[a,b,*]

[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, SRM University-AP, Amaravati, Andhra Pradesh 522 502, India
[d] Key Laboratory of Low-grade Energy Utilisation Technologies and Systems, Chongqing University, Chongqing 400044, China

Chemical Engineering Journal 437 (2022) 134988

Contents lists available at ScienceDirect

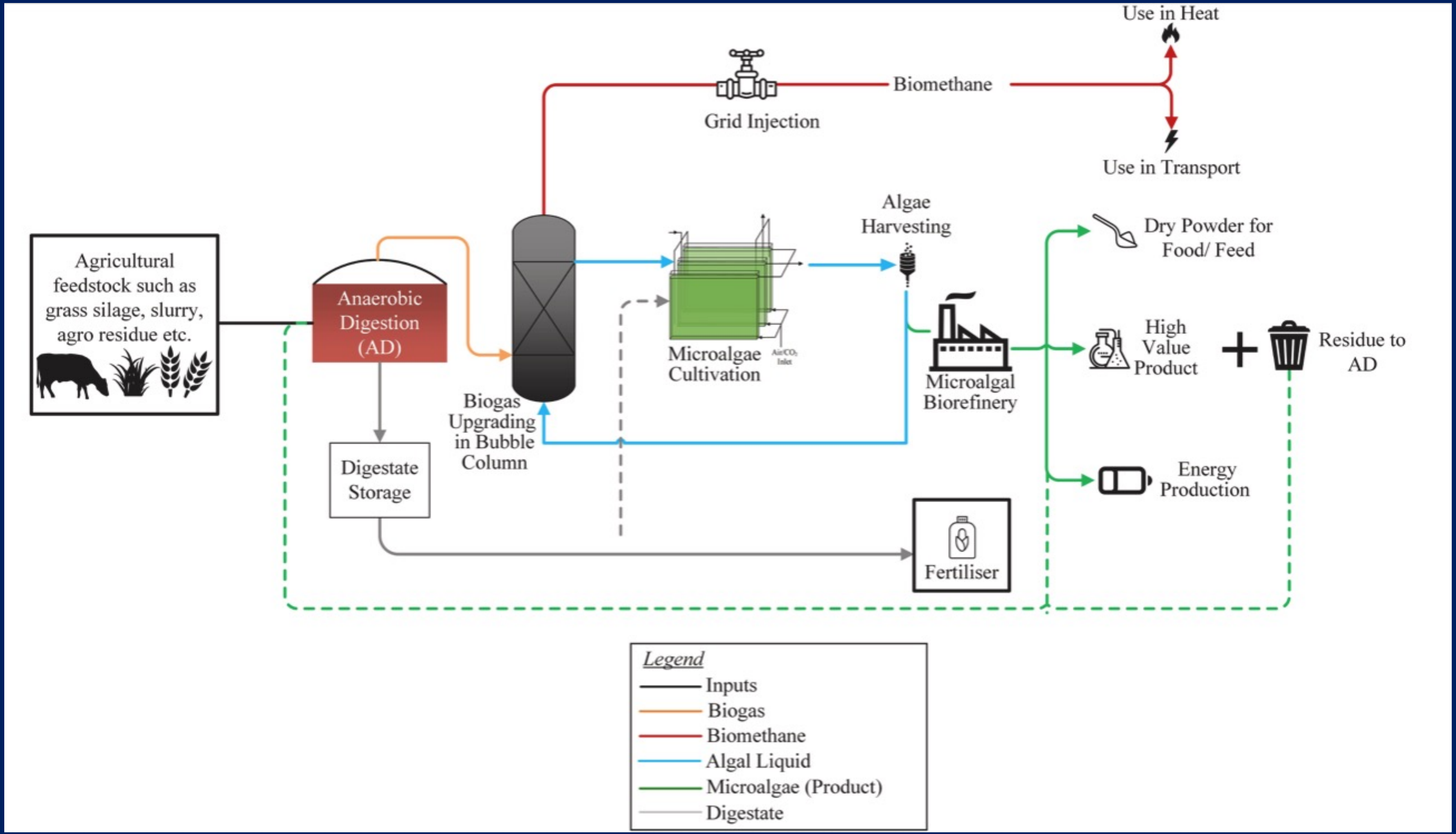
Chemical Engineering Journal

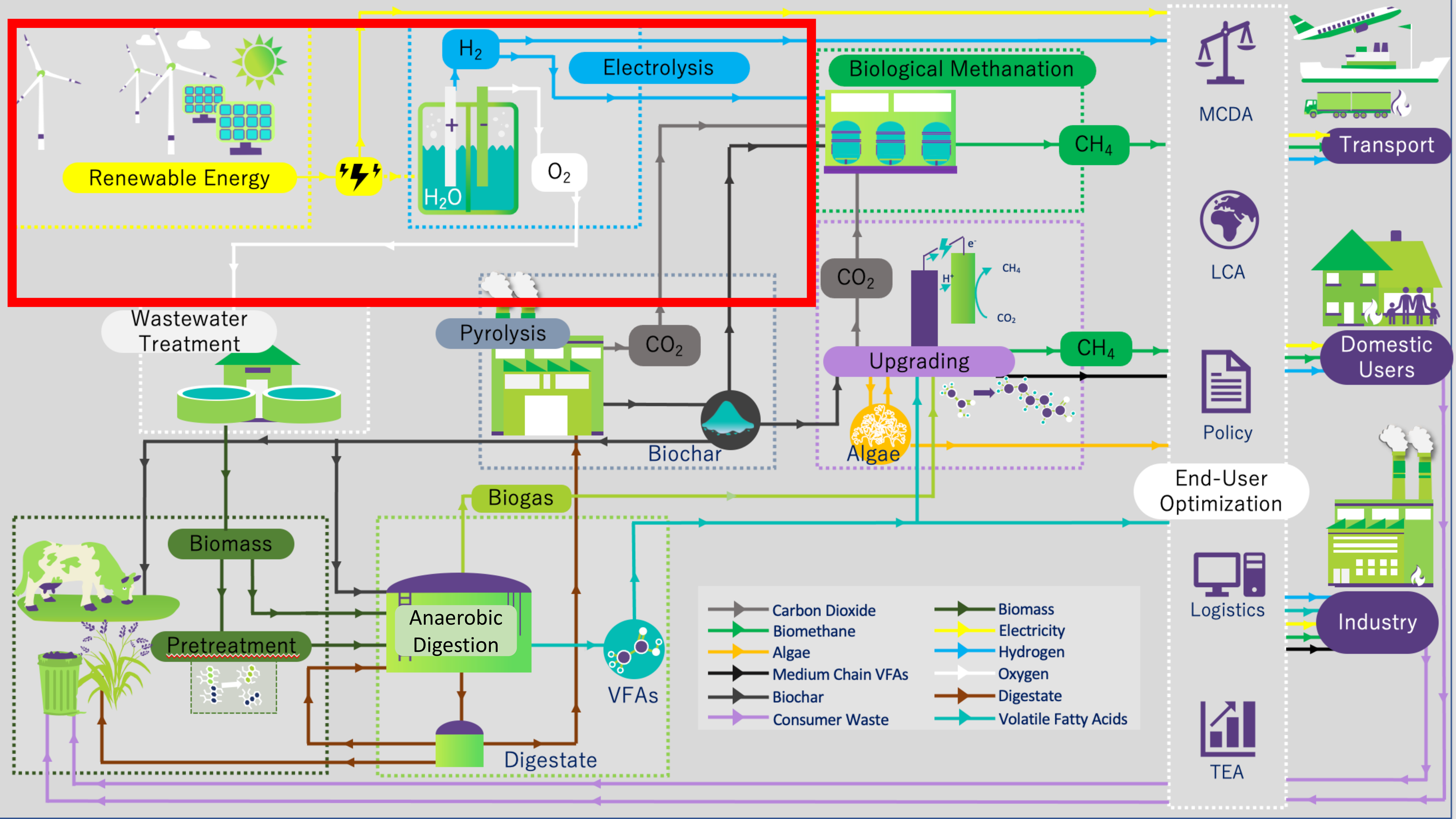
journal homepage: www.elsevier.com/locate/cej

**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]

[a] Environmental Research Institute, MaREI Centre, University College Cork, Cork, Ireland
[b] School of Engineering and Architecture, University College Cork, Cork, Ireland
[c] Process and Chemical Engineering, University College Cork, Cork, Ireland
[d] Civil, Structural, and Environmental Engineering, University College Cork, Cork, Ireland





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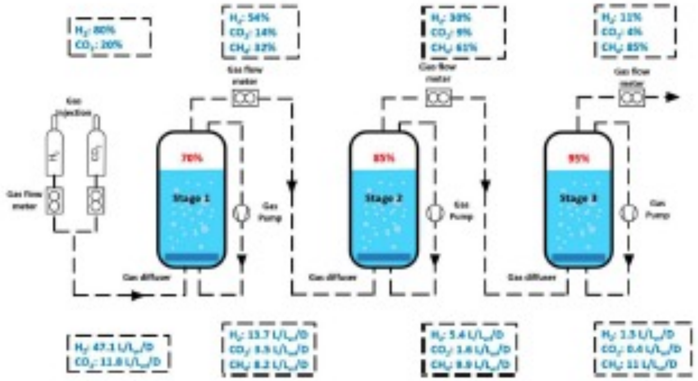
IEA Bioenergy

Technology Collaboration Programme

# Circular economy approaches to integration of anaerobic digestion with Power to X technologies

IEA Bioenergy: Task 37 January 2024




Technology Collaboration Programme

by iea

# Circular economy approaches to integration of anaerobic digestion with Power to X technologies


Authors:

Jerry D Murphy, Davis Rusmanis, Nathan Gray, Richard O'Shea, MaREI centre, University College Cork, Ireland

Reviewed by: David Wall, John Paul Deane, and Maria Welsch

Edited by: Jan Liebetrau


Citation:

Murphy, J.D., Rusmanis, D., Gray, N., O'Shea, R. (2023) Circular economy approaches to integration of anaerobic digestion with Power to X technologies, Liebetrau, J. (Ed.) IEA Bioenergy Task 37, 2024:1.

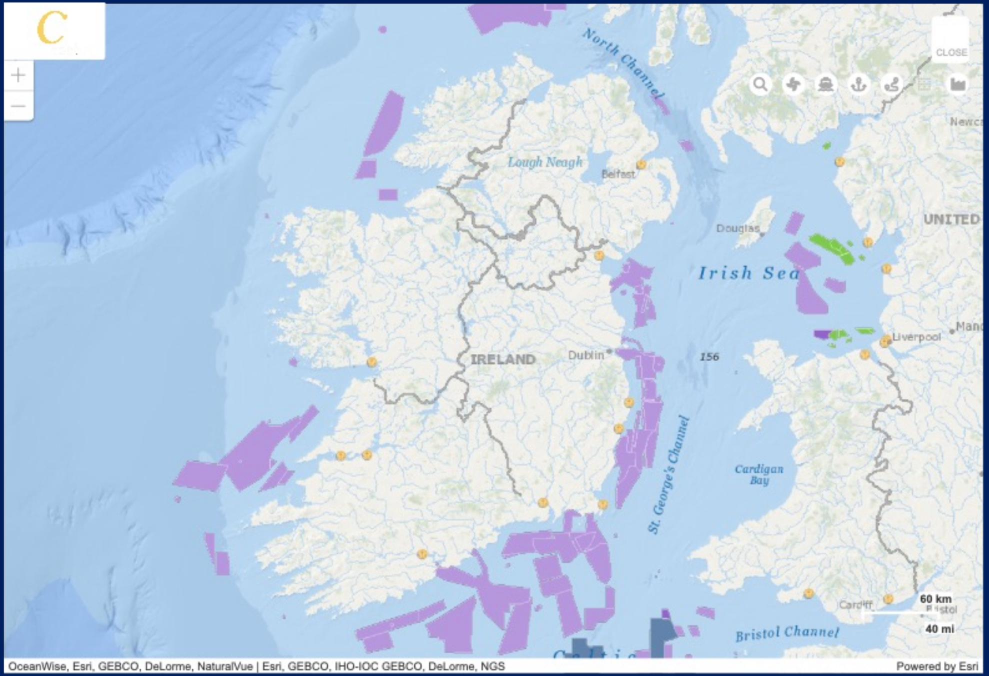


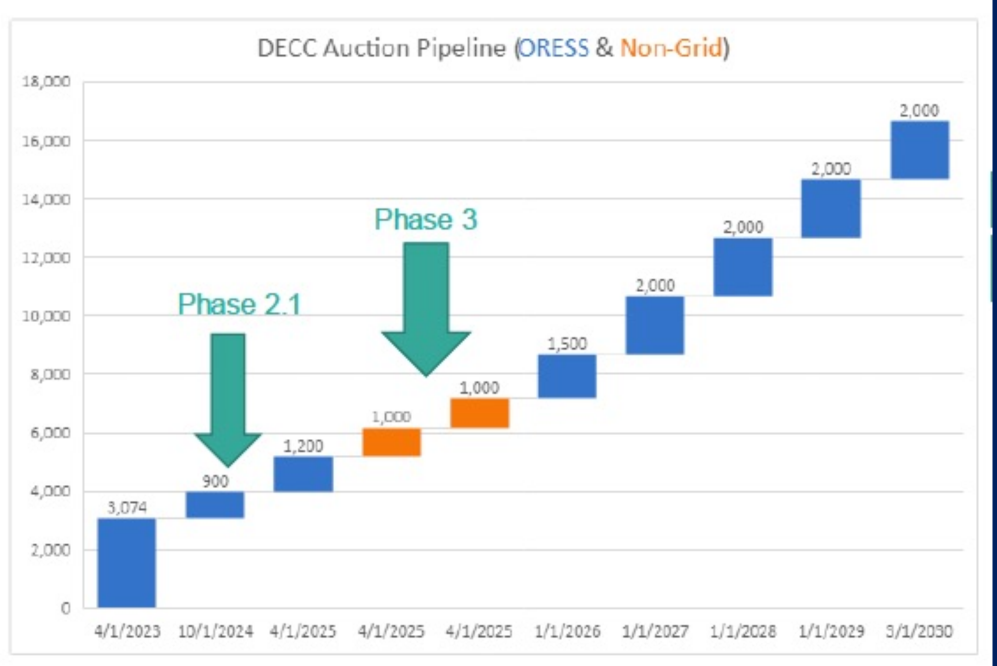

ISBN: (eBook electronic edition).

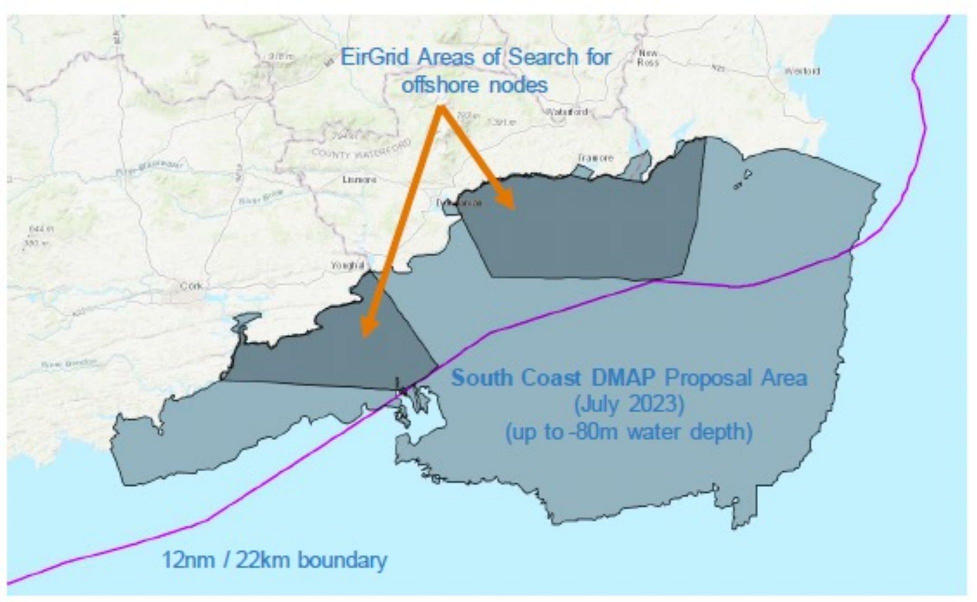
**Cover graphic:** Adapted from Voleklein et al. (2019)

**Published by IEA Bioenergy:**

# OFFSHORE WIND FOR PRODUCTION OF ELECTRICITY




Plans for 16.5 GW of offshore wind for a country that has never used more than 6 GW

- 2GW for non-grid use
- Highly likely 1 GW will be in south coast DMAP
- Cork requires about 200 MW
- Opportunity for energy hub in Cork
- Opportunity for hydrogen in Cork
- Opportunity for Power to X in Cork

# THE CHALLENGES OF NET ZERO AND RATIONALE FOR BIOGAS & POWER TO X

X = 1 Hydrogen ($H_4$):

- We need renewable hydrogen to replace fossil hydrogen. The hydrogen molecule is ubiquitous

X = 2 Methane ($CH_4$):

- Energy consumed from natural gas grid is up to twice that from electricity grid in EU and USA

X = 3 Methanol ($CH_3OH$):

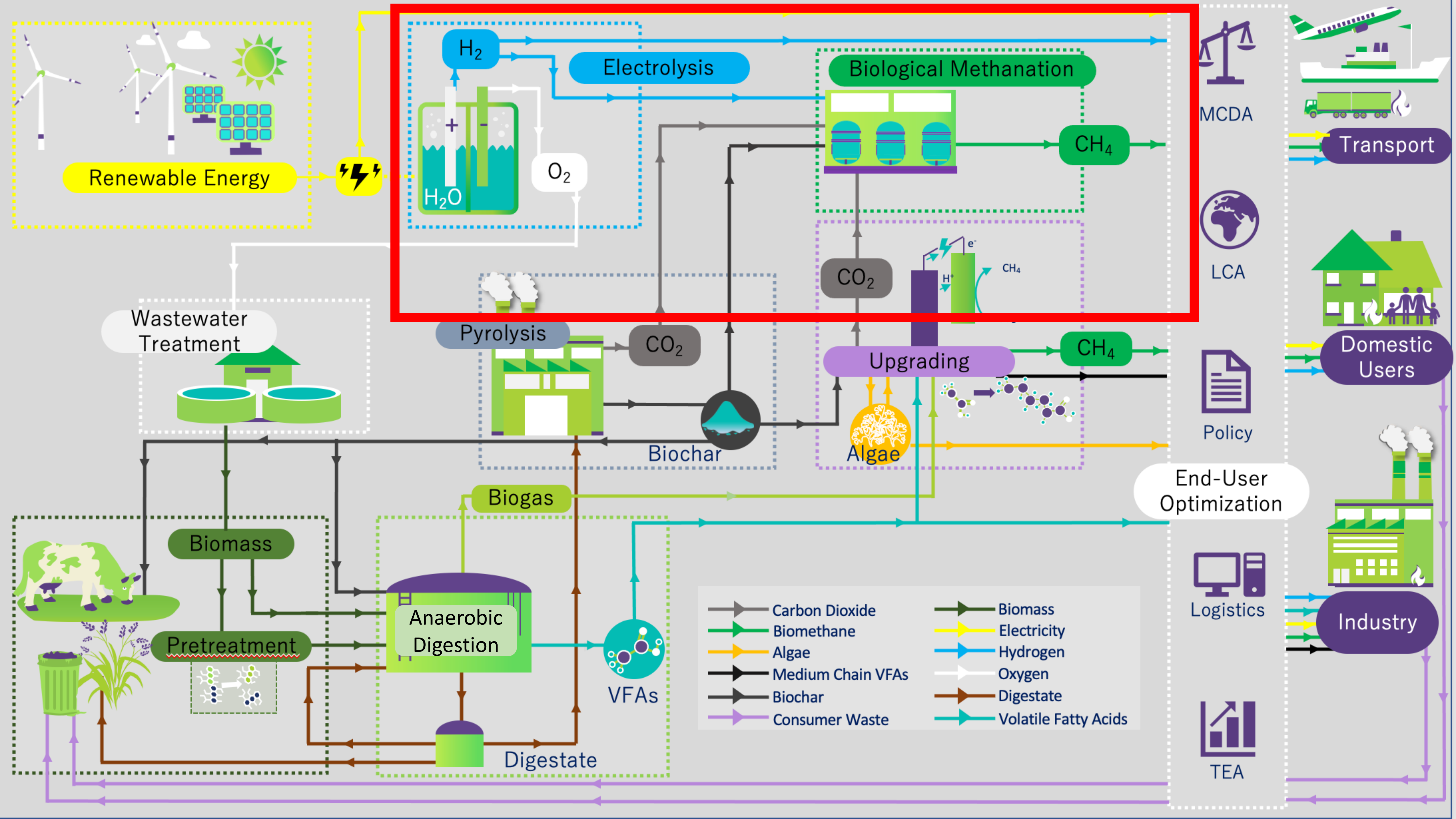
- Worldwide production of 110 million tonnes in 2021 used to make plastics, paints, cosmetics and fuels

X = 4 Ammonia ($NH_3$):

- World production 150 million tonnes; 80% used for fertiliser, 20% for plastics, fibres, explosives, nitric acid

Agriculture:

- responsible for 37% of GHG emissions in Ireland



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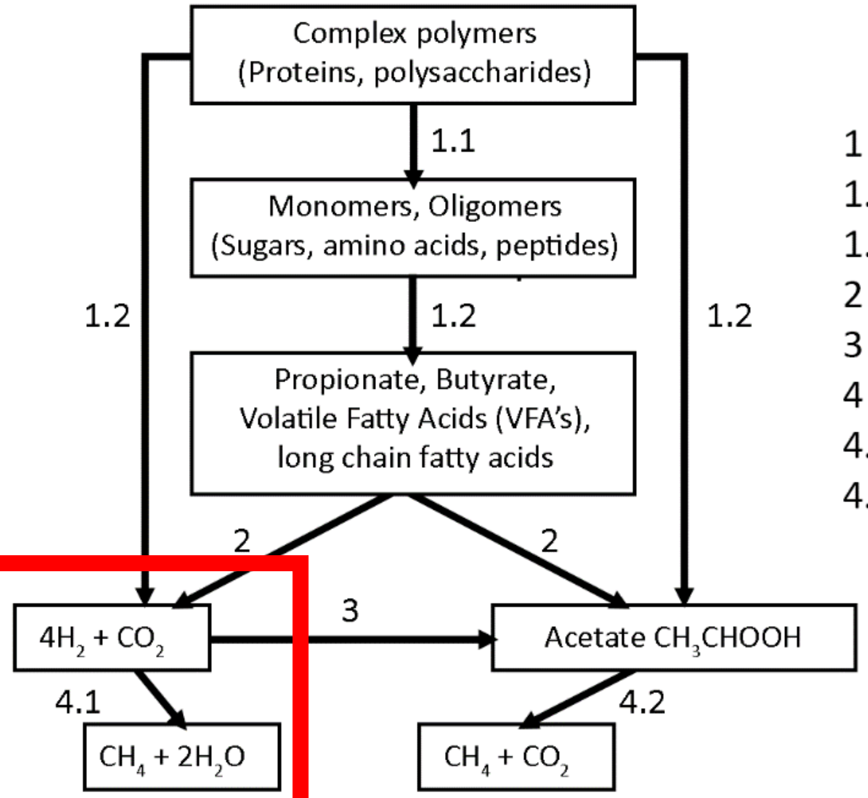
# ANAEROBIC DIGESTION PROCESS




| | |
|---|---|
| 1 | Acidogenic bacteria |
| 1.1 | Hydrolytic bacteria |
| 1.2 | Fermentative bacteria |
| 2 | Acetogenic bacteria |
| 3 | Homoacetogenic bacteria |
| 4 | Methanogenic archaea |
| 4.1 | Hydrogenotrophic Methanogenic archaea |
| 4.2 | Acetoclastic Methanogenic archaea |

| | | | ΔG (kJ/reaction) |
|---|---|---|---|
| Species 2 | $CH_3CH_2OH + H_2O$ | $= CH_3COO^- + H^+ + 2H_2$ | +5.95 |
| Species 4.1 | $2H_2 + 0.5CO_2$ | $= 0.5CH_4 + H_2O$ | −65.45 |
| Species 4.2 | $CH_3COO^- + H^+$ | $= CH_4 + CO_2$ | −28.35 |
| Net | $CH_3CH_2OH$ | $= 1.5CH_4 + 0.5CO_2$ | −87.85 |

# BIOLOGICAL CONVERSION OF HYDROGEN TO METHANE

Bioresource Technology 225 (2017) 308–315

Contents lists available at ScienceDirect

Bioresource Technology

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

Study of the performance of a thermophilic biological methanation system

Amita Jacob Guneratnam [a], Eoin Ahern [a], Jamie A. FitzGerald [a,d], Stephen A. Jackson [d], Ao Xia [c], Alan D.W. Dobson [d], Jerry D. Murphy [a,b,*]

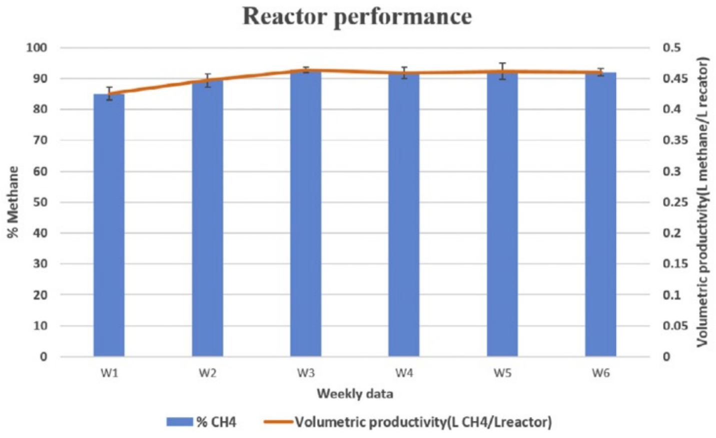



**Fig. 3.** Methane composition and volumetric productivity at 65 °C (fresh inoculum) for 24 h.

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \quad \Delta H_R = -165\ kJ/mol$$

*Methanothermobacter Wolfeii*

Applied Energy 235 (2019) 1061–1071

Contents lists available at ScienceDirect

Applied Energy

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

Biological methanation: Strategies for in-situ and ex-situ upgrading in anaerobic digestion

M.A. Voelklein*, Davis Rusmanis, J.D. Murphy

MaREI Centre, Environmental Research Institute (ERI), University College Cork (UCC), Ireland
School of Engineering, UCC, Ireland

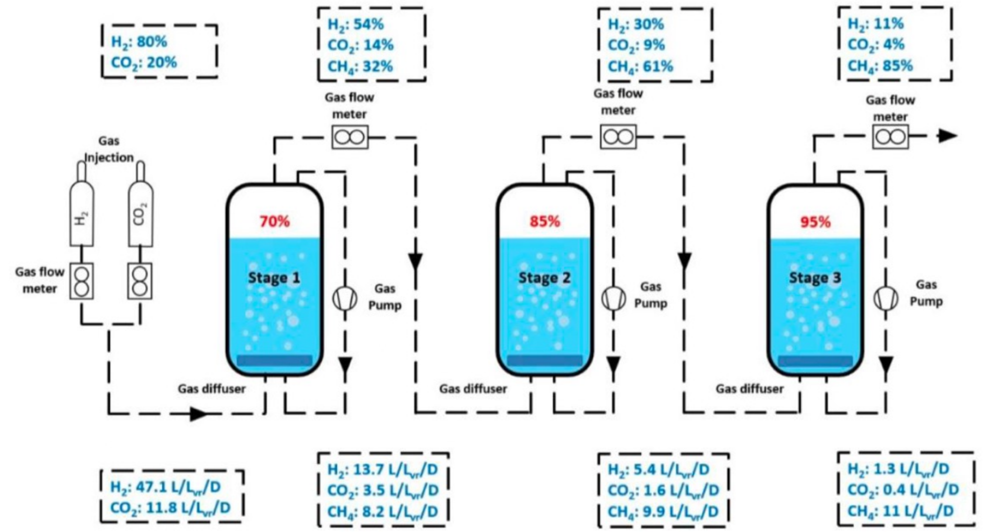
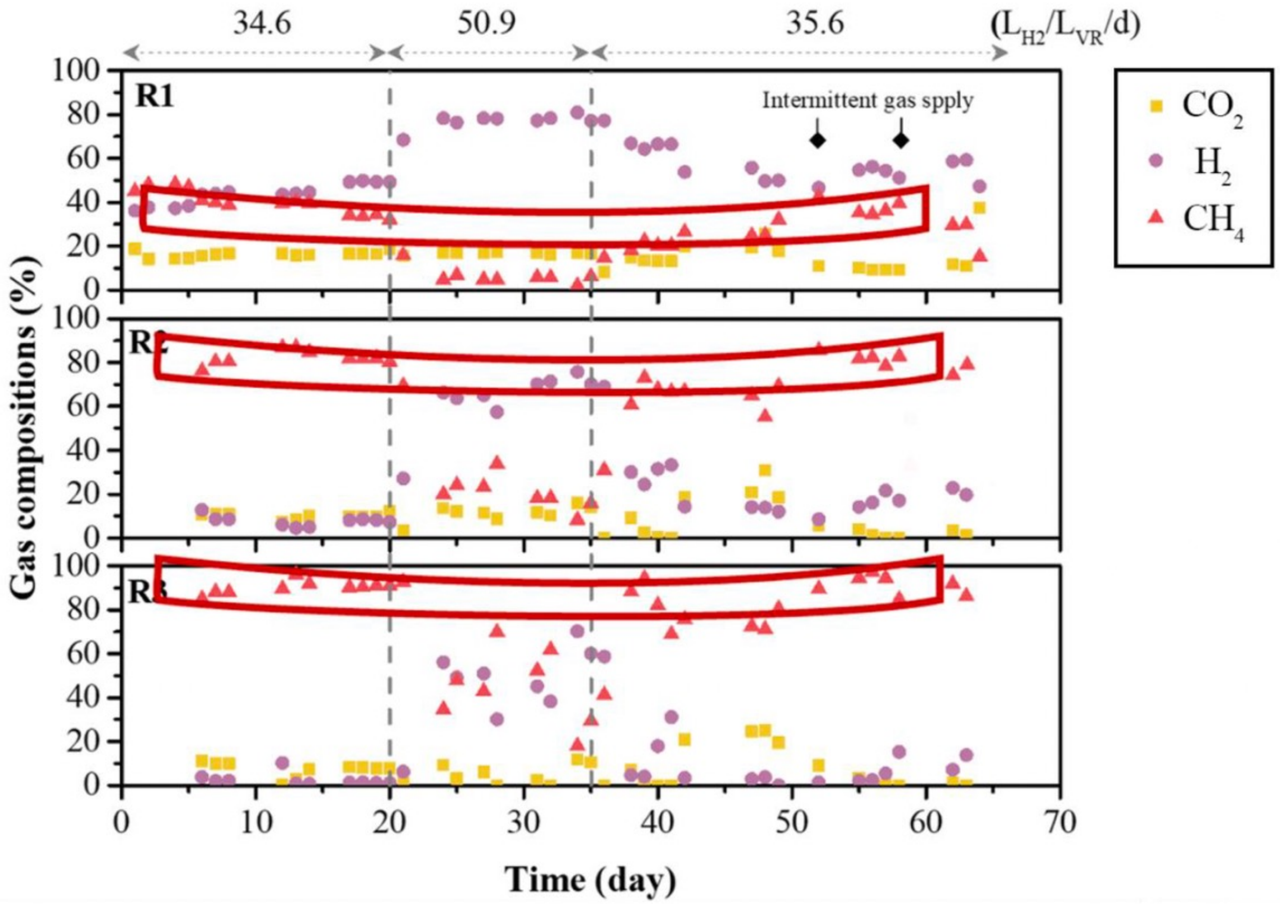
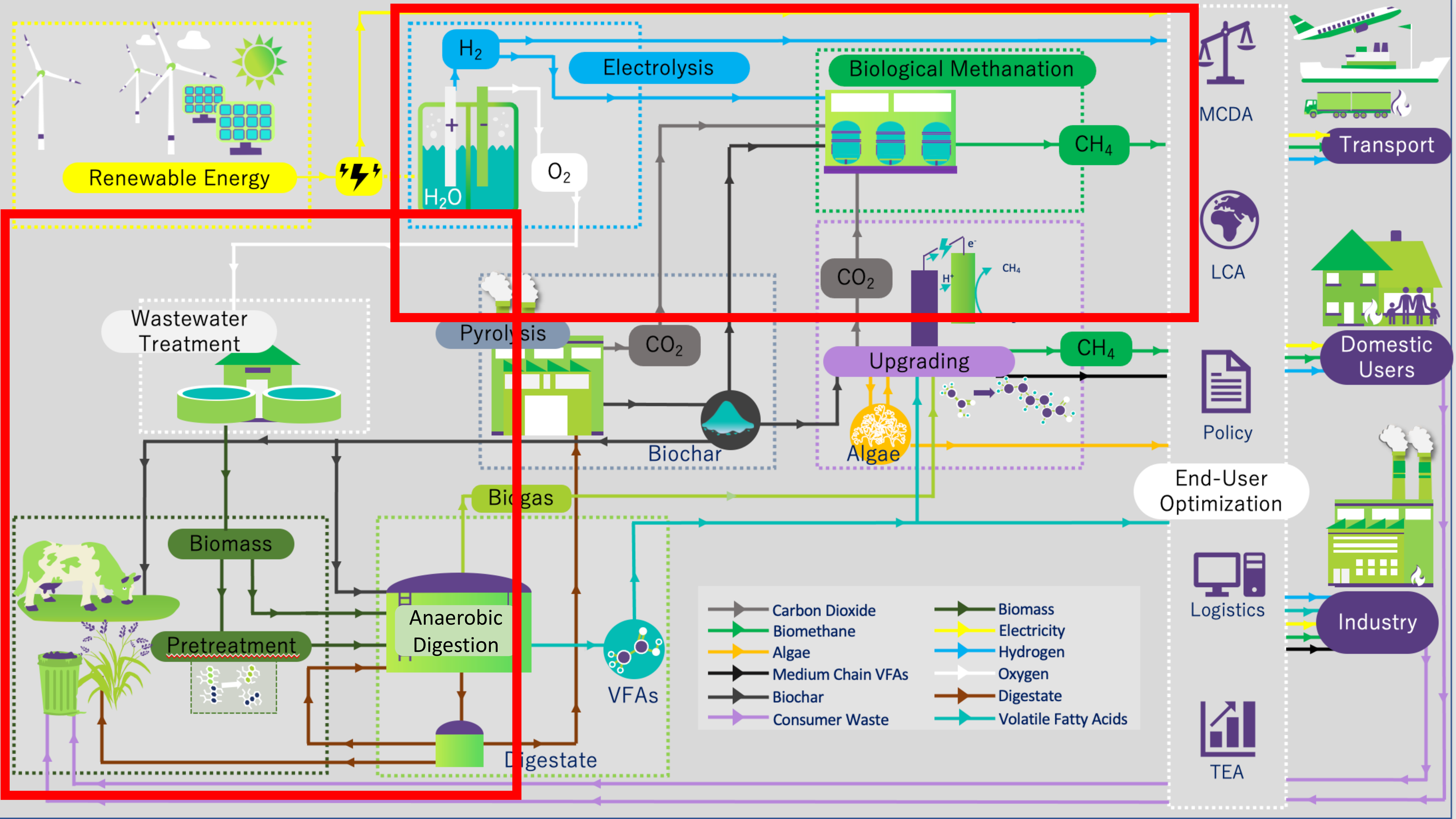



*Figure 3.2. Experimental and modelled output of a small lab scale continuous ex-situ biological methanation process (adapted from Voelklein et al., 2019)*

# UPGRADING BIOGAS TO BIOMETHANE IN BIOLOGICAL METHANATION SYSTEMS



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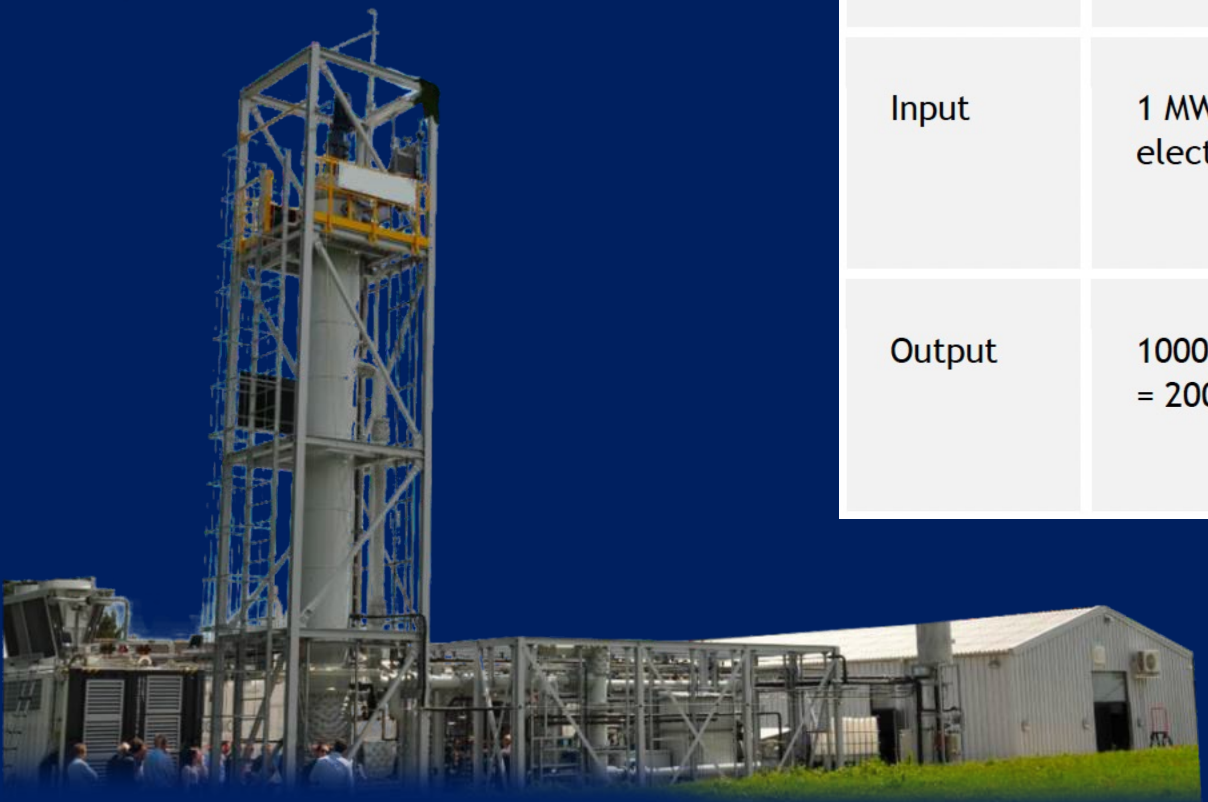
Domestic Users
Industry

# CASE STORY: BIOCAT, AVEDØRE, DENMARK

| | Alkaline Electrolysis Cell Electrolyser | Methanation reactor |
|---|---|---|
| Theory | $2H_2O = 2H_2 + O_2$<br>$H_2$ LHV of 3kWh/m$^3$ or 33.33kWh/kg | $4H_2 + CO_2 = CH_4 + 2H_2O$ |
| Input | 1 MW electrolyser using 1000 kWh of electricity per hour | 125 m$^3$ raw biogas/h<br>75 m$^3$ $CH_4$/h & 50 m$^3$ $CO_2$/h |
| Output | 1000 kW$_e$h at 60% capacity = 600 kWh = 200 m$^3$ $H_2$ /h | 75 m$^3$ $CH_4$ from biogas plus<br>50 m$^3$ $CH_4$ from biological methanation facility |



# MAKE HYDROGEN AT A WASTEWATER TREATMENT PLANT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Operation of a circular economy, energy, environmental system at a wastewater treatment plant

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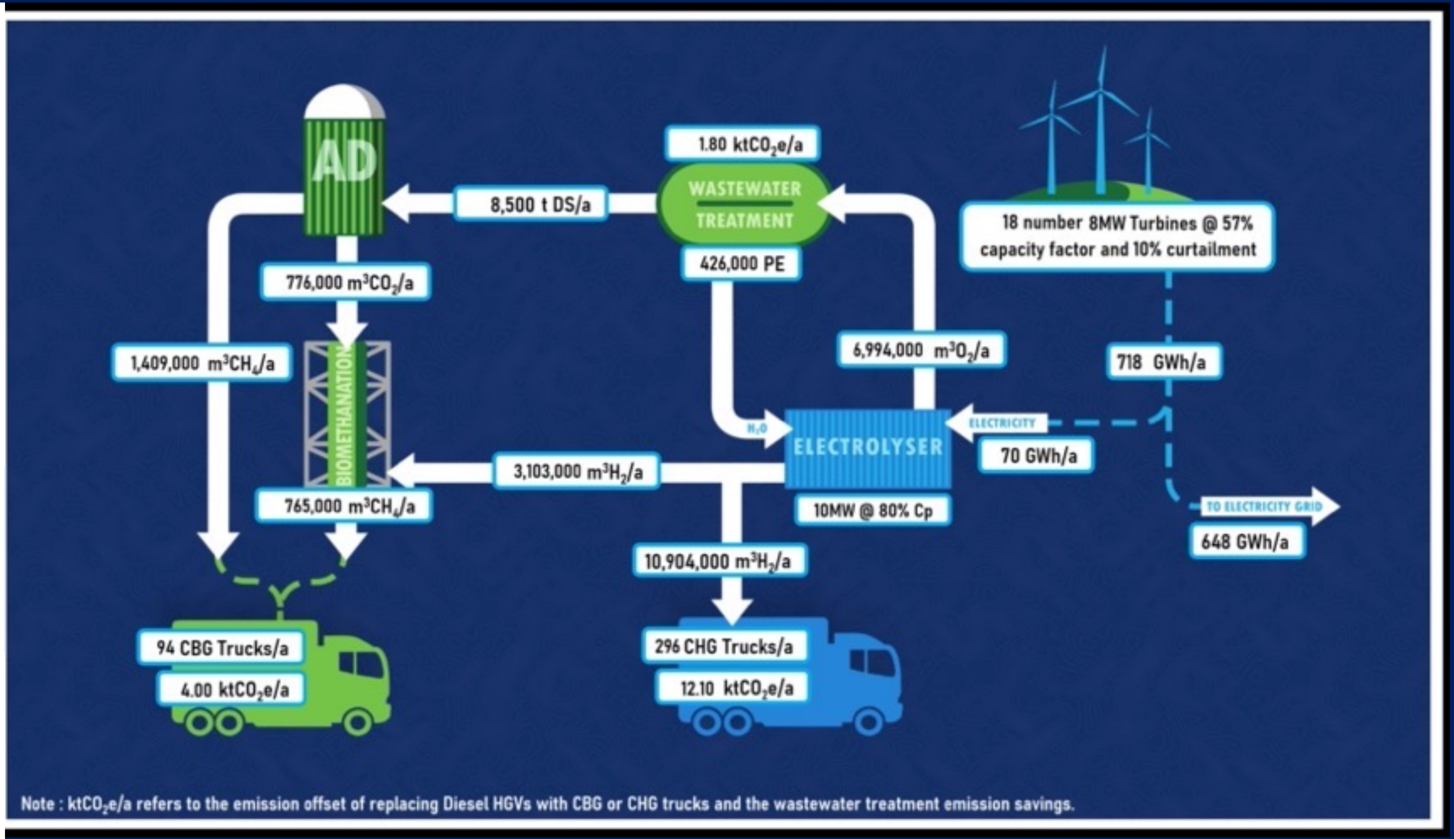
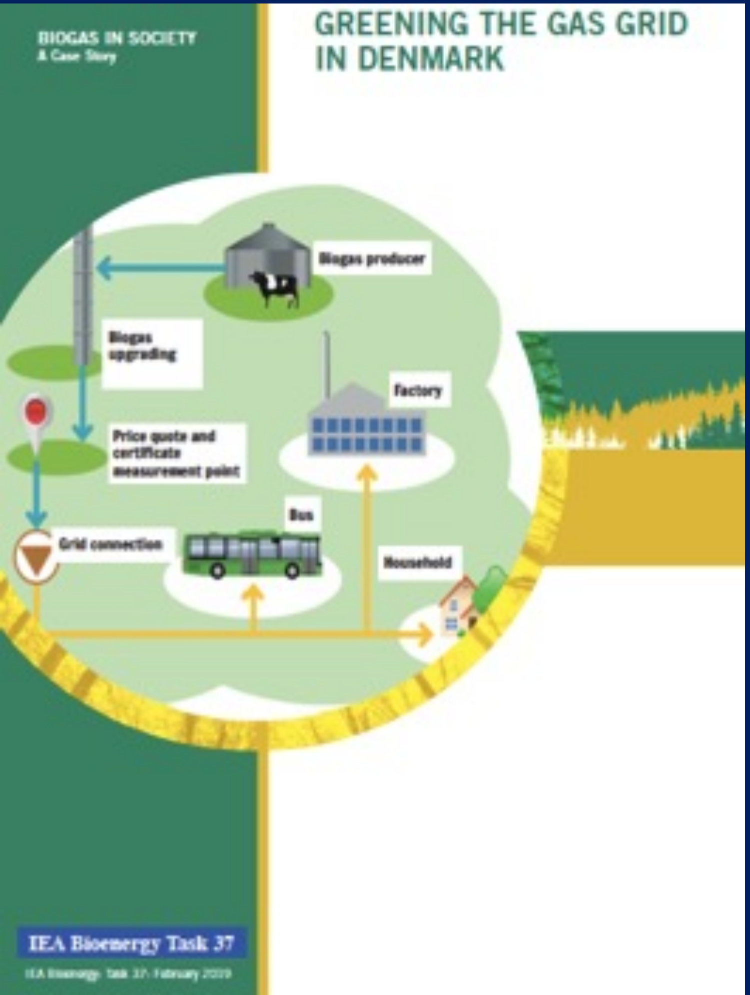



- Curtailed electricity from a 144 MW offshore wind farm can supply a 10MW electrolyser.
- 10 MW electrolyser can supply $O_2$ to a 426,400 person wastewater treatment facility.
- 22% of produced $H_2$ is used for methanation of $CO_2$ from sludge digestion.
- Pure $O_2$ aeration can reduce emissions by 40% at the WWTP.
- Excess $H_2$ and biomethane can fuel 390 heavy goods vehicles.

# GREENING THE GAS GRID IN DENMARK

Denmark intends decarbonising the gas grid with 72PJ of renewable gas by 2035 leading to 100% green gas
Already at 39% substitution of natural gas; Addition of Power to $CH_4$ (biomethanation) would see 65% green gas



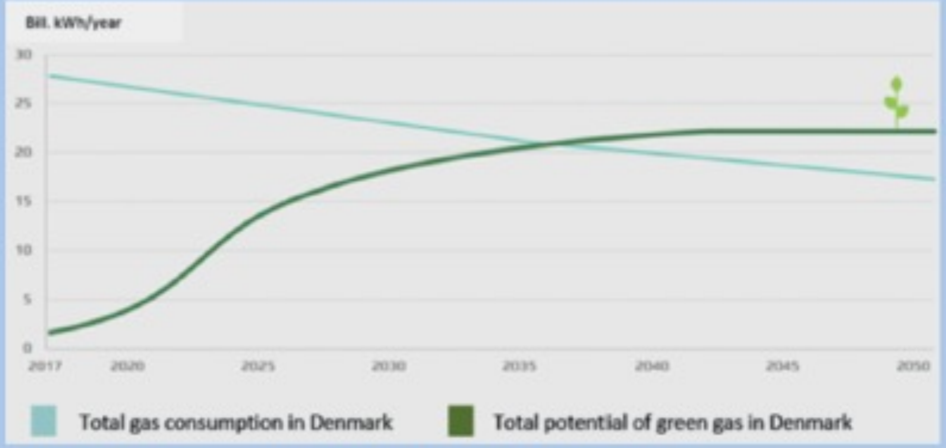
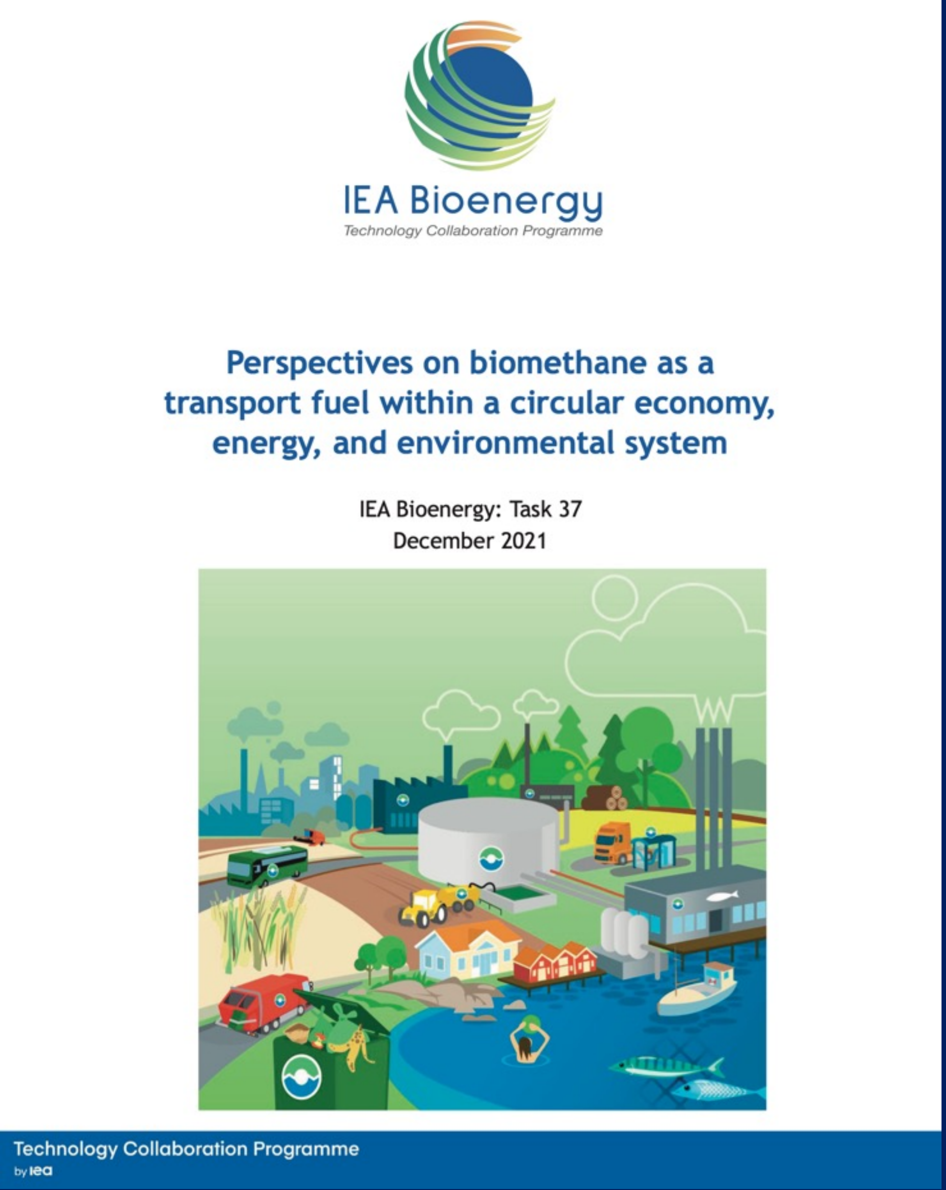




**Figure 1:** Gas consumption and potential of green gas in Denmark (from Green Gas Denmark)

**Figure 3:** Holsted Biogas Plant, producing 20.7 million $m^3$ gas / year. Source: Nature Energy

# INCREASE ROLE OF BIOMETHANE TO FUEL HEAVY TRANSPORT


IEA Bioenergy
Technology Collaboration Programme

Perspectives on biomethane as a transport fuel within a circular economy, energy, and environmental system

IEA Bioenergy: Task 37
December 2021

Technology Collaboration Programme
by iea

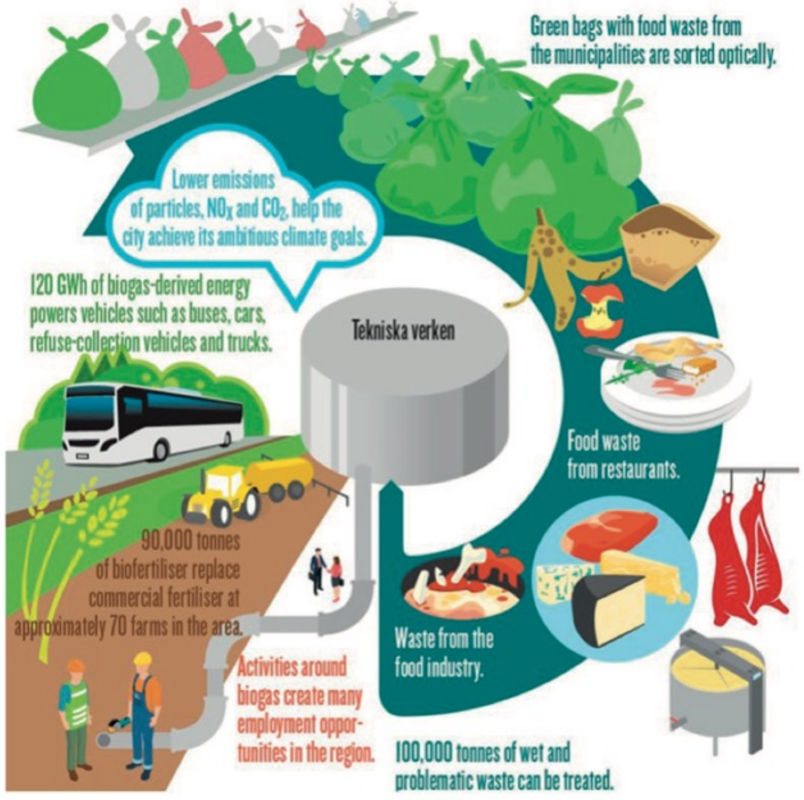



Figure 27. Illustration of biogas solutions in and around Linköping, where the municipally owned utility Tekniska Verken has a central position. *Illustration: Mattias Schläger.*


Figure 28. A truck filling liquid biomethane, at a filling station that has been establish as part of the cooperation between Tekniska Verken and Toyota Material Handling Manufacturing Sweden. *Source: Svensk Biogas*

Figure 31. Double decker buses fueled by biomethane in Bristol; *photo from Jon Craig, Jon Craig Photography, courtesy of JBP Bristol.*

Figure 34. A long distance coach powered by liquid biomethane operating the Stockholm-Oslo route. This is based on collaboration between Scania, mobility provider Flixbus and gas supplier Gasum. *Scania CV AB.*

# DECARBONISATION PATHWAYS IN FOOD AND BEVERAGE INDUSTRY

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

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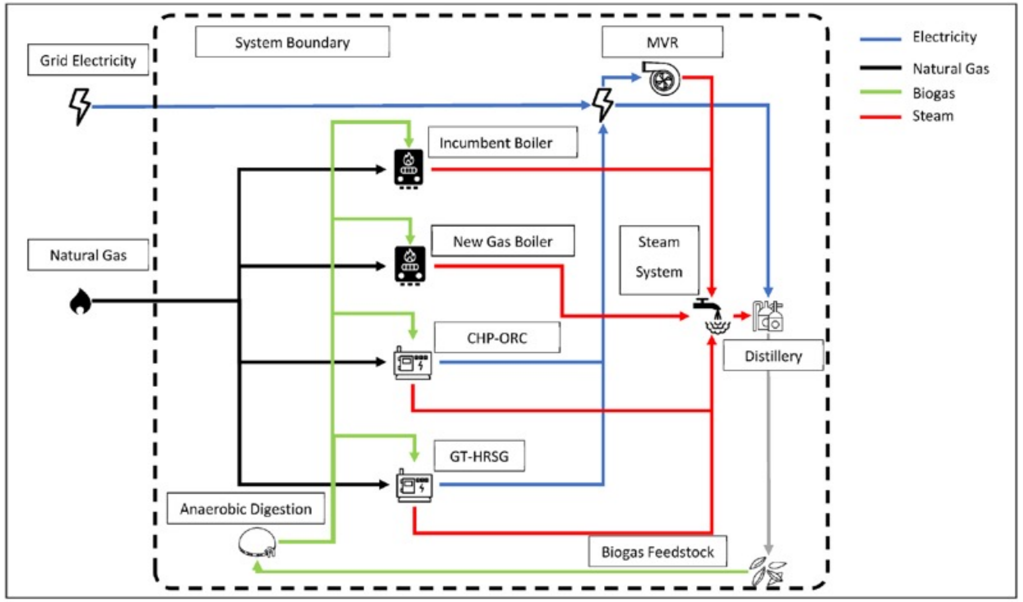


**Fig. 2.** Energy system schematic. CHP: Combined heat and power. ORC: Organic rankine Cycle.GT: Gas turbine. Hrsg: Heat recovery steam generator. MVR: Mechanical vapour recompression.

**Table 2**
Decarbonisation pathways.

| Pathway | Rationale | Component Technologies | | | | | | Pathway abbreviation |
|---|---|---|---|---|---|---|---|---|
| | | New Boilers | CHP ORC[a] | GT HRSG[b] | Anaerobic Digestion | Heat Recovery | 38 kV | |
| 1 | Efficient steam | X | | | | | | Boiler |
| 2 | Power generation | | X | | | | | CHP ORC |
| 3 | Power generation | | | X | | | | CHP GT |
| 4 | Heat recovery | | | | | X | X | 38 kV – MVR |
| 5 | Biogas | | | | X | | | Biogas only |
| 6 | Efficient steam<br>Power generation | X | X | | | | | Boiler – CHP ORC |
| 7 | Efficient steam<br>Power generation | X | | X | | | | Boiler – CHP GT |
| 8 | Efficient steam<br>Biogas | X | | | X | | | Boiler – Biogas |
| 9 | Efficient steam<br>Heat recovery | X | | | | X | X | Boiler – 38 kV- MVR |
| 10 | Power generation<br>Biogas | | X | | X | | | CHP ORC – Biogas |
| 11 | Power generation<br>Biogas | | | X | X | | | CHP GT – Biogas |
| 12 | Power generation<br>Heat recovery | | X | | | X | | CHP ORC – MVR |
| 13 | Power generation<br>Heat recovery | | | X | | X | | CHP GT – MVR |
| 14 | Heat recovery<br>Biogas | | | | X | X | X | 38 kV MVR – Biogas |
| 15 | Efficient steam | X | X | | | X | | Boiler – CHP ORC – MVR |
| 16 | Power generation<br>Heat recovery | X | | X | | X | | Boiler – CHP GT– MVR |
| 17 | Efficient steam<br>Power import<br>Heat recovery<br>Biogas | X | | | X | X | X | Boiler – 38 kV – MVR – Biogas |
| 18 | Efficient Steam | X | X | | X | | | Boiler – CHP ORC – Biogas |
| 19 | Power generation<br>Biogas | X | | X | X | | | Boiler – CHP GT – Biogas |
| 20 | Efficient Steam | X | X | | X | X | | Boiler – CHP ORC – MVR – Biogas |
| 21 | Power generation<br>Heat recovery<br>Biogas | X | | X | X | X | | Boiler – CHP GT - MVR – Biogas |

[a] CHP ORC: Combined heat and power organic Rankine cycle.
[b] GT HRSG: Gas turbine with a heat recovery steam generator.

To achieve GHG emissions savings greater than 67%, biogas from the anaerobic digestion of distillery feed products is required.

# POWER TO METHANOL ($CH_3OH$)

$3CH_4 + CO_2 + 2\ H_2O = 4\ CH_3OH$

$CO + 2\ H_2 = CH_3OH$

Worldwide production of methanol is 110 million tonnes

We need renewable hydrogen (such as from offshore wind) and "climate neutral" $CO_2$

Direct Air Capture of $CO_2$ is expensive

We need biogenic $CO_2$ (from biogas or distilleries)

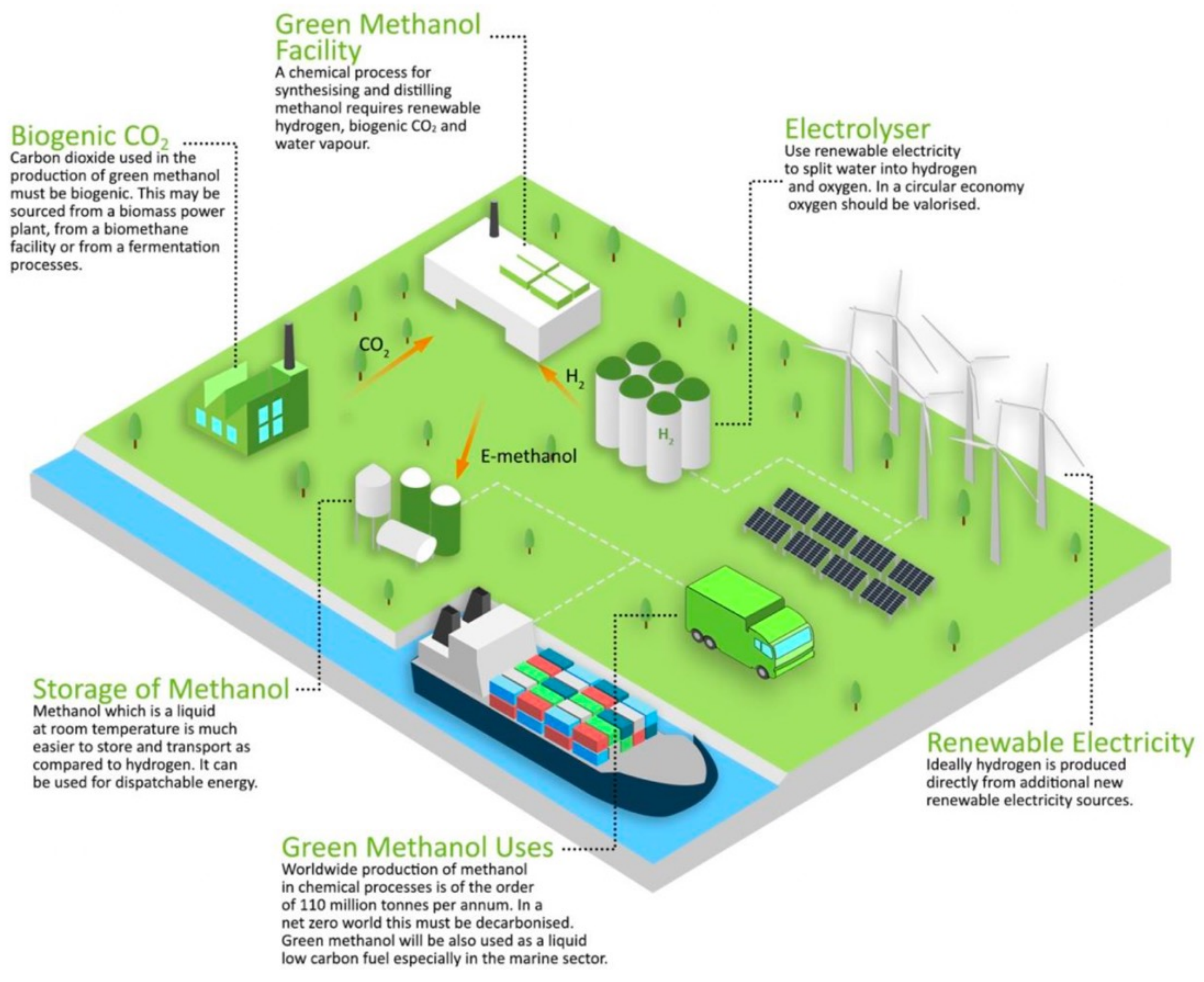


*Figure 5.1. Green Methanol production system, adapted from: https://www.iberdrola.com/documents/20125/2056775/metanol-verde-infografia-EN.pdf*

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# GREEN AMMONIA FROM GREEN HYDROGEN AND NITROGEN (FROM AIR)

Haber Bosch Process used to react Hydrogen (typically from natural gas) with Nitrogen (from air) at high temperatures & pressure over an iron catalyst to produce $NH_3$

World production of $NH_3$ 150 million tonnes.

Produces 430 million tonnes of $CO_2$ when produced from natural gas

Green $NH_3$ is both a carbon free fuel and a source of fertiliser


Credit: Siemens Energy

*Figure 5.2. Green Ammonia Production System, from (Boerner, 2019)*

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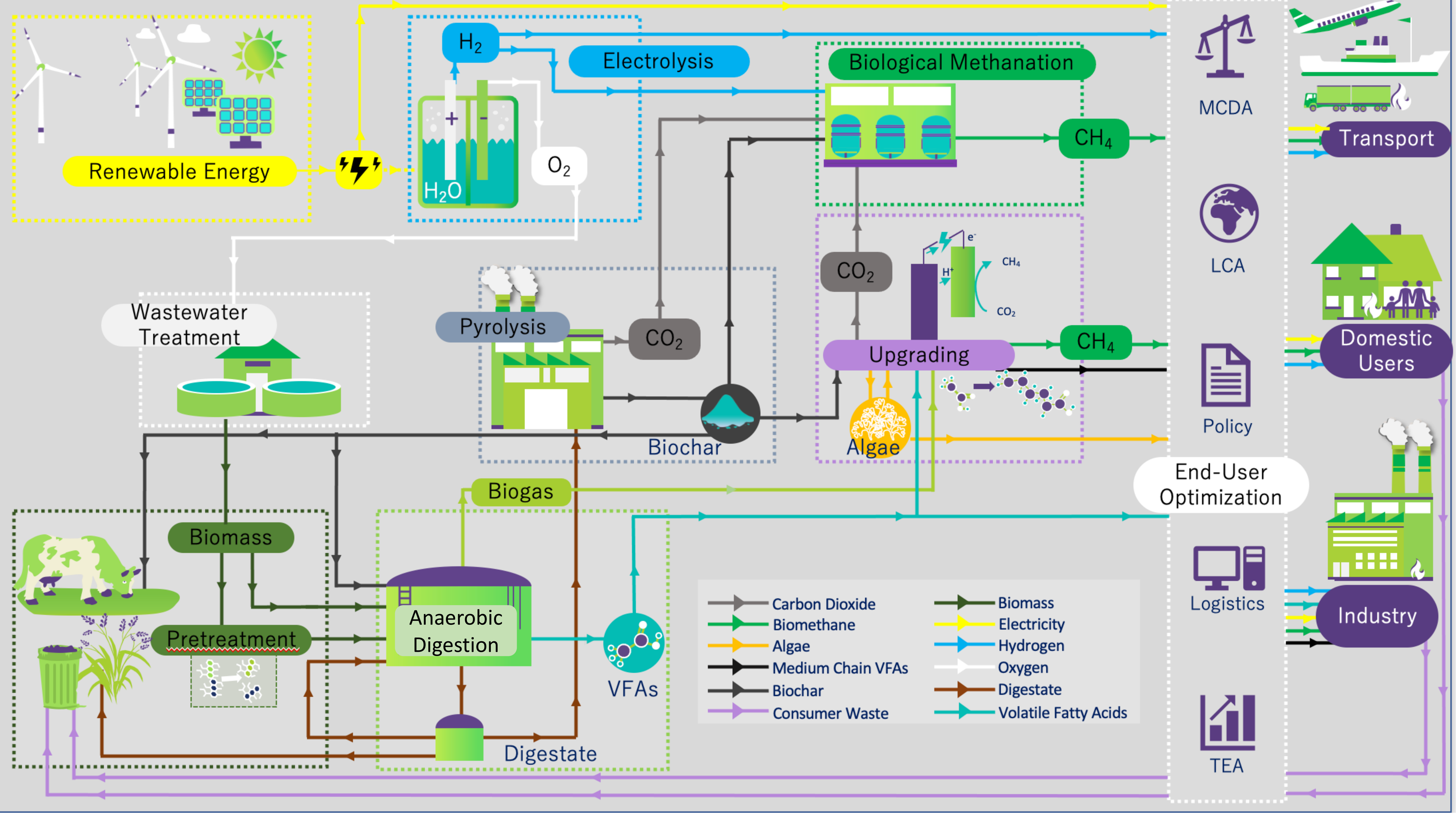

Renewable Energy
$H_2$
Electrolysis
$H_2O$
$O_2$
Biological Methanation
$CH_4$
MCDA
Transport
LCA
Domestic Users
Policy
Wastewater Treatment
Pyrolysis
$CO_2$
$CO_2$
e⁻
$H^+$
$CH_4$
$CO_2$
$CH_4$
Upgrading
Biochar
Algae
End-User Optimization
Biogas
Biomass
Anaerobic Digestion
Pretreatment
VFAs
Digestate
Logistics
Industry
TEA
Carbon Dioxide
Biomethane
Algae
Medium Chain VFAs
Biochar
Consumer Waste
Biomass
Electricity
Hydrogen
Oxygen
Digestate
Volatile Fatty Acids