Role of biogas systems in circular economy, energy and environmental systems

Prof Jerry Murphy,

At: IEA Bioenergy webinar on Integrated biogas systems – sustainable solutions beyond energy

Date: December 15th, 2022

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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)

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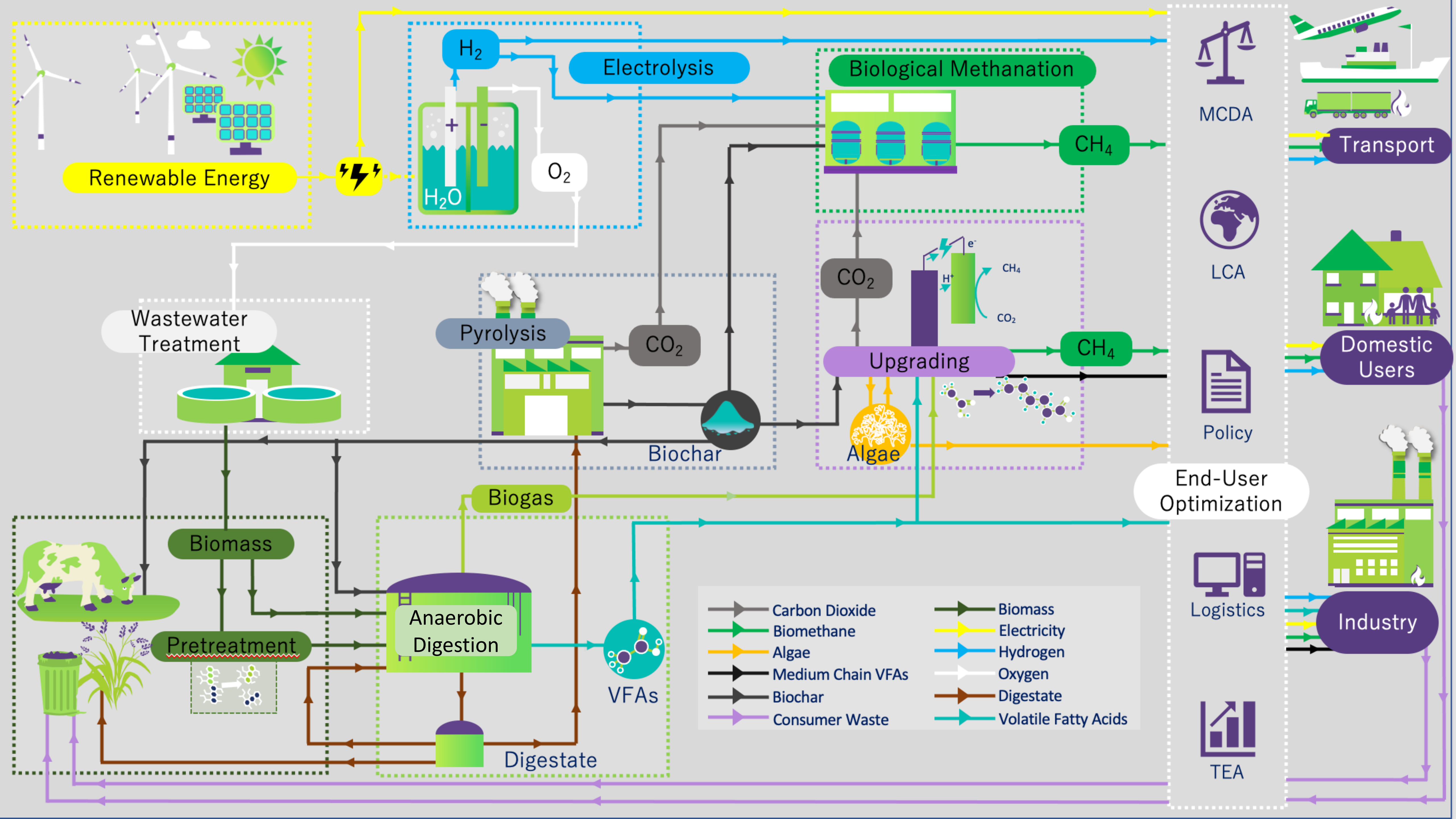

Renewable Energy
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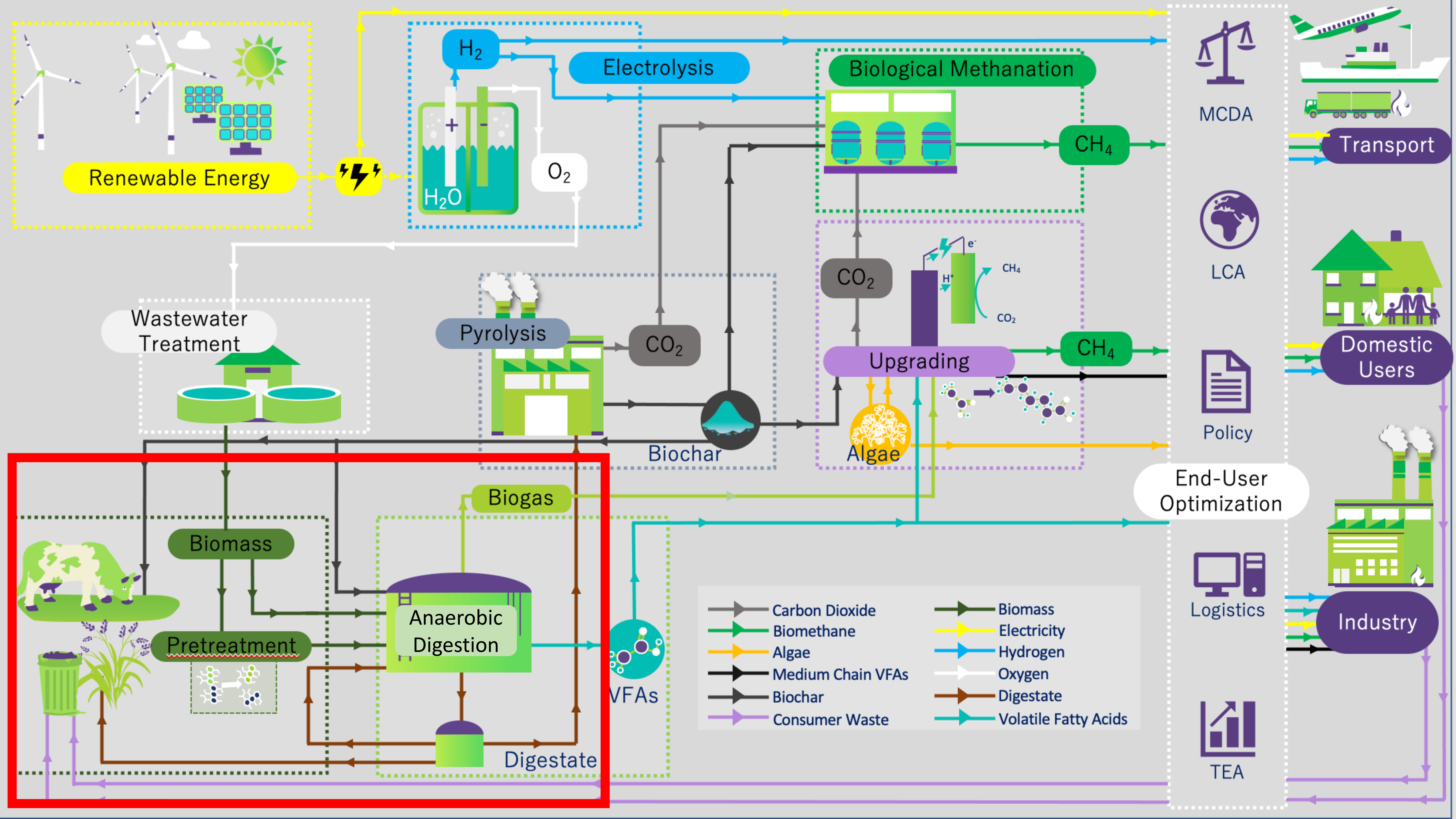
Electrolysis
H_2O
O_2
Biological Methanation
CH_4
MCDA
Transport
LCA
CO_2
e⁻
H⁺
CO_2
Upgrading
CH_4
Domestic Users
Policy
Wastewater Treatment
Pyrolysis
CO_2
Biochar
Algae
End-User Optimization
Biogas
Biomass
Pretreatment
Anaerobic Digestion
VFAs
Digestate
Logistics
Industry
TEA
Carbon Dioxide
Biomethane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



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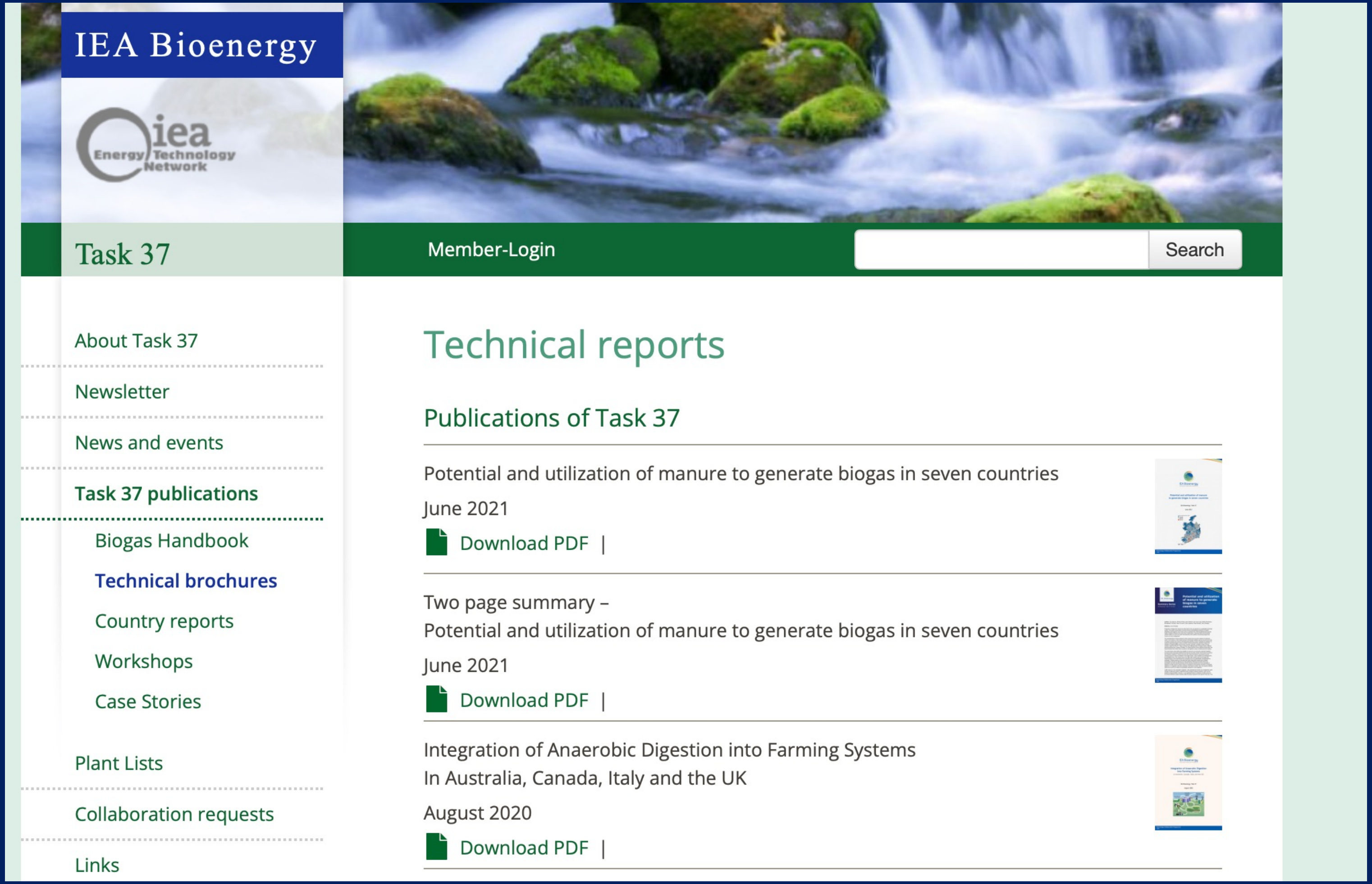


Case Stories:

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

Technical Reports

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

The role of anaerobic digestion and biogas in the circular economy

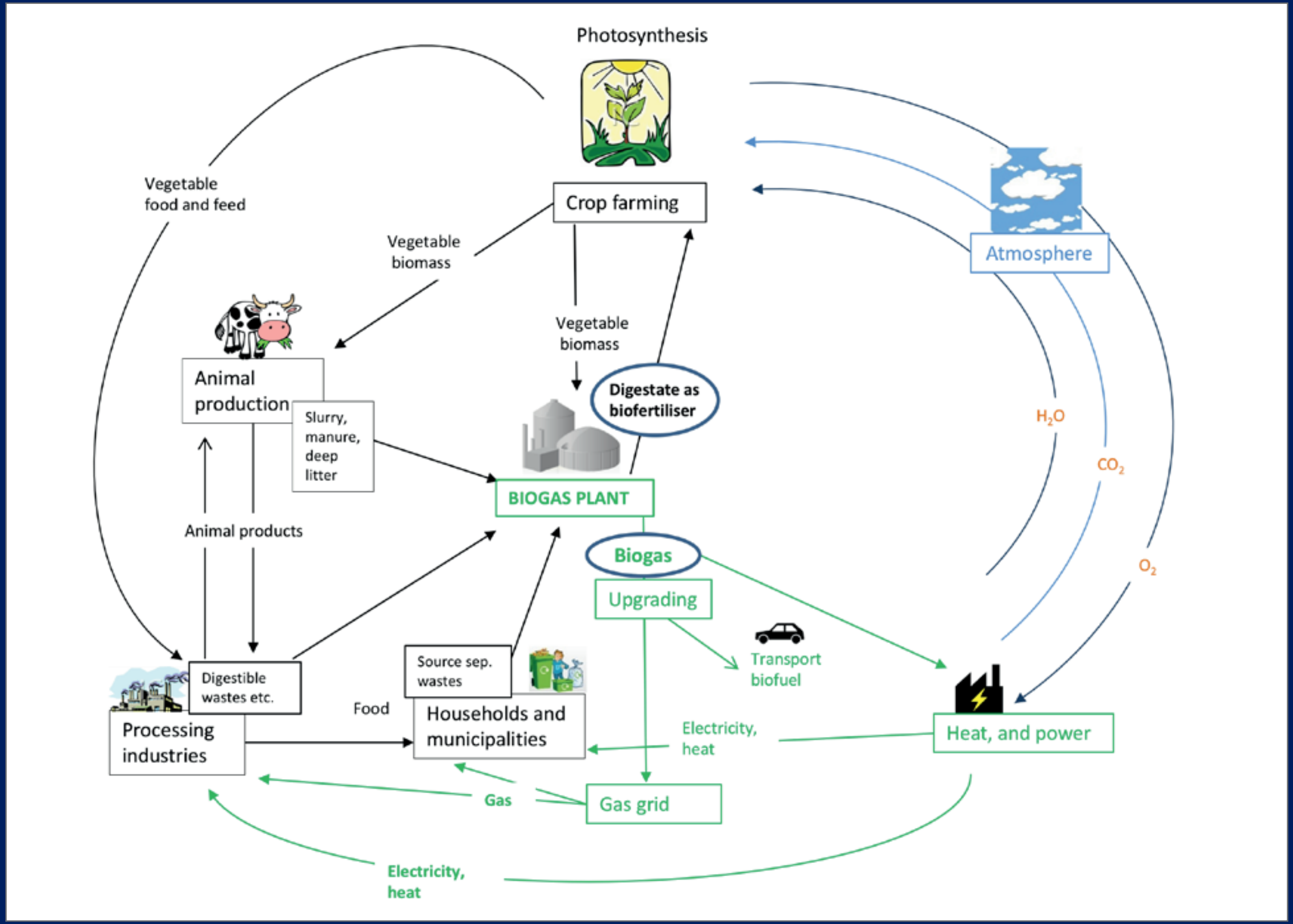


Figure 4. An example of how a modern co-digestion biogas plant fits into the circular economy (Source: Al Seadi et al. 2018)

Organic biogas improves nutrient supply

Table 1: Inputs to the organic biogas facility at Kroghsminde Bioenergy I/S, Denmark

Daily Feedstock expressed in t/d	
Organic grass silage	5t/d
Corn	4t/d
Organic poultry manure	1t/d
Horse manure	1t/d
Organic silage (horse bean, lupine, barley / ryegrass)	2t/d
Organic deep litter	9t/d
Organic cattle slurry	48t/d
Total	**69t/d**

Milk from 140 cattle farm assessed as GHG negative at -0.82 kg CO_2/ l produced.

Parkland grass cuttings to transport biofuel, Brazil

60 cars fueled from 400 ha of parkland campus

Centralised biogas upgrading: distribution of biogas to upgrading facility

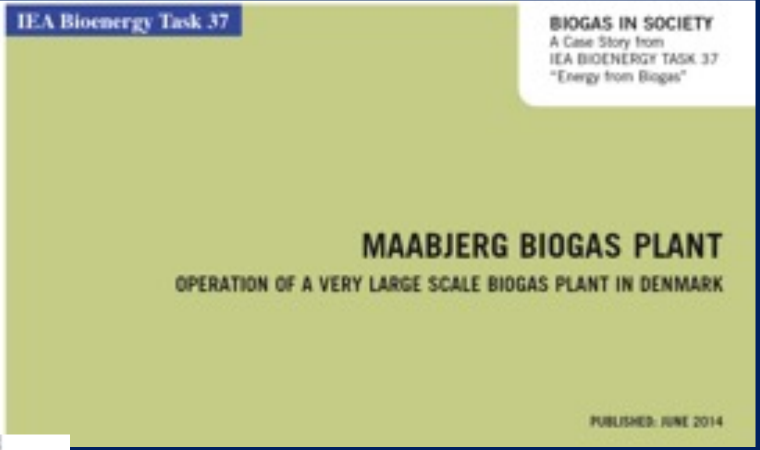
Figure 2: gas upgrading membranes at the Wijster green gas hub

Technique	Capacity Nm^3 biogas/ hour	Green Gas Nm^3 biogas/h	Year of installation
PSA.	1200	840	1989
Water Scrubbing	1000	700	2012
Membrane	800	560 (plus liquid CO_2)	2014

Table 1: Attero's gas refining installations at Wijster

Pipelines to extend catchment of biogas

Figure 1: General view of Maabjerg BioEnergy Plant, (Photo: Maabjerg BioEnergy)



IEA Bioenergy Task 37

BIOGAS IN SOCIETY
A Case Story from
IEA BIOENERGY TASK 37
"Energy from Biogas"

MAABJERG BIOGAS PLANT

OPERATION OF A VERY LARGE SCALE BIOGAS PLANT IN DENMARK

PUBLISHED: JUNE 2014

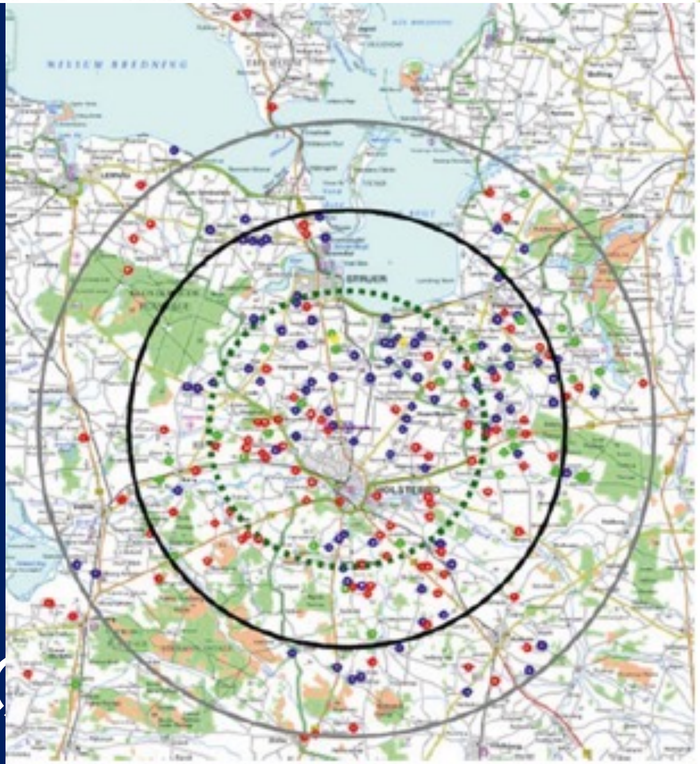


Figure 2: The area of animal slurry collection around the biogas plant, with the average radius of 20 km. Source: Maabjerg BioEnergy

Denmark set a target for 50% slurry digestion by 2020 and has already met this

Table 1: INPUT

Green line	**tons/year**
Animal slurry	460.000
Animal manure	20.000
Dairy waste	120.000
Potato pulp	15.000
Yeast cream	15.000
Abattoir waste	10.000
Total green line	**640.000**
Industry line	**tons/year**
Wastewater sludge	75.000
Flotation sludge	10.000
Total industry line	**85.000**
Total input	**725.000**

Table 2: OUTPUT

Green line	**tons/year**
Liquid fertilizer (digestate)	550.000
Fertilizer fibres	40.000
Industry line	**tons/year**
Sludge (30 % TS)	10.000
Biogas utilisation	**m^3/year**
Vinderup Varmeværk (District heating)	7.500.000
Måbjergværket (District heating)	3.500.000
Maabjerg BioEnergy	7.000.000
Total industry line	**85.000**
Biogas total	**18.000.000**

Source: Maabjerg BioEnergy

Pipeline systems consist of double pipes; slurry from collection tanks to digester and sanitized biodigestate from digester back to collection point. Piping system reduces the need for 50 – 70 deliveries per day and facilitates collection of diffuse sources of slurry

Biogas for Large Energy Users (LEUs)

Contents lists available at ScienceDirect

Applied Energy

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

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

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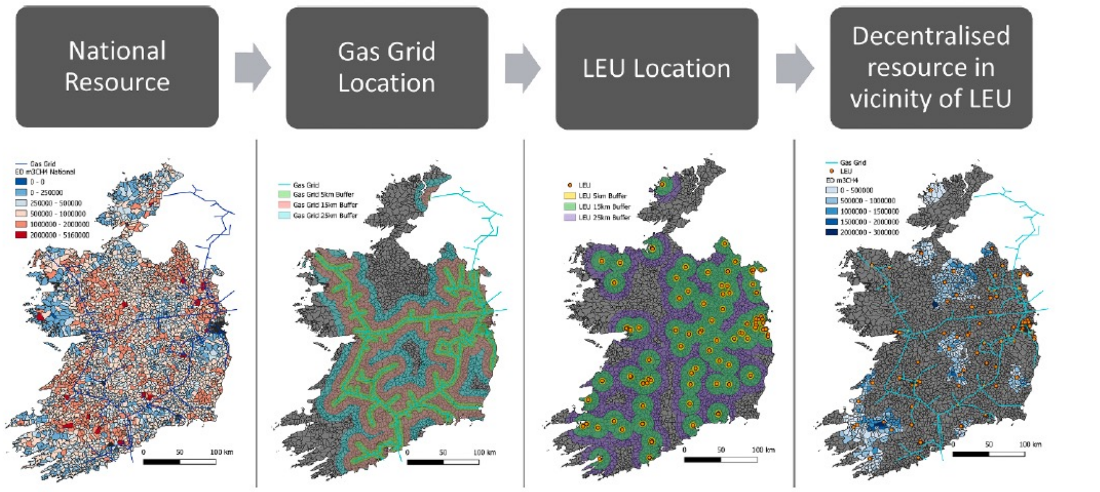
Civil, Structural and Environmental Engineering, School of Engineering and Architecture, University College Cork, Cork, Ireland

HIGHLIGHTS

- Decentralised biomass is defined as biomass in excess of 15 km from the gas grid.
- Over 17% of national on-farm biomass is decentralised but within 15 km of industry.
- On-farm biomethane resource is equivalent to 200% of industry gas use in Ireland.
- Industry heat demand in two studies can be met by biomethane produced within 2.5 km.

GRAPHICAL ABSTRACT



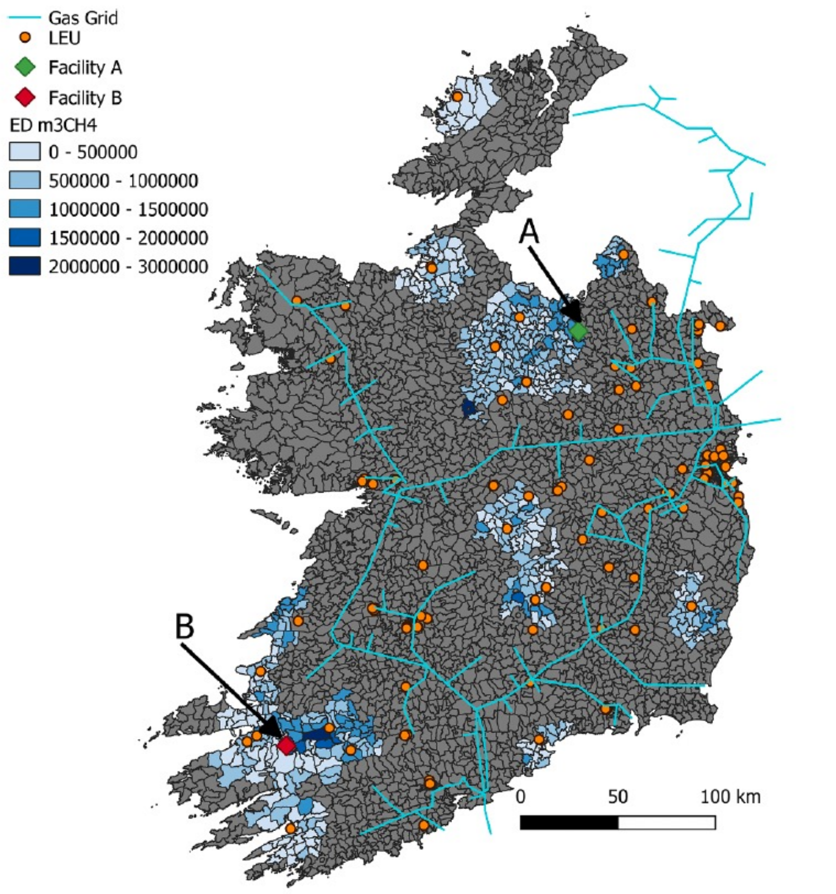


Fig. 9. Gross biomethane resource in EDs more than 15 km from the gas grid and within 15 km of a LEU.

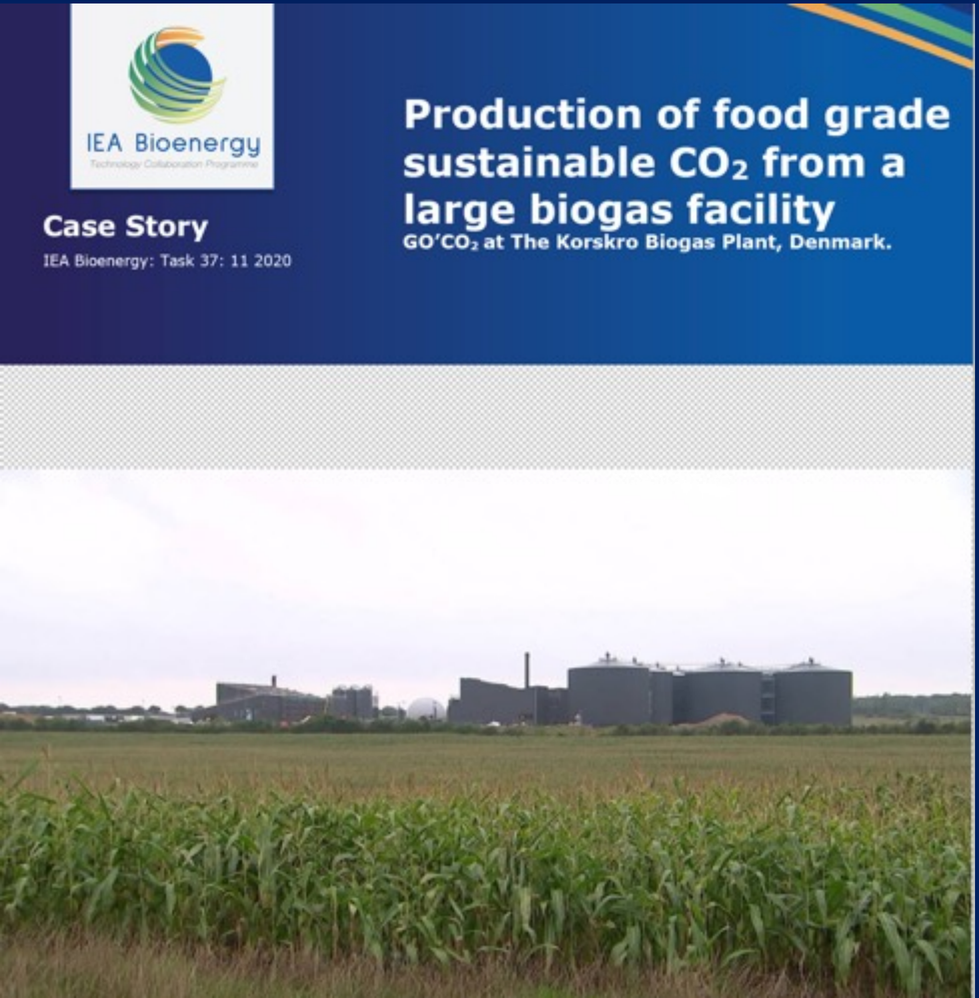
The role of biogas in greening brewing industry, Austria

Figure 2: Biogas facility at Gösser brewery

Table 1: Inputs and outputs of biogas plant at brewery Gösser

Input		Output	
Brewers spent grains	13,621 t/a	Biogas produced	2.3 million m³/a
		Biogas to brewery (boiler)	3.3 million kWh/a
		Electricity (from CHP)	3.4 million kWh/a
		Heat (from CHP)	2.2 million kWh/a

Production of food grade CO_2 from a biogas facility



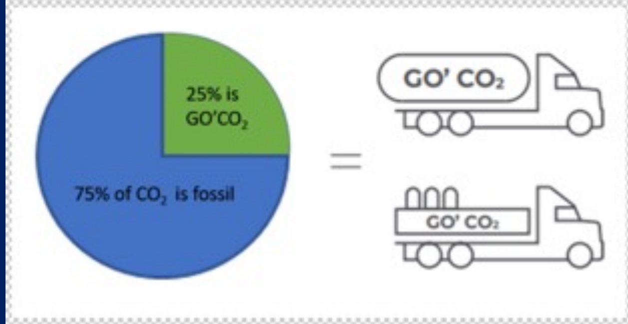


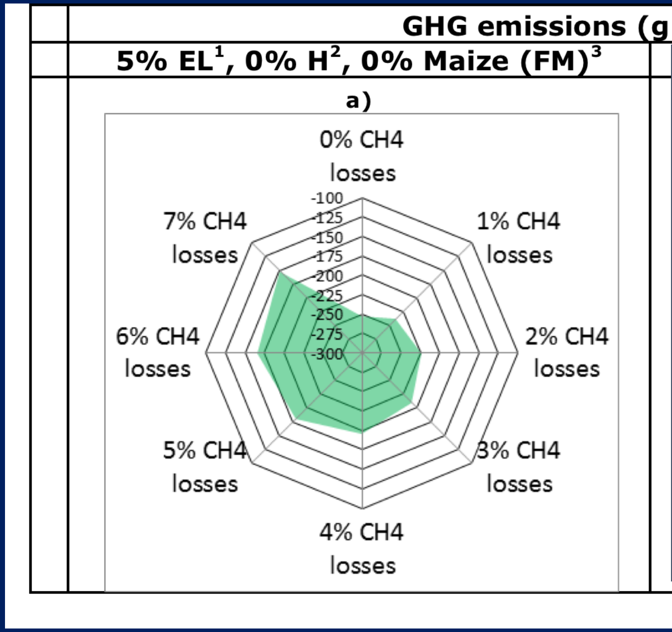
Figure 3: Up to 25 % of the CO2 consumption in Denmark is covered by sustainable GO' CO2.

Food industry • Cooling food • Modified Atmosphere (MA) packing of minced meat • Supplement to soft drinks and beer • Stunning animals before slaughter.	Iron & machine industry • Laser cutting • Welding in black steel • Shielding gas.
Healthcare sector • Laparoscopy (surgical procedure) • Dry ice for sending samples • Cooling eggs and sperm in fertility clinics.	Pharmaceutical industry • pH control • Dry ice for the transport of stem cells • Controlling oxygen levels in cell culture.

Fugitive methane emissions from biogas plants

Open slurry storage emits 17.5% of methane.

At 2% methane slippage: biomethane from slurry GHG negative (-250 g CO_2/MJ)



GHG negative biomethane for advanced transport biofuel.

Ideal for haulage and bus services.

California Air Resources Board awarded a Carbon Intensity score of -255 gCO_2e/MJ for a dairy waste to vehicle fuel pathway.

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Integration of biogas systems into the energy system

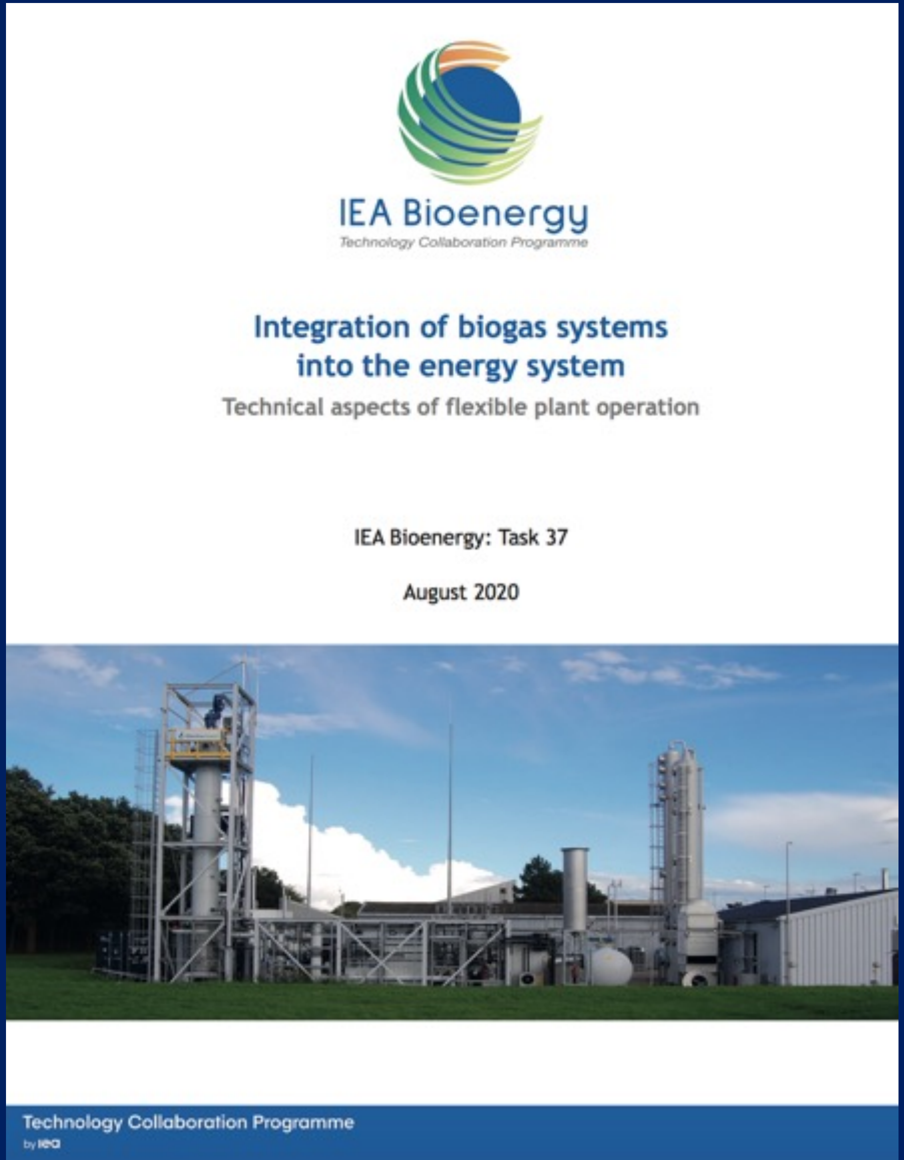

Figure 12: Fleco Power Structure to combine flexibility of decentralized installations

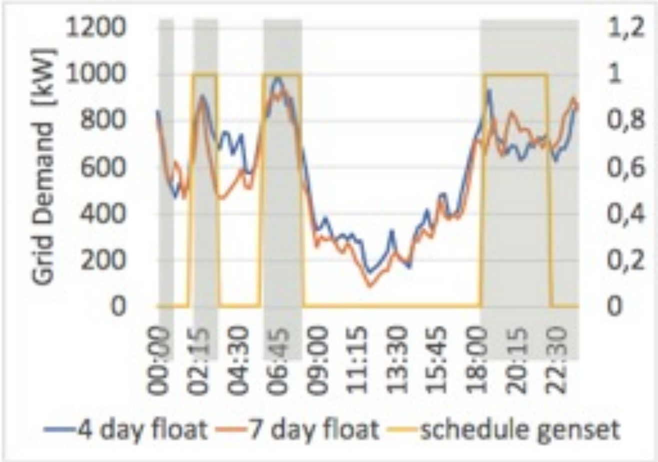

Figure 14: Example of a 1-day flexibility control time course of a biogas installation in Switzerland in Autumn.
grey: peak load time windows. blue/red: Historical load curves of electricity demand.
yellow: biogas CHP timetable

Modelling Demand Driven Biogas

Bioresource Technology 216 (2016) 238–249

Contents lists available at ScienceDirect

Bioresource Technology

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

Modelling a demand driven biogas system for production of electricity at peak demand and for production of biomethane at other times

R. O'Shea, D. Wall *, J.D. Murphy

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

HIGHLIGHTS

- A biogas model incorporating production of electricity and biomethane is proposed.
- Demand driven biogas, facilitates intermittent renewable electricity.
- A demand driven biogas system can ramp up hourly electricity by a factor of 4.5.
- The biogas model suggests sending 21% of biogas to electricity and 79% to upgrading.
- The grass silage should be fed 127 min in advance of producing electricity.

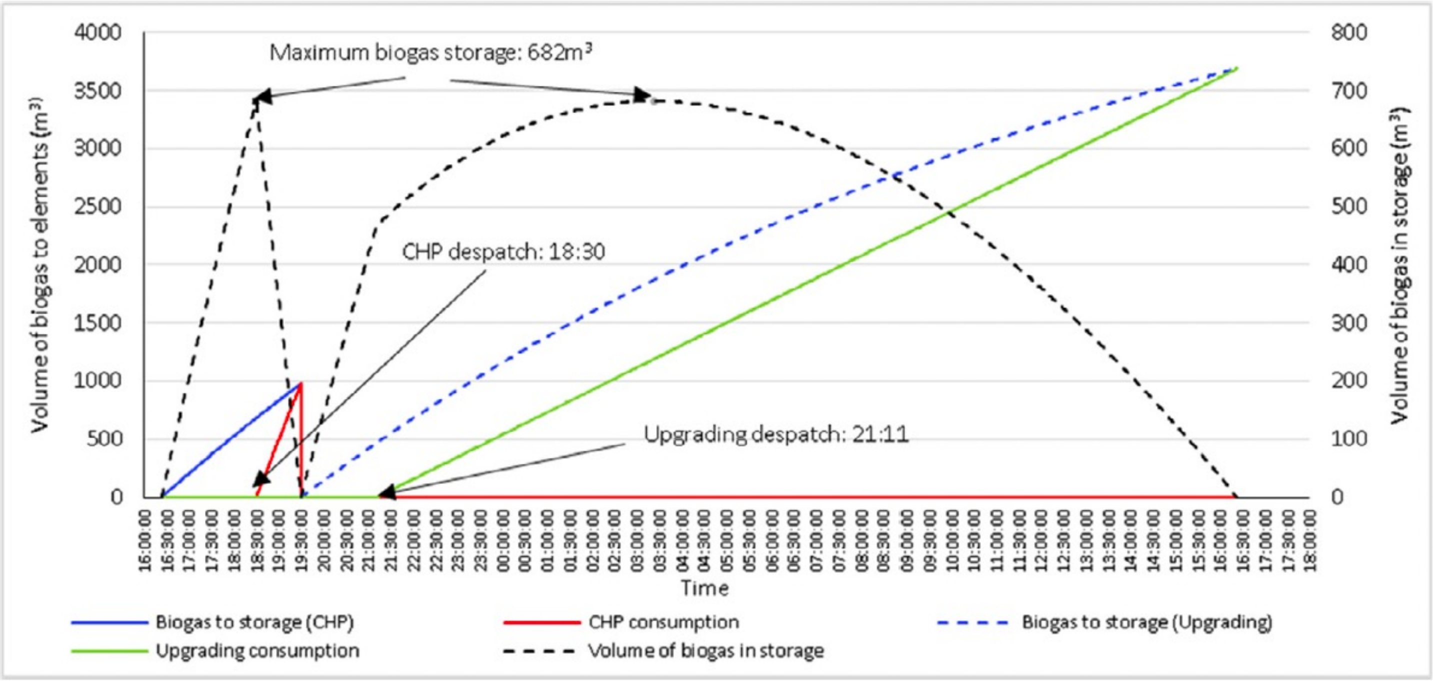

Fig. 4. Example of biogas flows in pulse fed reactor. Feedstock is grass silage, organic loading rate of 2 kg VS/m^3/day, reactor volume of 4000m^3.

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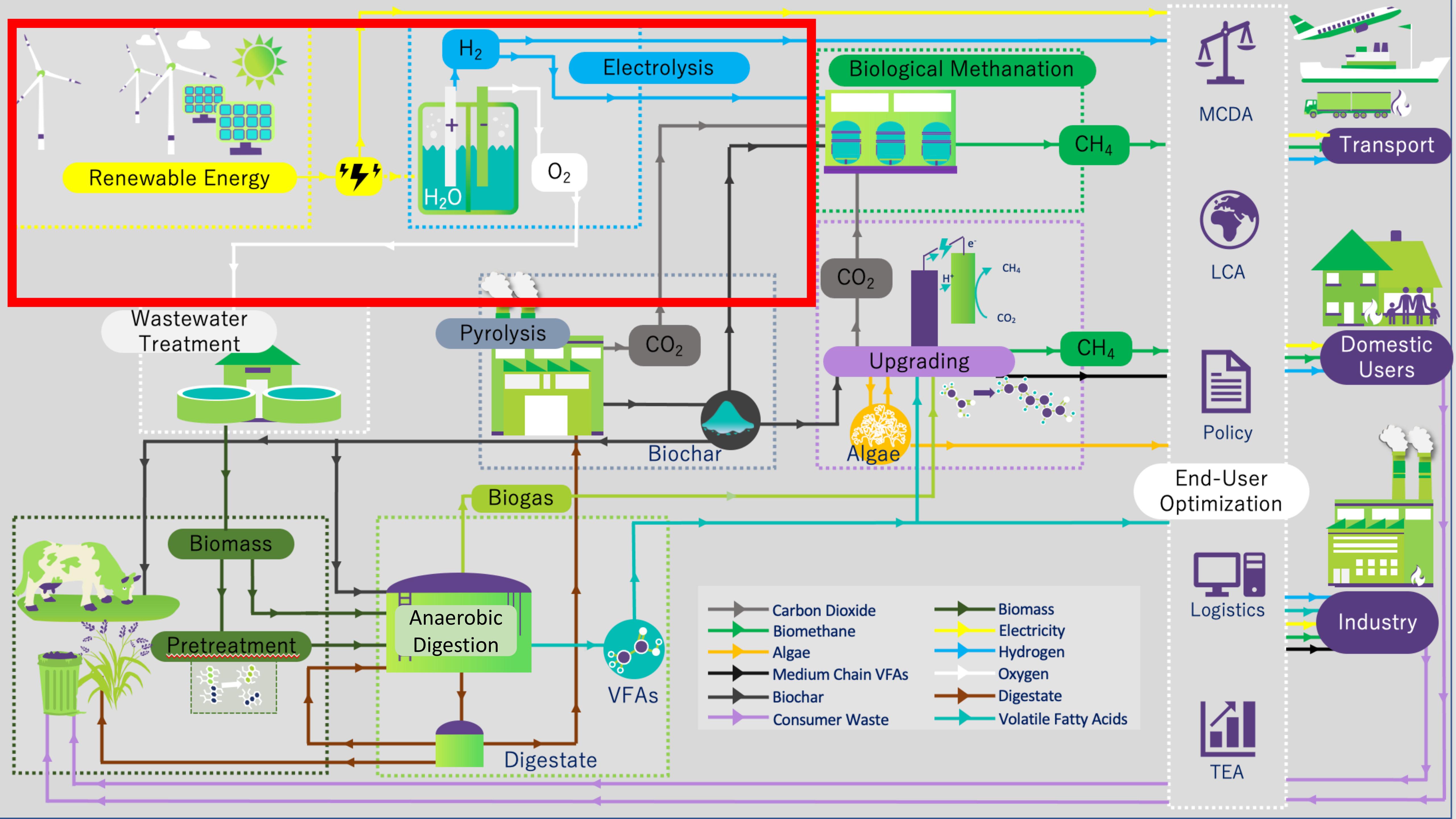

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Volatile Fatty Acids

GREEN HYDROGEN: INTERCONNECTIVITY OF ELECTRICITY AND GAS GRIDS

$$SNSP = \frac{Wind \quad generation + Imports}{System \quad demand + Exports}$$

- In the EU and US, up to twice as much energy is sourced from gas grid as electricity grid.
- Ireland has c. 8 GWe electrical capacity at 40% RES-E
- Ireland's electricity grid has already experienced and sustained some of the highest system nonsynchronous penetration (SNSP) in any national electricity grid
- Ireland targets a further 7 GWe of offshore wind by 2030 leading to 80% RES-E.
- Target of 2GW hydrogen
- Dublin Declaration 260 GW offshore wind by 2050
- This level of intermittency on an island grid is extremely challenging and may lead to periods of over production, negative pricing, instability and requirements for storage.

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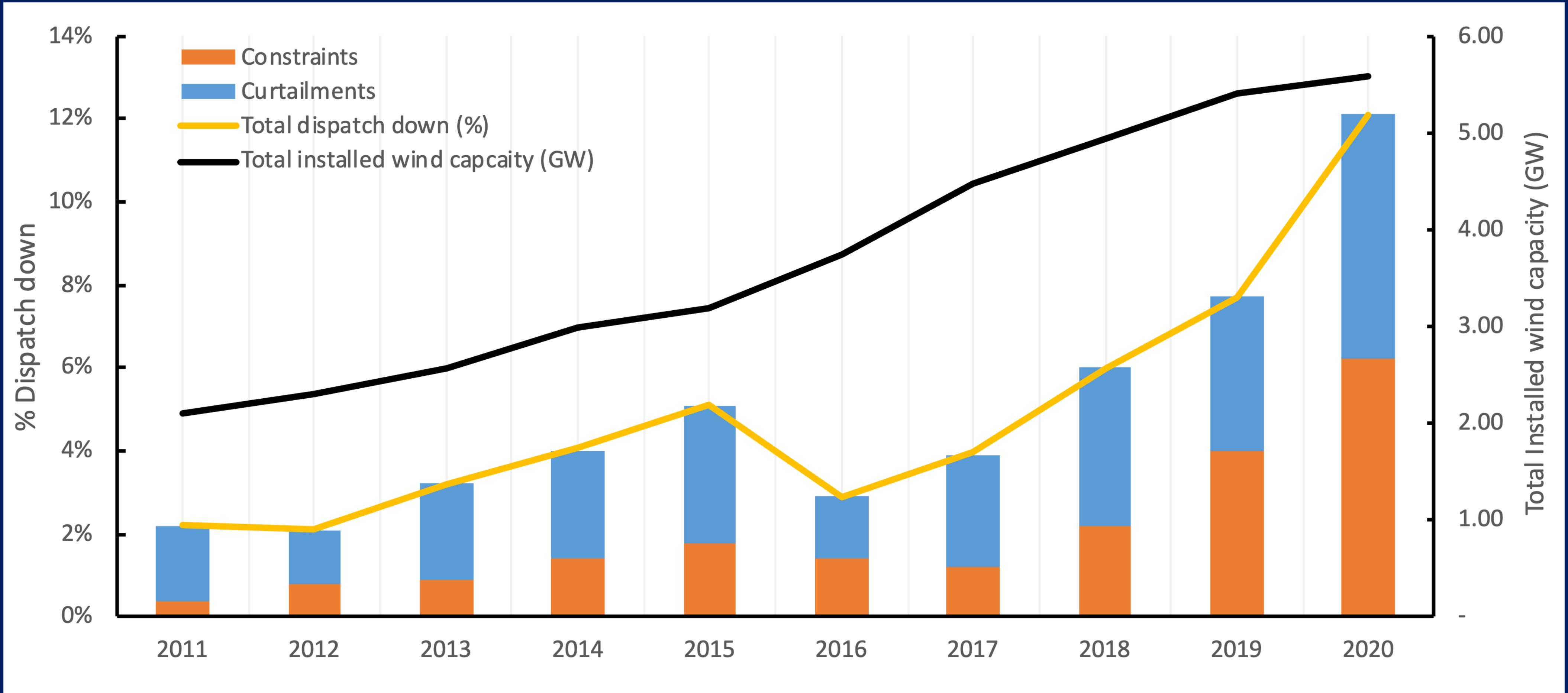
Yearly breakdown of dispatch-down levels into constrain and curtailment on island of Ireland



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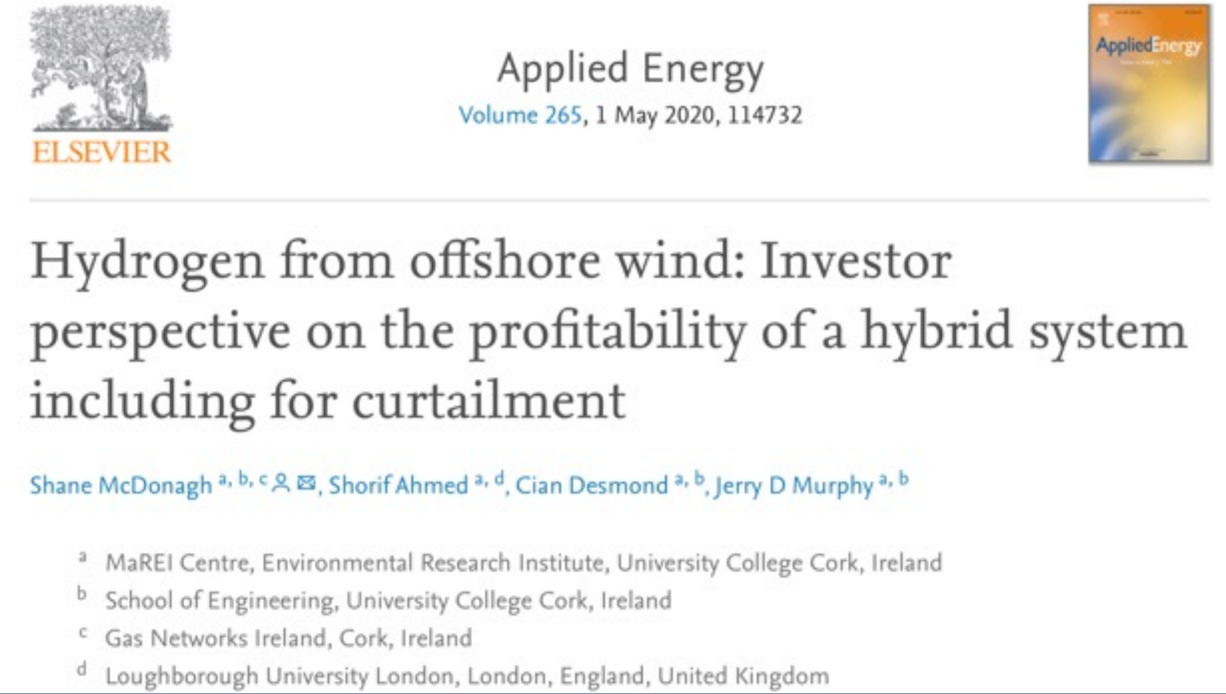
Hybrid system allows for production of electricity and hydrogen



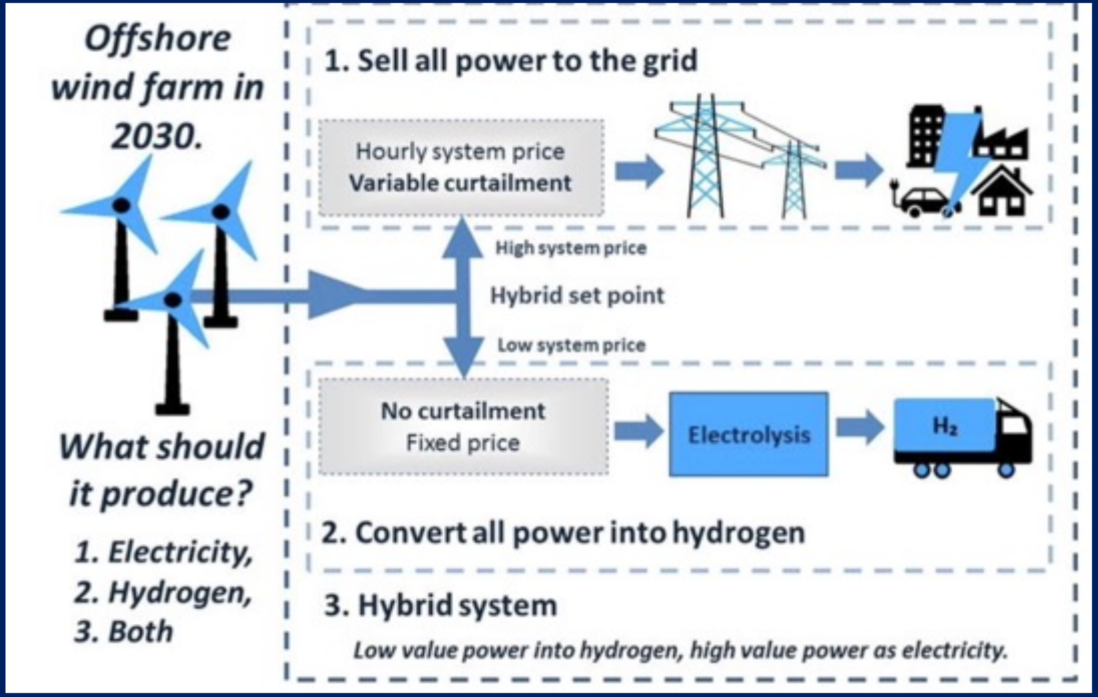
ELSEVIER

Applied Energy
Volume 265, 1 May 2020, 114732

Hydrogen from offshore wind: Investor perspective on the profitability of a hybrid system including for curtailment

Shane McDonagh [a, b, c], Shorif Ahmed [a, d], Cian Desmond [a, b], Jerry D Murphy [a, b]

[a] MaREI Centre, Environmental Research Institute, University College Cork, Ireland
[b] School of Engineering, University College Cork, Ireland
[c] Gas Networks Ireland, Cork, Ireland
[d] Loughborough University London, London, England, United Kingdom



- Levelised wind farm cost of 4.23c/kWhe gives levelised H2 cost of 11.3c/kWh (€3.77/kg).
- Round cycle electricity to H_2 back to electricity (at 60% electrical efficiency) equates to 18c/kWh_e which is expensive
- As a transport fuel, 11.3c/kWh equates to ca. €1.13 per L diesel equivalent. Even better if used in a fuel cell (greater efficiency than IC engine 50% vs 40%), equates to ca. €0.90/L per L diesel equivalent

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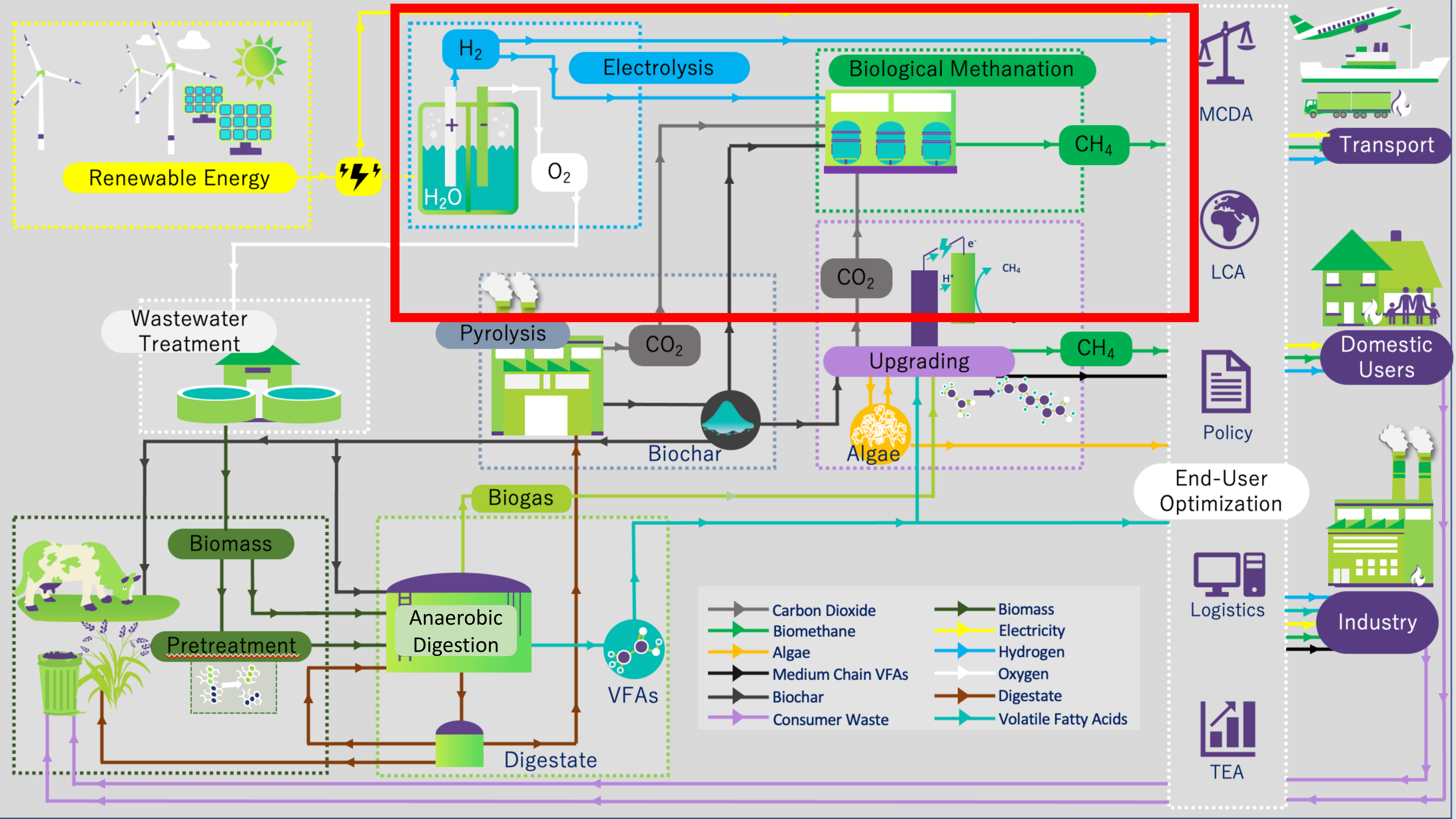

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Power to methane

Sabatier Equation: $4H_2 + CO_2 = CH_4 + 2H_2O$

Audi E-gas at Wertle, Germany - Catalytic Sabatier process

Food waste biomethane

Production of hydrogen in 6MW electrolyser

Production of methane via Sabatier

1000 Audi NGVs

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Biological conversion of hydrogen to methane in a batch system

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,*]

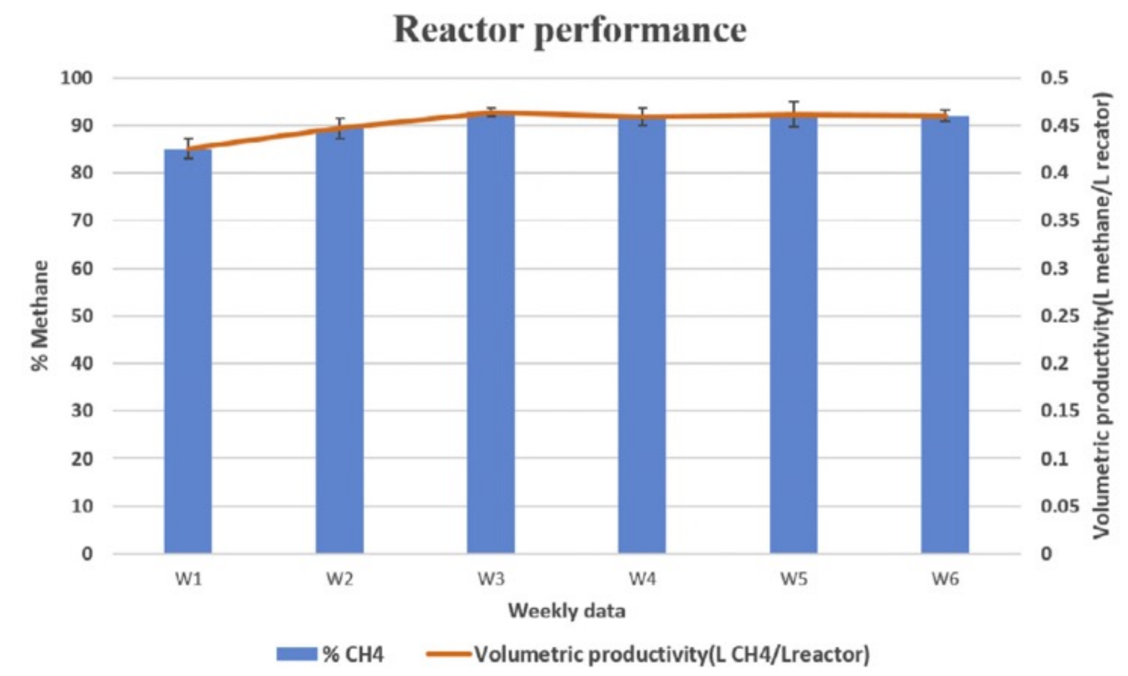

Fig. 3. Methane composition and volumetric productivity at 65 °C (fresh inoculum) for 24 h.

Methanothermobacter Wolfeii

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

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Biological methanation in continuous systems

Applied Energy 235 (2019) 1061–1071

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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

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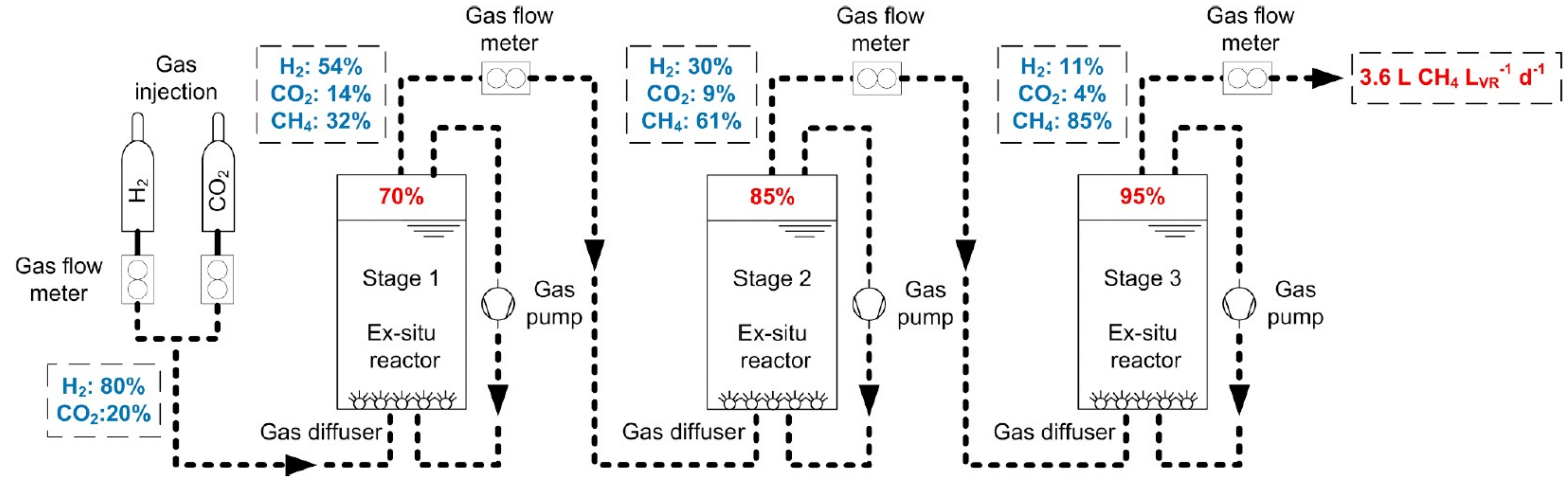
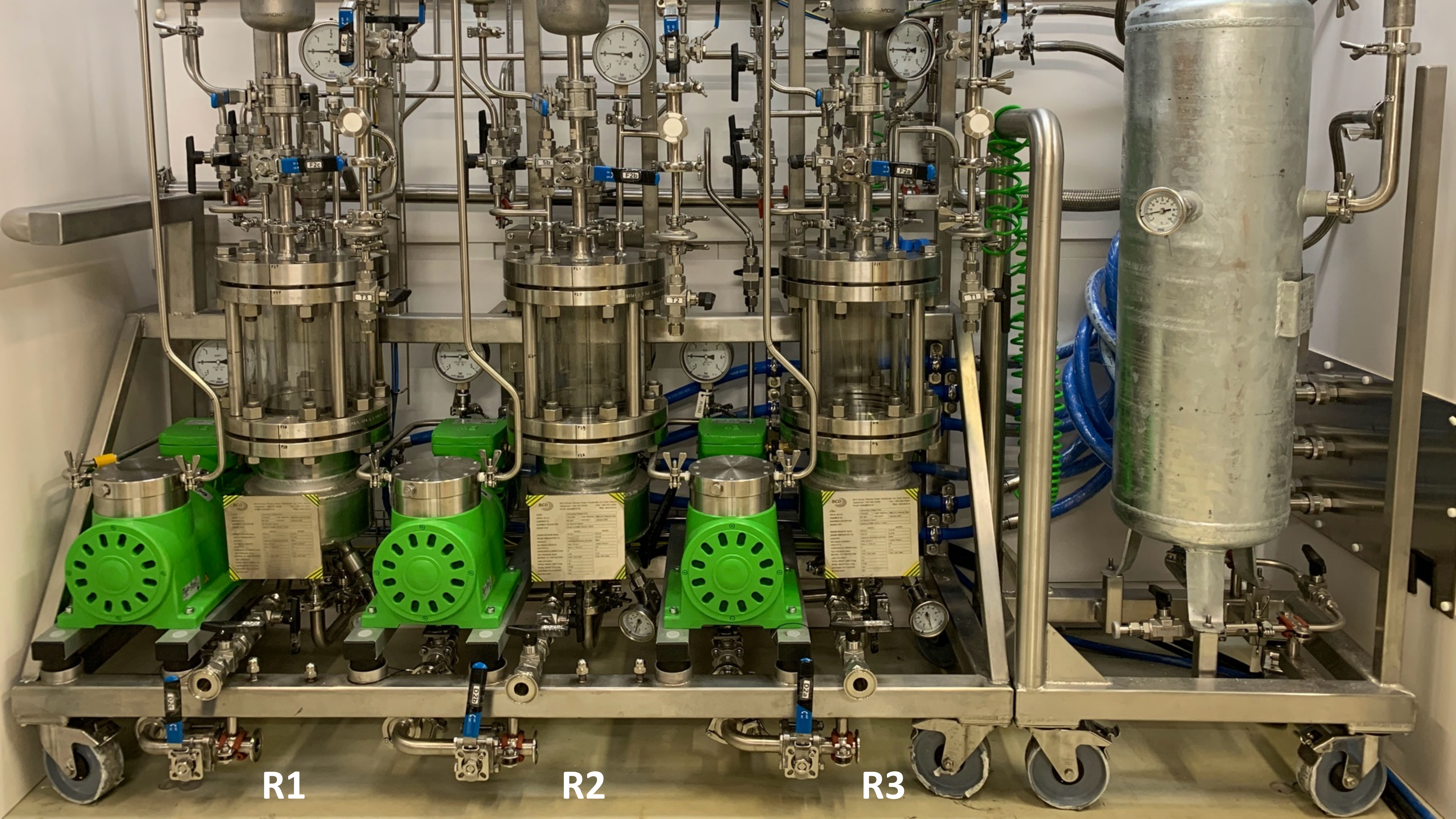


Fig. 6. Theoretic model and approach for a full-scale three-stage sequential ex-situ methanation unit at a methane formation rate of $3.6\,L\,CH_4\,L_{VR}^{-1}\,d^{-1}$. The conversion of carbon dioxide to methane corresponds to 70% (after stage 1), 85% (after stage 2) and 95% (after stage 3).


R1
R2
R3

Upgrading biogas to biomethane in biological methanation systems

- The final output CH_4 concentration reached 97.1%.
- Increase of H_2 loading rate decreased the output CH_4 concentration.
- Short periods of intermittent gas supply did not affect the biomethanation performance.

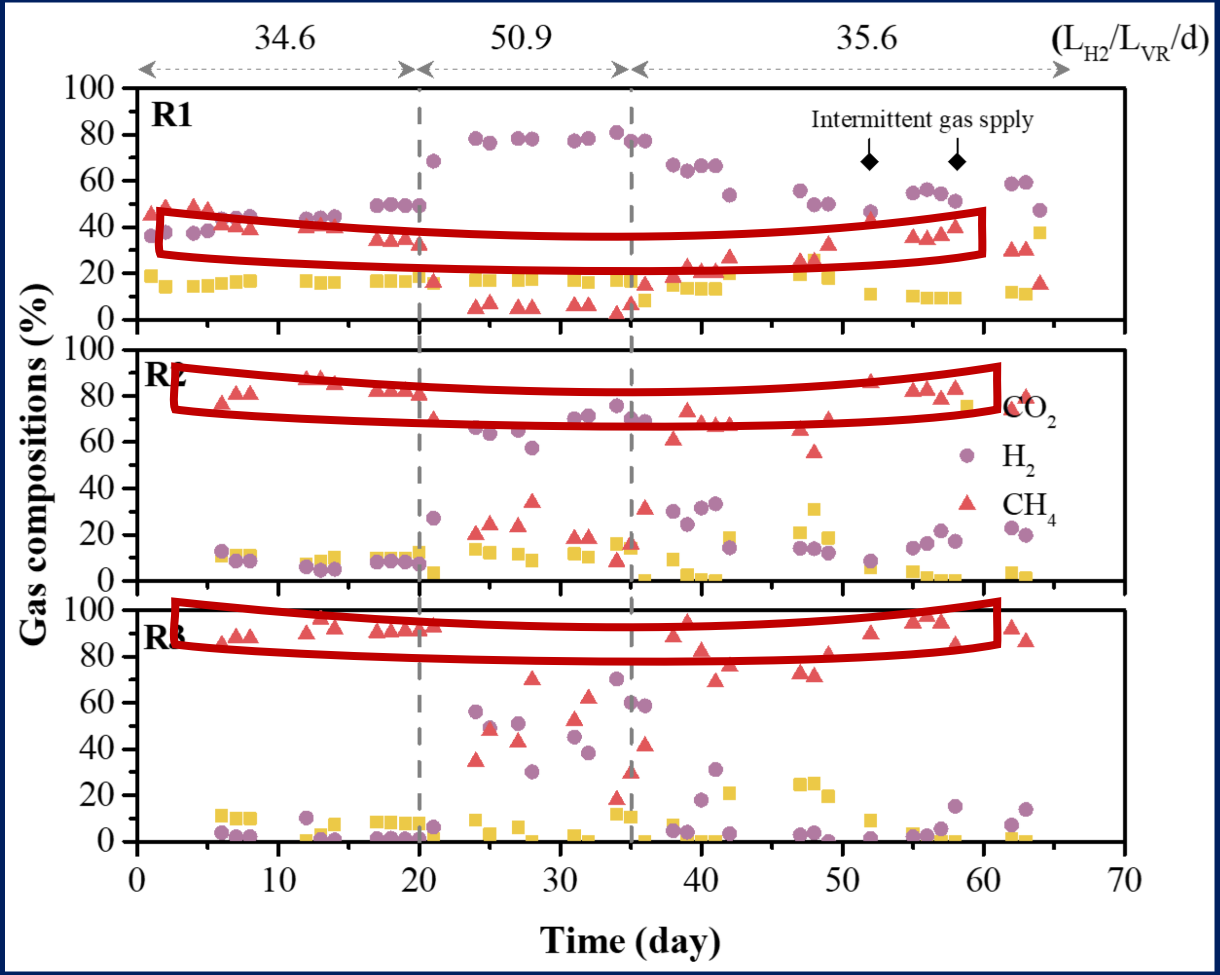


Fig. Gas compositions of the reactors in sequence (R1-R2-R3).

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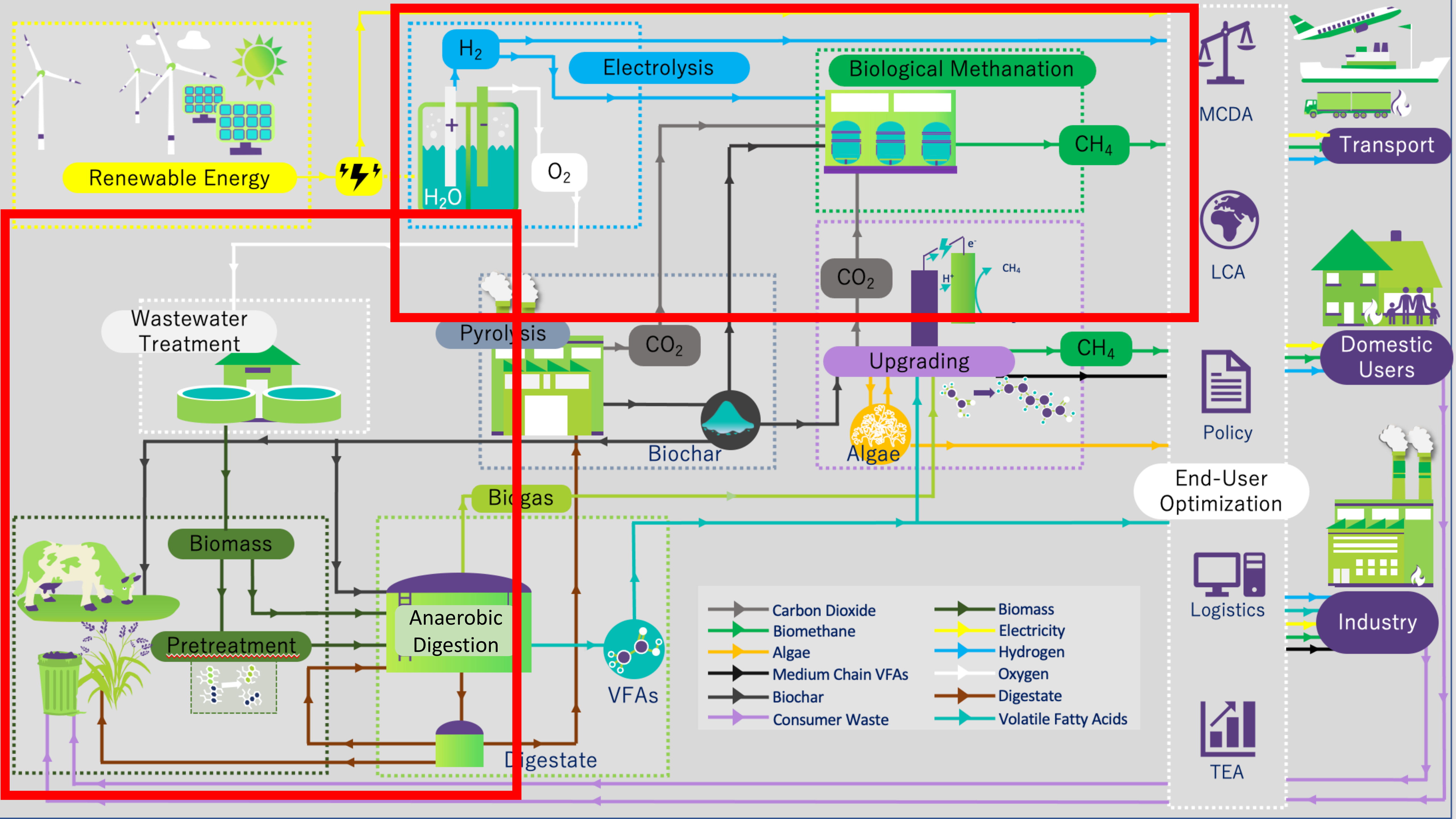

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Potential to integrate electrolysers at wastewater treatments plants

Advances in Applied Energy 8 (2022) 100109

Contents lists available at ScienceDirect

Advances in Applied Energy

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

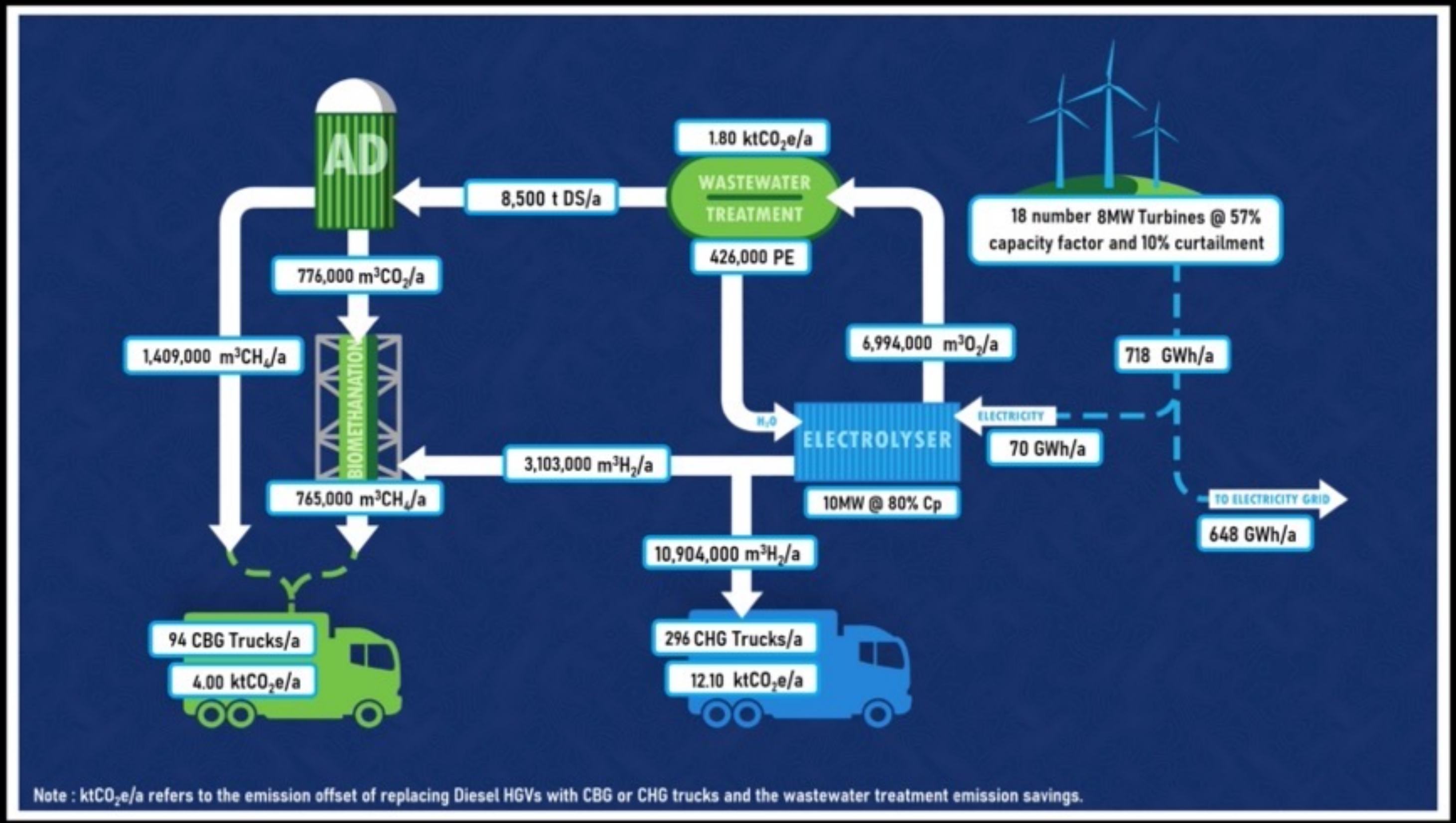
Operation of a circular economy, energy, environmental system at a wastewater treatment plant

Davis Rusmanis[a,b], Yan Yang[a,b], Richen Lin[a,b,c], David M. Wall[a,b], Jerry D. Murphy[a,b,*]

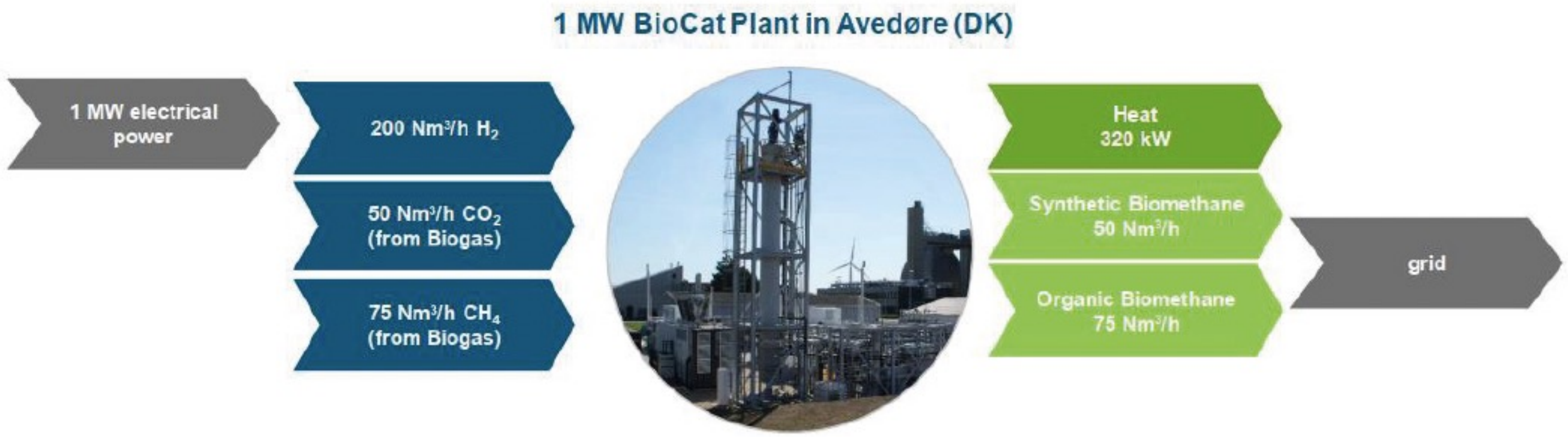
[a] SFI MaREI Centre for Energy, Climate and Marine, Environmental Research Institute, University College Cork, Ireland
[b] Civil, Structural and Environmental Engineering, School of Engineering and Architecture, University College Cork, Cork, Ireland
[c] Key Laboratory of Energy Thermal Conversion and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

Highlights

- Curtailed electricity from a 144 MW offshore wind farm can supply a 10MW electrolyser.
- A 10 MW electrolyser can supply O_2 to a 426,400 person wastewater treatment facility.
- Only 22% of the H_2 is required for methanation of biogas from sludge digestion.
- Pure O_2 aeration can result in a 40% reduction in emissions at the treatment facility.
- Excess H_2 and biomethane could together fuel 390 heavy goods vehicles.



Increased output of methane from power to methane system



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

Potential to incorporate electrolysers at existing anaerobic digestion facilities

Applied Energy 235 (2019) 1061–1071

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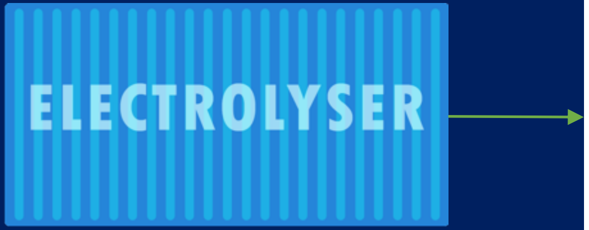

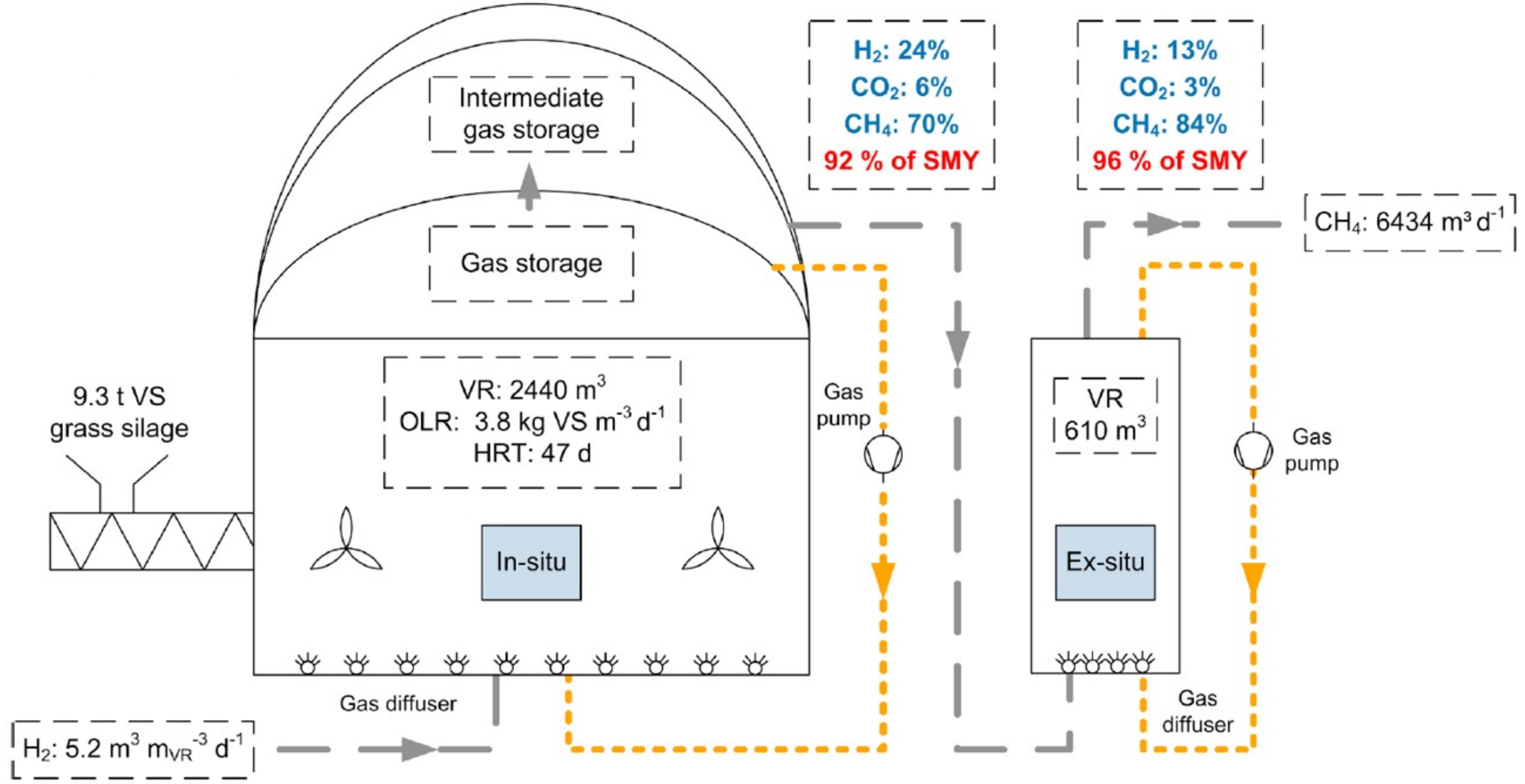

Fig. 7. Hybrid concept of sequential in-situ and ex-situ methanation with triple gas storage membrane on top of in-situ digester (SMY: specific methane yield, VR: reactor volume, OLR: organic loading rate, HRT: hydraulic retention time, VS: volatile solids).

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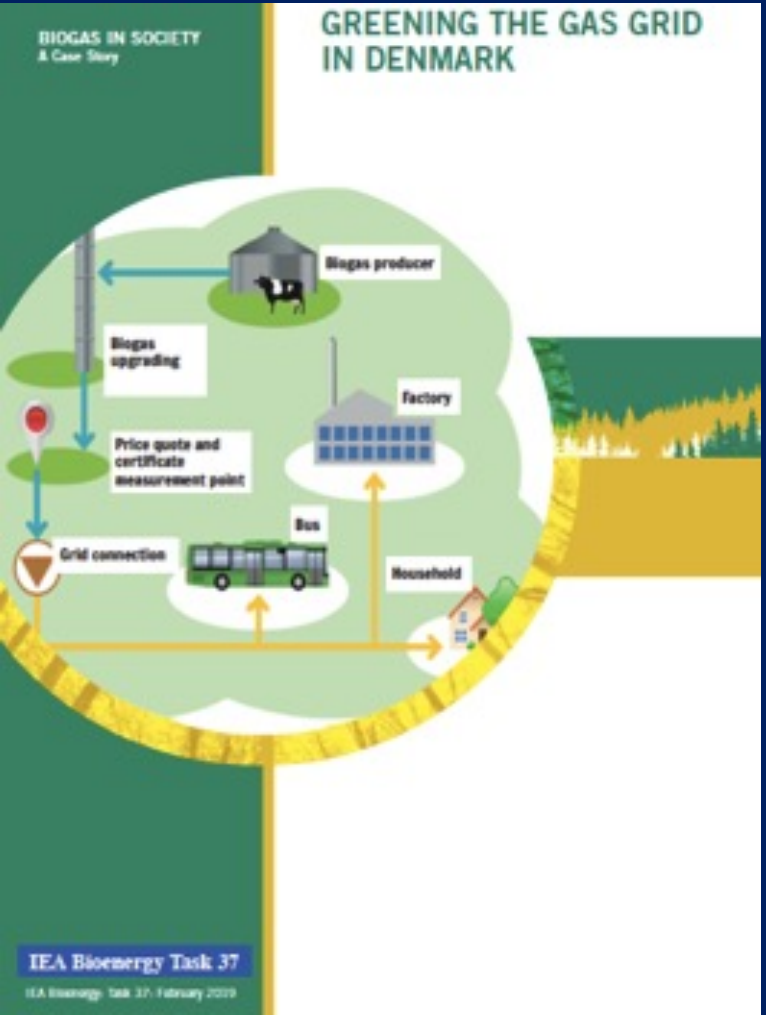
Greening the gas grid in Denmark

Denmark intends decarbonising the gas grid with 72PJ of renewable gas by 2035. Addition of P2G systems could see a resource of 100 PJ, in advance of gas demand.



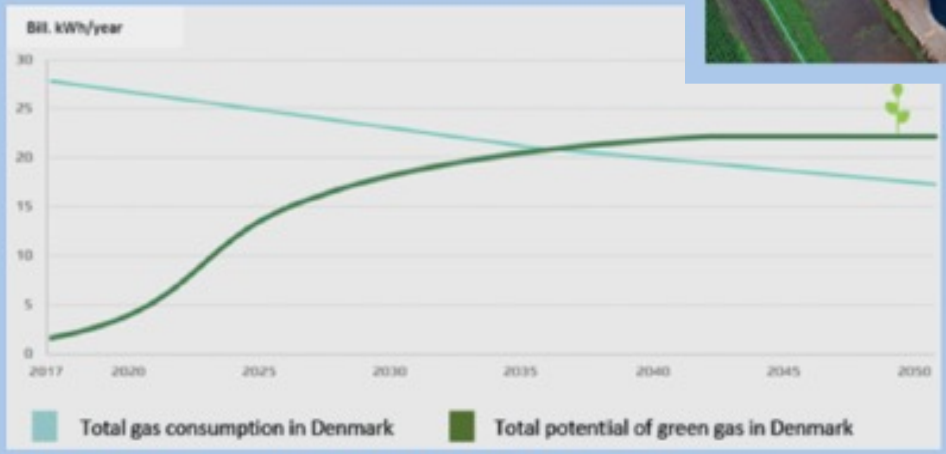
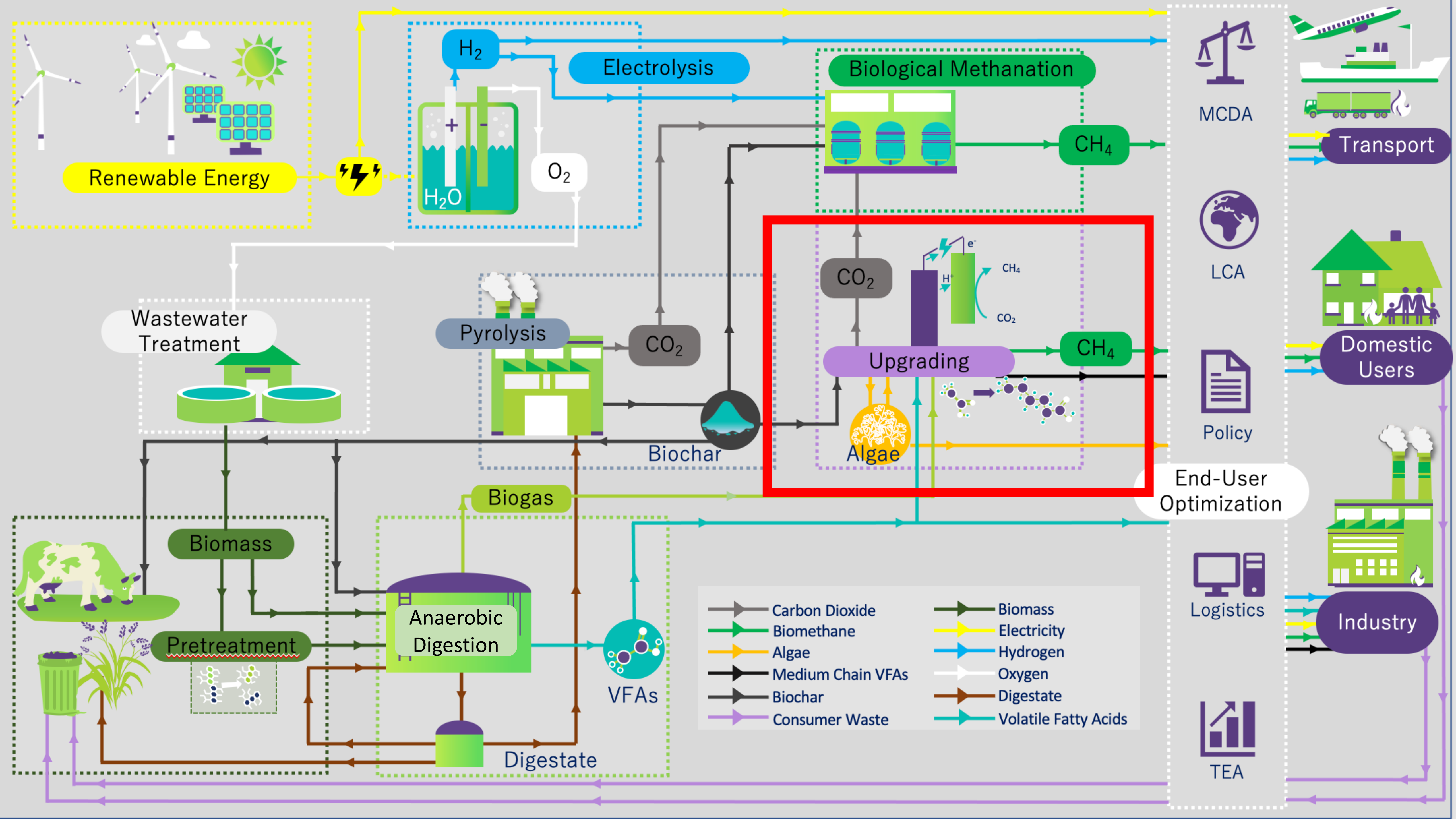


Figure 1: Gas consumption and potential of green gas in Denmark (from Green Gas Denmark)

Figure 3: Holsted Biogas Plant, producing 20.7 million m³ gas / year. Source: Nature Energy



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

PHOTOSYNTHETIC BIOGAS UPGRADING

Biotechnology Advances 37 (2019) 107444

Contents lists available at ScienceDirect

Biotechnology Advances

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

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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 Utilization Technologies and Systems, Chongqing University, Chongqing 400044, China

Chemical Engineering Journal 437 (2022) 134988

Contents lists available at ScienceDirect

Chemical Engineering Journal

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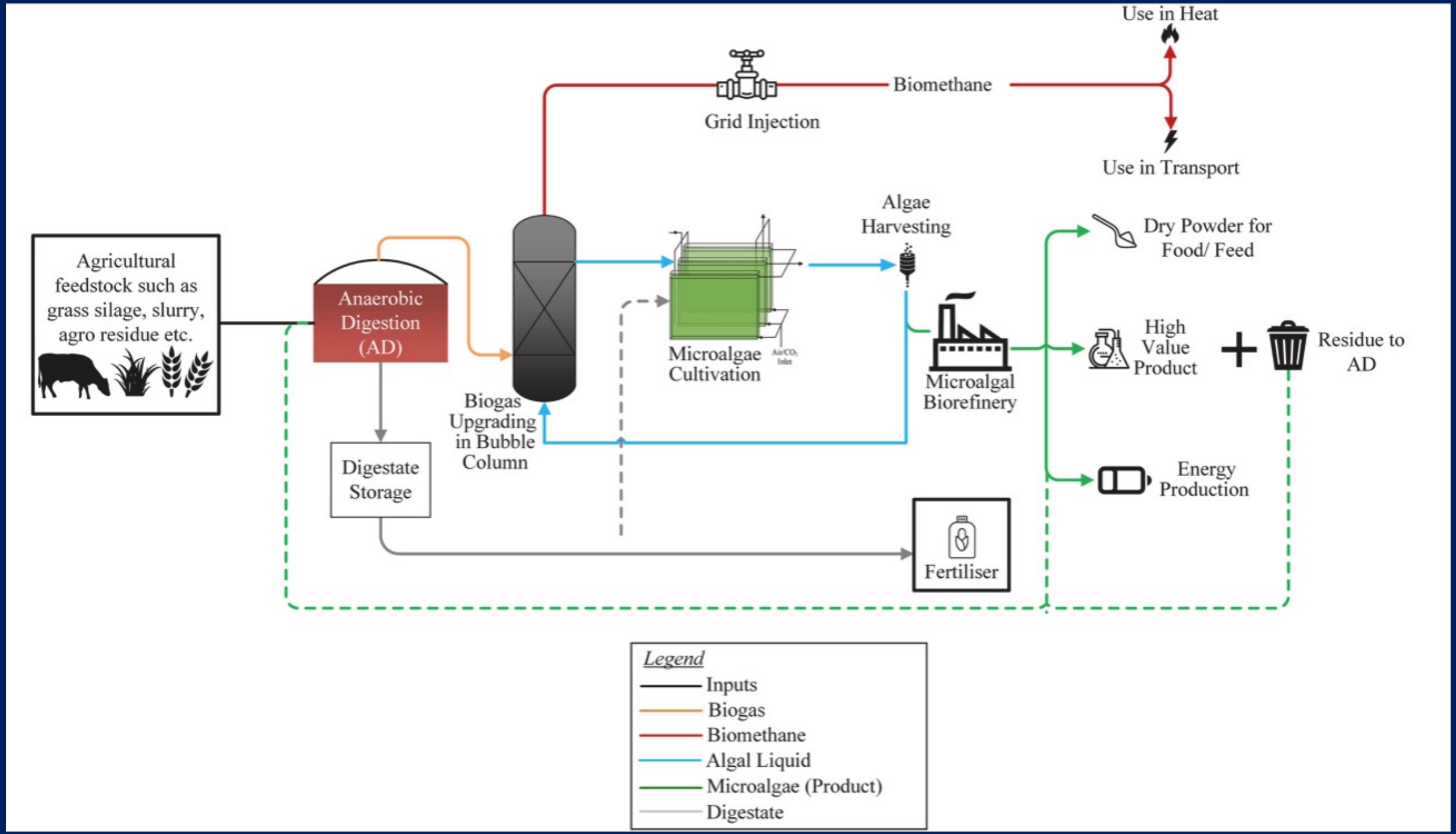
Optimisation and performance prediction of photosynthetic biogas upgrading using a bubble column

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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MARGINAL ABATEMENT CURVE

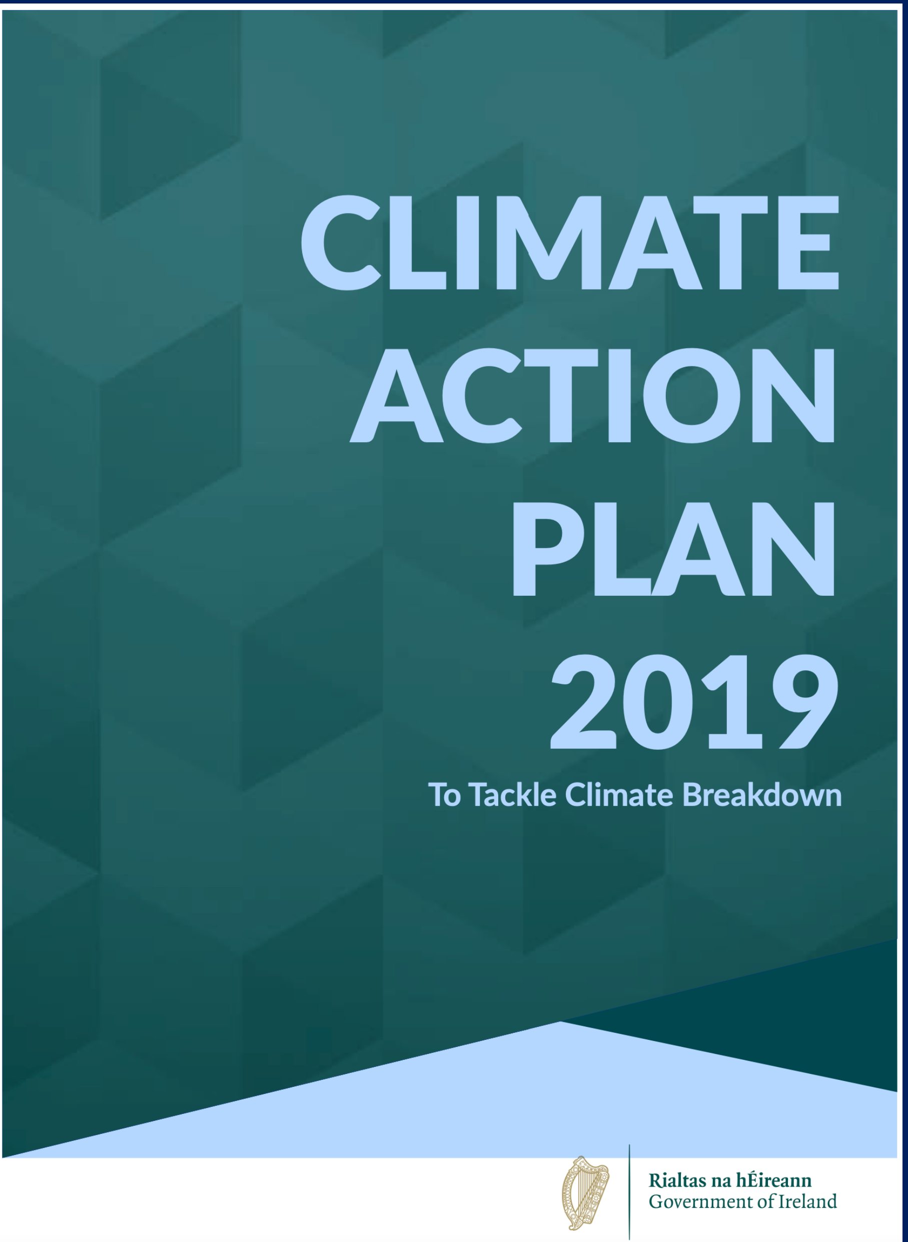
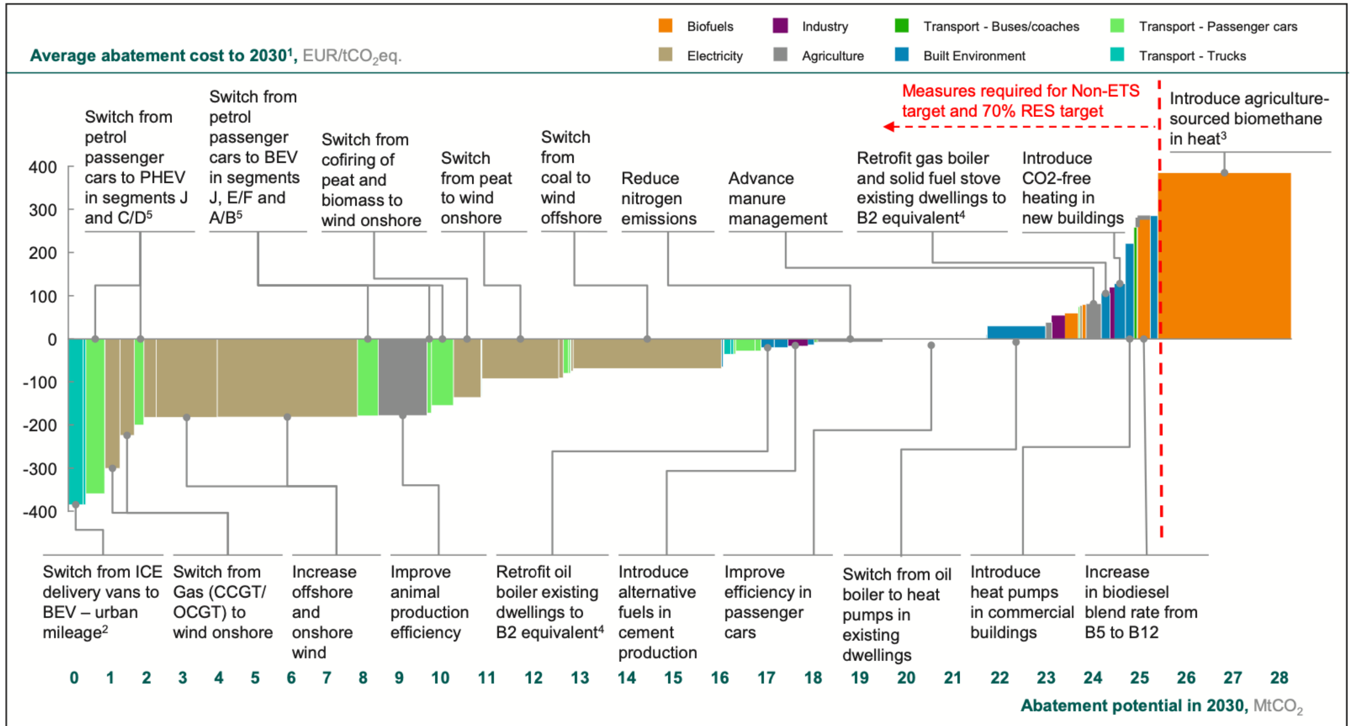


Figure 4.2 Marginal Abatement Cost Curve for Ireland to 2030



Note: The horizontal axis shows the abatement potential of the technology switches. The vertical axis displays the average abatement cost as EUR/tC02 for each switch. The C02 price of the EU ETS is included in the cost of measures for industry and power and heat

MARGINAL ABATEMENT COSTS OF CO-PRODUCING BIOMETHANE, VEGAN FOOD & BIOFERTILISER

Renewable and Sustainable Energy Reviews 169 (2022) 112946

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Check for updates

The marginal abatement cost of co-producing biomethane, food and biofertiliser in a circular economy system

Archishman Bose [a,b], Richard O'Shea [a,c,*], Richen Lin [d,a], Aoife Long [a,c], Karthik Rajendran [e], David Wall [a,c], Sudipta De [f], Jerry D. Murphy [a,c]

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[b] Process and Chemical Engineering, School of Engineering and Architecture, University College Cork, Cork, T12 K8AF, Ireland
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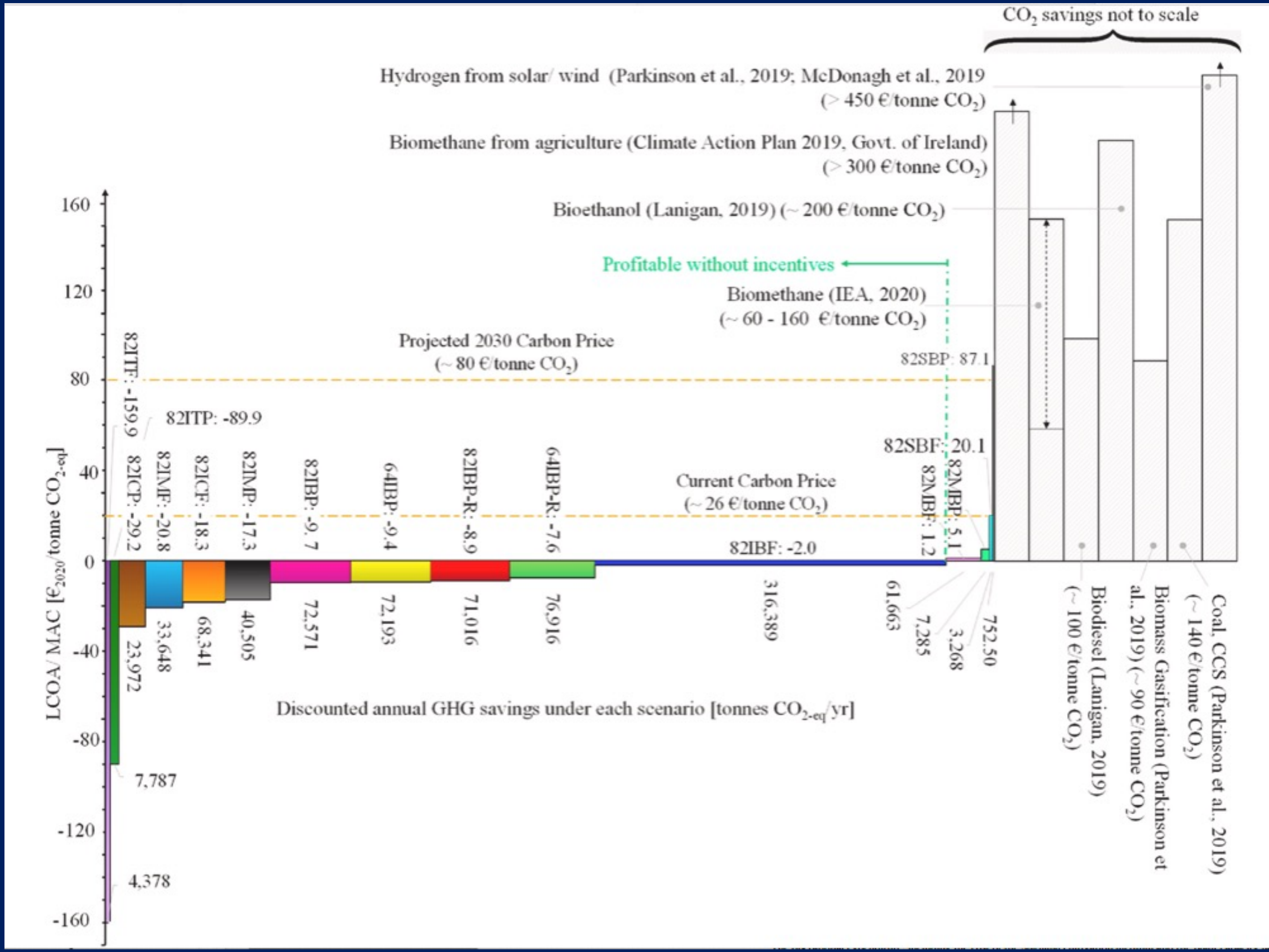
[e] Department of Environmental Science and Engineering, SRM University-AP, Mangalgiri, Andhra Pradesh, 522 240, India
[f] Department of Mechanical Engineering, Jadavpur University, Kolkata, West Bengal, 700 032, India



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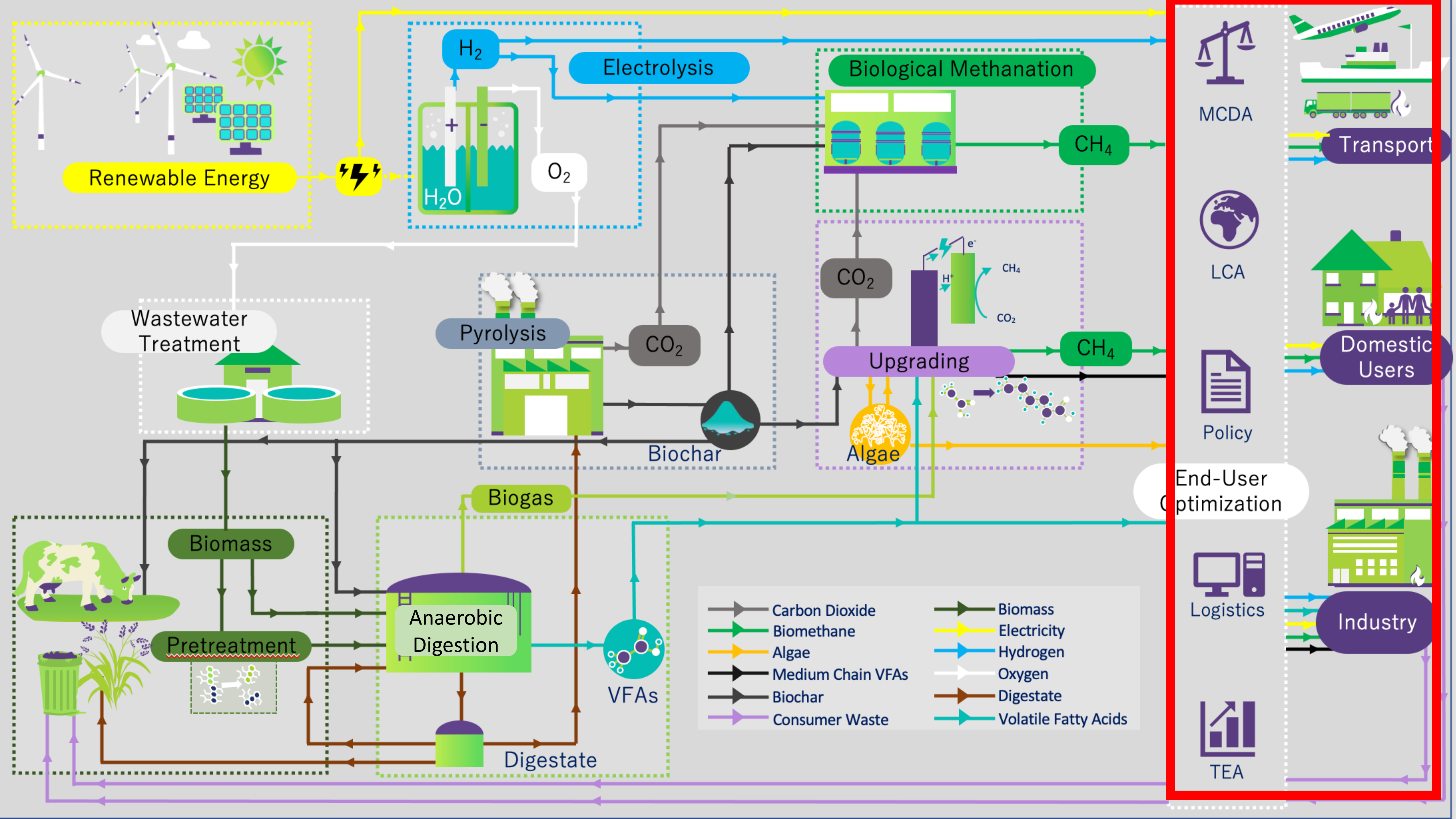

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Anaerobic Digestion
VFAs
Digestate
Carbon Dioxide
Biomethane
Algae
Medium Chain VFAs
Biochar
Consumer Waste
Biomass
Electricity
Hydrogen
Oxygen
Digestate
Volatile Fatty Acids
MCDA
LCA
Policy
End-User Optimization
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TEA
Transport
Domestic Users
Industry

DECARBONISATION PATHWAYS IN FOOD AND BEVERAGE INDUSTRY

Journal of Cleaner Production 371 (2022) 133534

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

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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]

[a] MaREI Centre, Environmental Research Institute, University College Cork, Cork, Ireland
[b] Civil, Structural, and Environmental Engineering, School of Engineering, University College Cork, Cork, Ireland
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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 Power generation	X	X					Boiler – CHP ORC
7	Efficient steam Power generation	X		X				Boiler – CHP GT
8	Efficient steam Biogas	X			X			Boiler – Biogas
9	Efficient steam Heat recovery	X				X	X	Boiler – 38 kV- MVR
10	Power generation Biogas		X		X			CHP ORC – Biogas
11	Power generation Biogas			X	X			CHP GT – Biogas
12	Power generation Heat recovery		X			X		CHP ORC – MVR
13	Power generation Heat recovery			X		X		CHP GT – MVR
14	Heat recovery Biogas				X	X	X	38 kV MVR – Biogas
15	Efficient steam	X	X			X		Boiler – CHP ORC – MVR
16	Power generation Heat recovery	X		X		X		Boiler – CHP GT– MVR
17	Efficient steam Power import Heat recovery Biogas	X			X	X	X	Boiler – 38 kV – MVR – Biogas
18	Efficient Steam	X	X		X			Boiler – CHP ORC – Biogas
19	Power generation Biogas	X		X	X			Boiler – CHP GT – Biogas
20	Efficient Steam	X	X		X	X		Boiler – CHP ORC – MVR – Biogas
21	Power generation Heat recovery 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.

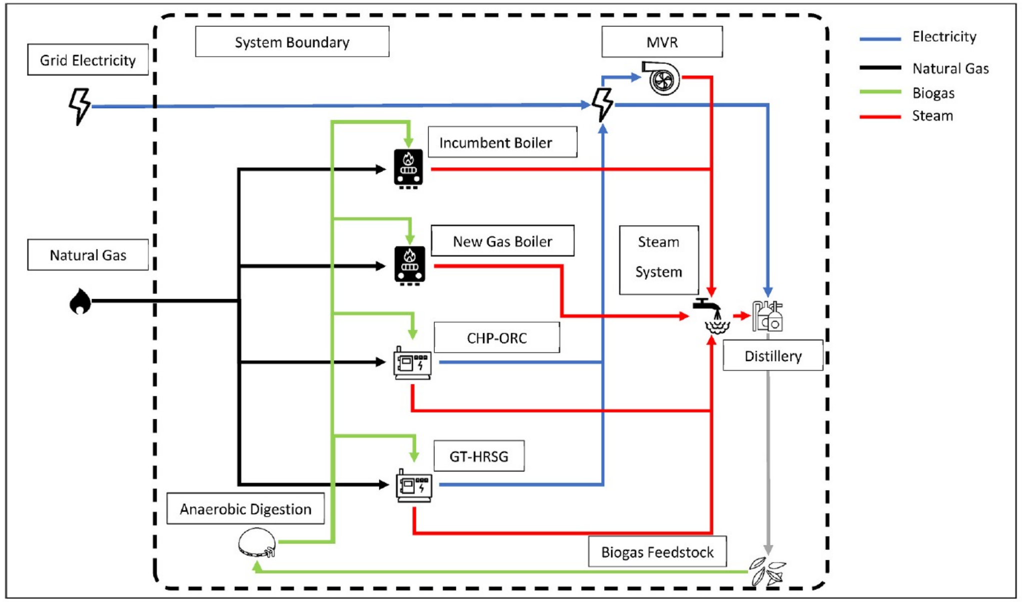


Fig. 2. Energy system schematic. CHP: Combined heat and power. ORC: Organic rankine Cycle.GT: Gas turbine. Hrsg: Heat recovery steam generator. MVR: Mechanical vapour recompression.

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

DECARBONISING 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

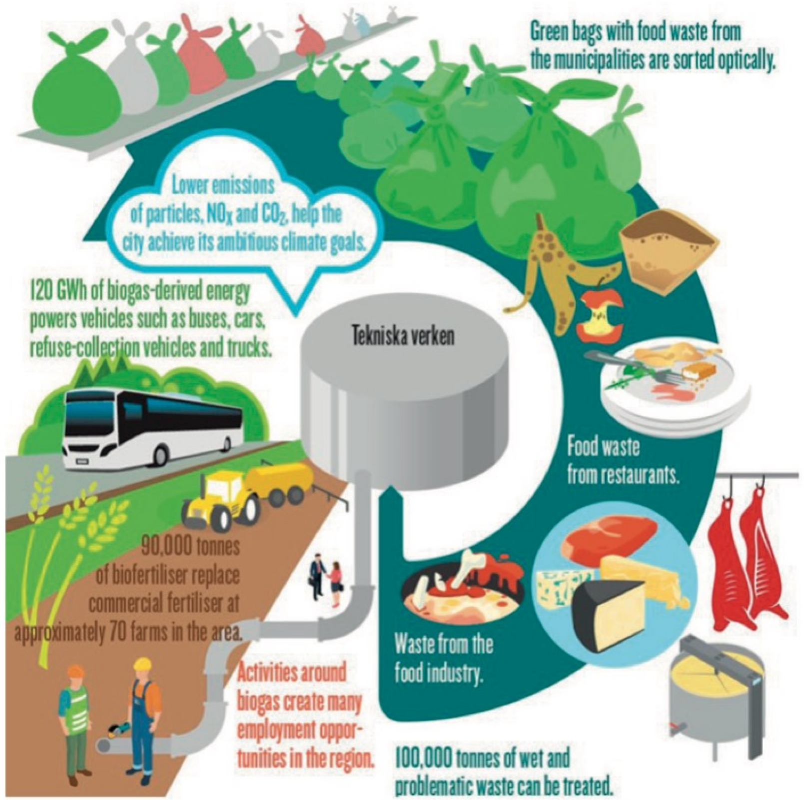


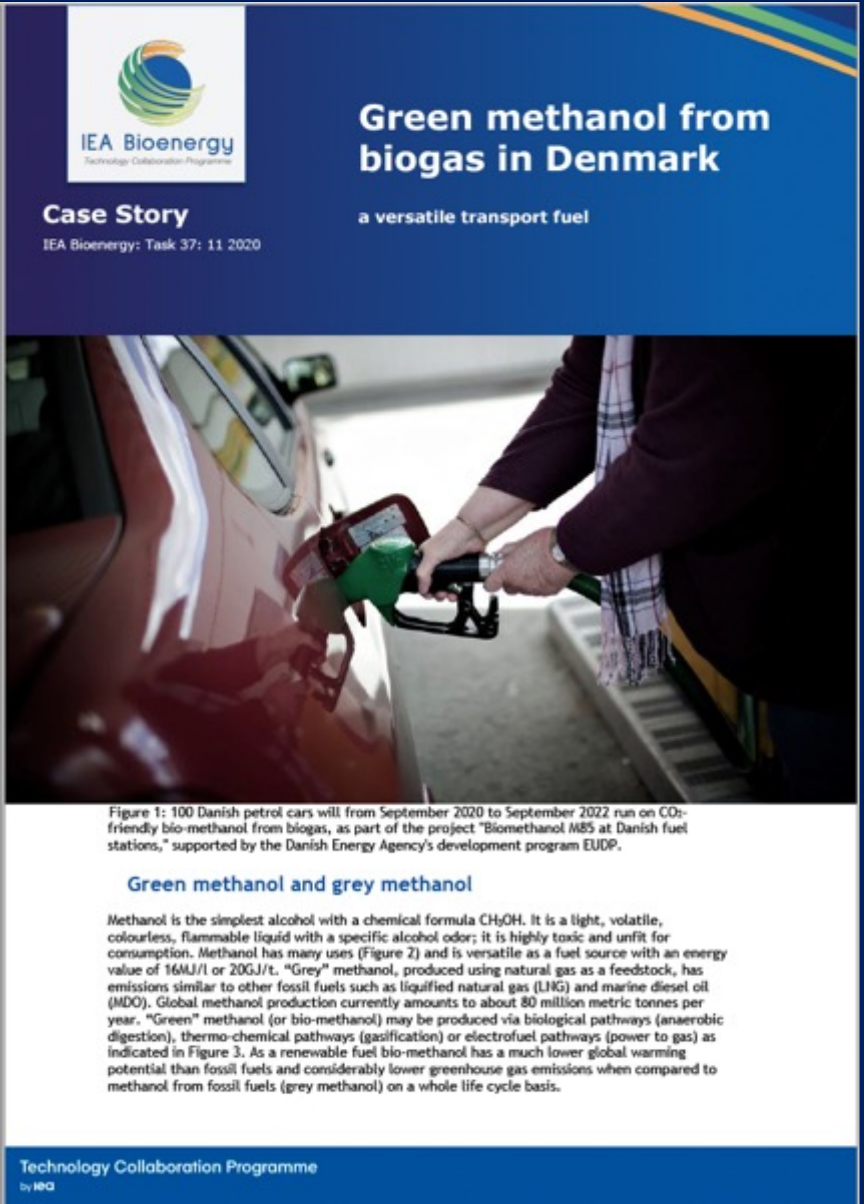
Figure 27. Illustration of biogas solutions in and around Linköping, where the municipally owned utility Tekniska Verken has a central position.
Illustration: Mattias Schläger.

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.*

POWER TO METHANOL (CH_3OH)



IEA Bioenergy

Technology Collaboration Programme

Green methanol from biogas in Denmark

a versatile transport fuel

Case Story

IEA Bioenergy: Task 37: 11 2020

Figure 1: 100 Danish petrol cars will from September 2020 to September 2022 run on CO_2-friendly bio-methanol from biogas, as part of the project "Biomethanol M85 at Danish fuel stations," supported by the Danish Energy Agency's development program EUDP.

Green methanol and grey methanol

Methanol is the simplest alcohol with a chemical formula CH_3OH. It is a light, volatile, colourless, flammable liquid with a specific alcohol odor; it is highly toxic and unfit for consumption. Methanol has many uses (Figure 2) and is versatile as a fuel source with an energy value of 16MJ/l or 20GJ/t. "Grey" methanol, produced using natural gas as a feedstock, has emissions similar to other fossil fuels such as liquified natural gas (LNG) and marine diesel oil (MDO). Global methanol production currently amounts to about 80 million metric tonnes per year. "Green" methanol (or bio-methanol) may be produced via biological pathways (anaerobic digestion), thermo-chemical pathways (gasification) or electrofuel pathways (power to gas) as indicated in Figure 3. As a renewable fuel bio-methanol has a much lower global warming potential than fossil fuels and considerably lower greenhouse gas emissions when compared to methanol from fossil fuels (grey methanol) on a whole life cycle basis.

Technology Collaboration Programme

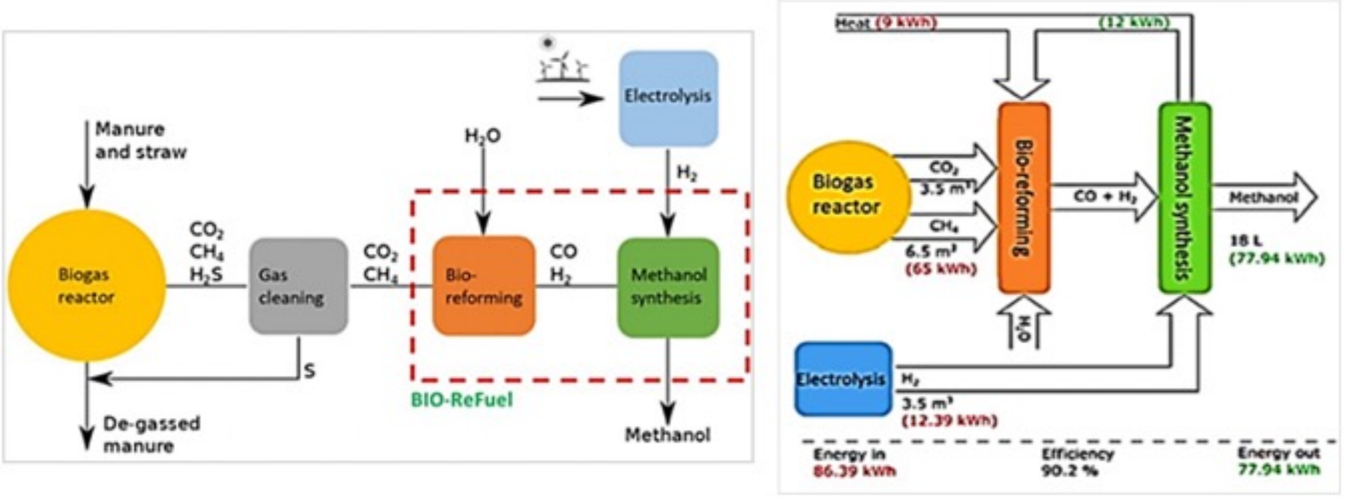


Figure 4: The process flow of bio-methanol production
Source: Lemvig Biogas

Figure 5: Energy balance
Source: Lemvig Biogas

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

$CO + 2\,H_2 = CH_3OH$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Coláiste na hOllscoile Corcaigh
Thank you
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