IEA Bioenergy Task 37

IEA Bioenergy Webinar Series

Green Gas

Prof Jerry D Murphy
Leader IEA Task 37
Director MaREI Centre,
Vice Director Environmental Research Institute,
University College Cork, Cork, Ireland

Energy Technology Network

IEA Bioenergy

MaREI
Centre for Marine and Renewable Energy

ERI
Environmental Research Institute
University College Cork

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

"MaREI: Unlocking the potential of our marine and energy resources through the power of research and innovation"

- **Marine and renewable energy research, development & innovation hub**
- **SFI research centre coordinated by the Environmental Research Institute at University College Cork with partners across 6 academic institutions**
- **Headquartered in the ERI Beaufort Building on the IMERC campus in Cork Harbour which also houses the Lir National Ocean Test Facility**

LiR National Ocean Test Facility

Irish Maritime and Energy Resource Cluster
imerc

We combine the expertise of a wide range of research groups and industry partners with the shared mission of solving the main scientific, technical and socio-economic challenges across the marine and energy spaces.

Science Foundation Ireland sfi For what's next

European Union
European Regional Development Fund

Ireland's European Structural and Investment Funds Programmes 2014-2020
Co-funded by the Irish Government and the European Union

UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh

NUI Galway OÉ Gaillimh

University of Limerick Ollscoil Luimnigh

Maynooth University National University of Ireland Maynooth

UCD Dublin

CIT Cork Institute of Technology Institiúid Teicneolaíochta Chorcaí

Environmental Research Institute (ERI)

Research enabling a low carbon and resource efficient future

The ERI is UCC's flagship Institute for environmental, marine and energy research bringing research teams from across science, engineering, business and humanities to address global environmental challenges in a multi-disciplinary approach

- **300 researchers from 10 schools and 3 centres**
  Marine Renewable Energy Ireland (MaREI)
  Aquaculture and Fisheries Development Centre (AFDC)
  Centre for Research on Atmospheric Chemistry (CRAC)
- **150 active research projects with €44 M of funding**
- **7000 m^2 of offices, laboratories and workshops in two dedicated research buildings on UCC campus**

Member countries participating in Task 37

Australia	Bernadette McCabe
Austria	Bernard Drosg / Günther Bochmann
Brazil	Cícero Jayme Bley
Denmark	Teodorita Al-Seadi
Finland	Saija Rasi
France	Olivier Théobald / Guillaume Bastide
Germany	Jan Liebertrau
Ireland	Jerry Murphy
Korea	Ho Kang
Norway	Tormod Briseid
Sweden	Mattias Svensson
Switzerland	Urs Baier
The Netherlands	Mathieu Dumont
United Kingdom	Clare Lukehurst / Charles Banks

Technical Reports Triennium 2013 - 2015

1. A perspective on algal biogas,
2. Nutrient recovery by biogas digestate processing,
3. A perspective on the potential role of biogas in smart energy grids,
4. Pretreatment of feedstock for enhanced biogas production,
5. Process monitoring in biogas plants
6. Source separation of municipal solid waste
7. Sustainable biogas production in municipal wastewater treatment plants
8. Exploring the viability of small scale anaerobic digesters in livestock farming

Technical Reports Triennium 2016 - 2018

1. Food waste digestion systems.
2. International approaches to sustainable anaerobic digestion
3. Grid injection and greening of the gas grid
4. The role of biogas in the circular economy
5. Validity of BMP results
6. Methane emissions
7. Biomethane as a transport fuel
8. Sustainable Bioenergy Chains (Collaboration with Task 40)

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Green Gas in Ireland

Network Development Plan 2015

assessing future demand and supply position

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Annual RNG Capacity (GWh)	20	170	400	960	1440	2280	2640	3120	4350	5980
% of Demand	0.04%	0.34%	0.8%	2%	3%	5%	5%	6%	9%	12%

Major demand for Green Gas is from Foreign Direct Investment (Multi-nationals)

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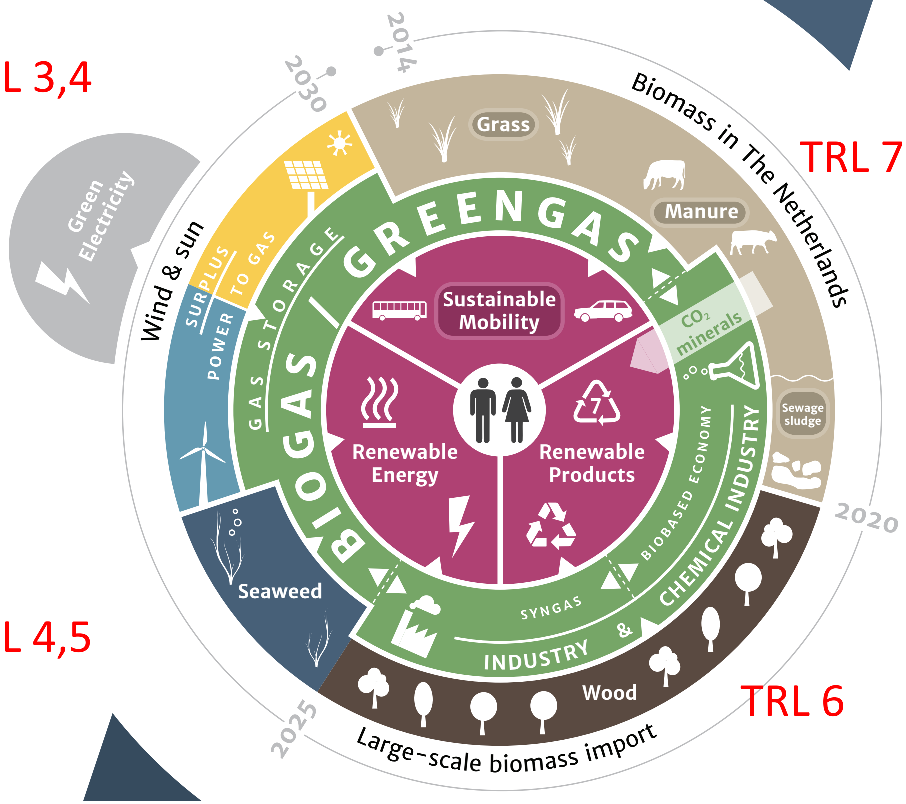
Centre for Marine and Renewable Energy

TRL 3,4

TRL 7-9



TRL 4,5

TRL 6

Green Gas

6 European gas grids have committed to 100% green gas in the gas grid by 2050

Centre for Marine and Renewable Energy

Murphy, J.D (2015) A bioenergy model for Ireland: greening the gas grid. Engineers Journal available In:
http://www.engineersjournal.ie/bioenergy-model-ireland-greening-gas-grid/

Table 1: Simplified analysis of renewable energy targets

Energy Vector	Percentage of final energy consumption	Renewable Energy Target	Contribution to renewable energy target
Electricity	20%	40%	8%
Thermal Energy	40%	12%	4.8%
Transport energy	40%	10%	4%
Total	100%	16%	

Why should agricultural sector do anything about biofuels?

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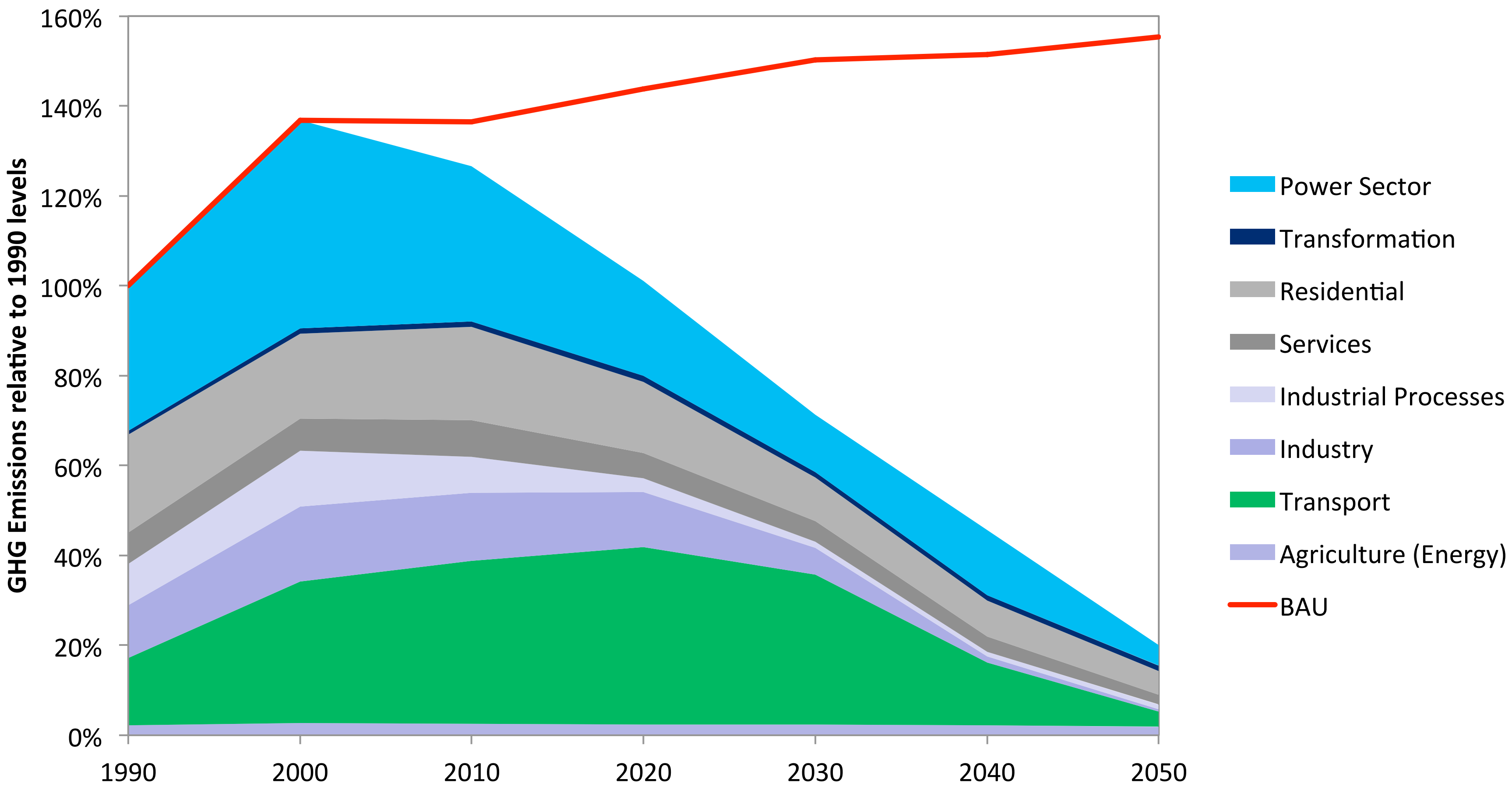
Ireland's Energy *Low Carbon Pathway*

UCC Energy Policy and Modelling Group



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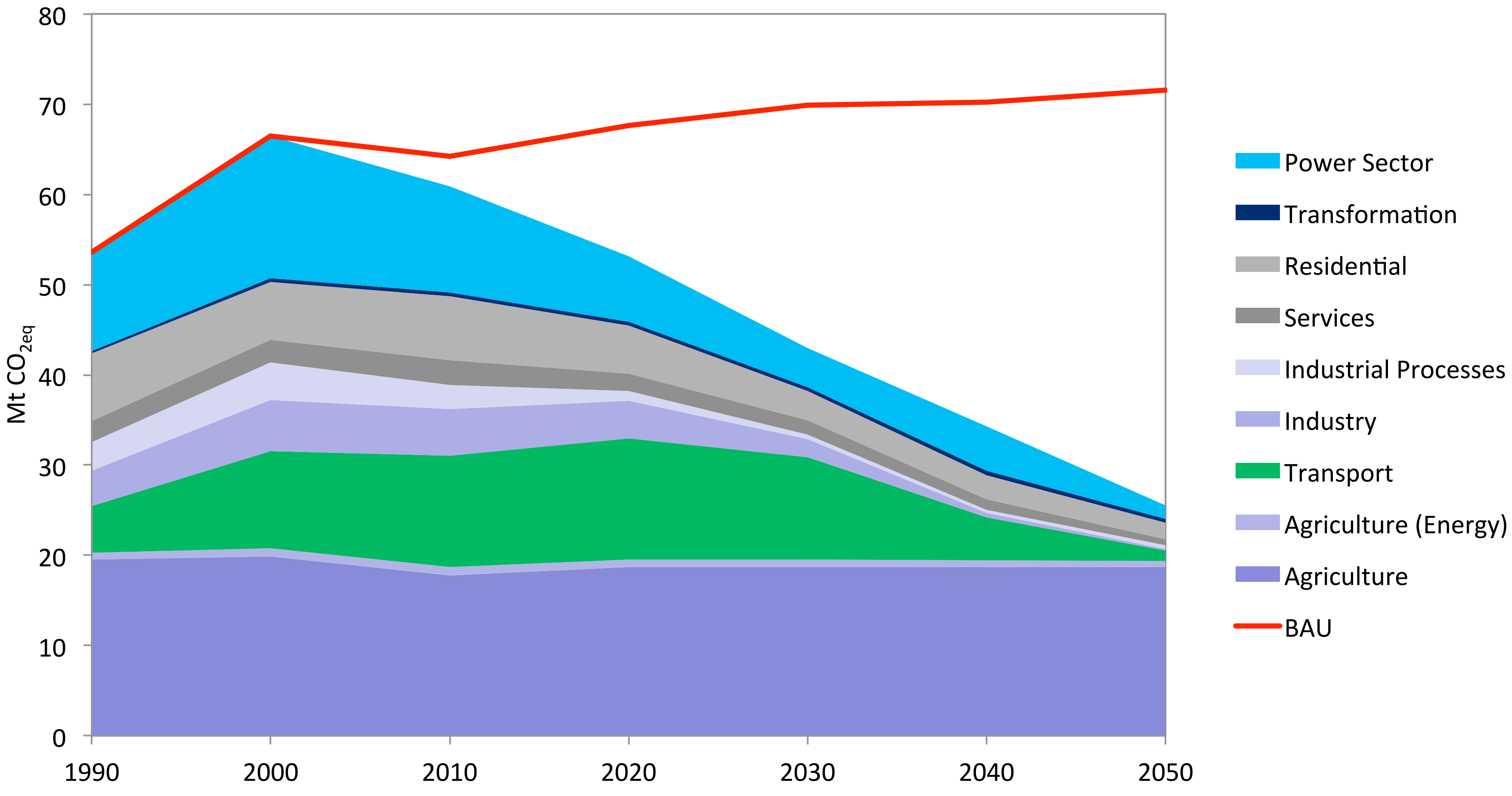
But 80% CO2 reduction = 50% GHG reduction

UCC Energy Policy and Modelling Group



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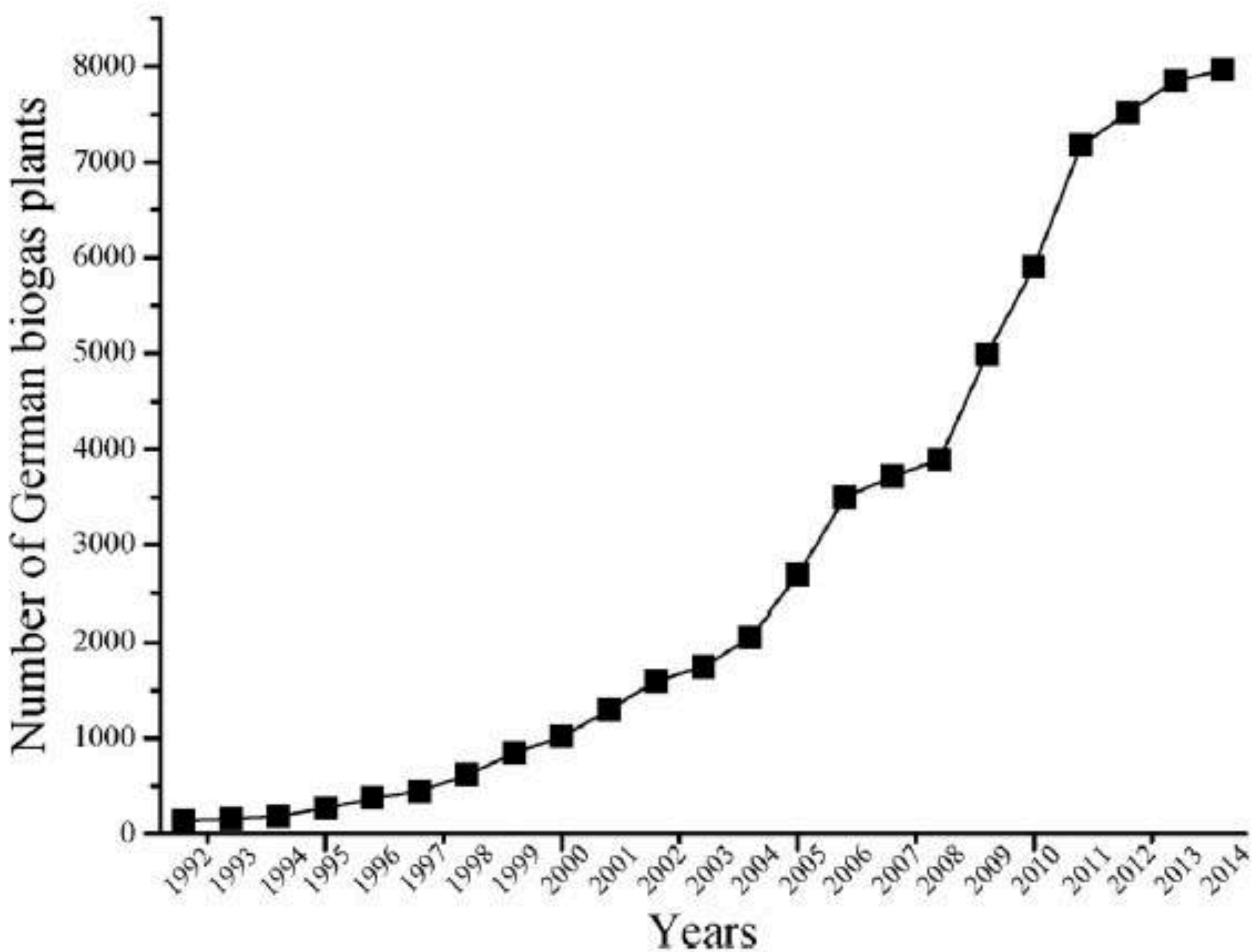
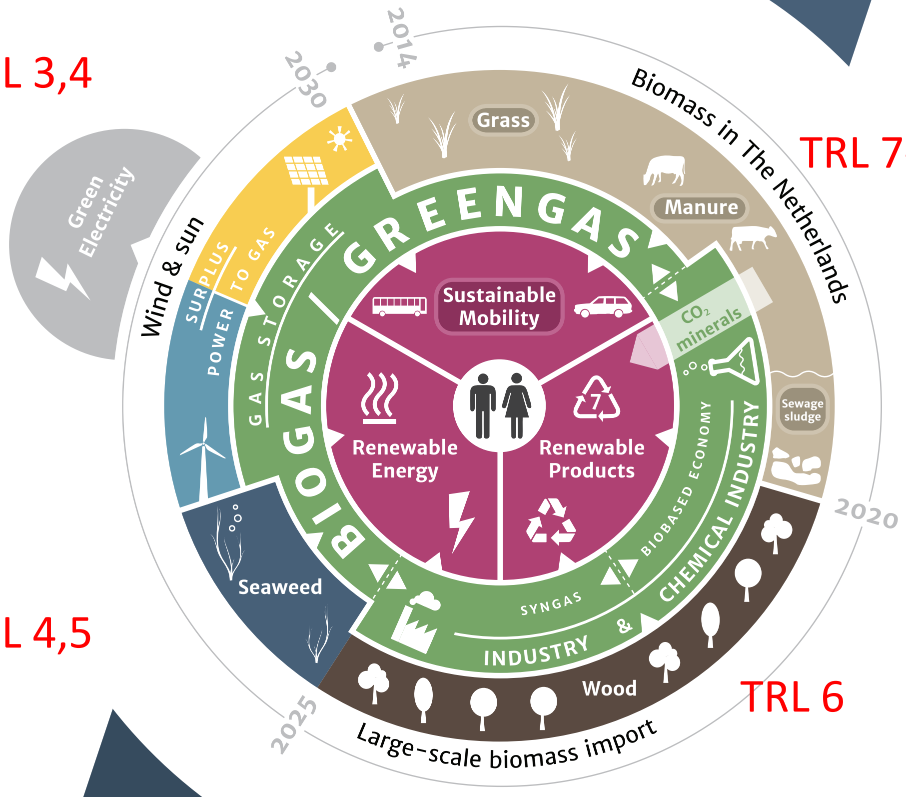
German approach to carbon capture in agriculture





Initiation of Industry

Green Gas from residues, slurries and grass

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Centre for Marine and Renewable Energy

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Applied Energy 175 (2016) 229–239

Contents lists available at ScienceDirect

Applied Energy

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

ELSEVIER

Quantification and location of a renewable gas industry based on digestion of wastes in Ireland

CrossMark

Richard O'Shea [a,b], Ian Kilgallon [c], David Wall [a,b,*], Jerry D. Murphy [a,b]

[a] MaREI Centre, Environmental Research Institute, University College Cork, Cork, Ireland
[b] School of Engineering, University College Cork, Cork, Ireland
[c] Gas Networks Ireland, Gasworks Road, Cork, Ireland

HIGHLIGHTS

- A spatial assessment of the biomethane resource in Ireland was undertaken.
- Biomethane from residues can supply 26.5% of industrial gas use in Ireland.
- Biomethane from residues can supply 7% of energy in transport in Ireland.
- The resource of biomethane from cattle slurry is 76% of the total resource.
- The resource is equivalent to woody energy crops from 17% of arable land in Ireland.

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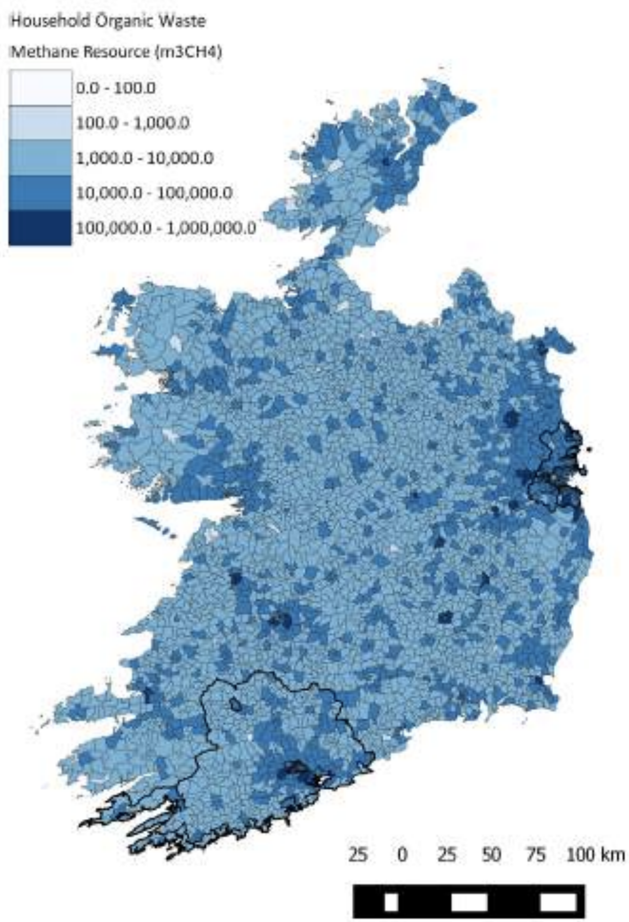

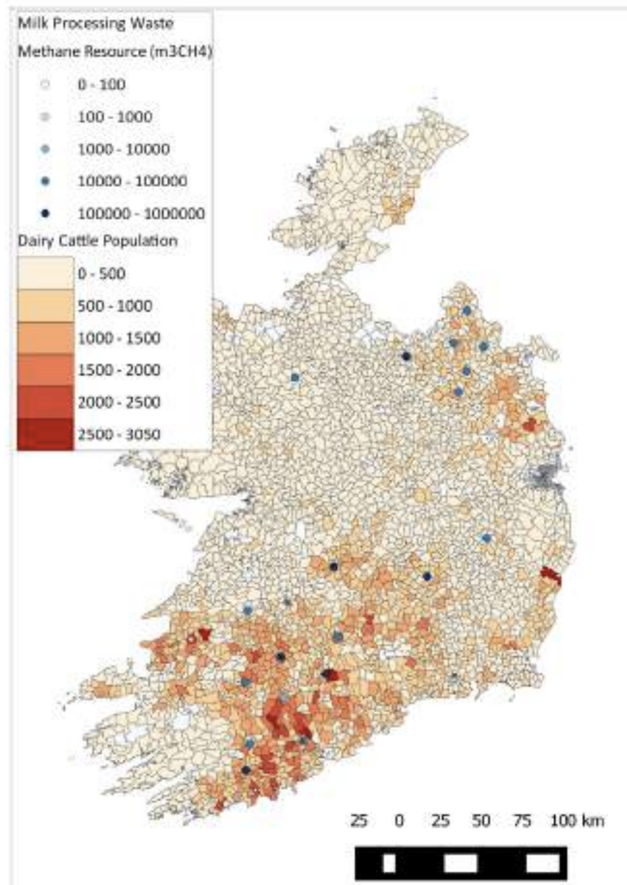

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Available at www.sciencedirect.com

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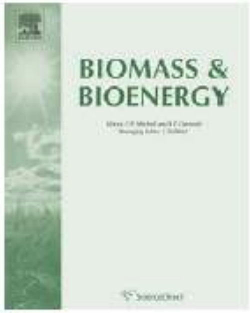
http://www.elsevier.com/locate/biombioe

ELSEVIER



An argument for using biomethane generated from grass as a biofuel in Ireland

Jerry D. Murphy[a,b,*], *Niamh M. Power*[c]

[a] *Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland*
[b] *Environmental Research Institute, University College Cork, Cork, Ireland*
[c] *Department of Civil, Structural and Environmental Engineering, Cork Institute of Technology, Cork, Ireland*

Grass is a perennial
Grass lands sequester carbon
Grass can be outside food fuel debate
Grass is ligno-cellulosic?
Grass is a second generation gaseous biofuel which can be used in NGV vehicles
Natural Gas Grid can be distribution system.

Grass to transport fuel

harvest →

weigh bridge →

silage storage ↓

macerator ←

anaerobic digester ←

Scrubbing & storage ←

Biogas service station

Source: energiewerkstatt, IEA and personal photos

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Renewable and Sustainable Energy Reviews 13 (2009) 2349–2360

ELSEVIER

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

What is the energy balance of grass biomethane in Ireland and other temperate northern European climates?

Beatrice M. Smyth [a,b], Jerry D. Murphy [a,b,*], Catherine M. O'Brien [a,b]

[a] Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland
[b] Environmental Research Institute, University College Cork, Cork, Ireland

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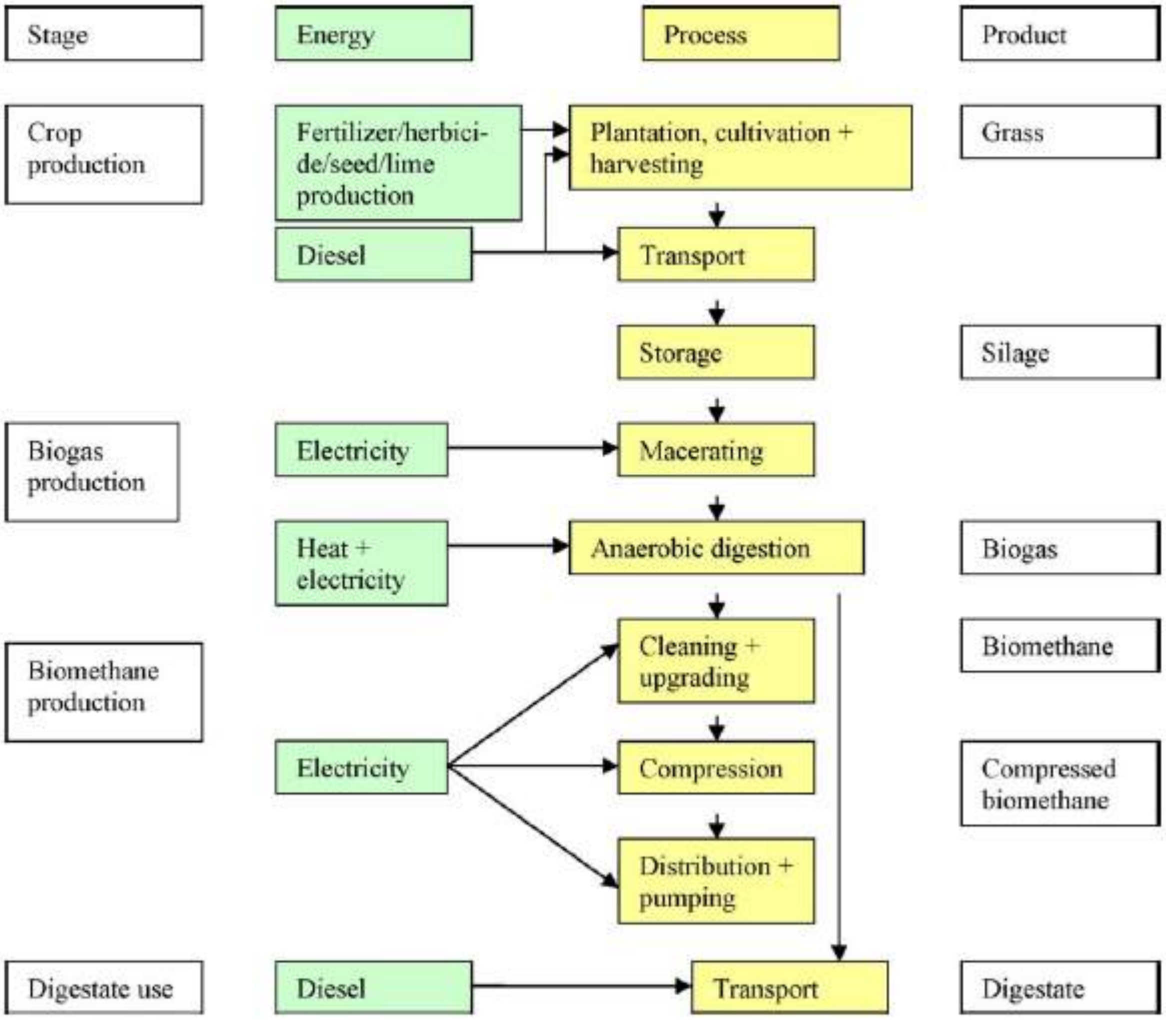
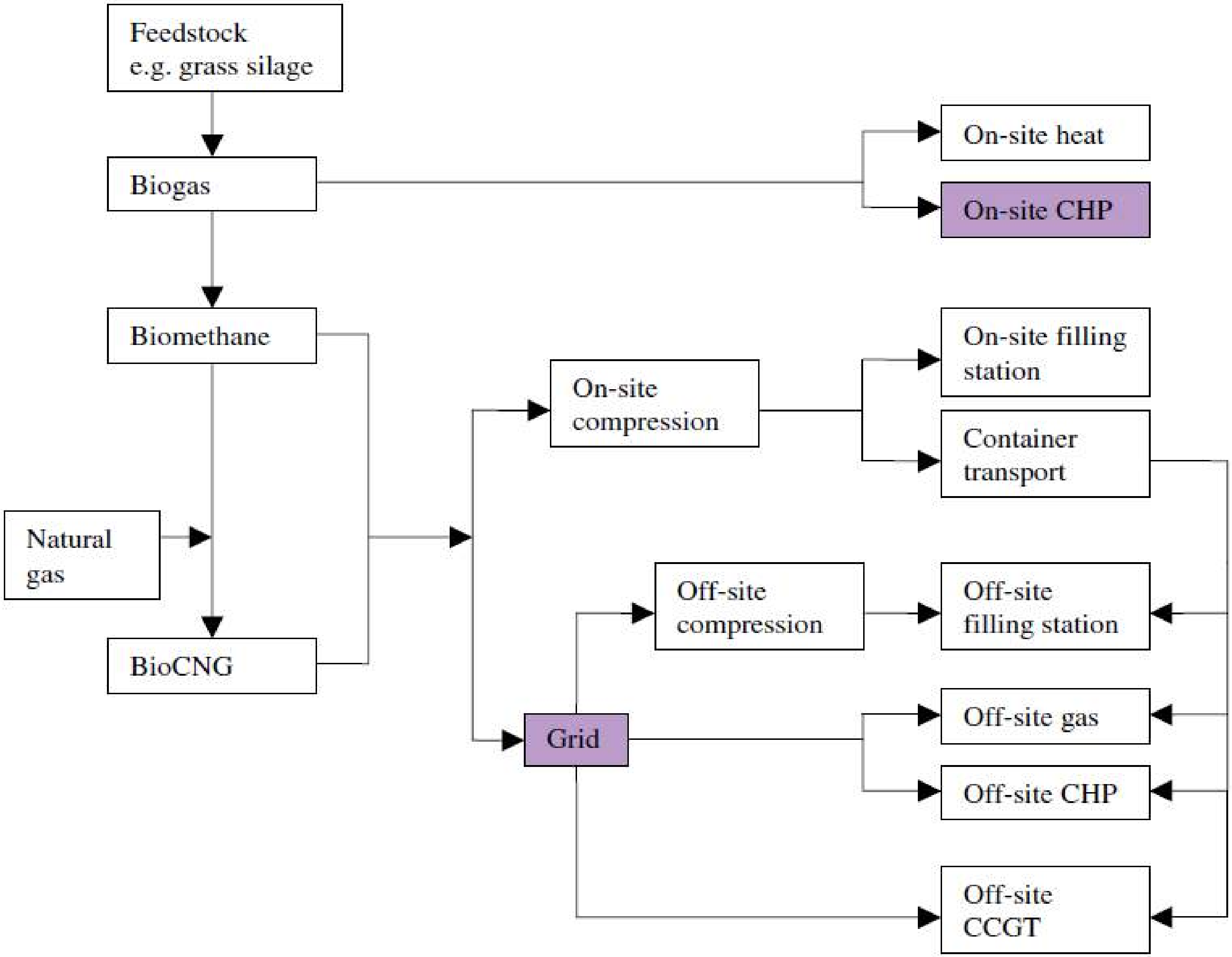


Pathways for use of biogas



Net energy yield per hectare of crops

	Maize	Grass
Methane yield $m^3 . ha^{-1}$	5,748	4,303
$GJ . ha^{-1}$	217	163
Process energy demand for digestion $GJ. ha^{-1}$	33	24
Energy requirement in cropping $GJ. ha^{-1}$	17	17
Total energy requirement $GJ. ha^{-1}$	50	41
Net energy yield $GJ.ha^{-1}$	167	122
$\frac{\text{Output } (GJ.ha^{-1})}{\text{Input (tot. Energy)}}$	4.3	4.0

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Modeling and Analysis

Biofpr
Biofuels Bioproducts & Biorefining

Is grass biomethane a sustainable transport biofuel?

Nicholas E. Korres, Anoop Singh, Abdul-Sattar Nizami and Jerry D. Murphy,* Biofuels Research Group, Environment Research Institute, University College Cork, Ireland

Received December 15, 2009; revised version received February 8, 2010; accepted February 11, 2010
Published online in Wiley InterScience (www.interscience.wiley.com); DOI: 10.1002/bbb.228;
***Biofuels, Bioprod, Bioref.* 4: 310–325 (2010)**

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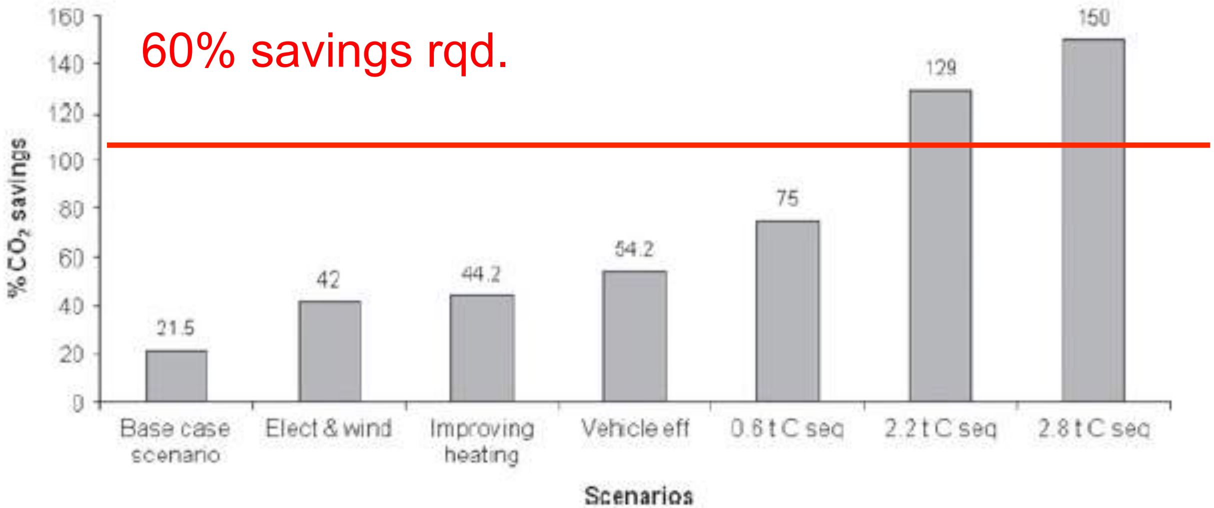

Figure 3. Percent CO_2 savings over fossil diesel under a range of C sequestration and various scenarios in biomethane production (The scenarios are cumulative left to right, for example improving heat includes for elect & wind and base case scenario).

Table 10. Typical values for greenhouse gas savings for biofuel systems from the renewable energy directive[4]

Biofuel system	% savings in greenhouse gas compared to fuel replaced
Wheat ethanol	32%
Rapeseed biodiesel	45%
Sunflower biodiesel	58%
Sugarbeet ethanol	61%
Palm oil biodiesel	62%
Biogas from MSW	80%

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Modeling and Analysis

Biofpr
Biofuels Bioproducts & Biorefining

Can grass biomethane be an economically viable biofuel for the farmer and the consumer?

Beatrice M. Smyth, Environmental Research Institute (ERI), University College Cork (UCC), Ireland
Henry Smyth, Bord Gáis Éireann, Cork, Ireland
Jerry D. Murphy, ERI, UCC, Ireland

Economic viability of biogas from energy crops

Table 7. Break even of compressed biomethane from grass silage as a vehicle fuel.

	Base case (€c kWh^{-1})[a]			Reduced operating costs and depreciation (€c kWh^{-1})[b]		
	50%G	30%G	NG	50%G	30%G	NG
Break-even price of biomethane injected to grid	10.0	10.8	12.1	6.7	7.5	8.8
Cost of compression to 250 bar + filling station[c]	1.1	1.1	1.1	1.1	1.1	1.1
Break-even price of compressed biomethane	11.1	11.9	13.2	7.8	8.6	9.9
- including 21% VAT	13.4	14.4	16.0	9.4	10.4	12.0
- including 21% VAT (€ m^{-3})	1.37	1.47	1.63	0.96	1.06	1.22

[a]Excludes farming subsidy.
[b]Includes farming subsidy (€461 ha^{-1}).
[c]Estimated from values in the literature[15] and discussions with industry.

1 m^3 CH_4 = 10 kWh = 1L diesel equiv

9.9 c/ kWh = 99 c / m^3 CH_4

Biofuel Obligation Certificates (BOCs) and REHEAT

Natural gas is sold at ca. 29c/L of diesel equivalent 29 c /L

Required subsidy for renewable heat 70 c /L

2 BOC's are available if the fuel is 2nd generation or residue

1 BOC is valued as the difference in price between 1L of imported diesel and 1L of biodiesel. Trades between 15 - 35 c/l.

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Renewable and Sustainable Energy Reviews 15 (2011) 4537–4547

Contents lists available at SciVerse ScienceDirect

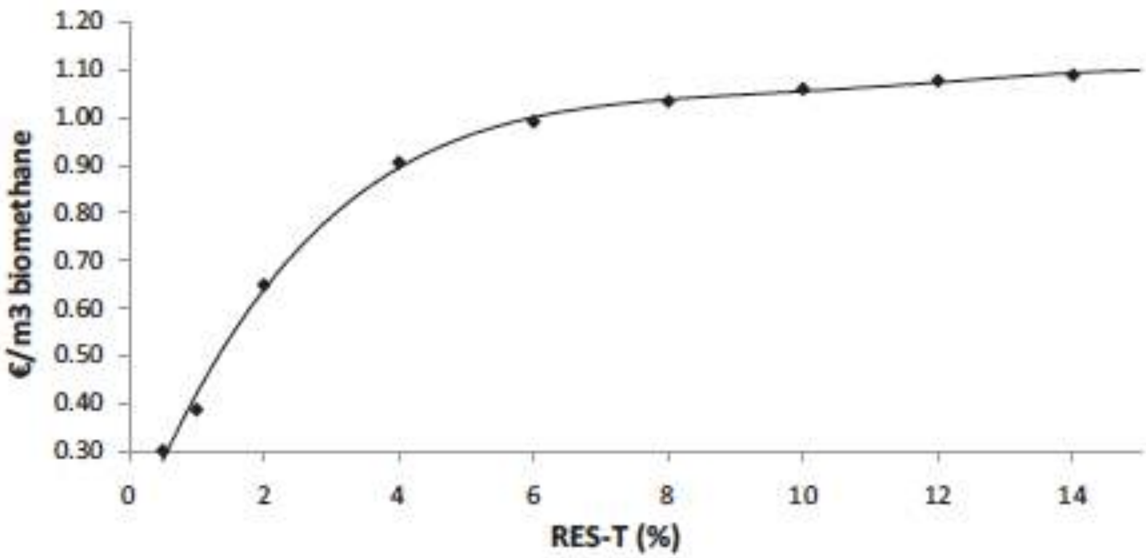
Renewable and Sustainable Energy Reviews

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

Assessing the cost of biofuel production with increasing penetration of the transport fuel market: A case study of gaseous biomethane in Ireland

James Browne[a,b], Abdul-Sattar Nizami[a,b], T Thamsiriroj[a,b], Jerry D. Murphy[a,b,*]

[a] Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland
[b] Biofuels Research Group, Environmental Research Institute, University College Cork, Cork, Ireland



Co-digestion of grass and slurry

Bioresource Technology 149 (2013) 425–431

Contents lists available at ScienceDirect

Bioresource Technology

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

The potential for biomethane from grass and slurry to satisfy renewable energy targets

David M. Wall [a,b,c], Padraig O'Kiely [c], Jerry D. Murphy [a,b,*]

[a] Bioenergy and Biofuels Research Group, Environmental Research Institute, University College Cork, Cork, Ireland
[b] School of Engineering, University College Cork, Cork, Ireland
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Biomethane Potential Assays

Grass %VS	Slurry %VS
100	0
80	20
60	40
50	50
40	60
20	80
0	100
Cellulose	

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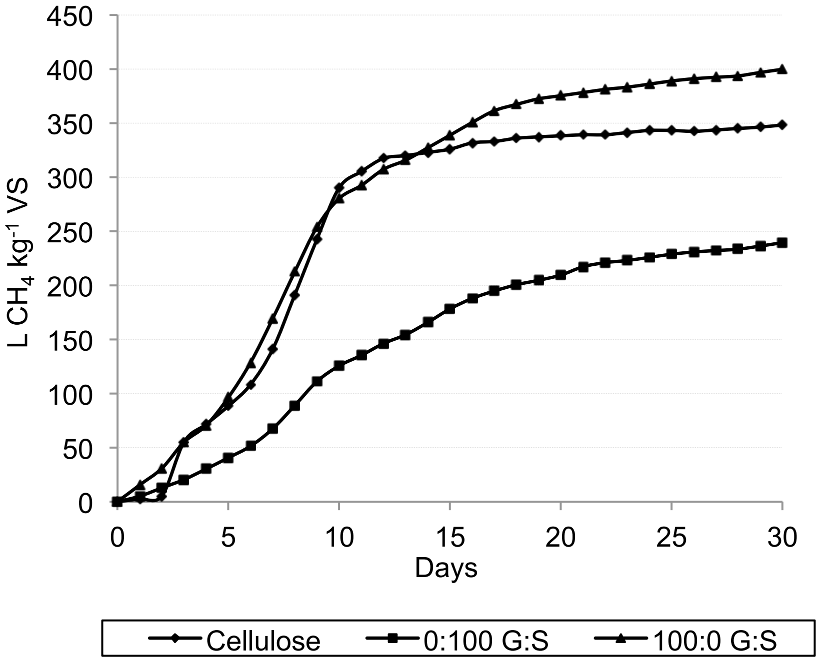
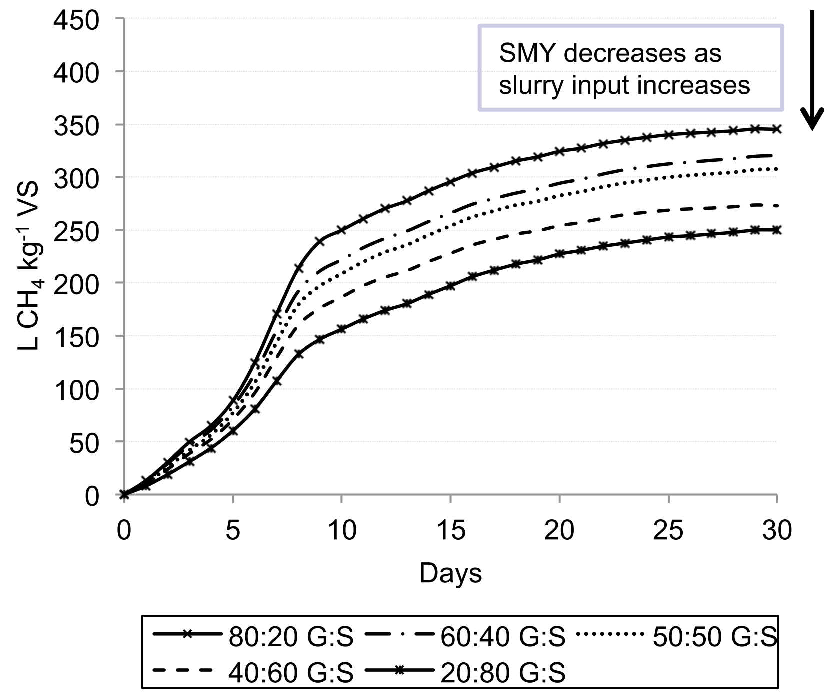
Specific methane yields for mono-digestion.



Specific methane yields for co-digestion.



107 m^3 CH_4 t^{-1} Grass Silage v. 16 m^3 CH_4 t^{-1} Dairy Slurry

Scale of Grass Biogas industry

Table 5
Potential mixes of grass silage and slurry with associated renewable energy production.

Grass: Slurry VS basis	Energy in biomethane (PJ a^{-1})	% of expected energy in transport 2020 (%)	RES-T allowing for double credit (%)
Scenario 1 (equivalent to 0.4% of grass land)			
100:0	2.20	1.17	2.34
80:20	2.37	1.26	2.52
60:40	2.94	1.56	3.13
50:50	3.39	1.80	3.61
40:60	3.75	1.99	3.99
0:100	1.31		1.39
Scenario 2 (equivalent to 1.1% of grass land)			
100:0	6.60	3.51	7.02
80:20	7.11	3.78	7.56
60:40	8.82	4.69	9.38
50:50	10.16	5.40	10.81
0:100	3.94	2.10	4.19
Scenario 3 (equivalent to 2.8% of grass land)			
100:0	16.07	8.55	17.10
80:20	17.32	9.21	18.43
Scenario 4 (equivalent to 8.3% of grass land)			
100:0	48.21	25.64	51.29

1.1 % Grassland in Ireland

170 digesters treating 10,000 t a^{-1} of grass and 40,000 t a^{-1} of dairy slurry

Bioresource Technology 173 (2014) 422–428

Contents lists available at ScienceDirect

Bioresource Technology

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

ELSEVIER

Optimisation of digester performance with increasing organic loading rate for mono- and co-digestion of grass silage and dairy slurry

David M. Wall [a,b,d], Eoin Allen [a,b], Barbara Straccialini [c], Padraig O'Kiely [d], Jerry D. Murphy [a,b,*]

Bioresource Technology 172 (2014) 349–355

Contents lists available at ScienceDirect

Bioresource Technology

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

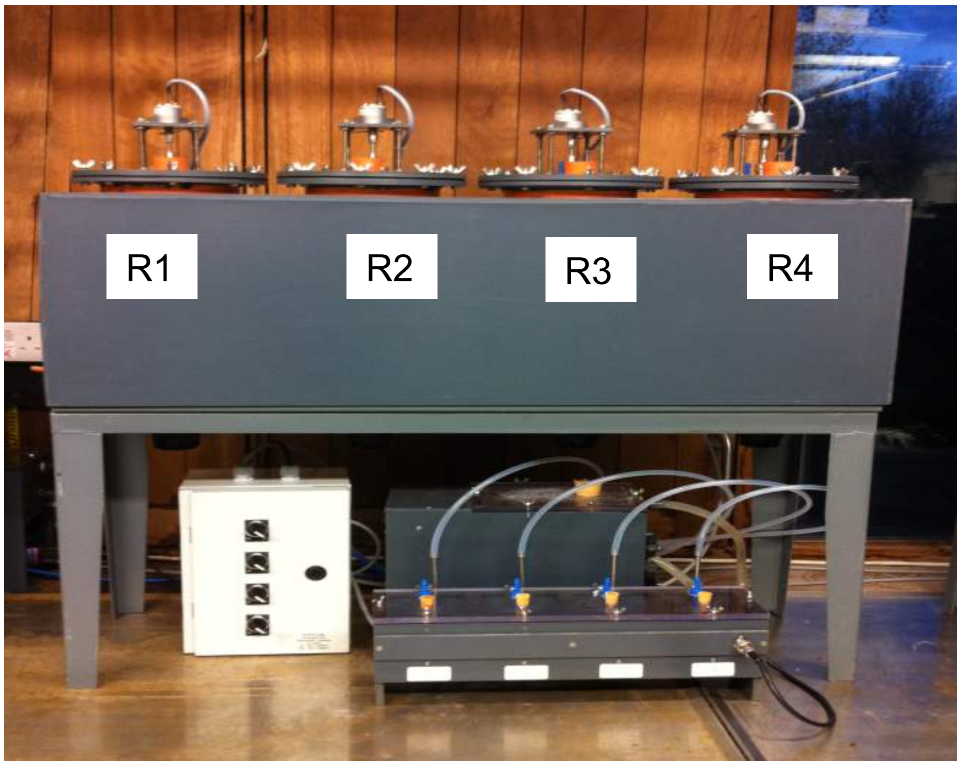
ELSEVIER

The effect of trace element addition to mono-digestion of grass silage at high organic loading rates

David M. Wall [a,b,d], Eoin Allen [a,b], Barbara Straccialini [c], Padraig O'Kiely [d], Jerry D. Murphy [a,b,*]

Continuous digestion of grass and slurry

Higher Grass Silage Input

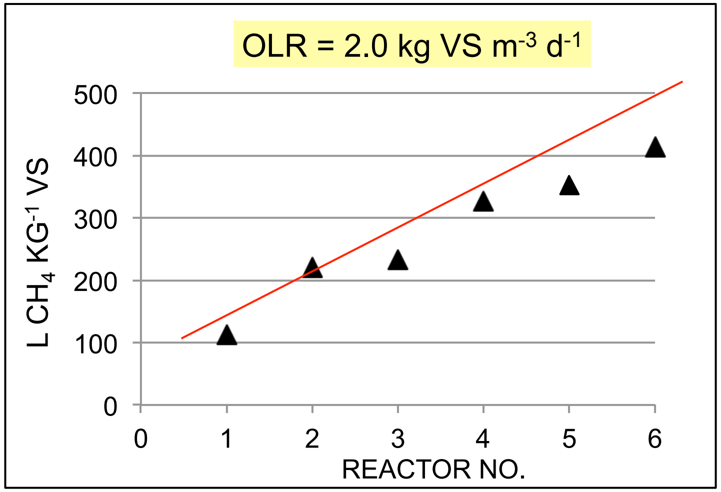


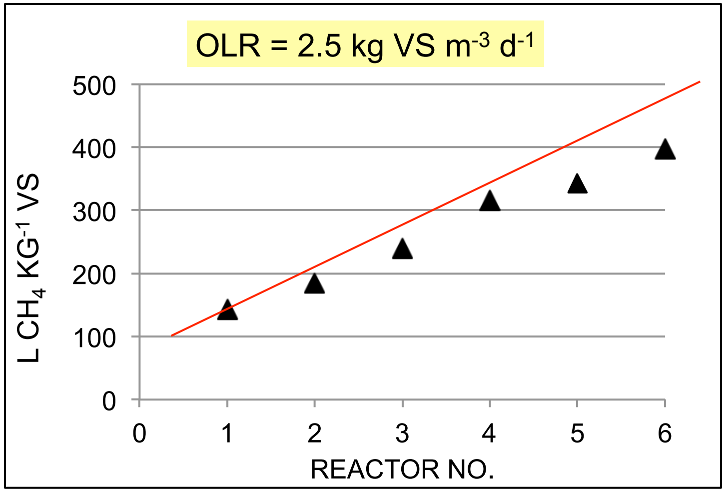
+ R5 & R6

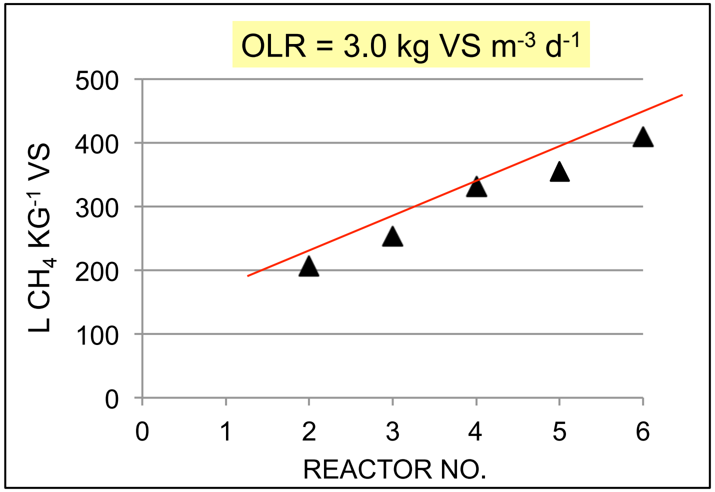
Higher Dairy Slurry Input

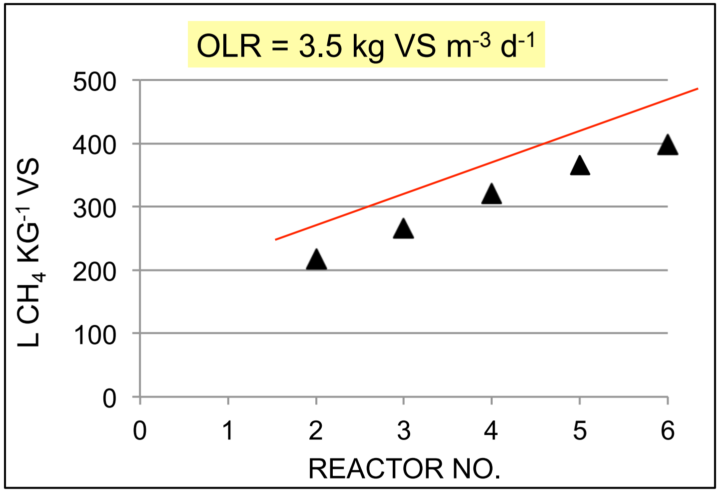
	Grass %VS	*Slurry %VS*
R6	100	0
R5	80	20
R4	60	40
R3	40	60
R2	20	80
R1	0	100

Increased gas production with increased grass

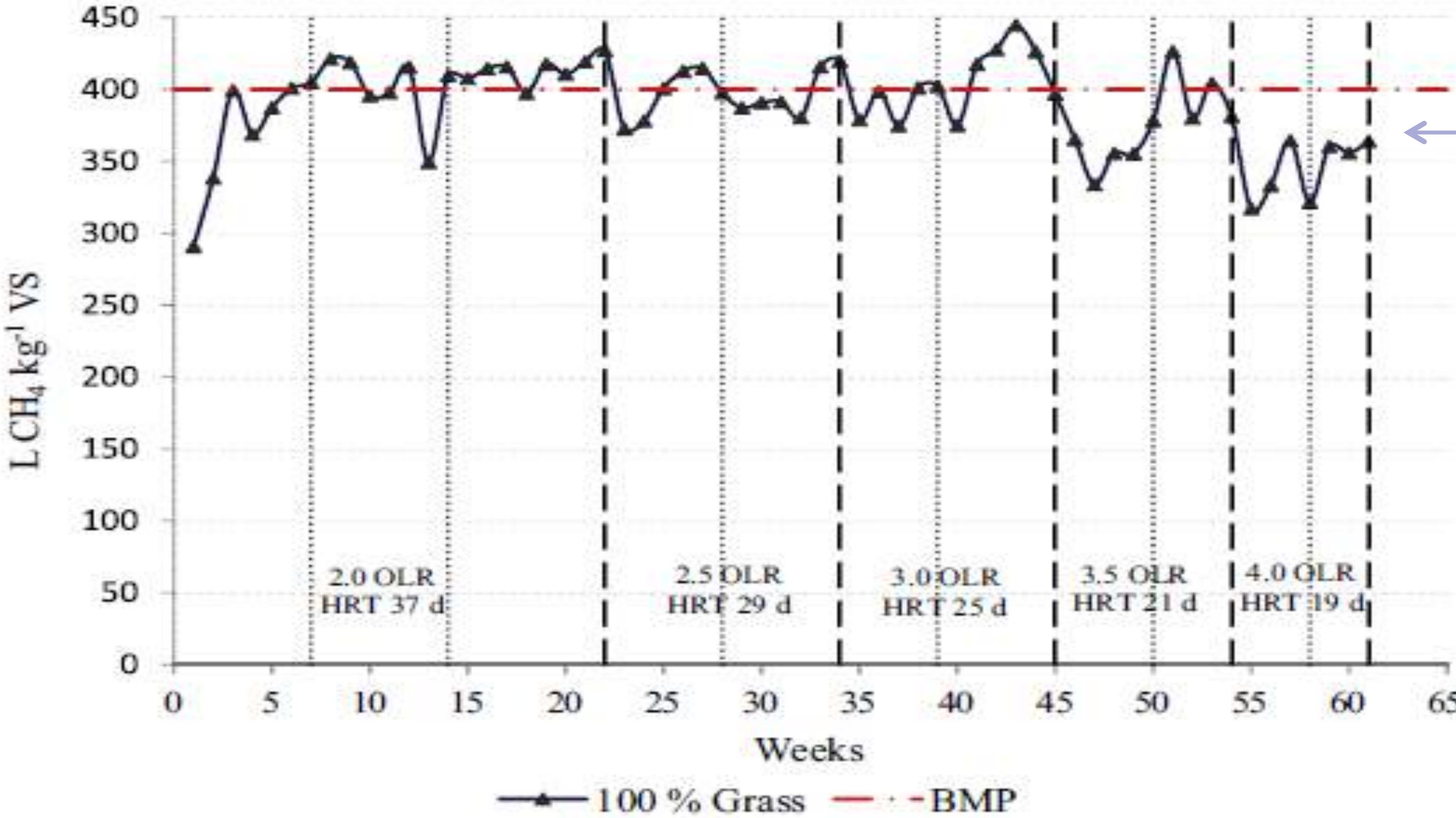








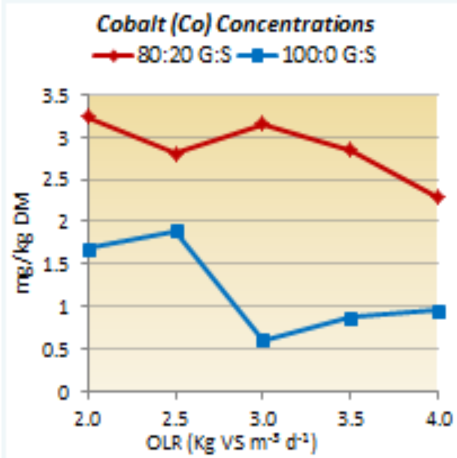
Reduction in yield of mono-digestion at high OLR

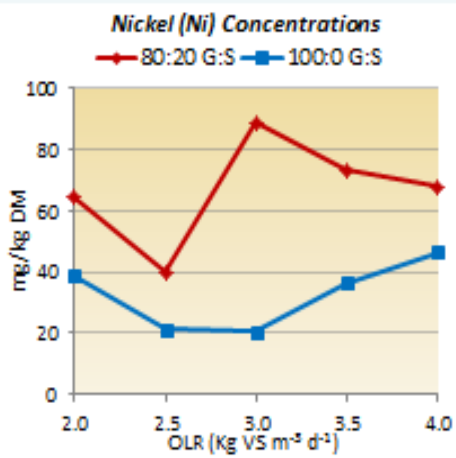


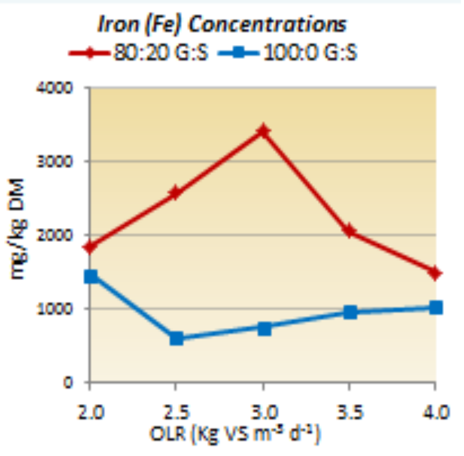
12% decrease in SMY

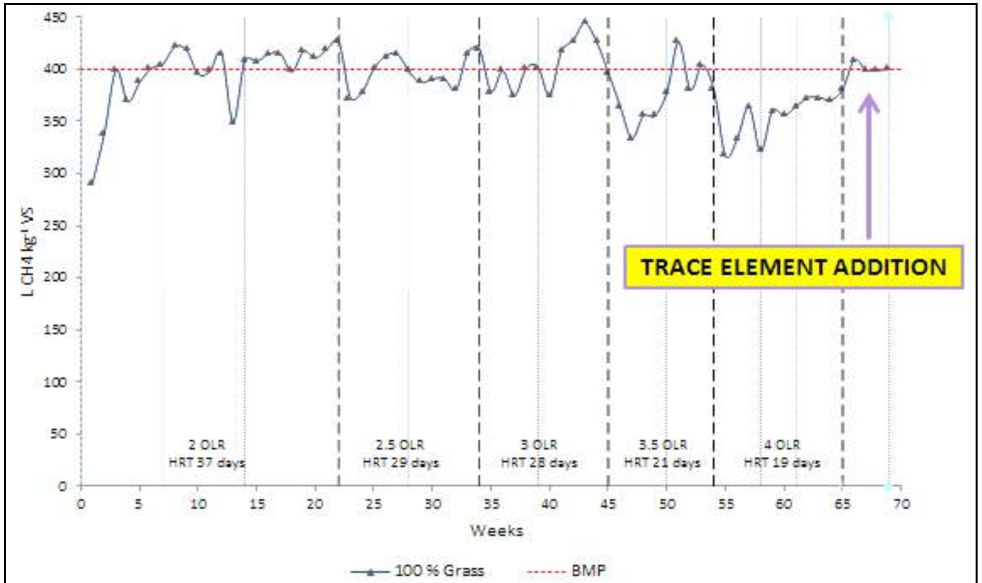
Fig. 1. Specific methane yield for R6 (mono-digestion of grass).

Trace element analysis









A perspective on the potential role of biogas in smart energy grids

Tobias PERSSON, Jerry MURPHY,
Anna-Karin JANNASCH, Eoin AHERN,
Jan LIEBETRAU, Marcus TROMMLER,
Jeferson TOYAMA

SUMMARY

This report documents the potential role of biogas in smart energy grids. Biogas systems can facilitate increased proportions of variable renewable electricity on the electricity grid through use of two different technologies:

- Demand driven biogas systems which increase production of electricity from biogas facilities at times of high demand for electricity, or store biogas temporarily at times of low electricity demand.
- Power to gas systems when demand for electricity is less than supply of electricity to the electricity grid, allowing conversion of surplus electricity to gas.

The report is aimed at an audience of energy developers, energy policy makers and academics and was produced by IEA Bioenergy Task 37. Task 37 is a part of IEA Bioenergy, which is one of the 42 Implementing Agreements within IEA. IEA Bioenergy Task 37 addresses the challenges related to the economic and environmental sustainability of biogas production and utilisation.

iea Energy Technology Network

IEA Bioenergy

Demand Driven Biogas

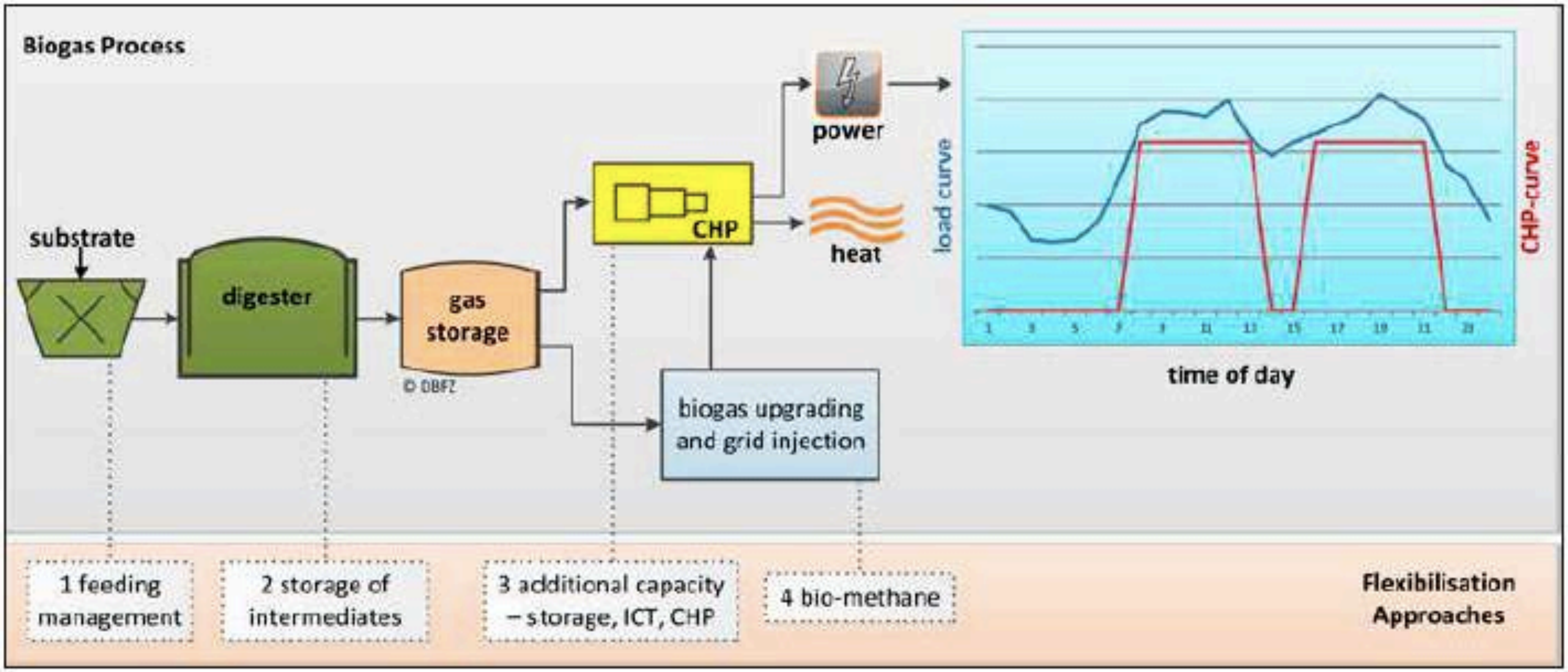


Figure 6: Approaches for biogas-based demand driven power production (Szarka et al, 2013)

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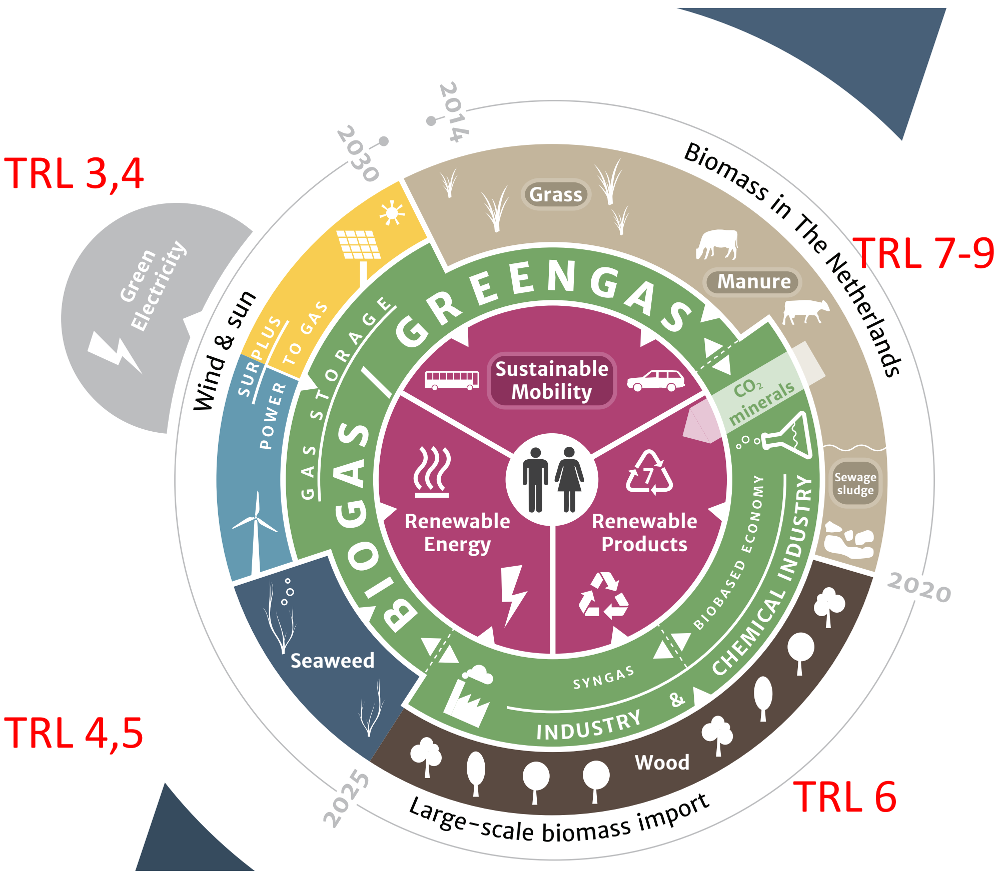


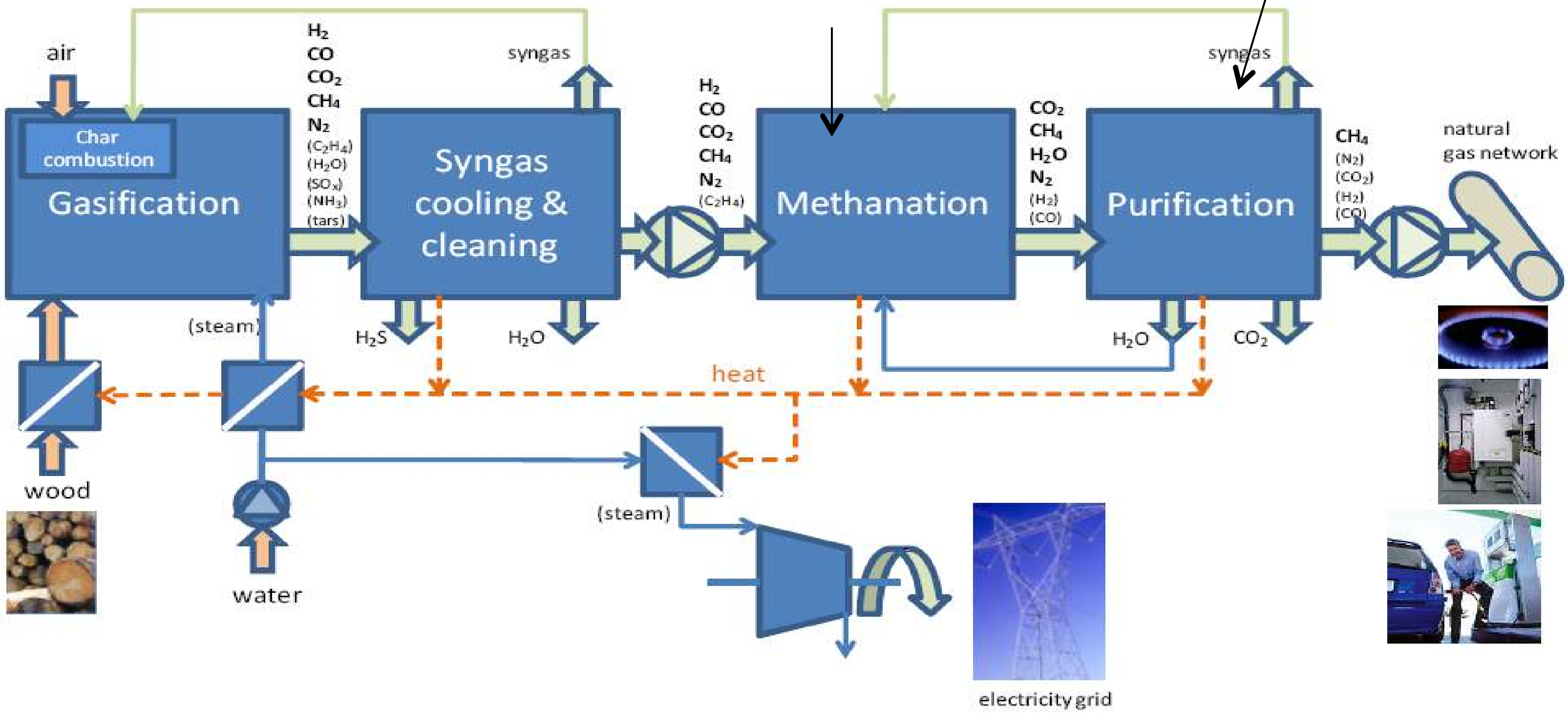
Second stage of Industry

Green Gas from gasification of woody crops

Thermal production of Biomethane

$CO + 3H_2 = CH_4 + H_2O$
$CO_2 + 4\ H_2 = CH_4 + 2H_2O$
$2CO + 2H_2 = CH_4 + CO_2$

Gas upgrading
Removal of CO2



Typically ca. 65% energy efficiency

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Applied Energy 108 (2013) 158–167

Contents lists available at SciVerse ScienceDirect

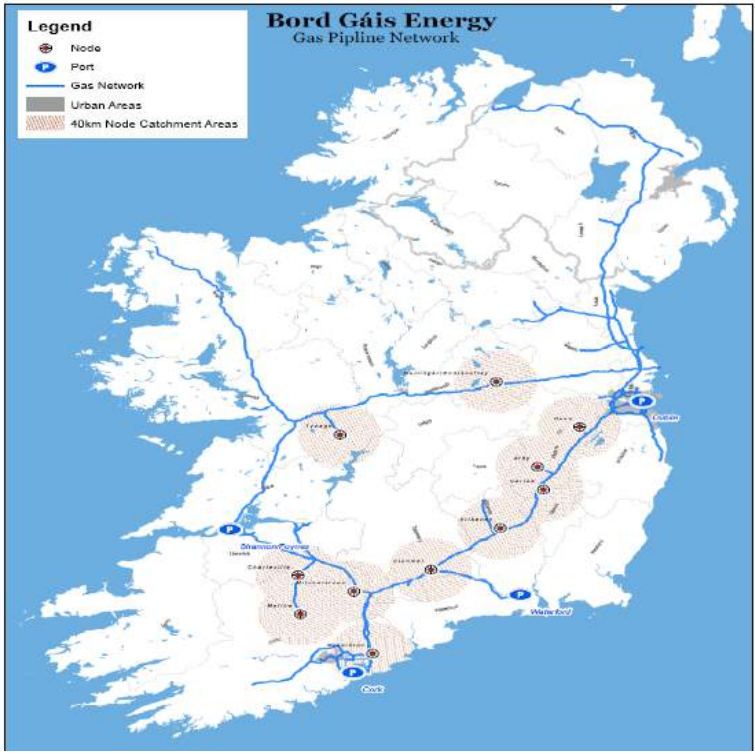
Applied Energy

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

What is the realistic potential for biomethane produced through gasification of indigenous Willow or imported wood chip to meet renewable energy heat targets?

Cathal Gallagher [a], Jerry D. Murphy [b,c,*]

Plant Size MW	50
Land area (ha)	6800
Number of plants required	11
As a % Energy in Transport	5.5%
As a % of agricultural land	1.7%



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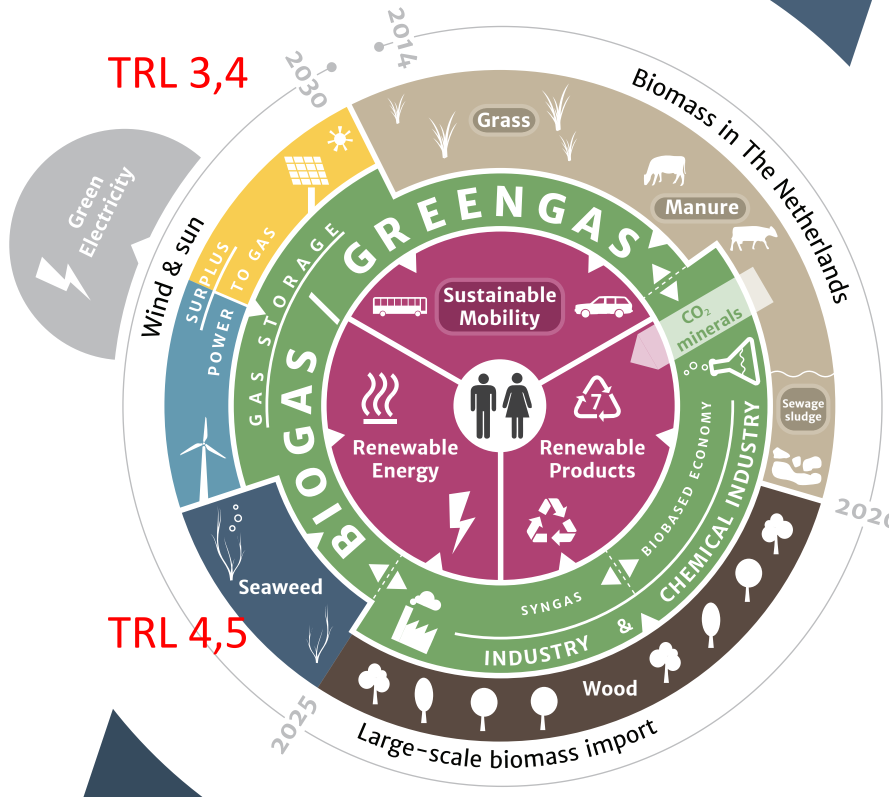
TRL 3,4

TRL 7-9



TRL 4,5

TRL 6

Third stage of Industry

Green Gas from seaweed

MaREI
Centre for Marine and Renewable Energy

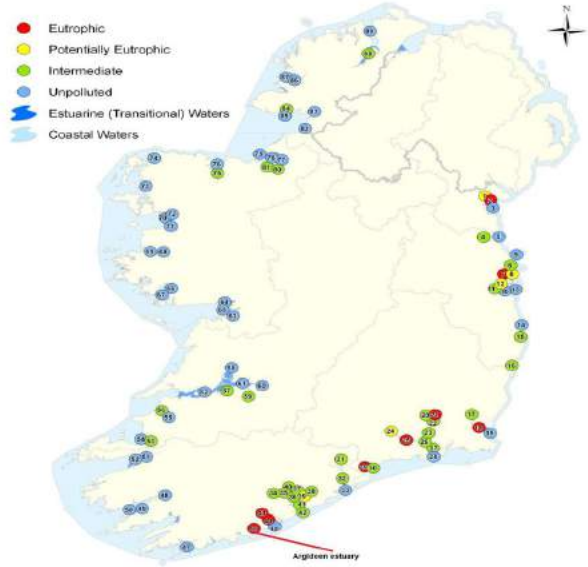
IEA Bioenergy Task 37

Waste Management 33 (2013) 2425–2433

Contents lists available at SciVerse ScienceDirect

Waste Management

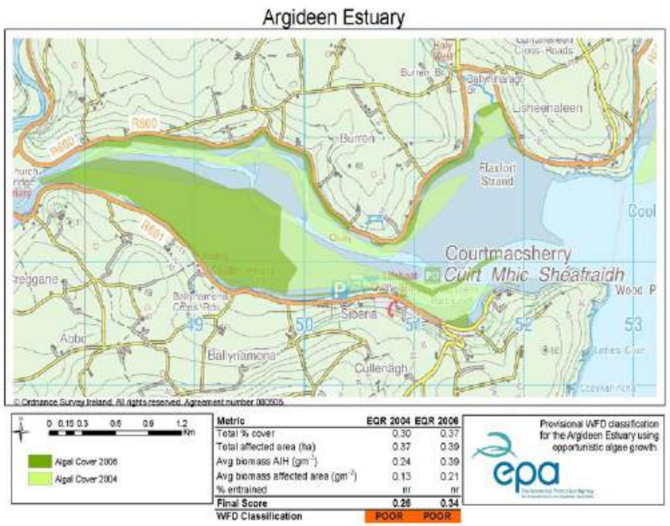
journal homepage: www.elsevier.com/locate/wasman



The potential of algae blooms to produce renewable gaseous fuel

E. Allen [a], J. Browne [a], S. Hynes [a], J.D. Murphy [a,b,*]

[a] Environmental Research Institute, University College Cork, Cork, Ireland
[b] Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland



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Energy xxx (2015) 1–9

Contents lists available at ScienceDirect

Energy

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

What is the gross energy yield of third generation gaseous biofuel sourced from seaweed?

Eoin Allen [a], David M. Wall [a], Christiane Herrmann [a], Ao Xia [a], Jerry D. Murphy [a, b, *]

[a] *Environmental Research Institute, University College Cork, Lee Road, Cork, Ireland*
[b] *School of Engineering, University College Cork, Cork, Ireland*

Specific methane yields of Seaweed

L. Digitata

S. latissima

Substrate	BMP yield ($L\ CH_4\ kg\ VS^{-1}$)	Theoretical composition of biogas (CH_4 %)	Theoretical yield ($L\ CH_4\ kg\ VS^{-1}$)	Biodegradability index	Specific yield ($m^3\ CH_4\ t^{-1}$ wwt)
A. nodosum	$166.3^{bc} \pm 20$	53	488	0.34	32.3
H. elongate	$260.9^{f} \pm 2.05$	36	334	0.78	21.1
L. digitata	$218.0^{de} \pm 4.14$	53	479	0.46	22.5
F. spiralis	$235.2^{ef} \pm 9.43$	55	540	0.44	32.7
F. serratus	$101.7^{a} \pm 9.37$	54	532	0.19	13.5
F. vesiclosus	$126.3^{ab} \pm 11.38$	37	249	0.51	19.4
S. polyschides	$263.3^{f} \pm 4.23$	48	386	0.68	34.5
S. latissima	$341.7^{g} \pm 36.40$	50	422	0.81	34.5
A. esculenta	$226.0^{def} \pm 5.66$	53	474	0.48	26.9
U. lactuca	$190.1^{cd} \pm 3.10$	48	465	0.41	20.9
Cellulose	$357.4^{g} \pm 15.20$	-	414	0.86	-

Different superscript letters [abcdefg] Indicate significant differences between BMP yield means of substrates ($P < 0.05$, adjustment = SIMULATE). wwt = wet weight.

Table 2. Biomethane production for seaweed using results of BMP analysis and theoretical analysis.

A. Nodosum

S. Polyschide

IEA Bioenergy Task 37

Bioresource Technology 209 (2016) 213–219

Contents lists available at ScienceDirect

Bioresource Technology

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

ELSEVIER

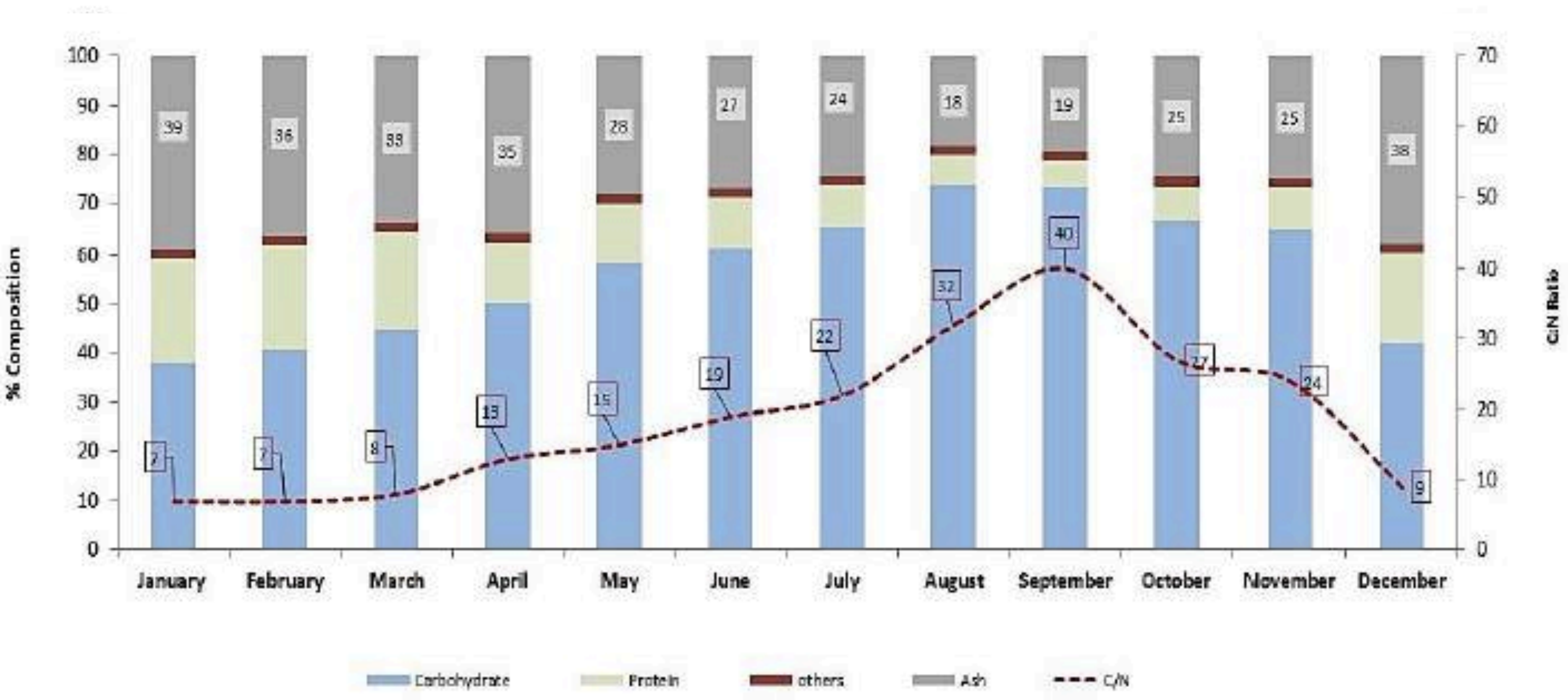
The effect of seasonal variation on biomethane production from seaweed and on application as a gaseous transport biofuel

CrossMark

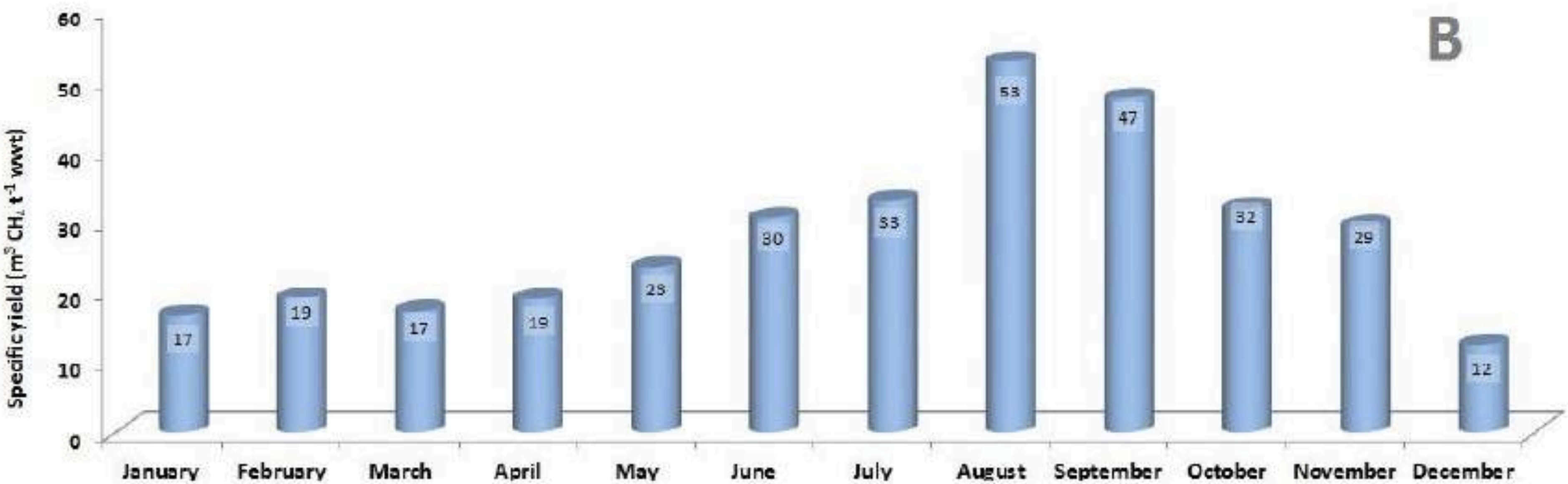
Muhammad Rizwan Tabassum [a], Ao Xia [b,*], Jerry D. Murphy [a,c]

[a] MaREI Centre, Environmental Research Institute, University College Cork, Cork, Ireland
[b] Key Laboratory of Low-grade Energy Utilization Technologies and Systems, Chongqing University, Chongqing 400044, China
[c] School of Engineering, University College Cork, Cork, Ireland

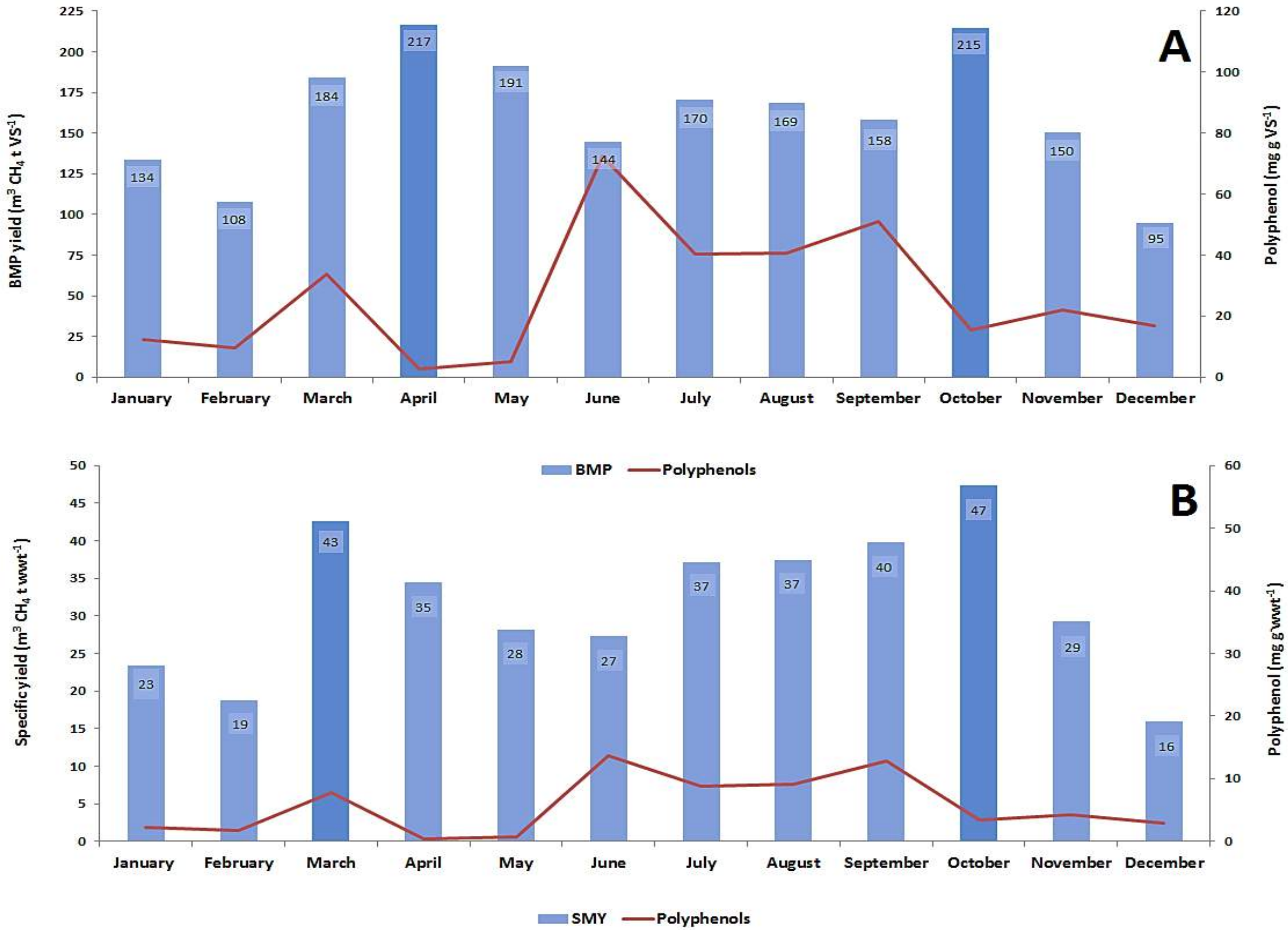
Seasonal Variation in composition of Laminaria Digitata



Seasonal Variation in biomethane yield from Laminaria Digitata

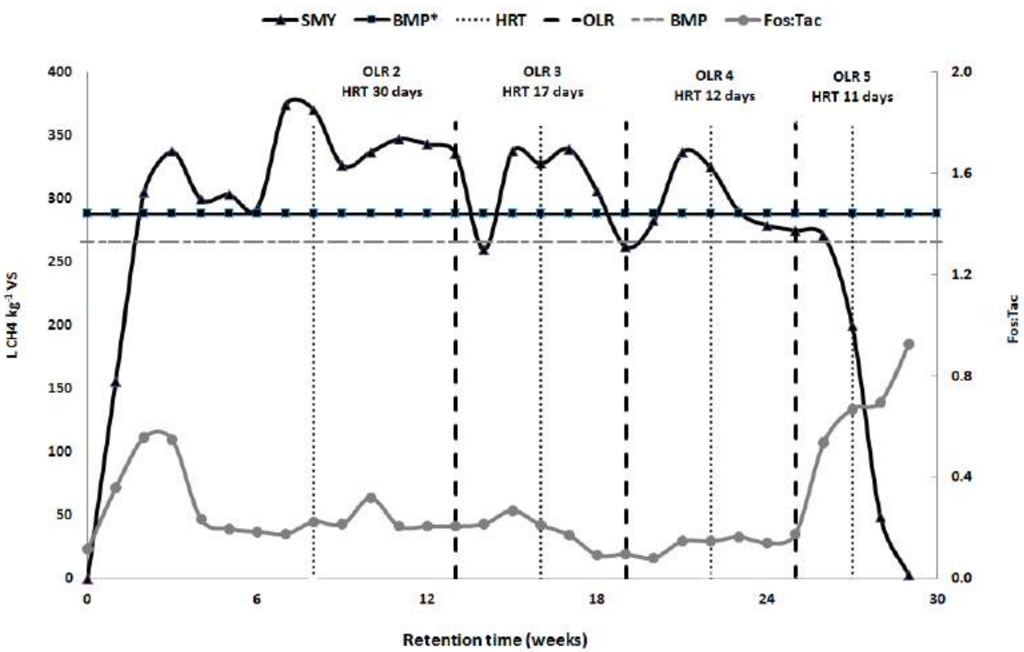


Seasonal Variation in A. *nodosum*



Tabassum, M., Xia, A., Murphy, J.D. (2016) Impact of seasonal polyphenol variation on biomethane production from brown seaweed *Ascophyllum nodosum* Bioresource Technology (In Press)

Long term digestion of seaweed



Mono-digestion of *L. digitata*: SMY and FOS:TAC with increasing organic loading rate

Tabassum, M., Wall D., Murphy, J.D. (2016) Third generation gaseous biofuel generated through mono- and co-digestion of natural and cultivated seaweeds, with dairy slurry Bioresource Technology (In Review)

IEA Bioenergy Task 37

International Journal of Environmental Science and Development, Vol. 7, No. 11, November 2016

Seaweed Biofuel Derived from Integrated Multi-trophic Aquaculture

Amita Jacob, Ao Xia, Daryl Gunning, Gavin Burnell, and Jerry D. Murphy

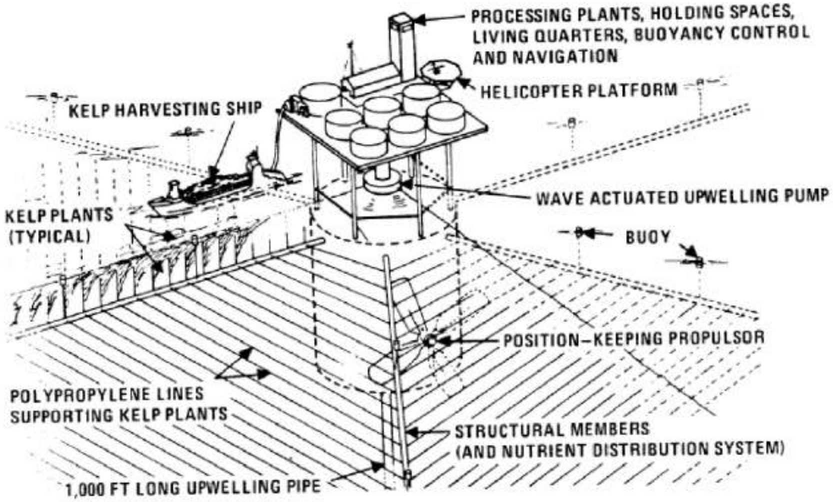


Figure 1. Conceptual design of 405 ha (1,000 acre) ocean food and energy farm unit. (Leese 1976) Source: David Chynoweth.

IEA Bioenergy Task 37

Bioresource Technology 196 (2015) 301–313

Contents lists available at ScienceDirect

Bioresource Technology

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

Ensiling of seaweed for a seaweed biofuel industry

Christiane Herrmann [a], Jamie FitzGerald [a], Richard O'Shea [a], Ao Xia [a], Pádraig O'Kiely [b], Jerry D. Murphy [a,*]

[a] Science Foundation Ireland (SFI), Marine Renewable Energy Ireland (MaREI), Environmental Research Institute, School of Engineering, University College Cork, Cork, Ireland
[b] Teagasc Animal & Grassland Research and Innovation Centre, Grange, Dunsany, Co. Meath, Ireland

Higher methane yields after ensiling can compensate for silage fermentation losses.

No losses in methane yield occurred during 90 day storage for 4 of 5 species.

IEA Bioenergy Task 37

A perspective on algal biogas

Jerry D MURPHY
Bernhard DROSG
Eoin ALLEN
Jacqueline JERNEY
Ao XIA
Christiane HERRMANN

SUMMARY

Algae are suggested as a biomass source with significant growth rates, which may be cultivated in the ocean (seaweed) or on marginal land (microalgae). Biogas is suggested as a beneficial route to sustainable energy; however the scientific literature on algal biogas is relatively sparse. This report comprises a review of the literature and provides a state of the art in algal biogas and is aimed at an audience of academics and energy policy makers. It was produced by IEA Bioenergy Task 37 which addresses the challenges related to the economic and environmental sustainability of biogas production and utilisation.

iea Energy Technology Network

IEA Bioenergy

MaREI
Centre for Marine and Renewable Energy

IEA Bioenergy Task 37

Applied Energy 148 (2015) 396–402

Contents lists available at ScienceDirect

Applied Energy

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

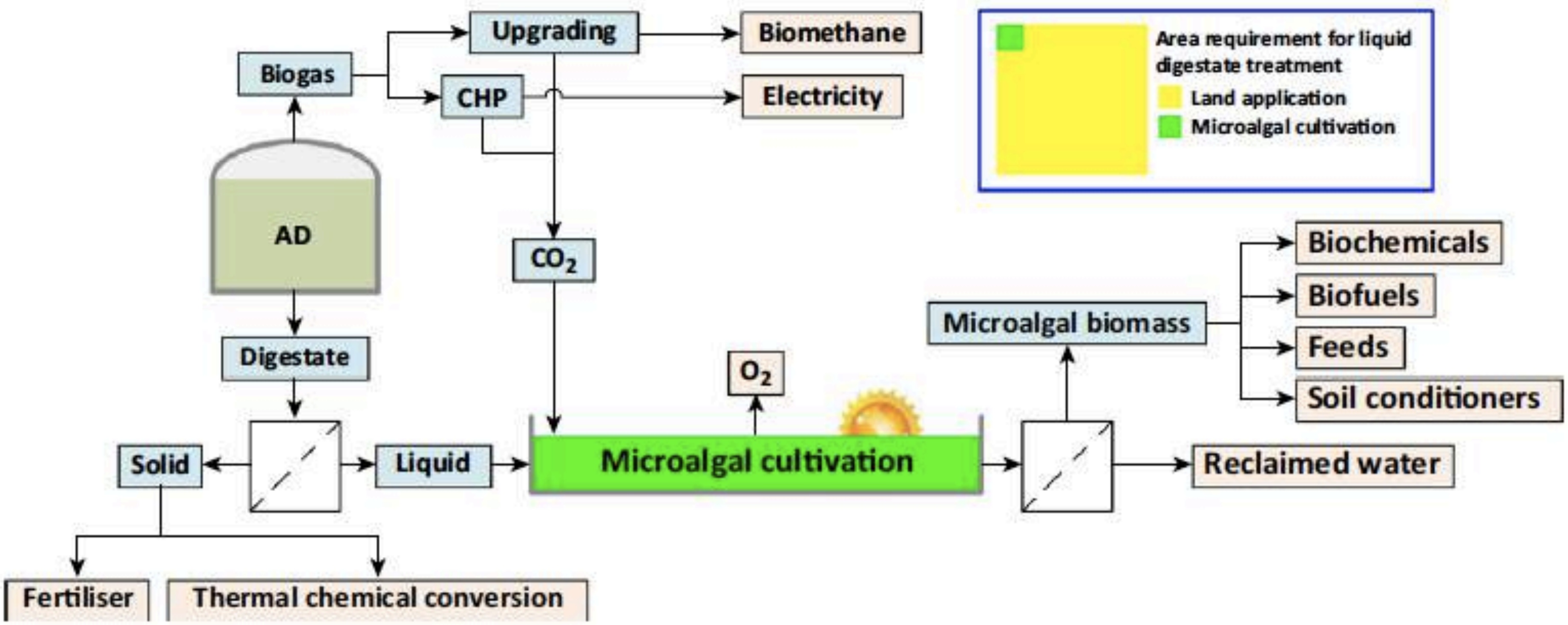
A perspective on gaseous biofuel production from micro-algae generated from CO_2 from a coal-fired power plant

Figure 8: Open cultivation systems for cultivation of microalgae; left: Race way ponds at pilot-scale (© Elad Zohar, Erber Future Business GmbH); right: cascade system (= thin film system) (© Jiri Kopecky, Institute of Microbiology, Trebon)

Opinion

Microalgal Cultivation in Treating Liquid Digestate from Biogas Systems

Ao Xia[1,2] and Jerry D. Murphy[1,3,*]



IEA Bioenergy Task 37

Bioresource Technology 214 (2016) 328–337

Contents lists available at ScienceDirect

Bioresource Technology

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

Optimised biogas production from microalgae through co-digestion with carbon-rich co-substrates

Christiane Herrmann [a,c], Navajyoti Kalita [a], David Wall [a,b], Ao Xia [a,d], Jerry D. Murphy [a,b,*]

[a] The MaREI Centre, Environmental Research Institute, University College Cork, Ireland
[b] School of Engineering, University College Cork, Cork, Ireland
[c] Leibniz Institute for Agricultural Engineering Potsdam-Bornim, Department of Bioengineering, Max-Eyth-Allee 100, 14469 Potsdam, Germany
[d] Key Laboratory of Low-grade Energy Utilization Technologies and Systems, Chongqing University, Chongqing 400044, China

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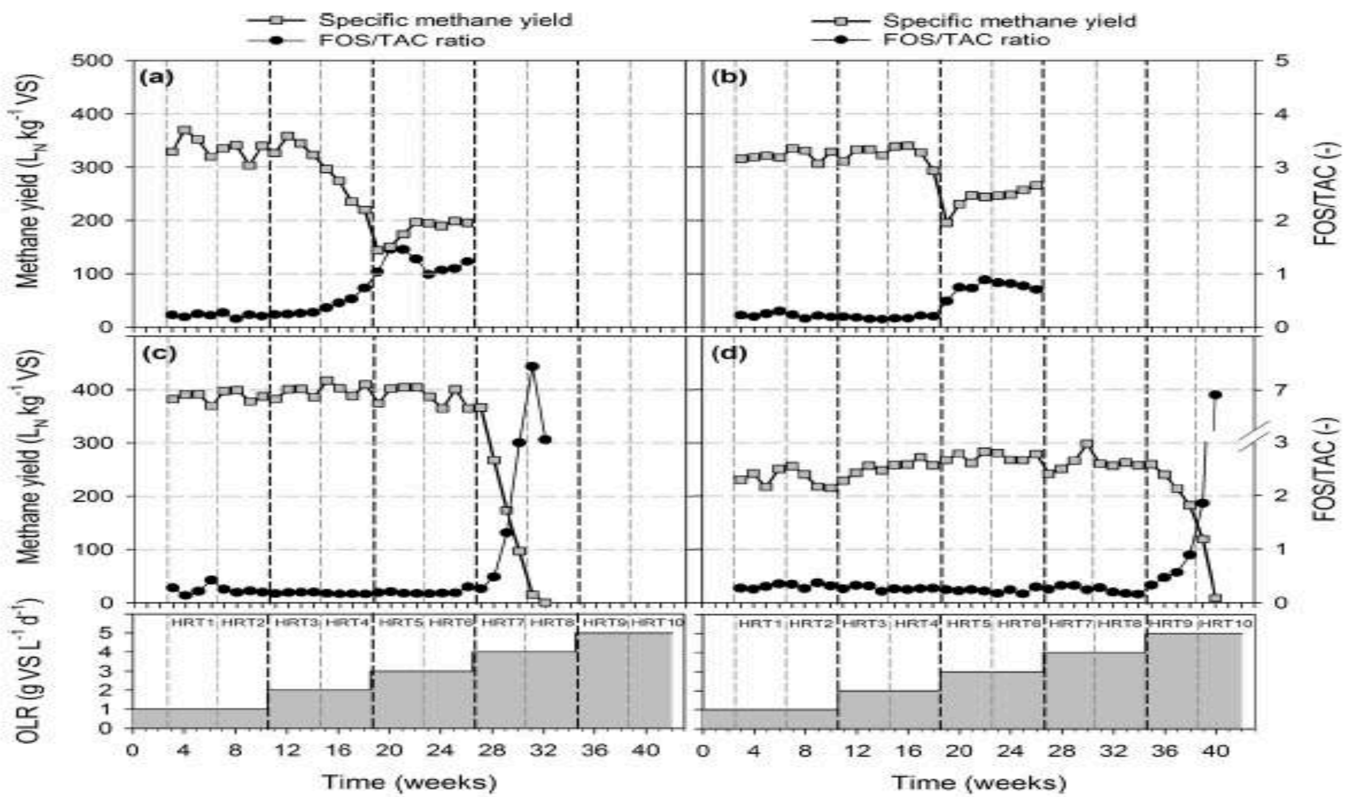

- Mono-digestion of *A. platensis* was assessed in reactor 1 (R1).
- Reactor 2 (R2) was fed with a mixture of 85% VS of *A. platensis* and 15% VS of barley straw.
- Reactor 3 (R3) was fed with a mixture of 45% VS of *A. platensis* and 55% VS of energy beet silage.
- Reactor 4 (R4) was operated with a mixture of 15% VS of *A. platensis* and 85% VS of macroalga *L. digitata*.

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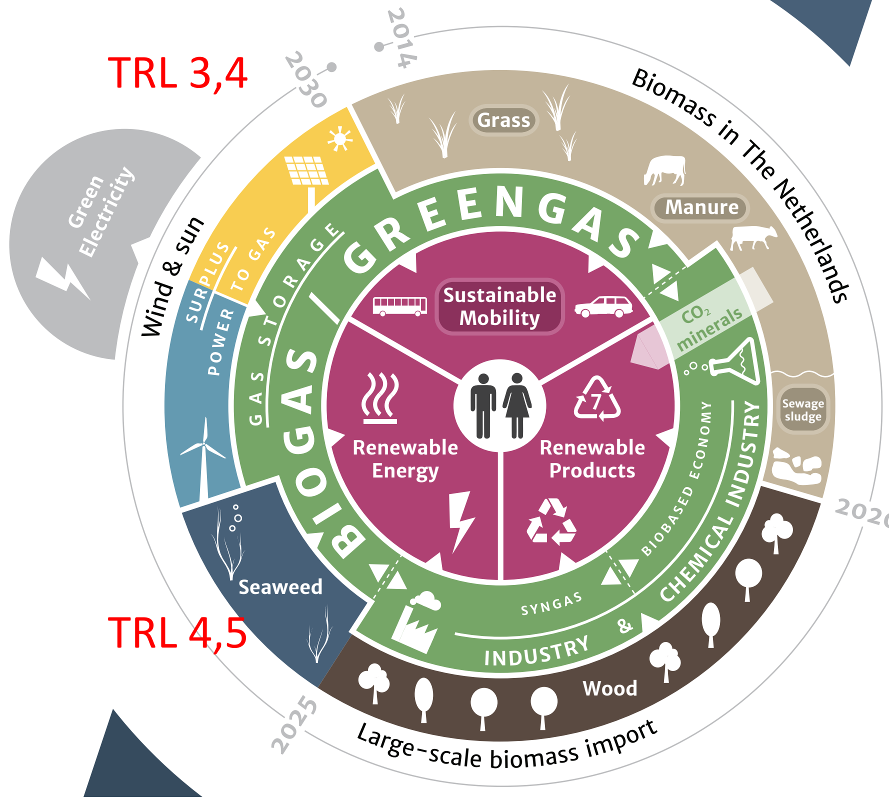
Fourth stage of Industry

Green Gas from electricity



MaREI
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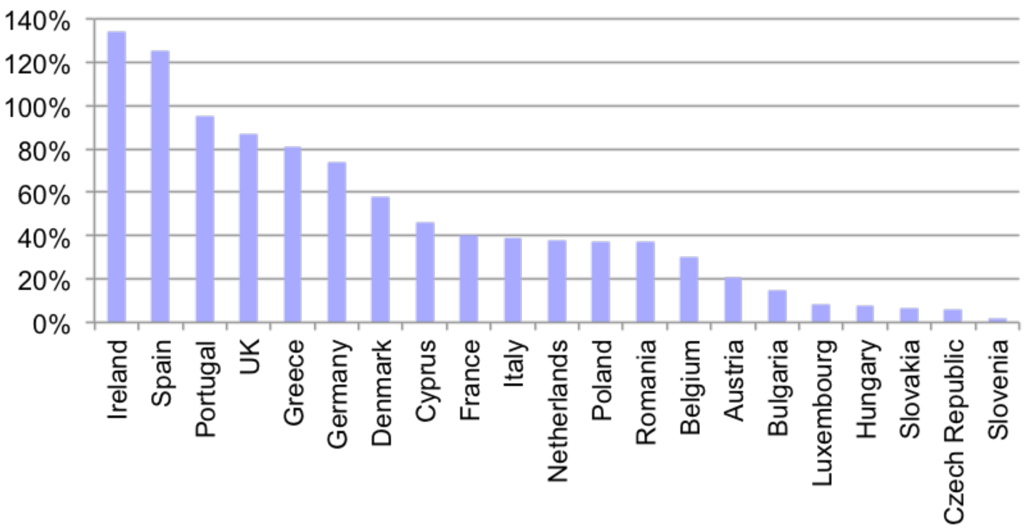
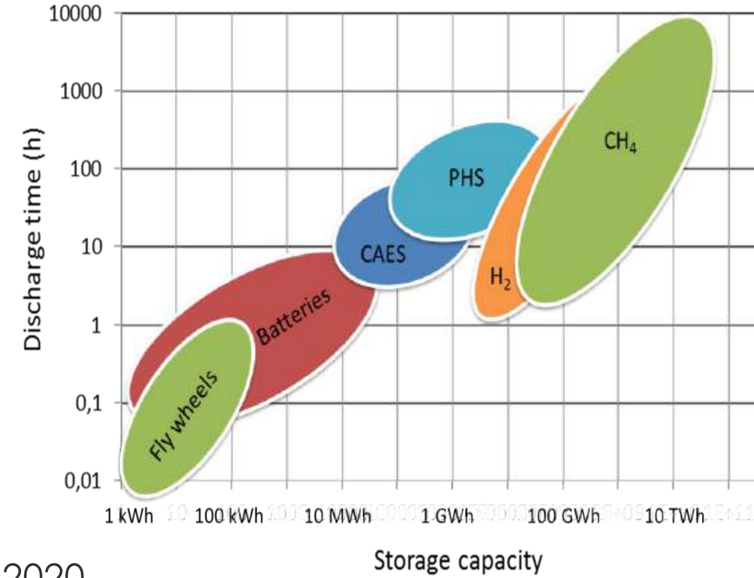
Curtailment and storage of variable renewable electricity





Wind capacity as a proportion of minimum demand in summer 2020

P2G: Electrolysis followed by Methanation

2 MW Power-to-Gas unit (Falkenhagen, Germany).
Hydrogen is injected into the grid without methanation

Windmill at a biogas facility. (Source: Xergi)

Electrolysis: Electricity converted to H2 at 70- 90% η

Methanation: $4H_2 + CO_2 = CH_4 + 2H_2O$ at 80– 90% η

Overall: 55 - 80% η

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Renewable Energy 78 (2015) 648–656

Contents lists available at ScienceDirect

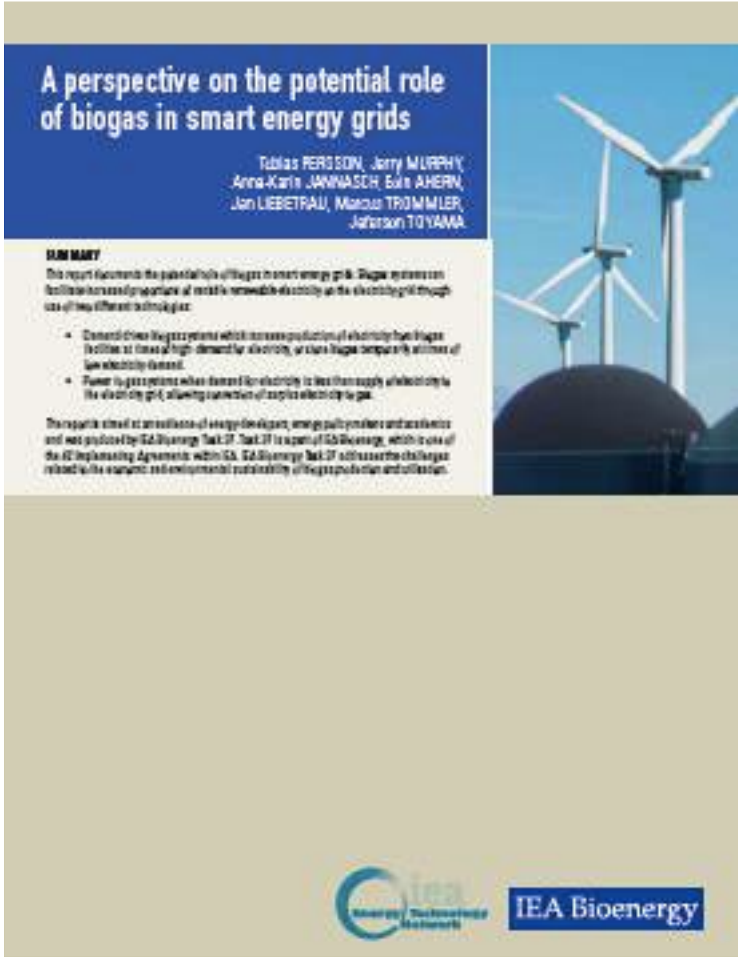
Renewable Energy

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

A perspective on the potential role of renewable gas in a smart energy island system

Eoin P. Ahern [a, b, c], Paul Deane [a, c], Tobias Persson [d], Brian Ó Gallachóir [a, c], Jerry D. Murphy [a, b, c, *]

[a] Environmental Research Institute, University College Cork, Ireland
[b] Science Foundation Ireland (SFI), Marine Renewable Energy Ireland (MaREI) Centre, Ireland
[c] School of Engineering, University College Cork, Ireland
[d] Energiforsk AB – Swedish Energy Research Centre, Sweden



Resource of Power to Gas

Table 2
Total potential of renewable gas in Ireland as a renewable transport fuel.

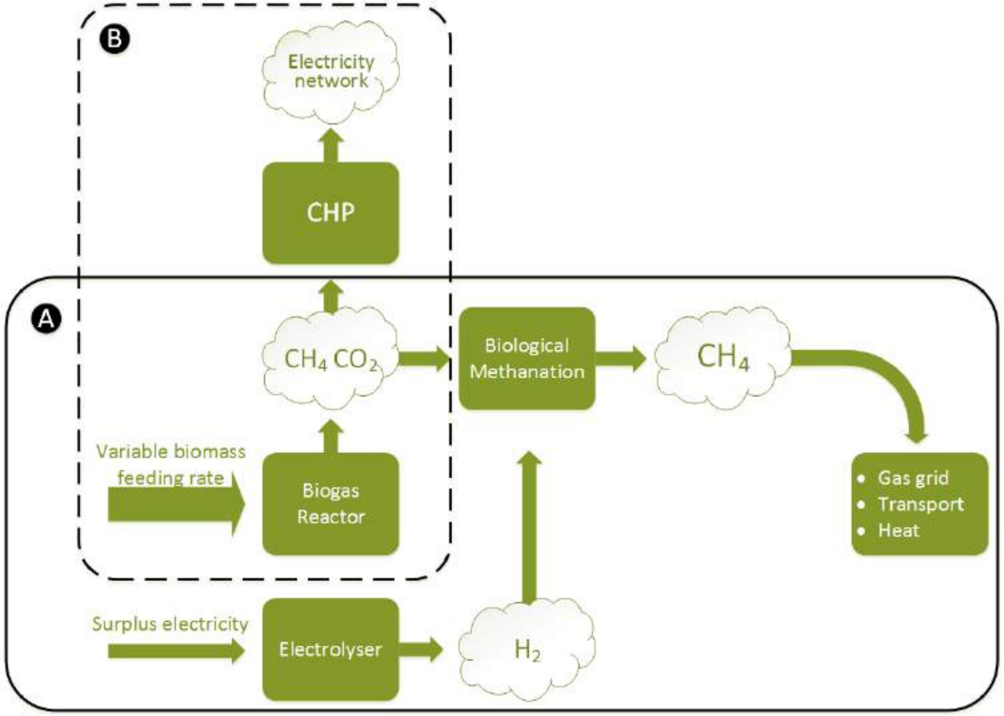
	Agricultural slurries	Slaughter waste	OFMSW	Grass	Total
RES-T from anaerobic digestion of selected substrates					
Feedstock (Mt/a)[a]	2.79	0.21	0.22	4.16	7.38
CH_4 yield (m_n^3/t)[a]	17.8	86	68	107.6	71.9
CH_4 from AD (Mm_n^3/a)[a]	49.76	18.08	14.98	447.59	530.41
Practical resource from AD (PJ/a)[b]	1.88	0.68	0.57	16.07	19.20
Percentage of energy in transport (%)[c]	1.00	0.36	0.30	8.55	10.21
RES-T from AD (%)[d]	2.00	0.72	0.60	17.10	20.42
RES-T from biological Power to Gas					
% CO_2 in biogas	45	45	35	45	–
CO_2 from AD (Mm_n^3/a)	40.71	14.79	8.07	366.21	429.78
H_2 required (Mm_n^3/a)[e]	162.85	59.16	32.26	1464.84	1719.13
Electricity required to provide H_2 (PJ/a)[f]	2.63	0.95	0.52	23.63	27.73
Energy from Power to Gas (PJ/a)[g]	1.58	0.57	0.31	14.18	16.64
CH_4 from Power to Gas (Mm_n^3/a)	41.72	15.16	8.27	375.32	440.47
Percentage of energy in transport (%)	0.84	0.30	0.17	7.54	8.85
RES-T from Power to Gas (%)[h]	1.68	0.6	0.34	15.08	17.7
RES-T from renewable gas					
RES-T from AD and P2G (%)	3.68	1.32	0.94	32.18	38.12

[a] From Singh et al. [16] and Wall et al. [17].
[b] Energy value of CH4 taken as 37.8 MJ/m_n^3.
[c] Energy in transport in 2020 expected as 188 PJ in Republic of Ireland.
[d] Residues and grasses are allowed a weighting of 2 in Renewable Energy Directive.
[e] H_2 required at 4 times the volume of CO_2.
[f] Energy value of H_2 taken as 12 MJ/m_n^3. Electricity converted to H_2 at 75% efficiency.
[g] Overall electricity to H_2 efficiency of 60% (80% * 75%).
[h] Power to Gas allowed a weighting of 2 in RED.

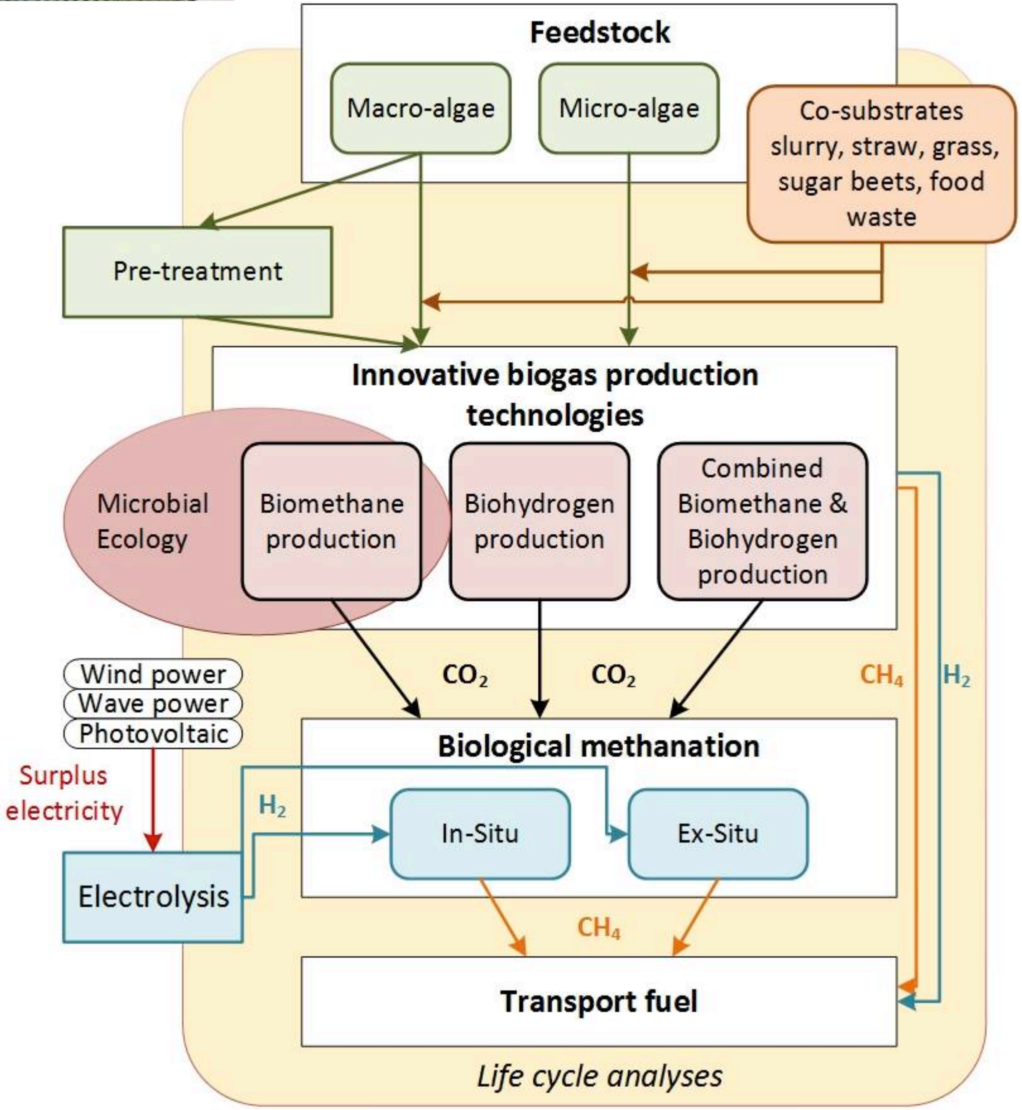
Gaseous biofuel from non-biological origin

H_2: energy Density 12.1 MJ/m_n^3 : CH_4: Energy density 37.6 MJ/m_n^3

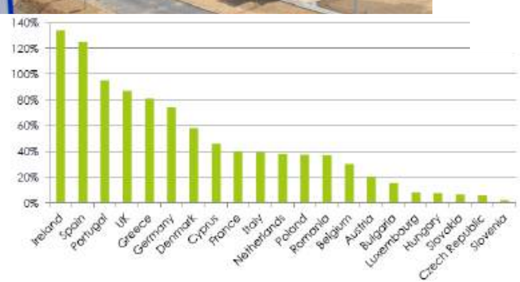
Sabatier Equation: $4H_2 + CO_2 = CH_4 + 2H_2O$



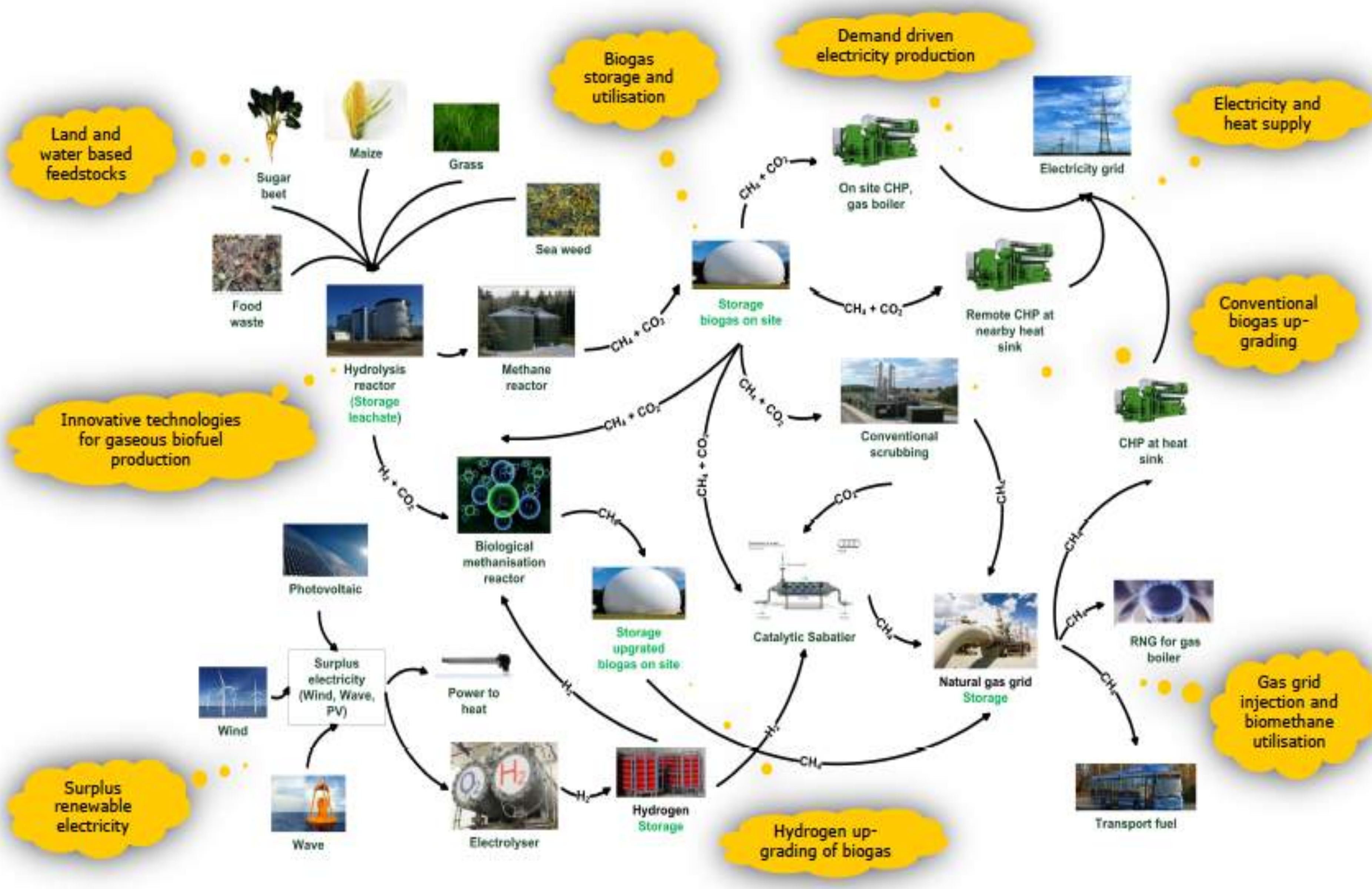
Source of CO2 from biogas:
Mix biogas (50% CH4 and 50% CO2) with H2; generate double the CH4 (1 mol CO2 generates 1 mol CH4).


Feedstock
Macro-algae
Micro-algae
Co-substrates slurry, straw, grass, sugar beets, food waste
Pre-treatment
Innovative biogas production technologies
Microbial Ecology
Biomethane production
Biohydrogen production
Combined Biomethane & Biohydrogen production
Wind power
Wave power
Photovoltaic
Surplus electricity
CO_2
CO_2
CH_4
H_2
Biological methanation
H_2
In-Situ
Ex-Situ
Electrolysis
CH_4
Transport fuel
Life cycle analyses


Food Waste


140%
120%
100%
80%
60%
40%
20%
0%
Ireland
Spain
Portugal
UK
Greece
Germany
Denmark
Cyprus
France
Italy
Netherlands
Poland
Romania
Belgium
Austria
Bulgaria
Luxembourg
Hungary
Slovakia
Czech Republic
Slovenia

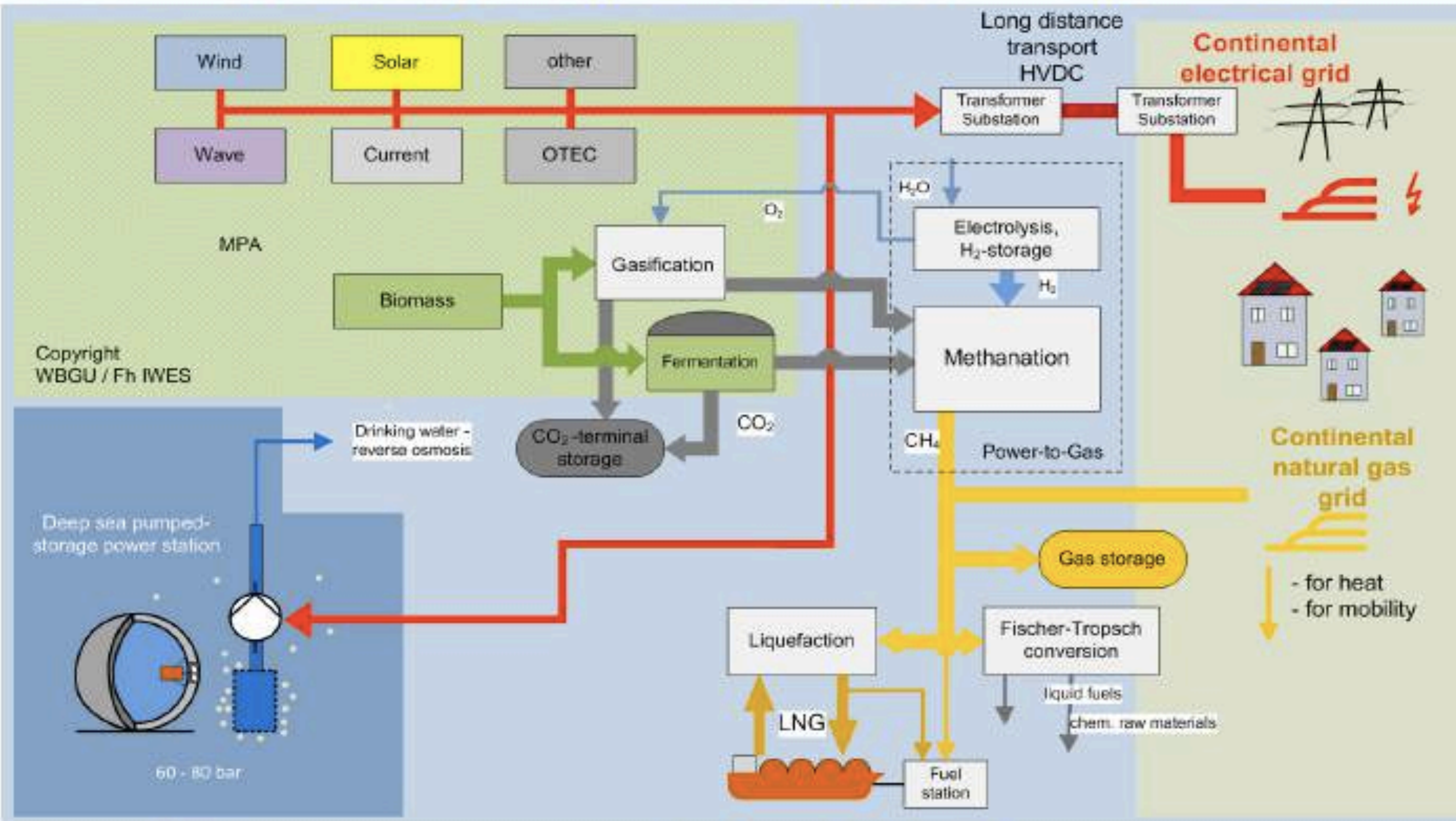

CCG 656



Land and water based feedstocks
Sugar beet
Maize
Grass
Sea weed
Food waste
Hydrolysis reactor (Storage leachate)
Methane reactor
Biogas storage and utilisation
Demand driven electricity production
Electricity and heat supply
Storage biogas on site
On site CHP, gas boiler
Electricity grid
Remote CHP at nearby heat sink
Conventional biogas up-grading
Conventional scrubbing
CHP at heat sink
Innovative technologies for gaseous biofuel production
Biological methanisation reactor
Storage upgrated biogas on site
Catalytic Sabatier
Natural gas grid Storage
RNG for gas boiler
Transport fuel
Gas grid injection and biomethane utilisation
Photovoltaic
Surplus electricity (Wind, Wave, PV)
Power to heat
Wind
Wave
Electrolyser
Hydrogen Storage
Surplus renewable electricity
Hydrogen up-grading of biogas

IEA Bioenergy Task 37

Integrated system approach: marine energy, storage and fuels



Source: "World in Transition: Governing the Marine Heritage",
German Advisory Council on Global Change, Flagship Report 2013

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