IEA Bioenergy Task 37

The role of biogas in supporting intermittent renewable electricity

Prof Jerry D Murphy, Director of MaREI, (Centre for Marine and Renewable Energy), Environmental Research Institute, University College Cork, Ireland

Task Leader International Energy Agency (IEA) Energy from Biogas (2016 – 2018)

Australia Bioenergy, Brisbane November 2016

ERI Environmental Research Institute University College Cork

UCC Coláiste na hOllscoile Corcaigh, Éire University College Cork, Ireland

MaREI Centre for Marine and Renewable Energy

sfi Fondúireacht Eolaíochta Éireann Science Foundation Ireland

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)
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- **150 active research projects with €44 M of funding**

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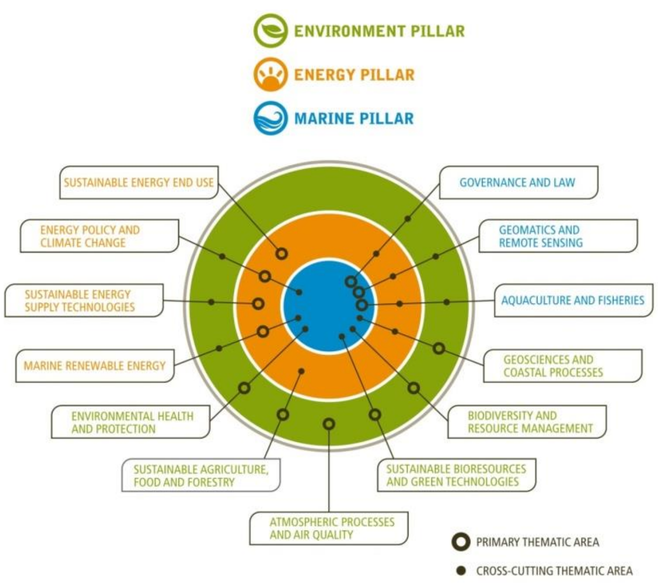


"MaREI: Unlocking the potential of our marine and energy resources through the power of research and innovation"

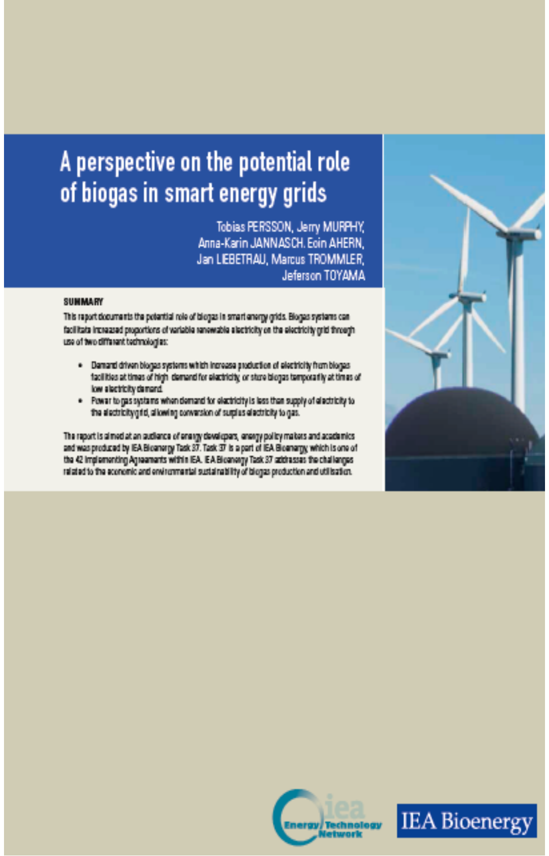
- **Marine and renewable energy research, development & innovation hub**
- **SFI research centre coordinated by the Environmental Research Institute at University College Cork with partners across 6 academic institutions**
- **Headquartered in the ERI Beaufort Building on the IMERC campus in Cork Harbour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

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.

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

IEA Bioenergy Task 37



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:

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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 Bioenergy

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 Bioenergy

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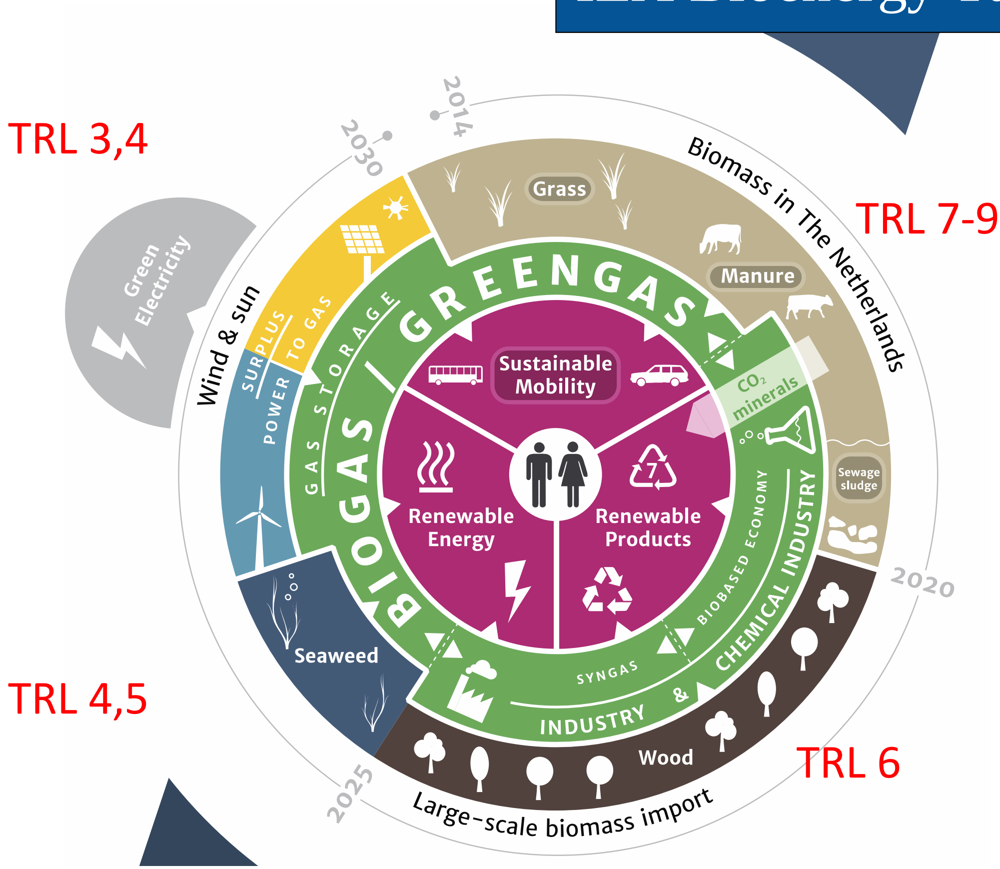
IEA Bioenergy Task 37



Green Gas

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

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Peer review papers (ca. 100 published since 2004)

Renewable Energy 55 (2013) 474–479

Contents lists available at SciVerse ScienceDirect

Renewable Energy

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

ELSEVIER

The resource of biomethane, produced via biological, thermal and electrical routes, as a transport biofuel

Jerry D. Murphy[a,b,*], James Browne[a,b], Eoin Allen[a,b], Cathal Gallagher[c]

Waste Management xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Waste Management

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

ELSEVIER

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

Modeling and Analysis

Biofpr Biofuels Bioproducts & Biorefining

Is it better to produce biomethane via thermochemical or biological routes? An energy balance perspective

Cathal Gallagher, Bord Gais Energy, Cork, Ireland
Jerry D Murphy, University College Cork, Cork, Ireland

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

Applied Energy 104 (2013) 170–177

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

ELSEVIER

Assessment of the resource associated with biomethane from food waste

James D. Browne, Jerry D. Murphy *

Department of Civil and Environmental Engineering, University College Cork, Ireland
Environmental Research Institute, University College Cork, Ireland

Environmental Science & Technology

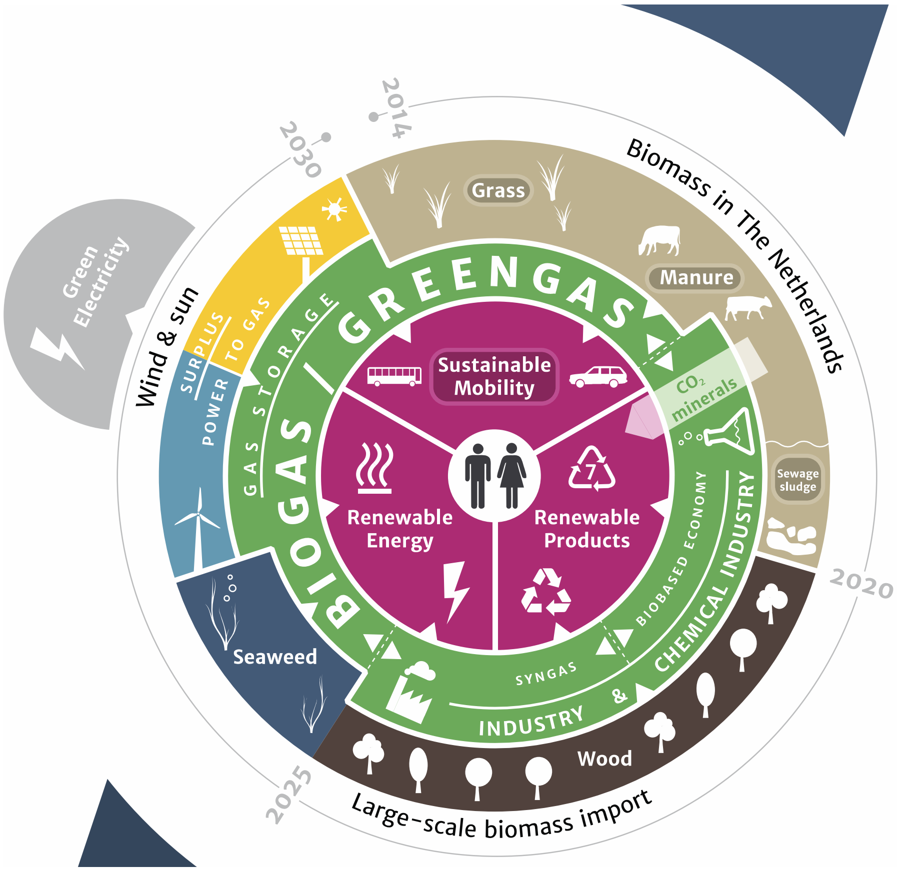
ARTICLE

pubs.acs.org/est

Optimizing the Operation of a Two-Phase Anaerobic Digestion System Digesting Grass Silage

Abdul-Sattar Nizami and Jerry D. Murphy*

Department of Civil and Environmental Engineering, and Biofuels Research Group, Environmental Research Institute, University College Cork, Cork, Ireland



Initiation of Industry

Green Gas from grass and slurries

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Grass to transport fuel

harvest →

weigh bridge →

silage storage ↓

macerator ←

anaerobic digester ←

Scrubbing & storage ←

Biogas service station

Source: energiewerkstatt, IEA and personal photos

IEA Bioenergy Task 37

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

ELSEVIER

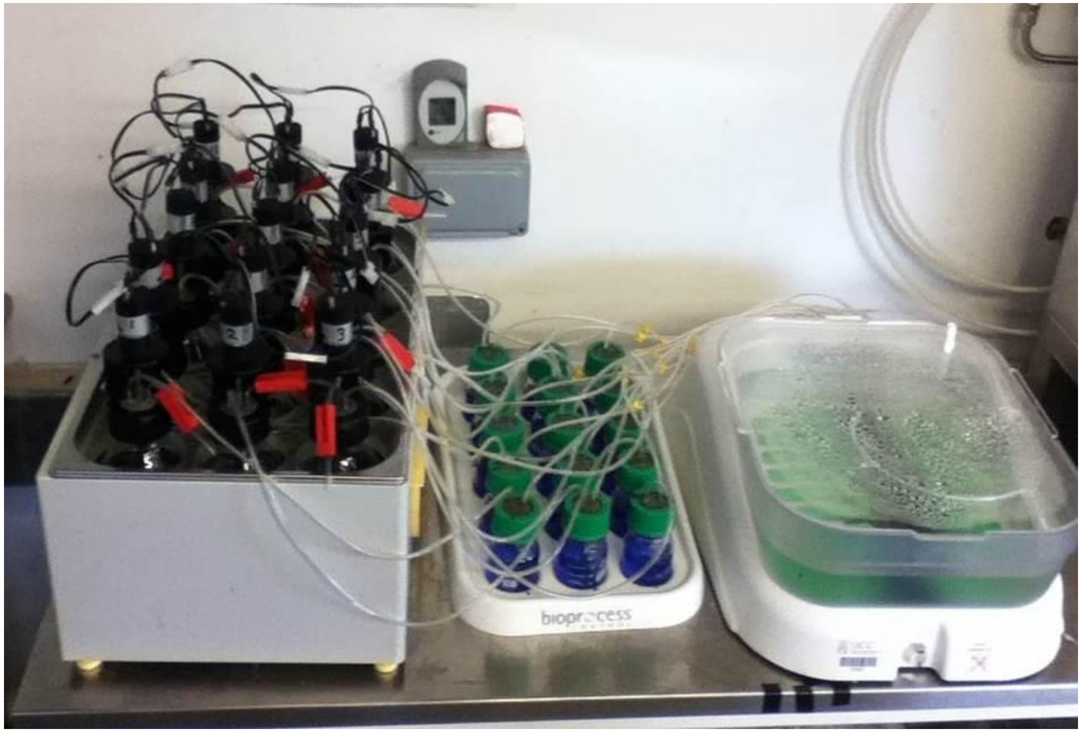
The potential for biomethane from grass and slurry to satisfy renewable energy targets

CrossMark

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
[c] Animal & Grassland Research and Innovation Centre, Teagasc, Grange, Dunsany, Co. Meath, Ireland

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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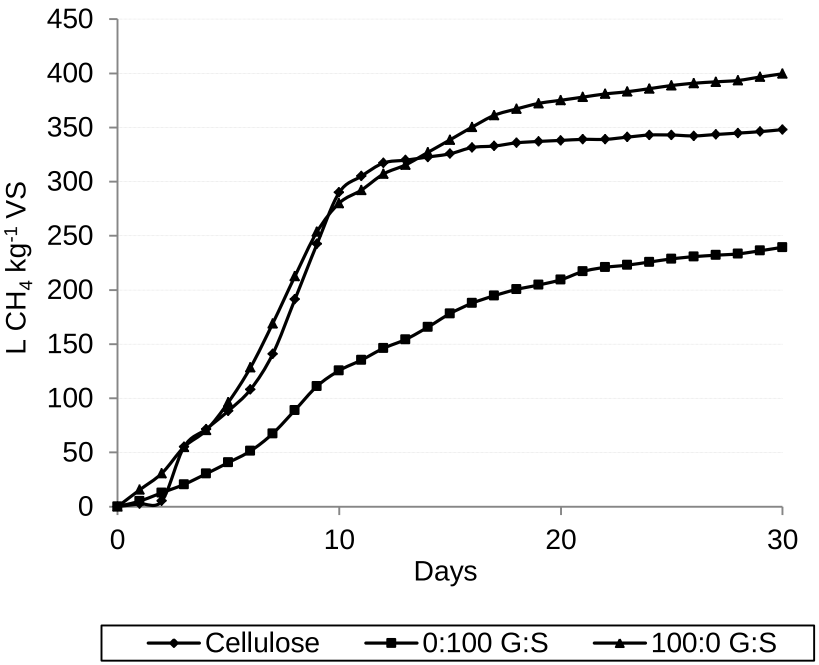
Specific methane yields for mono-digestion.



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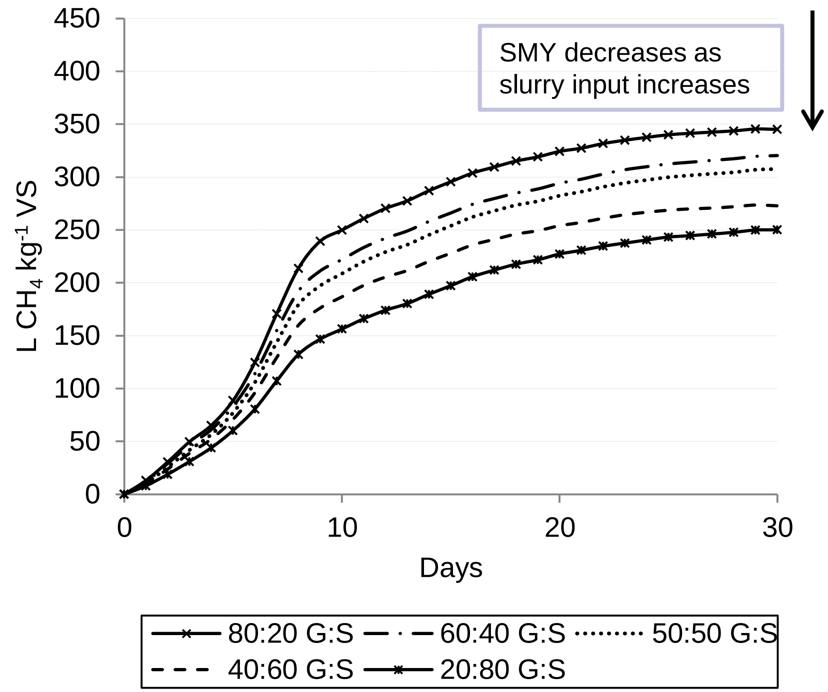

107 m^3 CH_4 t^{-1} Grass Silage v. 16 m^3 CH_4 t^{-1} Dairy Slurry

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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	[illegible]	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

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IEA Bioenergy

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Demand Driven Biogas

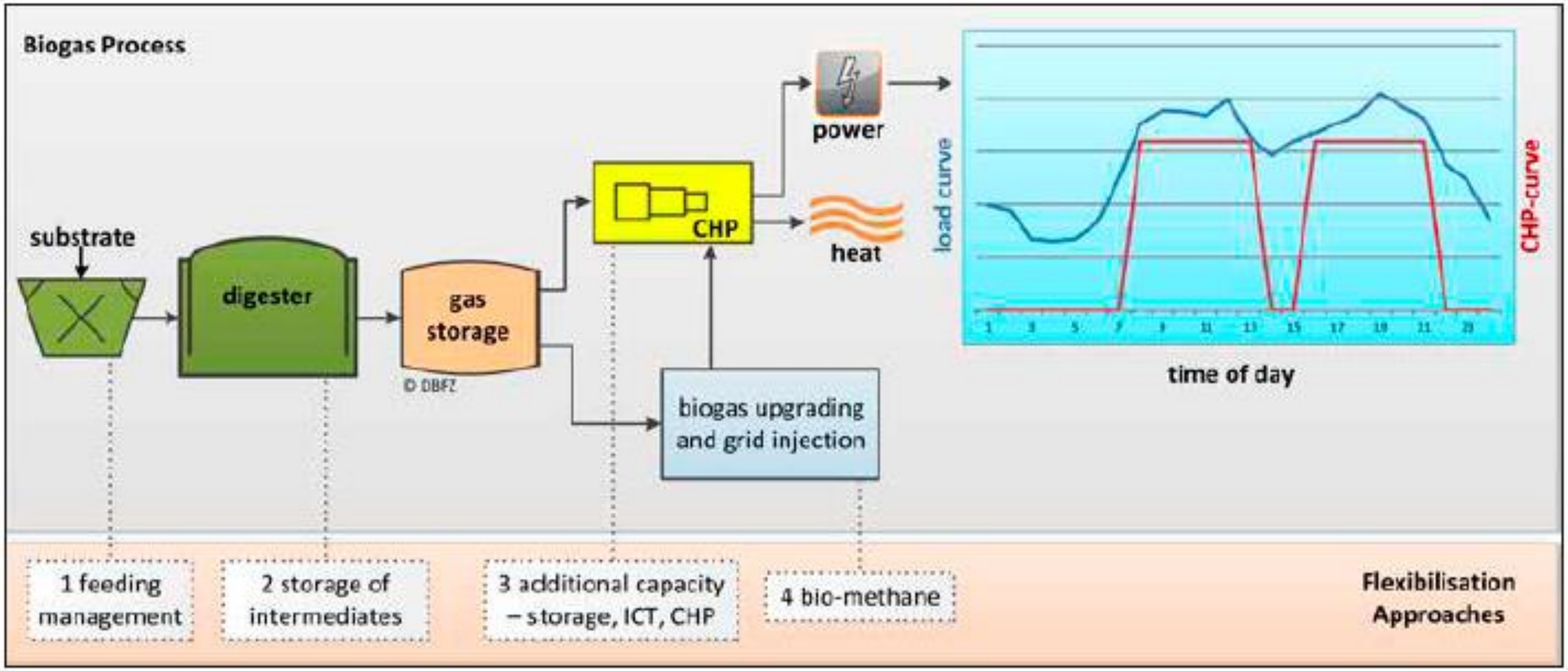

Figure 6: Approaches for biogas-based demand driven power production (Szarka et al, 2013)

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Intermittent feeding of biogas facility

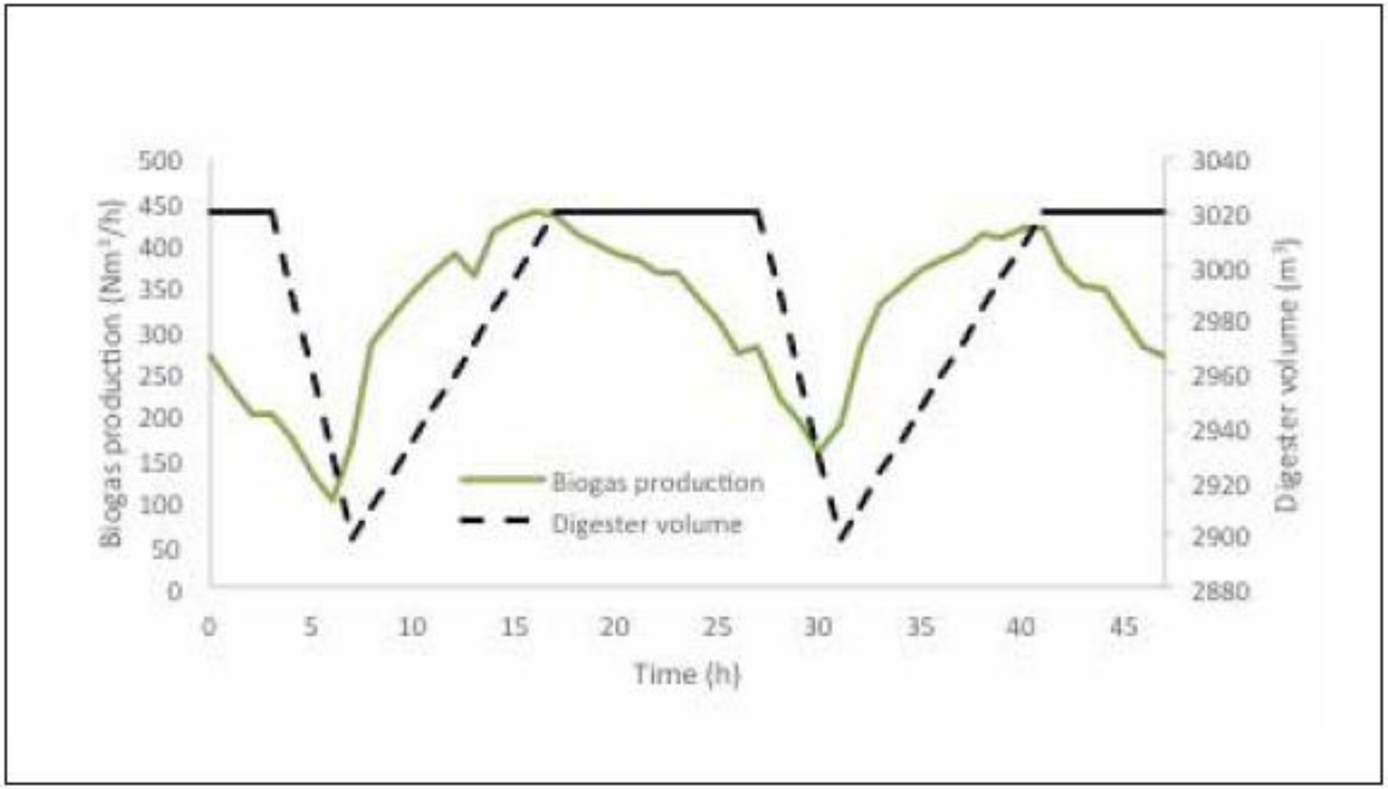

Figure 7: Biogas production and feed injection during a 48 hour period at Sobacken biogas plant in Borås. (Source: Borås Energi och Miljö)

10 hours of feeding
10 hours no feeding
4 hours of digestate discharge

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Effect of flexible biogas production on gas

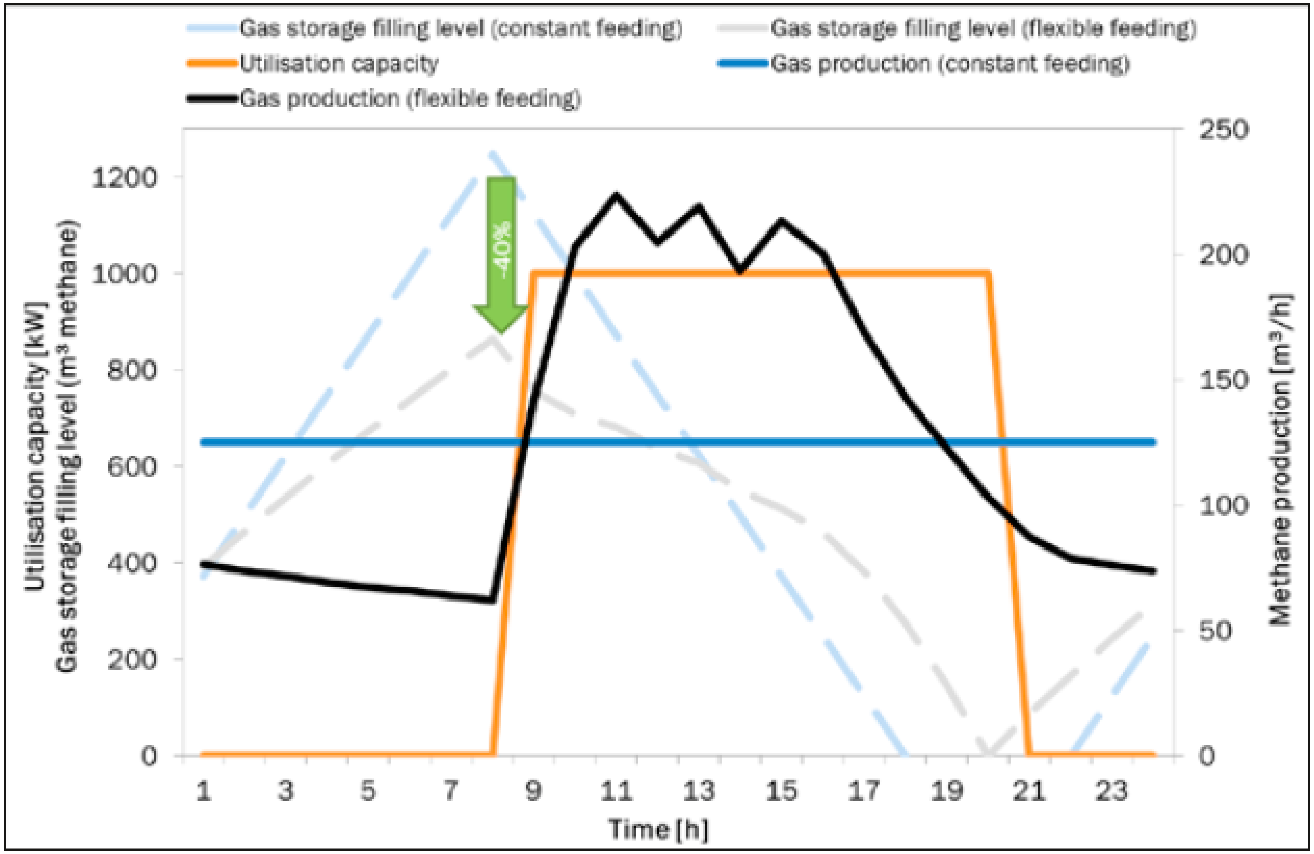

Figure 8: Cost reduction by means of lower gas storage need based on flexible biogas production (Jacobi et al, 2014a)

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Bioresource Technology 216 (2016) 238–249

Contents lists available at ScienceDirect

Bioresource Technology

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

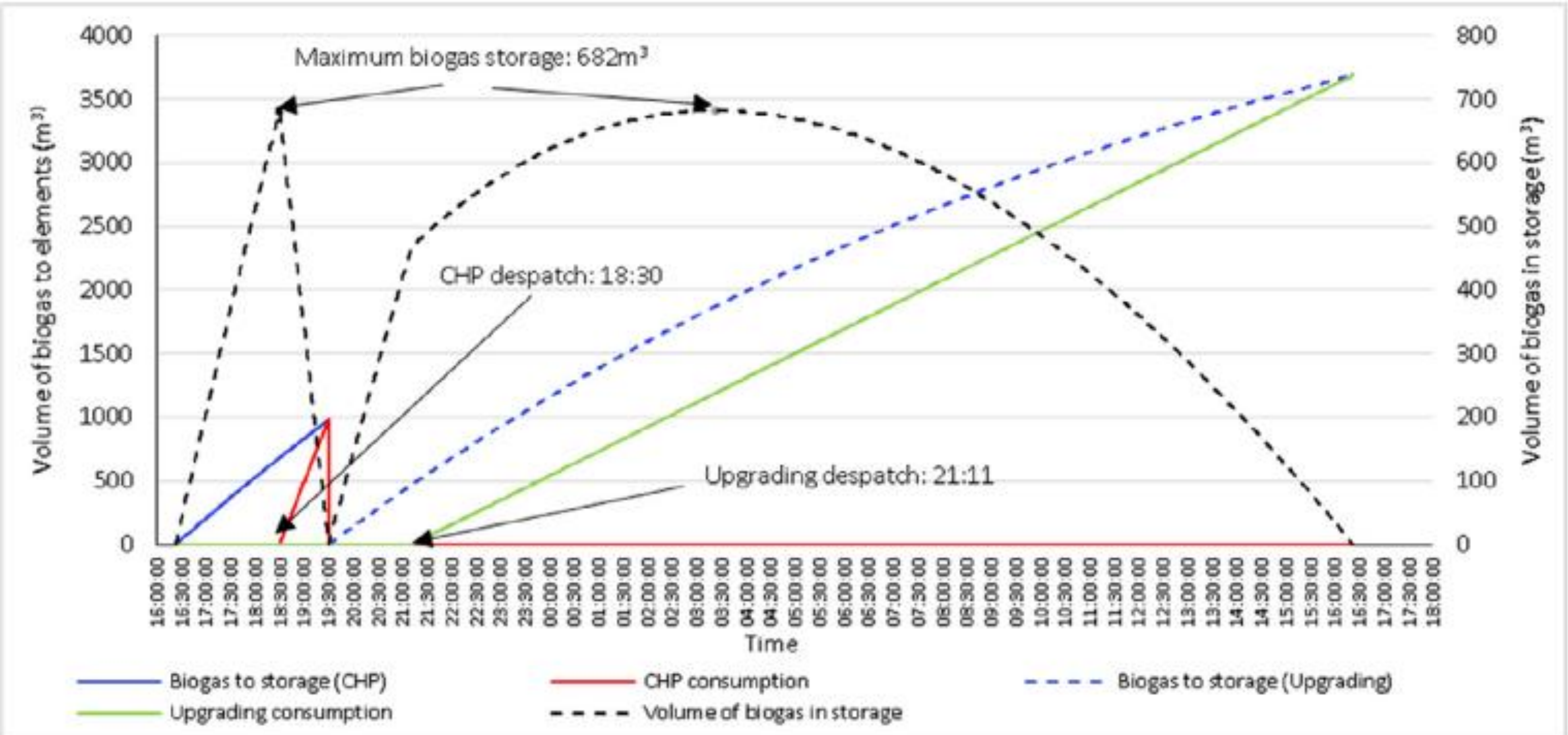
ELSEVIER

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

CrossMark

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

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



A theoretical grass silage digester that would produce 435 kWe in a continuous fed system was adapted to demand driven biogas. System required 187 min to produce sufficient methane to run a 2MWe combined heat and power (CHP) unit for 60 min. 21% of biogas was used in CHP and 79% was upgraded.

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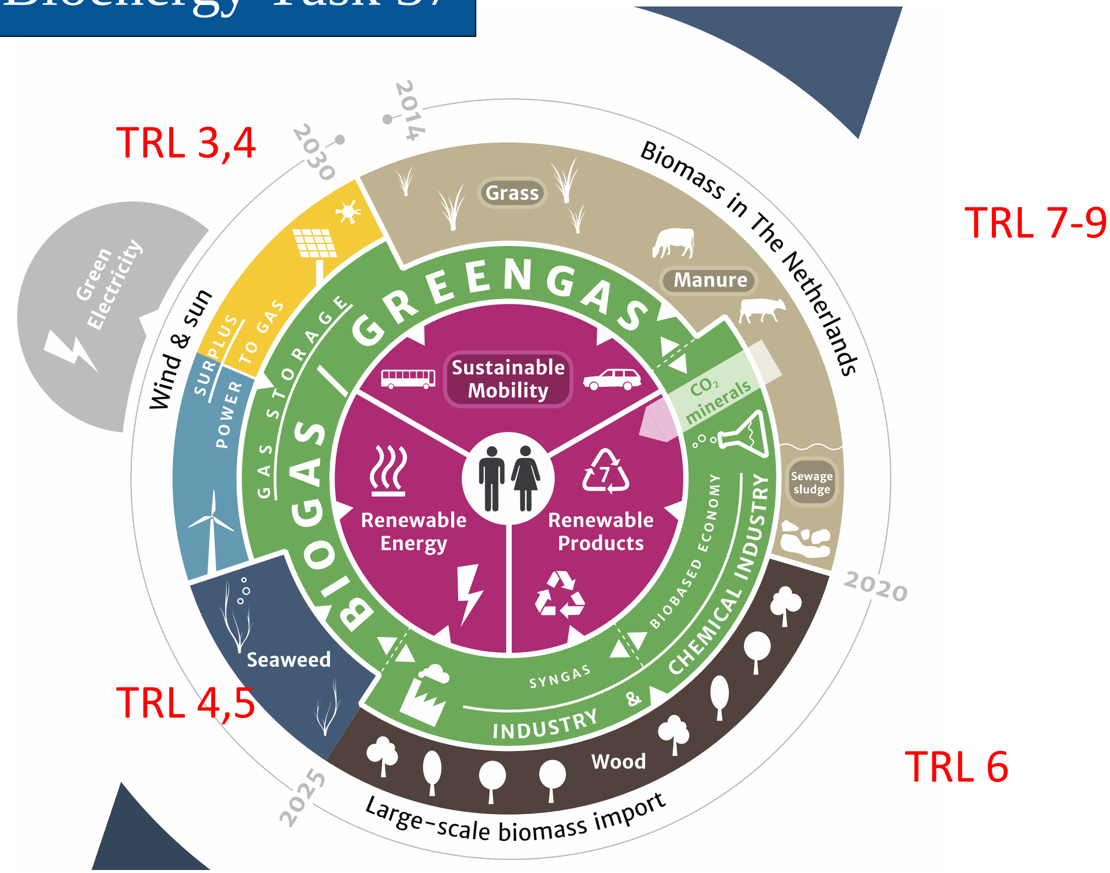

Third stage of Industry

Green Gas from seaweed

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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

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[a] Environmental Research Institute, University College Cork, Cork, Ireland

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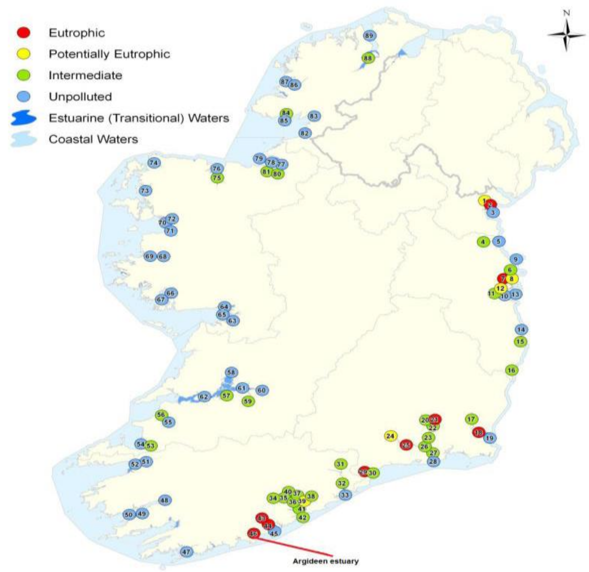
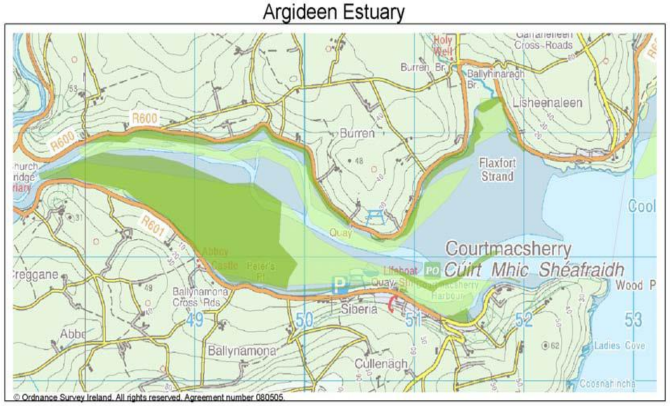


Argideen Estuary



Metric	EQR 2004	EQR 2006
Total % cover	0.30	0.37
Total affected area (ha)	0.37	0.39
Avg biomass AIH (gm^{-2})	0.24	0.39
Avg biomass affected area (gm^{-2})	0.13	0.21
% entrained	nr	nr
Final Score	**0.26**	**0.34**
WFD Classification	POOR	POOR

Provisional WFD classification for the Argideen Estuary using opportunistic algae growth.

IEA Bioenergy Task 37

- Green tides in eutrophic estuaries
- Ulva Lactuca has a C:N < 10 and 5% sulphur content..not pleasant
- 10,000 tonnes of sea lettuce arise in West Cork annually
- Sufficient to power 264 cars per annum

20m^3 CH_4 /t wet vs 100 m^3 CH_4/t dry

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Brown Seaweeds

- C/N ratio in range 20 – 30
- Low sulphur
- Suitable for mono-digestion

A. Laminaria digitata

B. Saccharina latissima

C. Ascophyllum nodosum

D. Fucus serratus

E. Fucus vesiculosus

F. Fucus spiralis

G. Ulva species

H. Palmaria palmate

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IEA Bioenergy Task 37

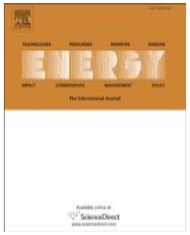
Energy xxx (2015) 1–9

Contents lists available at ScienceDirect

Energy

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

ELSEVIER



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*

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IEA Bioenergy Task 37

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 = SIM ATE). wt = wet weight.

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

A. Nodosum

S. Polyschides

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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

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

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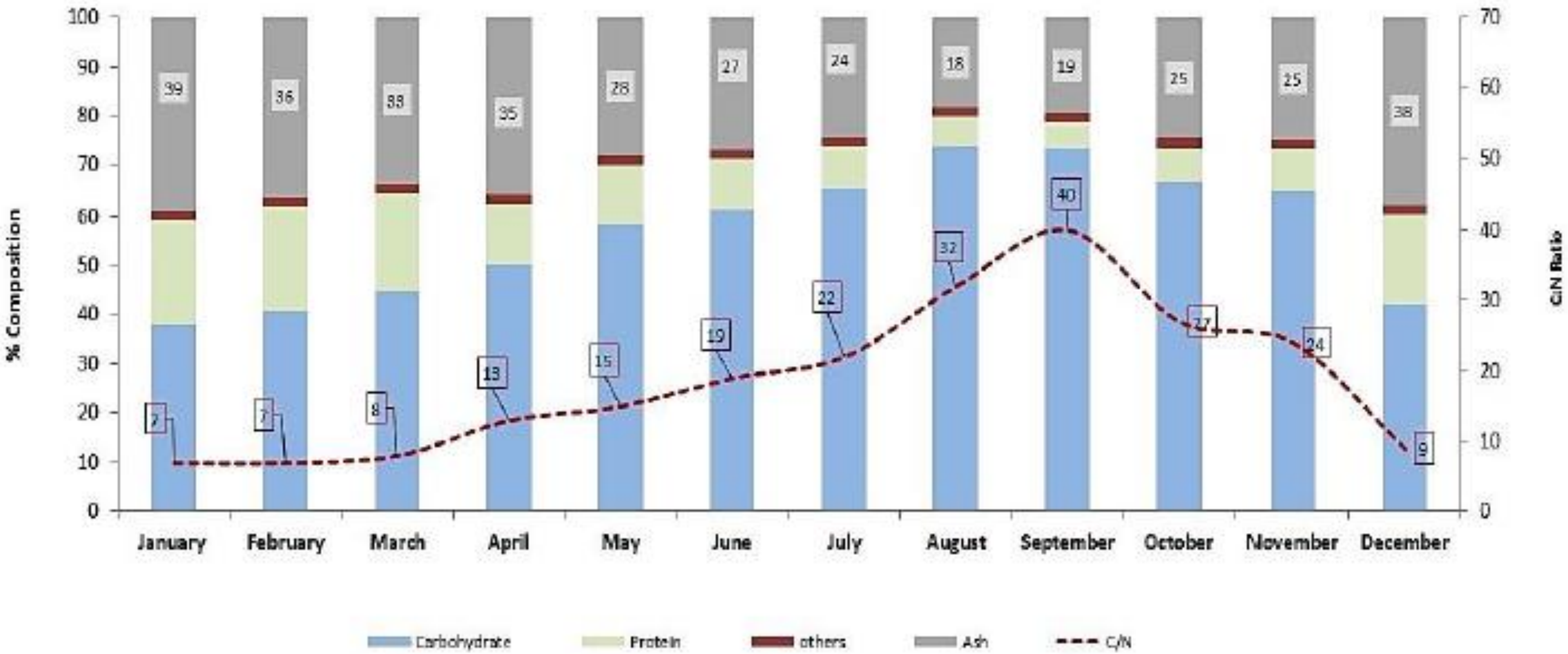
IEA Bioenergy Task 37

Seasonal Variation in composition of Laminaria Digitata

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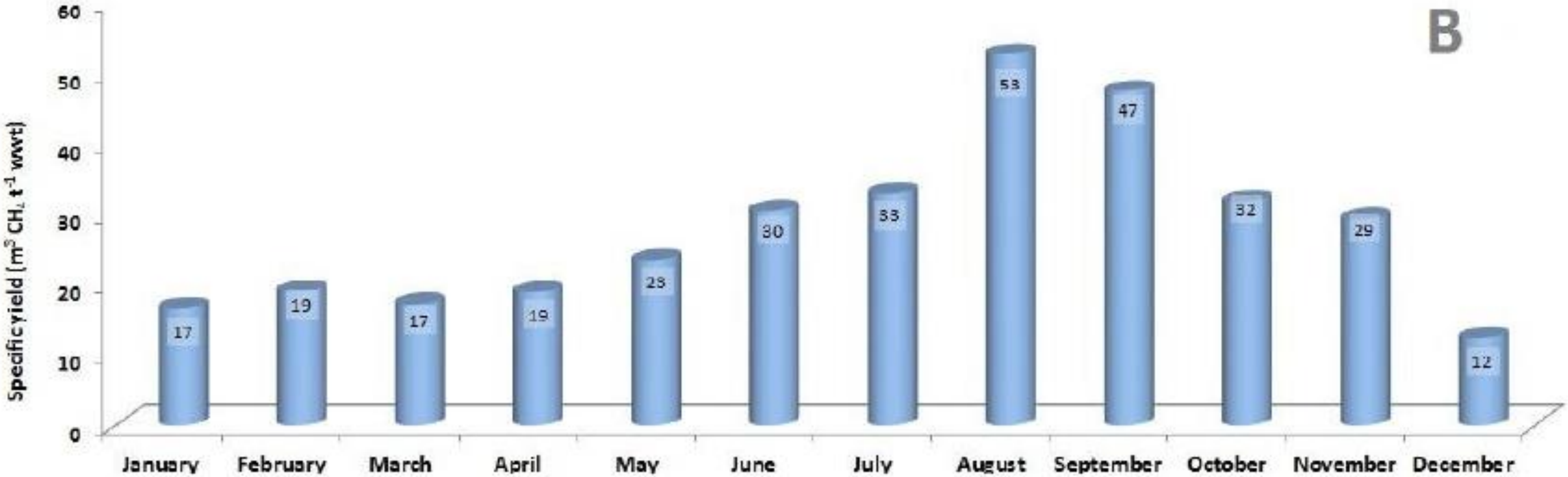
Renewable Energy

IEA Bioenergy Task 37

Seasonal Variation in biomethane yield from Laminaria Digitata



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IEA Bioenergy Task 37

Bioresource Technology 216 (2016) 219–226

Contents lists available at ScienceDirect

Bioresource Technology

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

ELSEVIER

Seasonal variation of chemical composition and biomethane production from the brown seaweed *Ascophyllum nodosum*

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

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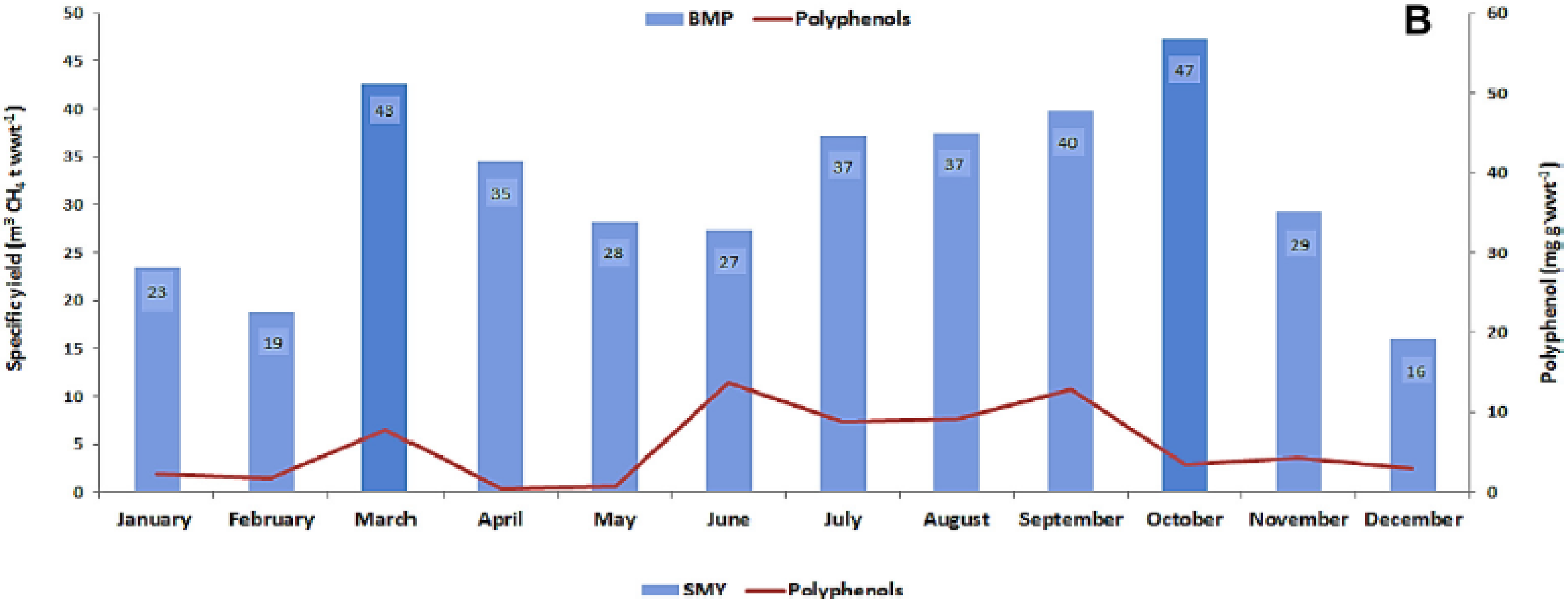
Seasonal Variation in A. *nodosum*



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IEA Bioenergy Task 37

Bioresource Technology 196 (2015) 301–313

Contents lists available at ScienceDirect

Bioresource Technology

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

ELSEVIER

Ensiling of seaweed for a seaweed biofuel industry

CrossMark

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

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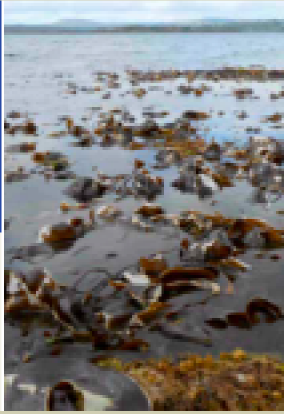

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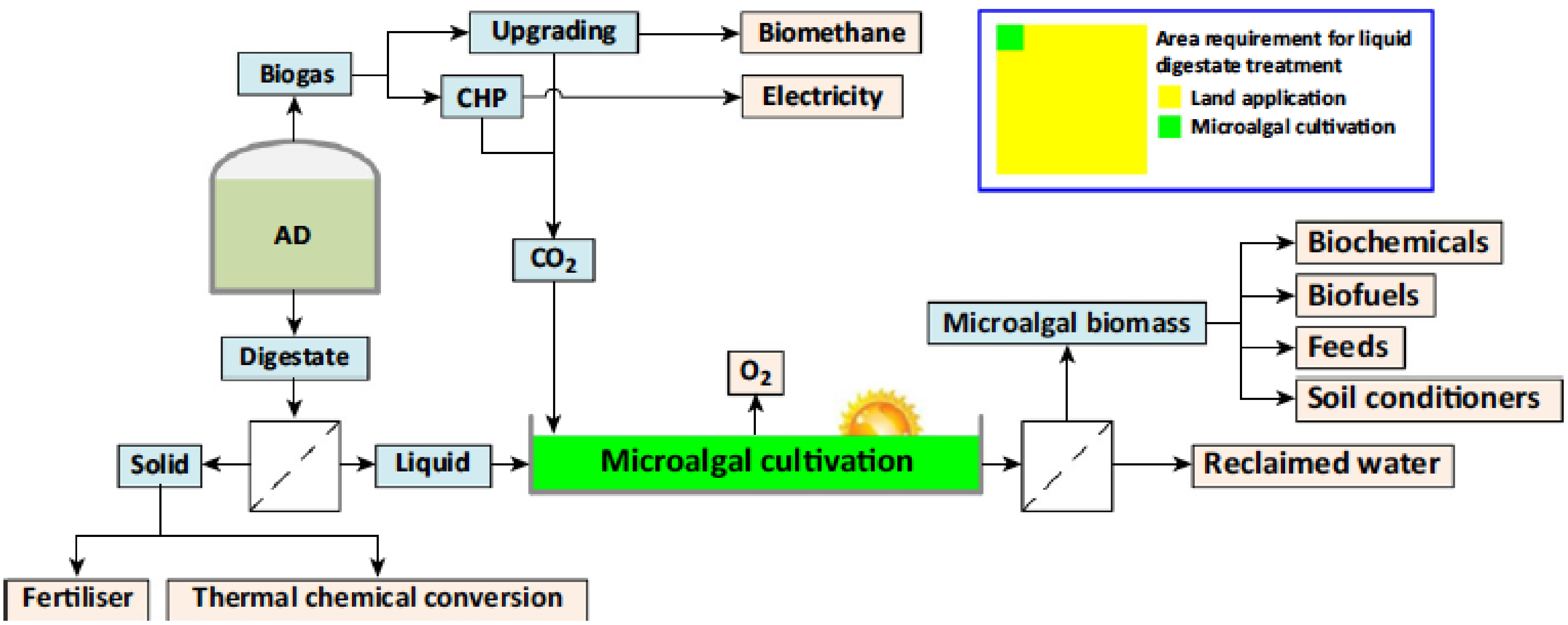
Opinion

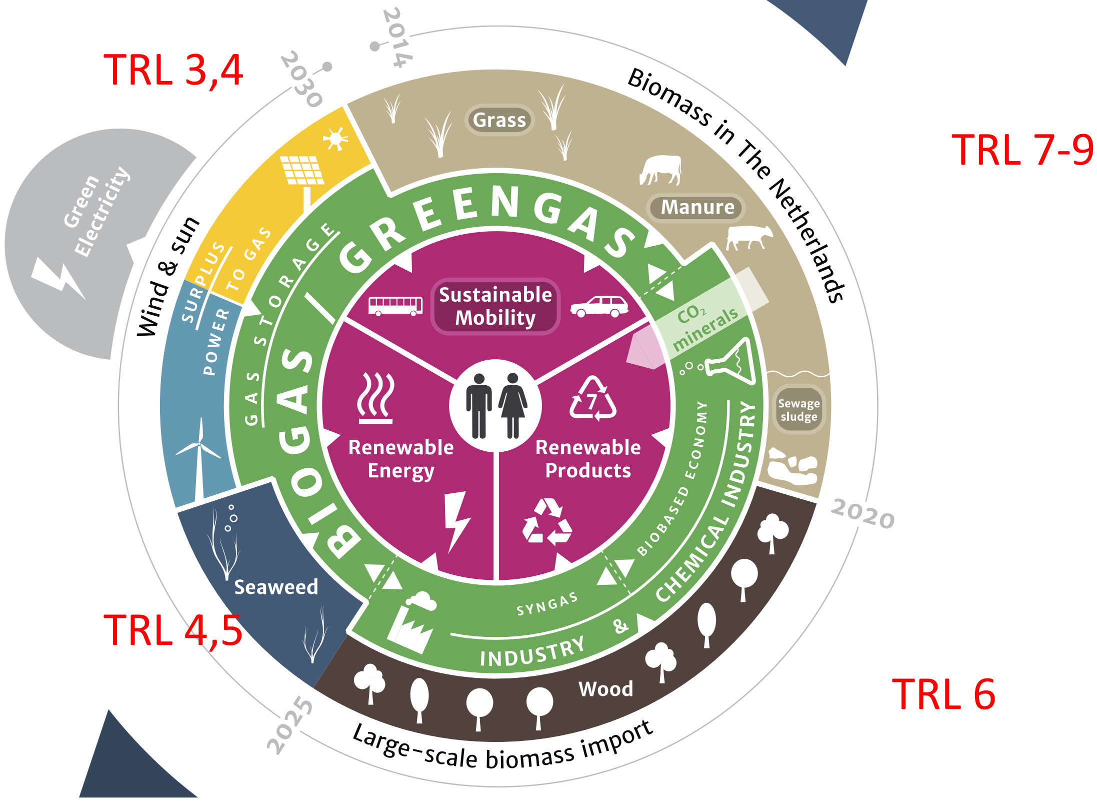
Microalgal Cultivation in Treating Liquid Digestate from Biogas Systems

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



Fourth stage of Industry

Green Gas from electricity



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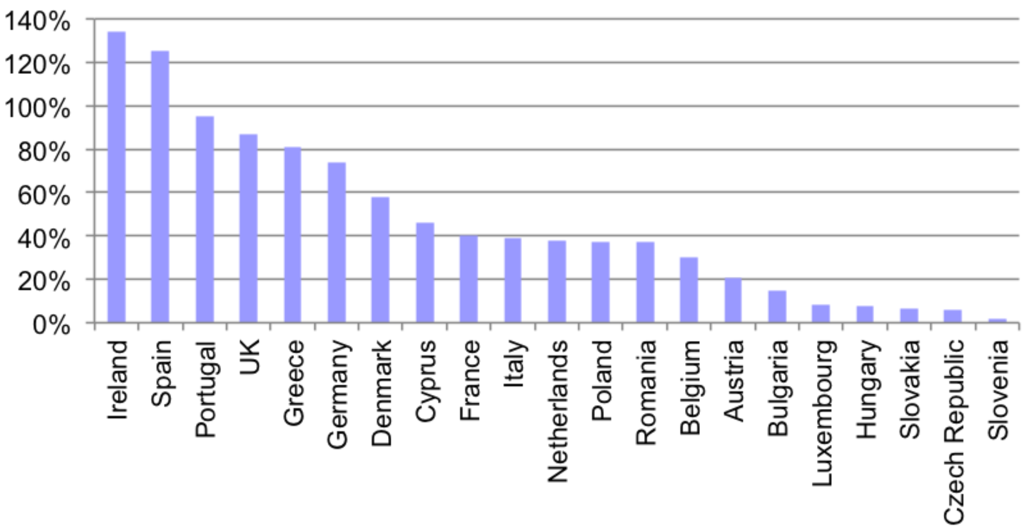
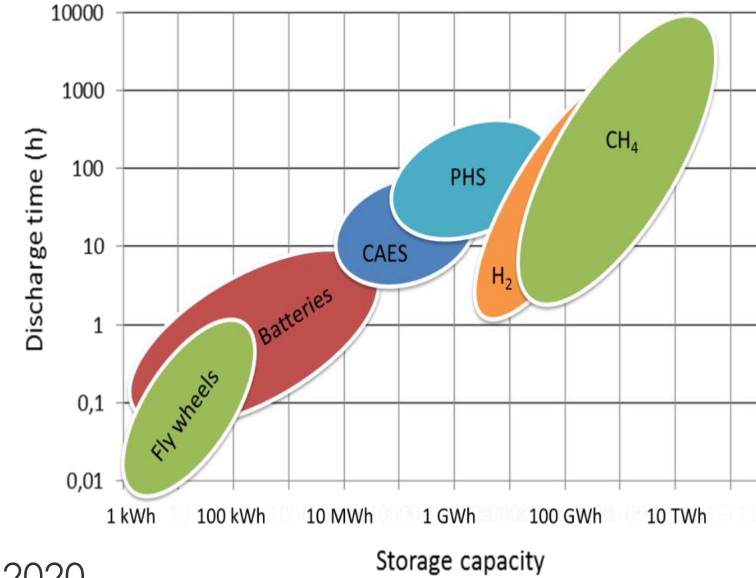
Curtailment and storage of variable renewable electricity





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)

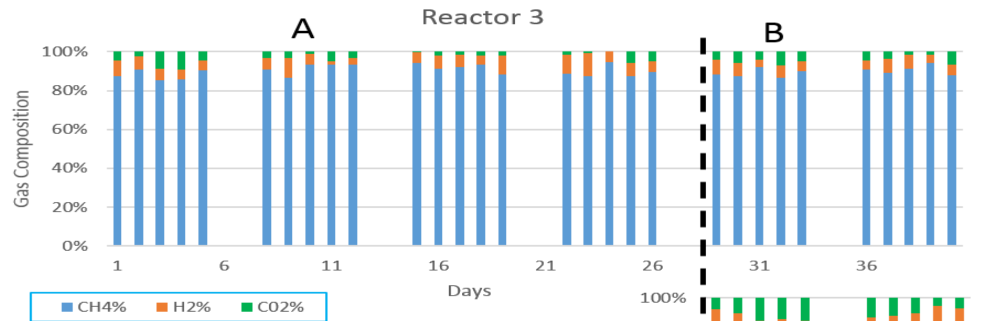
Electrolysis: Electricity converted to H2 at 70- 90% η

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

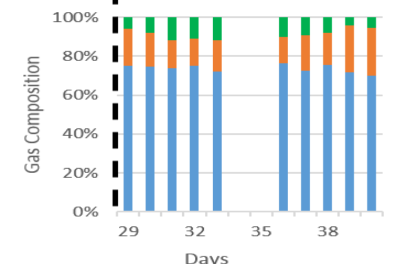
Overall: 55 - 80% η

IEA Bioenergy Task 37

Amita Jacob Guneratnam, Eoin Ahern, Ao Xia, Jerry Murphy (2016) "A Study of the Performance of a Thermophilic Biological Methanation System" In Preparation



A: Steady state
B: 18 hour measurement also done



18 hour gas data

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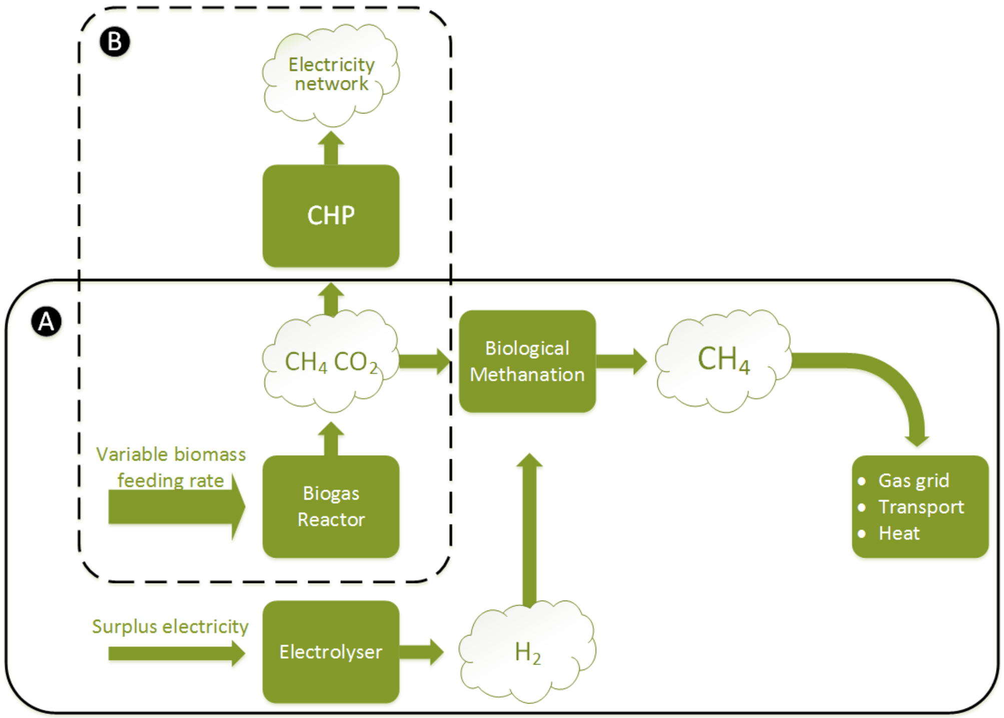
Centre for Marine and Renewable Energy

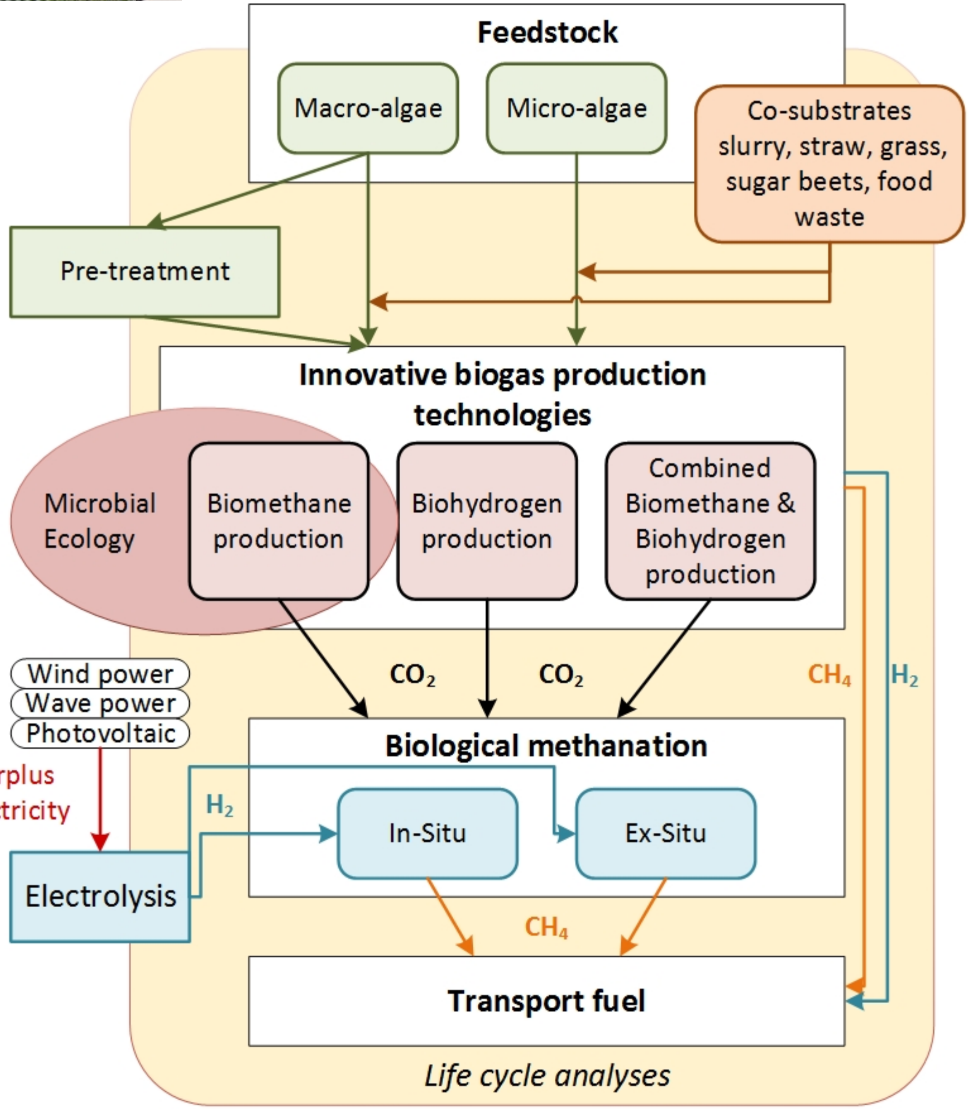
Gaseous biofuel from non-biological origin

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

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



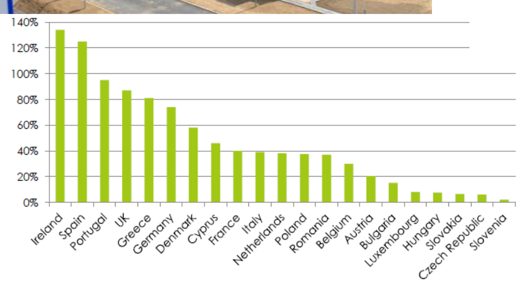
Source of CO2 from biogas:
Mix biogas (50% CH4 and 50% CO2) with H2; generate double the CH4 (1 mol CO2 generates 1 mol CH4).



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
CO_2
CO_2
CH_4
H_2
Wind power
Wave power
Photovoltaic
Surplus electricity
Biological methanation
H_2
In-Situ
Ex-Situ
Electrolysis
CH_4
Transport fuel
Life cycle analyses

Food Waste

CCG 656



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

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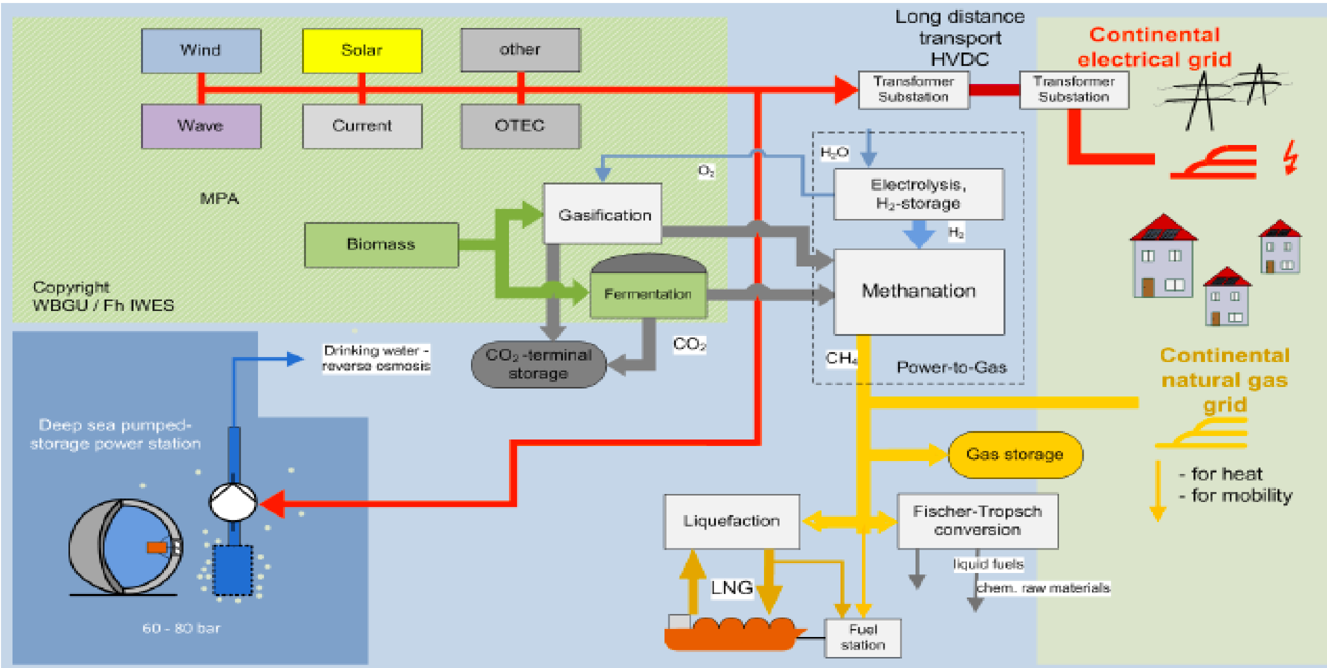
Integrated system approach: marine energy, storage and fuels



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

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MaREI
Centre for Marine and Renewable Energy

ERI
ENVIRONMENTAL RESEARCH INSTITUTE
UNIVERSITY COLLEGE CORK

UCC
Coláiste na hOllscoile Corcaigh, Éire
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