IEA Bioenergy Task 37

IEA Bioenergy Task 37, 6 April 2017, Vlijmen, The Netherlands

# Task 37 Work Programme and Green Gas

**Prof Jerry D Murphy**

Task Leader International Energy Agency (IEA) Energy from Biogas, Director of MaREI (Centre for Marine and Renewable Energy), University College Cork, Ireland

MaREI Centre for Marine and Renewable Energy

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and energy reso
power of resear

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NOVEL MATER
OBSERVATION & MONITO
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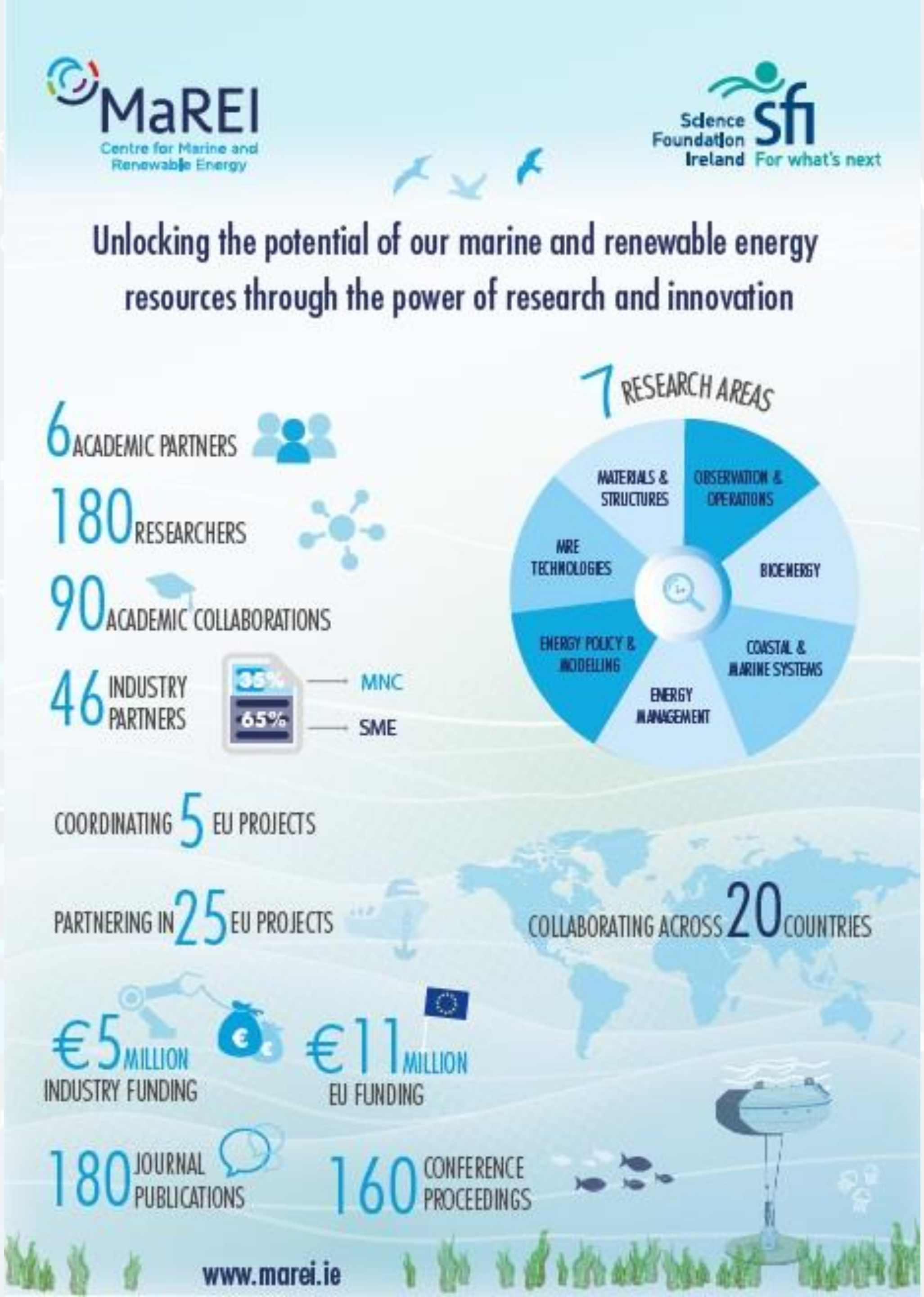
AQUACULTU
GREEN GAS
ENERGY STORAGE
& MARINE MANAGEMENT
DEVICE DESIGN & TESTING
LING
BIOFUELS

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IEA Bioenergy Task 37

# 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 |

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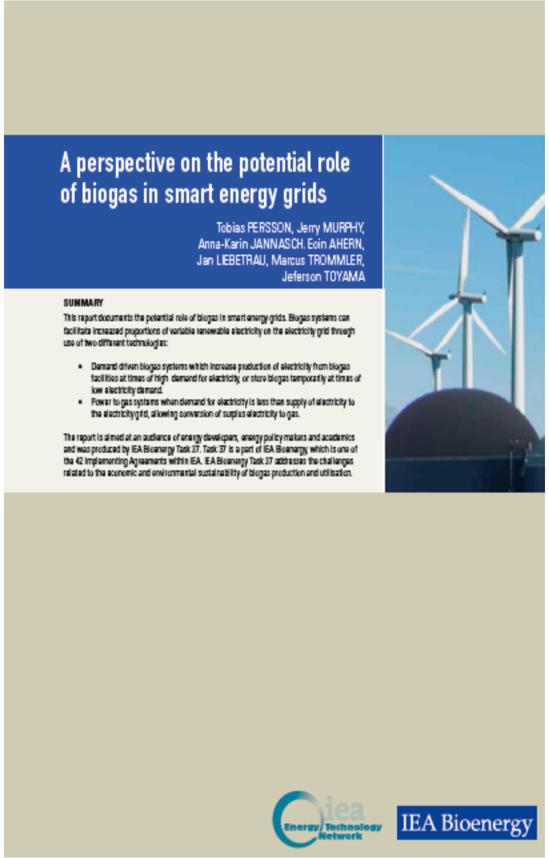

A perspective on the potential role of biogas in smart energy grids

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 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.

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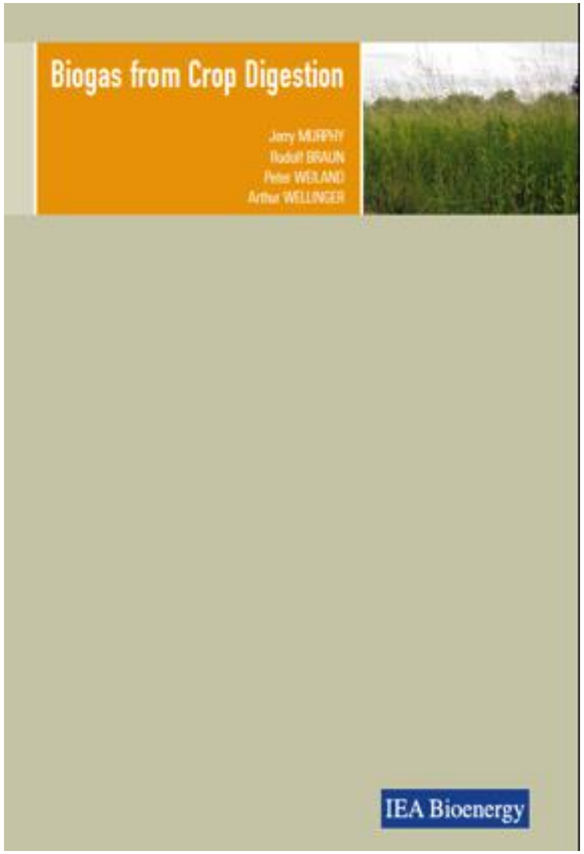

Biogas from Crop Digestion

Jerry MURPHY
Rudolf BRAUN
Peter WEILAND
Arthur WELLINGER

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[http://task37.ieabioenergy.com/technical-brochures.html](http://task37.ieabioenergy.com/technical-brochures.html)

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# 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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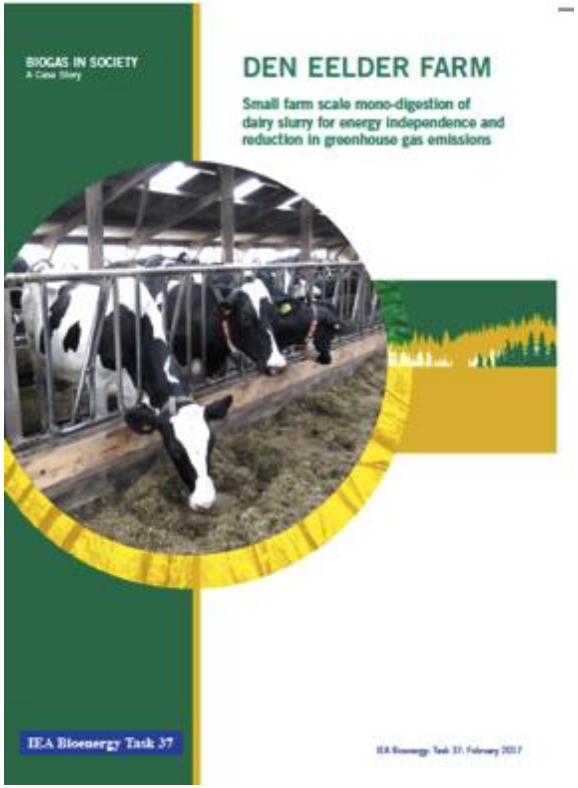
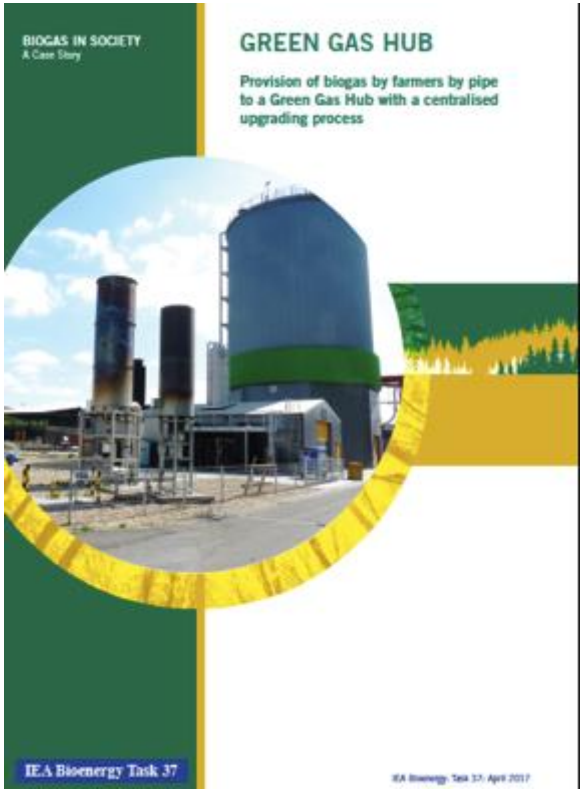
# Case Studies 2016 - 2018




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

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## Green Gas

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

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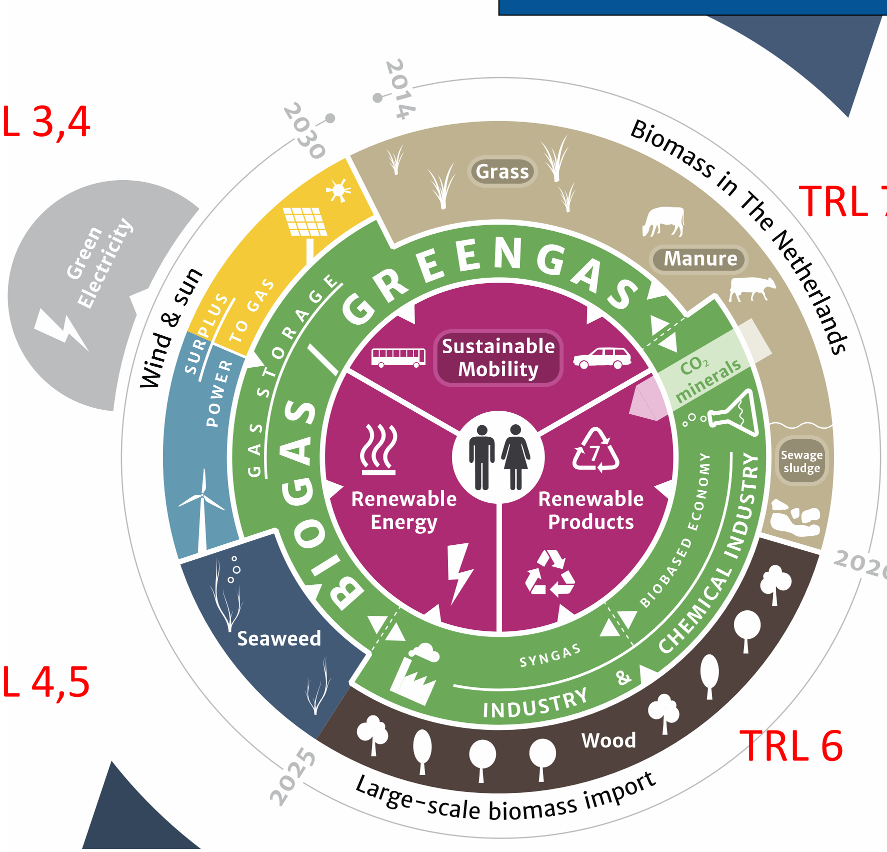


## Initiation of Industry

Green Gas from residues, slurries and grass

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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

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# 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

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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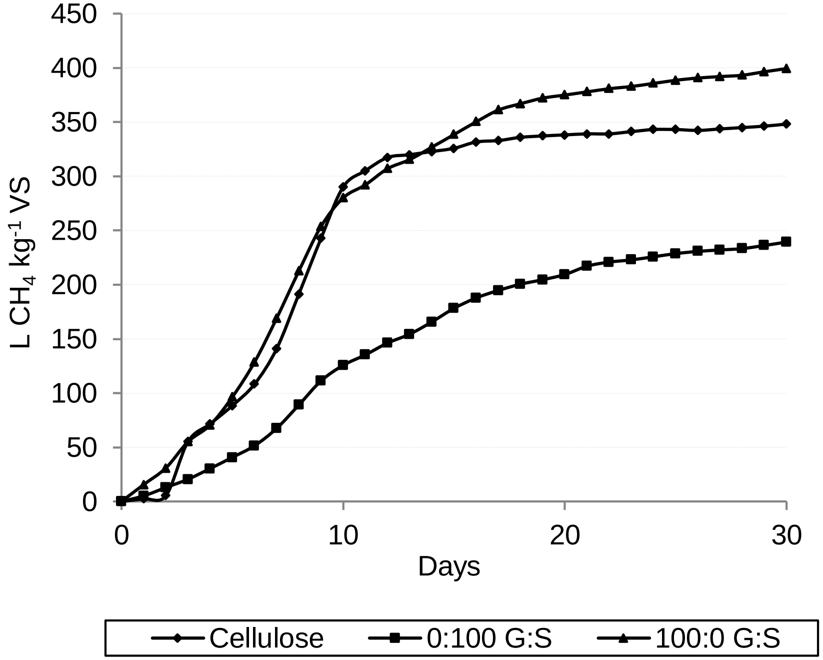
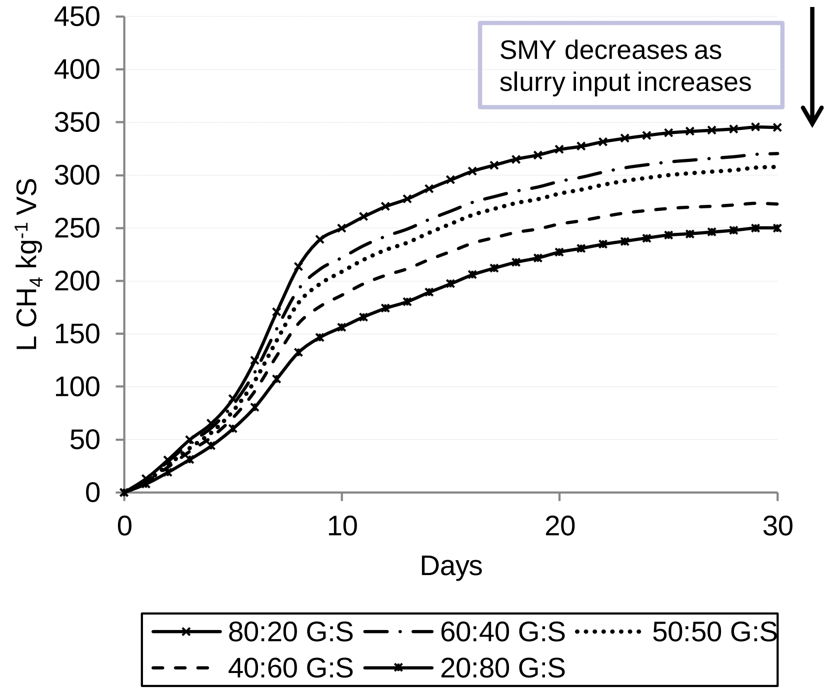
Specific methane yields for mono-digestion.




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

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**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**

# Scale of Grass Biogas industry

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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

CrossMark

Bioresource Technology 172 (2014) 349–355

Contents lists available at ScienceDirect

Bioresource Technology

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

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

CrossMark

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

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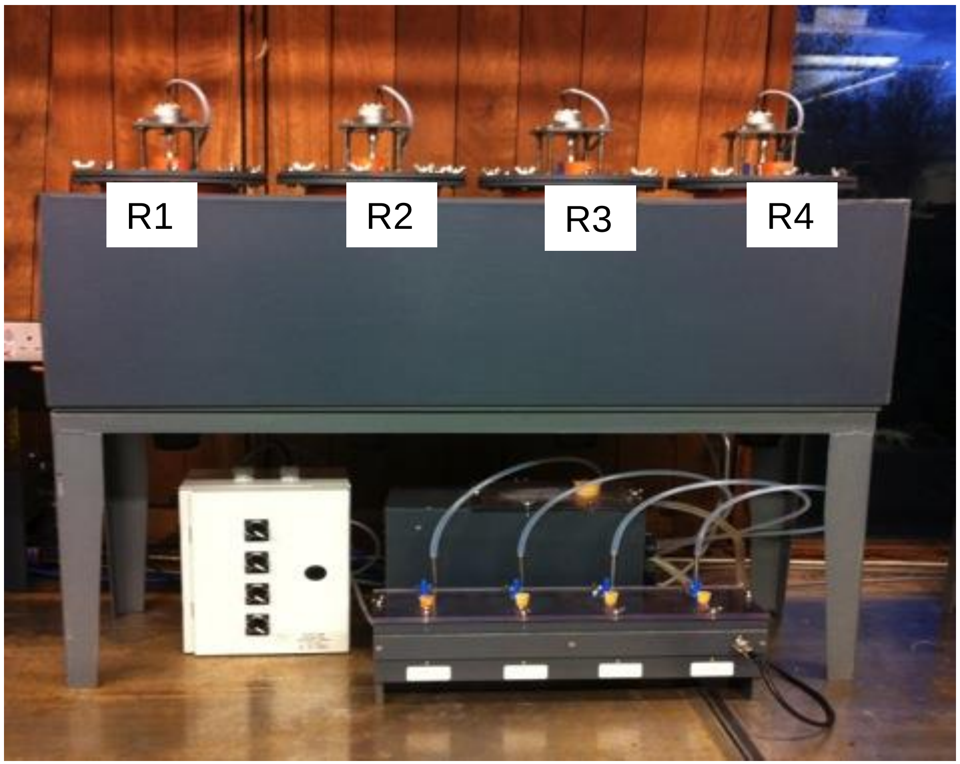
# Continuous digestion of grass and slurry

Higher Grass Silage Input

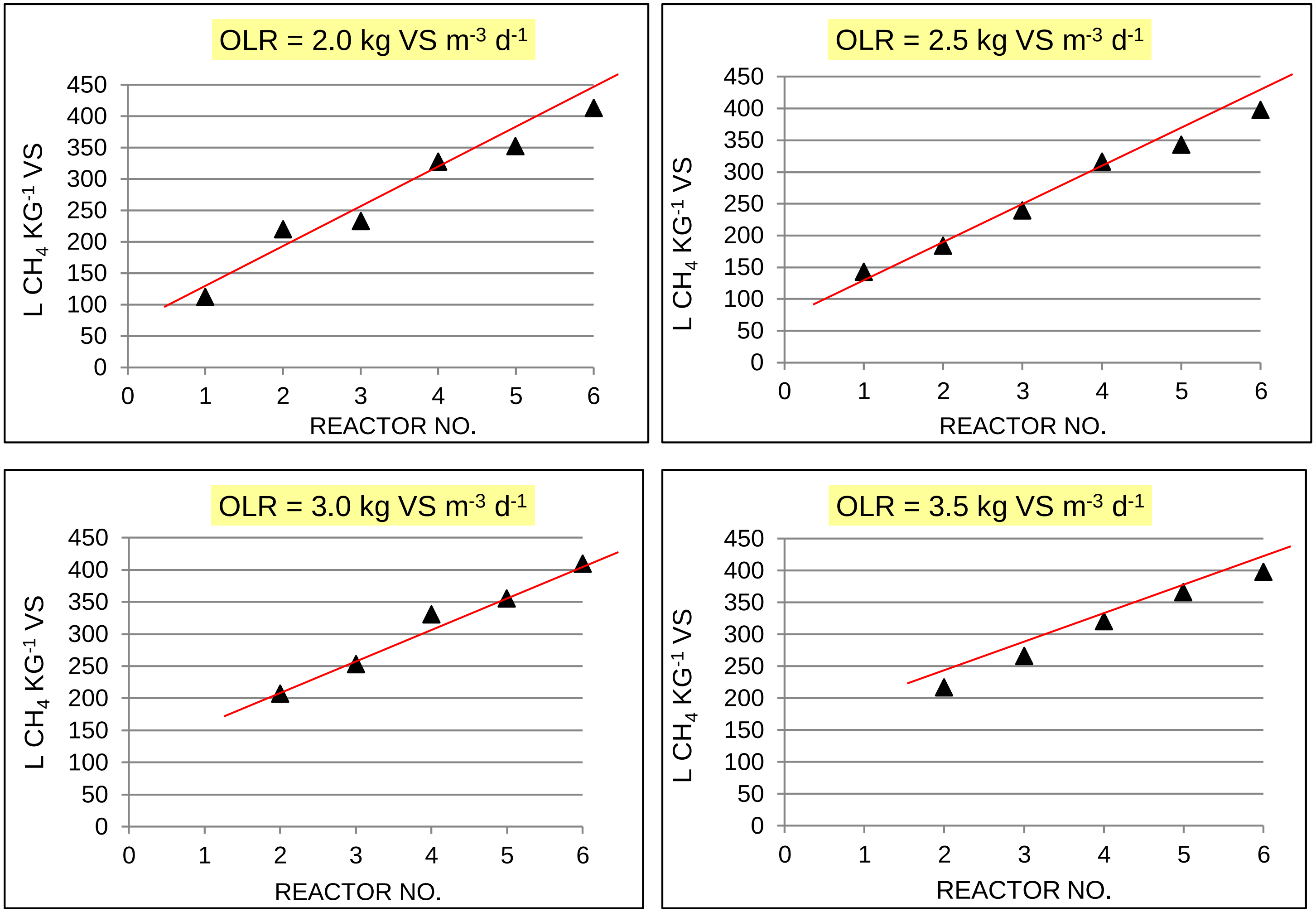



+ R5 & R6

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

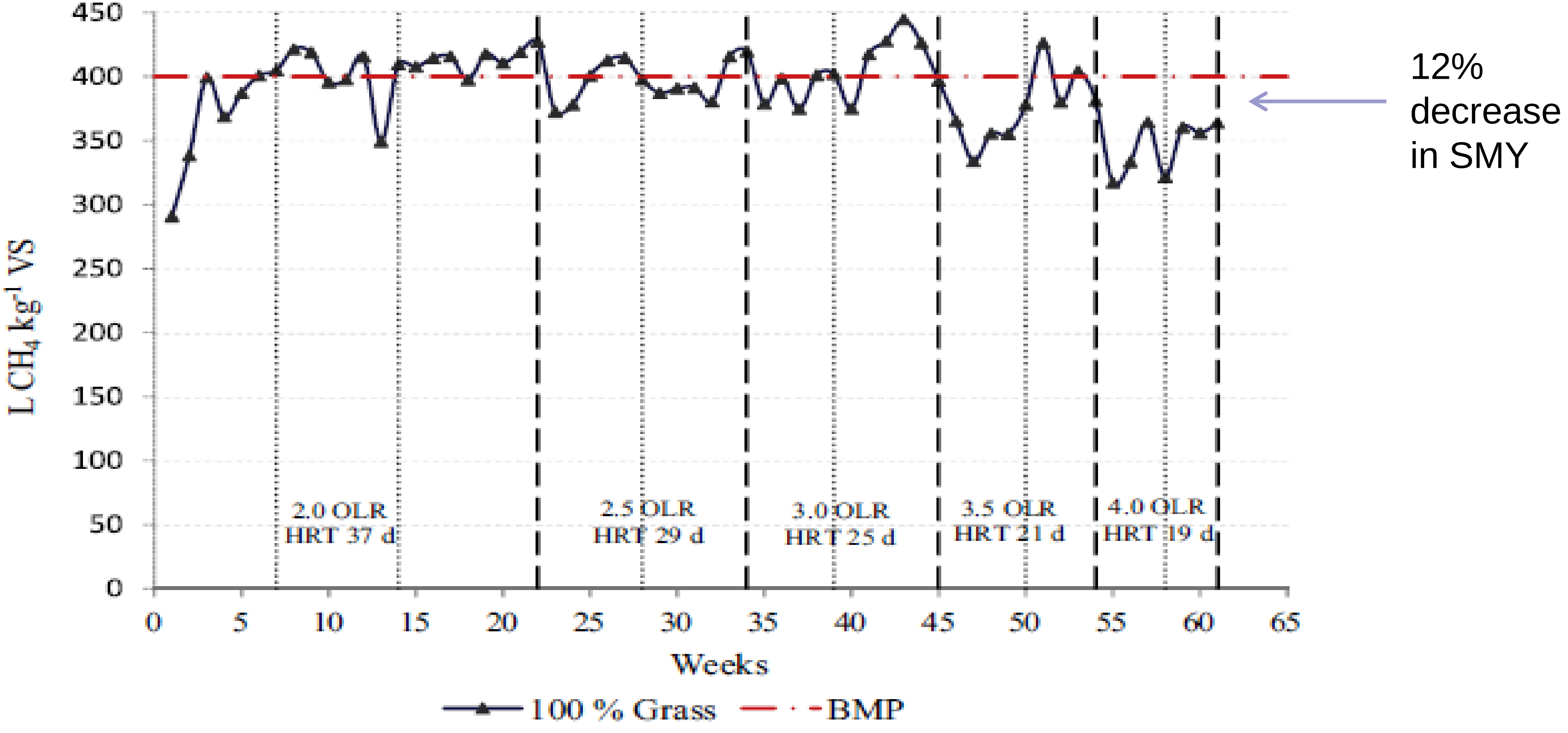




Fig. 1. Specific methane yield for R6 (mono-digestion of grass).

# Reduction in yield of mono-digestion at high OLR

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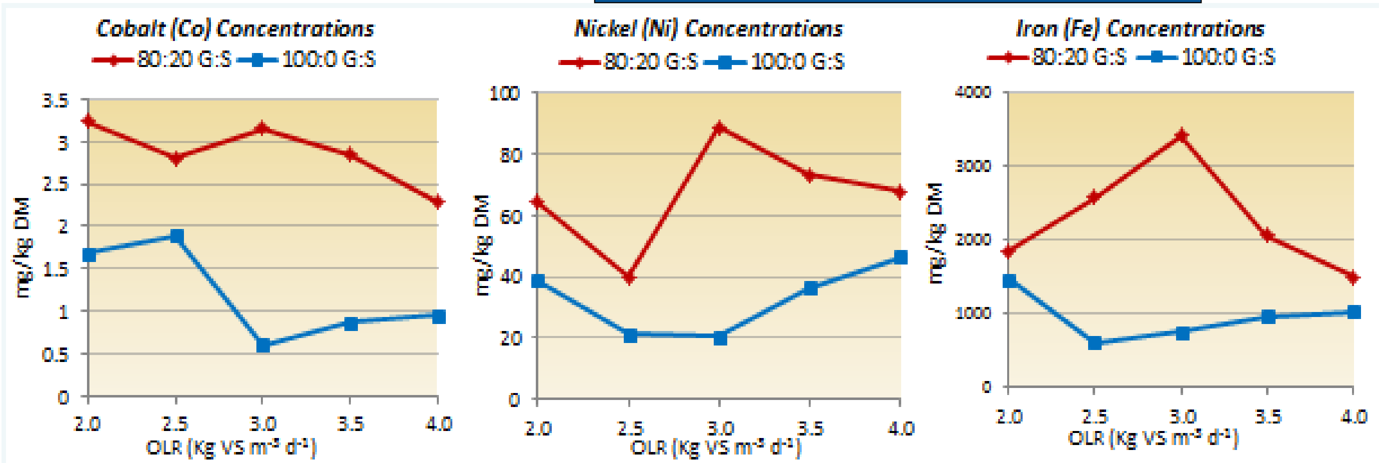


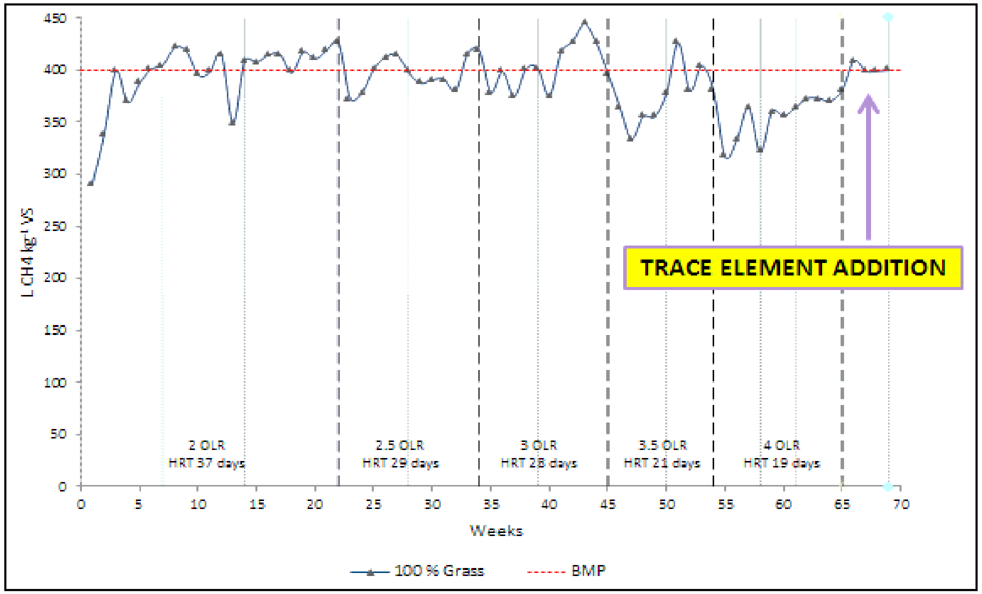


# Trace element analysis

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Bioresource Technology 216 (2016) 238–249

Contents lists available at ScienceDirect

Bioresource Technology

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

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

Tobias PERSSON, Jerry MURPHY,
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Jan LIEBETRAU, Marcus TROMMLER,
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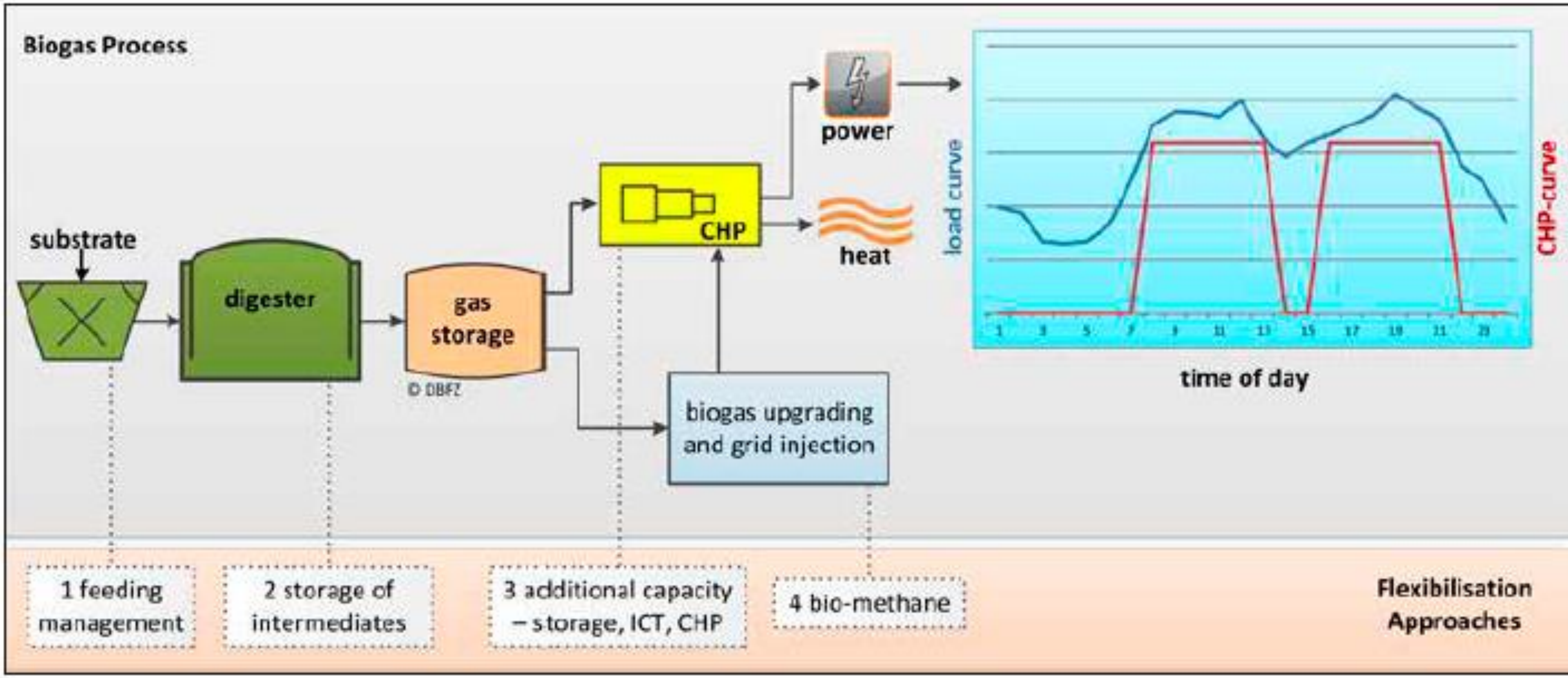


**Figure 6:** Approaches for biogas-based demand driven power production (Szarka et al, 2013)

# Demand Driven Biogas

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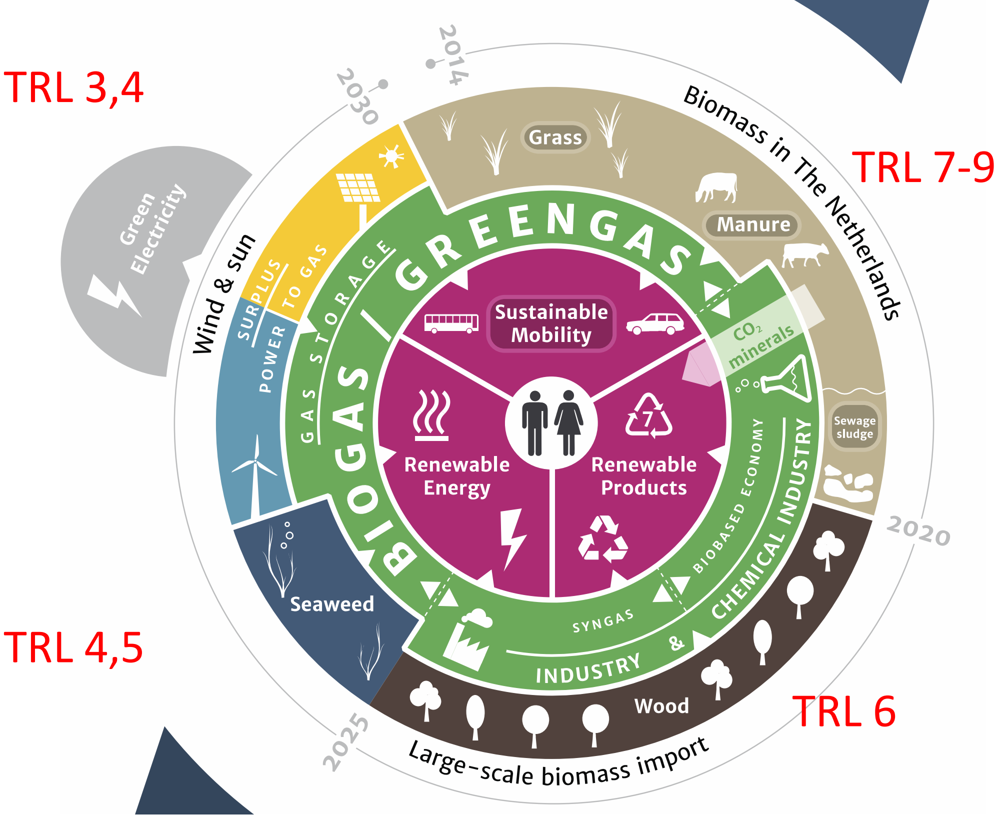


## Second stage of Industry

Green Gas from gasification of woody crops

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# Gothenburg Biomass Gasification Project (GoBiGas)

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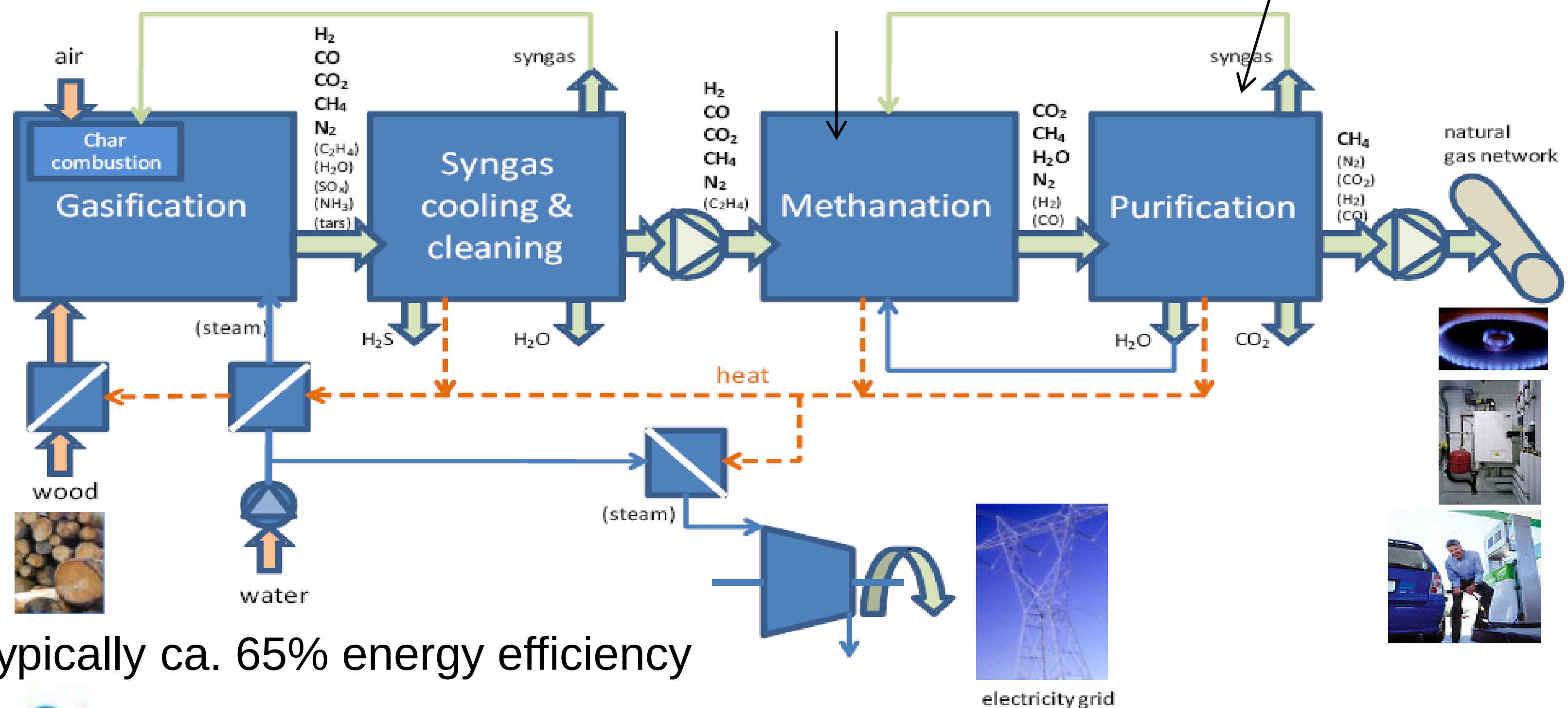
# Thermal production of Biomethane

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

Gas upgrading
Removal of CO2




Typically ca. 65% energy efficiency

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# IEA Bioenergy Task 37

Applied Energy 108 (2013) 158–167

Contents lists available at SciVerse ScienceDirect

Applied Energy

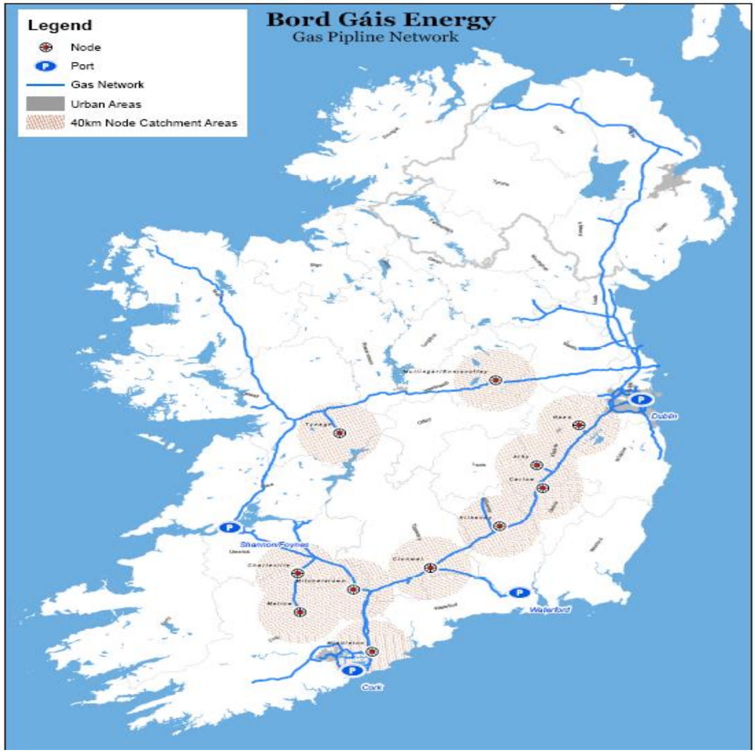
journal homepage: www.elsevier.com/locate/apenergy

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

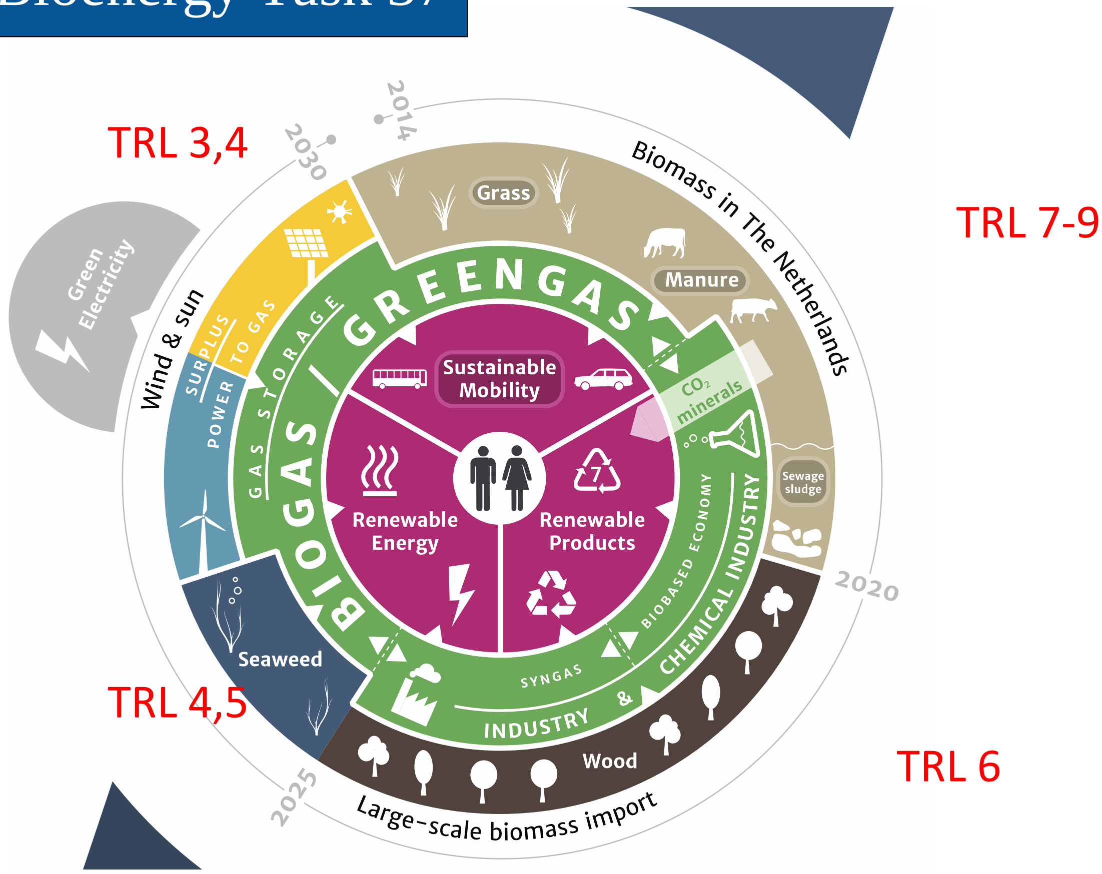
Cathal Gallagher[a], Jerry D. Murphy[b,c,*]

| | |
|---|---|
| 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% |

Compare with 170 digesters



# IEA Bioenergy Task 37




## Third stage of Industry

Green Gas from seaweed

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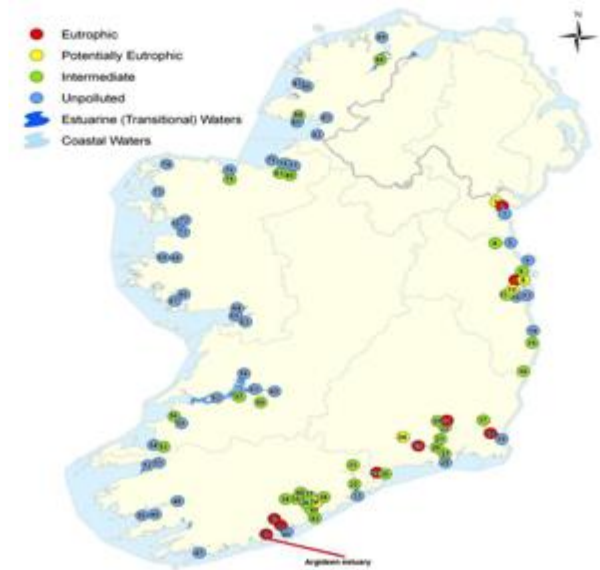
Waste Management 33 (2013) 2425–2433

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


# IEA Bioenergy Task 37

Bioresource Technology 209 (2016) 213–219

Contents lists available at ScienceDirect

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Bioresource Technology

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

## 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

Bioresource Technology 216 (2016) 219–226

Contents lists available at ScienceDirect

ELSEVIER

Bioresource Technology

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

## 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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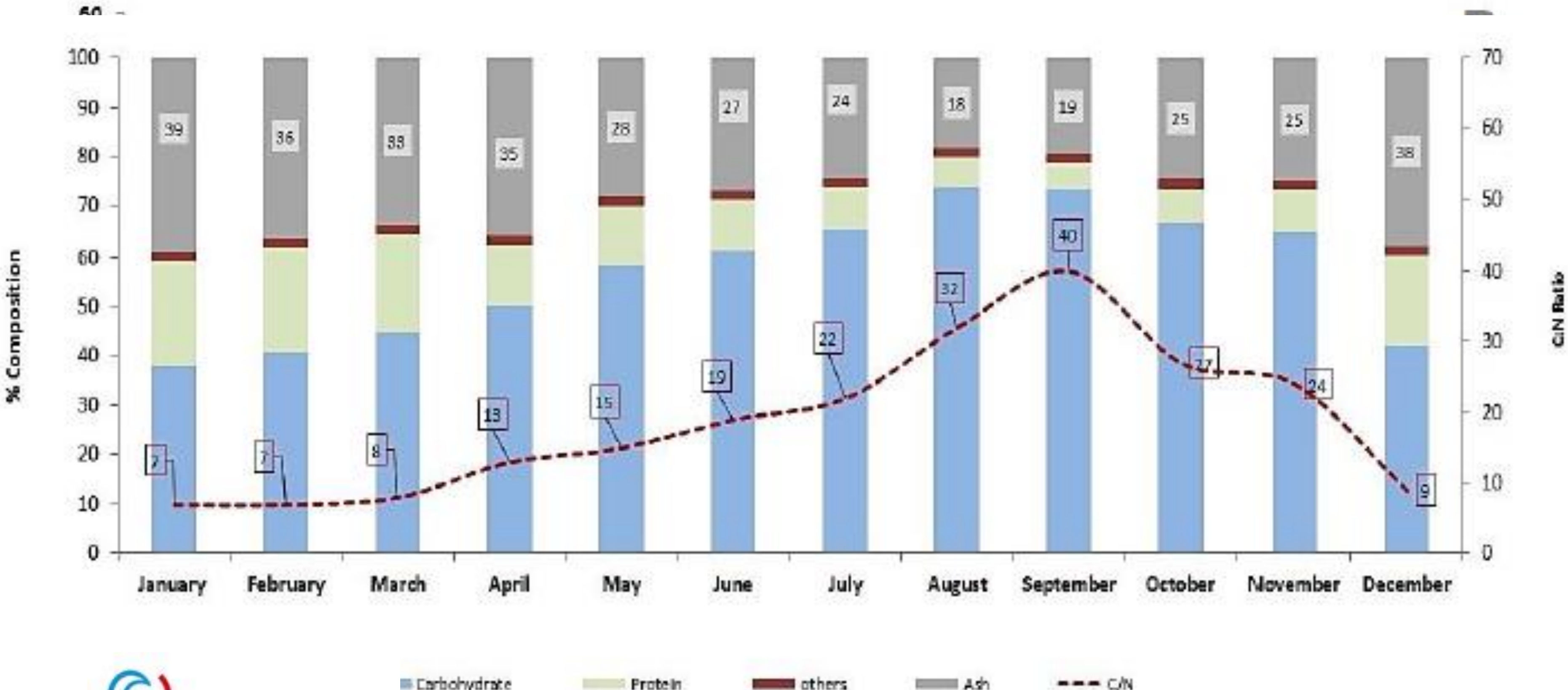
# Seasonal Variation in composition of Laminaria Digitata

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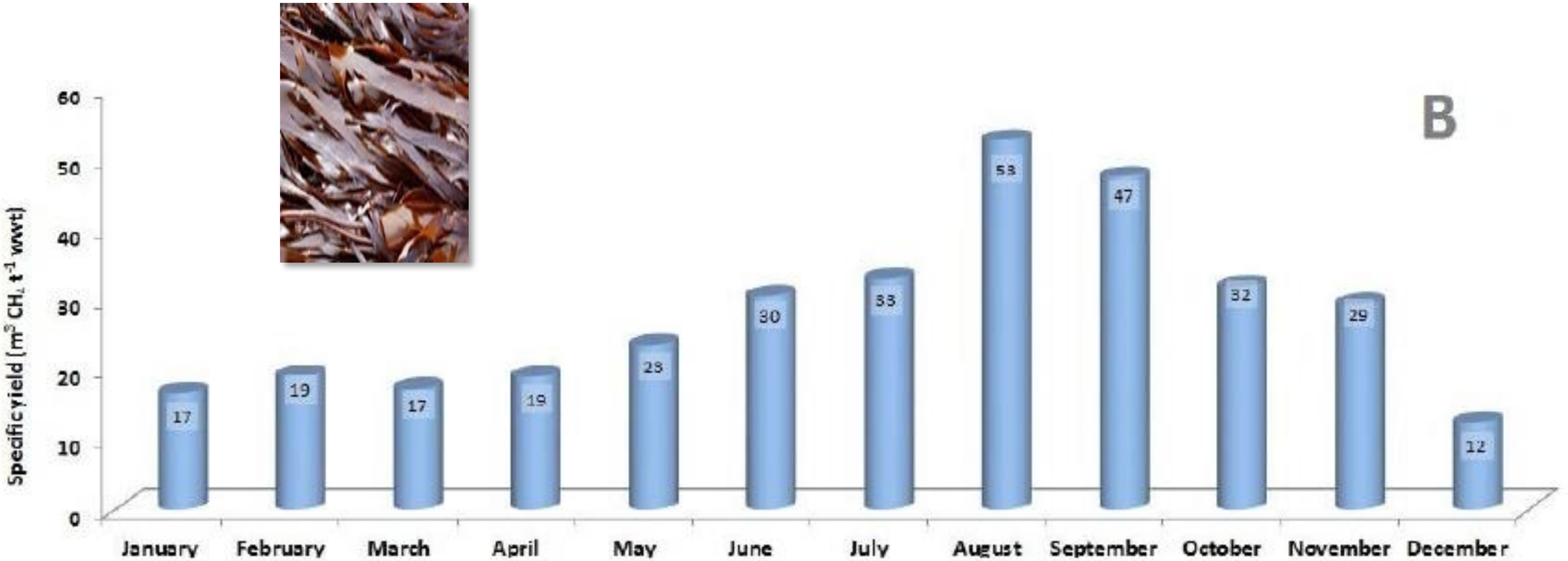
# Seasonal Variation in biomethane yield from Laminaria Digitata

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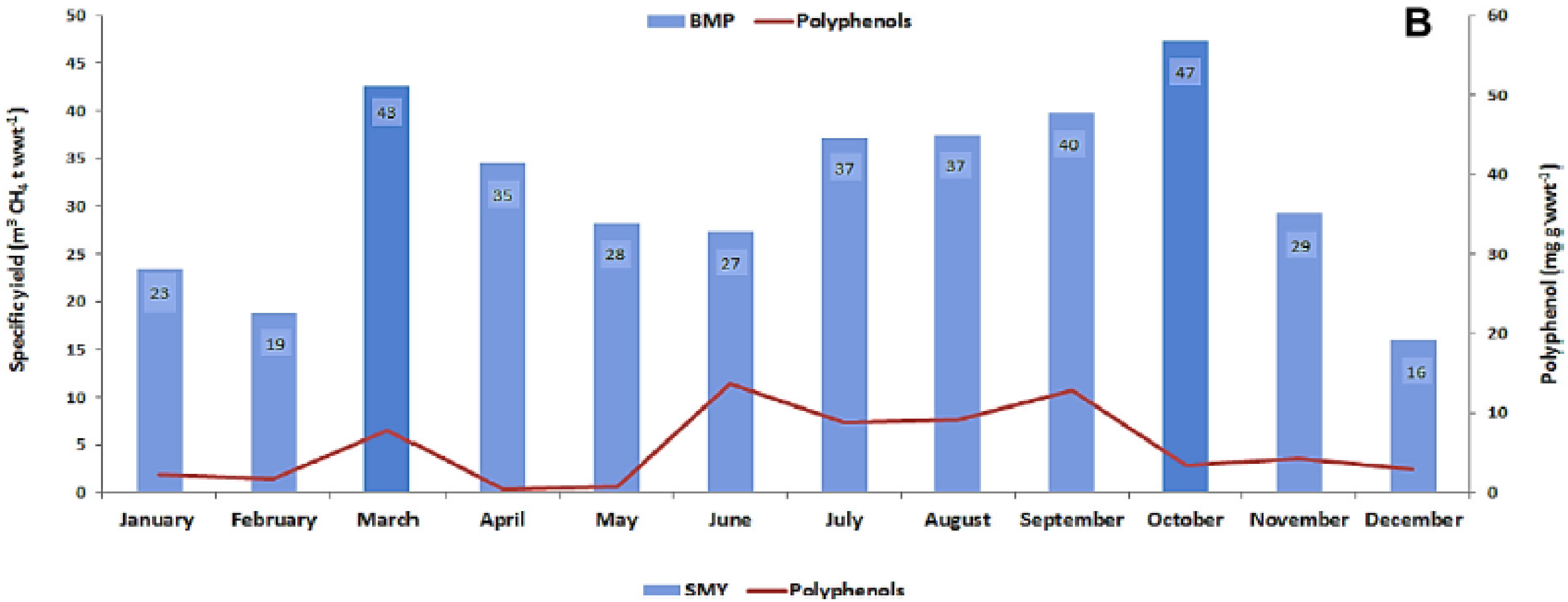
# Seasonal Variation in A. *nodosum*

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# Cultivating Seaweed

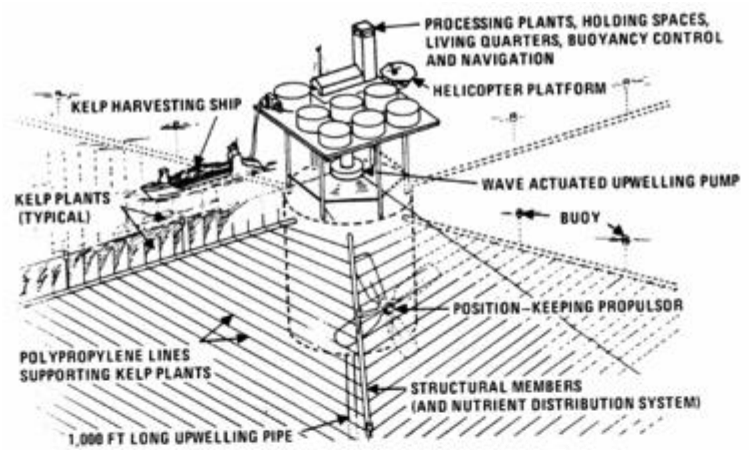


Figure 1. Conceptual design of 405 ha (1,000 acre) ocean food and energy farm unit. (Leese 1976) Source: David Chynoweth.

Position adjacent to fish farms, protect fish from jelly fish

Increased yields of seaweed as compared to pristine waters

Clean water of excess nutrients

Harvest when yield is highest

# IEA Bioenergy Task 37

Bioresource Technology 219 (2016) 228–238

Contents lists available at ScienceDirect

Bioresource Technology

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


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## Biogas production generated through continuous digestion of natural and cultivated seaweeds with dairy slurry

CrossMark

Muhammad Rizwan Tabassum, David M. Wall *, Jerry D. Murphy

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# Long term co-digestion of seaweed with dairy slurry

**Table 1**
Characteristics of substrates for batch and continuous digestion.

| Characteristics | Dairy slurry | *S. latissima* | *L. digitata* |
|---|---|---|---|
| Total solids (%wwt) | 7.00 (0.15) | 9.21 (0.27) | 17.66 (0.34) |
| Volatile solids (%wwt) | 5.60 (0.10) | 5.27 (0.16) | 14.42 (0.21) |
| Ash (% of TS) | 20.23 (0.62) | 42.80 (0.81) | 18.31 (0.66) |
| C% (% of TS) | 40.60 (0.18) | 27.85 (0.16) | 33.45 (0.22) |
| H% (% of TS) | 5.32 (0.14) | 3.58 (0.02) | 4.71 (0.01) |
| N% (% of TS) | 2.53 (0.10) | 1.80 (0.28) | 1.22 (0.05) |
| O% (% of TS) | 31.32 (0.33) | 24.02 (0.51) | 42.31 (0.77) |
| C:N | 16 (0.56) | 15.84 (1.37) | 27.42 (1.25) |

Standard deviation is in parentheses.

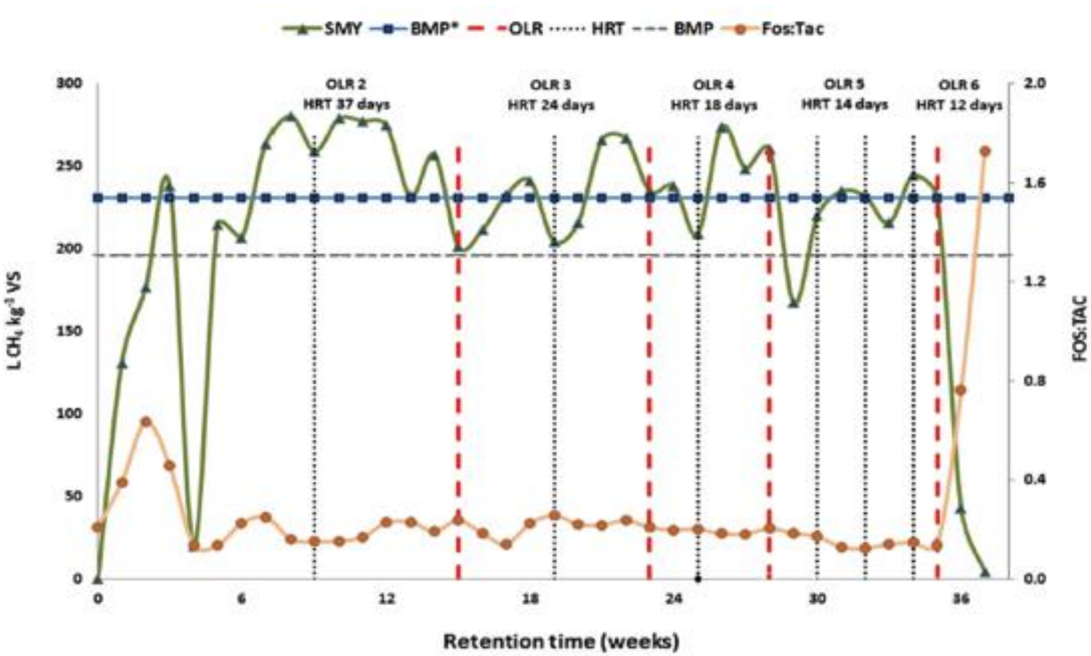


Fig. 1A. Co-digestion of 66.6% *L. digitata* with 33.3% dairy slurry: Variation in SMY and FOS:TAC with increasing organic loading rate. Specific methane yield (SMY), biomethane potential before acclimatization (BMP), after acclimatization (BMP*), and the fermentation stability (FOS:TAC). Vertical darker lines indicate changes in organic loading rate (OLR), vertical small dashed lines indicate retention times (HRTs).

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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

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
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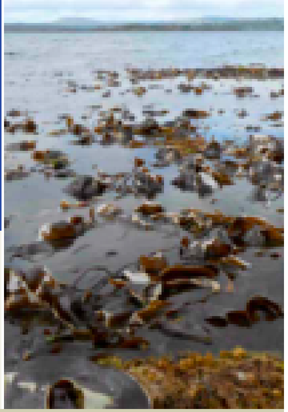

**SUMMARY**

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 utilization.

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Applied Energy 148 (2015) 396–402

Contents lists available at ScienceDirect

Applied Energy

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

ELSEVIER

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

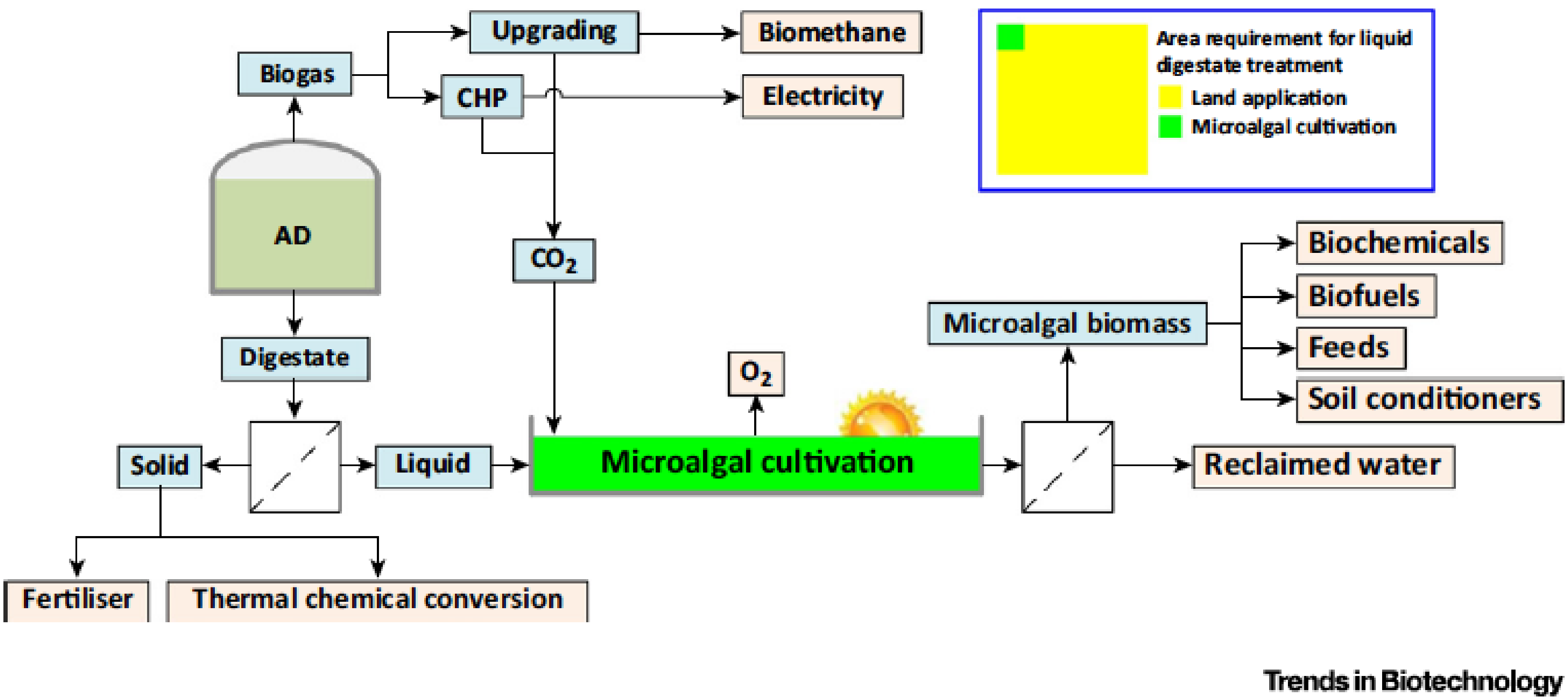
Figure 8: Open cultivation systems for cultivation of microalgae; left: Race way ponds at pilot-scale (© Elad Zohar, Erber Future Business GmbH); right: cascade system (= thin film system) (© Jiri Kopecky, Institute of Microbiology, Trebon)

Trends in Biotechnology

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

ELSEVIER

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

CrossMark

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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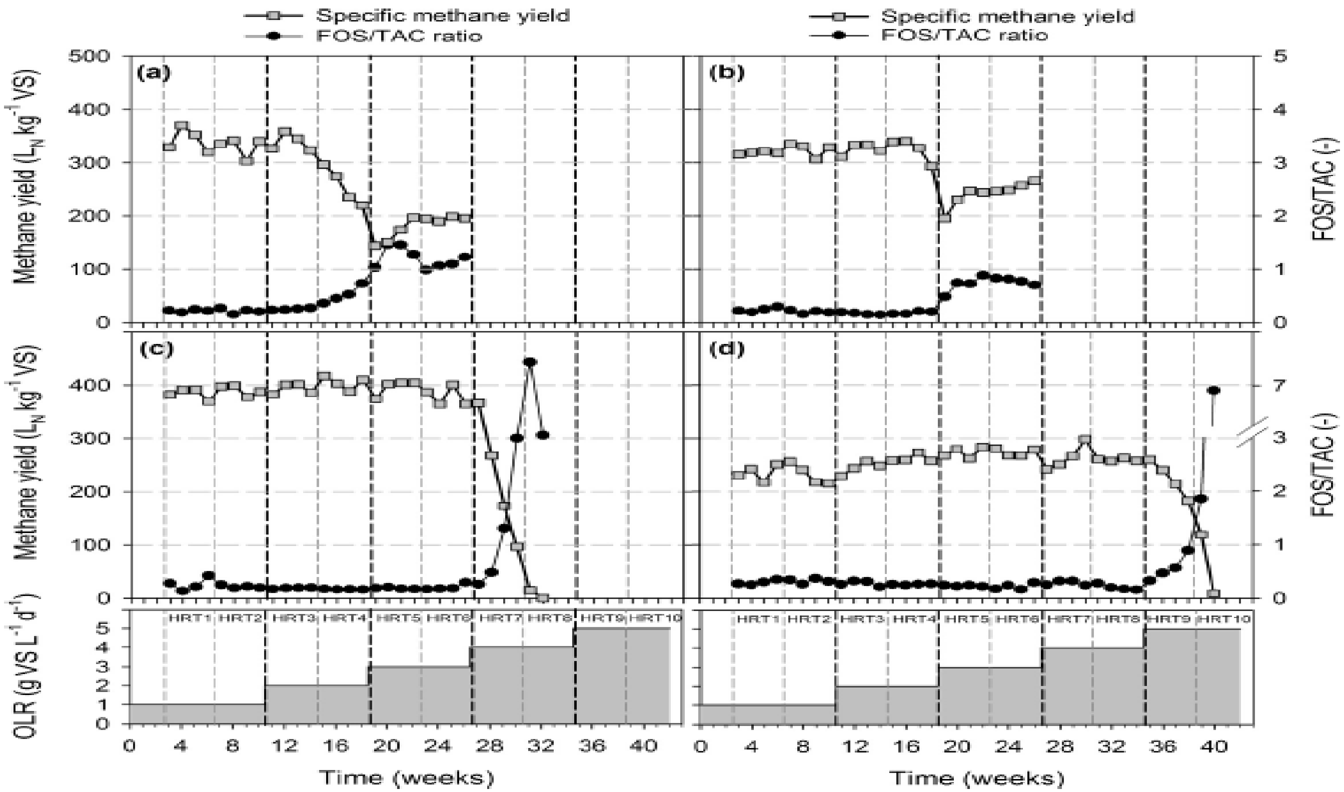


- Mono-digestion of *A. platensis* was assessed in reactor 1 (R1).
- Reactor 2 (R2) was fed with a mixture of 85% VS of *A. platensis* and 15% VS of barley straw.
- Reactor 3 (R3) was fed with a mixture of 45% VS of *A. platensis* and 55% VS of energy beet silage.
- Reactor 4 (R4) was operated with a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

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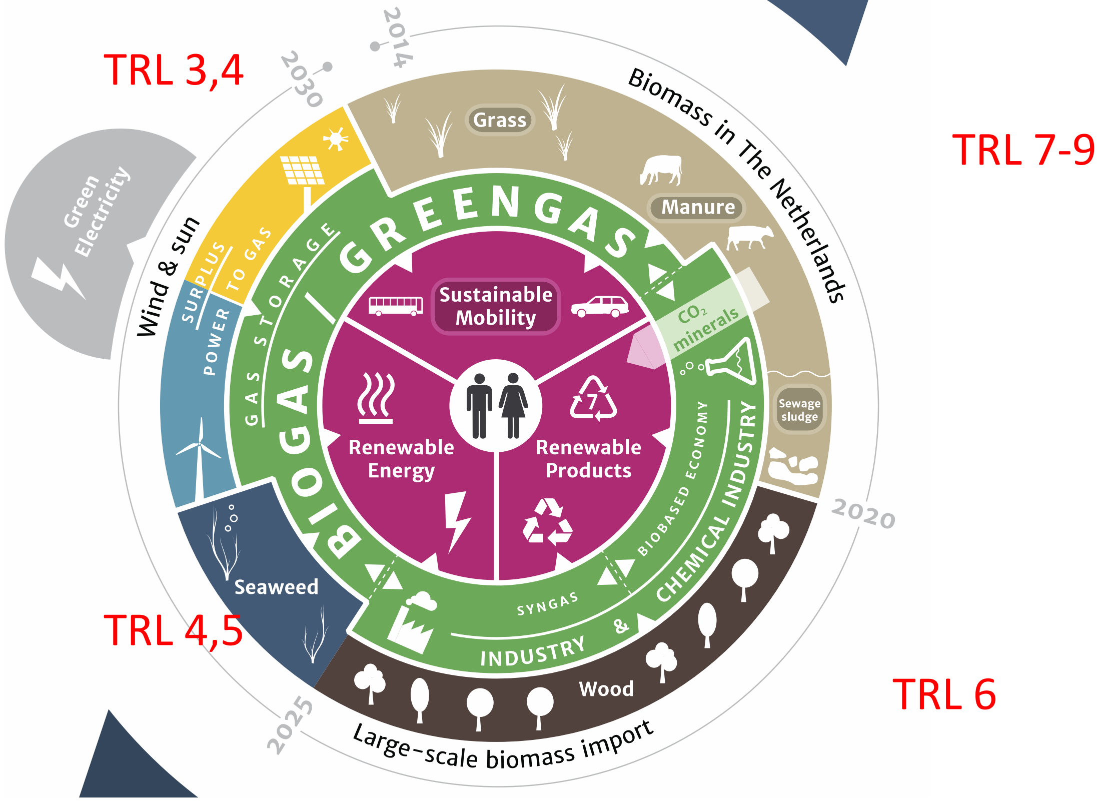
# Fourth stage of Industry

Green Gas from electricity

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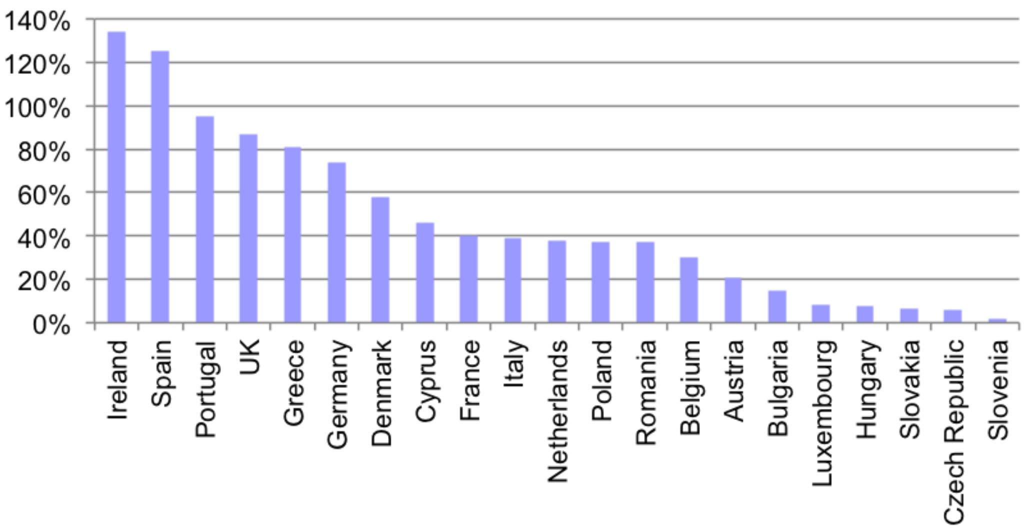
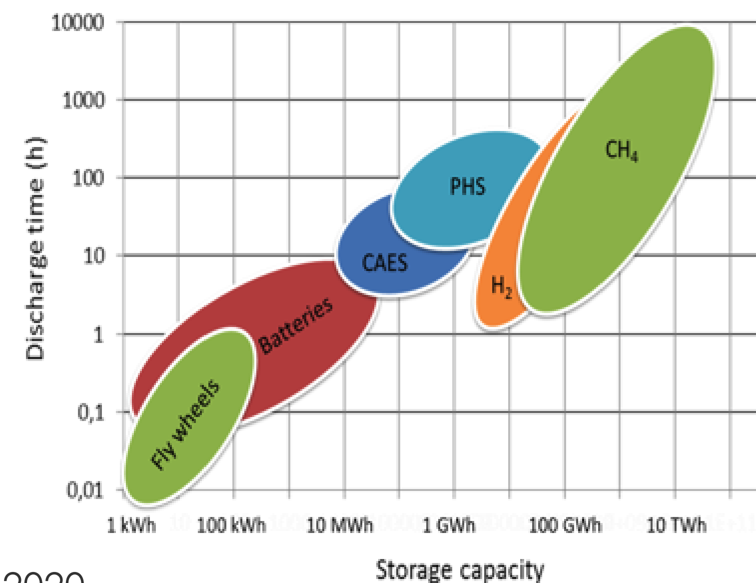
# Curtailment and storage of variable renewable electricity




Wind capacity as a proportion of minimum demand in summer 2020

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UC

# IEA Bioenergy Task 37

Renewable Energy 78 (2015) 648–656

Contents lists available at ScienceDirect

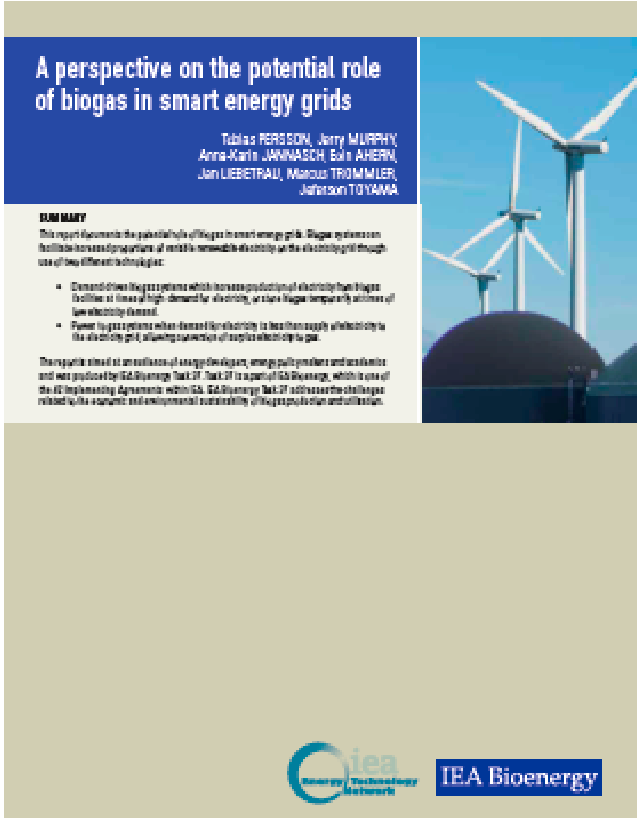
Renewable Energy

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


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, Jefferson TOYAMA

SUMMARY

IEA Bioenergy

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Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com



# 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, *]

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

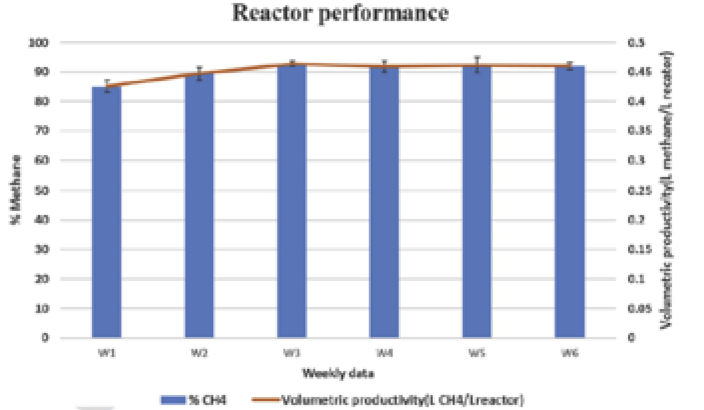


Fig. 3. Methane composition and volumetric productivity at 65 °C (fresh inoculum) for 24 h.

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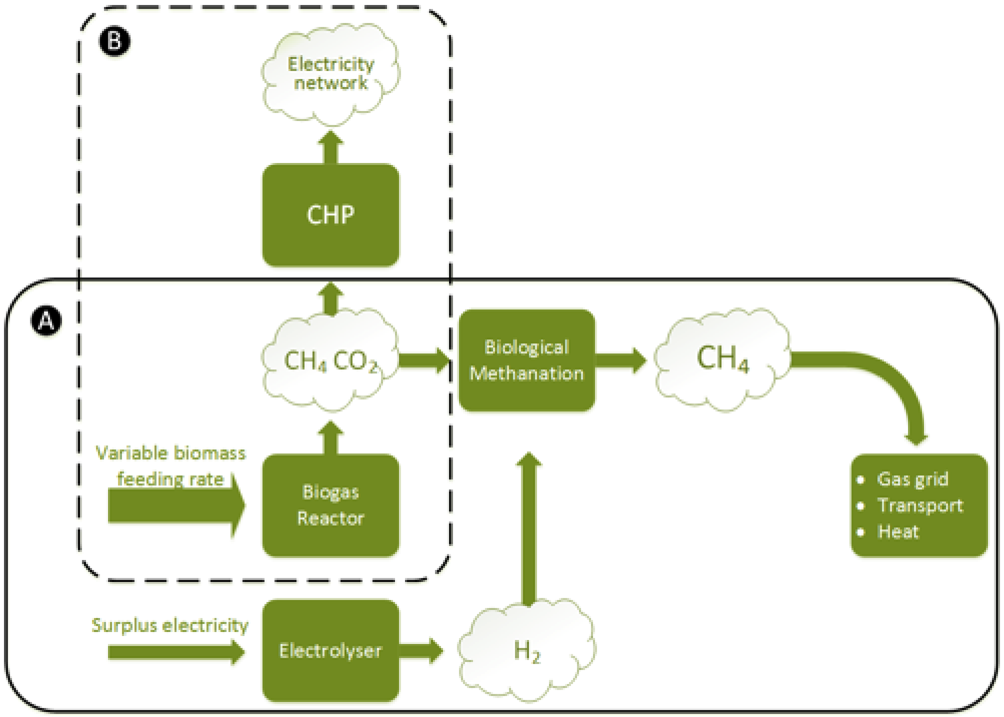
# Gaseous biofuel from non-biological origin

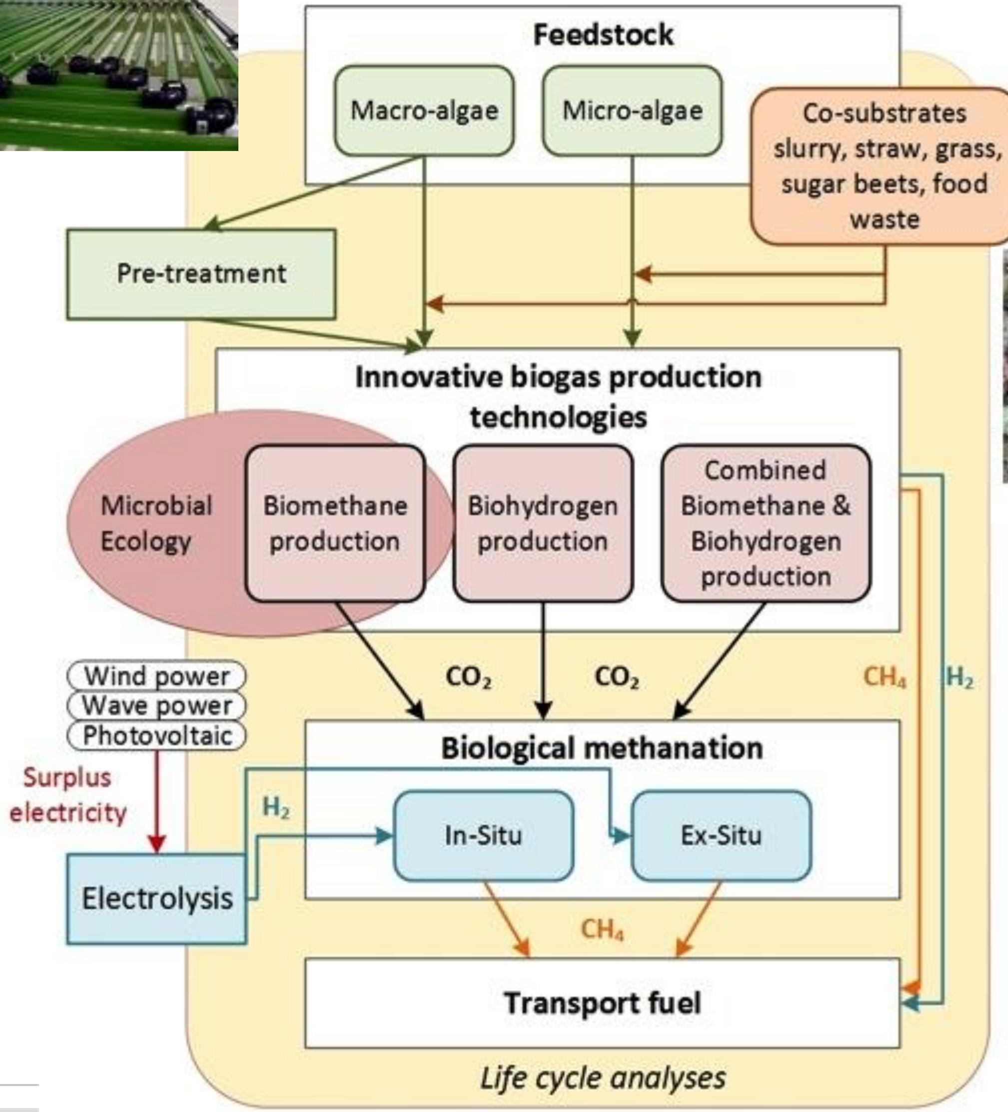
$H_2$: energy Density 12.1 MJ/$m_n^3$ : CH$_4$: Energy density 37.6 MJ/$m_n^3$

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

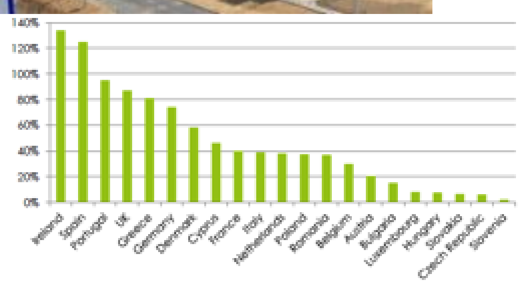



**Source of CO2 from biogas:**
Mix biogas (50% CH4 and 50% CO2) with H2; generate double the CH4 (1 mol CO2 generates 1 mol CH4).





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
CO₂
CO₂
CH₄
H₂
Wind power
Wave power
Photovoltaic
Surplus electricity
Electrolysis
H₂
Biological methanation
In-Situ
Ex-Situ
CH₄
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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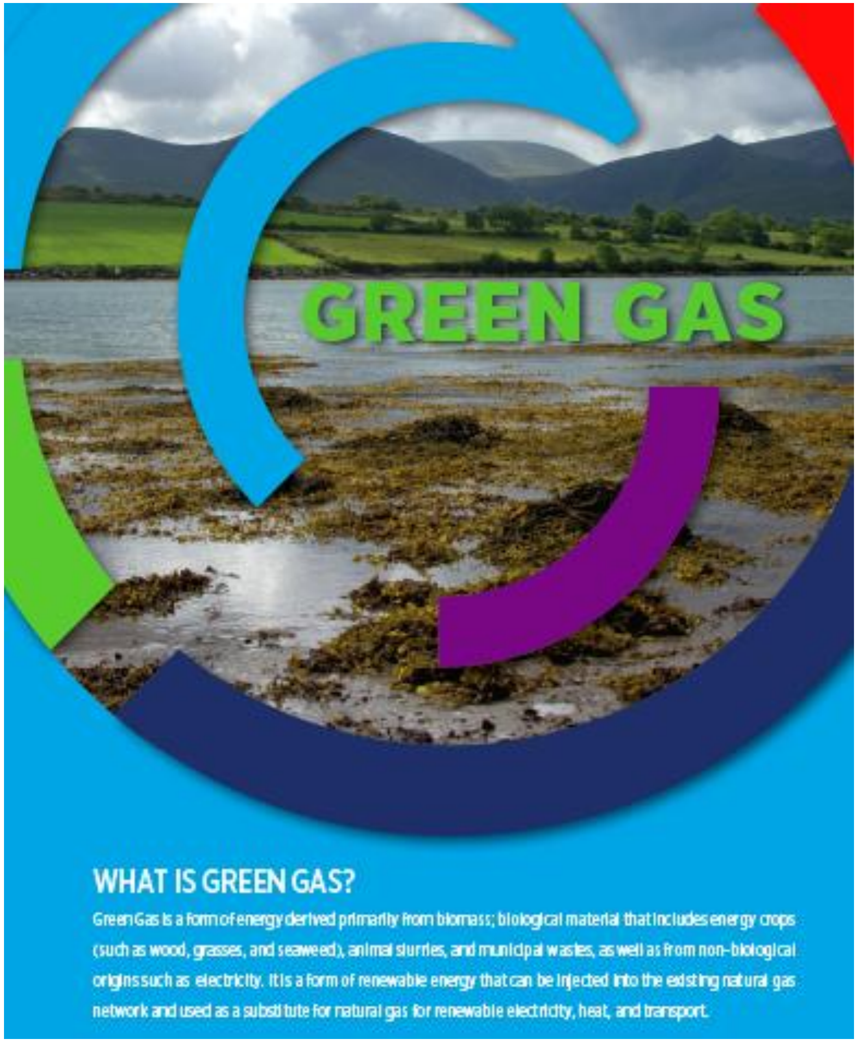
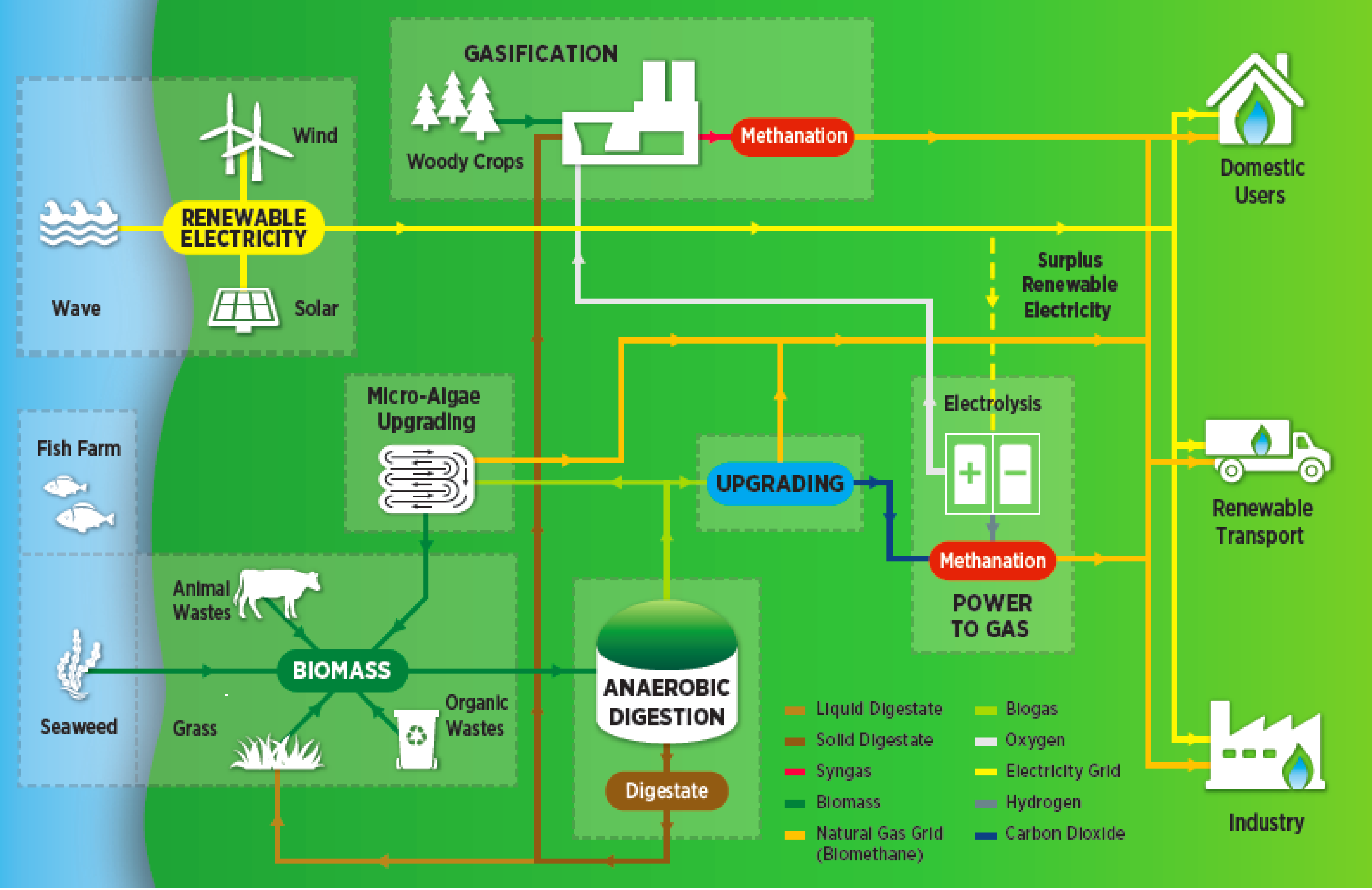



http://www.marei.ie/wp-content/uploads/2017/03/MaREI-4-pg-A4-Brochure-v8-Single-pages.pdf


GASIFICATION
Woody Crops
Methanation
Wind
RENEWABLE ELECTRICITY
Wave
Solar
Domestic Users
Surplus Renewable Electricity
Micro-Algae Upgrading
Electrolysis
UPGRADING
Fish Farm
Renewable Transport
Methanation
POWER TO GAS
Animal Wastes
BIOMASS
ANAEROBIC DIGESTION
Seaweed
Grass
Organic Wastes
Digestate
Liquid Digestate
Solid Digestate
Syngas
Biomass
Natural Gas Grid (Biomethane)
Biogas
Oxygen
Electricity Grid
Hydrogen
Carbon Dioxide
Industry