IEA Bioenergy Task 37

# IEA Bioenergy Task 37 Energy from biogas: Innovation in biogas systems


**Prof Jerry D Murphy, Director SFI MaREI centre**
**Chair of Civil, Structural and Environmental Engineering**
**Leader IEA Bioenergy Task 37**


**ABLC Global San Francisco USA**
**Wednesday November 7, 2018**

Energy Technology Network

IEA Bioenergy

MaREI
Centre for Marine and Renewable Energy


# Member countries participating in Task 37

| | |
|---|---|
| Australia | Bernadette McCabe |
| Austria | Bernard Drosg / Günther Bochmann |
| Brazil | Rodrigo Regis / Marcello Alves de Sousa |
| Denmark | Teodorita Al-Seadi |
| Estonia | Elis Volimer |
| Finland | Saija Rasi |
| France | Olivier Théobald / Guillaume Bastide |
| Germany | Jan Liebertrau |
| Ireland | Jerry Murphy |
| Korea | Soon Chul Park |
| Norway | Tormod Briseid |
| Sweden | Anton Fagerstrom |
| Switzerland | Urs Baier |
| The Netherlands | Mathieu Dumont |
| United Kingdom | Clare Lukehurst / Charles Banks |






IEA Bioenergy Task 37

# Task 37
# Work Programme 2016-2018




# Case studies Triennium 2016 - 2018

1. Den Eelder Farm: small farm scale mono-digestion of dairy slurry.
2. Green Gas Hub: provision of biogas by farmers by pipe to a Green Gas Hub with a centralised upgrading process.
3. Biomethane demonstration: Innovation in urban waste treatment and in biomethane vehicle fuel production in Brazil.
4. Profitable on- farm biogas in the Australian pork sector.
5. Sondrerjysk Biogas Bevtoft: Hi tech Danish biogas installation a key player in local rural development
6. Icknield Farm Biogas: an integrated farm enterprise

# IEA Bioenergy Task 37

BIOGAS IN SOCIETY
A Case Story

## DEN EELDER FARM

Small farm scale mono-digestion of dairy slurry for energy independence and reduction in greenhouse gas emissions

IEA Bioenergy Task 37

IEA Bioenergy: Task 37: February 2017


**Specifications of digester system at Den Eelder farm**

- Technique: mono-digestion
- Input (per year): 15,000 tons of fresh cow manure
- Capacity: 66 kW electricity / 700 kW heat
- Net output (per year): 500,000 kWh of electricity and 1.5 million kWh of heat

# IEA Bioenergy Task 37


BIOGAS IN SOCIETY
A Case Story

GREEN GAS HUB

Provision of biogas by farmers by pipe to a Green Gas Hub with a centralised upgrading process

IEA Bioenergy Task 37

IEA Bioenergy: Task 37: April 2017


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

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

Table 1: Attero's gas refining installations at Wijster

# IEA Bioenergy Task 37

BIOGAS IN SOCIETY
A Case Story

BIOMETHANE DEMONSTRATION

Innovation in urban waste treatment and in biomethane vehicle fuel production in Brazil



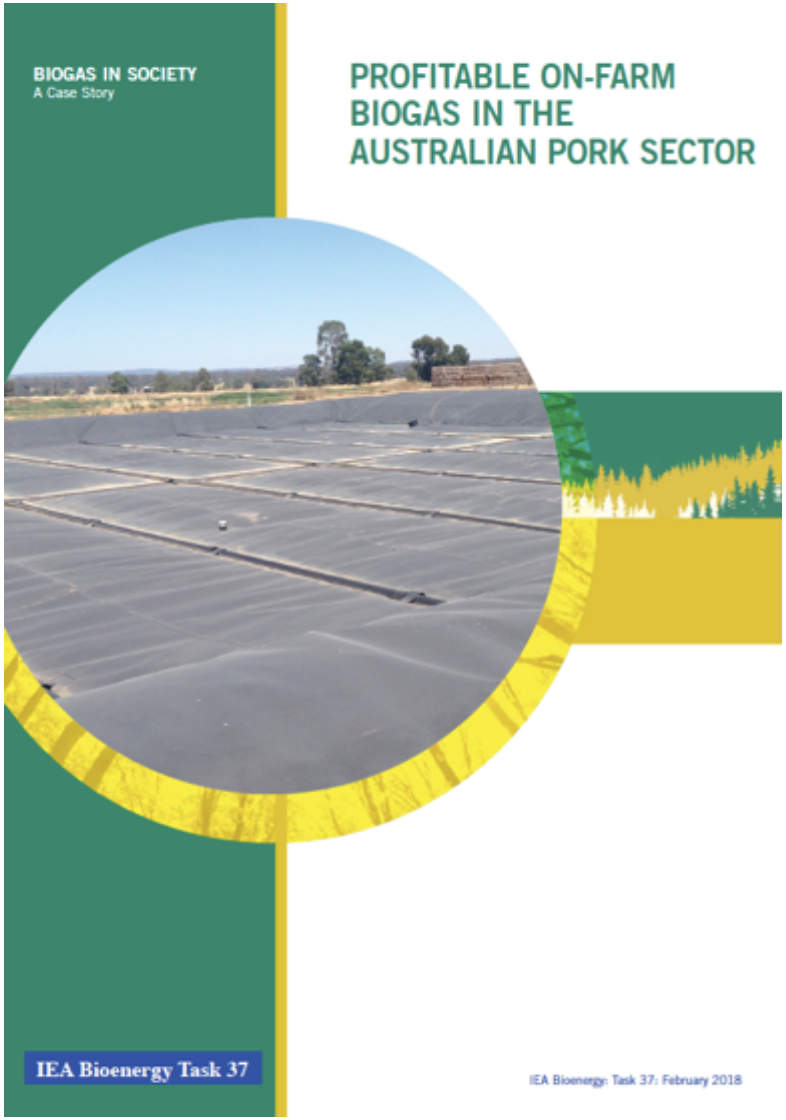
IEA Bioenergy Task 37

IEA Bioenergy: Task 37: November 2017



60 cars fuelled

# IEA Bioenergy Task 37



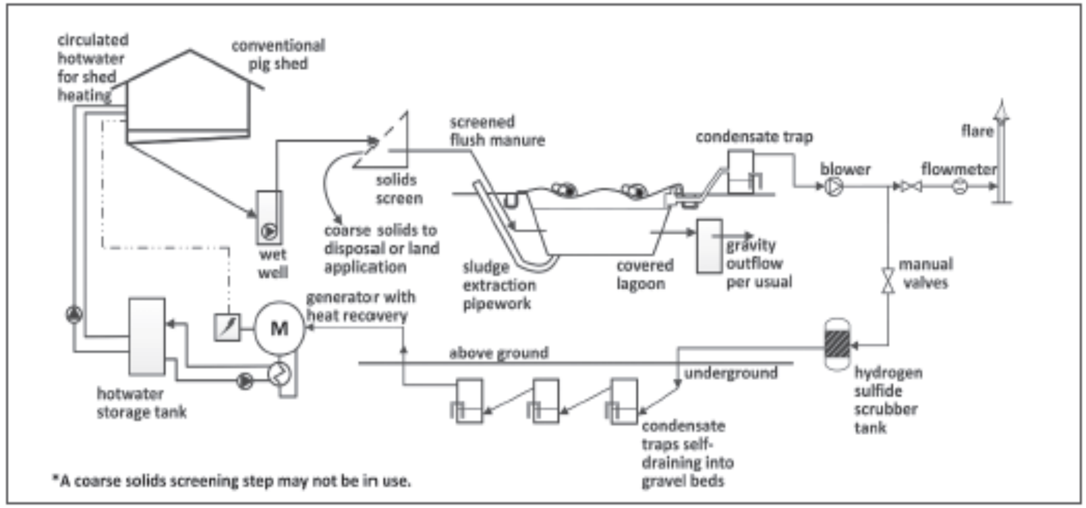




**Figure 3:** A schematic overview of a covered lagoon biogas set-up at a piggery

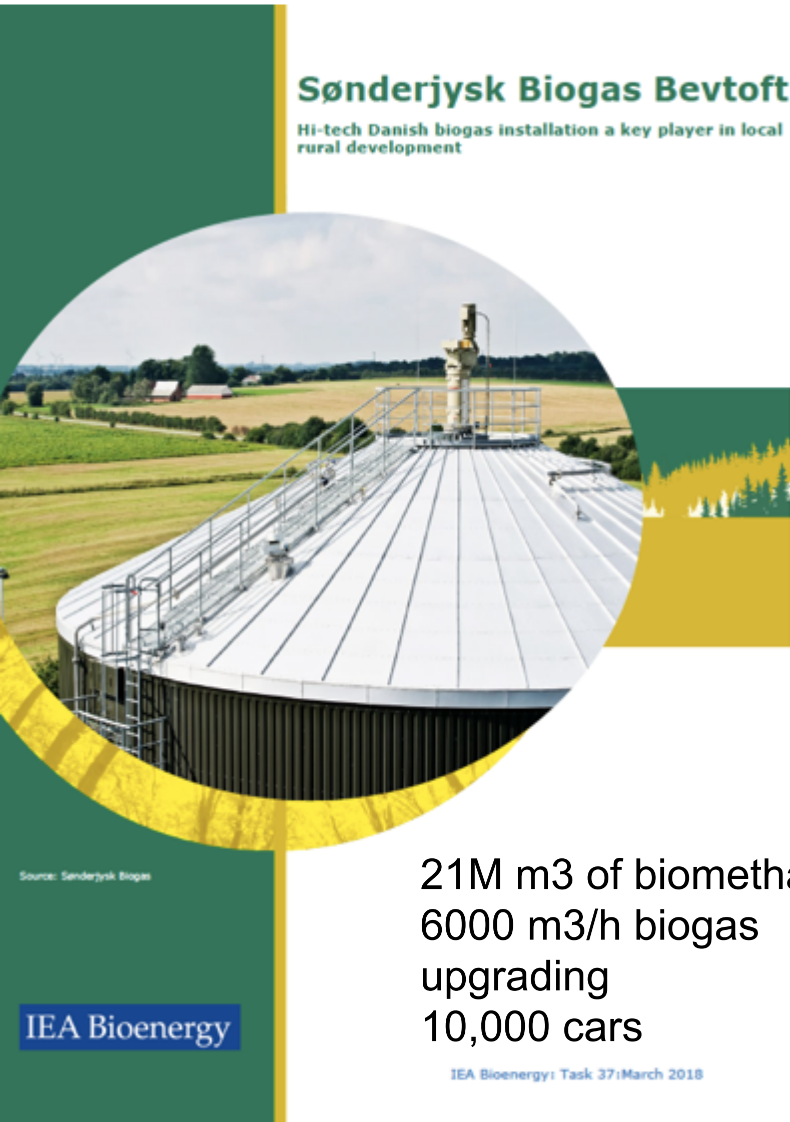
**Table 1: Results from five feasibility studies of various Australian piggeries**

| Piggery | – Standard Pig Units (SPU)* | Payback period (years) | 10 year return on investment (%) | Total capital cost (AUD) |
|---|---|---|---|---|
| Multi-site farrow-to-finish | 12,692 | 4.2 | 198 | 411,900 |
| Grow-out unit | 5,112 | 8.5 | 7 | 279,400 |
| Sow multiplier | 7,089 | 1.8 | 597 | 170,200 |
| Farrow-to-finish | 5,432 | 4.7 | 151 | 345,600 |
| Farrow-to-finish | 6,975 | 7.2 | 64 | 298,300 |

*A standard pig unit (SPU) has a waste output (volatile solids production) equivalent to a typical 40 kg (live weight) grower pig. Expressing piggery capacities in terms of SPUs provides a measure of the piggery waste production for various types of production units (e.g. breeder, grower and farrow to finish). For example, a typical 100-sow farrow-to-finish piggery has a capacity of about 1000 SPUs.

Source: Pork CRC http://porkcrc.com.au/wp-content/uploads/2013/08/4C-102-Final-Report-130420.pdf

# IEA Bioenergy Task 37




21M m3 of biomethane
6000 m3/h biogas upgrading
10,000 cars

| Type | Tons |
|---|---|
| Animal slurries | 425,000 |
| Animal bedding /deep litter | 10,000 |
| Straw | 50,000 |
| Organic wastes | 55,000 |
| **TOTAL** | **540,000** |


# Technical Reports Triennium 2016 - 2018

1. Methane emissions from biogas plants
2. Green Gas
3. Integrated Biogas Systems
4. The role of anaerobic digestion and biogas in the circular economy
5. Governance of environmental sustainability
6. Value of batch tests for biogas potential analysis
7. Food waste digestion systems.

IEA Bioenergy Task 37

# IEA Bioenergy Task 37

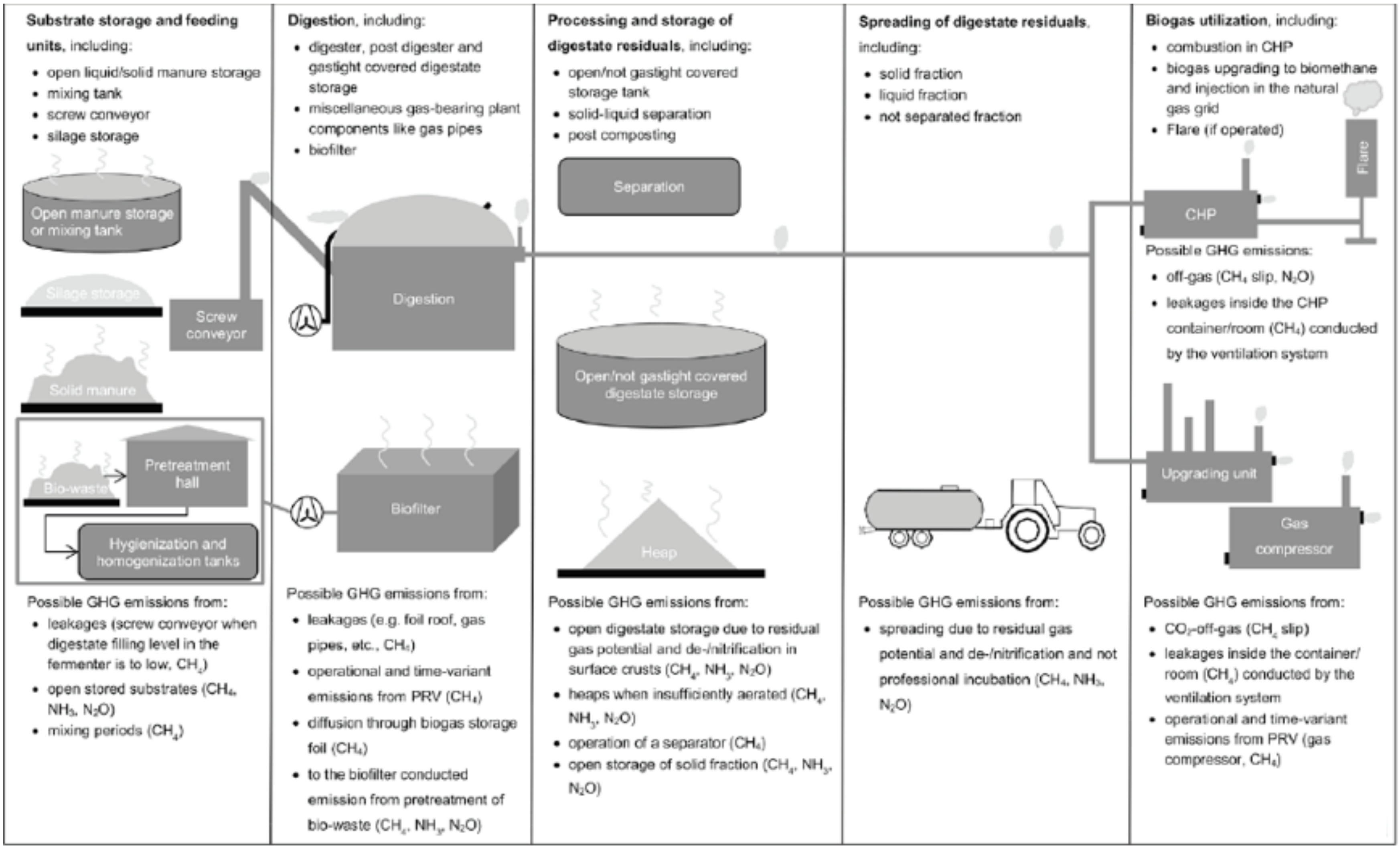
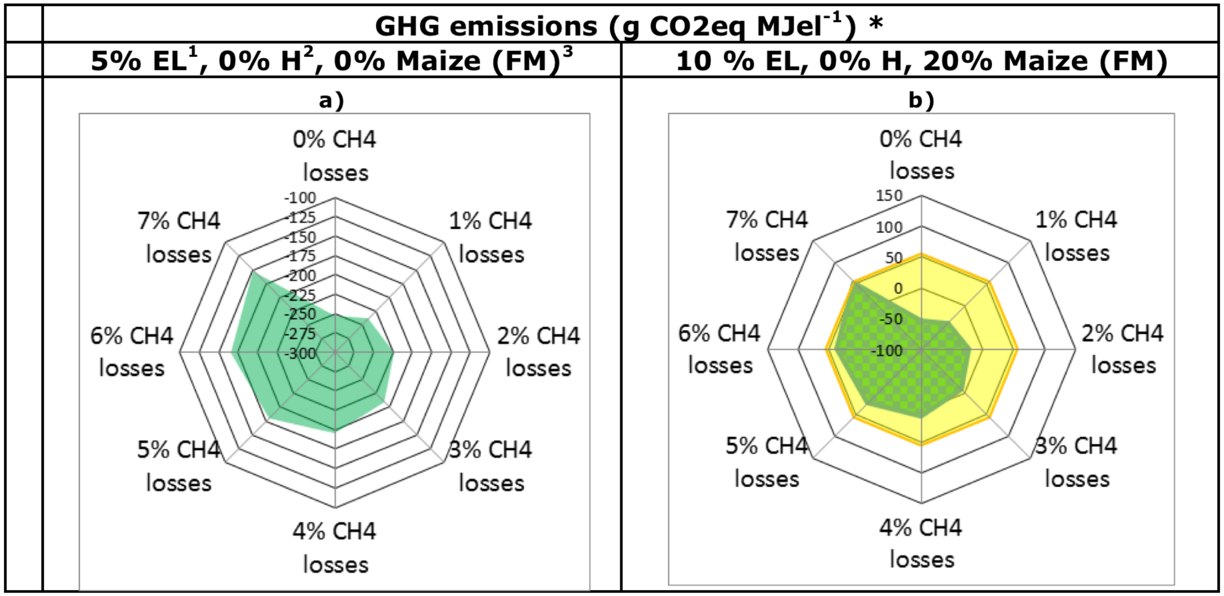



Figure 25: Overview about GHG emission sources from components and processes applied within biogas production and utilisation

# IEA Bioenergy Task 37

All slurry




20% Maize
80% slurry

Methane slippage and sustainability

Must save 70% GHG savings as compared to fossil fuel displaced to be deemed sustainable

Fossil fuel comparator (FFC) is equal to 186 g CO2eq. per MJ of electricity

30 % of the FFC, which corresponds to 55.8 $gCO_2$/MJ

Slurry storage without digestion assumed to produce 17.5% of methane produced; thus carbon negative feedstock

IEA Bioenergy Task 37


**Decarbonised buses**

California Air Resources Board (CARB) awarded a Carbon Intensity (CI) score of -254.94 gCO2e/MJ for a dairy waste to vehicle fuel pathway. This is the lowest ever issued by CARB.

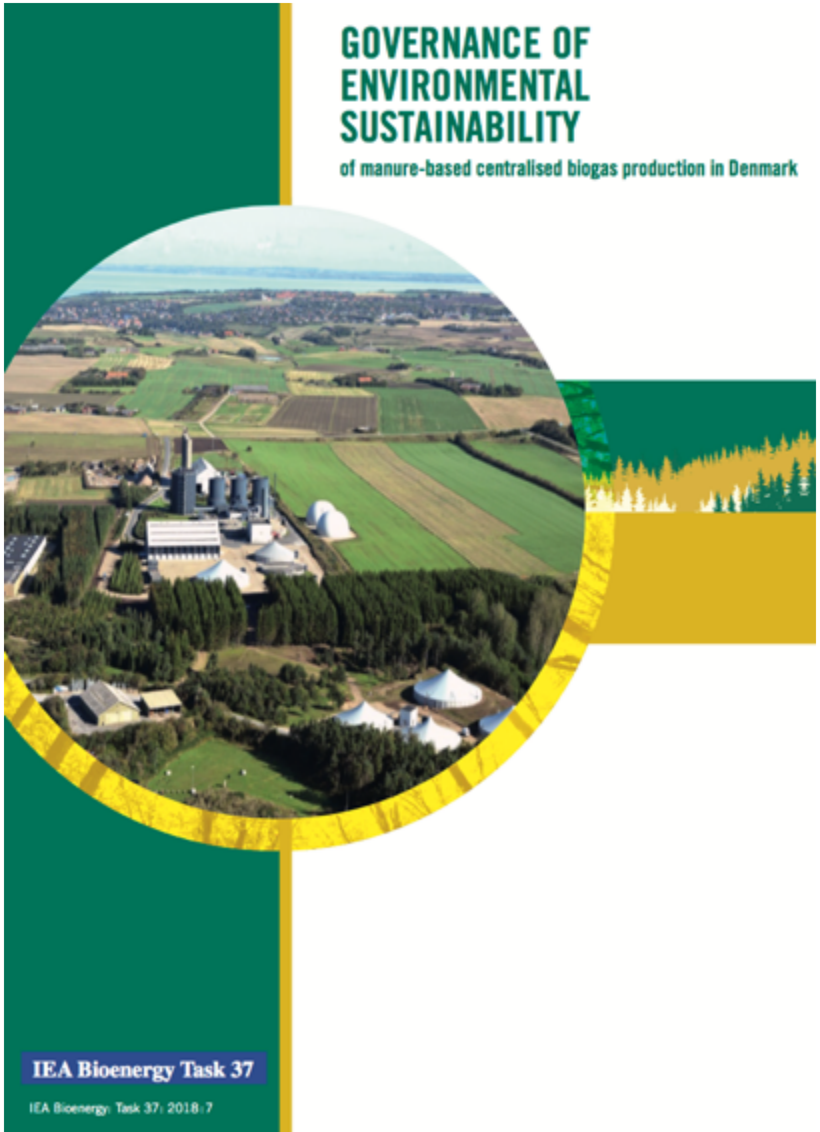
Renewable Energy Directive requires 3.6% of transport energy by 2030 to be from advanced biofuels. Ryegrass is a significant source of advanced biofuel.

# IEA Bioenergy Task 37



Figure 5.8 (a) Building underground domes (b) Garden over a sewage treatment plant
Source: Ashden (www.Asden.org)

IEA Bioenergy Task 37



# IEA Bioenergy Task 37

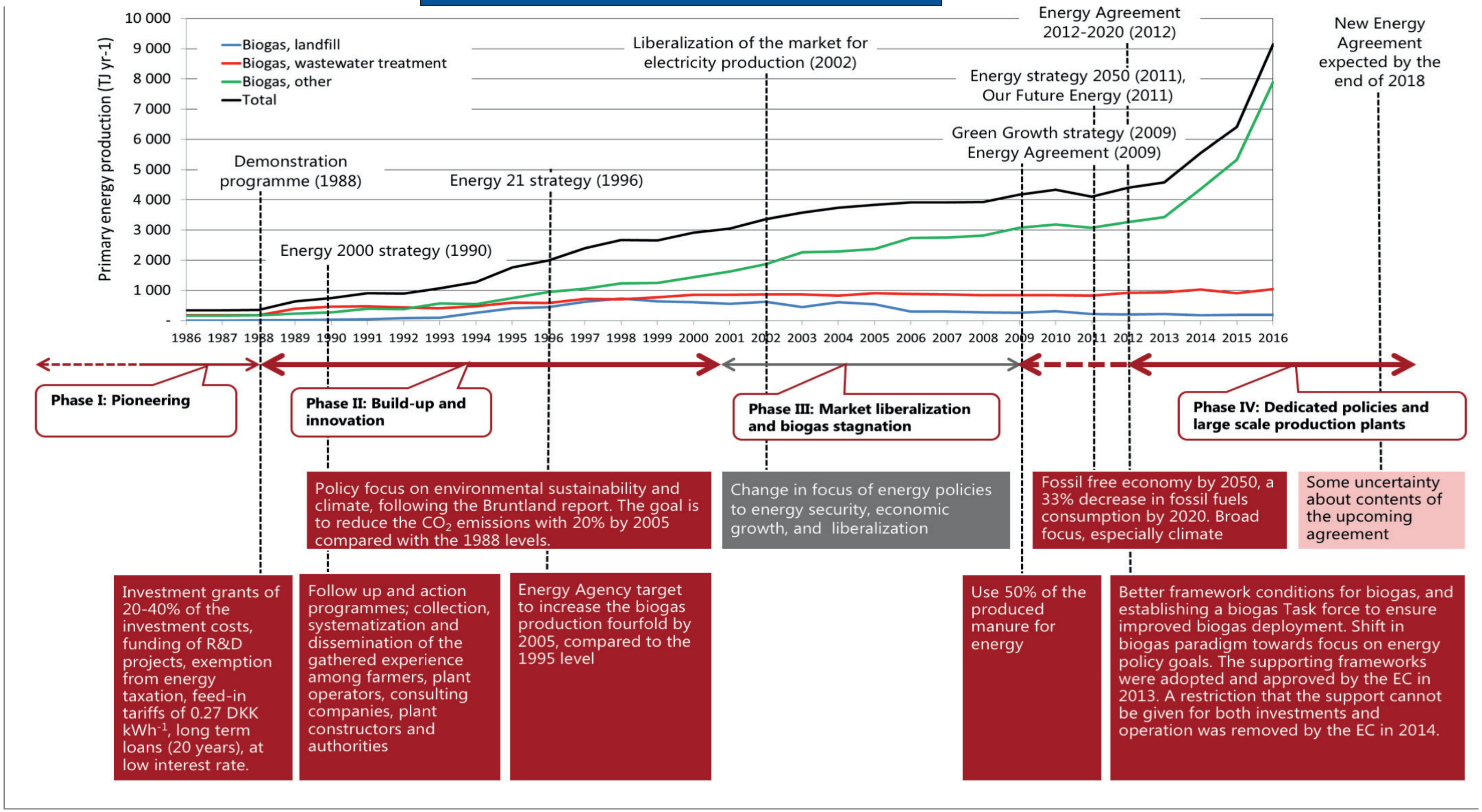



Figure 6. Comparison of biogas production levels with selected relevant energy, agricultural and environmental policy strategies and agreements during the period 1986-2016. A new energy agreement is expected in 2018

# IEA Bioenergy Task 37


Bioresource Technology 243 (2017) 1207–1215

Contents lists available at ScienceDirect

Bioresource Technology

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

ELSEVIER

Review

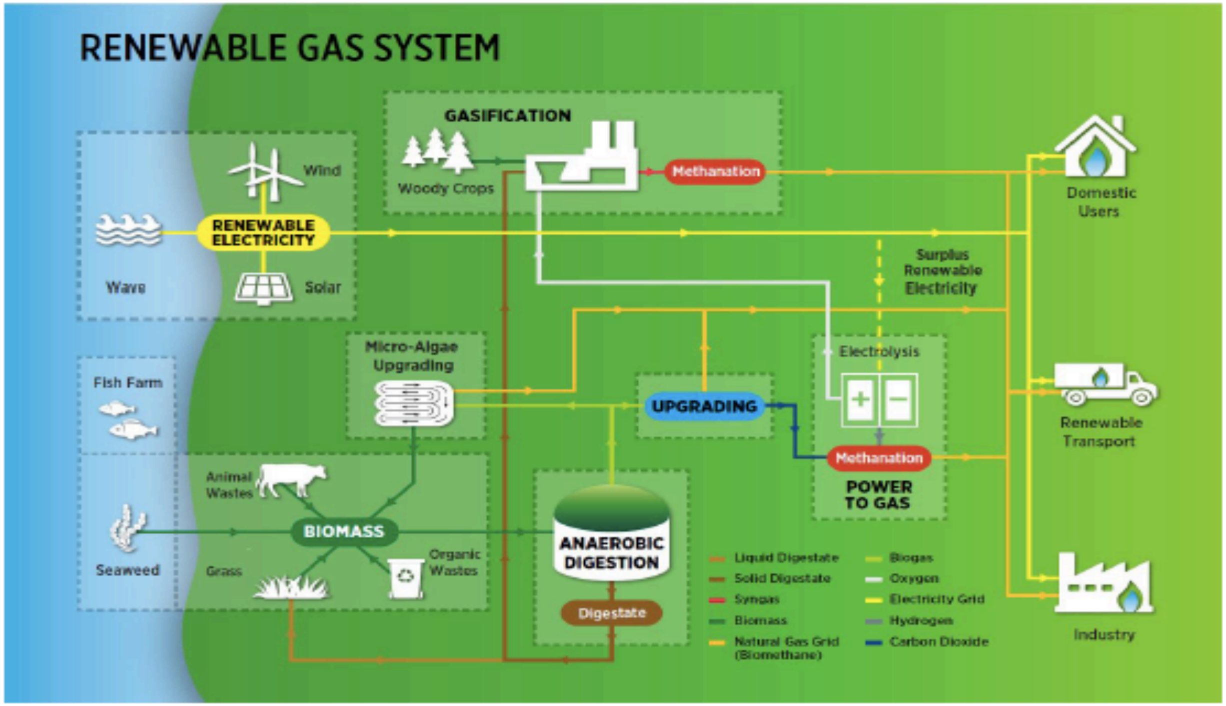
Cascading biomethane energy systems for sustainable green gas production in a circular economy

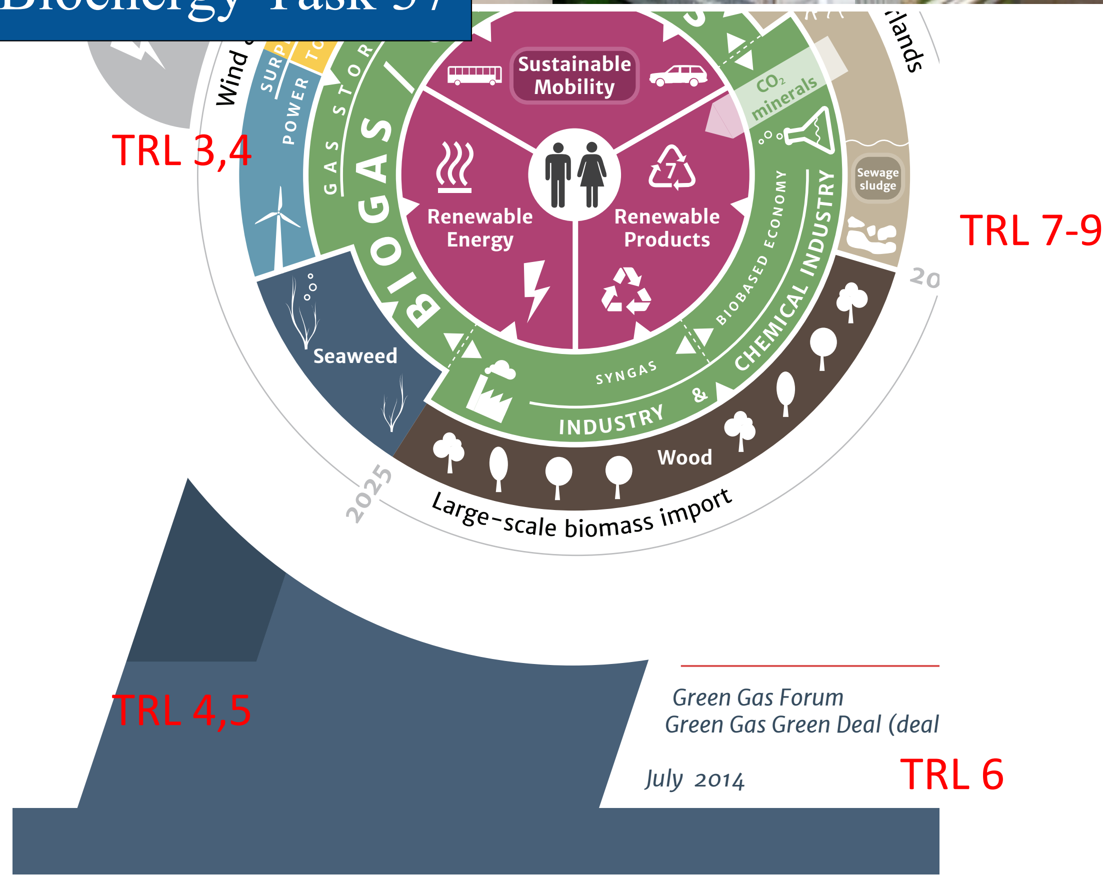
CrossMark

David M. Wall[a,b], Shane McDonagh[a,b], Jerry D. Murphy[a,b,c,*]

[a] MaREI Centre, Environmental Research Institute (ERI), University College Cork (UCC), Ireland
[b] School of Engineering, University College Cork (UCC), Ireland
[c] International Energy Agency Bioenergy Task 37 "Energy from Biogas"

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




# Third stage of Industry

Green Gas from seaweed

MaREI
Centre for Marine and Renewable Energy

# IEA Bioenergy Task 37

*1.1. Worldwide use of algae*

Algae may be split into two groups: micro-algae and macro-algae. Both algae types were investigated as potential fuel sources during the oil crises of the 1970s in Japan and the USA (NREL, 1998). However over the last 15 years research is dominated by micro-algae biodiesel (Singh et al., 2011) whilst research on digestion of digestion of micro-algae is very limited partly due to the poor returns in biomethane production (Mata et al., 2009).

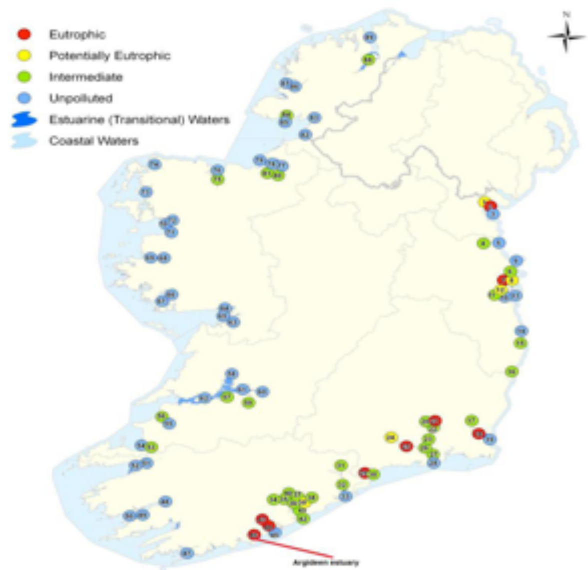
* Corresponding author at: Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland. Tel.: +353 21 490 2286.

*E-mail address:* jerry.murphy@ucc.ie (J.D. Murphy).

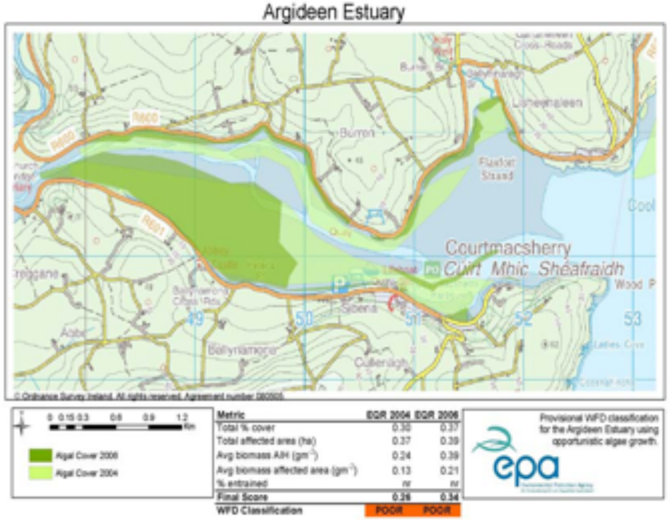
0956-053X/$ - see front matter 
http://dx.doi.org/10.1016/j.wasman.2013.06.017

*1.2. Macro-algae as a source of gaseous biofuel*

Biofuels from sugars, starches and oil crops may be con
first generation biofuels. Biofuels from lingo cellulosic biom
residues are considered second generation. Biofuels from al
considered third generation. There is a significant call to li
production of first generation biofuels; second generation l
from lignocellulosic biomass (such as willow or *Miscantl*
quire agriculture land and are as such, still an issue in the fo
debate (Smyth et al., 2010). The energy balance of micro-alg
diesel (due to the need to separate the lipids from the micr
solution) is poor (EASAC, 2012).




Argideen Estuary




Bioresource Technology 209 (2016) 213–219

Contents lists available at ScienceDirect

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

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
[c] School of Engineering, University College Cork, Cork, Ireland

Bioresource Technology 216 (2016) 219–226

Contents lists available at ScienceDirect

Bioresource Technology

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

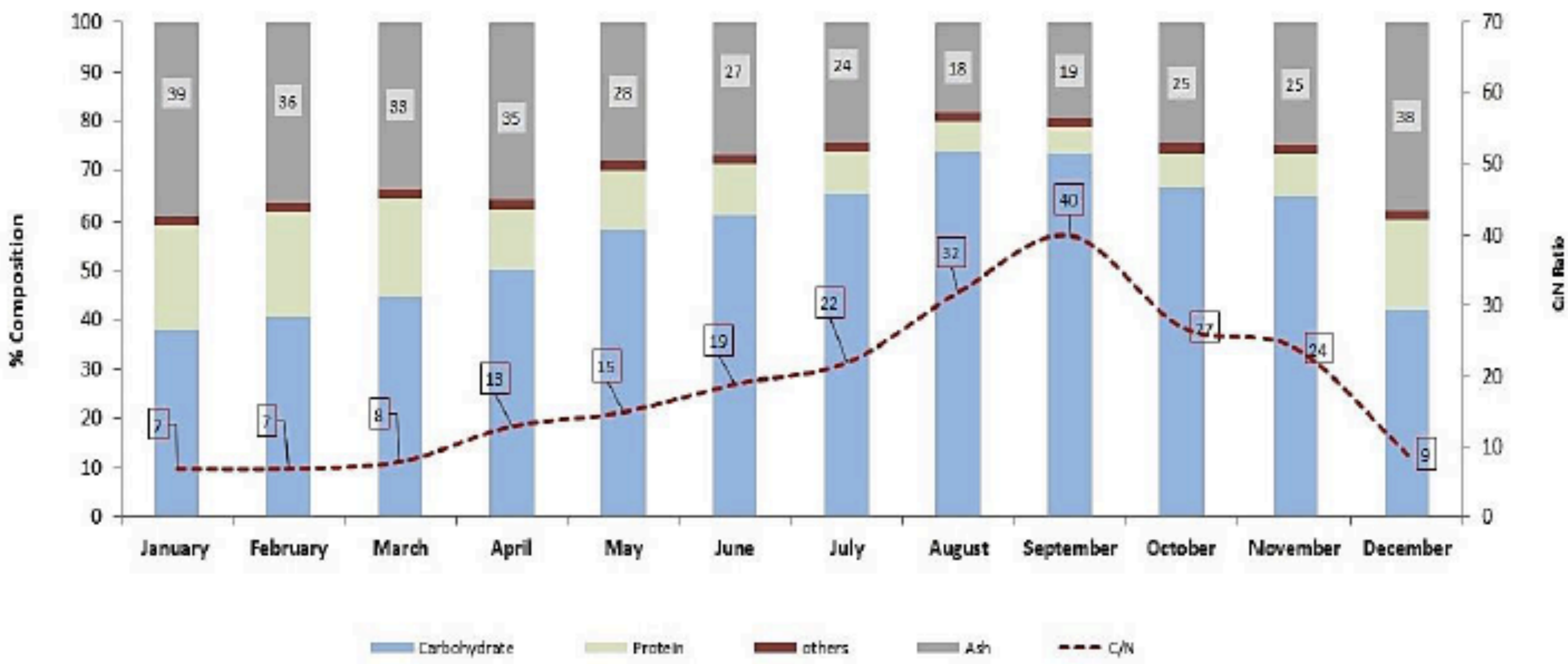
## Seasonal variation of chemical composition and biomethane production from the brown seaweed *Ascophyllum nodosum*

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

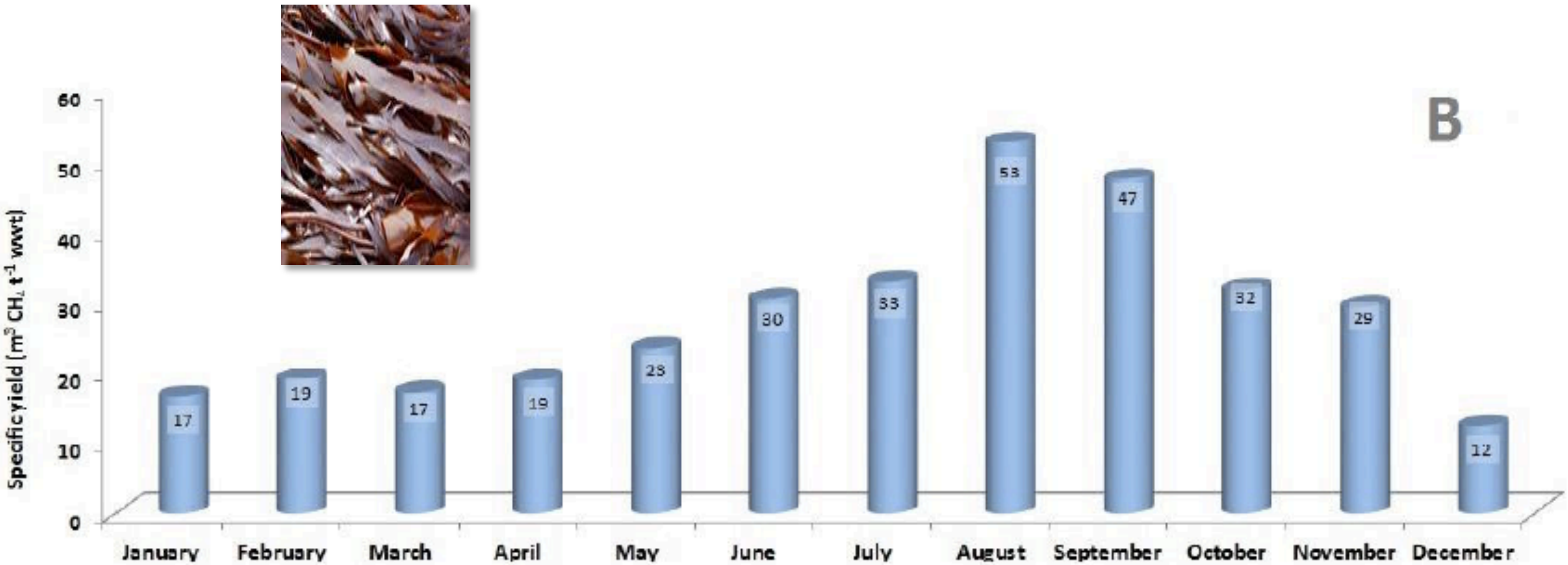
# TRL 4-5 Seaweed

Seasonal Variation in composition of Laminaria Digitata



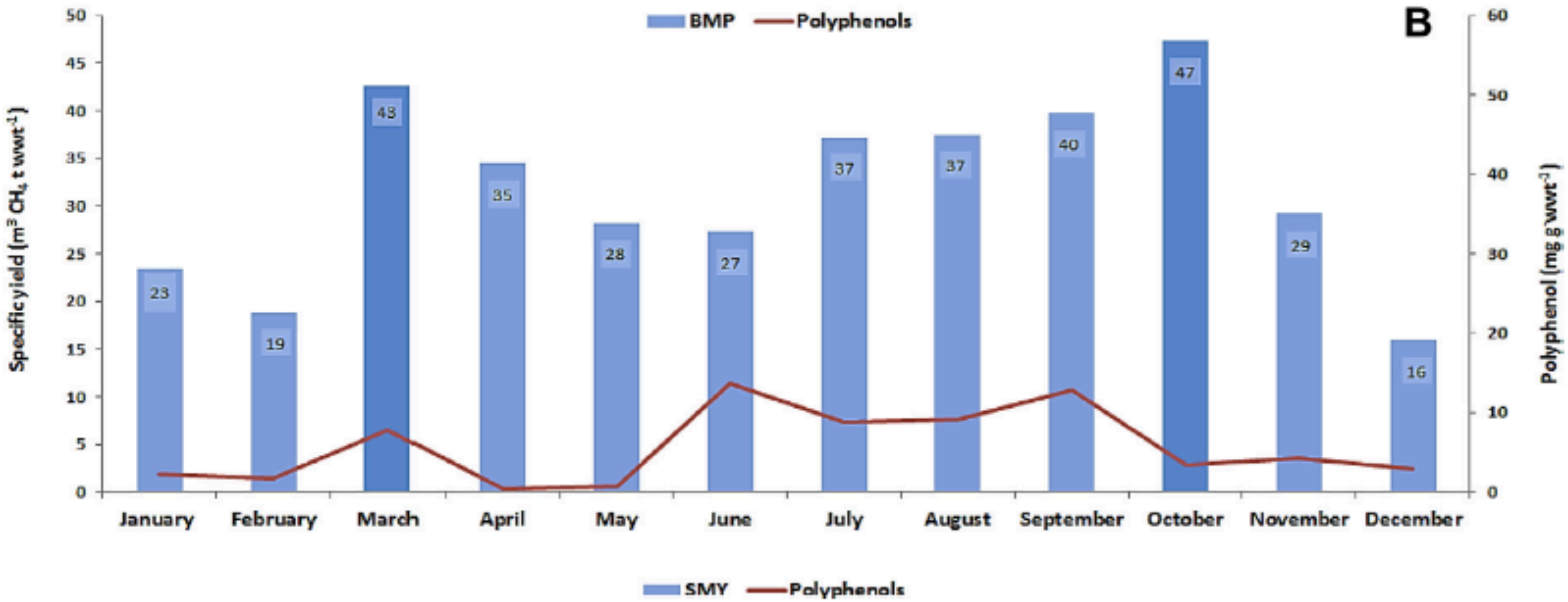


# Seasonal Variation in biomethane yield from Laminaria Digitata



IEA Bioenergy Task 37

# Seasonal Variation in A. *nodosum*




MaREI
Centre for Marine and Renewable Energy

IEA Bioenergy Task 37

Bioresource Technology 219 (2016) 228–238

Contents lists available at ScienceDirect

Bioresource Technology

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

ELSEVIER


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

CrossMark

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

MaREI
Centre for Marine and Renewable Energy

IEA Bioenergy Task 37

# 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.

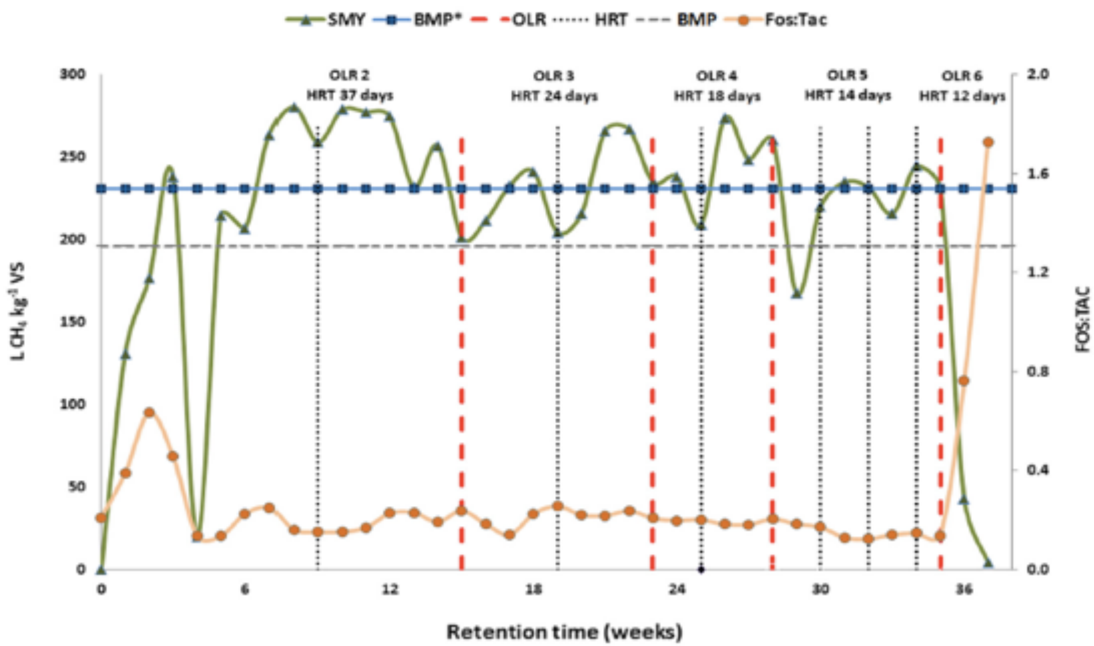



**Fig. 1A** Co-digestion of 66.6% *L. digitata* with 33.3% dairy slurry: Variation in SMY and FOS:TAC with increasing organic loading rate. Specific methane yield (SMY), biomethane potential before acclimatization (BMP), after acclimatization (BMP*), and the fermentation stability (FOS:TAC). Vertical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

MaREI
Centre for Marine and Renewable Energy



# Cultivating Seaweed

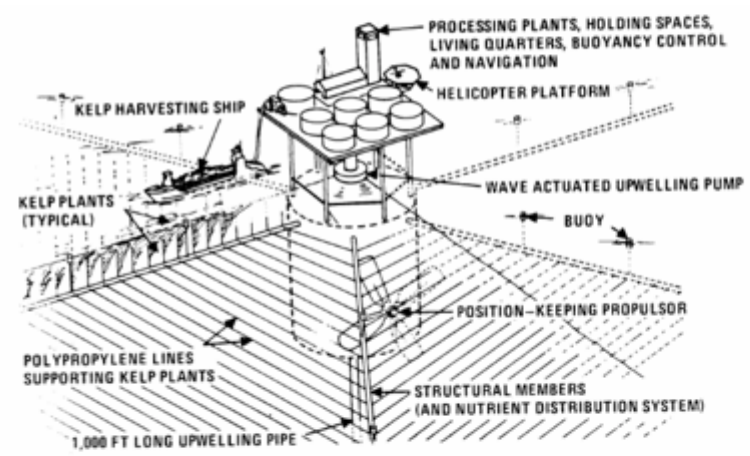



Figure 1. Conceptual design of 405 ha (1,000 acre) ocean food and energy farm unit. (Leese 1976) Source: David Chynoweth.

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 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

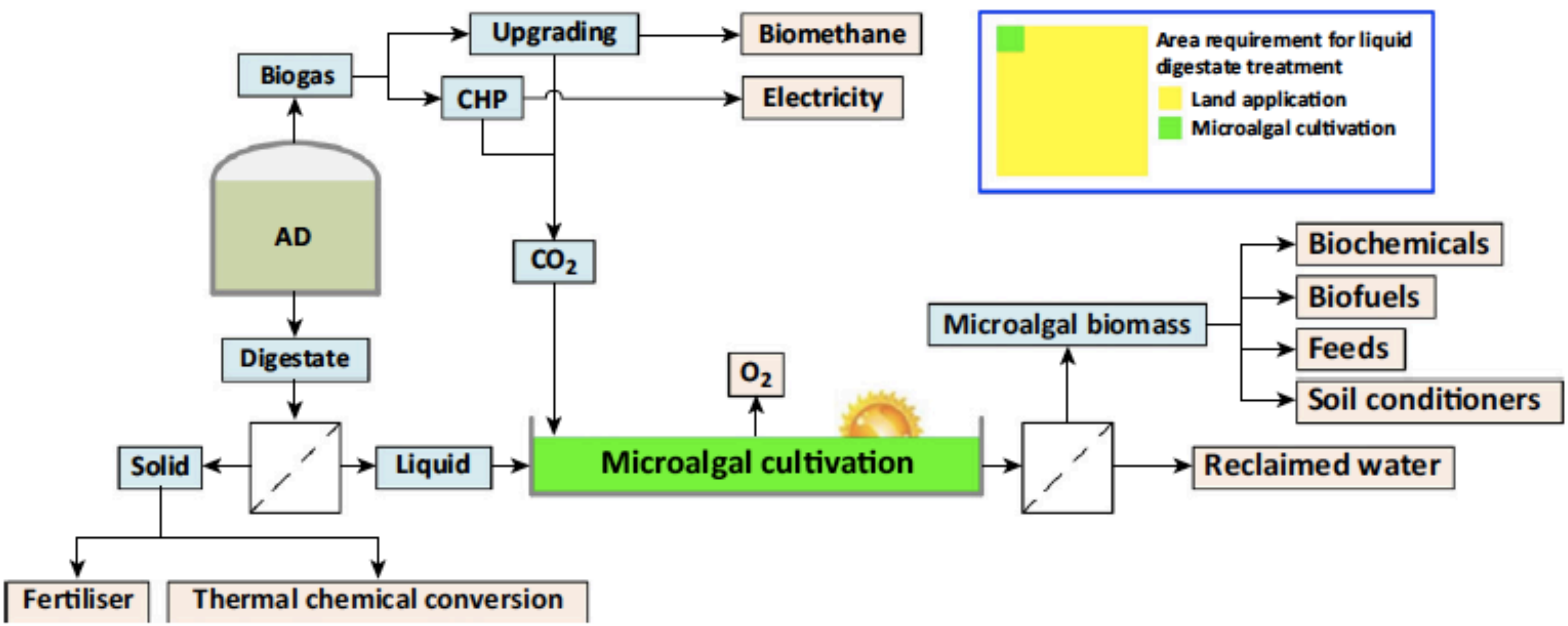
Higher methane yields after ensiling can compensate for silage fermentation losses.

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

Opinion

# Microalgal Cultivation in Treating Liquid Digestate from Biogas Systems

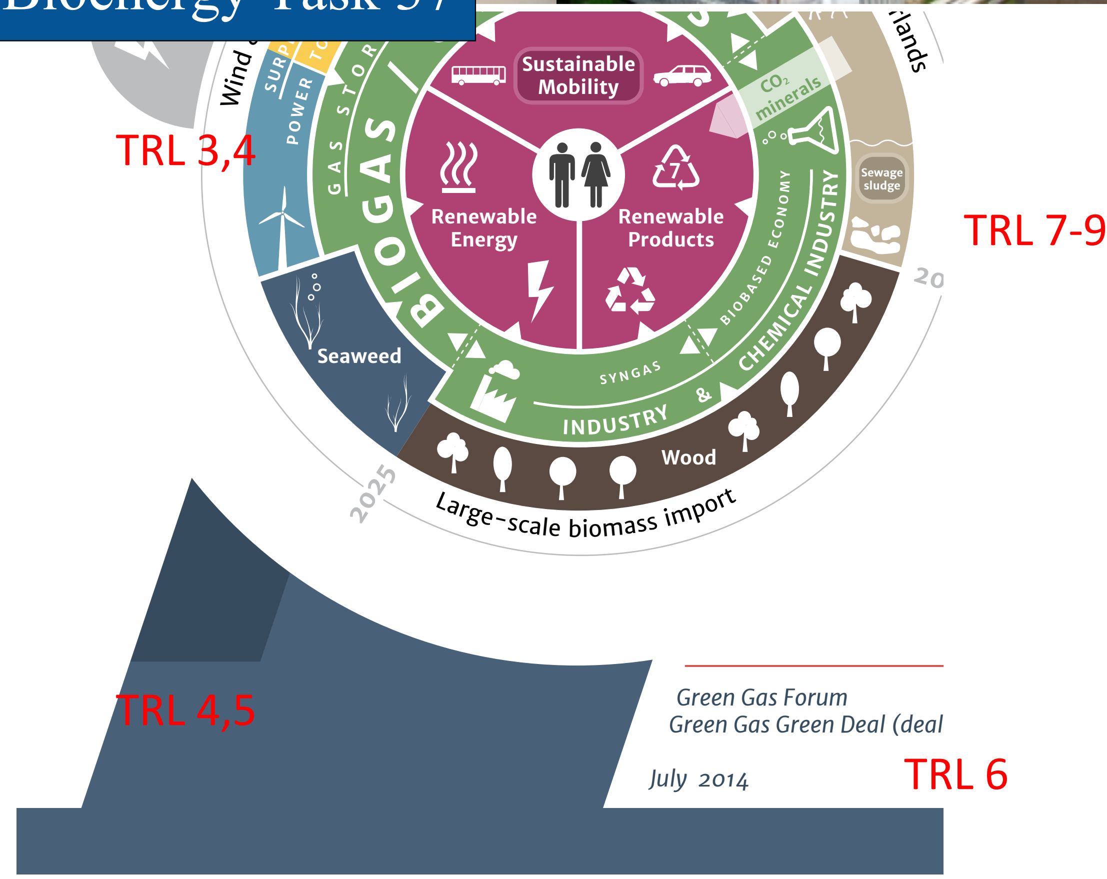
Ao Xia[1,2] and Jerry D. Murphy[1,3,*]



IEA Bioenergy Task 37

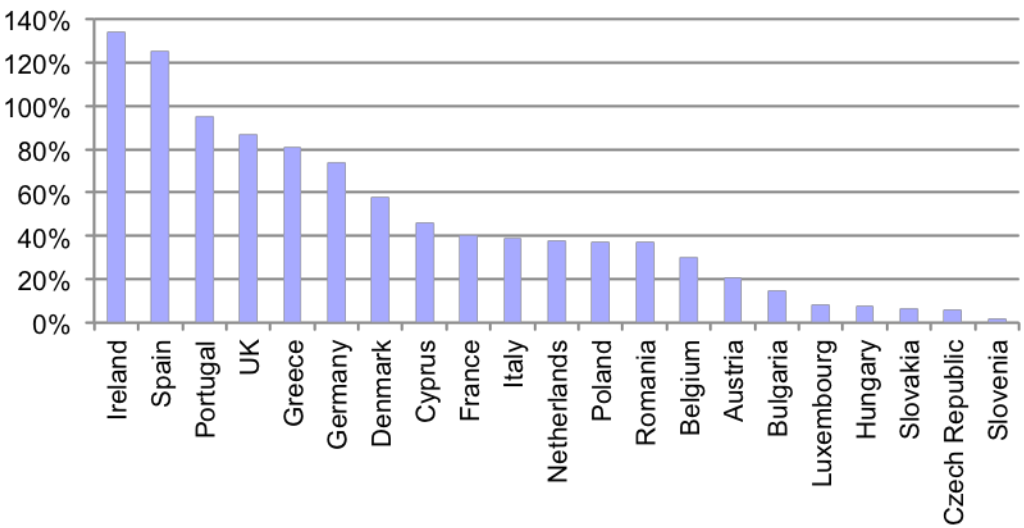
# Fourth stage of Industry

Green Gas from electricity

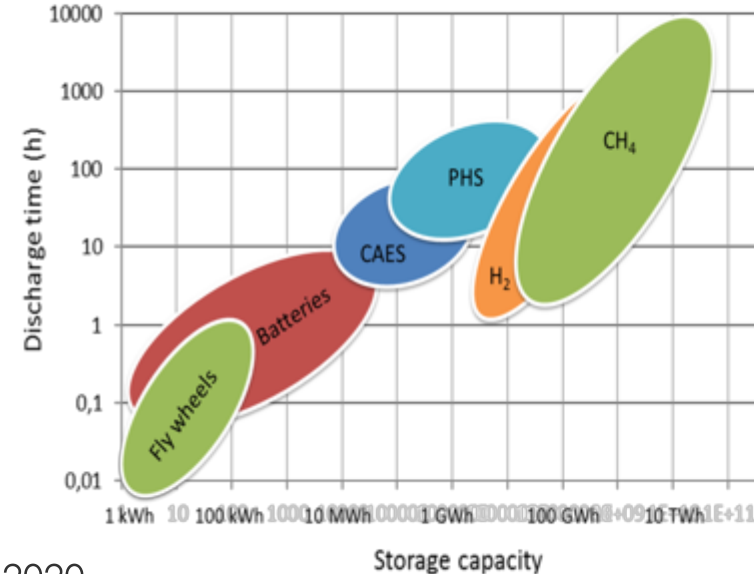



MaREI
Centre for Marine and Renewable Energy


# Curtailment and storage of variable renewable electricity




Wind capacity as a proportion of minimum demand in summer 2020




MaREI
Centre for Marine and Renewable Energy

UC

IEA Bioenergy Task 37

# Audi E-gas at Wertle, Germany

Food waste biomethane

Production of hydrogen in 6 MW electrolysis

Production of methane via Sabatier


1000 Audi NGVs

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

Cascading bioenergy, circular economy, carbon capture, carbon negative!

MaREI
Centre for Marine and Renewable Energy






# IEA Bioenergy Task 37

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com

ELSEVIER

## 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

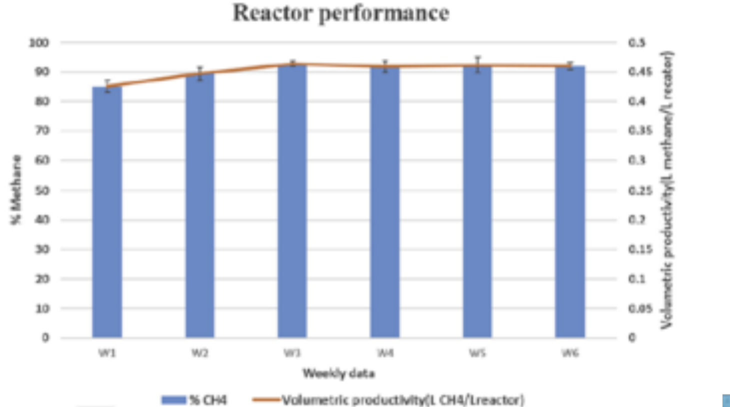
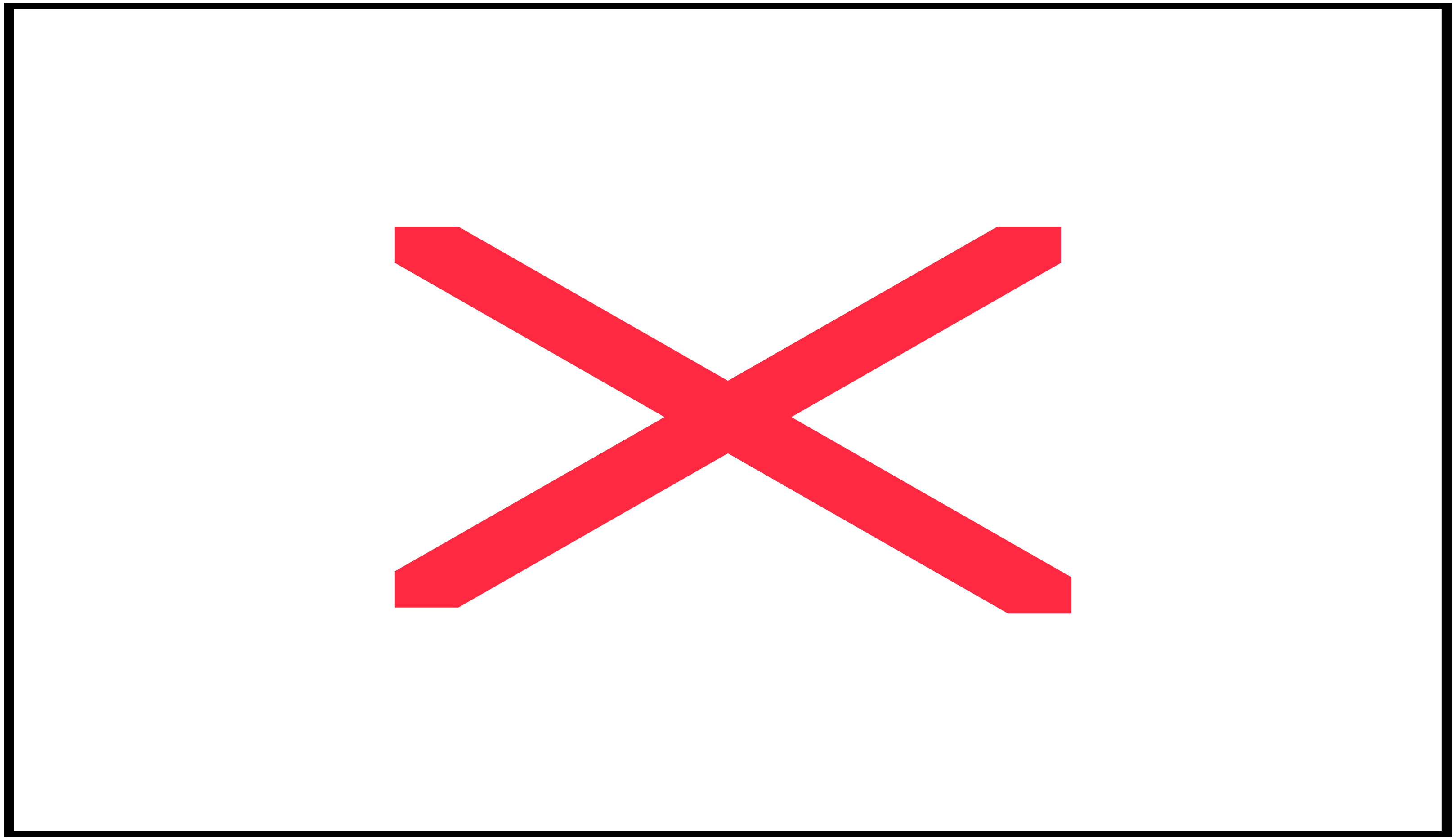



Fig. 3. Methane composition and volumetric productivity at 65 °C (fresh inoculum) for 24 h.

MaREI
Centre for Marine and Renewable Energy

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

# Power to $CH_4$ improve sustainability of biogas?



# S1: Conventional upgrading biogas to biomethane

# S3: H2 ex-situ upgrading biogas to biomethane

# Comparison of Sustainability of S1 & S3

Base case 80:20 Grass: slurry on a VS basis; 2% fugitive $CH_4$ losses: 41% green electricity
Sequestration of 2.2t$CO_2$/ha/a considered

# Green gas from electricity

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, 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:

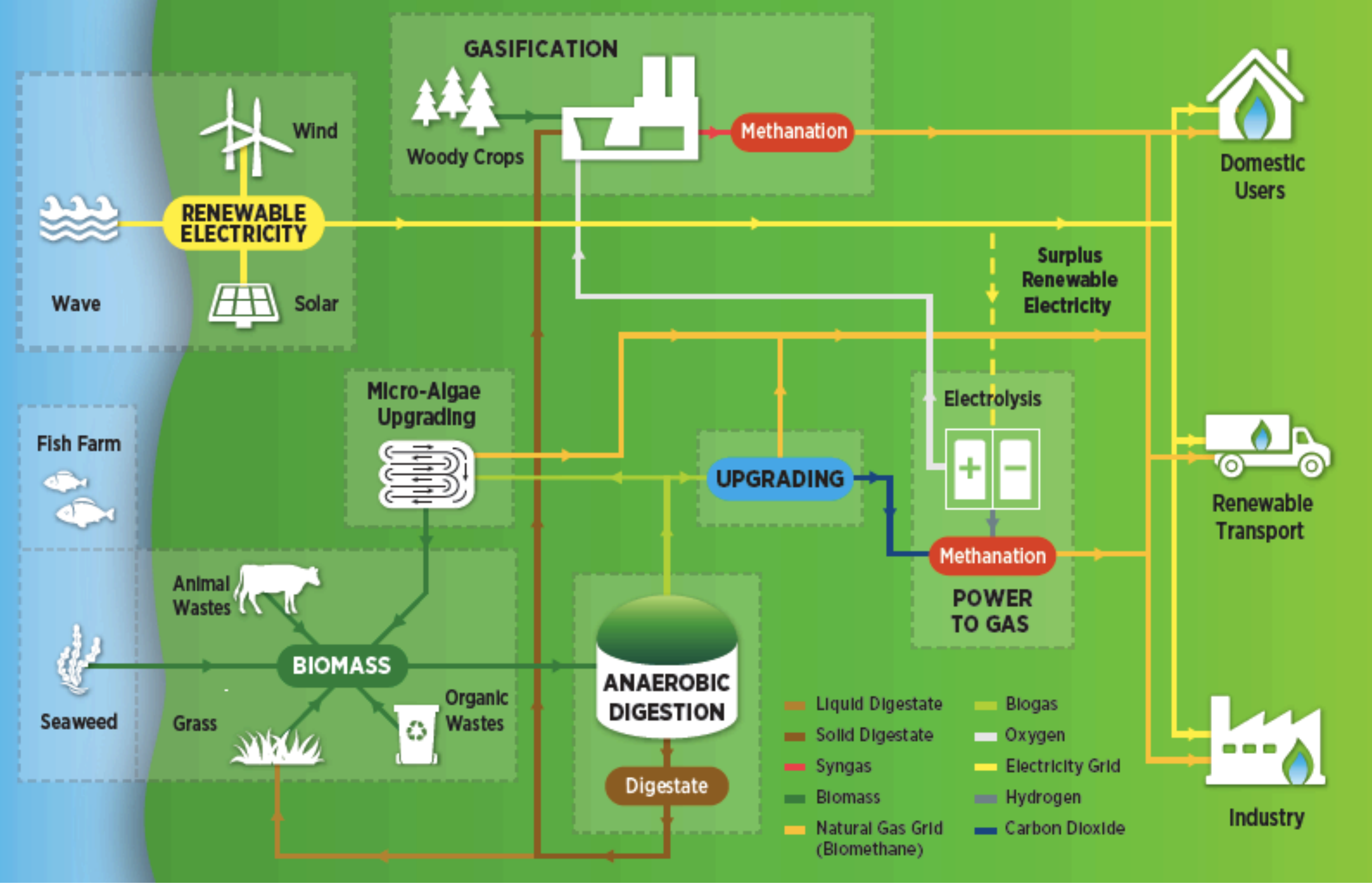
- Demand driven biogas systems which increase production of electricity from biogas facilities at times of high demand for electricity, or store biogas temporarily at times of low electricity demand.
- Power to gas systems when demand for electricity is less than supply of electricity to the electricity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

The report is aimed at an audience of energy developers, energy policymakers and academics and was produced by IEA Bioenergy Task 37. Task 37 is a part of IEA Bioenergy, which is one of the 40 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

University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

MaREI



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

"Unlocking the **potential** of our **marine** and **renewable energy resources** through the **power** of **research** and **innovation**"

www.marei.ie

MaREI Centre

@MaREIcentre

MaREI
Centre for Marine and Renewable Energy