MaREI
Centre for Marine and Renewable Energy

Green gas in the energy transition

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Leader International Energy Agency Bioenergy Biogas Task
MaREI Seminar on Climate Action Policy May 17th, 2019, ESRI, Dublin

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Science Foundation Ireland sfi For what's next

Biogas in Circular Economy

How do we account for the social and environmental benefits of anaerobic digestion?

Anaerobic digestion is not merely a source of renewable energy.

It can not be compared to a wind turbine or PV array.

Anaerobic digestion is a means of treating waste, is a means to reduce greenhouse gas in agriculture and in energy.

It is a source of biofertilizer, through mineralisation of nutrients in slurry to optimise availability.

It is a means of protecting water quality in streams and aquifers.

It is a source of renewable dispatchable electricity, heat and of advanced gaseous biofuel.






Agri-Food Waste Treatment




from 7000 t/a pig slurry, 47000 t/a slaughter waste, and blood

Linkoping, Sweden fuels 65 buses, 10 waste collection lorries, 600 cars and a train


Ireland has 8% of EU cattle herd and less than 1% of the population

Renewable Energy Directive

Greenhouse gas savings thresholds in RED II

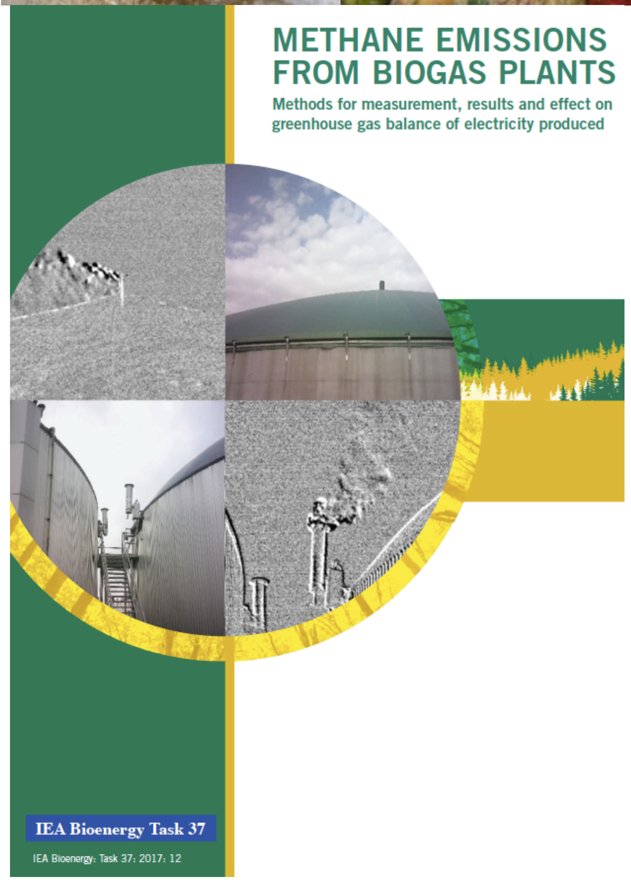
Plant operation start date	Transport biofuels	Transport renewable fuels of non-biological origin	Electricity, heating and cooling
After October 2015	60%	-	-
After January 2021	65%	70%	70%
After January 2026	**65%**	**70%**	**80%**

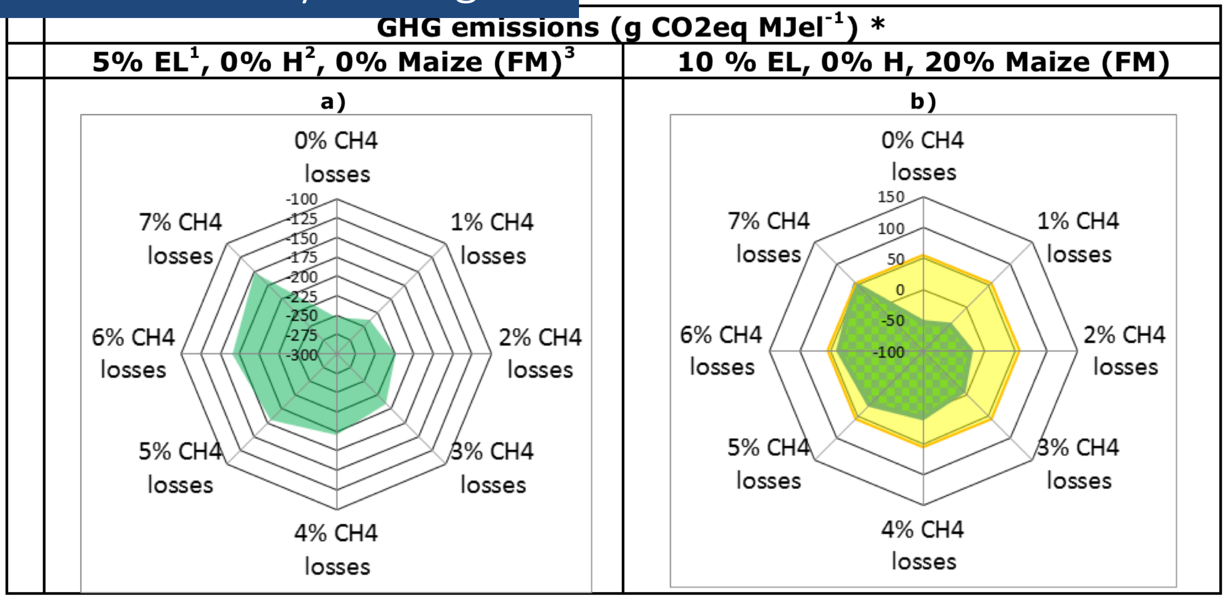
RED II states that perennial **rye grass is an advanced biofuel counted at twice its energy content**
The contribution of advanced biofuels and biogas produced from the feedstock listed in Part A of Annex IX shall be at least 3.5 % in 2030.
Annex IX Part A. Feedstocks for the production of biogas for transport and advanced biofuels, the contribution of which towards the minimum shares referred to in ..Article 25(1) may be considered to be twice their energy content:
This includes (p) “Other non-food cellulosic material” whose definition includes: (42) **grassy energy crops with a low starch content, such as ryegrass**, switchgrass, miscanthus, giant cane;






Sustainability of biogas





All slurry

20% Maize 80% slurry

Open slurry storage emits 17.5% of methane
At 2% methane slippage:

- Biomethane from slurry GHG negative feedstock (-250 g CO2/MJ)
- Biomethane from 20% Maize and 80% Slurry GHG still negative

California Air Resources Board (CARB) awarded a Carbon Intensity (CI) score of -255 gCO2e/MJ for a dairy waste to vehicle fuel pathway.

Carbon Efficient Farming

BIOGAS IN SOCIETY
A Case Story

ORGANIC BIOGAS IMPROVES NUTRIENT SUPPLY

KROGHSMINDE BIOENERGY I/S, DENMARK

IEA Bioenergy Task 37

IEA Bioenergy: Task 37: February 2019

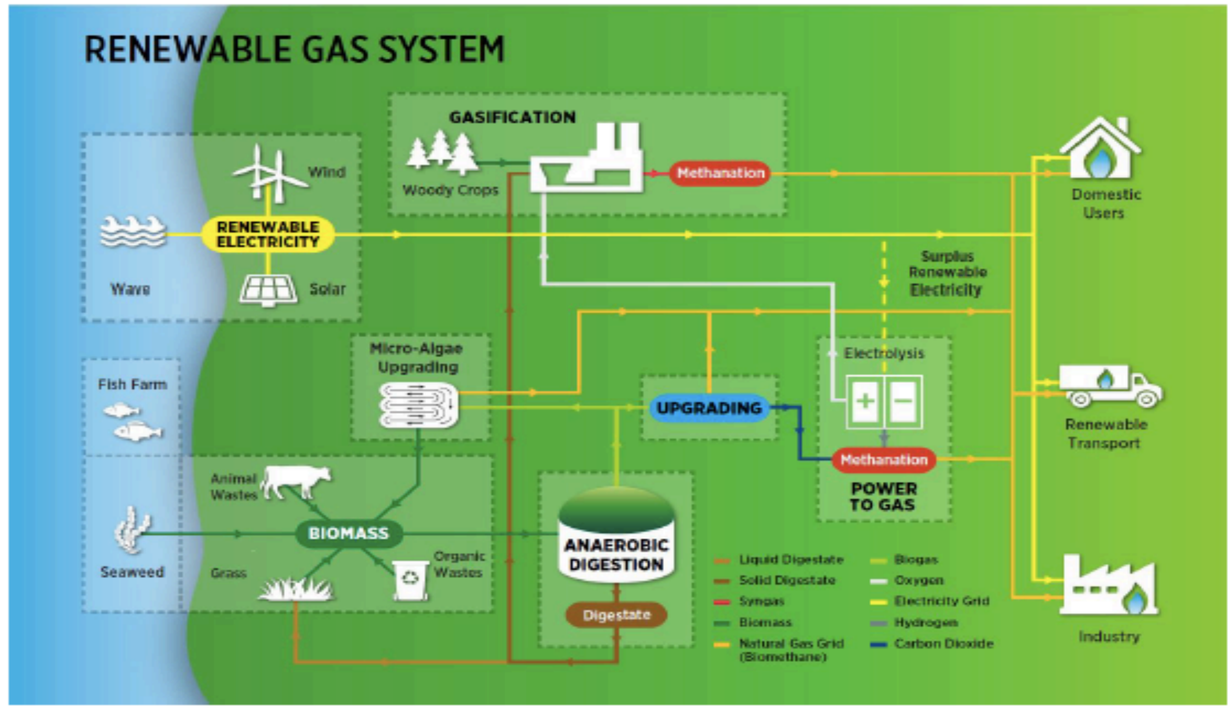
Table 1: Inputs to the organic biogas facility at Kroghsminde Bioenergy I/S, Denmark

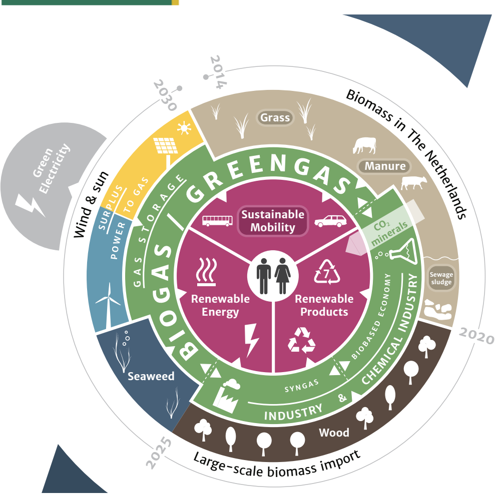
Daily Feedstock expressed in t/d	
Organic grass silage	5t/d
Corn	4t/d
Organic poultry manure	1t/d
Horse manure	1t/d
Organic silage (horse bean, lupine, barley / ryegrass)	2t/d
Organic deep litter	9t/d
Organic cattle slurry	48t/d
Total	**69t/d**

The farm produces milk from 140 cow and crops on a 450 hectare farm. The digester converts high dry matter content bedding material to a liquified organic fertilizer, the only source of fertilizer.

<u>Milk produced is assessed as GHG negative at -0.82 kg CO_2/ l produced.</u>

Green Gas Technologies





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






Centralised Biogas Upgrading


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

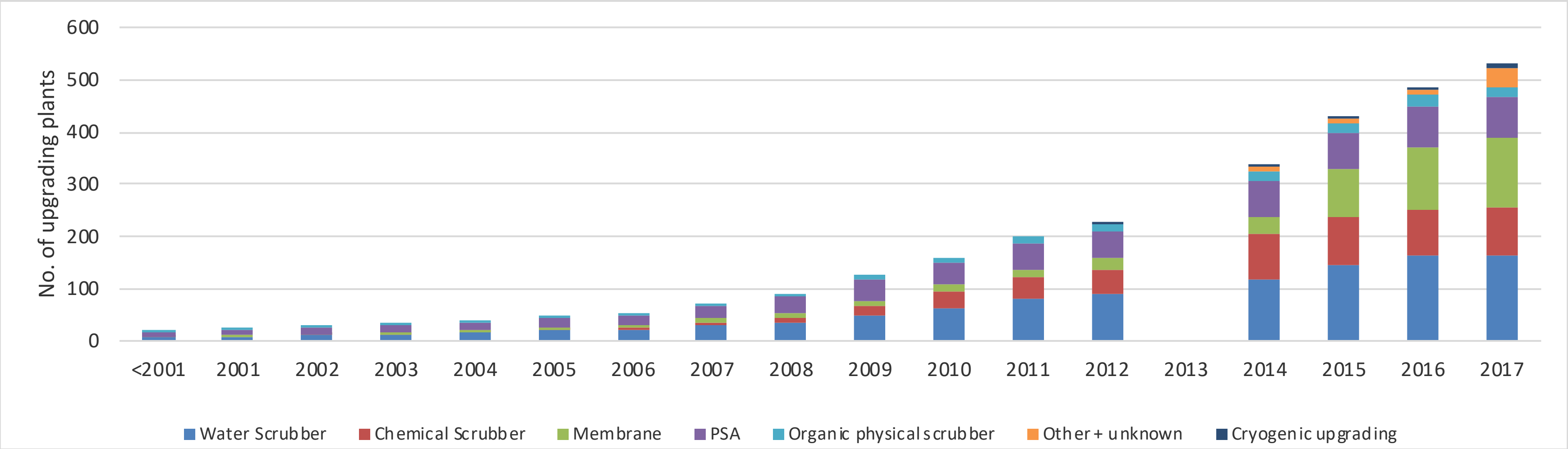
IEA Bioenergy: Task 37: April 2017

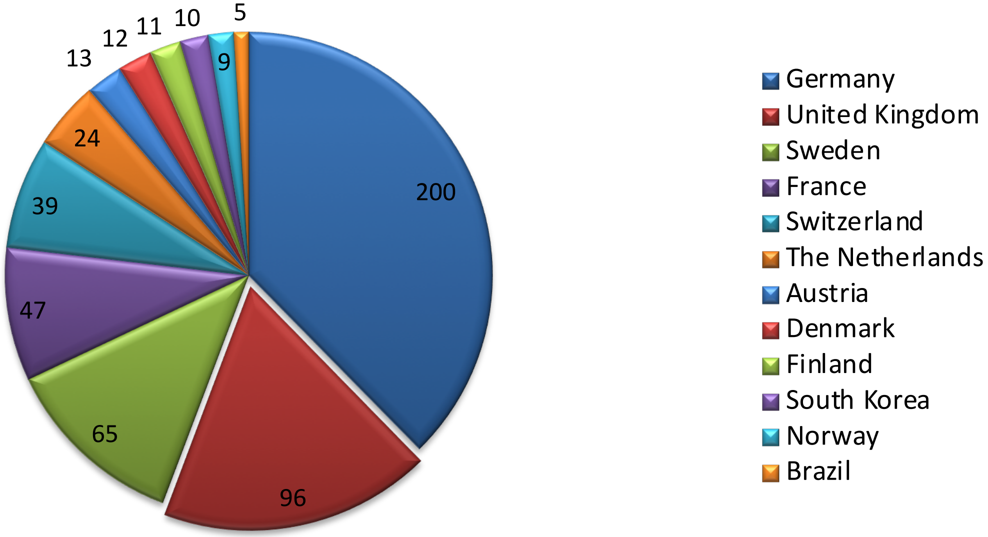
Figure 2:gas upgrading membranes at the Wijster green gas hub

Technique	Capacity Nm³ biogas/ hour	Green Gas Nm³ 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

Extent of Biogas Upgrading



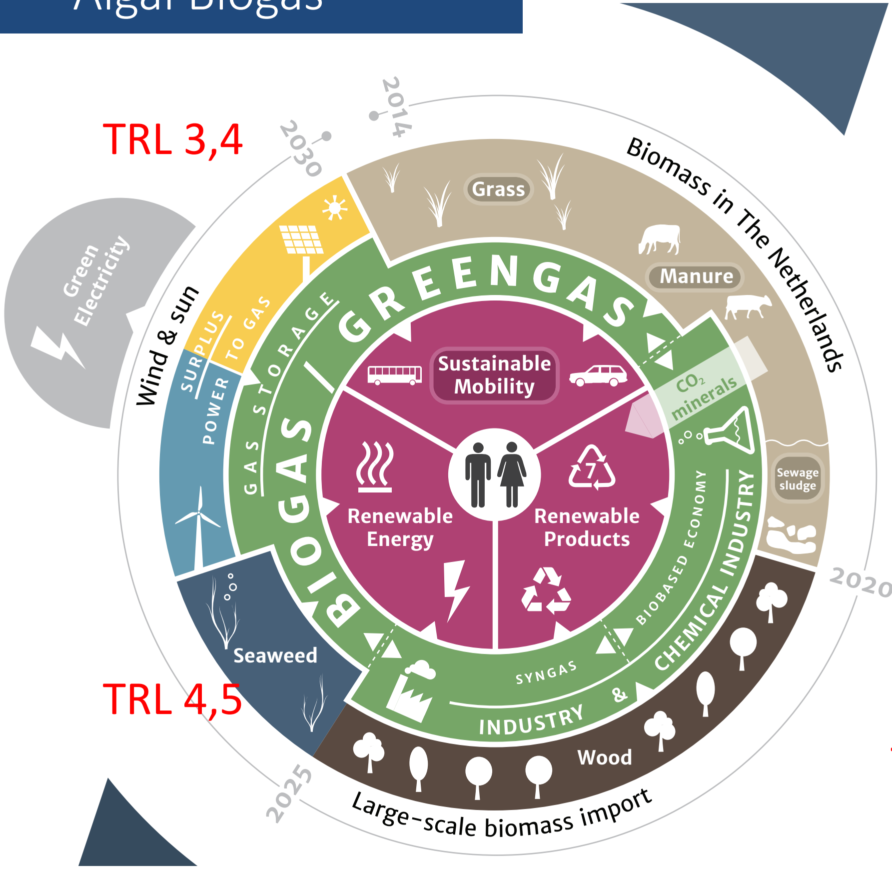


Growth and evolution of biogas upgrading in IEA Bioenergy Task 37 countries

Algal Biogas

TRL 3,4

TRL 7-9



TRL 4,5

TRL 6

Algal Biogas






Algal Biogas

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,*]

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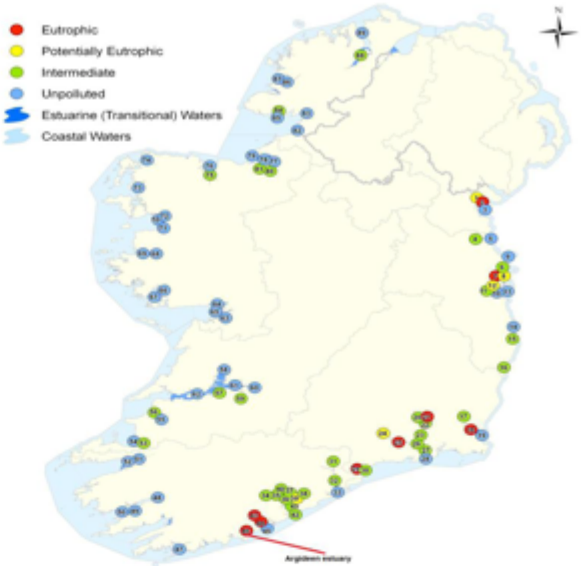

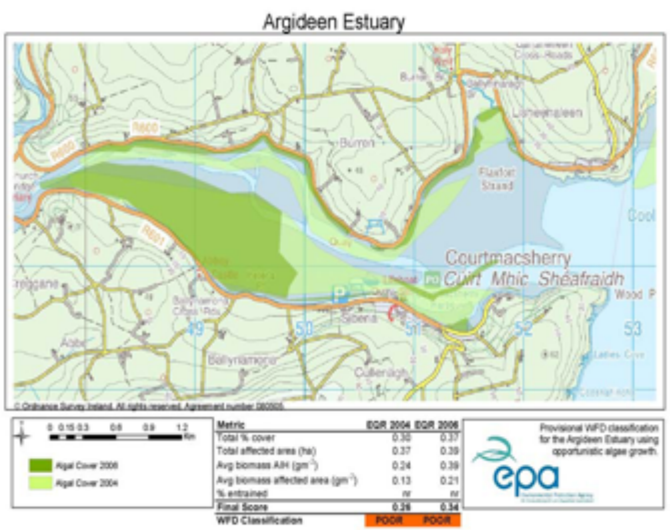






Algal Biogas

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

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[b] Key Laboratory of Low-grade Energy Utilization Technologies and Systems, Chongqing University, Chongqing 400044, China
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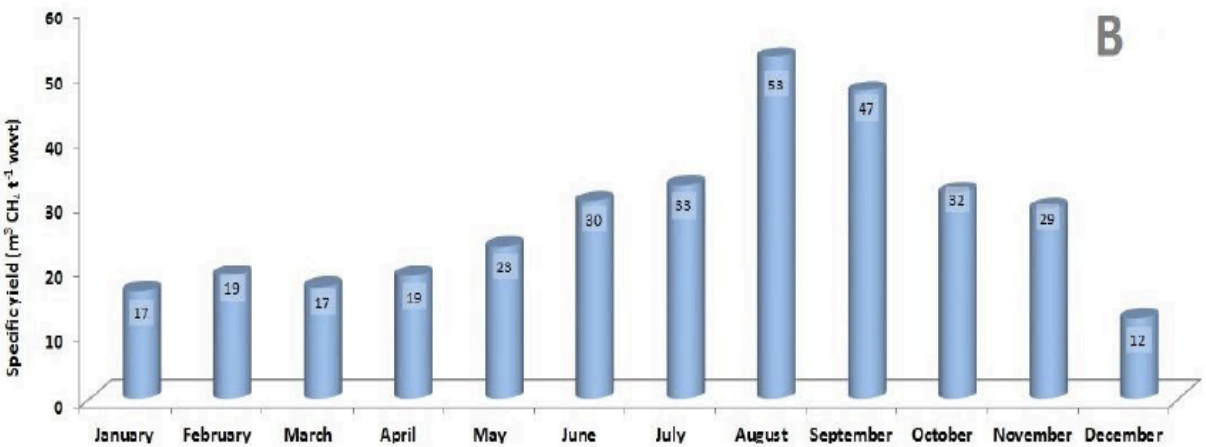


Seasonal Variation in biomethane yield from Laminaria Digitata

Cultivating Seaweed

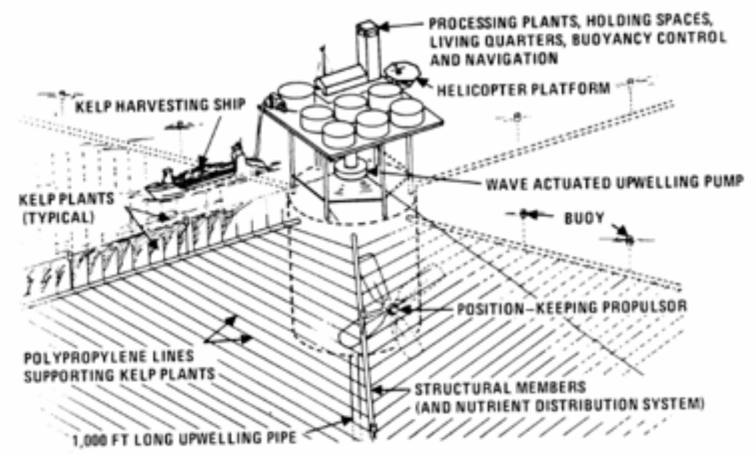


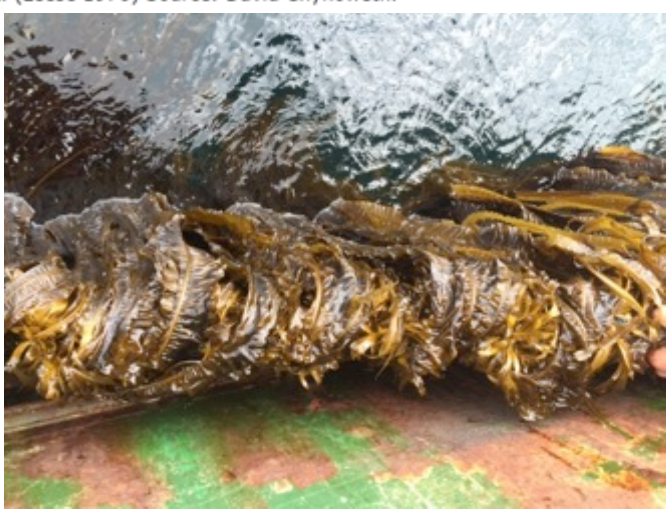
Figure 1. Conceptual design of 405 ha (1,000 acre) ocean food and energy farm unit. (Leese 1976) Source: David Chynoweth.

Position adjacent to fish farms, protect fish from jelly fish

Increased yields of seaweed as compared to pristine waters

Clean water of excess nutrients

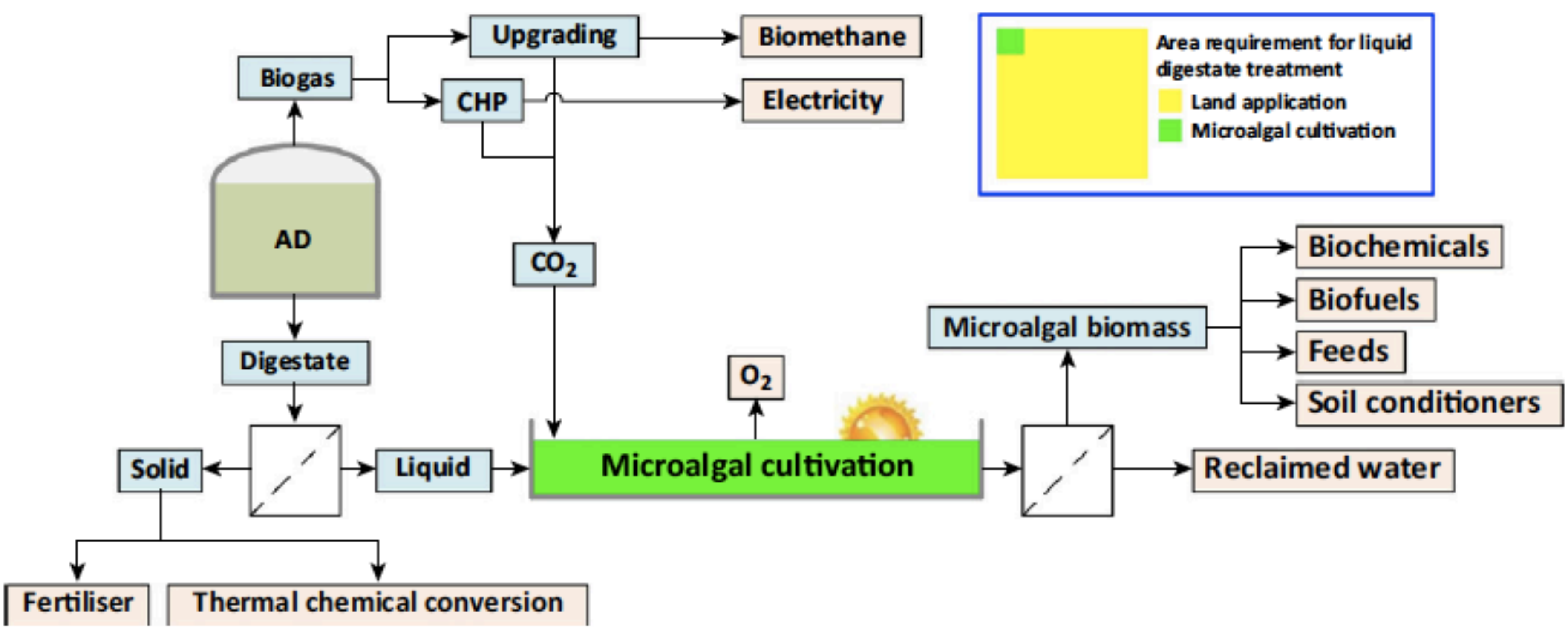
Harvest when yield is highest



Opinion

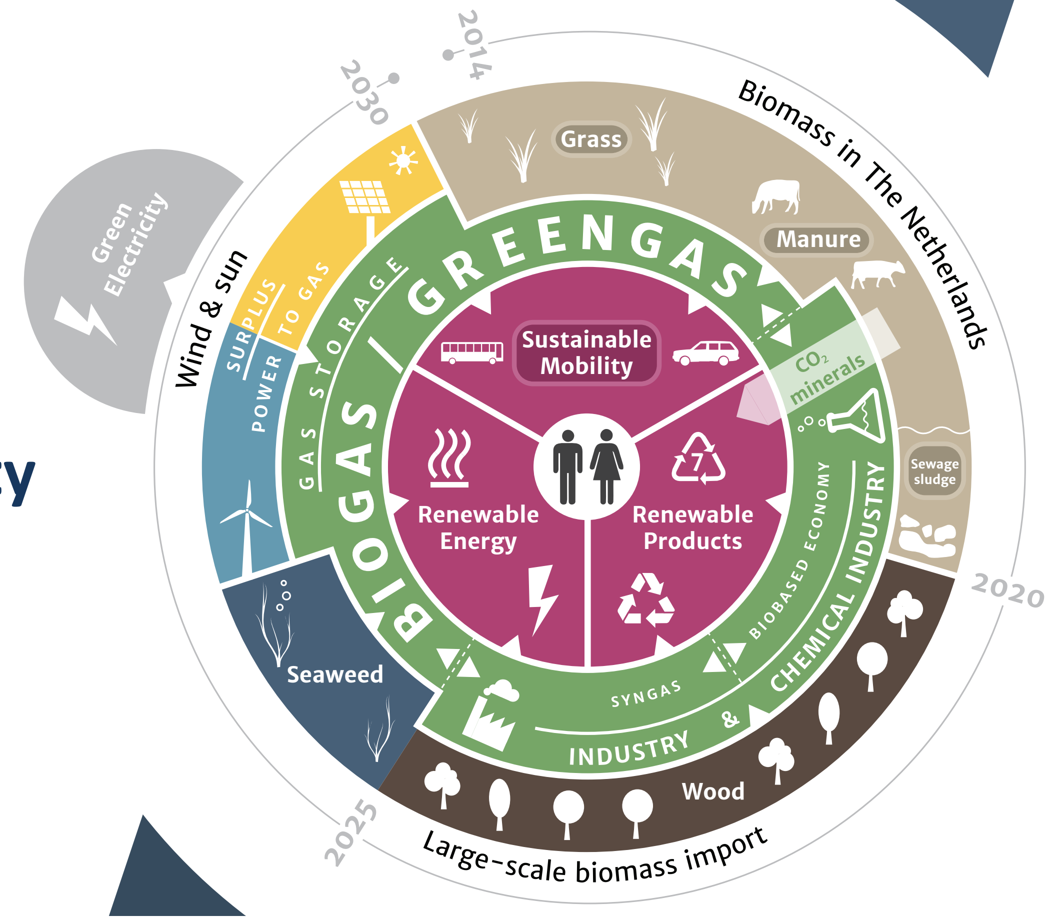
Microalgal Cultivation in Treating Liquid Digestate from Biogas Systems

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



Electro fuels

Green gas from electricity



Electro fuels

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.

Electro fuels

Bioresource Technology xxx (2016) xxx-xxx

ELSEVIER

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,*]

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[c] Key Laboratory of Low-grade Energy Utilisation Technologies and Systems, Chongqing University, Chongqing 400044, China
[d] School of Microbiology, University College Cork, Ireland

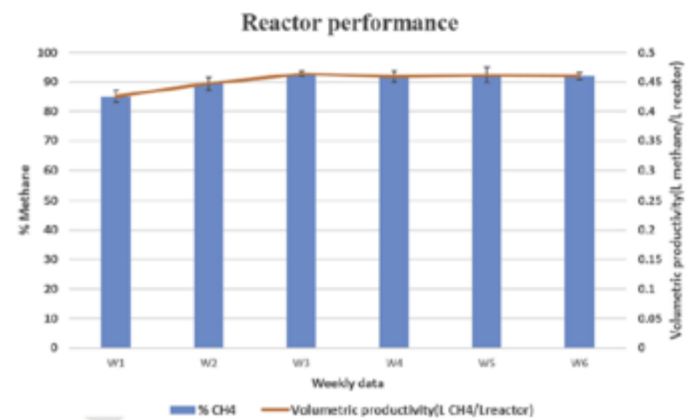

Fig. 3. Methane composition and volumetric productivity at 65 °C (fresh inoculum) for 24 h.

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

Electro fuels

Renewable Energy 131 (2019) 364–371

Contents lists available at ScienceDirect

Renewable Energy

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

The effect of electricity markets, and renewable electricity penetration, on the levelised cost of energy of an advanced electro-fuel system incorporating carbon capture and utilisation

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

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[c] Gas Networks Ireland, Cork, Ireland

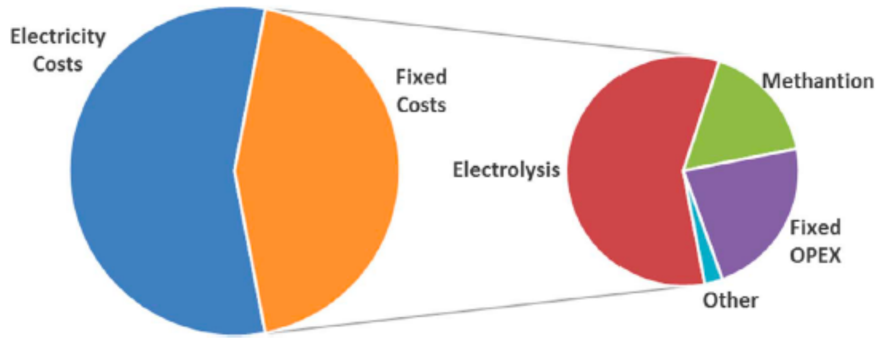

Fig. 3. Breakdown of the system LCOE into its components for 2020 base scenario.

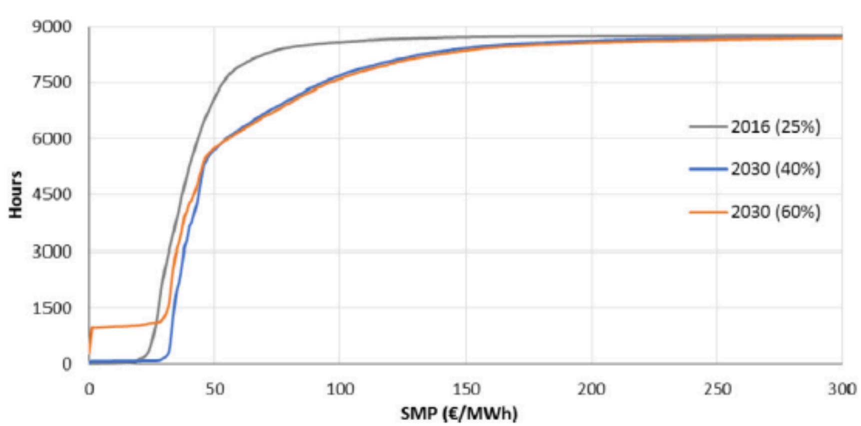

Fig. 3. Cumulative number of hours for which electricity is available at a given SMP.

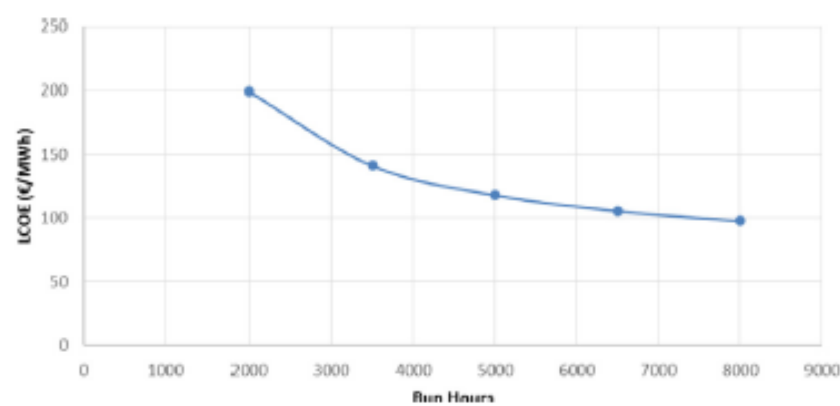

Fig. 7. Change in LCOE with increasing run hours and a fixed cost of electricity of €35/MW$_e$h.

Electro fuels

Applied Energy 247 (2019) 716–730

Contents lists available at ScienceDirect

Applied Energy

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

Are electrofuels a sustainable transport fuel? Analysis of the effect of controls on carbon, curtailment, and cost of hydrogen

Shane McDonagh[a,b,c,*], Paul Deane[a,b], Karthik Rajendran[a,d], Jerry D. Murphy[a,b]

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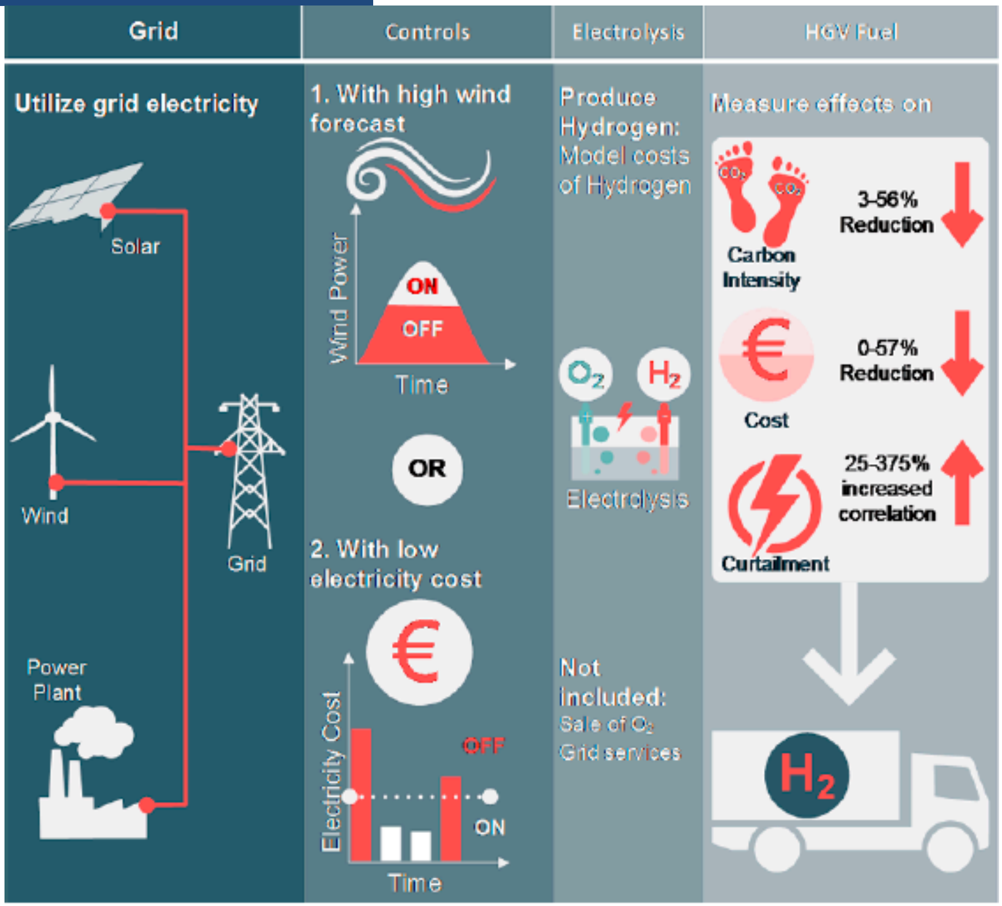
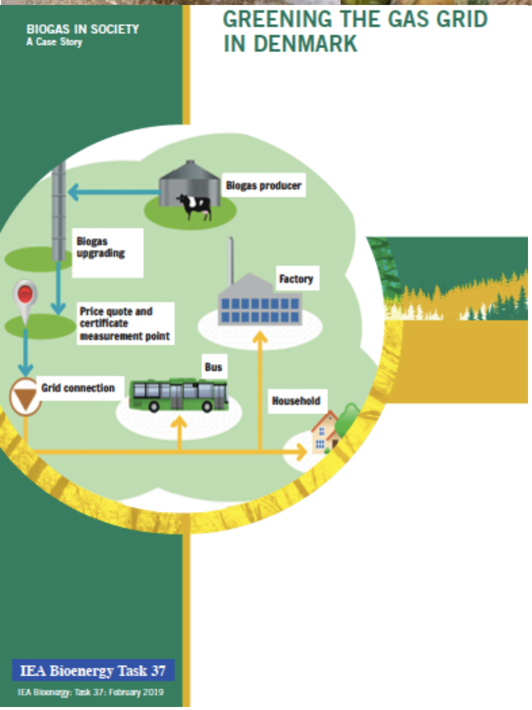
[c] Gas Networks Ireland, Cork, Ireland
[d] Department of Environmental Science, SRM University-AP, Amaravathi, Andhra Pradesh, India



Extent of Green Gas in Denmark



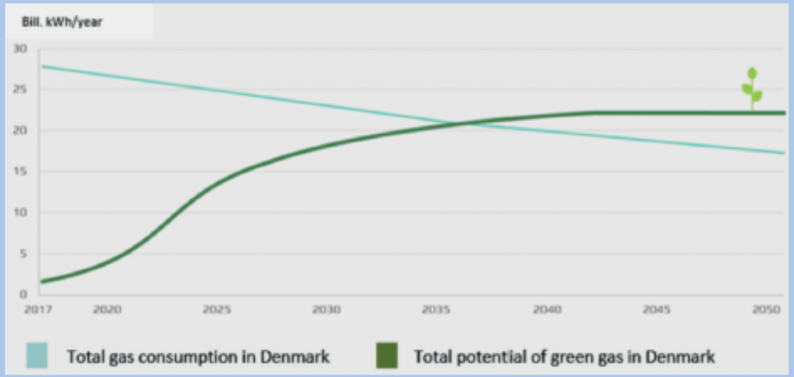


Figure 1: Gas consumption and potential of green gas in Denmark (from Green Gas Denmark)

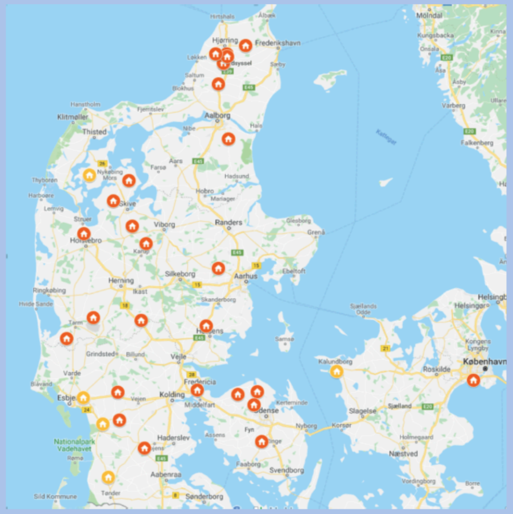


Figure 2: Grid connections for green gas in Denmark (yellow marks indicate connections established in 2017)

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

Denmark which at present has c. 10% renewable gas (with an equal amount going to CHP) intends decarbonising the gas grid with 72PJ of renewable gas by 2035. Addition of Power to Gas systems could see a resource of 100 PJ which would be in advance of gas demand.

Pipelines to extend catchment of biogas

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

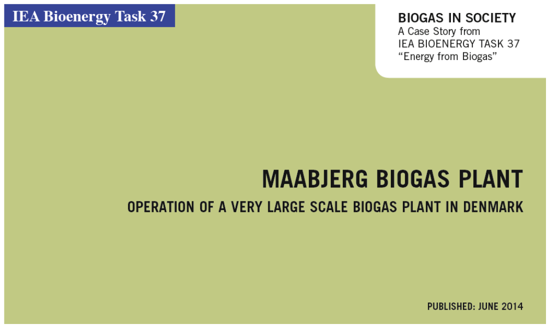


Table 1: INPUT

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

Table 2: OUTPUT

Green line	**tons/year**
Liquid fertilizer (digestate)	550.000
Fertilizer fibres	40.000
Industry line	**tons/year**
Sludge (30 % TS)	10.000
Biogas utilisation	**m³/year**
Vinderup Varmeværk (District heating)	7.500.000
Måbjergværket (District heating)	3.500.000
Maabjerg BioEnergy	7.000.000
Total industry line	**85.000**
Biogas total	**18.000.000**

Source: Maabjerg BioEnergy

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

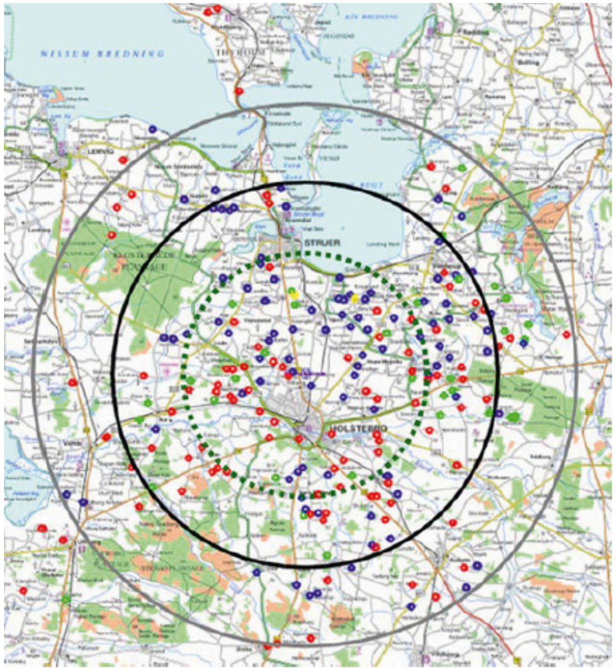
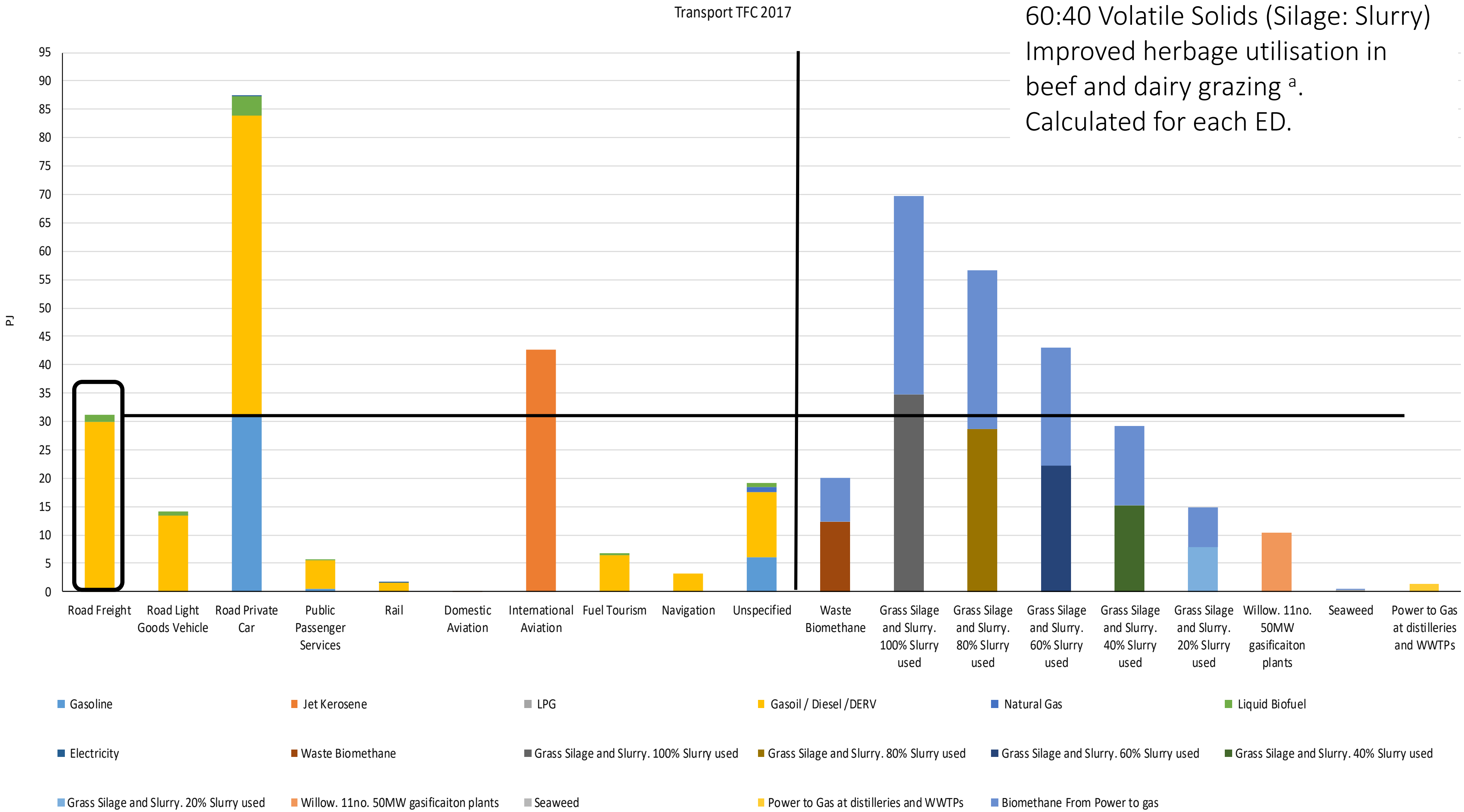


Figure 2: The area of animal slurry collection around the biogas plant, with the average radius of 20 km. Source: Maabjerg BioEnergy

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

Resource of biogas in Ireland

60:40 Volatile Solids (Silage: Slurry)
Improved herbage utilisation in beef and dairy grazing [a].
Calculated for each ED.



[a] Mceniry, J. et al., 2013. How much grassland biomass is available in Ireland in excess of livestock requirements ? *Irish Journal of Agricultural and Food Research*, 52, pp.67–80. Available at: http://t-stor.teagasc.ie/bitstream/11019/451/1/ijafr_67-80.pdf.






Cost of Biogas Systems

Modeling and Analysis

Biofpr Biofuels Bioproducts & Biorefining

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

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Henry Smyth, Bord Gáis Éireann, Cork, Ireland
Jerry D. Murphy, ERI, UCC, Ireland

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

As a rule of thumb the following is used in Sweden and Germany:

- 22c/m3 biomethane to make biogas,
- 22c/m3 to upgrade to biomethane,
- 11c/m3 biomethane to compress and 11c/m3 biomethane to distribute.
- This is 66c/m3 biomethane or 66c/L diesel equivalent or 6.6c/kWh.

If you buy all the feedstock this rises. Say €35/ t silage (silage @ 28% VS and 380 m3 CH4/tVS = 106 m3 CH4/ t;) adds 33c/ m3. This would lead to an overall cost of 99 c/m3 or 9.9 c/kWh. This should be lowered as we do not see 100% mono-digestion as a good model.

On the other hand for food waste there is a decrease in cost; (say 28% VS and 380 m3/tVS =) 106m3 CH4/t with a gate fee of €35/t drops the cost by 33c/m3 to 33c/m3 biomethane or 3.3 c/kWh

Highlights

1. **How do we cost the asset value associated with the circular economy benefits of anaerobic digestion?** Biogas systems include for waste treatment and can help decarbonise agriculture. The by-products include for organic biofertilizer & green CO2. Biogas systems improve both ground water and surface water quality. One third of Irish wells are contaminated.

2. **The EU requires 3.5% advanced biofuel by 2030.** Biogas produced from perennial rye grass is a viable commercially available advanced biofuel, which is cheaper than other advanced biofuels such as FT diesel. This is particularly important for **haulage and coaches** as there are few alternatives to decarbonise this sector of transport.

3. **Grass and slurry in a 60:40 VS ratio results in a 80% GHG savings**. This allows compliance with the 65% and 80% GHG savings required by the RED for transport and heat respectively.

4. **The cost of biomethane varies between 33 to 99 c/L diesel equivalent (3.3 to 9.9 c/kWh)**

5. **Policy such as the Danish target of 50% digestion of slurries by 2020 can increase the slurry resource significantly**. 80% of the geographical specific resource of grass and slurry is available within 25 km of the gas grid. With power to gas we can generate 40 PJ/a (in excess of HGV demand)

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