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RESEARCH CENTRE
FOR ENERGY RESOURCES
AND CONSUMPTION

Bioenergy training: Biogas

Alessandro Carmona, PhD ↗

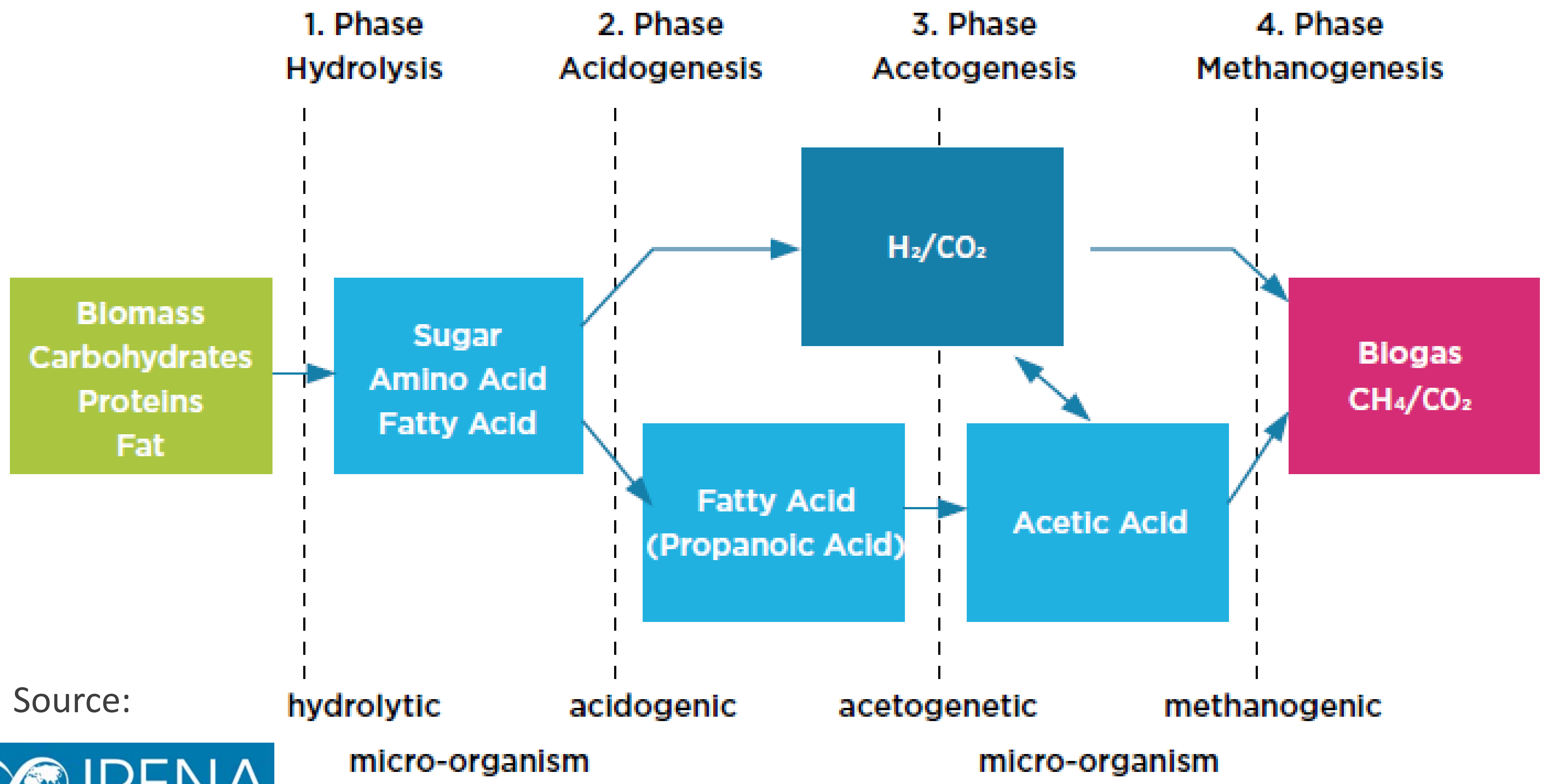
December the 11th, 2020

Meeting's agenda

1. Current Technologies at small scale; focus on rural areas
2. Current industrial examples

The anaerobic digestion process

Stages of organic material degradation by microorganisms under anaerobic conditions



Source:

IRENA
International Renewable Energy Agency

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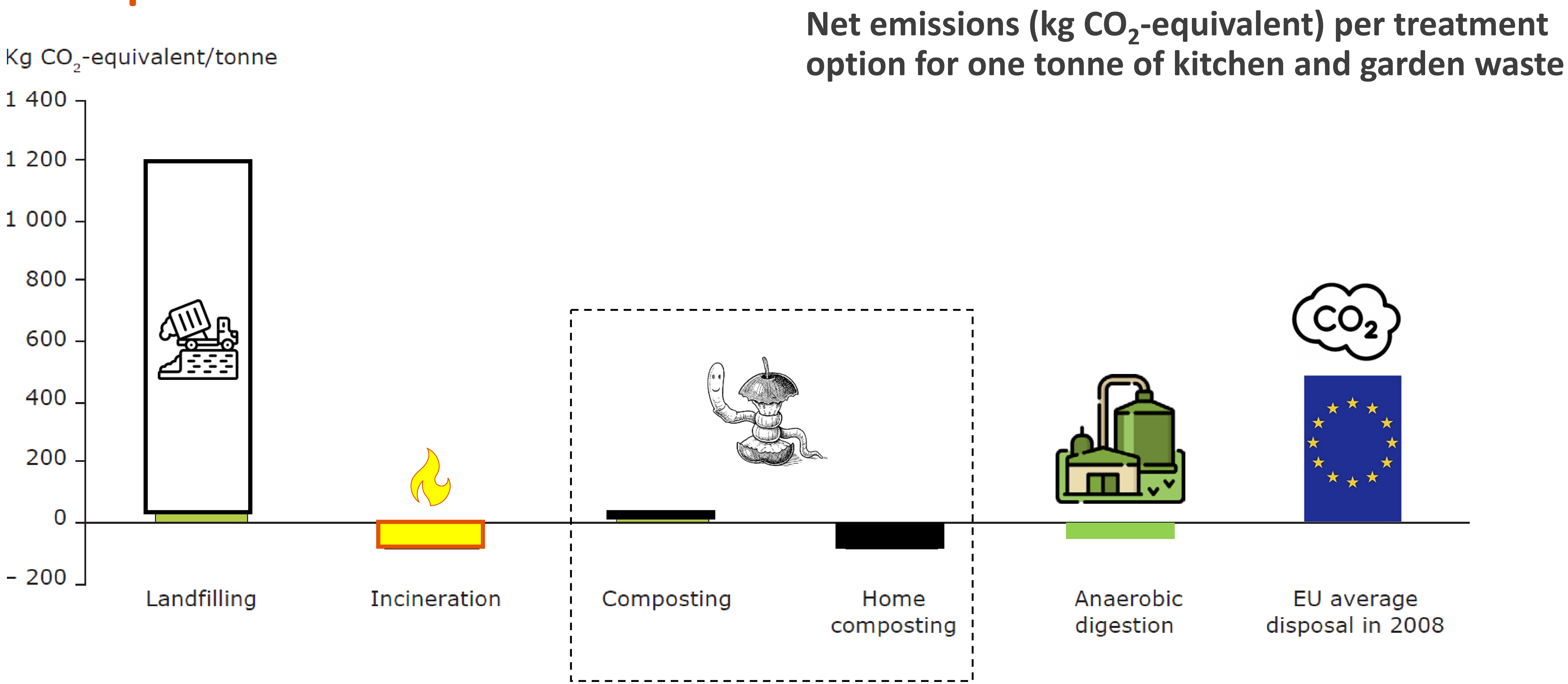
Importance of AD

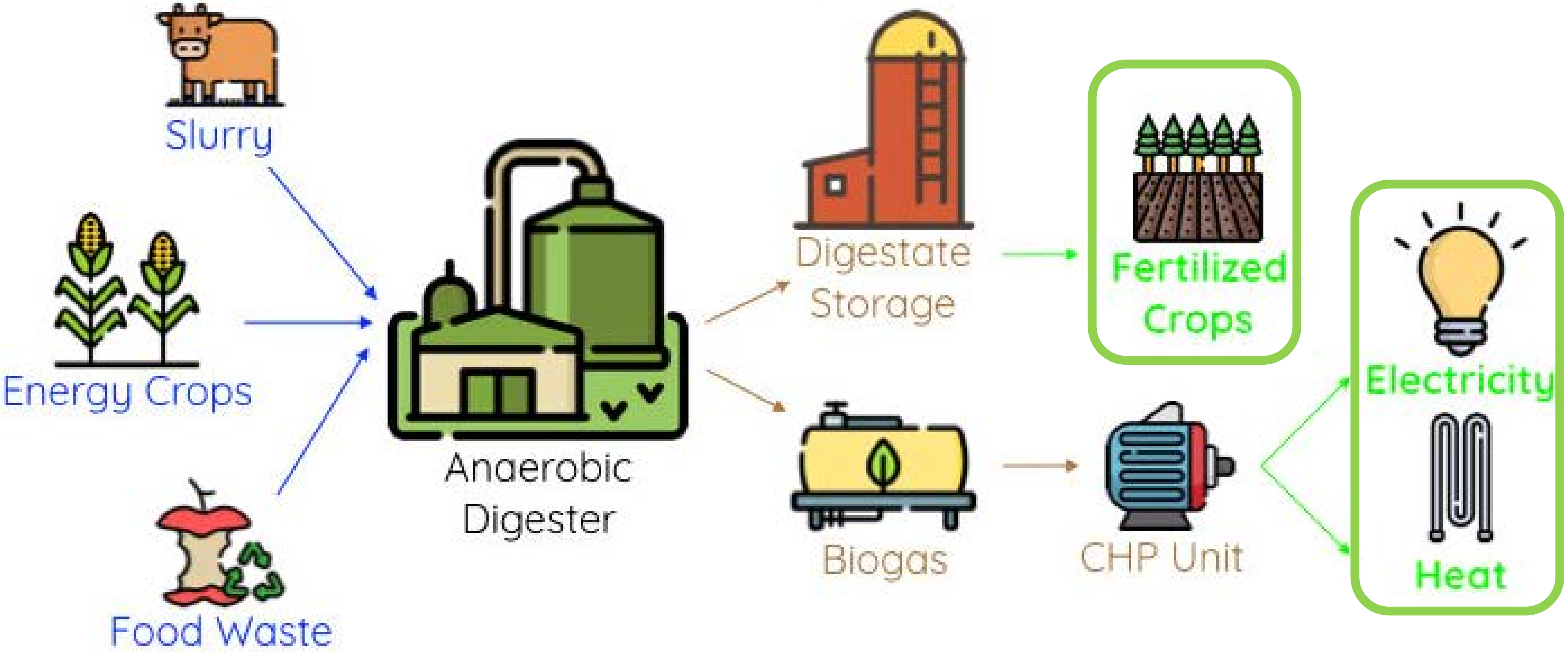


Note: Emissions cover only the waste management stage of the life cycle.

Source: European Environment Agency

The anaerobic digestion process

Simplified diagram of the anaerobic digestion process



Source: Clean Coast Resources

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SECTION 1

Current Technologies at small scale; focus on rural areas

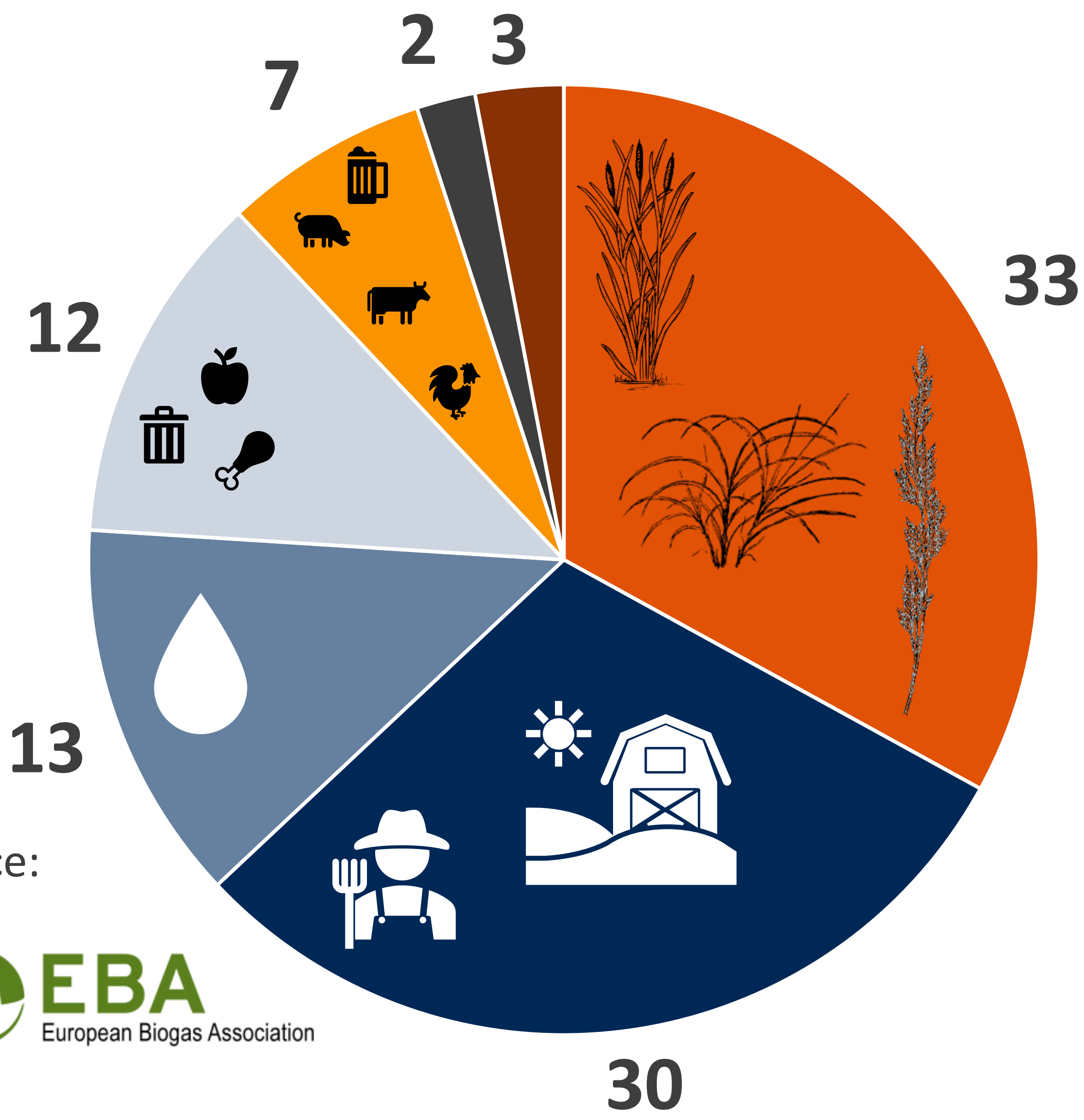
Traditional technologies

- **Differences between agricultural residues and other type of feedstock for the anaerobic digestion process**
- Pretreatment technologies (physical, chemical and biological pretreatments)
- Logistics (Costs Distance for transportation of biomass and Investment schedule)
- Storage and seasonality of biomass (biomass ensiling of biomass for AD)
- Technologies for biogas upgrading
- Good Practice for Efficient Use of Heat from Biogas Plants
- Novel added-value products from biogas besides heat and power

Traditional technologies

Source: Renewable and Sustainable Energy Reviews, Volume 28, December 2013, Pages 900-916 — An overview of biofuels from energy crops: Current status and future prospects — Günnur Koçar, Nilgün Civaş

Distribution of biomethane plants per feedstock type in %



- ENC Energy Crops
- AGR Agricultural Residues, Manure, Plant residues
- SWW Sewage Sludge
- MSW Bio- and Municipal Waste
- FAB Industrial OW: Food & Beverage Industries
- LAN Landfill
- Unknown

Source: EBA European Biogas Association

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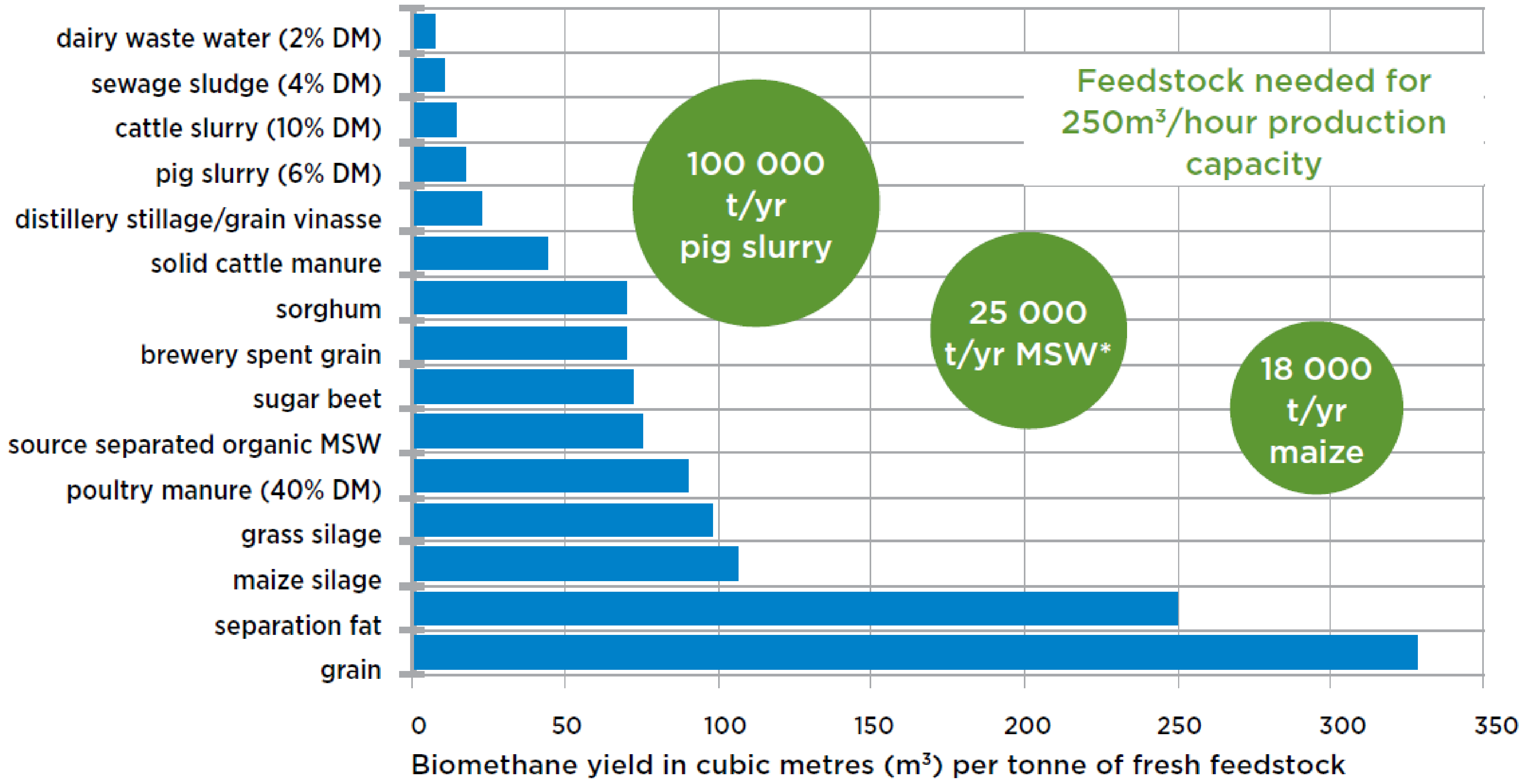
Traditional technologies

Biomethane yield from different feedstocks

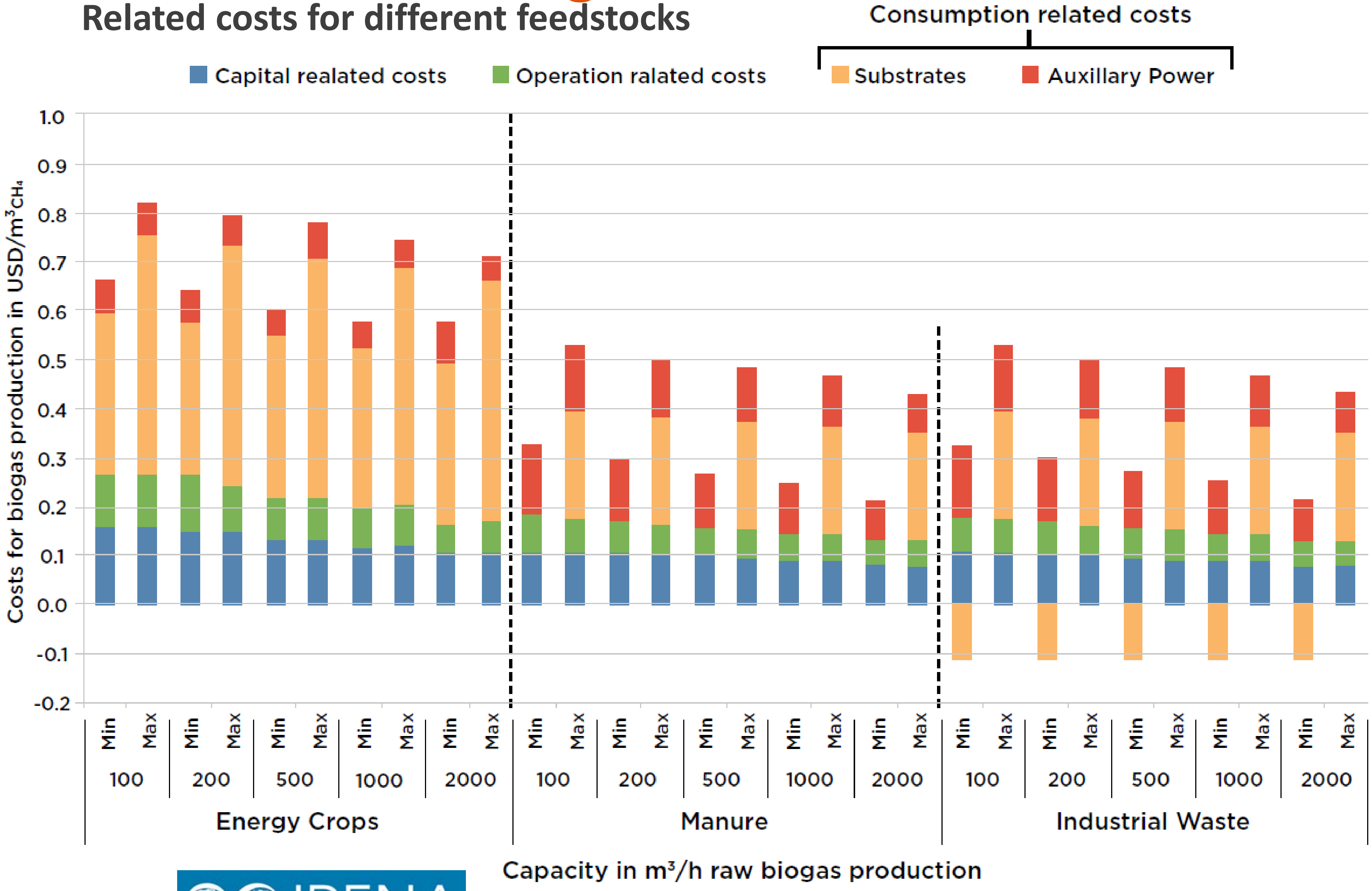
Source: IRENA International Renewable Energy Agency

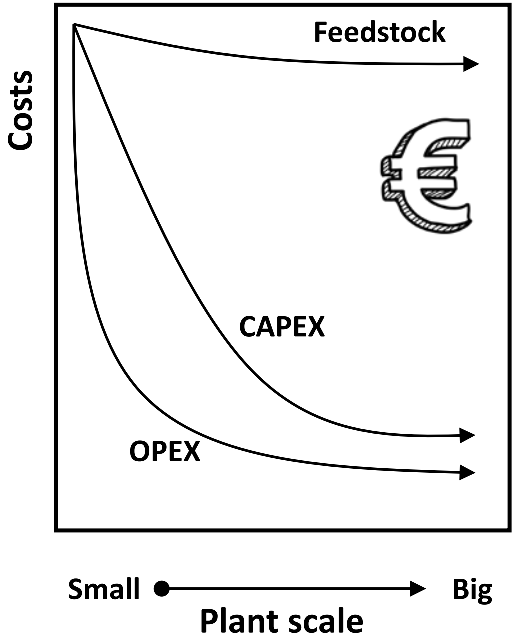


DM = dry matter MSW = municipal solid waste t/yr = tonnes per year

Traditional technologies

Related costs for different feedstocks





Source: IRENA International Renewable Energy Agency

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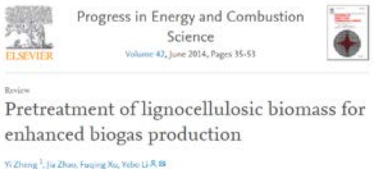
Pre-treatment technologies (1/2)

Source:

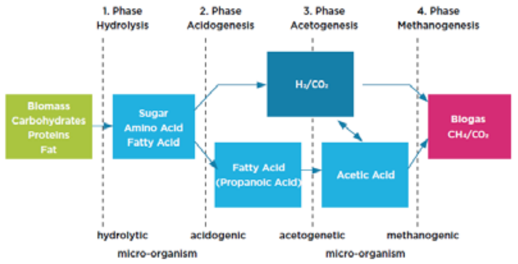


Effect of pretreatment on the compositional and structural alteration of lignocellulosic biomass. (Adapted from Hendriks and Zeeman [29]).[a]

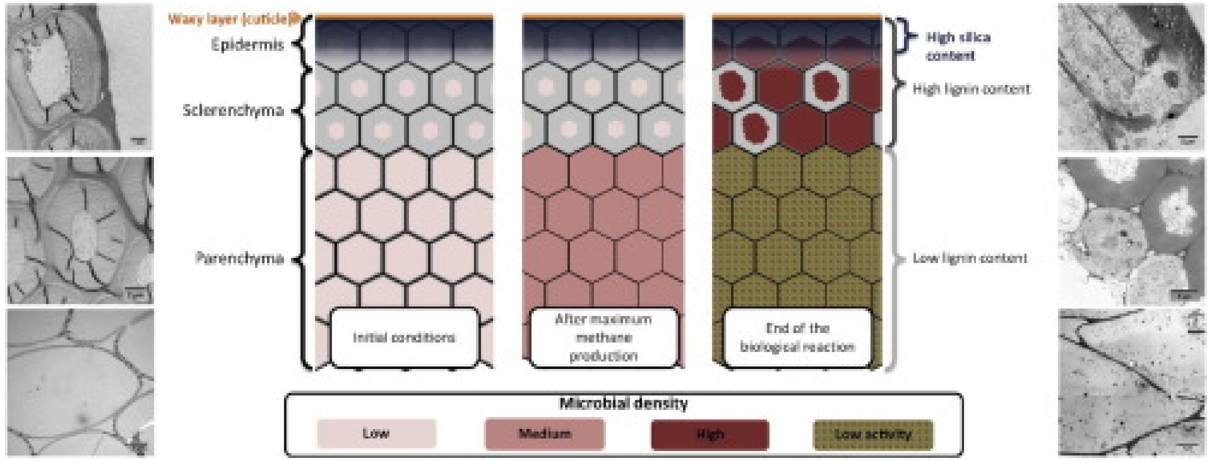
	Pretreatment	Increase of accessible surface area	Decrystallization of cellulose	Solubilization of hemicellulose	Solubilization of lignin	Alteration of lignin structure	Formation of furfural/ hydroxymethylfurfural (HMF)
Physical	Mechanical	●	●				
	Irradiation	●	○	○			○
	Steam-explosion	●		●	○	●	●
	Liquid hot water	●	ND	●	○	○	○
Chemical	Catalyzed steam-explosion	●		●	●/○	●/○	●
	Acid	●		●	○	●	●
	Alkaline	●		○	●/○	●	○
	Oxidative	●	ND		●/○	●	○
	Ionic liquids	●	●	○			
	Thermal acid	●	ND	●			●
	Thermal alkaline	●	ND	○	●/○	●	○
	Thermal oxidative	●	ND	○	●/○	●	○
	Ammonia fiber explosion	●	●	○	●	●	○
	Biological pretreatment	●	ND	●	●	●	

[a] ● = major effect, ○ = minor effect, ND = not determined, and blank = no effect.

Y. Zheng et al. / Progress in Energy and Combustion Science xxx (2014) 1–19



Source:



Pre-treatment technologies (2/2): “biological ones”

U. Brémond et al. Renewable and Sustainable Energy Reviews 90 (2018) 583–604

Table 5
Biological pretreatments: Effect on biogas and methane yield and *existing full-scale technology* in function of the feedstock.

		Agricultural waste		OFMSW	FW	MSW Landfill	Sludge (WAS)
		Lignocellulose rich	Easily biodegradable				
Enzymes	Protease	--		-/+	-/+		++
	Lipase	/		-/+	-/+		-/+
	Carbohydrase	++ *Methaplus® – Optimash®*	+ *Methaplus® – Optimash®*	-/+	-/+	++	++
	Lignin-modifying	++				++	
Anaerobic	Two-Stage	-/+	+ *Bioplex process*	+ *Gicon® - Biomet®*	+ *Gicon® - Biomet®*	/	++ *Monsal™ ADT*
	Enhanced two-stage	+				/	
	Ensiling	+		/	/	/	/
Aerobic	Simple aeration	++ *Pile composting*		-	--	-/+	++
	Pure culture	+++		+		/	/
	Consortia (solid or liquid)	+++ *Methalyse® - Bacteriometha®*		+		/	

+/++/+++ : Lab or pilot scale positive results -/-- : Lab scale negative results [boxed cell] : Positive results with *existing full-scale technologies*

[green cell] : Unexplored field with expected positive results [hatched cell] : Unexplored field with expected negative results [/] : Not applicable

Source:

Renewable and Sustainable Energy Reviews
Volume 90, July 2018, Pages 583-604

Biological pretreatments of biomass for improving biogas production: an overview from lab scale to full-scale

Ulysse Brémond [a,b], Raphaëlle de Buyer [a], Jean-Philippe Steyer [b], Nicolas Bernet [b], Hélène Carrere [b]

SECTION 1

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Traditional technologies

An agricultural scheme of the anaerobic digestion process

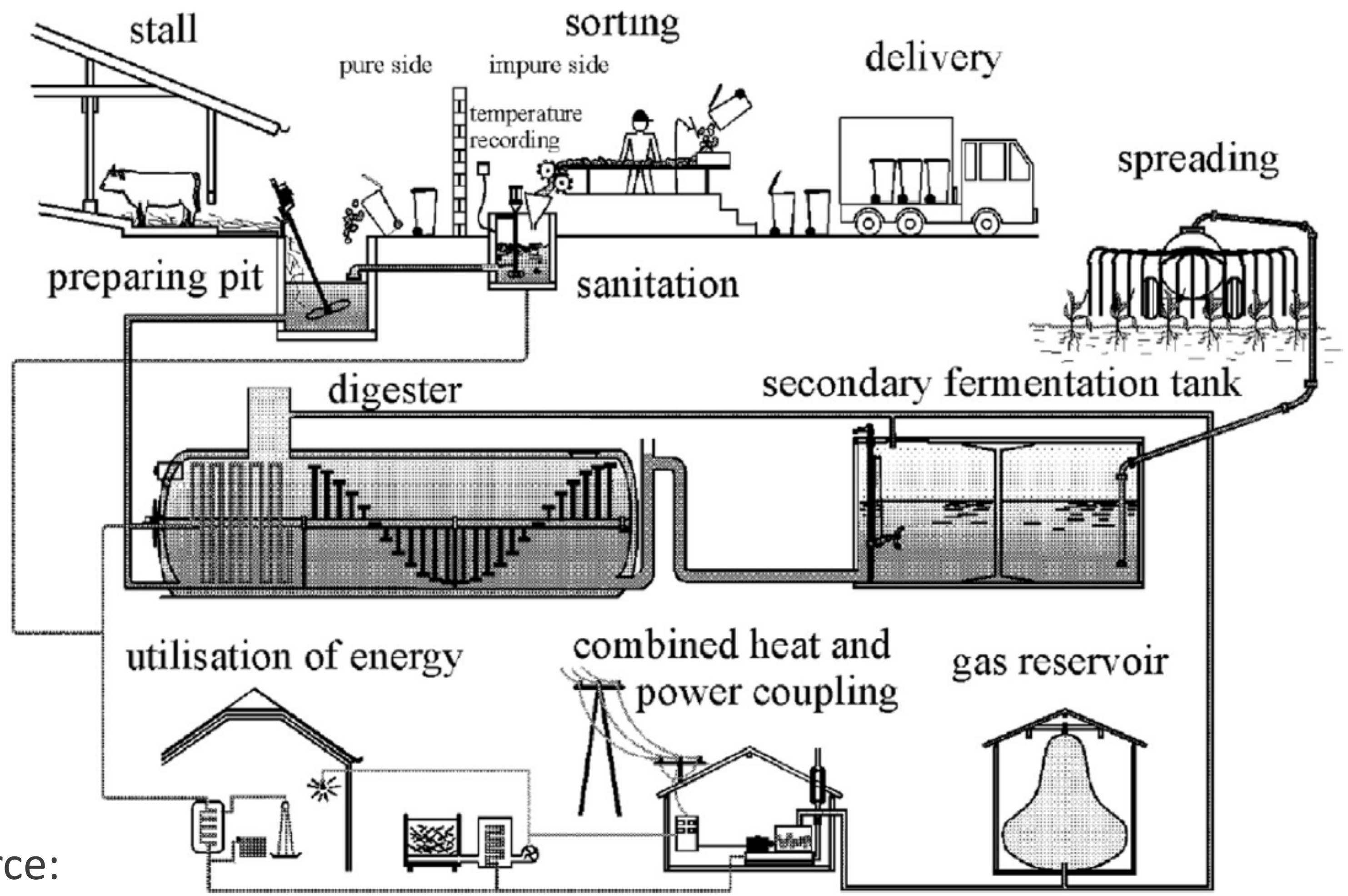


Table 1
Production of biogas and energy from selected plants.
Source: [23]

Type of feedstock	Yield of fresh mass [Mg ha^{-1}]	Production of biogas [m^3 ha^{-1}]	Energy yield [GJ ha^{-1}]
Maize	30–50	6 050–6 750	87–145
Lucerne	25–35	3 960–4 360	85–94
Rye	30–40	1 620–2 025	35–43
Sugar beet – root	40–70	10 260	220
Sunflower	30–50	2 430–3 240	52–70
Rape	20–35	1 010–1 620	22–37

Source:

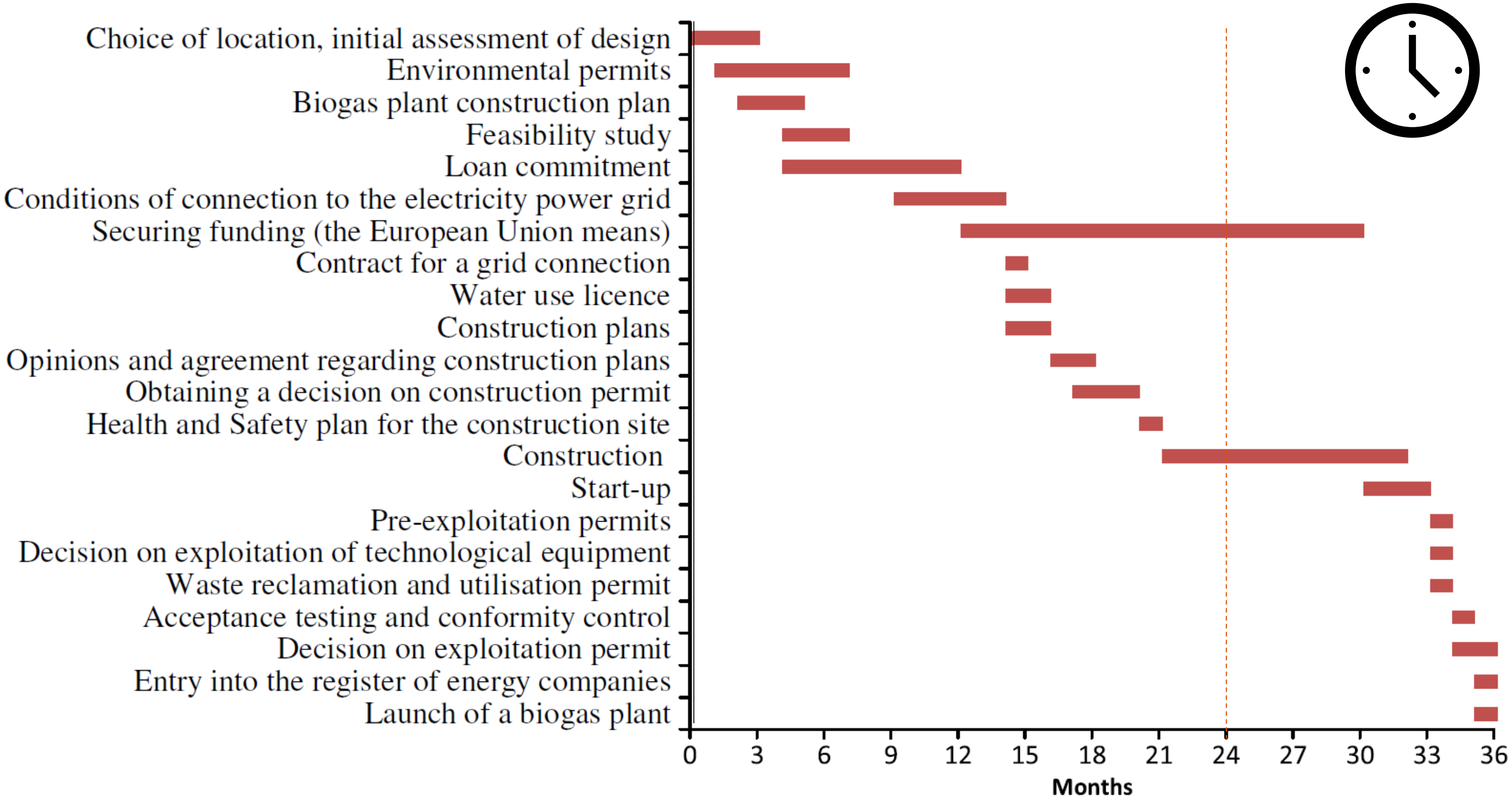
Renewable and Sustainable Energy Reviews
Volume 58, May 2016, Pages 69-74

Agricultural biogas plants in Poland – selected technological, market and environmental aspects

Arkadiusz Piwowar, Maciej Dzikuć, Janusz Adamczyk

Traditional technologies

Investment schedule of an agricultural biogas plant in Poland

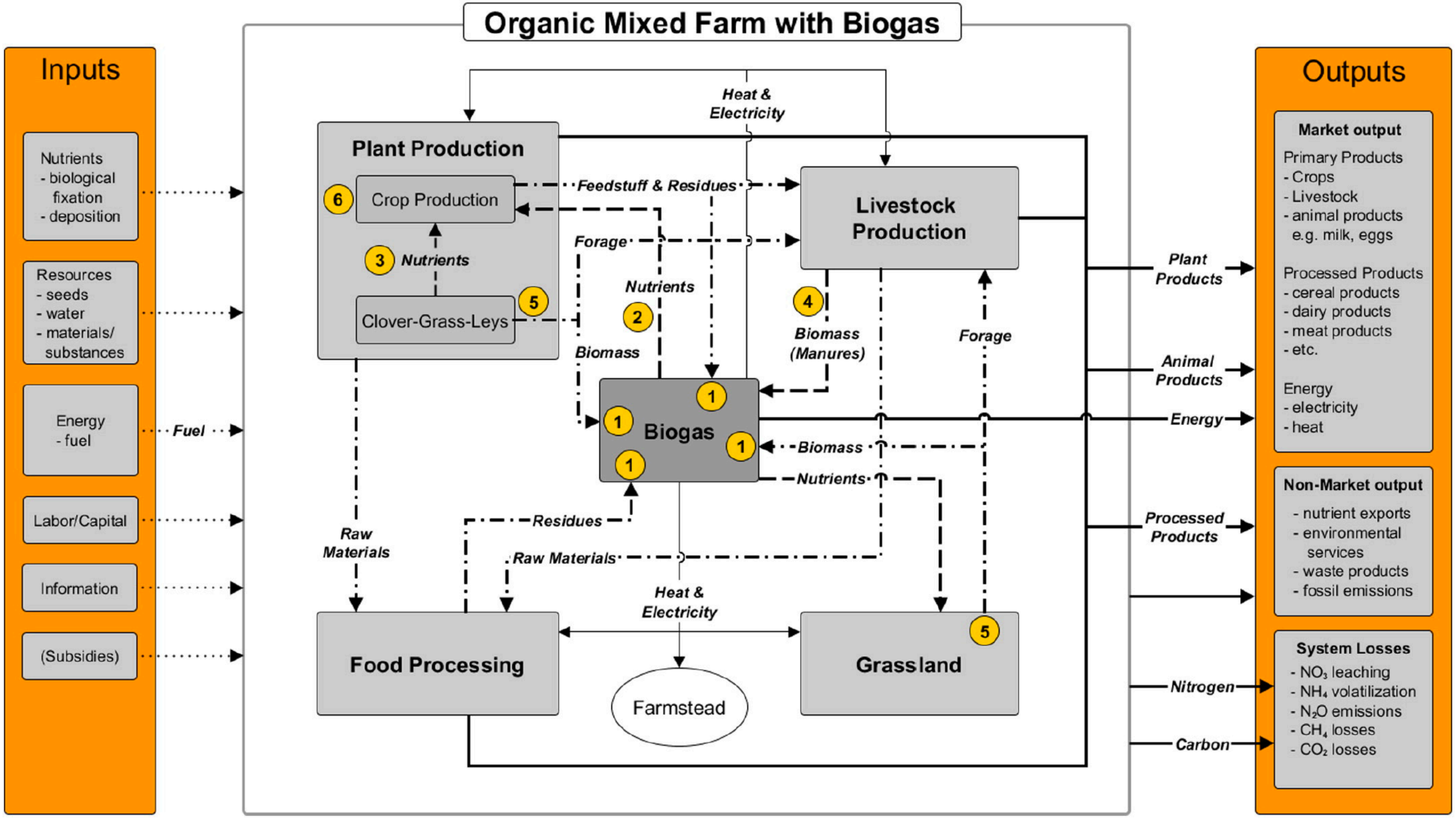


Source:

Renewable and Sustainable Energy Reviews
Volume 16, Issue 7, September 2012, Pages 4890-4900

Agricultural biogas plants in Poland: Investment process, economical and environmental aspects, biogas potential

Bartłomiej Igliński, Roman Buczkowski, Anna Iglińska, Marcin Cichosz, Grzegorz Piechota, Wojciech Kujawski



Source:

Agricultural Systems
Volume 139, October 2015, Pages 196-209

Farm biogas production in organic agriculture: System implications

Torsten Siegmeier, Benjamin Blumenstein, Detlev Möller

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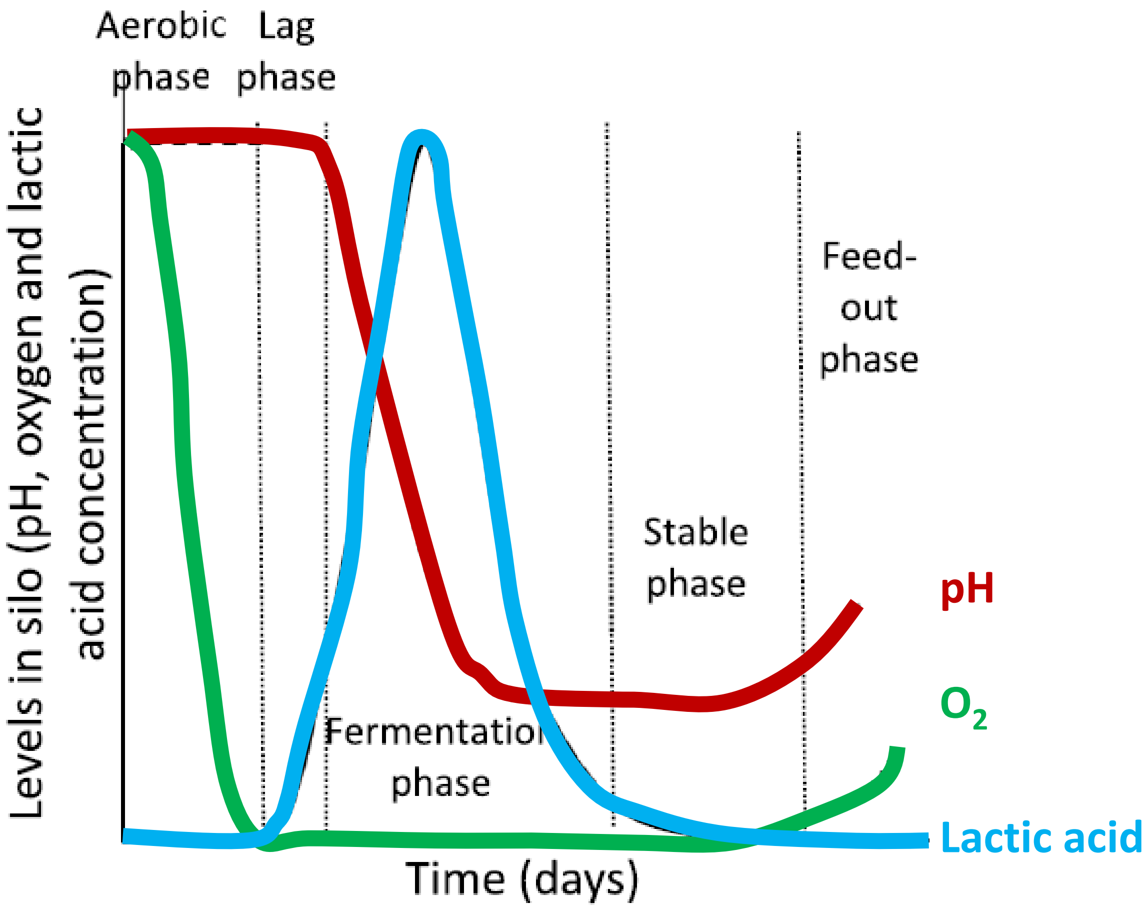
Storage and seasonality of biomass through Ensiling

Source:

Renewable and Sustainable Energy Reviews
Volume 134, December 2020, 110401

Ensiling for anaerobic digestion: A review of key considerations to maximise methane yields

Raffaella Villa [a], Lelia Ortega Rodriguez [b], Cecilia Fenech [b], Ogemdi Chinwendu Anika [a, c]

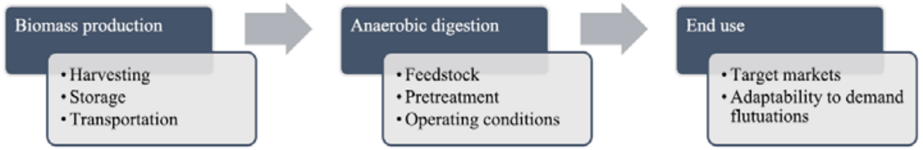


Source:

Biomass and Bioenergy
Volume 94, November 2016, Pages 94-104
Review

Ensiling for biogas production: Critical parameters. A review

Rúben Teixeira Franco, Pierre Buffière, Rémy Bayard



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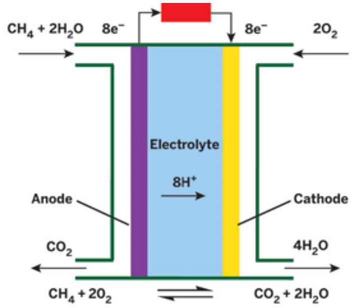
Traditional technologies

Biogas composition and Upgrading technologies



Components	Municipal waste	Wastewater	Agricultural/ Animal waste	Waste from agrofood industry	Landfill
CH_4 (vol.-%)	50 – 60[2]	61 – 65[1] 60 – 75[2] 55 – 77[3] 55 – 65[6]	55 – 58[1] 60 – 75[2] 50 – 70[3] 60 – 70[6]	68[2] 50 – 75[3]	47 – 57[1] 45 – 70[3] 40 – 70[4] 35 – 65 (avg.45)[5] 45 – 55[6]
CO_2 (vo.-%)	34 – 38[2]	36 – 38[1] 19 – 33[2] 30 – 45[3] 35 – 45[6]	37 – 38[1] 19 – 33[2] 30 – 50[3] 30 – 40[6]	26[2]	37 – 41[1] 35 – 40[3] 30 – 60[4] 15 – 50 (avg.40)[5] 30 – 40[6]
N_2 (vol.-%)	0 – 5[2]	< 2[1] < 1[2,6]	< 1[2] < 1 – 2[1] < 3[3]		< 1 – 17[1] < 3[3] 3 – 5[4] 5 – 40 (avg.15)[5] 5 – 15[6]
O_2 (vol.-%)	0 – 1[2]	< 1[1] < 0.5[2]	< 1[1] < 0.5[2]		< 1[1] < 0.2[3] 0 – 3[4] 0 – 5 (avg.1)[5]
H_2O (vol.-%)	100% (saturated at digester exit temperature)[3]	100% (saturated at digester exit temperature)[3]	100% (saturated at digester exit temperature)[3]	100% (saturated at digester exit temperature)[3]	100% (saturated at digester exit temperature)[3]
H_2 (vol.-%)					0 – 5[4] 0 – 3[5]
CO (vol.-%)					0 – 3[4]
H_2S (ppm)	70 – 650[2]	700 – 2800[2] 150 – 3000[3] 63[6]	2100 – 7000[2] 32 – 169[1] 3 – 1000[1]	280[2] < 21,500	36 – 115[1] 10 – 200[3] 0 – 20,000[4] < 100[5] 15 – 427[6]
Aromatic (mg/m^3)	0 – 200[2]				30 – 1900[4]
Ammonia			50 – 100[2] mg/m^3		5 ppm
Halogenated compounds (mg/m^3)	100 – 800[2]				1 –2900[4]
Benzene (mg/m^3)		0.1 – 0.3[1]	0.7 – 1.3[1]		0.6 – 2.3[1]
Toluene (mg/m^3)		2.8 – 11.8[1]	0.2 – 0.7[1]		1.7 – 5.1[1]
Siloxanes (ppmv)		2 – 15[3] 1.5 – 10.6[6]	< 0.4[6]		0.1 – 3.5[3] 0.7 – 4[6]
Non–methane organics (% dry weight)					0 – 0.25[3]
Volatile organics (% dry weight)					0 – 0.1[3]

[1] Delsinne, 2010; [2] Naskeo Environnment, 2009; [3] Lampe, 2006; [4] El–Fadel, 1997; [5] Persson, 2006; [6] Rasi, 2009.

Consequences:

Decrease in the specific calorific value

Explosion risk

Decrease in CH_4 concentration

Corrosion in pipelines, compressors, engines

Silicone oxide deposits: Abrasion & malfunctioning ofEngines

Source: DANISH TECHNOLOGICAL INSTITUTE

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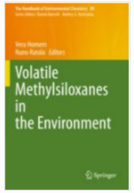
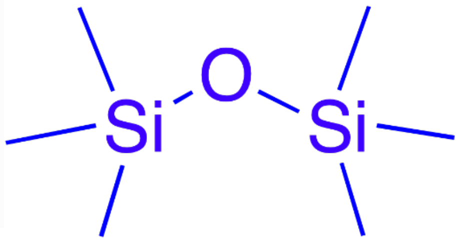


[Volatile Methylsiloxanes in the Environment](#) pp 131-157 | [Cite as](#)

Presence of Siloxanes in Sewage Biogas and Their Impact on Its Energetic Valorization

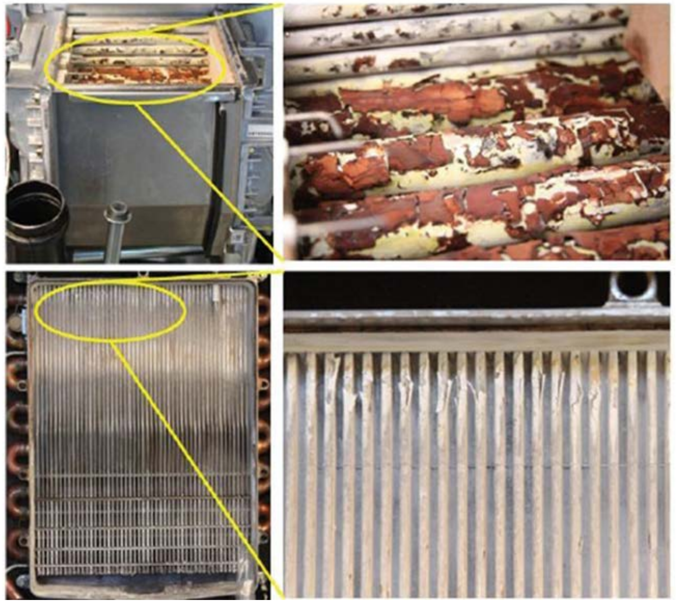
Authors   Authors and affiliations

N. de Arespacochaga, J. Raich-Montiu, M. Crest, J. L. Cortina



Why upgrading?

D

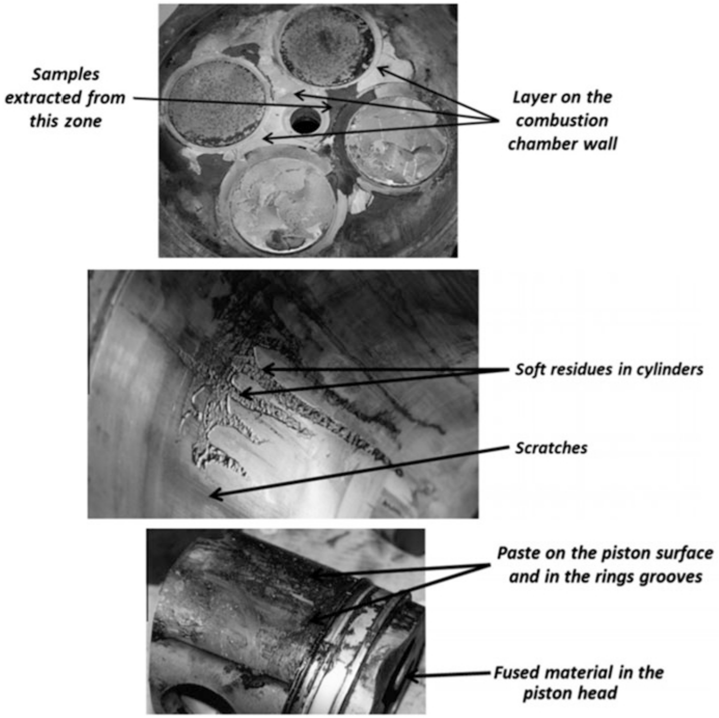


Silica deposits observed on domestic boilers

B

Silica deposit on spark plugs

A



Damages caused by siloxane-containing gas on reciprocating

C

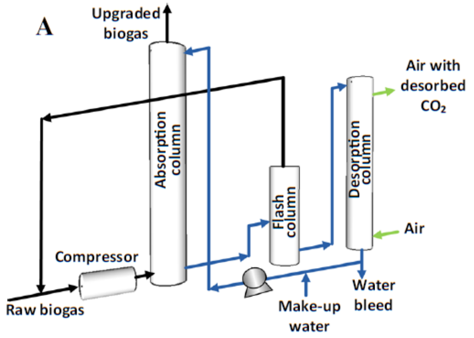
Combustion of siloxane-rich biogas in the blade wheels of microturbines

Biogas upgrading

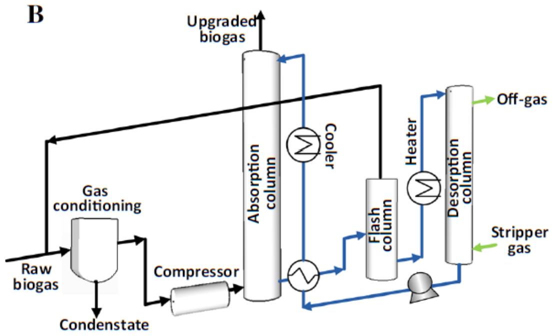
A review on the state-of-the-art of physical/chemical and biological technologies for biogas upgrading

Raúl Muñoz, Leslie Meier, Israel Diaz & David Jeison

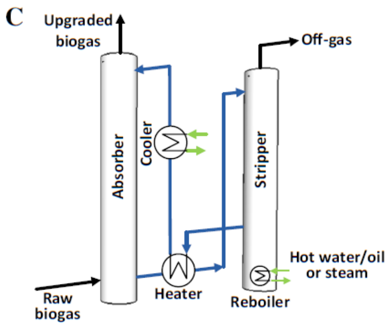
Reviews in Environmental Science and Bio/Technology 14, 727–759(2015) | Cite this article



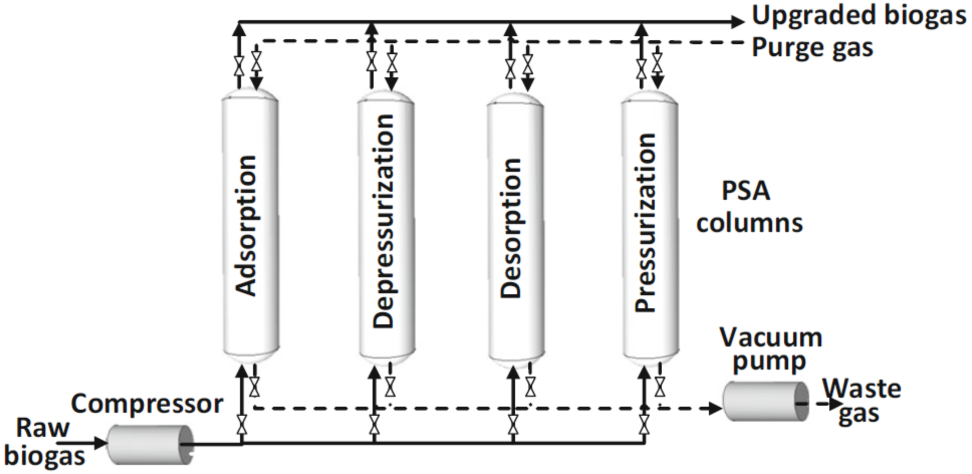
Water scrubbing



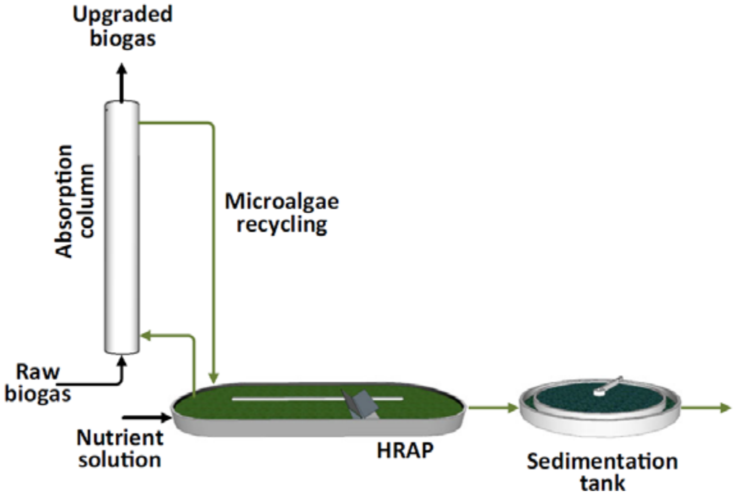
Organic solvent scrubbing



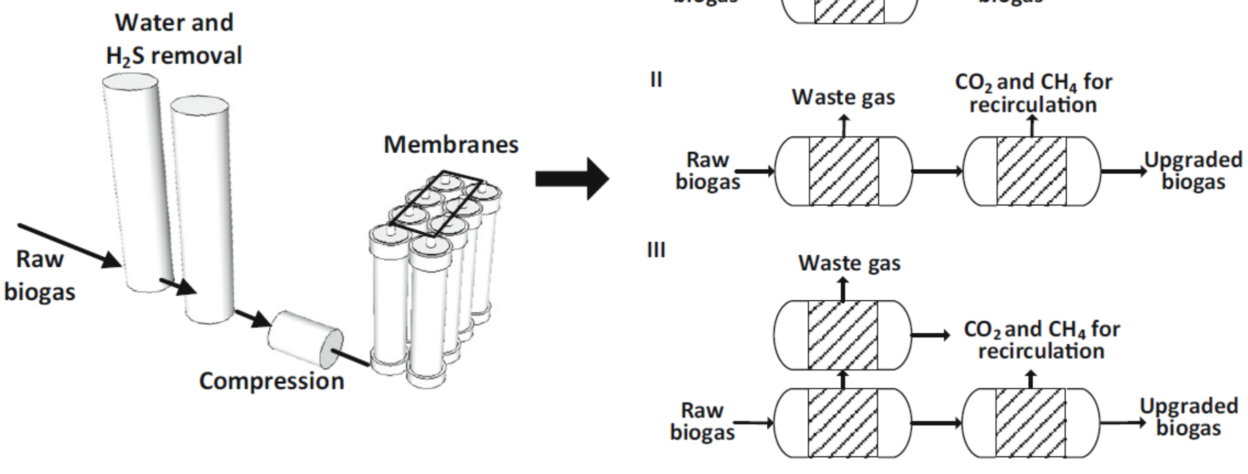
Chemical scrubbing



Pressure swing adsorption



Photosynthetic biogas upgrading



Membrane separation

Biogas upgrading

Industrial example 1

BRUCK AN DER LEITHA (AUSTRIA)

MEMBRANE UP-GRADING OF BIOGAS TO BIOMETHANE FOR GRID INJECTION

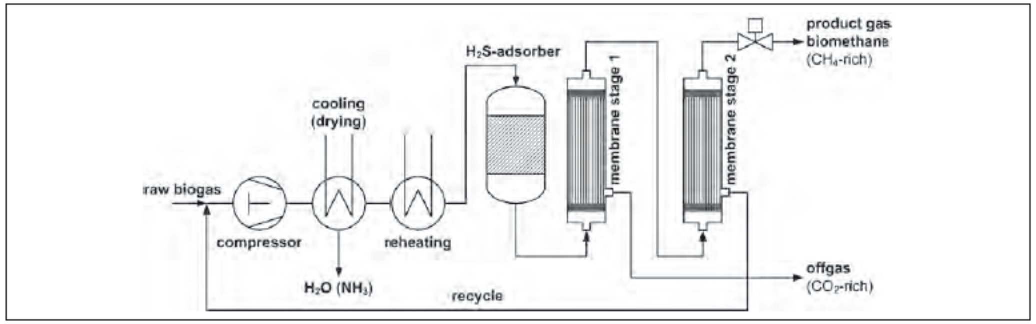


Figure 2: Schematic diagram of the main steps in the membrane up-grading process at Bruck.

Table 1; Summary of the biogas plant size and output data

Main digesters	3 x 3,000 m^3
Second digesters	2 x 5,000 m^3
CHP	2 x 836 kW_{el}
Biomethane	100 m^3 CH_4/h

Source: IEA Bioenergy Task 37

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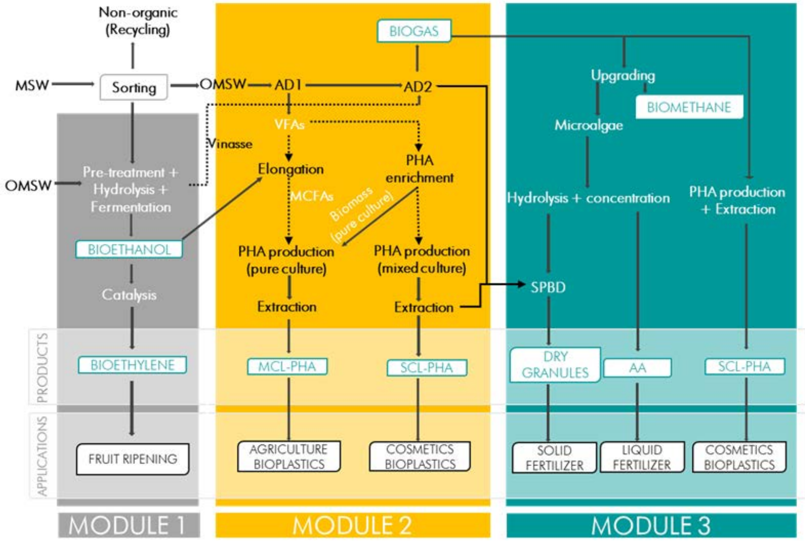
Biogas upgrading

Industrial example 2



Demo plant at CIAM (Zaragoza)
272 m^2

URBIOFIN urban biorefinery

European Commission HORIZON 2020

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Table 1: Process parameters of biogas upgrading technologies

Source: IRENA International Renewable Energy Agency

Technology (Company)	Electricity demand (kWh_e/m^3 raw biogas)	Heat demand (kWh_{th}/m^3 raw biogas)	Methane losses
Pressure Swing Adsorption (Carbotech)	< 0.19	0	< 1.5%
Water Scrubber (Malmberg)	0.2 - 0.23	0	≤ 1%
Water Scrubber (Greenlane)	0.17 - 0.23	0	< 1.0%
Physical Scrubber[a] (Haase)	0.23 - 0.27	0 [c]	≤ 1.0%
Chemical Scrubber[b] (MT Biomethane)	0.09	0.6	≤ 0.1%
Separation by Membranes (Axiom)	0.24	0	≤ 5.0%
Separation by Membranes (Evonik, > 1 stages)[d]	< 0.2	0	< 1.0%

Sources: Adler (2014); Evonik (n.d.); information from companies

a. using an organic solvent

b. using a solvent based on amines

c. requiring heat for regeneration of organic solvent, for which heat recovery from compression and off-gas treatment can help cover heat demand

d. numbers from company product flyers (2016)

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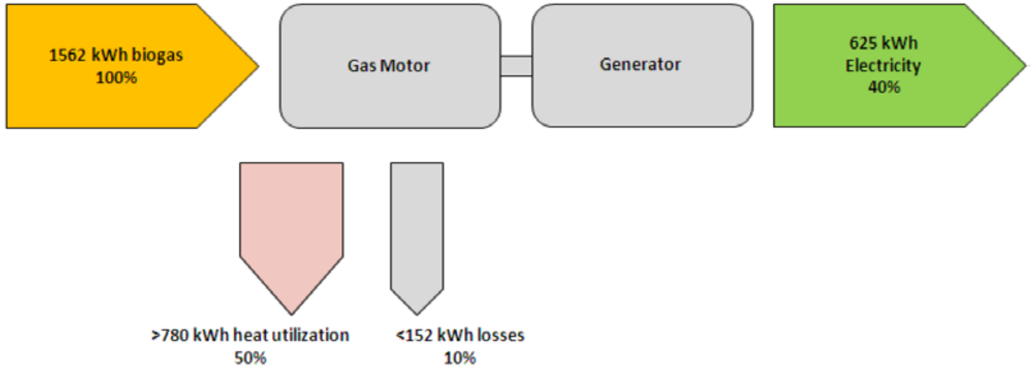
Good Practice for Efficient Use of Heat from Biogas Plants

Example 1: District heating for residential houses in Margarethen am Moos, Austria

Characteristics	
Commissioning date	2005
Input substrate	Mainly pig manure, Sudan grass, Forage rye, maize
Annual biogas production	ca. 2.1 million m^3
Annual electricity production	ca. 4,300 MWh
Annual district heating sales volume	ca. 4,000 MWh
Installed power	625 kW_{el}/1.2 MW_{th}
Investment	ca. 3 million EUR



Source: BIOGASHEAT

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Good Practice for Efficient Use of Heat from Biogas Plants

Example 2: Heating supply to a SPA center in Trebon, Czech Republic

Characteristics	
Commissioning date	December 2009
Installed power	1 MW_{el}
Process	Two-stage digestion with a retention time of 120 days
Input	Maize and grass silage, pig slurry
Heat utilisation	Heat supply to a spa and a residential building (5,000 MWh/a)
Investment	5 million EUR

Source: BIOGASHEAT

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Good Practice for Efficient Use of Heat from Biogas Plants

Example 3: Use of heat in aquaculture in Affinghausen, Germany

	Characteristics
Commissioning date	2006
Installed power	500 kW_{el}
Heat utilisation	Shrimp farm
Investment into the biogas pipeline	80,000 EUR

Source: BIOGASHEAT

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Good Practice for Efficient Use of Heat from Biogas Plants

Example 4: Digestate drying in Azienda Agricola Andretta farm in Marcon, Italy

Characteristics	
Commissioning date	2005 for the biogas plant, 2010 for the heating system
Installed power	800 kW_{el}
Heat utilisation	Digestate drying
Input/output	Sludge and biomass; organic dry matter and ammonium sulfate

Source: BIOGASHEAT

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Good Practice for Efficient Use of Heat from Biogas Plants

Example 5: Heating of greenhouses in Rumbula, Latvia

Characteristics	
Commissioning date of landfill gas collection plant	October 2002
Installed power	5.25 MW_{el} 6.15 MW_{th}
Feedstock	Landfill gas from municipal and industrial waste
Heat utilisation	In total 80% of heat is used for heating offices, infiltrate reactor, hot water preparation and heating the greenhouse complex.
CO_2 savings	7,600 tons/year

Source: BIOGASHEAT

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Good Practice for Efficient Use of Heat from Biogas Plants

Example 6: Heat supply to a residential area in Poderwijk, the Netherlands

Characteristics	
Substrates	Manure (>50%), maize, grass and waste products from food industry
Treating capacity	30,000 m^3/year
Digesters	2 x 2,500 m^3 + 1 post-digester
Digester type	Continuously stirred tank reactor
Retention time and temperature	50 days, 37 °C
Biogas pipe	Length 5.6 km, diameter 250 mm
CHP	0.25 MW_{el} (on farm) 1.06 MW_{el} and 1.27 MW_{th} (in residential area)
CO_2 emission savings	5,100 t/year

Source: BIOGASHEAT

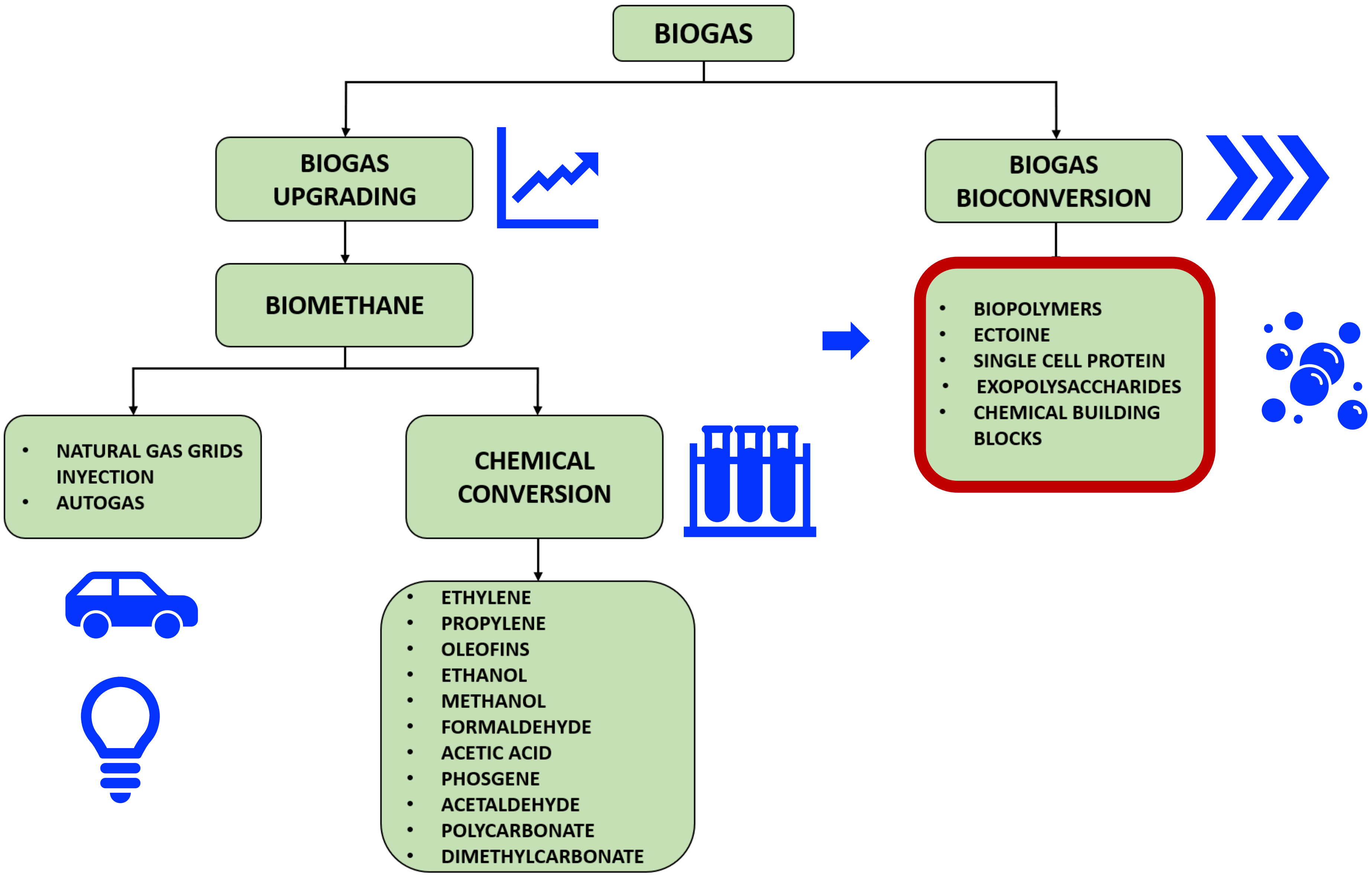
SECTION 1

Current Technologies at small scale; focus on rural areas

Traditional technologies

- Differences between agricultural residues and other type of feedstock for the anaerobic digestion process
- Pretreatment technologies (physical, chemical and biological pretreatments)
- Logistics (Costs Distance for transportation of biomass and Investment schedule)
- Storage and seasonality of biomass (biomass ensiling of biomass for AD)
- Technologies for biogas upgrading
- Good Practice for Efficient Use of Heat from Biogas Plants
- **Novel added-value products from biogas besides heat and power**

Novel technologies/trends?

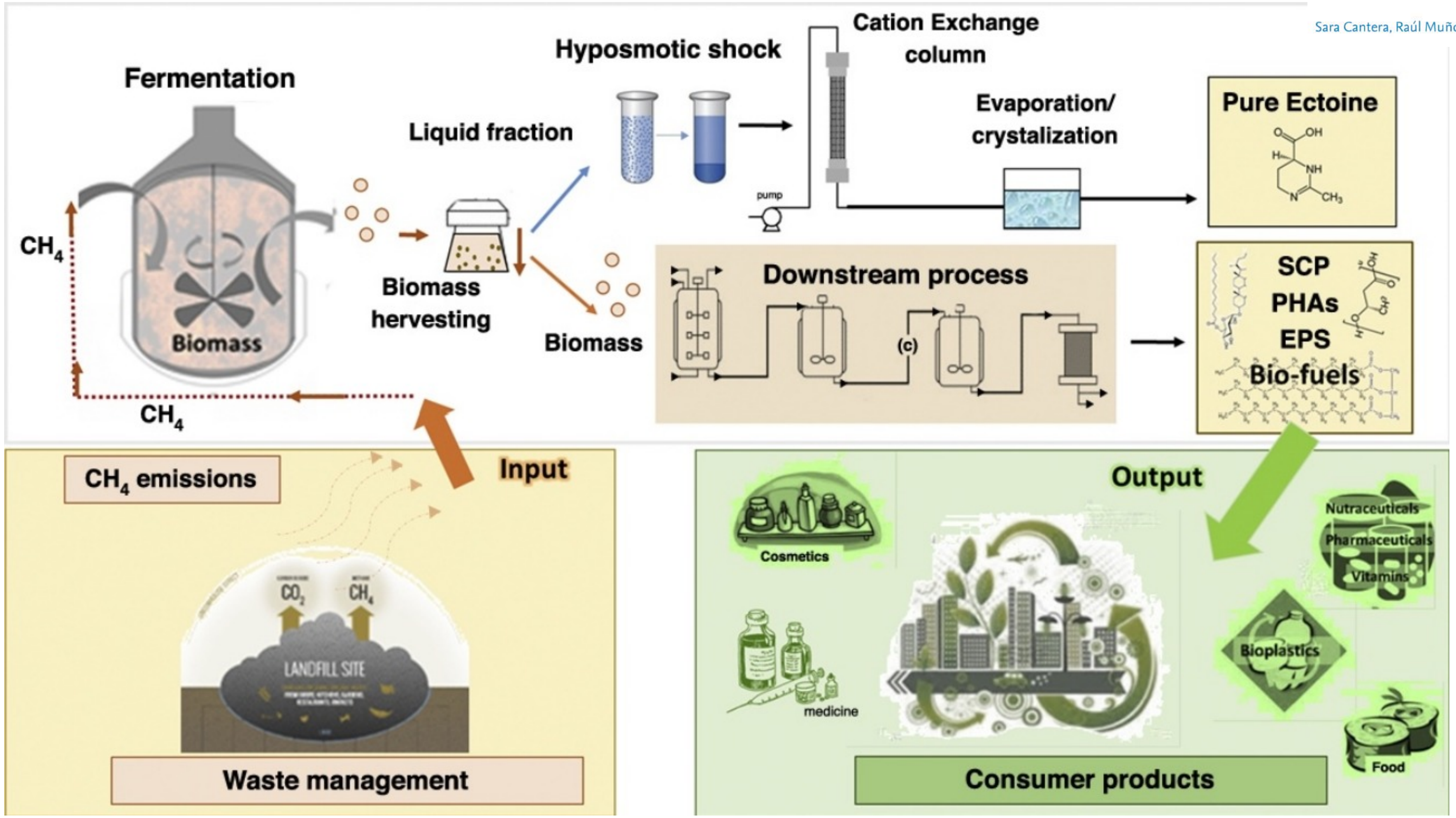


Novel technologies/trends?

Current Opinion in Biotechnology
Volume 50, April 2018, Pages 128-135

Technologies for the bioconversion of methane into more valuable products

Sara Cantera, Raúl Muñoz, Raquel Lebrero, Juan Carlos López, Yadira Rodríguez, Pedro Antonio García-Encina



Eur. J. Biochem. 149, 135–139 (1985)
© FEBS 1985

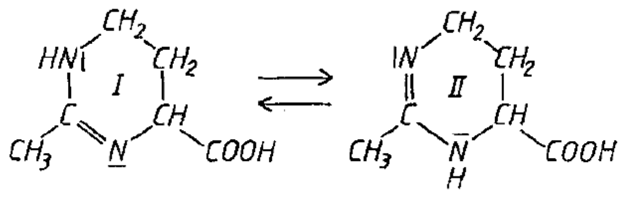
Ectoine

1,4,5,6-Tetrahydro-2-methyl-4-pyrimidinecarboxylic acid

A novel cyclic amino acid from halophilic phototrophic bacteria of the genus *Ectothiorhodospira*

Erwin A. GALINSKI[1], Heinz-Peter PFEIFFER[2] and Hans G. TRÜPER[1]

[1] Institut für Mikrobiologie; and
[2] Institut für Organische Chemie und Biochemie, Rheinische Friedrich-Wilhelms-Universität, Bonn



(I) 1,4,5,6-Tetrahydro- (II) 3,4,5,6-Tetrahydro-
-2-Methyl-4-Pyrimidinecarboxylic acid

- Water soluble solute with a low molecular weight
- ***Protection mechanism to provide an osmotic balance to a wide number of halotolerant bacteria***
- High effectiveness as stabilizer of enzymes, DNA-protein complexes and nucleic acids
- ***Ectoine has a value in the pharmaceutical industry of approximately 1000€/kg and a global consumption of 15000 tones/year***

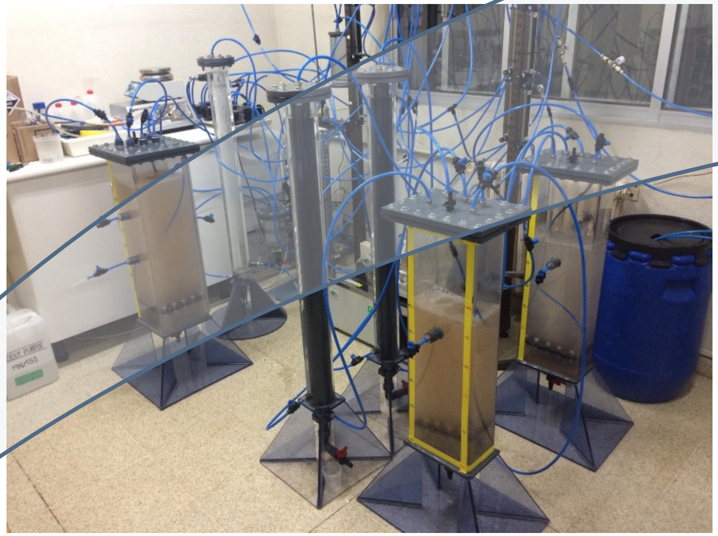
The upscaling of DEEP PURPLE

DEEP PURPLE
RECOVER ENERGY & VALUABLE RESOURCES
from urban waste streams
IN PHOTOBIOREFINERIES
with the help of
PURPLE PHOTOTROPIC BACTERIA

Universidad de Valladolid

0.005 m^3

0.02 m^3



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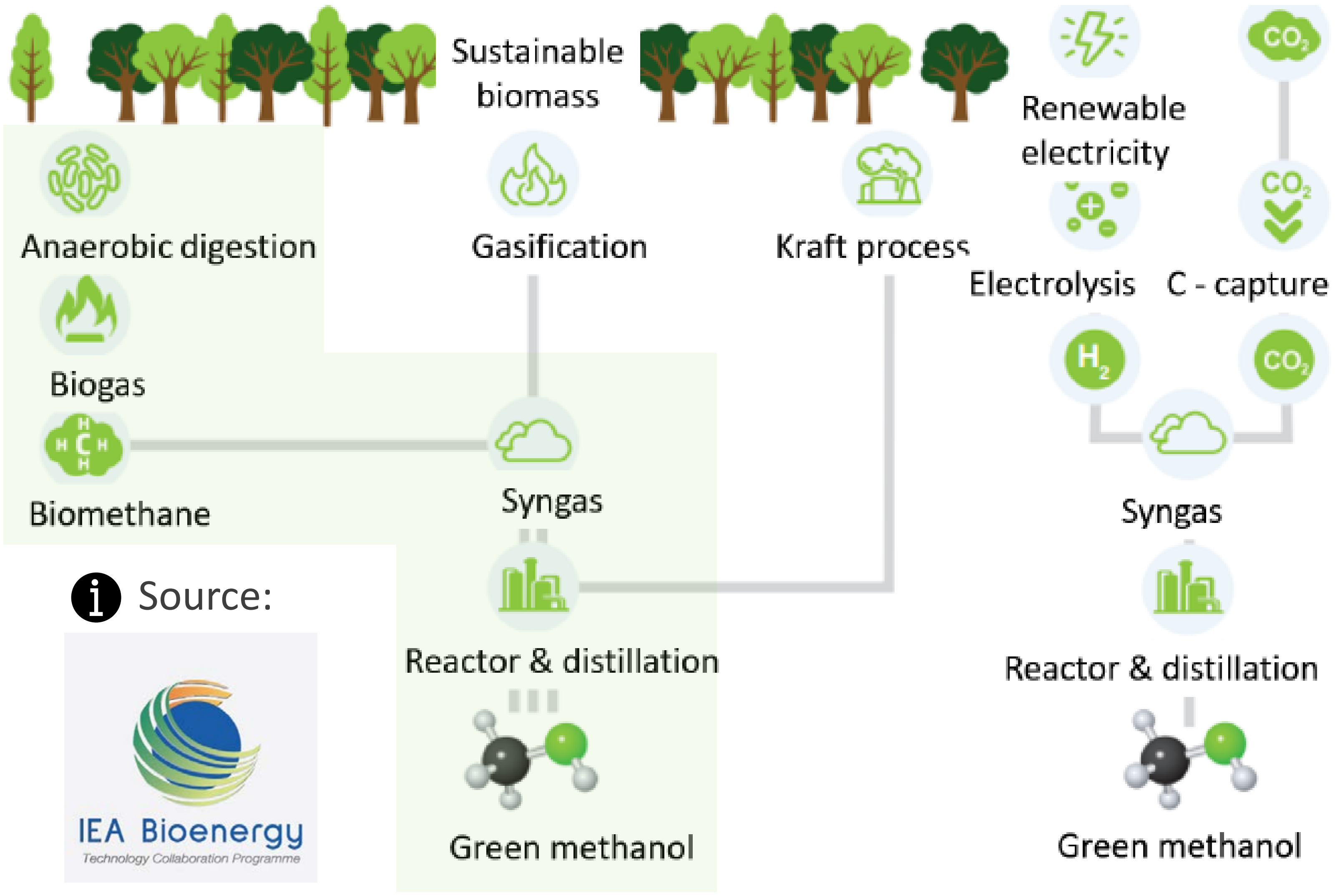
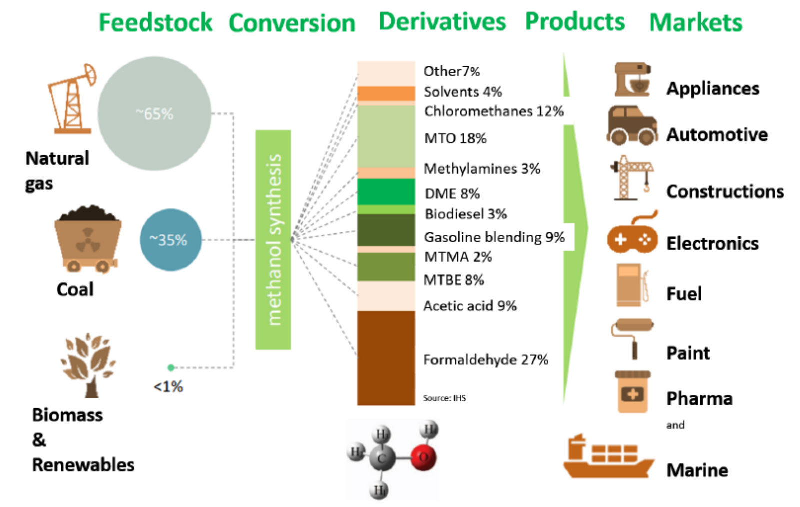
Green methanol from biogas in Denmark





2019: Global Methanol Demand = 83 Million Metric Tons or 27.6 billion gallons

Source:

IEA Bioenergy
Technology Collaboration Programme

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SECTION 2

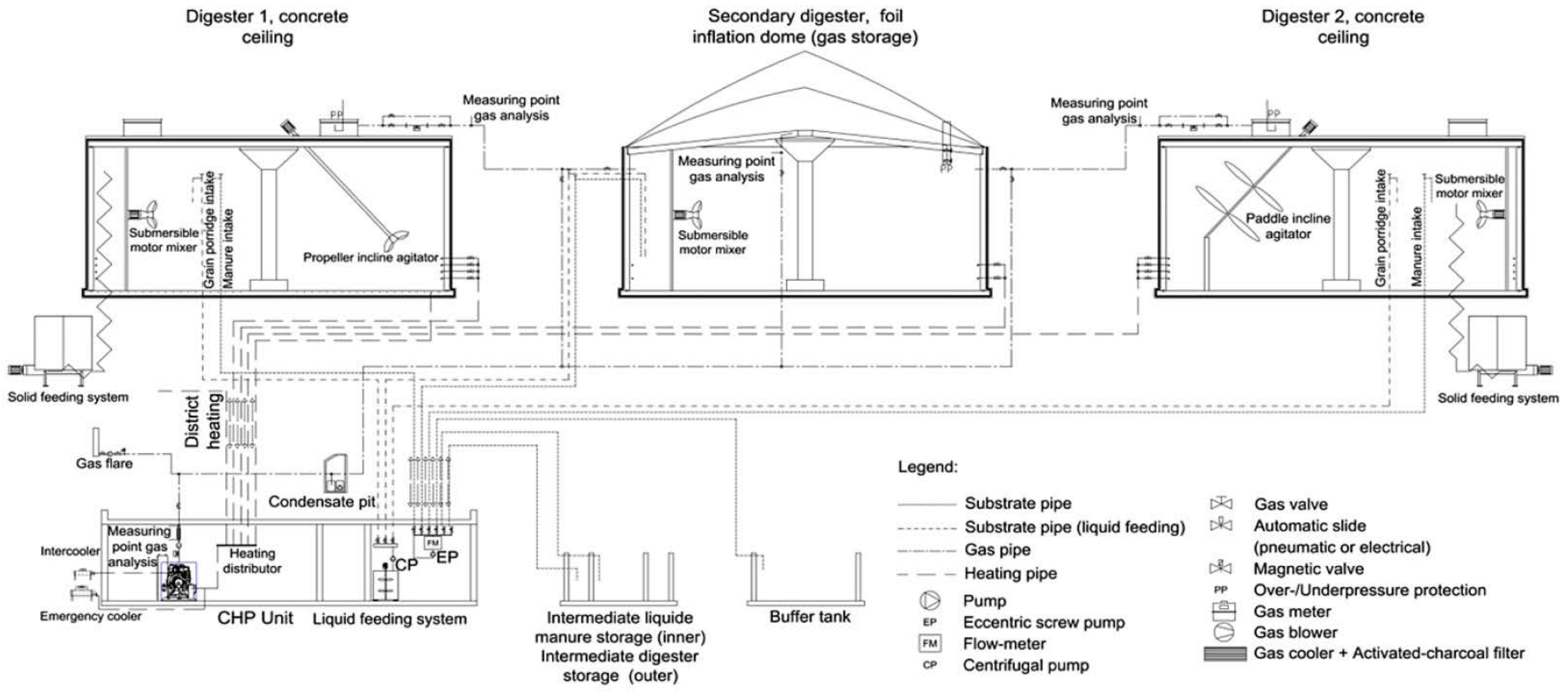
Current industrial examples

Biogas production technologies

- **Drivers: Energy demand for digestion production processes and auxiliary facilities**
- Success cases: Digestion of own residues
- Broadening the raw materials used as feedstock

Current industrial examples

Drivers: Energy demand for digestion production processes and auxiliary facilities



Source:

Energies **2012**, *5*, 5198-5214; doi:10.3390/en5125198

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energies
ISSN 1996-1073
www.mdpi.com/journal/energies

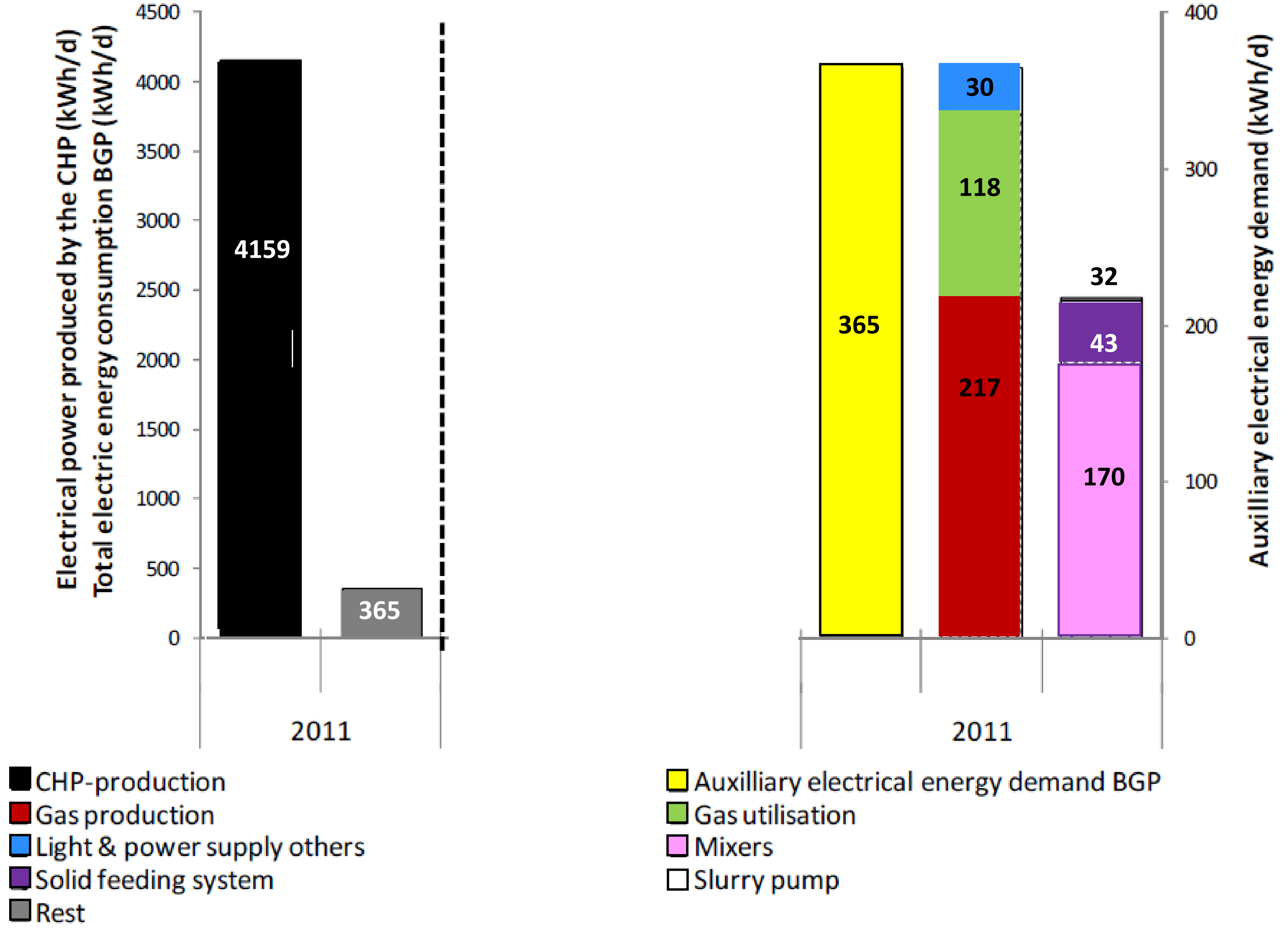
Article

Electric Energy Consumption of the Full Scale Research Biogas Plant "Unterer Lindenhof": Results of Longterm and Full Detail Measurements

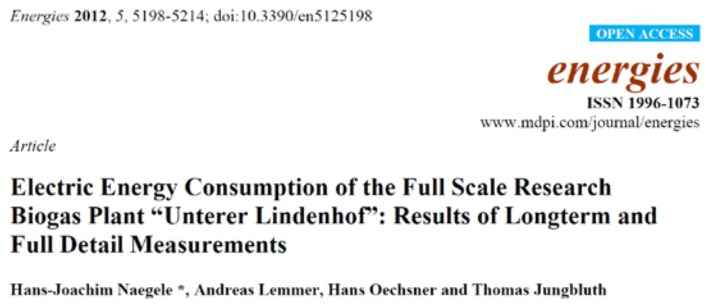
Hans-Joachim Naegele *, Andreas Lemmer, Hans Oechsner and Thomas Jungbluth

Current industrial examples

Electrical energy production and consumption of the entire BGP case for 2010 and 2011



Source:


Energies **2012**, *5*, 5198-5214; doi:10.3390/en5125198
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SECTION 2

Current industrial examples

Biogas production technologies

- Drivers: Energy demand for digestion production processes and auxiliary facilities
- **Success cases: Digestion of own residues**
- Broadening the raw materials used as feedstock

Success cases: Digestion of own residues

Example 1: MORE THAN 10 YEARS PRODUCTION OF FOSSIL FREE AUTOMOTIVE FUEL AND CERTIFIED DIGESTATE FROM FOOD WASTE VERA PARK in helsingborg, sweden

Facts & Figures

Organic waste capacity	160 000 tons/year
Methane in raw gas	65–72%
Biogas production	80 GWh
Digestate production	145 000 tons
Digester tanks	2 x 3000, 1 x 6000 m^3
Post-digestion tanks	2 x 1000 m^3
Digester temperature	37 °C
Digestate pipeline	10 km
Three upgrading units:	
PSA	350 Nm^3/h
Water scrubbers	650, 1400 Nm^3/h
Operational start-up	1996
Refurbishment doubling cap	2007
Refurbishment doubling cap	2014

Source: **IEA Bioenergy Task 37**

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Success cases: Digestion of own residues

Example 2: Nutrient recovery from digestate and biogas utilisation by up-grading and grid injection

Input	Tonnes/year
Pig manure	30,000
Industrial waste	15,000
Biowaste	16,000
Total	61,000
Output	
Solid digester output	13,000
Liquid fertilizer	10,000
Permeate	> 30,000
Total	53,000

FACTS

- Treatment of manure, biowaste and industrial biogenic waste
- Total biogas production corresponding to 3.4 Mio m^3/year
- Biomethane injection into the gas grid replacing 19 GWh natural gas annually

Source: IEA Bioenergy Task 37

Success cases: Digestion of own residues

Example 3: Pioneering biogas farming in Central Finland Farm scale biogas plant produces vehicle fuel, heat, electricity and bio-fertilizer

Biogas reactor	Reactor volume	1000 m^3
	Cow manure	2000 m^3/year
	Confectionary by-products	200 m^3/year
	Fat	600 m^3/year
	Post-storage tank	1500 m^3
Biogas (raw)	CH_4 content	62–64 %
CHP		25 kW_{el} 50 kW_{th}
Gas boiler		80 kW_{th}
Upgrading to traffic fuel	Capacity	50 Nm^3/h of raw biogas
	Electricity consumption	1.2–1.4 kWh/kg
	Water consumption	10 liter/kg
	CH_4 content	95% ± 2%
End-products	Electricity	75 MWh/year
	Heat	150 MWh/year
	Biomethane for traffic fuel	1000 MWh/year

Source: IEA Bioenergy Task 37

SECTION 2

Current industrial examples

Biogas production technologies

- Drivers: Energy demand for digestion production processes and auxiliary facilities
- Success cases: Digestion of own residues
- **Broadening the raw materials used as feedstock**

Broadening the raw materials used as feedstock

Example 2: Linko gas a reference plant for centralized co-digestion of animal manure and digestible wastes in Denmark

Table1: KEY FIGURES (2012)

Animal manure	630 tons/day
Organic wastes	140 tons/ day
Biogas production	19.7 mill.Nm³/year(2012)
Total digester capacity	14600 m³
Process temperature	53°C
Pasteurisation	MGRT 10 hours at 53°C
Utilization of biogas	1121 kW biogas engine (1)
Utilization of biogas	1047 kW biogas engine (2)
Utilization of biogas	1033 kW biogas engine (3)
Transport vehicles	4 x 30 m³ tankers and 1 x 25 & tanker
Investment costs	43.6 mill. DKK
Government grants	16.8 mill. DKK
Contractor	Krüger Ltd
Operation start-up	1990 (mesophilic)
Refurbishment	1999 (thermophilic)

Source: **IEA Bioenergy Task 37**

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Thank you very much for your attention

Alessandro Carmona, PhD

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- December the 11th, 2020