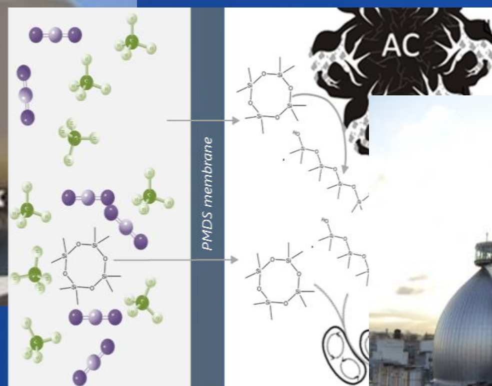
Universitat de Girona

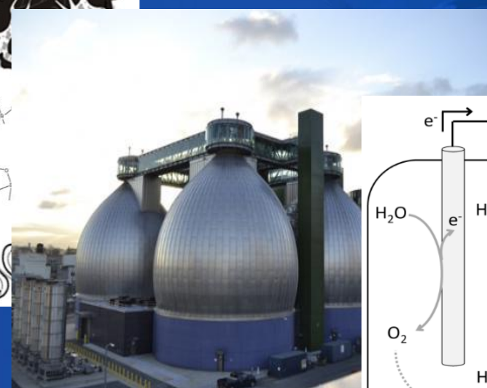
1º Jornada técnica en depuración de aguas residuales: Digestión Anaerobia

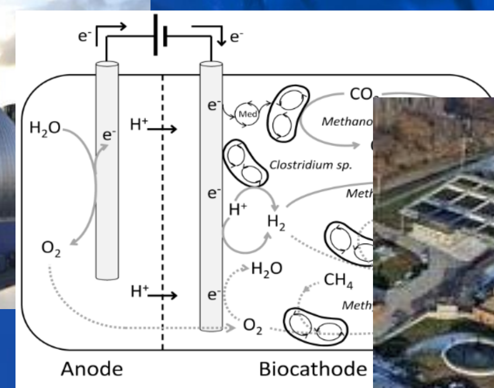
Cátedra FACSA de Innovación en el Ciclo Integral del Agua
Jueves 7 y viernes 8 de julio 2016.
Universitat Jaume I. Edifici Consell Social i Postgrau

lequia UdG ECO-INNOVATIVE WATER SOLUTIONS

Innovative technologies for biogas upgrading: from basic research to technology assessment







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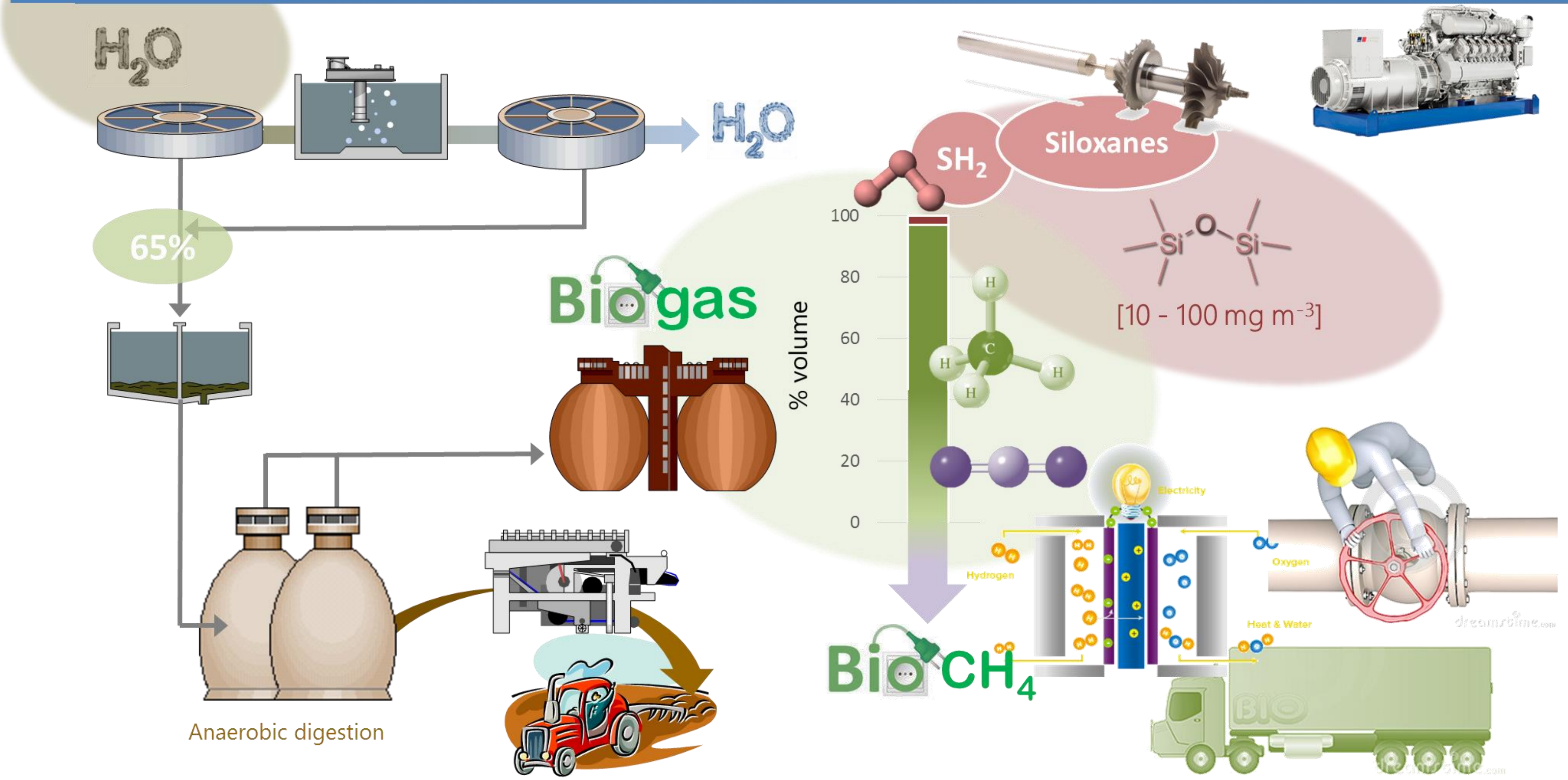
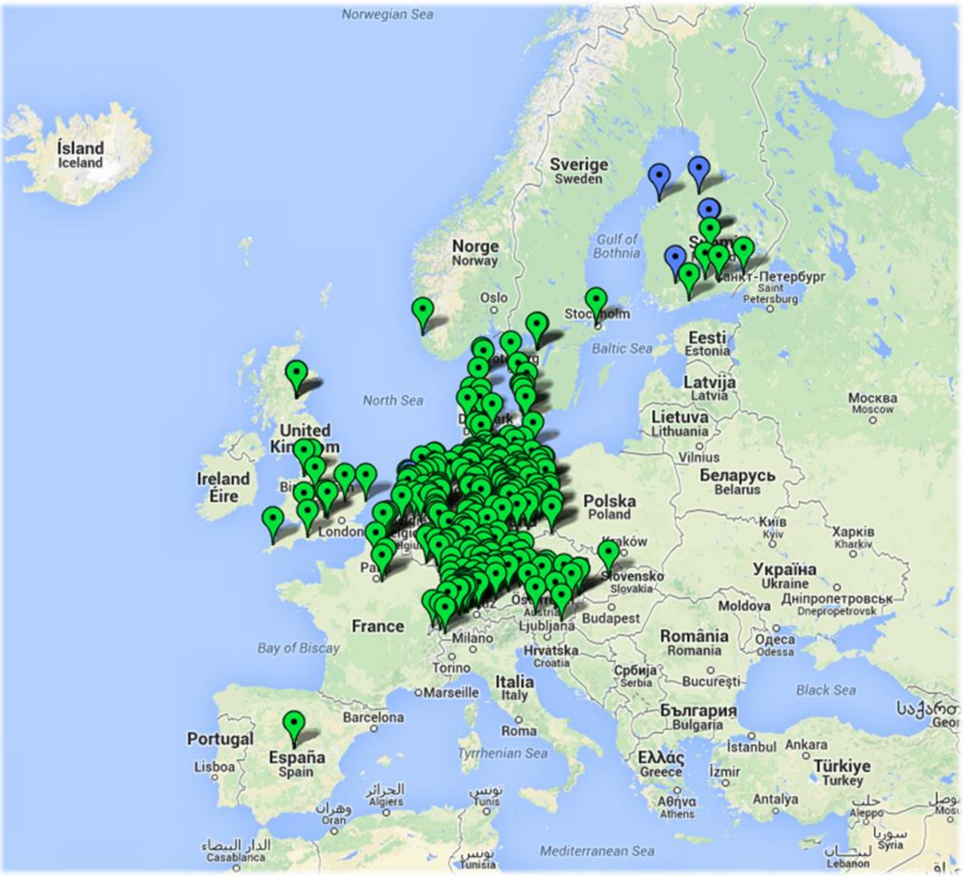
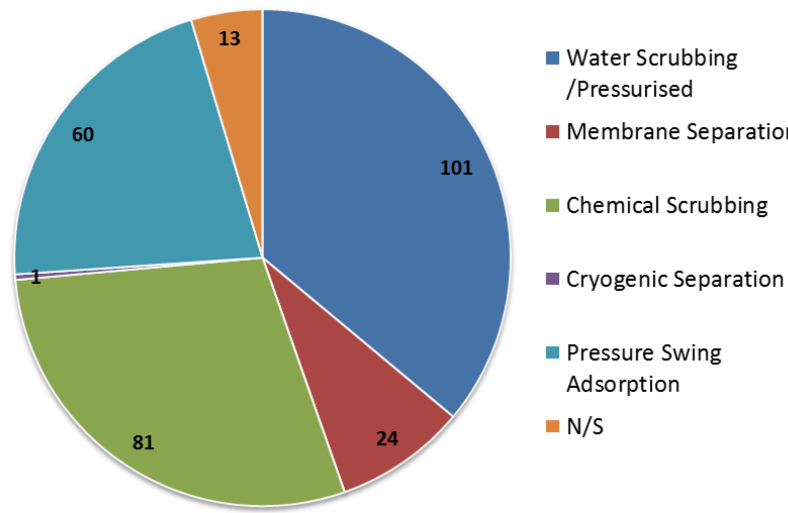
Biogas upgrading?



What about biogas upgrading plants in Europe?

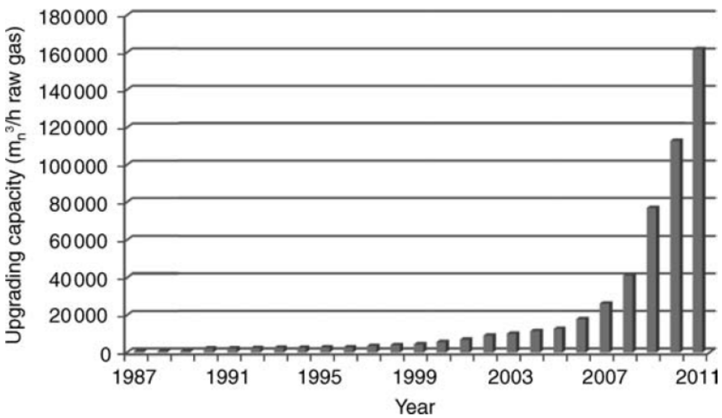


Upgrading and injection, Project map. *Source: Platform biogas partner. http://www.biogaspartner.de/en/project-map.html*

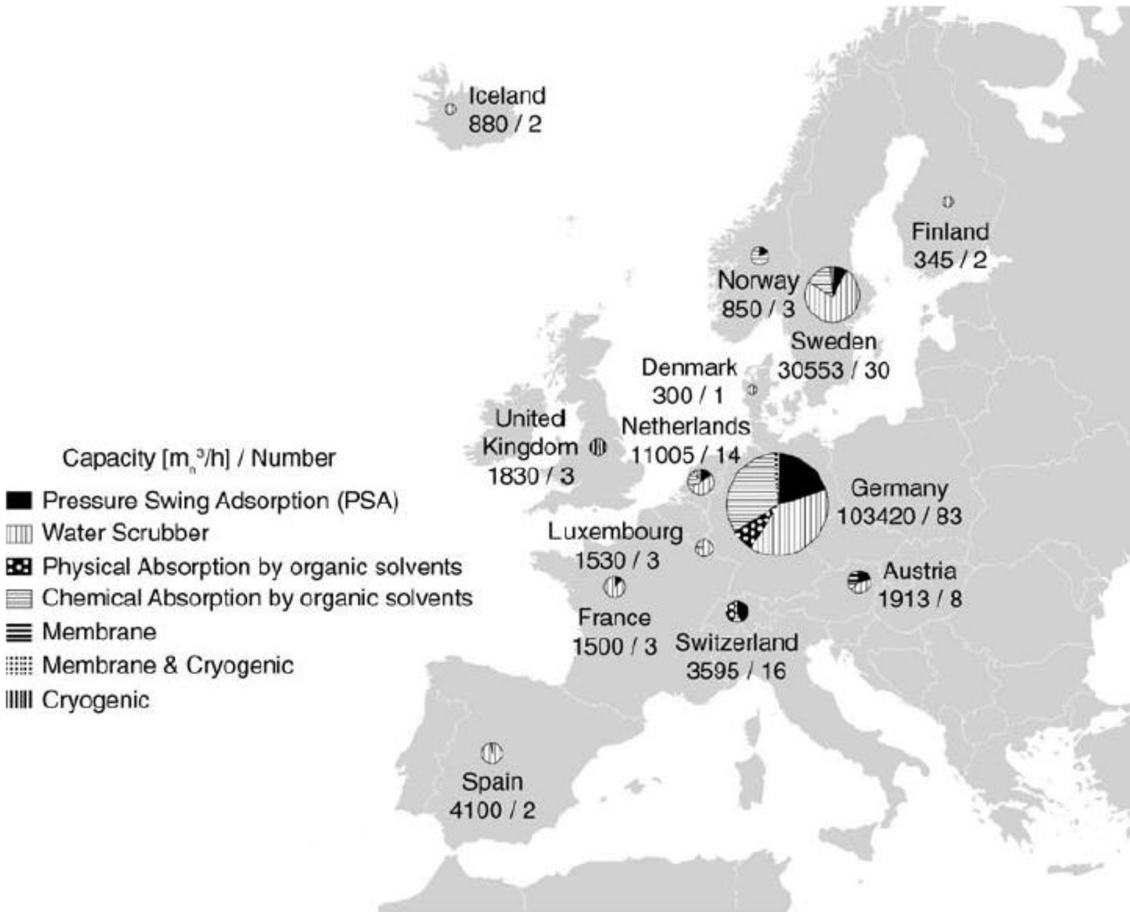


Source: IEA Bioenergy, Task 37.
http://www.iea-biogas.net/plant-list.html (19/08/2014)

What about biogas upgrading plants in Europe?



15.2 Upgrading capacity of European biogas upgrading plants in the period 1987–2011 related to raw biogas (Copyright: Fraunhofer IWES, 2012).

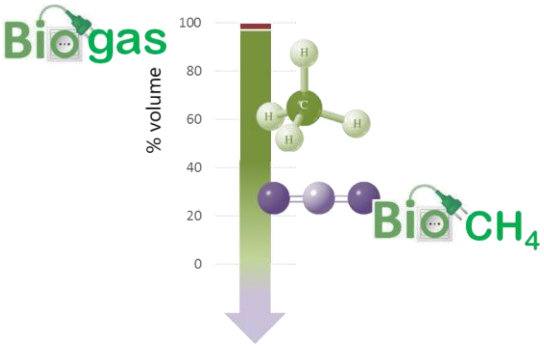


15.1 Overview of numbers of plants and raw biogas upgrading capacities in Europe as of December 2011 (Copyright: Fraunhofer IWES, 2012).

Biogas components

Tab. 2. Composition of biogas, landfill gas and natural gas.

		Biogas	Landfill gas	Natural gas (Danish)*	Natural gas (Dutch)
Compounds	Methane (vol-%)	60–70	35–65	89	81
	Other hydro carbons (vol-%)	0	0	9.4	3,5
	Hydrogen (vol-%)	0	0-3	0	–
	Carbon dioxide (vol-%)	30–40	15–50	0.67	1
	Nitrogen (vol-%)	~0.2	5–40	0.28	14
	Oxygen (vol-%)	0	0-5	0	0
	Hydrogen sulphide (ppm)	0–4000	0–100	2.9	–
	Ammonia (ppm)	~100	~5	0	–
	Lower heating value (kWh/Nm³)	6.5	4.4	11.0	8.8



Biogas to biomethane: what to clean?

Water contents.

condensation (plus ammonia removal)
hygroscopic salts, glycol solutions, …

Hydrogen sulphide (H2S)

precipitation
Adsorption on A.C.
Chemical Absortion (NaOH)
Biological treatment

Siloxanes

Adsoption (A.C. or zeolites)

And **CO_2**! To increase methane contents.

Biogas to biomethane: requirements

Tab. 3. Selected standard requirements for grid injection or for utilization as vehicle fuel.

Compound	Unit	France		Germany		Sweden	Switzerland		Austria	The Netherlands
		L gas	H gas	L gas grid	H gas grid		Lim. inject.	Unlim. Inject		
Higher Wobbe index	MJ/Nm^3	42.48–46.8	48.24–56.52	37.8–46.8 46.1–56.5					47.7–56.5	43.46–44.41
Methane content	Vol-%					95–99	>50	>96		>80
Carbon dioxide	Vol-%	<2		<6			<6		≤2[6]	
Oxygene	Vol-%			<3			<0.5		≤0.5[6]	
	ppmV	<100								
	Mol%									<0.5
Hydrogen	Vol-%	<6		≤5			<5		≤4[6]	<12
$CO_2+O_2+N_2$	Vol-%					<5				
Water dew point	°C	<-5[1]		<t[4]		<t[5]-5			<-8[7]	-10[8]
Relative humidity	ρ						<60 %			
Sulphur	mg/Nm^3	<100[2] <75[3]		<30		<23	<30		≤5	<45

[1] At MOP (Maximal Operating Pressure) downstream from injection point
[2] Maximum permitted
[3] Average content
[4] Ground temperature
[5] Ambient temperature
[6] Mole percentage
[7] At 40 bars
[8] At 10 bars

Biogas components solubility for water as solvent

Compilation of Henry's law constants (version 4.0) for water as solvent

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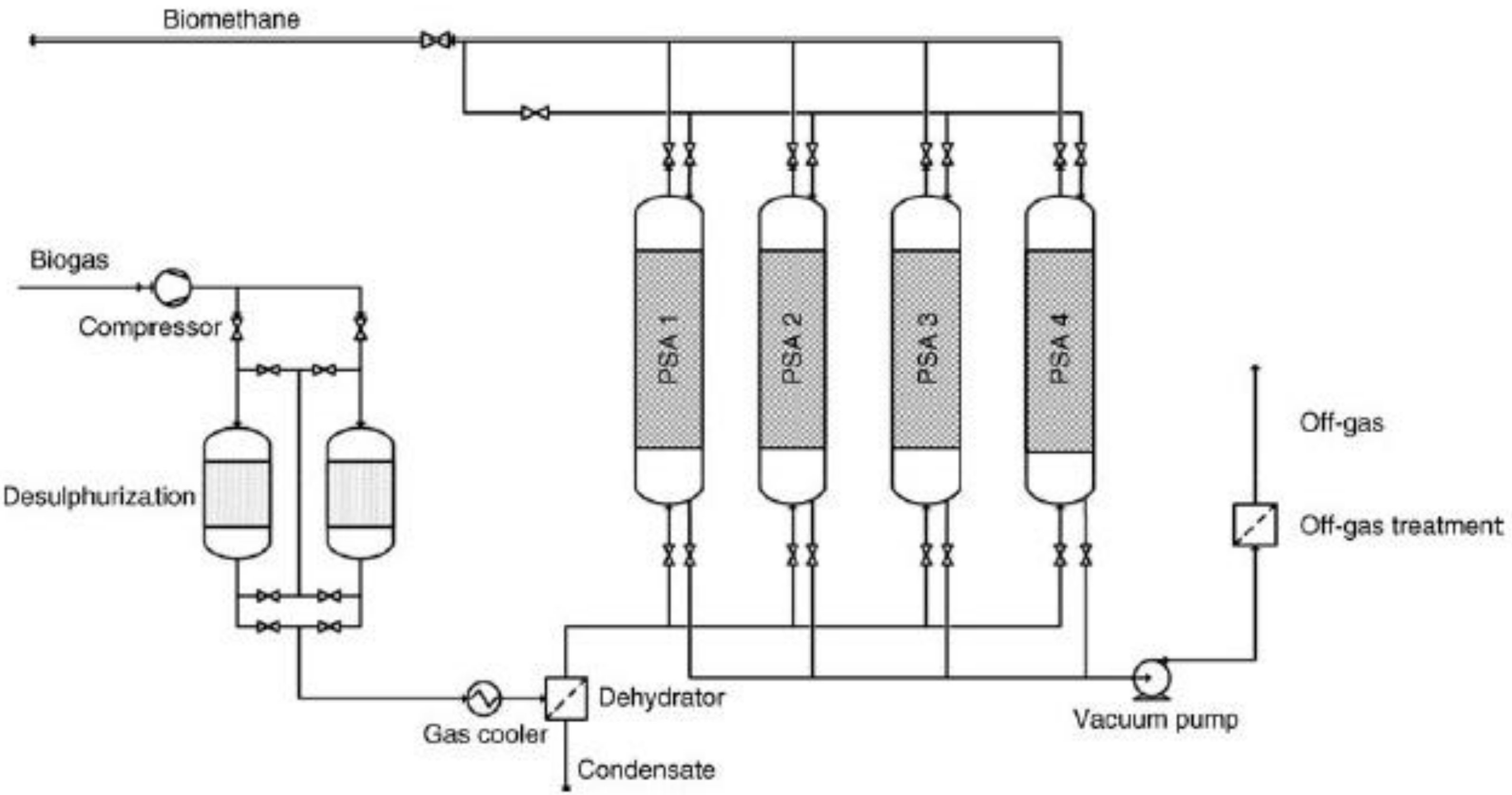
Atmos. Chem. Phys., 15, 4399–4981, 2015
www.atmos-chem-phys.net/15/4399/2015/
doi:10.5194/acp-15-4399-2015

Substance Formula (Other name(s)) [CAS registry number]	H^{cp} (at $T^{\ominus}$) $\left[\frac{mol}{m^3 Pa}\right]$	$\frac{d \ln H^{cp}}{d(1/T)}$ [K]	Reference
methane	1.4×10^{-5}	1900	Warneck and Williams (2012)
CH_4	1.4×10^{-5}	1600	Sander et al. (2011)
[74-82-8]	1.4×10^{-5}	1600	Sander et al. (2006)
carbon dioxide	3.3×10^{-4}	2400	Sander et al. (2011)
CO_2	3.3×10^{-4}	2400	Sander et al. (2006)
[124-38-9]	3.3×10^{-4}	2300	Fernández-Prini et al. (2003)
hydrogen sulfide	1.0×10^{-3}	2100	Sander et al. (2011)
H_2S	1.0×10^{-3}	2100	Sander et al. (2006)
[7783-06-4]	1.0×10^{-3}	2000	Fernández-Prini et al. (2003)

$H_2S > CO_2 > CH_4 > Si\ (L_x \text{ or } D_x)$

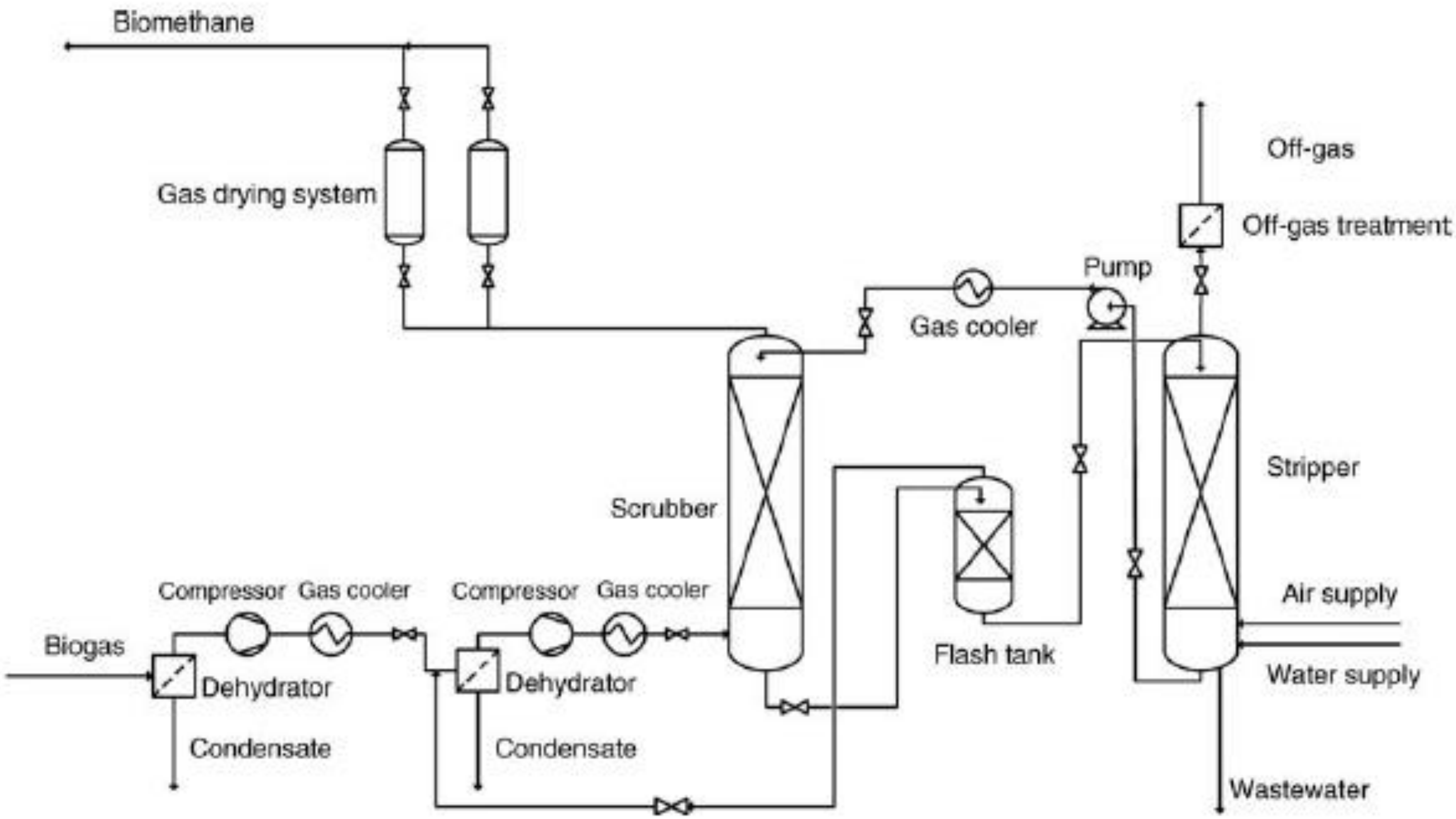
Substance Formula (Other name(s)) [CAS registry number]	H^{cp} (at $T^{\ominus}$) $\left[\frac{mol}{m^3 Pa}\right]$	$\frac{d \ln H^{cp}}{d(1/T)}$ [K]	Reference
hexamethylcyclotrisiloxane	5.6×10^{-6}		Mazzoni et al. (1997)
$C_6H_{18}O_3Si_3$			
(D3)			
[541-05-9]			
octamethylcyclotetrasiloxane	7.3×10^{-7}		Xu and Kropscott (2014)
$C_8H_{24}O_4Si_4$	8.3×10^{-7}		Xu and Kropscott (2012)
(D4)	1.7×10^{-5}		Kochetkov et al. (2001)
[556-67-2]	1.7×10^{-5}		Kochetkov et al. (2001)
	1.2×10^{-4}		Hamelink et al. (1996)
	1.5×10^{-6}		Xu and Kropscott (2014)
	1.6×10^{-6}		Kochetkov et al. (2001)
	8.3×10^{-7}		Mazzoni et al. (1997)
decamethylcyclopentasiloxane	2.8×10^{-7}		Xu and Kropscott (2014)
$C_{10}H_{30}O_5Si_5$	3.0×10^{-7}		Xu and Kropscott (2012)
(D5)	3.4×10^{-5}		Kochetkov et al. (2001)
[541-02-6]	3.1×10^{-5}		Kochetkov et al. (2001)
	7.4×10^{-5}		David et al. (2000)
	2.3×10^{-6}		Xu and Kropscott (2014)
	2.2×10^{-6}		Kochetkov et al. (2001)
	1.5×10^{-6}		Mazzoni et al. (1997)
dodecamethylcyclohexasiloxane	4.0×10^{-7}		Xu and Kropscott (2012)
$C_{12}H_{36}O_6Si_6$	6.8×10^{-5}		Kochetkov et al. (2001)
(D6)	1.5×10^{-4}		Kochetkov et al. (2001)
[540-97-6]	3.9×10^{-6}		Kochetkov et al. (2001)

PSA: pressure swing adsorption.



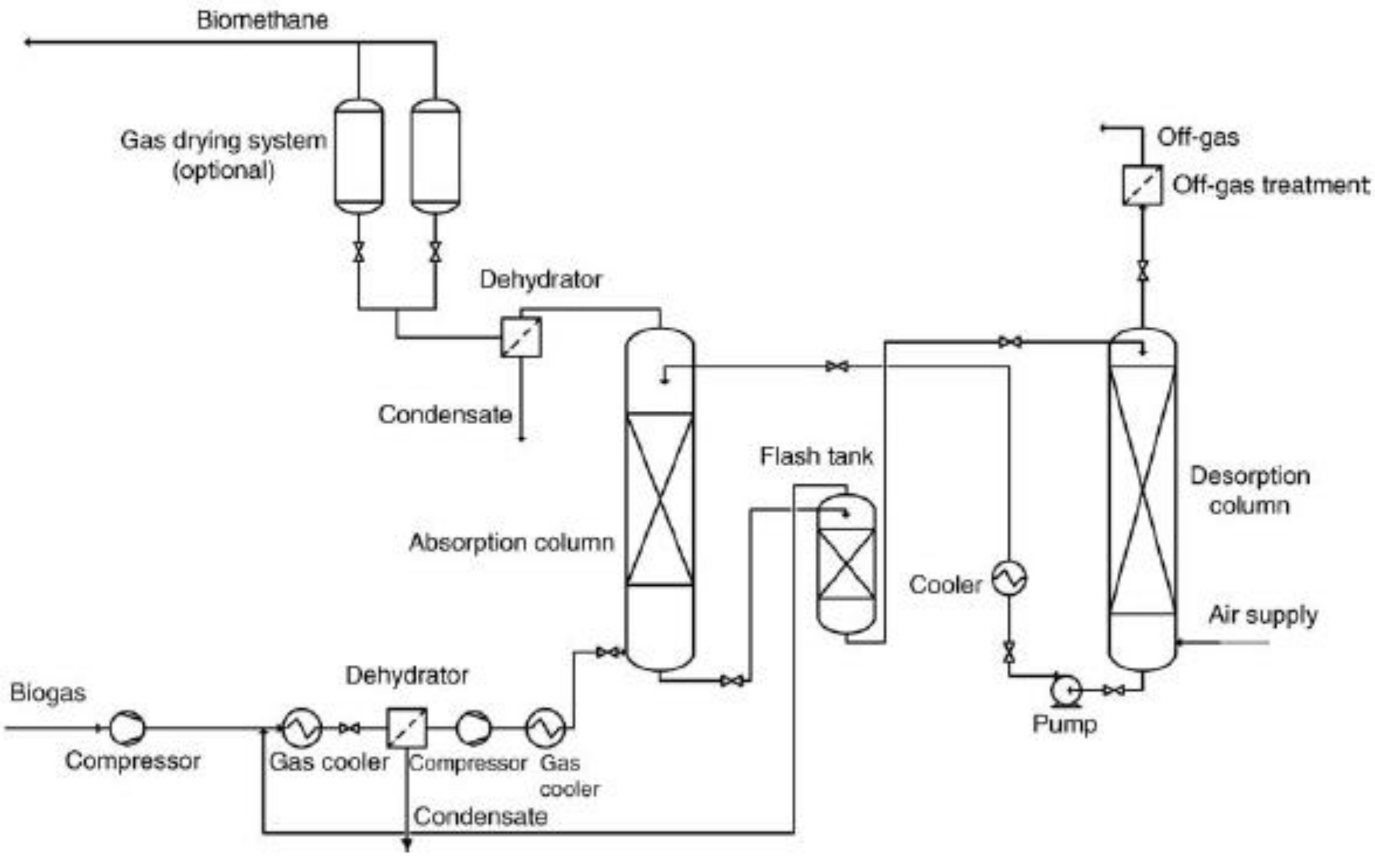
15.4 Process scheme of the pressure swing adsorption process (Copyright: Fraunhofer IWES, 2012).

Water scrubbing



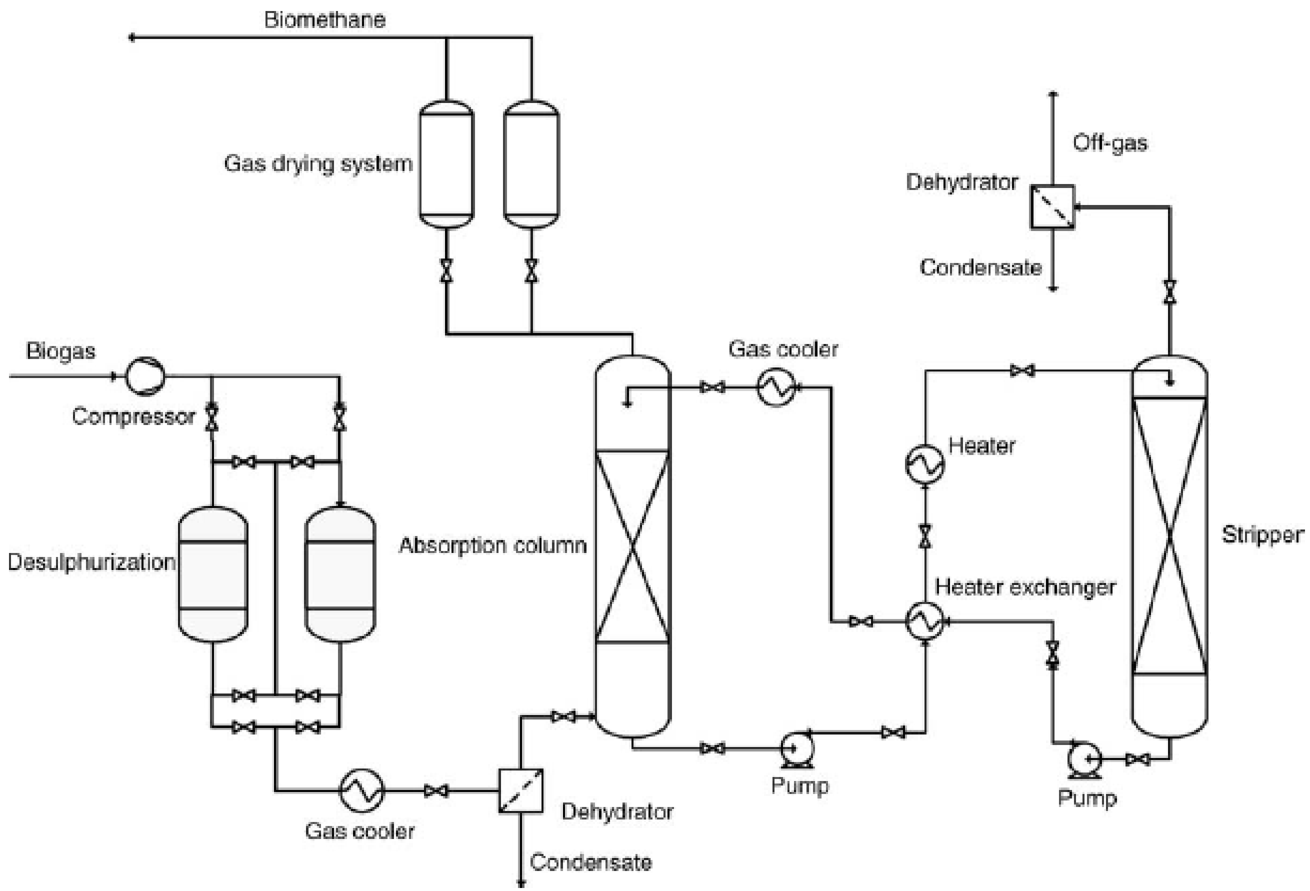
15.6 Process scheme of water scrubber process (Copyright: Fraunhofer IWES, 2012).

Physical Absorption



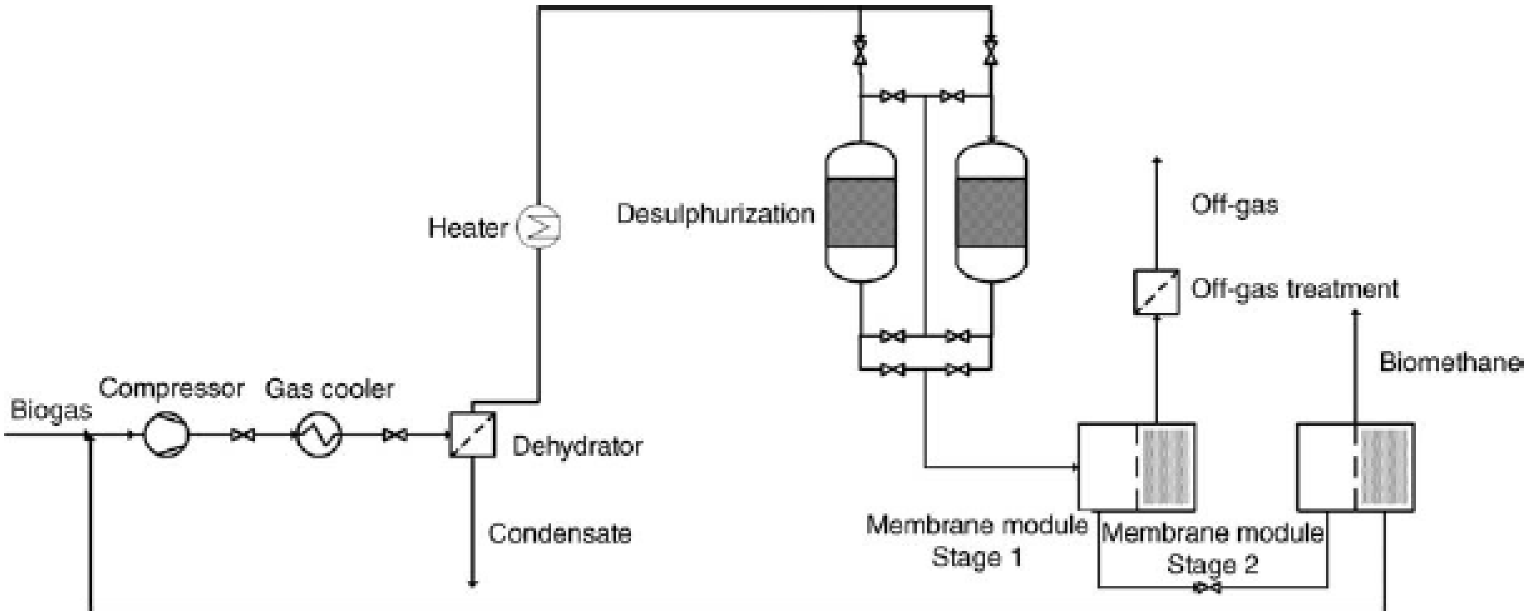
15.8 Process scheme of physical absorption (using organic solvents) (Copyright: Fraunhofer IWES, 2012).

Chemical absorption



15.10 Process scheme of chemical absorption (using organic solvents) (Copyright: Fraunhofer IWES, 2012).

Membrane separation.



15.12 Process scheme of a two-stage membrane separation system for biogas upgrading (Copyright: Fraunhofer IWES, 2012).

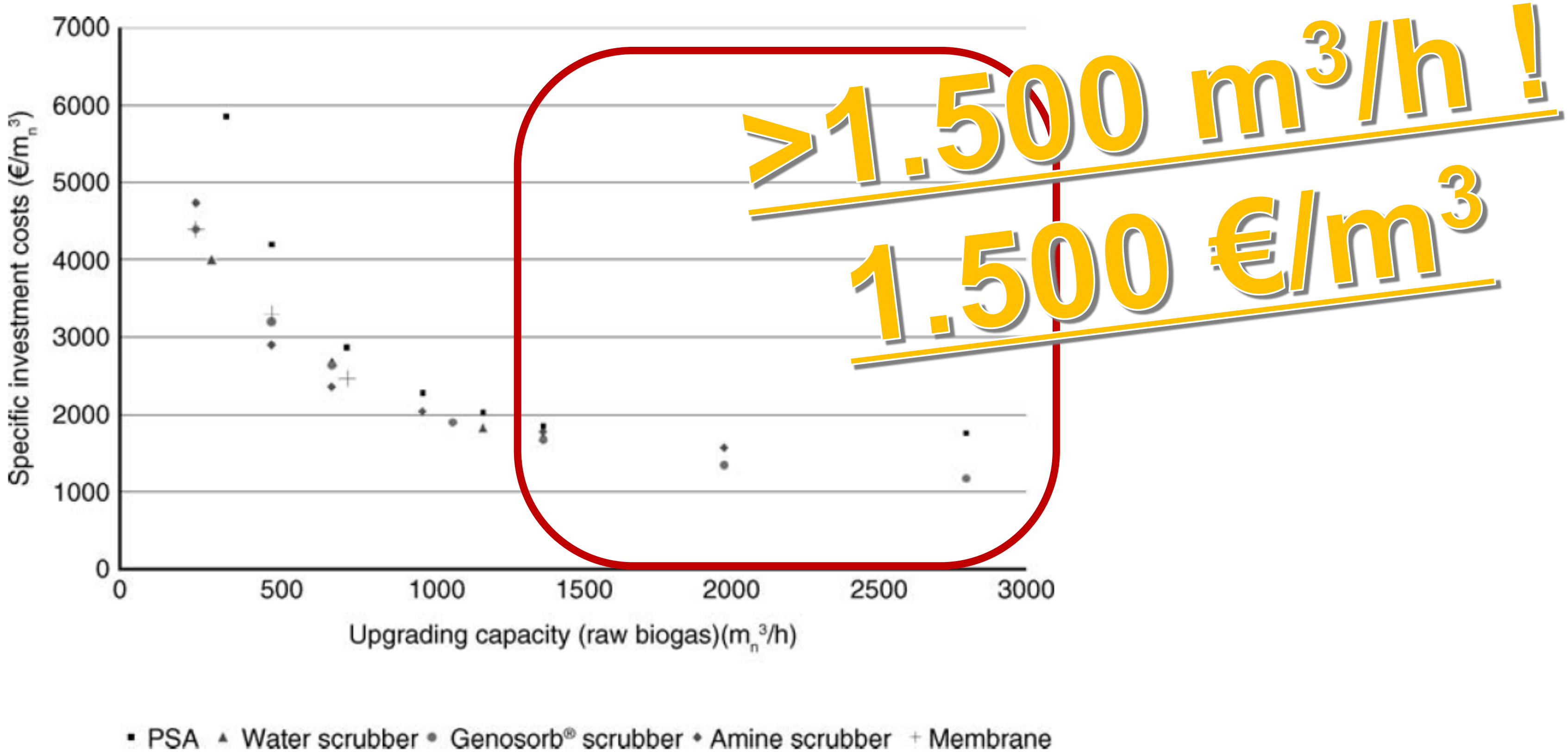
Biogas upgrading tecnologies. Key parameters

Table 15.1 Overview of key parameters of biogas upgrading technologies (Copyright: Fraunhofer IWES, 2012)

	PSA	Water Scrubber	Physical absorption (organic solvents)	Chemical absorption (organic solvents)	Membrane (high pressure, dry)	Cryogenic	Sources
Electricity demand (kWh/m_n^3BG)	0.16–0.35	0.20–0.30	0.23–0.33	0.06–0.17	0.18–0.35	0.18–0.25	[9–15, 18, 19, 23]
Heat demand (kWh/m_n^3BG)	0	0	0.10–0.15	0.4–0.8	0	0	[14,17,19]
Temperature process heat (in the column) (°C)	—	—	40–80	106–160	—	—	[11, 12, 20]
Operation pressure (bar)	1–10	4–10	4–8	0.05–4	7–20	10–25	[7,10–13, 21, 22, 25]
Methane loss (%)	1.5–10	0.5–2	1–4	~0.1	1–15	0.1–2.0	[11–13, 16, 17, 19, 21, 24, 26]
Methane recovery rate (%)	90–98.5	98–99.5	96–99	~99.9	85–99	98–99.9	[11–13, 16, 17, 19, 21, 24, 26]
Off-gas treatment recommended (methane loss > 1%)	Yes	Yes	Yes	No	Yes	Yes	
Precision desulphurization required	Yes	No	No	Yes (Depending on manufacturer)	Recommended	Yes	
Water demand	No	Yes	No	Yes	No	No	
Demand on chemical substances	No	No	Yes	Yes	No	No	

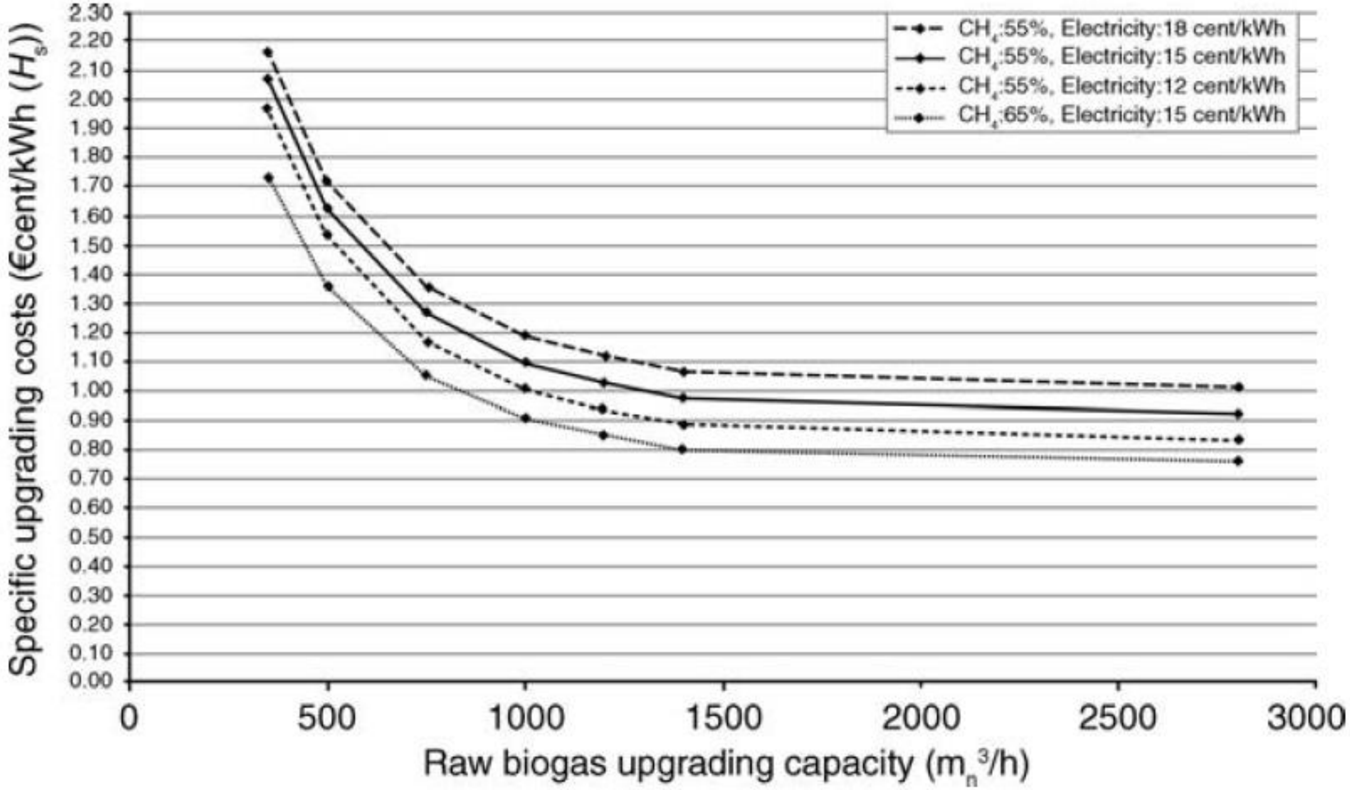
Treatment cost? CAPEX vs. OPEX

Capex comparison:



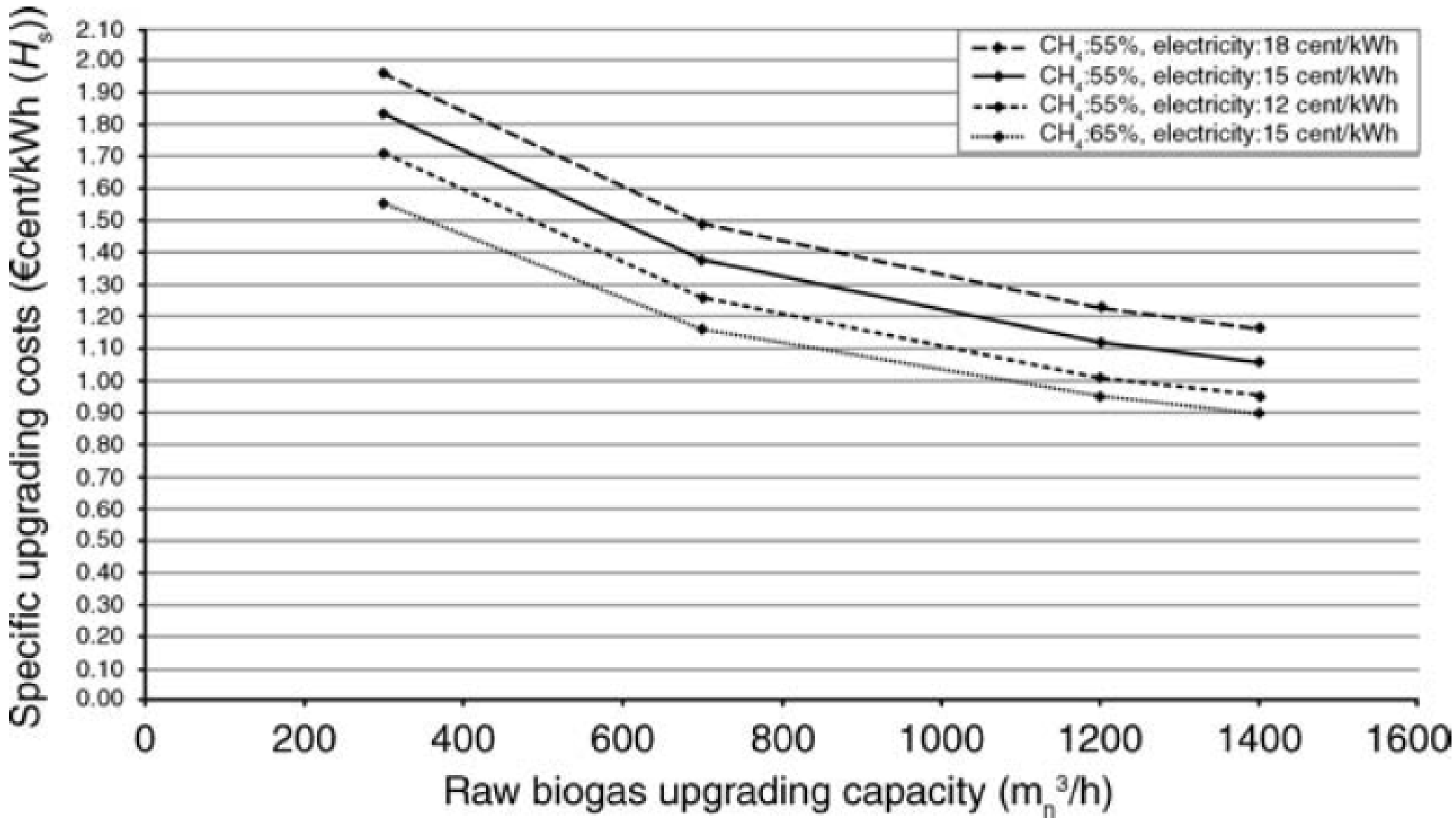
15.16 Specific investment costs in € per m_n^3 raw gas upgrading capacity of five biogas upgrading methods based on [14–17, 45] (Copyright: Fraunhofer IWES, 2012).

Treatment costs: PSA



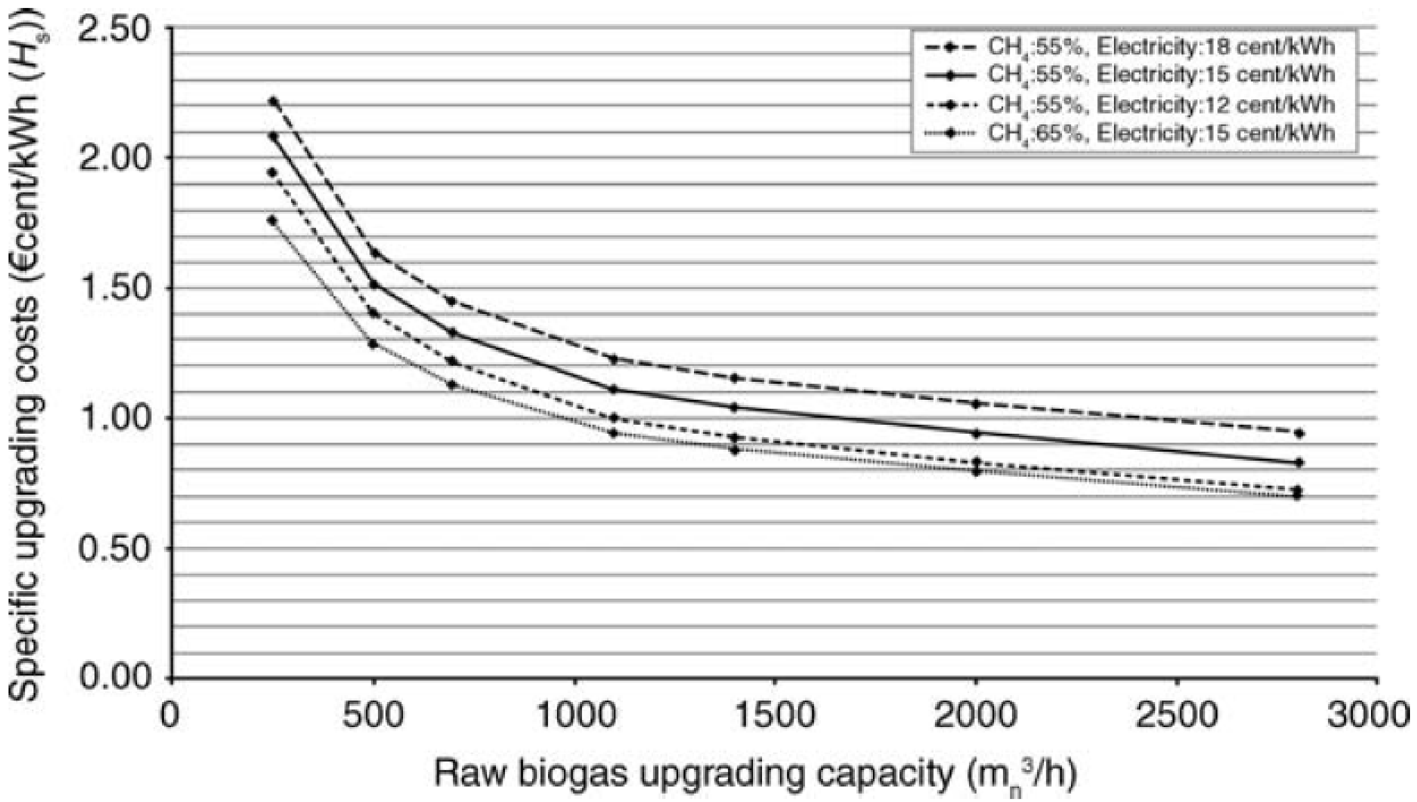
15.17 Specific biogas upgrading costs for PSA based on price indications and warranty values according to [16] (Copyright: Fraunhofer IWES, 2012).

Treatment costs: water scrubber



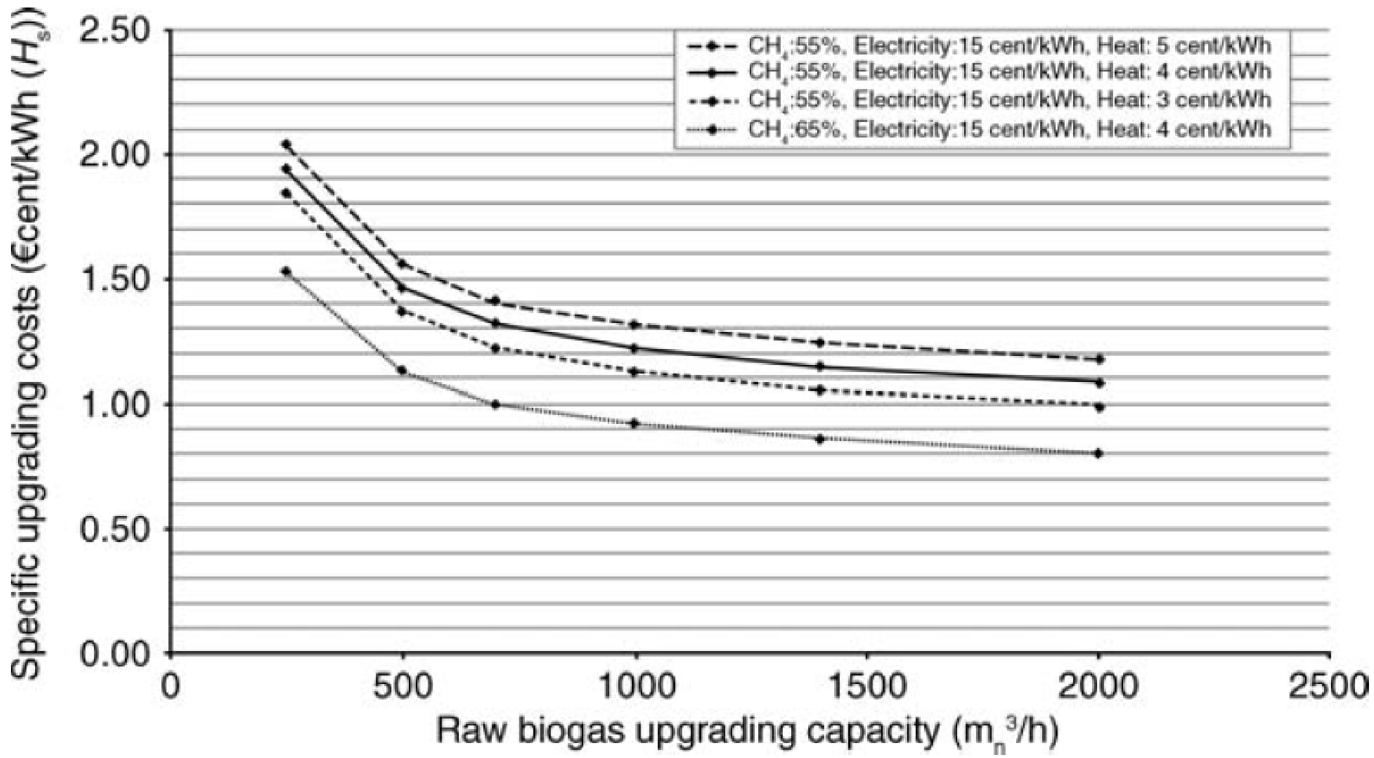
15.18 Specific biogas upgrading costs for water scrubber based on price indications and warranty values according to [15] (Copyright: Fraunhofer IWES, 2012).

Treatment costs: Genosorb® scrubbers



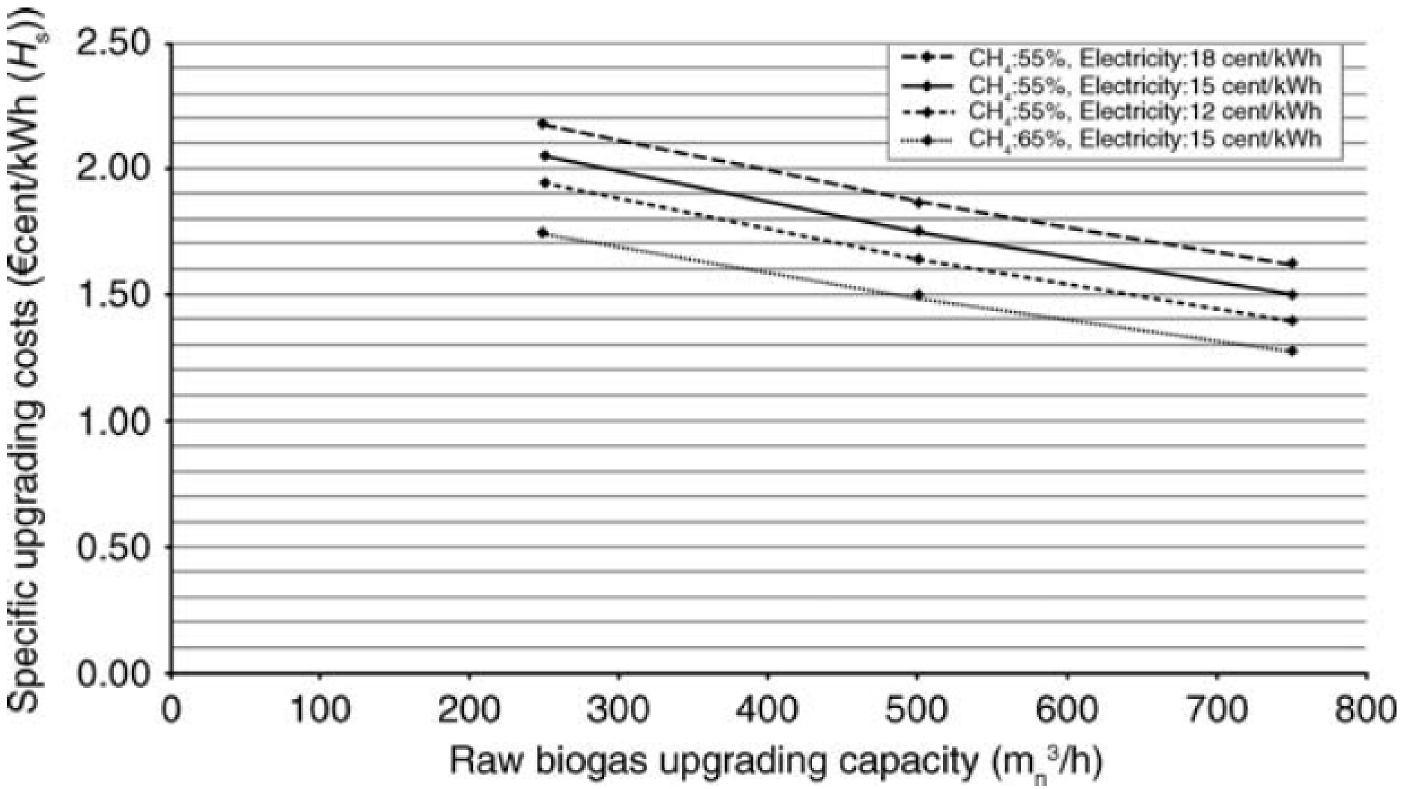
15.19 Specific biogas upgrading costs for Genosorb® scrubbers based on price indications and warranty values according to [14] (Copyright: Fraunhofer IWES, 2012).

Treatment costs: amine scrubbers



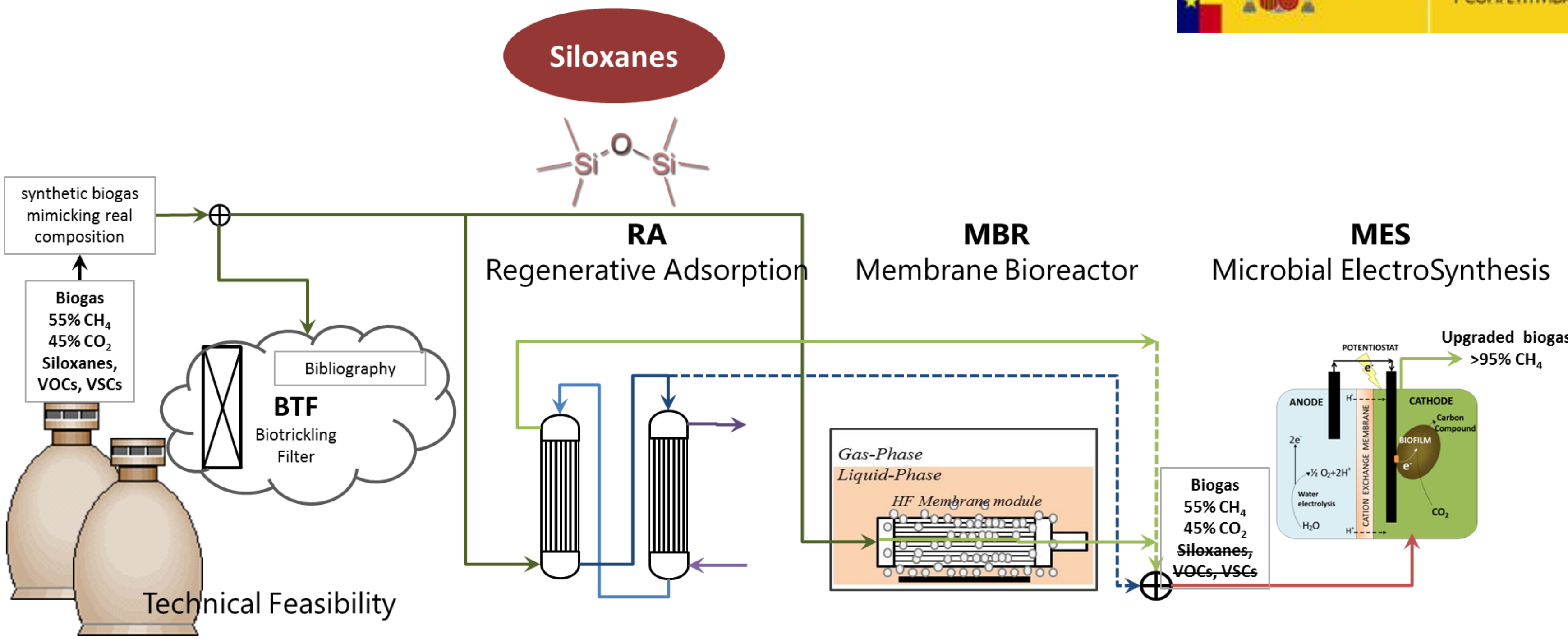
15.20 Specific biogas upgrading costs for amine scrubbers based on price indications and warranty values according to [17] (Copyright: Fraunhofer IWES, 2012).

Treatment costs: membrane separation



15.21 Specific biogas upgrading costs for a membrane separation system based on price indications and warranty values according to [45] (Copyright: Fraunhofer IWES, 2012).

Biogas upgrading. BiogasApp CTQ2014-53718-R



Economical Feasibility

Environmental Impacts (LCA)

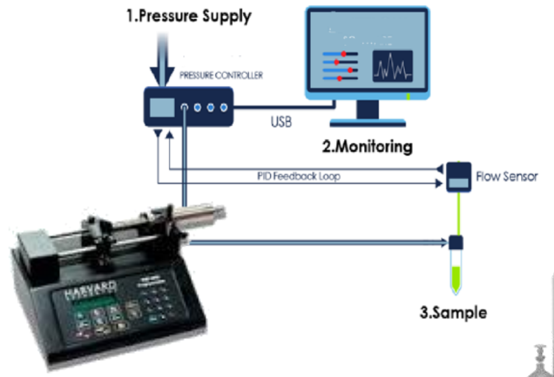
Social Benefits

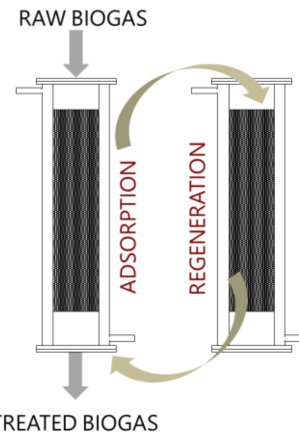
Integrated Decision-Making

Removal of siloxanes

On-site experimentation

Storage ΔP (<40 bar)





SYN-ADG

AD biogas

low concentration

pulseless

fast response

smooth

affordable cost

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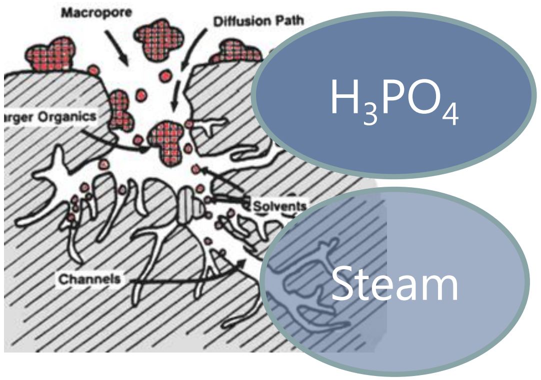
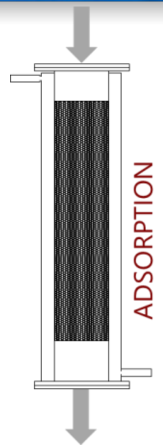
Removal of siloxanes

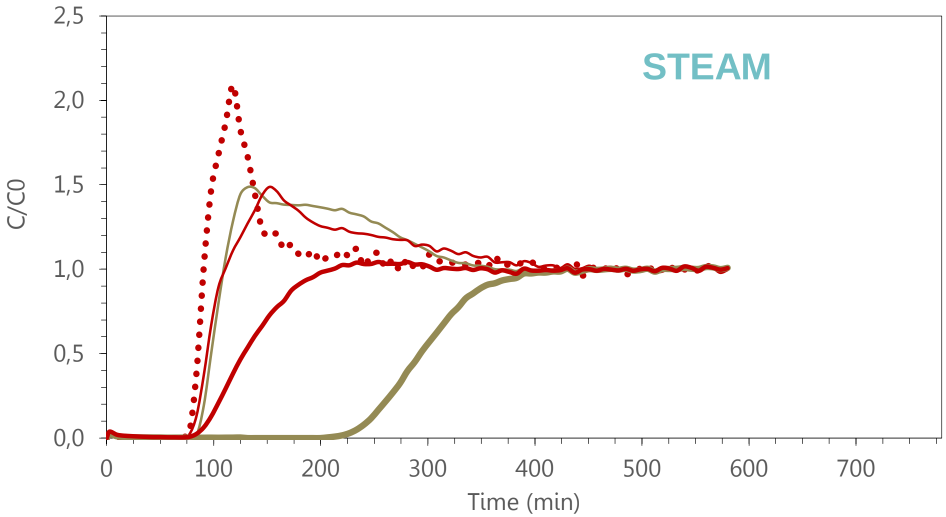
Multicomponent adsorption breaktrough curves

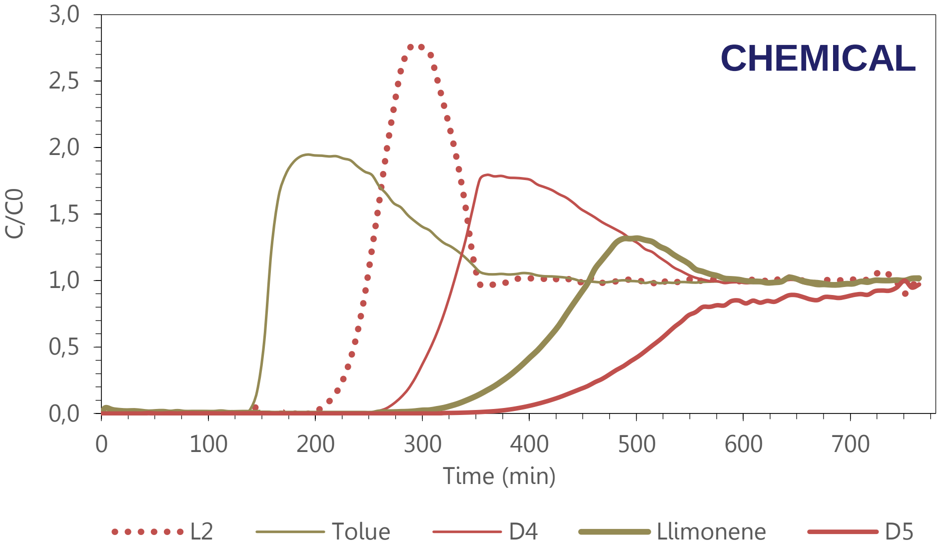
EBCT= 0,2s
Q=200 STPmL N_2/min

COMPOUND	[C] (mg m^{-3})
L2	380
D4	1892
D5	2064
Toluene	3886
Limonene	752

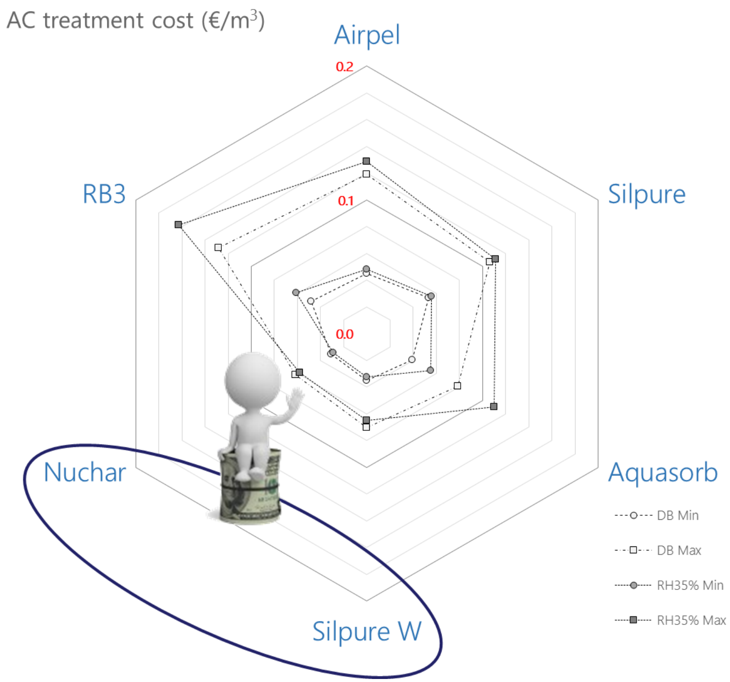


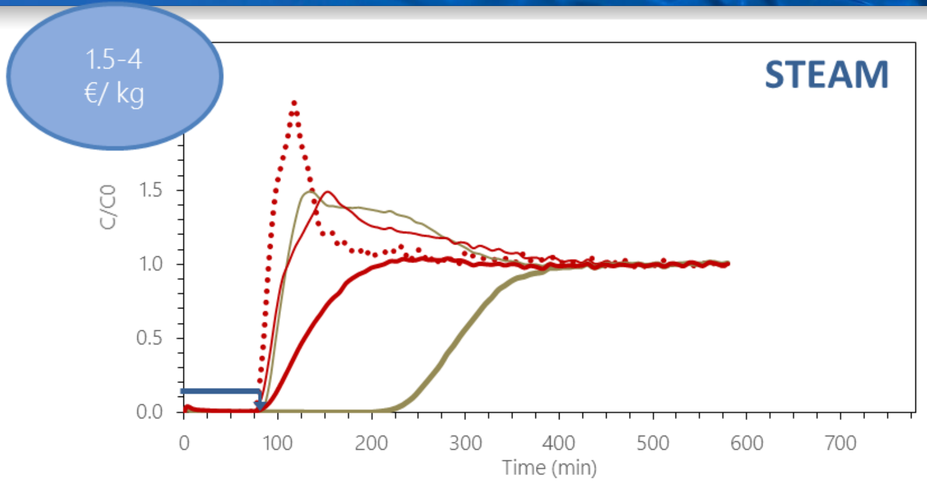


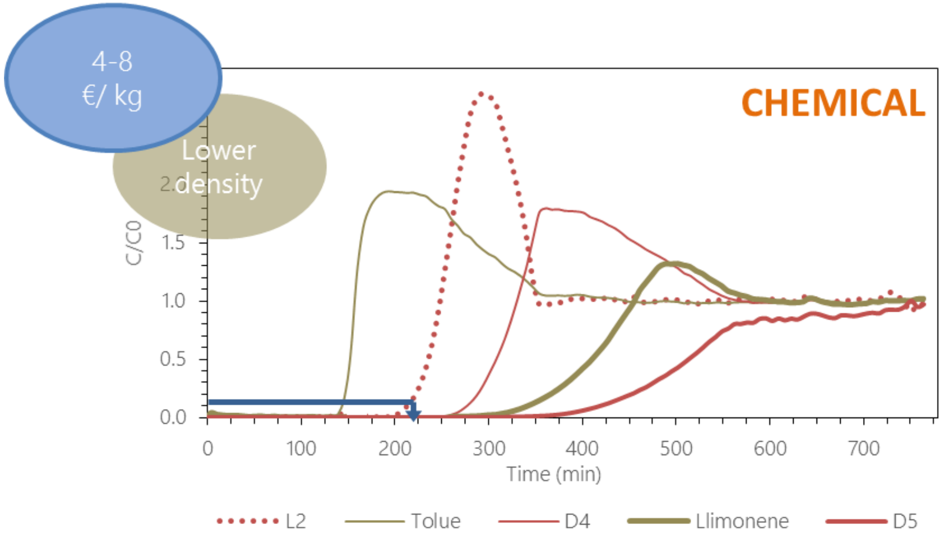




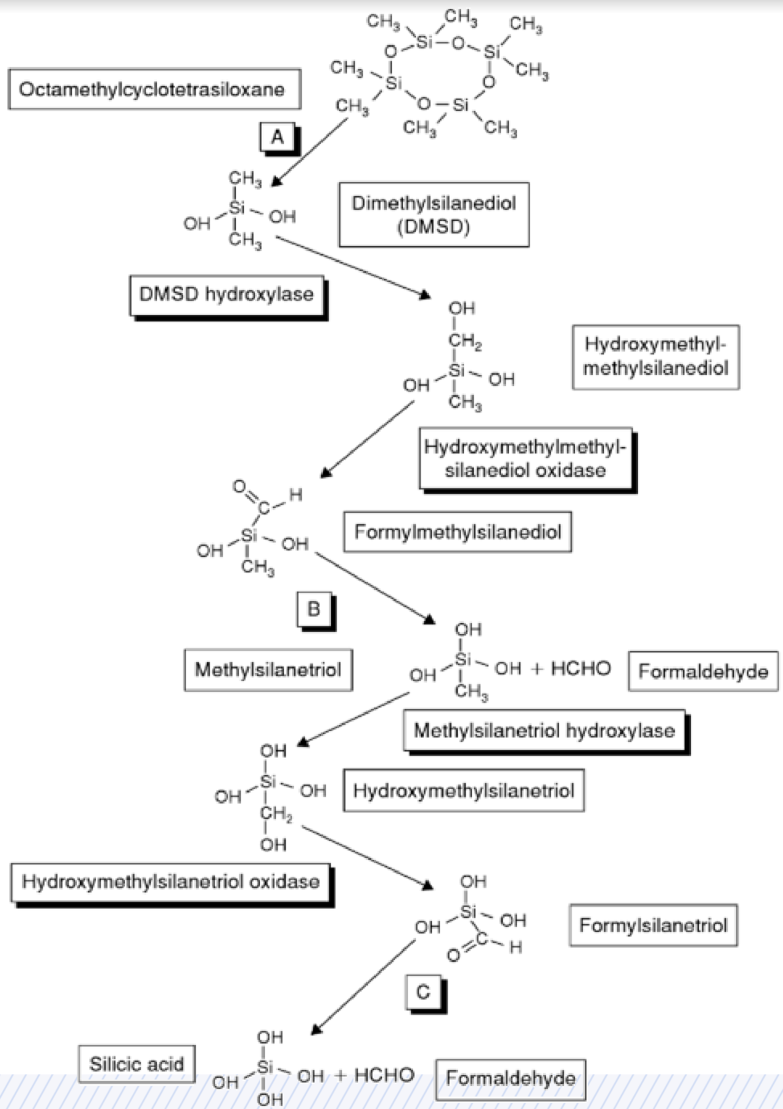
Removal of siloxanes: treatment costs.



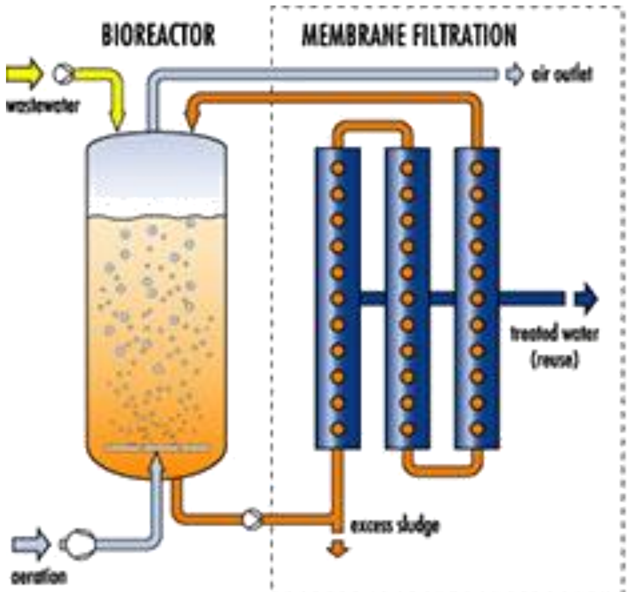


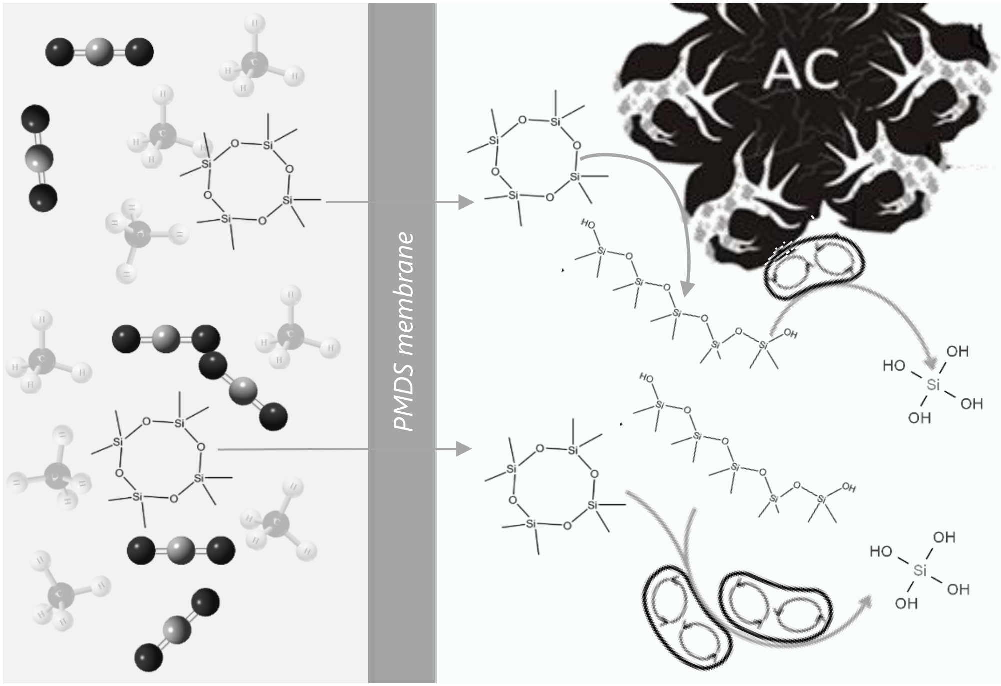


Removal of siloxanes: biological treatment?



Removal of siloxanes: biological treatment?



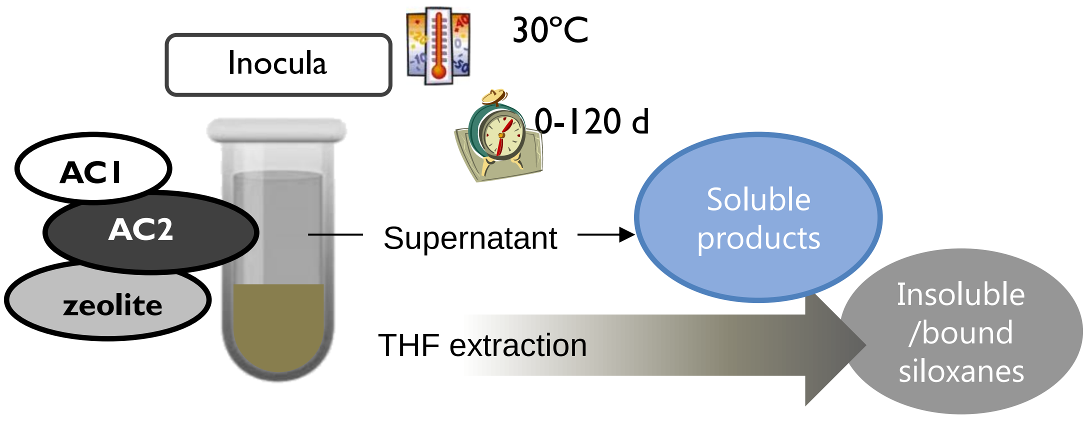


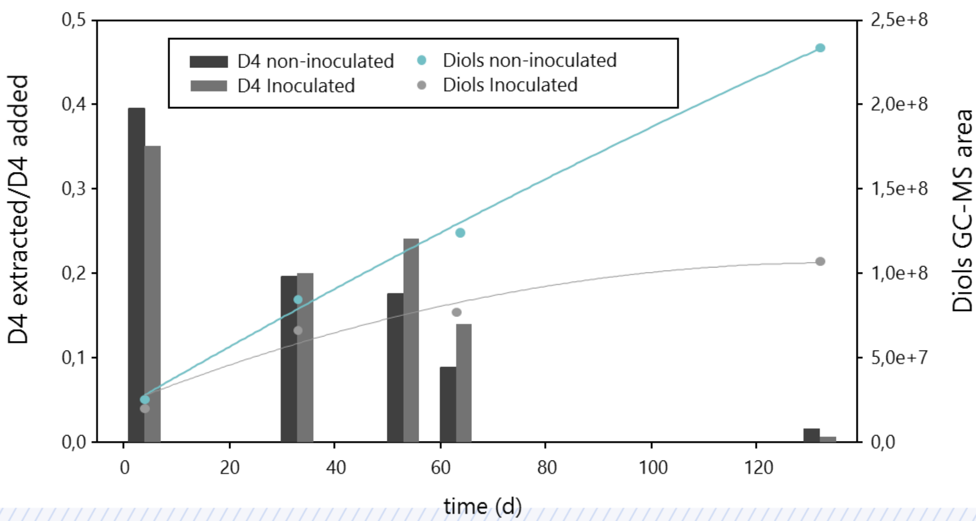
Removal of siloxanes: biological treatment?

- Cyclic volatile siloxanes are (fast enough?) biodegradable
- PDMS membranes are efficient for siloxane removal
- AC efficiently concentrates VSiC on its surface
- AC catalyzes siloxane bond cleavage

Removal of siloxanes: biological treatment?

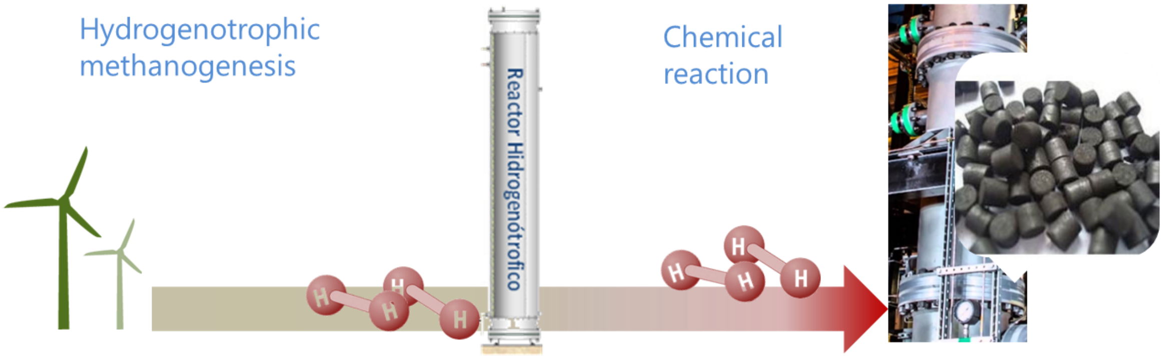
Batch tests



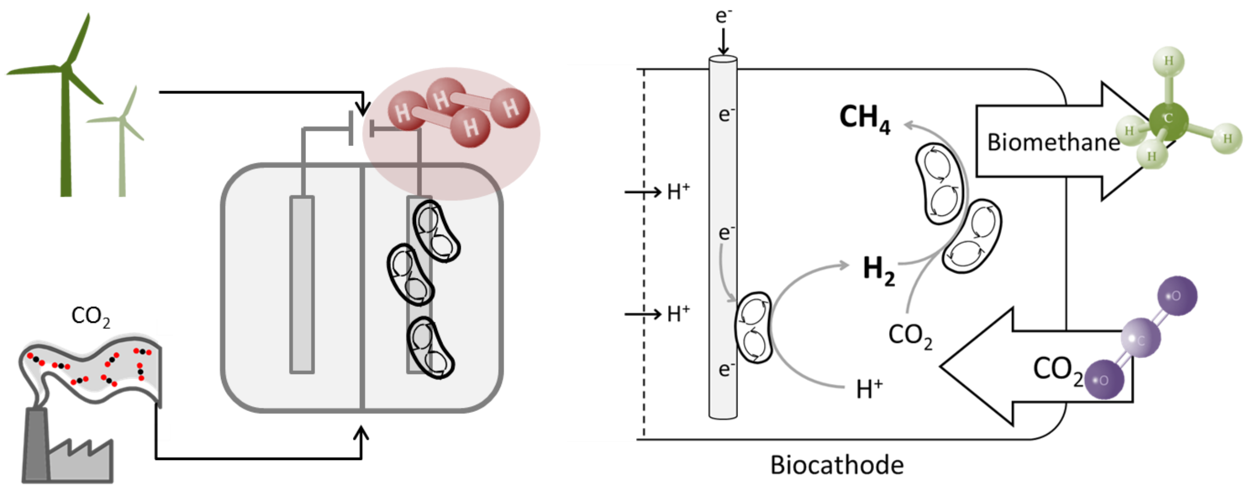


Conversion of CO_2 to CH_4?

Hydrogenotrophic methanogenesis



Bioelectrochemical systems



Microbial electrotechnologies (MET): what's that?

From where comes MET ?

Driving force: ΔG

$\Delta G<0$

- Oxidation environment
- (Biotic) Organic matter oxidation (removal COD)
- (Abiotic) water electrolysis, H_2 oxidation

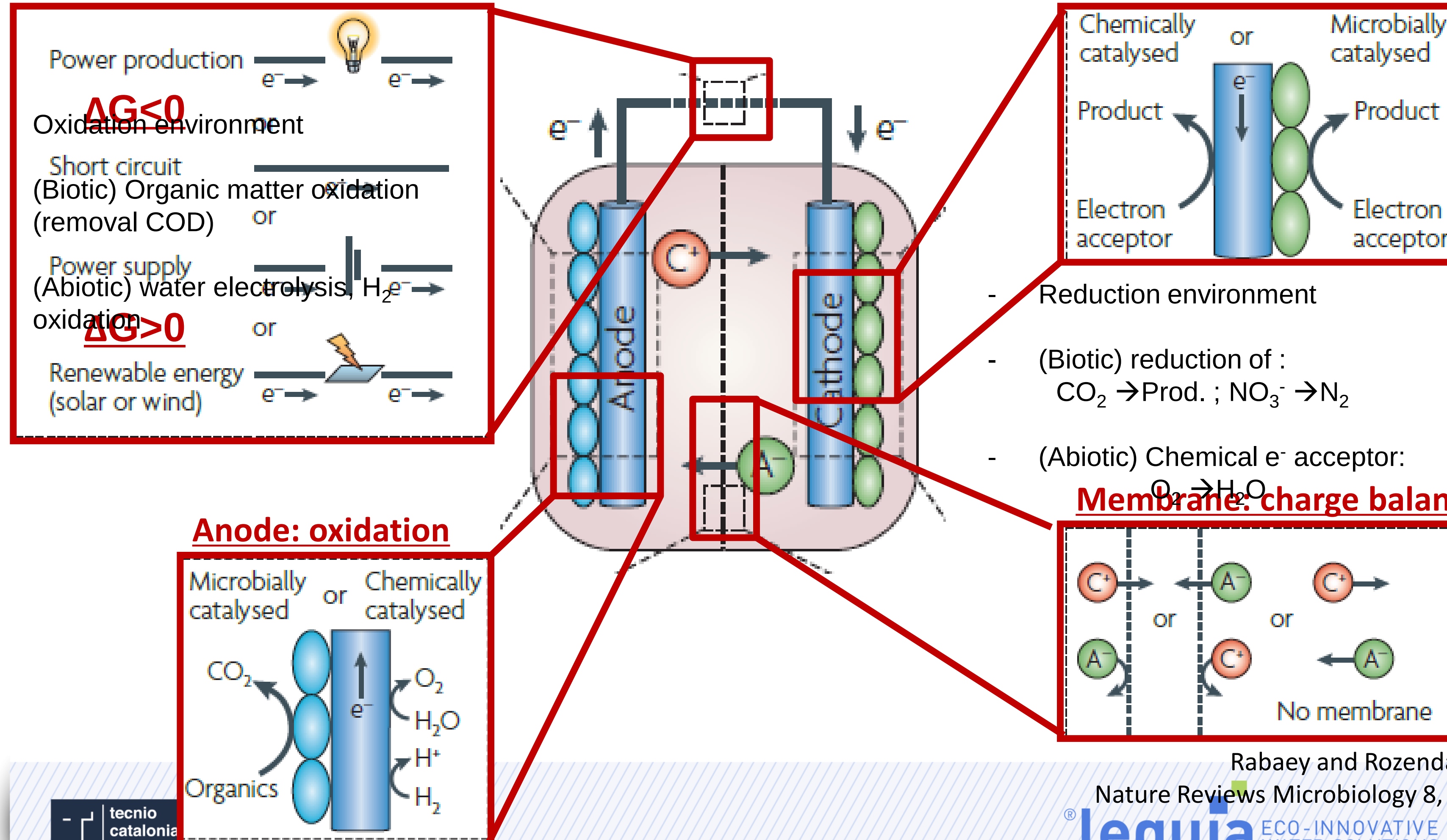
$\Delta G>0$

Cathode: reduction

- Reduction environment
- (Biotic) reduction of : $CO_2 \rightarrow$ Prod. ; $NO_3^- \rightarrow N_2$
- (Abiotic) Chemical e^- acceptor: $O_2 \rightarrow H_2O$

Anode: oxidation

Membrane: charge balance

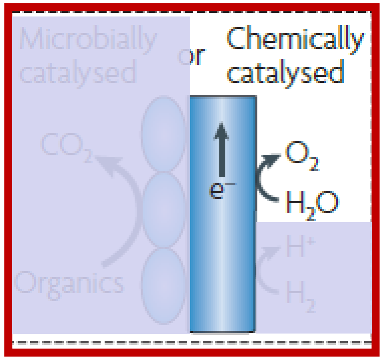


Rabaey and Rozendal (2010) Nature Reviews Microbiology 8, 706-716

Microbial electrotechnologies (MET): what's that?

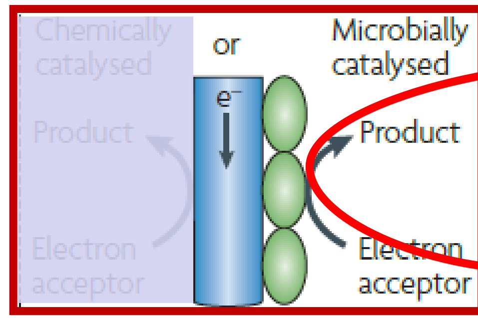
Source and products within MET: a **biocathode reaction**

Anode: oxidation



Driving force

Cathode: reduction



CO_2

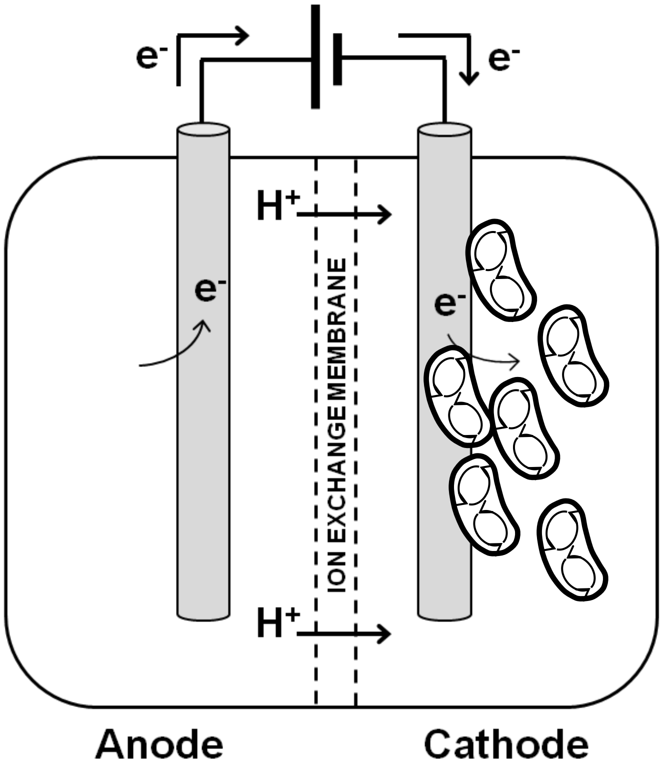
Valuable products:

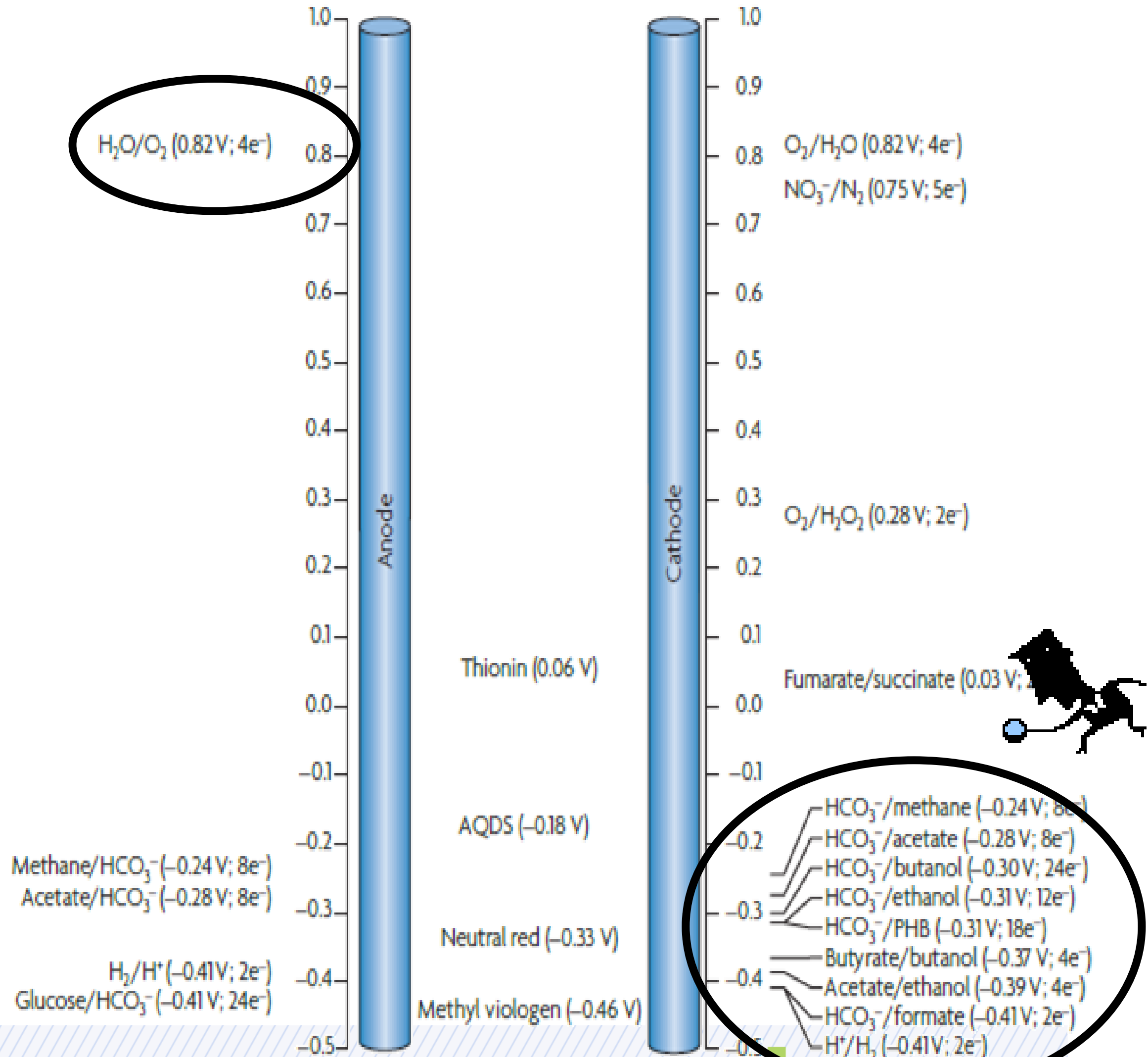
- **Carboxylic acids**: acetate, propionate, …
- **Methane**
- **Alcohols:** ethanol, butanol, …

Why it works:

- Anode: **water oxidation**
- Cathode: CO_2 reduction, **biocathode**
- Energy: **power supply**
- Membrane: C/A membrane or membrane less (study)

Microbial electrotechnologies (MET): what's that?





Ecell < 0
$\Delta G > 0$
Non spontaneous

Energy required

Rabaey and Rozendal, 2010. *Nature Rev Microbiol*

Microbial electrotechnologies (MET): Methane

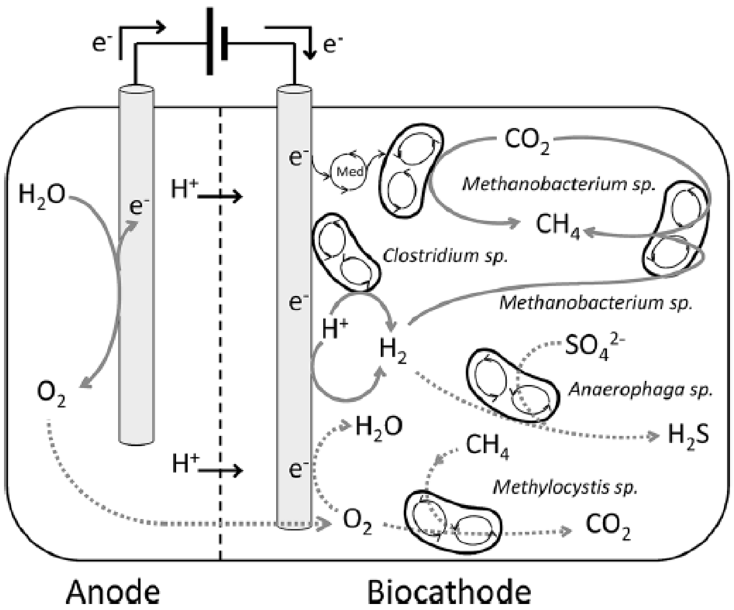
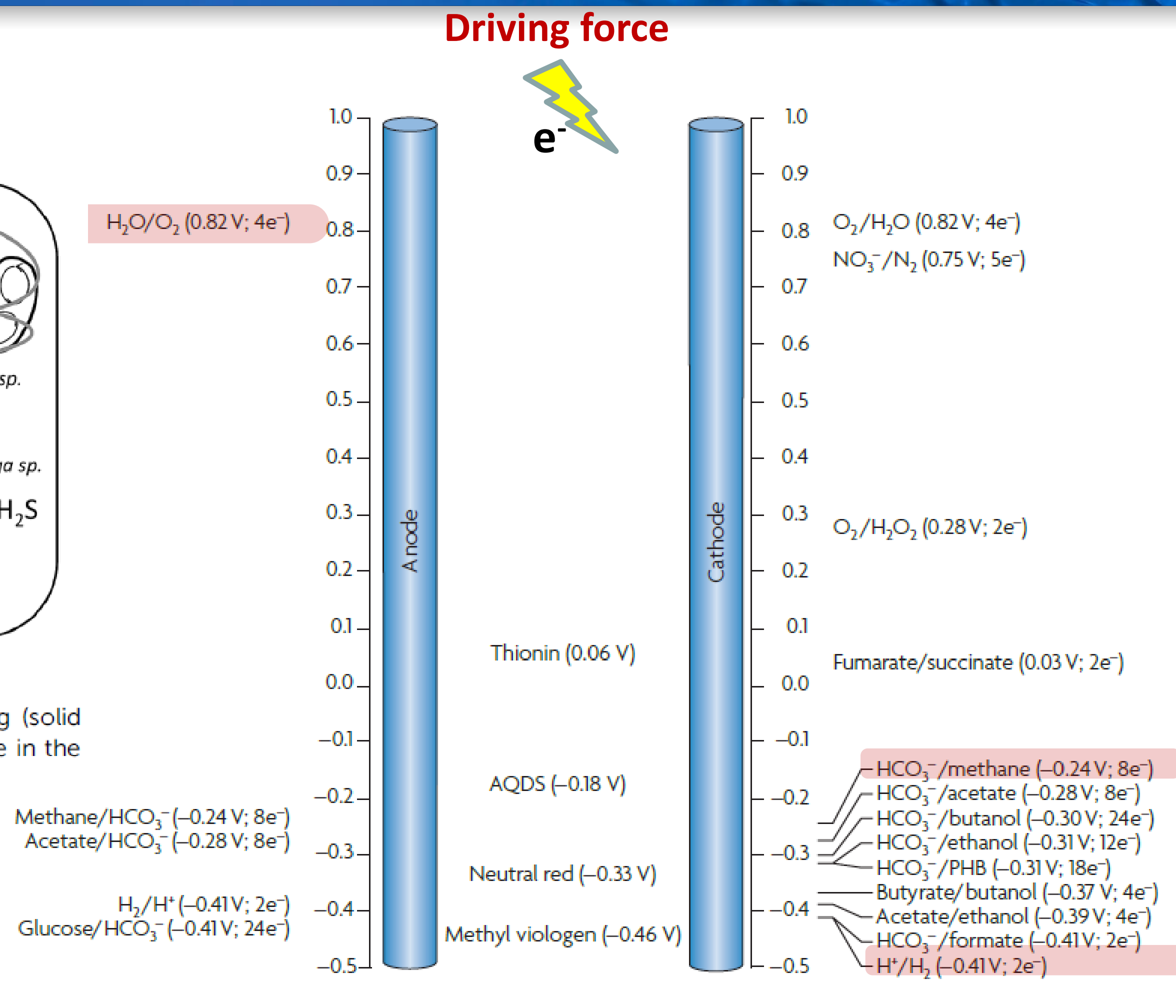


Fig. 4 Schematic representation of the methane producing (solid lines), and cross-over (dashed lines) reactions that took place in the biocathode.

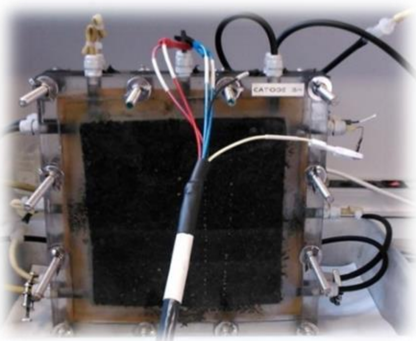


Batlle-Vilanova et al. 2015
RSC Adv., 2015, 5, 52243 Doi:10.1039/c5ra09039c

MET: CO_2 to Methane

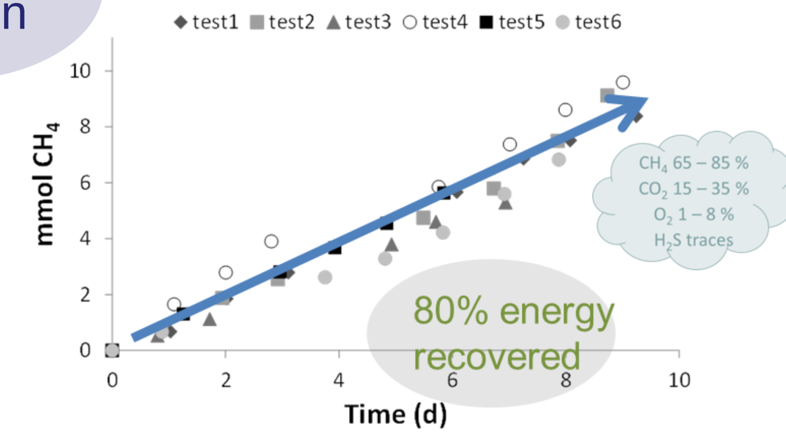
Lab scale BES

V_{cat}= 0,4L
Feed: CO_2-saturated mineral solution
Cathode potential: -0,8V

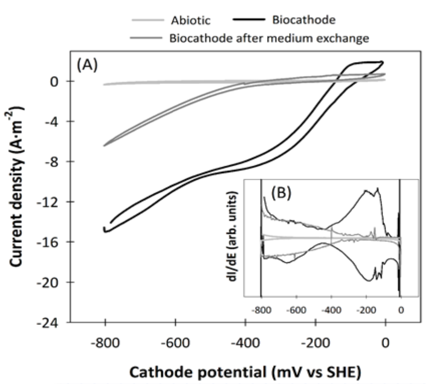


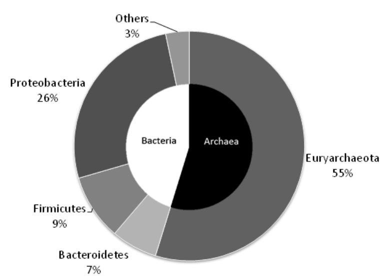
Batch operation

Continuous operation

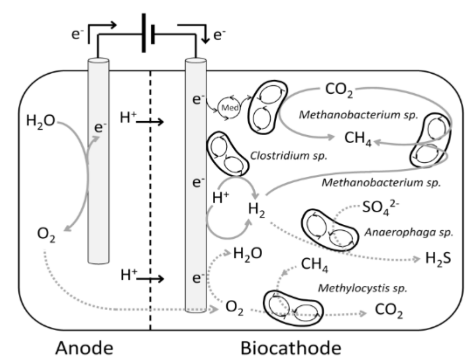


Electrochemical & Microbiological characterisation





Reaction mechanism



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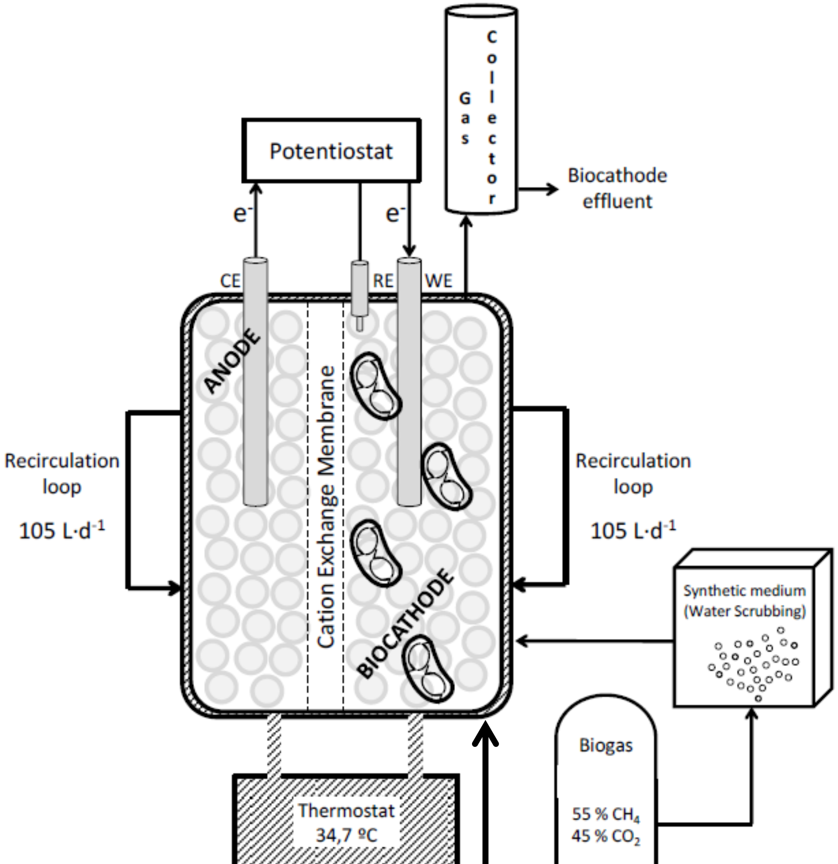
MET: the pilot



Inoculum from AD

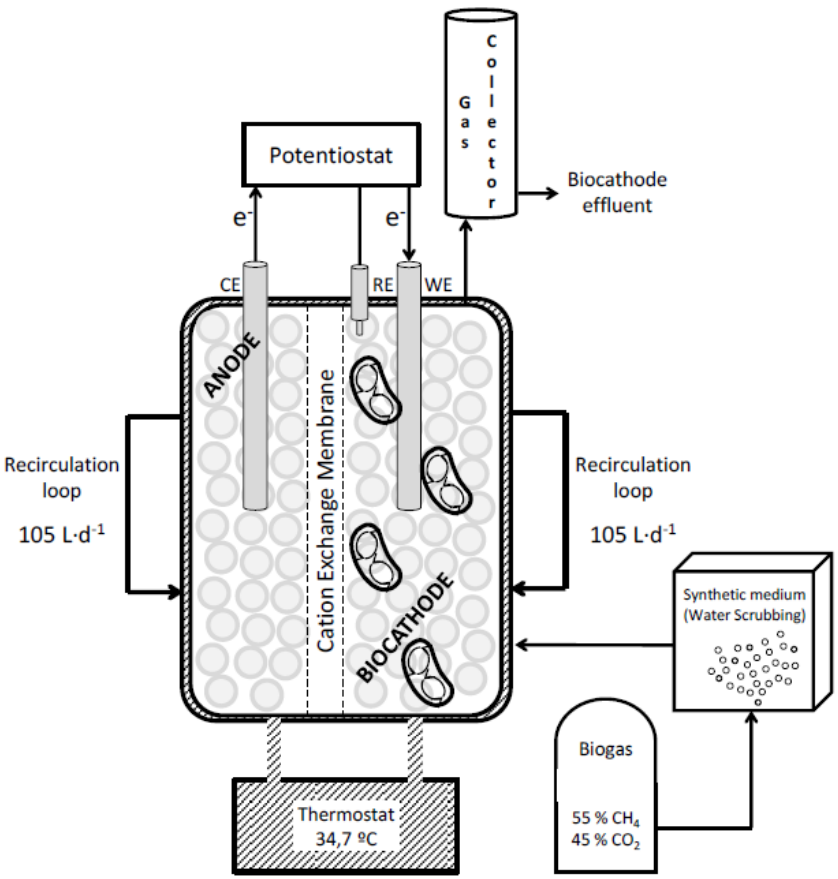
Biocathode volume 0,42 L

Electrode surface 0,57 m^2

Operation Batch / Continuous (HRT=18,3h)

Cathode potential -800 mV vs SHE

The reactions…



BIOCATHODE

Electromethanogenesis

$CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$ E'_0 = -0,24

Hydrogenotrophic methanogenesis

$2H^+ + e^- \rightarrow 4H_2$ E'_0 = -0,41

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

ANODE

Water electrolysis

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ E'_0 = +0,82

Thermodynamics

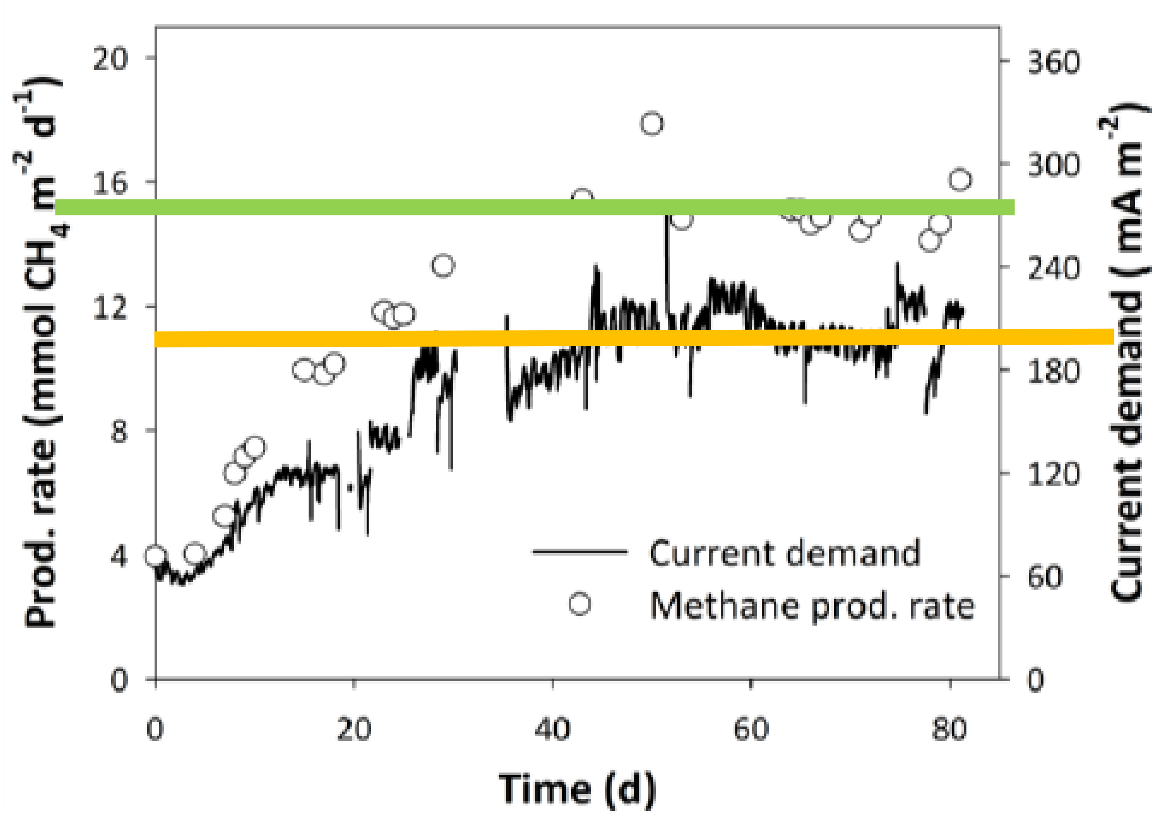
$$\Delta G = -n \cdot F \cdot E_{cell}$$

$$E_{cell} = E_{cat} - E_{an}$$

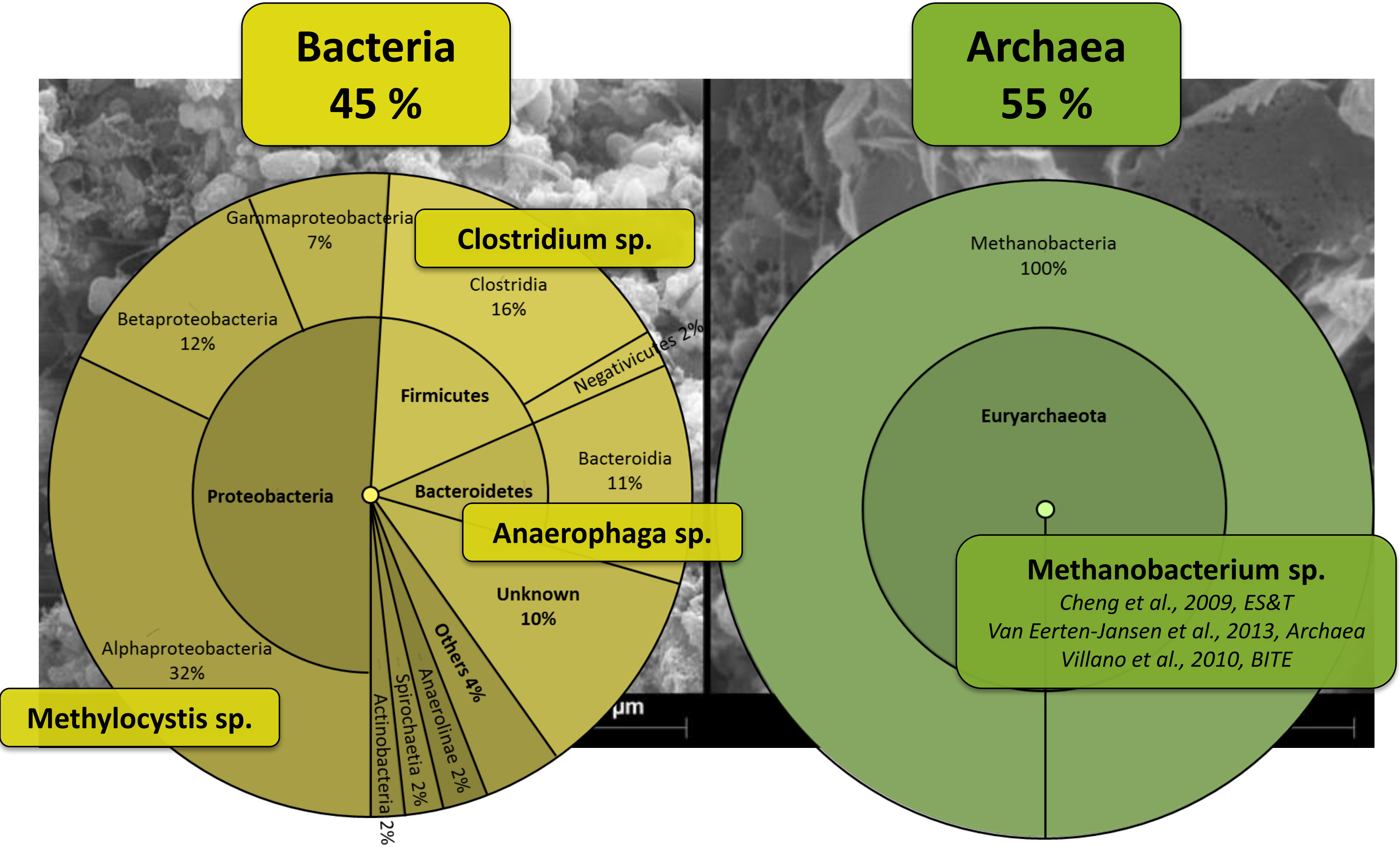
$\Delta G > 0$
Energy required

First results.....

Current demand (A m_{NCC}^{-3})	pH	Prod rate (mM C d^{-1})	CE (%)
201.7 ± 18.1	7.1 ± 0.2	15.4 ± 0.0	68.9 ± 0.8



First results….. – Microbial community



Results – Microbial community

BIOCATHODE

Hydrogenotrophic methanogenesis

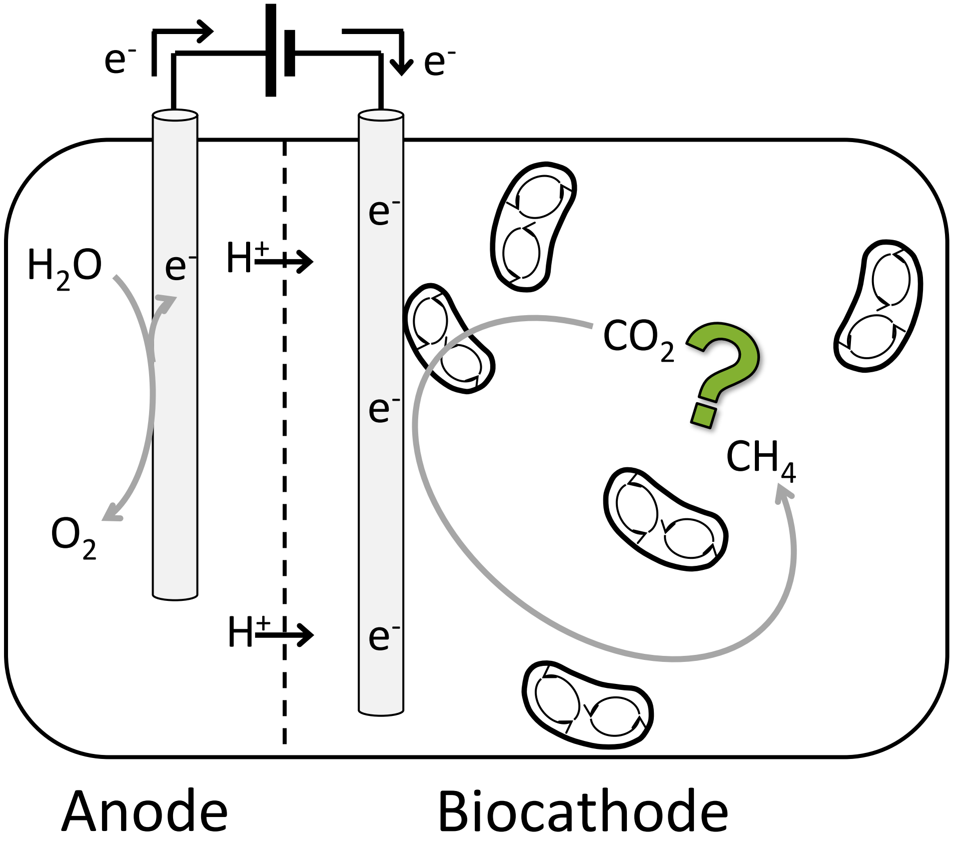
$2H^+ + e^- \rightarrow 4H_2$ E'$_0$ = -0,41 ?

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Electromethanogenesis ?

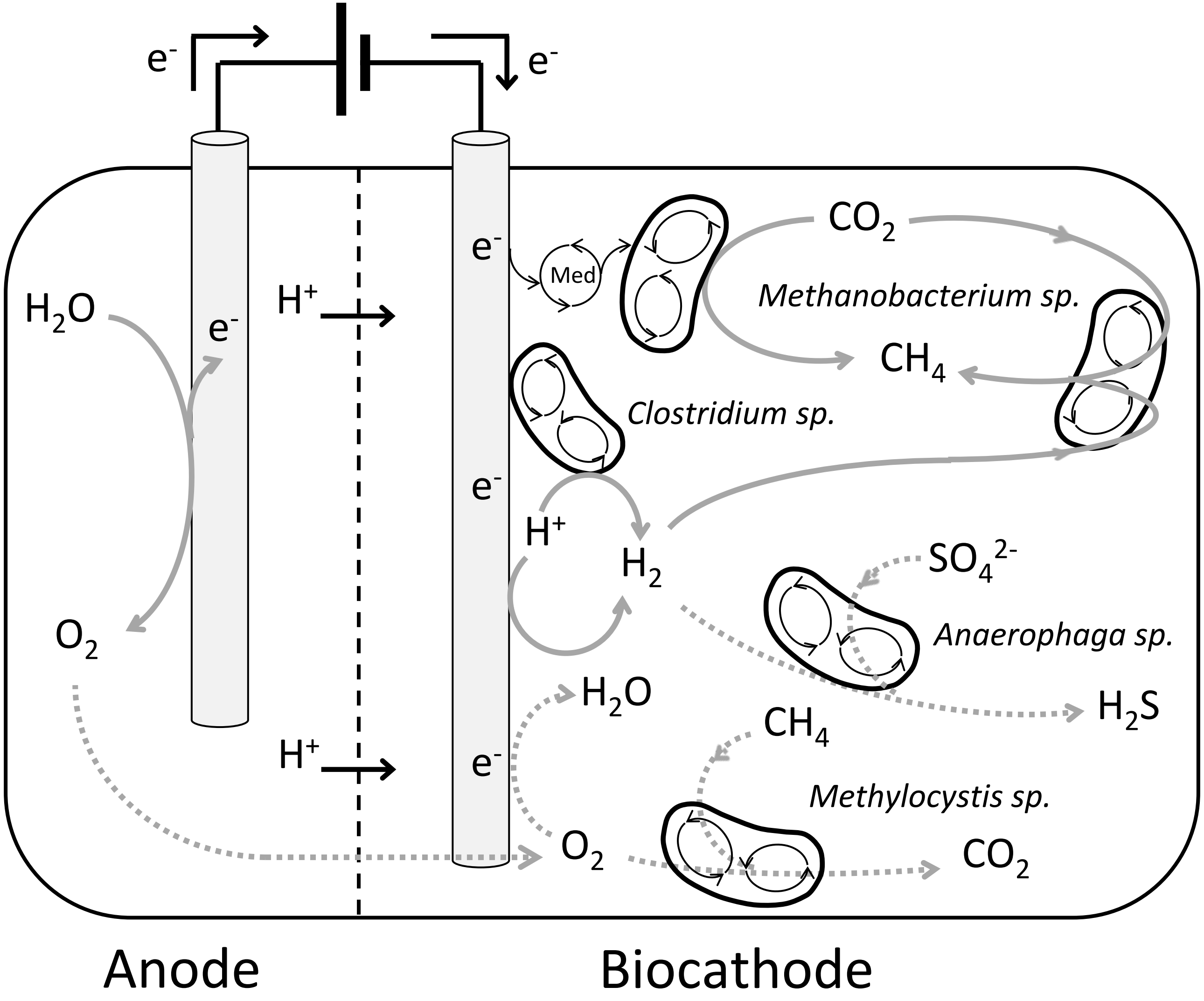
$CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$

E'$_0$ = -0,24



Electrochemical characterisation

Results – Methane production mechanism

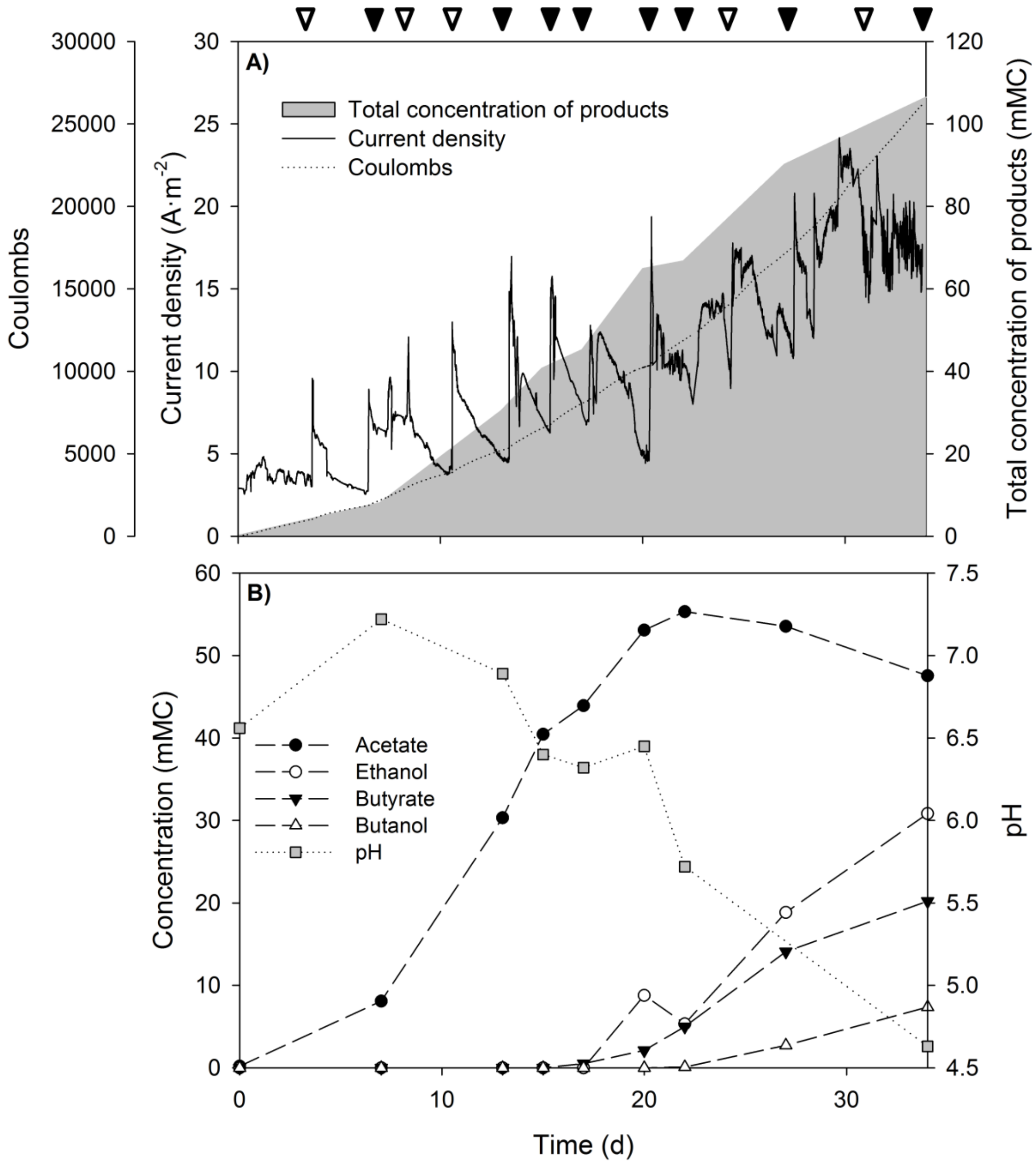


Batlle-Vilanova et al., 2015, RSC Advances

Other products from CO_2?

Ganigué et al. LEQUIA. (2015) Chem. Commun.

1st Proof of concept: Bioalcohols production



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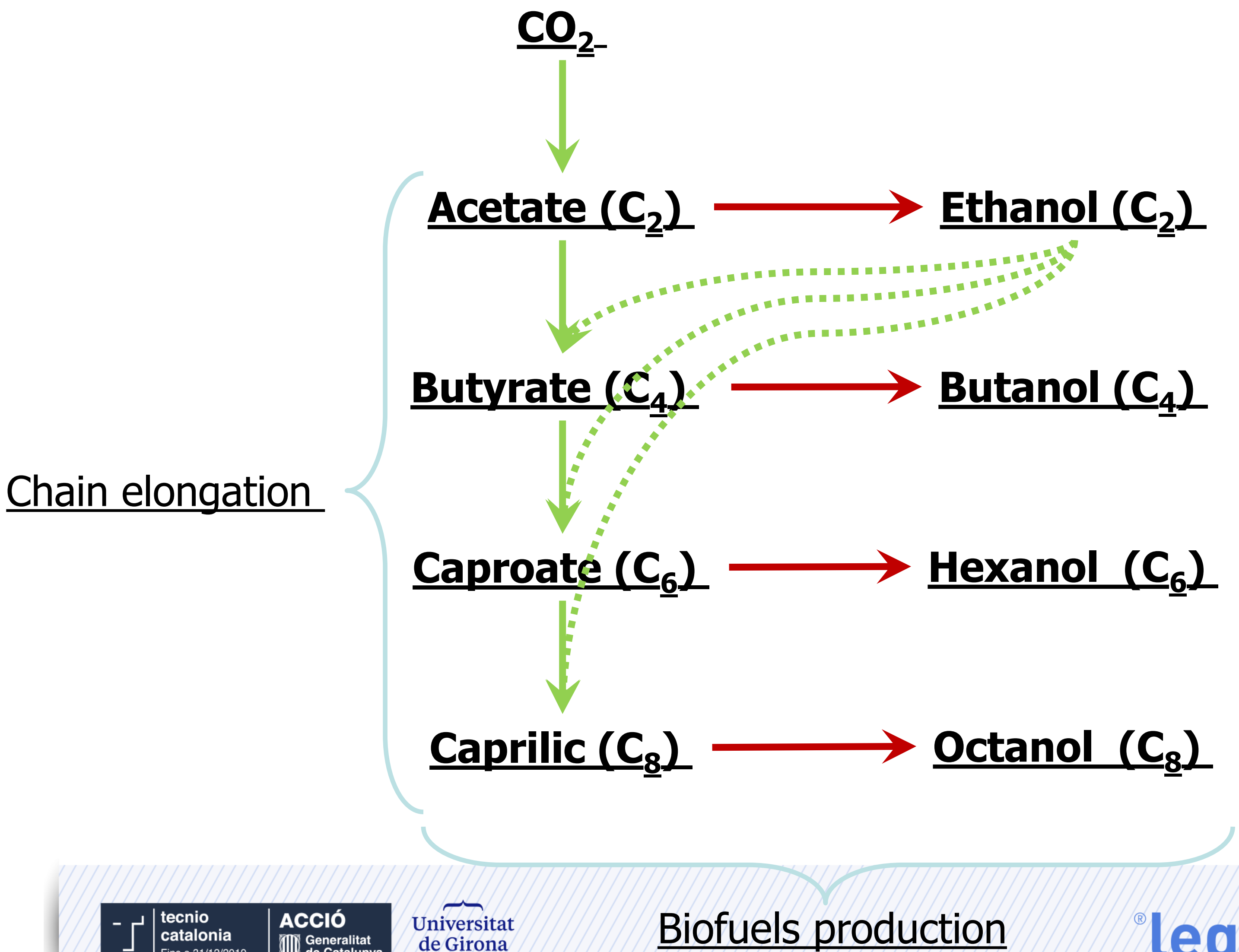
CO_2: Biological transformation



Upgrading plants

Upgrading plants

List of upgrading plants

COUNTRY	PLACE	SUBSTRATE	UTILISATION	CH_4 REQUIRE-MENTS (%)	TECHNOLOGY	PLANT CAPACITY (NM³/H RAW GAS)	IN OPERATION SINCE
Austria	Bruck/Leitha	Biowaste	Gas grid	97	Membrane	180	2007
	Linz	Sewage	Gas grid	97	Water scrubber	800	2008
	Margarethen am Moos	Energy Crops & Manure	Vehicle fuel	>95	Membrane	70	2007
	Pucking	Manure	Gas grid	97	PSA	10	2005
	Reitbach / Eugendorf	Energy crops	Gas grid Vehicle fuel	97	PSA	150	2008
Canada	Berthierville, (QC)	Landfill gas	Gas grid		Membrane		2003
France	Lille	Biowaste	Vehicle fuel	97	Waterscrubber	2*600	2007
	Lille Marquette				Water scrubber	100	2009
Germany	Altenstadt	Biowaste	Gas grid		Water scrubber	1250	2009
	Bottrop	Sewage sludge	Vehicle fuel		PSA	120	2008
	Burgrieden	Energy crops	Gas grid		PSA	300	2008
	Einbeck	Energy crops	Gas grid		Chemical scrubber	1000	2009
	Ettlingen	Energy crops	Gas grid		PSA	600	2008
	Forchheim	Energy crops	Gas grid		Genosorb scrubber	1000	2009
	Gemeinde Graben Landkreis Augsburg	Energy crops	Gas grid		PSA	1000	2008
	Godenstedt	Energy crops	Gas grid		Chemical scrubber	600	2009
	Güstrow, M-V	Energy crops	Gas grid		Water scrubber	10000	2009
	Hardegesen	Energy crops	Gas grid		Chemical scrubber	1000	2009
	Horn-Bad Meinberg (NRW)	Energy crops	Gas grid		Chemical scrubber	2000	2009
	Jameln	Manure Energy crops	Vehicle fuel, gas grid		Genosorb scrubber	160	2005
	Kerpen	Energy crops	Gas grid		PSA	1000	2008
	Ketzin	Energy crops	Gas grid		PSA	400	2008
	Könnern I	Manure, energy crops	Gas grid		Water scrubber	1250	2007
	Könnern II	Energy crops	Gas grid		Chemical scrubber	3400	2009
	Lüchow	Energy crops	Gas grid		Water scrubber	1250	2008
	Maihingen	Energy crops	Gas grid		Water scrubber	1250	2007
	Mühlacker	Energy crops	Gas grid		PSA	920	2007
	Niederndodeleben	Energy crops	Gas grid		Water scrubber	1250	2008
	Pliening	Energy crops	Gas grid		PSA	920	2006
	Rathenow	Energy crops	Gas grid		Genosorb scrubber	1130	2009
	Ronnenberg	Energy crops	Gas grid		Genosorb scrubber	650	2008
	Schwandorf I	Energy crops	Gas grid		Organic scrubber	1000	2007
	Schwandorf II	Energy crops	Gas grid		PSA	2000	2008
	Straelen	Energy crops, manure	Gas grid		PSA	1000	2006
	Utzensdorf	Biowaste	Gas grid	96	PSA	100	2009
	Werlte	Manure, biowaste	Gas grid		PSA	500	2007
	Wixhausen (Darmstadt)	Manure, energy crops	Gas grid		Waterscrubber	300	2008
	Wriezen	Energy crops	Gas grid		PSA	1200	2009
	Wüsting	Energy crops	Gas grid		PSA	1200	2009
Iceland	Reykjavik	Landfill gas	Vehicle fuel		Water scrubber	700	2005
Japan	Kobe	Sewage sludge	Vehicle fuel	97	Water scrubber	100	2004
	Kobe	Sewage sludge	Vehicle fuel	97	Water scrubber	2*225	2007
Norway	Fredrikstad		Vehicle fuel		PSA		2001
	Oslo	Sewage sludge	Vehicle fuel		Chemical Scrubber	750	2009
	Stavanger	Sewage sludge, biowaste	Gas grid		Chemical scrubber	500	2009
The Netherlands (information kindly supplied by Erik Polman, Kiwa)	Beverwijk	Landfill gas	Gas grid	88	Membrane		2006
	Collendoorn	Landfill gas	Gas grid	88	Membrane	375	1993
	Mijdrecht	Sewage sludge	Gas grid	88			2009
	Nuenen	Landfill gas	Gas grid	88	PSA	1500	1990
	Tilburg-De Spinder	Landfill gas	Gas grid	88	Water scrubber	2100	1987
	Wijster	Landfill gas	Gas grid	88	PSA	1150	1989
South Korea	Seoul				Waterscrubber	150	2008
Spain	Madrid	Biowaste	Vehicle fuel	96.5	Water scrubber	4000	2008
	Vacarisses (Barcelona)	Landfill gas	Vehicle fuel	>85	Chemical scrubber	100	2005
Sweden	Bjuv	Biowaste, manure	Gas grid	97	PSA	500	2007
	Boden	Sewage sludge, biowaste	Vehicle fuel	97	Water scrubber	360	2007
	Borås	Biowaste, sewage sludge	Vehicle fuel	97	Chemical scrubber	450	2002
	Bromma, Stockholm	Sewage sludge	Vehicle fuel	97	PSA	250	2002
	Bromma, Stockholm	Sewage sludge	Vehicle fuel	97	PSA	250	2003
	Eskiltuna	Biowaste, sewage sludge	Vehicle fuel	97	Water scrubber	330	2003
	Eslöv	Biowaste, sewage sludge	Vehicle fuel	97	Water scrubber	80	1999
	Falkenberg	Sewage sludge, biowa-ste, energy crops	Gas grid	97	Chemical scrubber	750	2009
	Falköping	Sewage sludge	Vehicle fuel	97	Water scrubber	200	2007
	Göteborg	Sewage sludge, biowaste	Gas grid	97	Chemical scrubber	1600	2007
	Helsingborg	Biowaste, manure	Vehicle fuel and Gas grid	97	PSA	350	2001
	Helsingborg	Biowaste, manure	Vehicle fuel and Gas grid	97	Water scrubber	650	2007
	Helsingborg	Sewage sludge	Gas grid	97	Water scrubber	250	2007
	Henriksdal, Stockholm	Sewage sludge	Vehicle fuel	97	Water scrubber	600	2004
	Henriksdal, Stockholm	Sewage sludge	Vehicle fuel	97	Water scrubber	800	2006
	Himmerfjärden, Stockholm	Sewage sludge	Vehicle fuel	97	Chemical scrubber	800	2009
	Jönköping	Sewage sludge, biowaste	Vehicle fuel	97	Water scrubber	300	2000
	Kalmar	Sewage sludge, manure	Vehicle fuel	97	Chemical scrubber	200	2008
	Katrineholm	Sewage sludge	Vehicle fuel	97	Water scrubber	80	2009
	Kristianstad	Biowaste, manure, sewage sludge	Vehicle fuel	97	Water scrubber	280	1999
	Kristianstad	Biowaste, manure, sewage sludge	Vehicle fuel	97	Water scrubber	600	2006
	Laholm	Biowaste, manure	Gas grid	97	Water scrubber	500	2000
	Linköping	Sewage sludge, biowaste	Vehicle fuel	97	Water scrubber	2*330	1997
	Linköping	Sewage sludge, biowaste	Vehicle fuel	97	Water scrubber	1400	2002
	Malmö	Sewage sludge	Gas grid	97	PSA	500	2008
	Motala	Sewage sludge	Vehicle gas	97	Water scrubber	80	2009
	Norrköping	Sewage sludge	Vehicle fuel	97	Water scrubber	250	2004
	Norrköping	Distiller's waste, Energy crops	Vehicle fuel	97	Water scrubber	240	2006
	Skellefteå	Sewage sludge	Vehicle fuel	97	Water scrubber	250	2005
	Skövde	Sewage sludge, slaughter waste	Vehicle fuel	97	PSA	140	2002
	Trollhättan	Biowaste, sewage sludge	Vehicle fuel	97	Water scrubber	200	1995
	Trollhättan	Biowaste, sewage sludge	Vehicle fuel	97	Water scrubber	400	2001
	Ulricehamn	Sewage sludge	Vehicle fuel	97	PSA	20	2003
	Uppsala	Sewage sludge, biowaste	Vehicle fuel	97	Water scrubber	400	2001
	Västervik	Sewage sludge	Vehicle fuel	97	Water scrubber	130	2009
	Västerås	Biowaste, sewage sludge	Vehicle fuel	97	Water scrubber	650	2004
	Örebro	Sewage sludge	Vehicle fuel	97	Water scrubber	450	2007
	Örebro	Sewage sludge	Vehicle fuel	97	Water scrubber	2000	2009
	Östersund	Sewage sludge	Vehicle fuel	97	Water scrubber	200	2006
Switzerland	Bachenbülach	Biowaste	Gas grid and vehicle gas	96	PSA	50	1996
	Berne	Sewage sludge	Gas grid	96	PSA	300	2007
	Bischofszell	Sewage sludge	Gas grid	96	Genosorb scrubber	100	2007
	Jona	Biowaste	Gas grid	96	Genosorb scrubber	55	2005
	Inwil	Biowaste, manure	Gas grid	96	PSA	225	2009
	Lavigny	Biowaste	Gas grid	96	PSA	150	2009
	Lucerne	Sewage sludge	Gas grid	96	PSA	75	2004
	Obermeilen	Sewage sludge	Gas grid	96	Chemical scrubber	100	2008
	Otelfingen	Biowaste	Vehicle gas	96	PSA	50	1998
	Pratteln	Biowaste	Gas grid	96	Genosorb scrubber	300	2006
	Roche	Sewage sludge	Gas grid	96	PSA	250	2008

Upgrading plants

List of biogas upgrading plant providers

Company	Technology	Website
Acrona-Systems	PSA	www.acrona-systems.com
Air Liquide	Membrane	http://www.airliquide.com
CarboTech	PSA, chemical absorption	http://www.carbotech.de
Cirmac	PSA, Chemical absorption, membrane	www.cirmac.com
Flotech Sweden AB	Water scrubber	www.flotech.com
Gasrec	PSA/Membrane	www.gasrec.co.uk
GtS	Cryogenic	www.gastreatmentservices.com
HAASE	Organic physical scrubbing	www.haase-energietechnik.de
Läckeby Water Group AB	Chemical absorption	www.lackebywater.se
Malmberg Water	Water scrubber	www.malmberg.se
MT-Energie	Chemical absorption	www.mt-energie.com/
Prometheus	Cryogenic	www.prometheus-energy.com
Terracastus Technologies	Membrane	www.terracastus.com
Xebec (QuestAir)	PSA	www.xebecinc.com

An updated version of plant providers can be found on www.iea-biogas.net.

Take home message

Biogas Upgrading:

- cleaning process: stablished.... To be optimized?
  Alternatives for SiO removal? Biological?

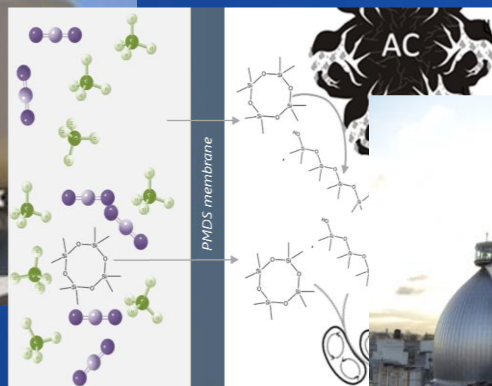
- Increase methane contents:
  CO_2 removal vs. CO_2 recovery
  CO_2 conversion to methane as energy storage
  Why not to convert to other valuable products?

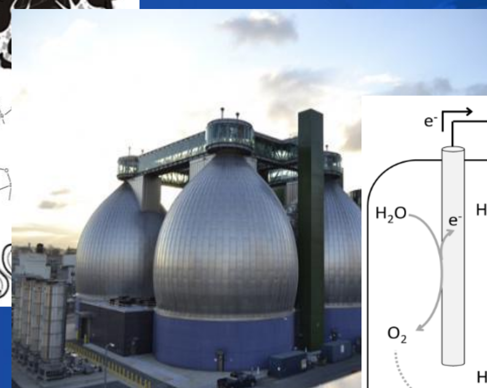
- Which is the best option?
  a DSS to assess process scheme definition

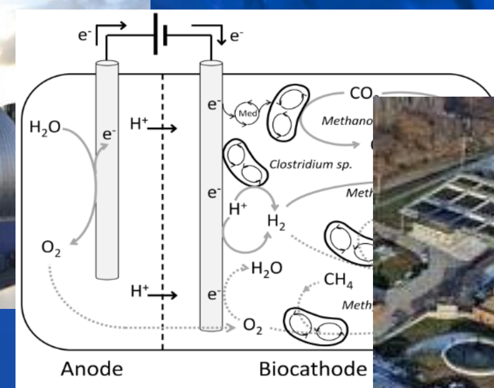
1º Jornada técnica en depuración de aguas residuales: Digestión Anaerobia

Cátedra FACSA de Innovación en el Ciclo Integral del Agua
Jueves 7 y viernes 8 de julio 2016.
Universitat Jaume I. Edifici Consell Social i Postgrau

Innovative technologies for biogas upgrading: from basic research to technology assessment







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J.Colprim@lequia.udg.cat

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