Great Opportunities for Anaerobic Digestion

Juan M. Lema

Department of Chemical Engineering

University of Santiago de Compostela, Spain

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Castelló, 7 de julio de 2016

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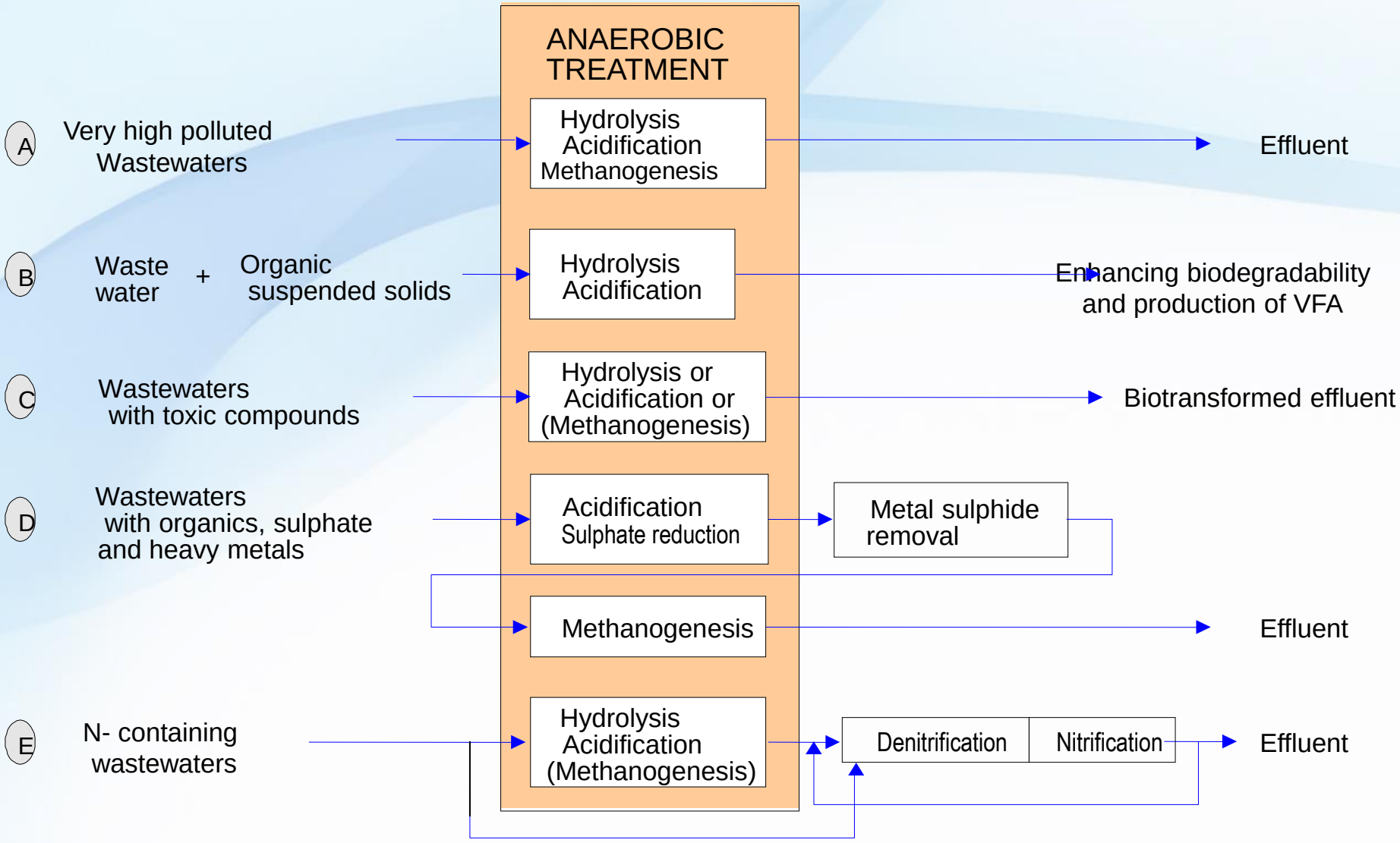
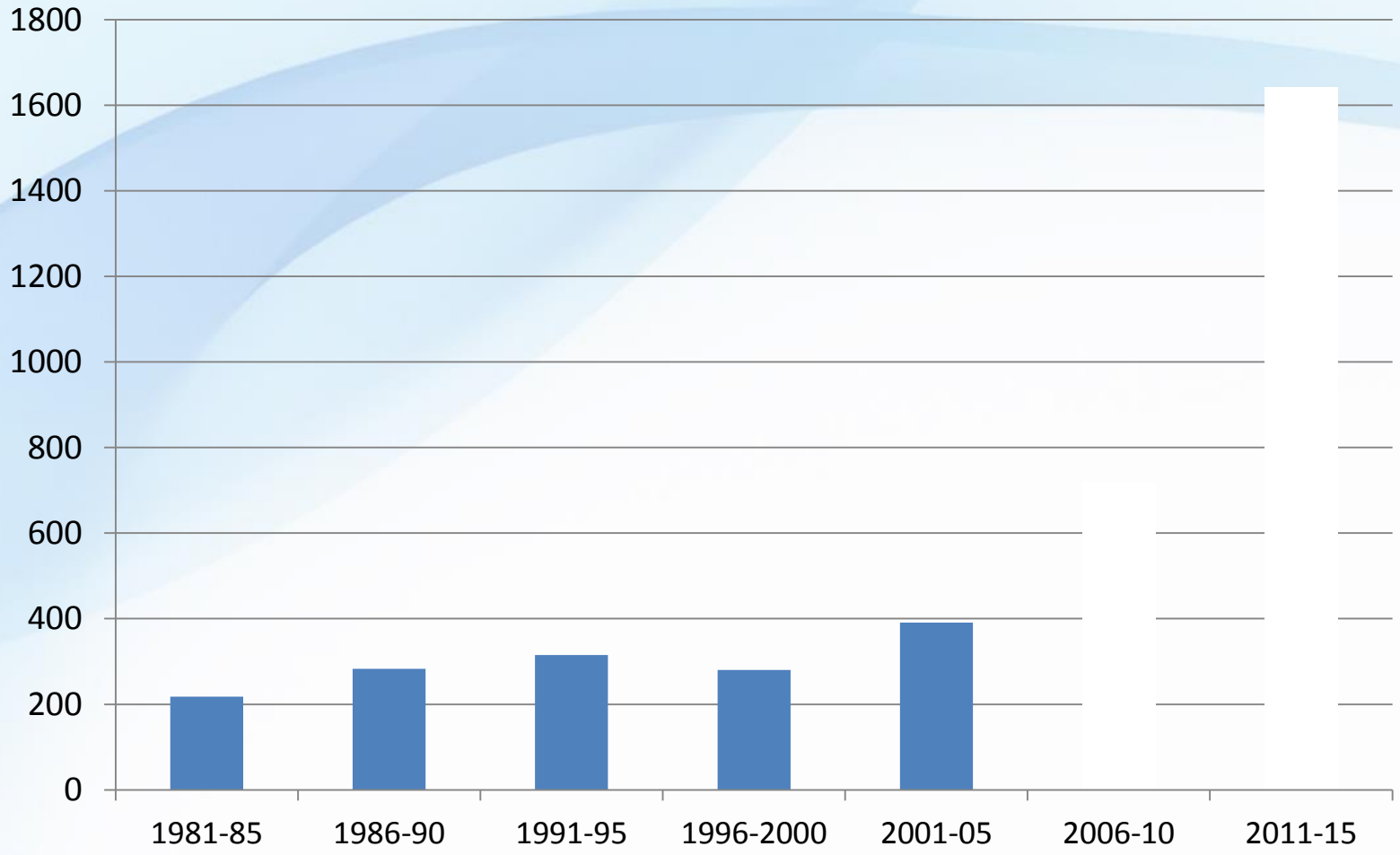
-The core of integrated processes (2001)



(Lema & Omil, Water Sci.Technol 2001)

-Papers on Anaerobic Digestion (Scopus)



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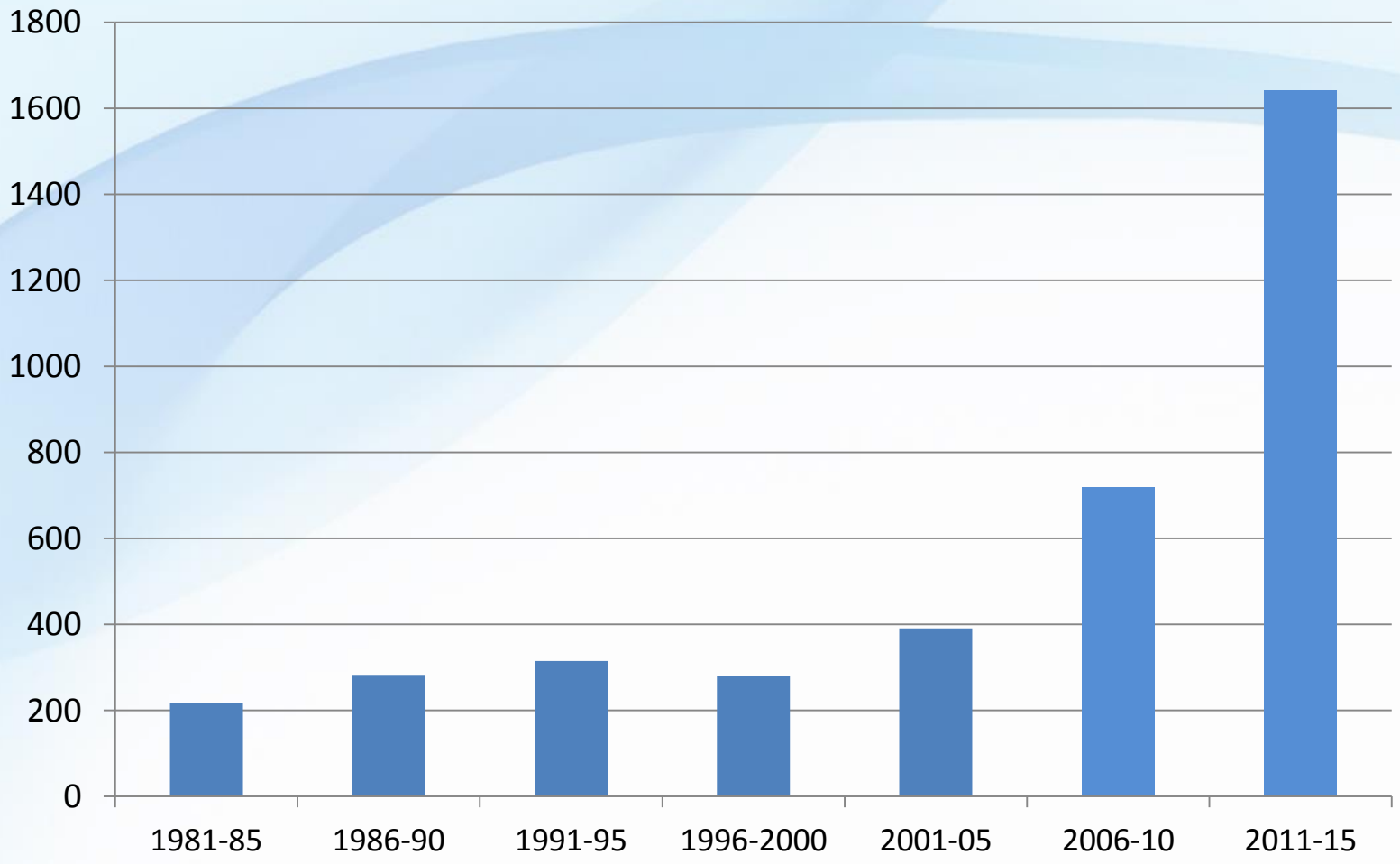
-Papers on Anaerobic Digestion (Scopus)



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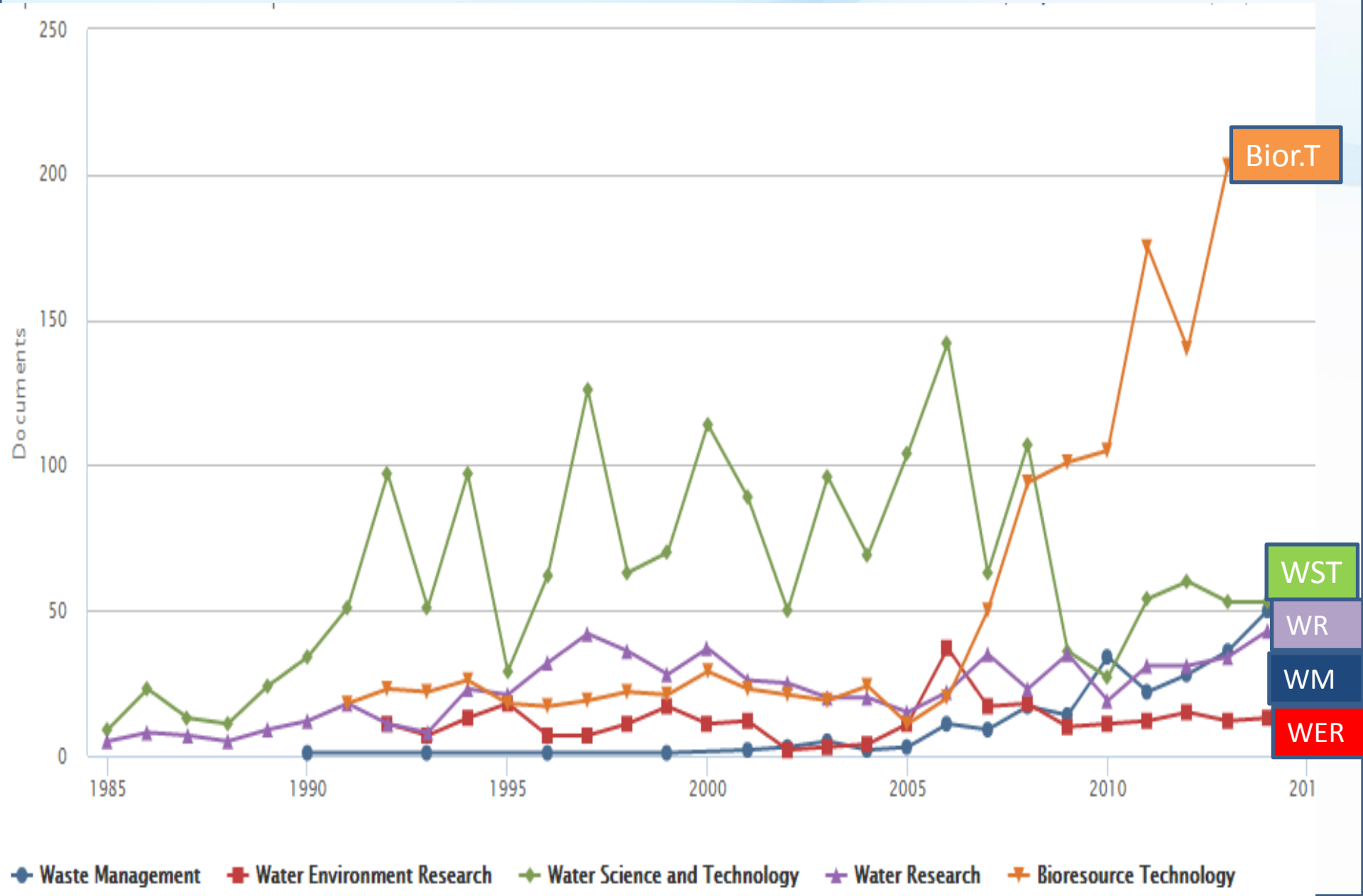
-Source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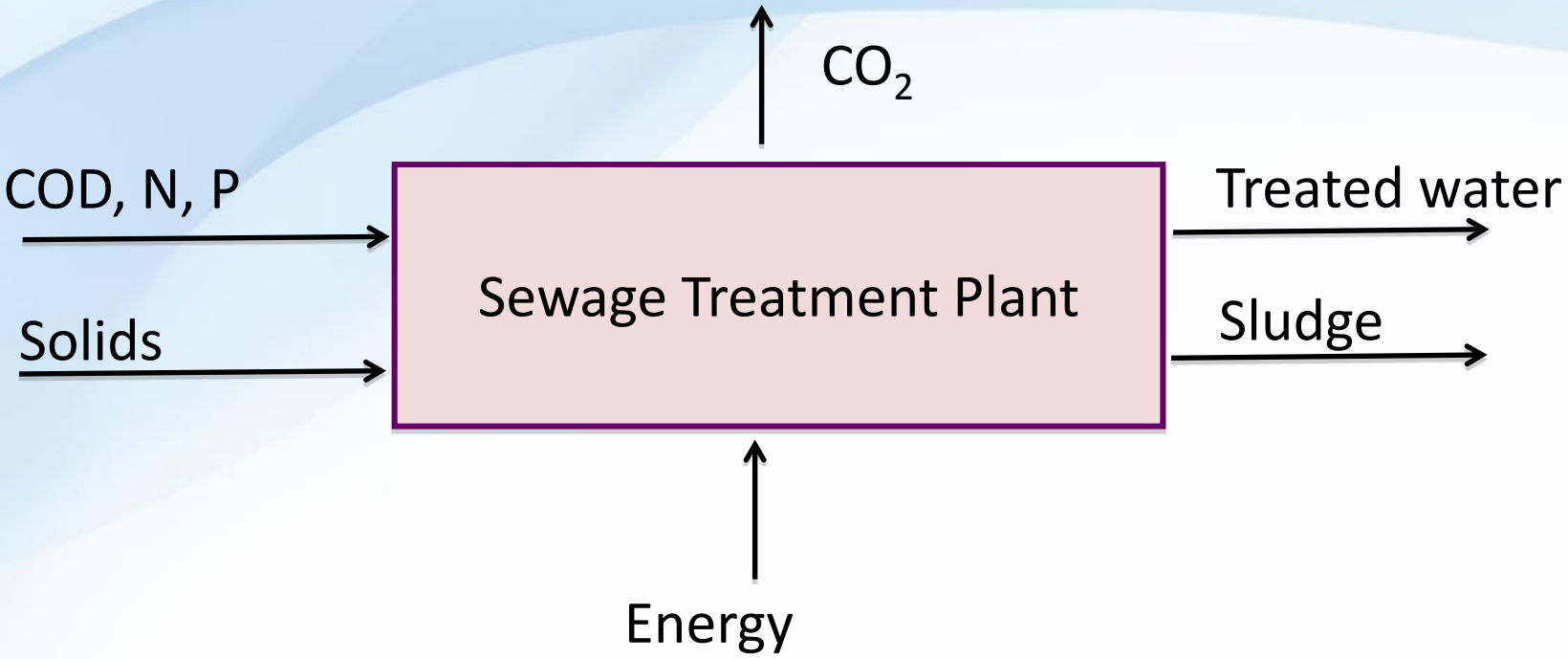
WER
Waste Management
Water Environment Research
Water Science and Technology
Water Research
Bioresource Technology

-Conventional STP



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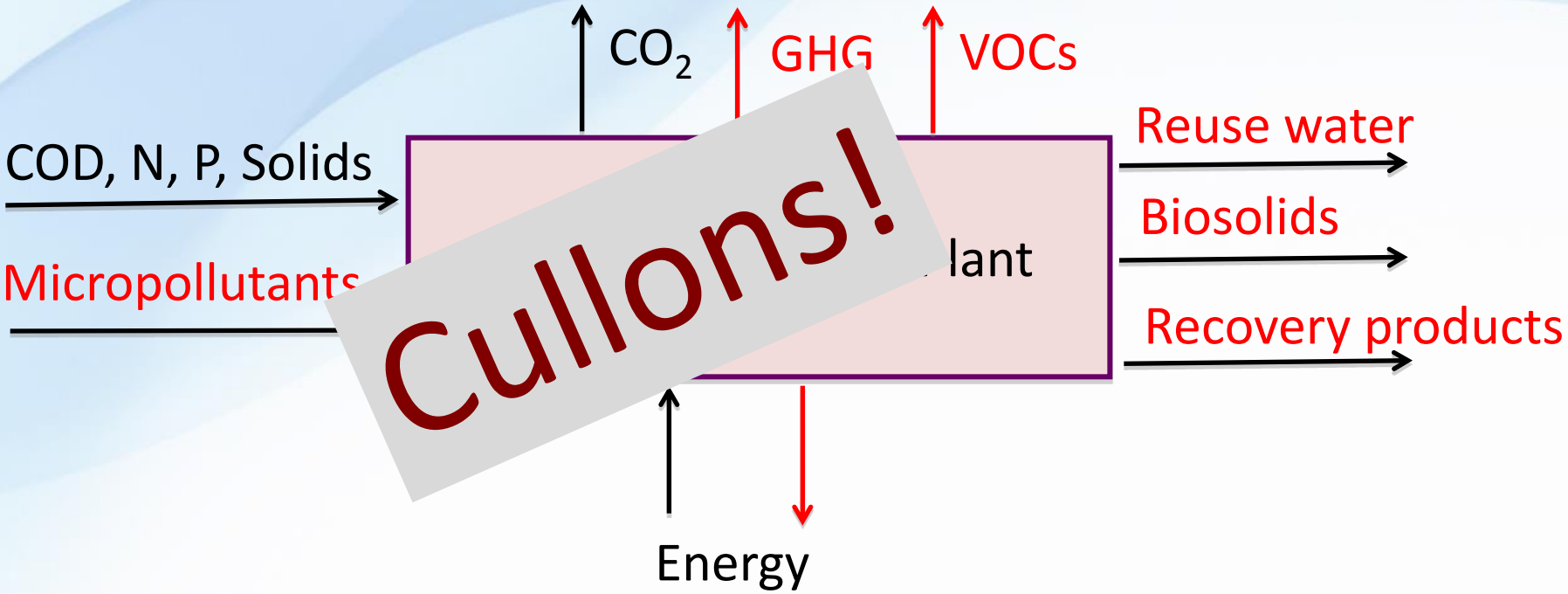
-A more advanced concept: Eco-Innovation



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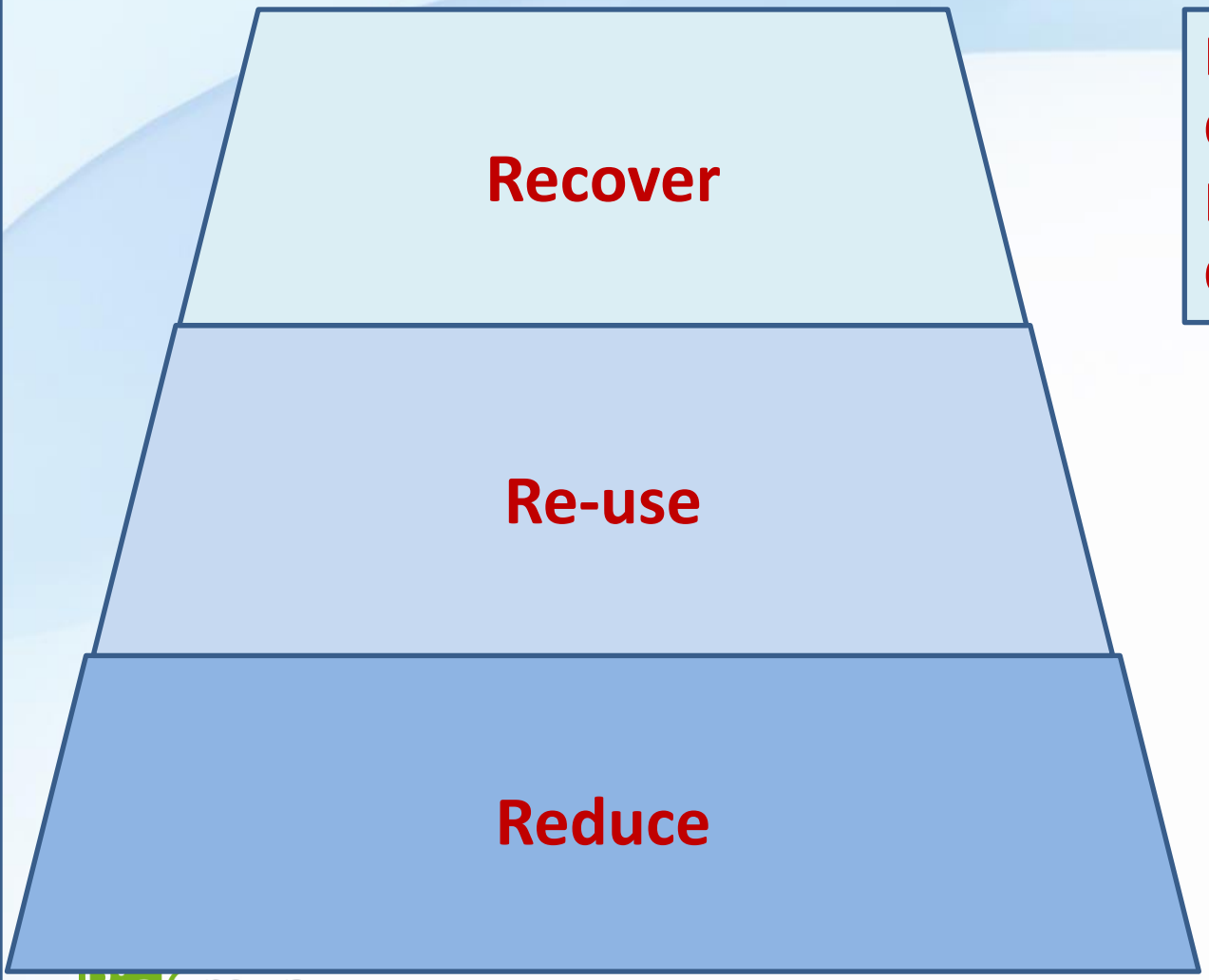
-“3 R” Objectives in WW Treatment

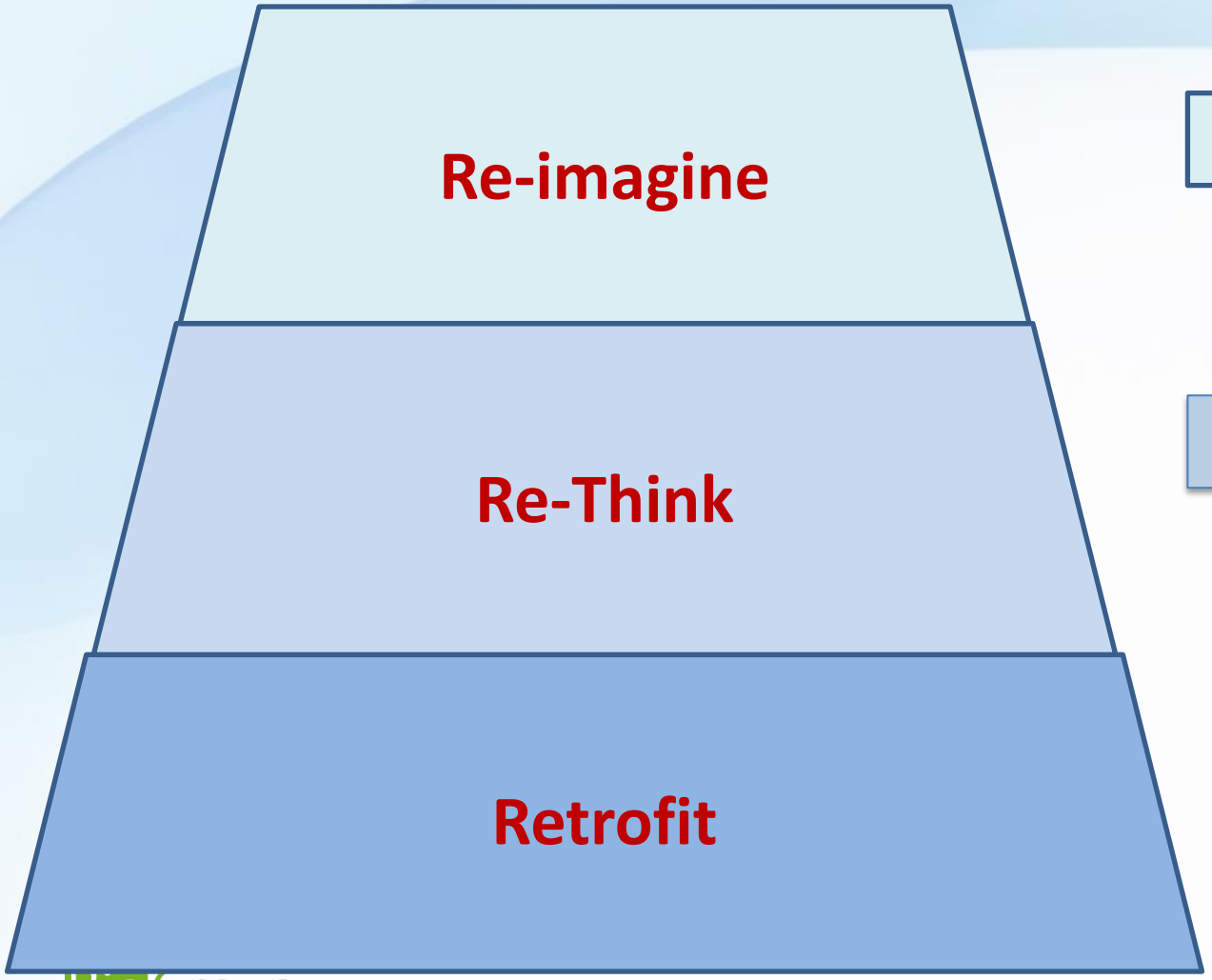


Energy, Metals Chemicals, Nutrients , Bioplastics, Electricity, Cellulose...

Water and sludge of sufficient quality

Energy, Sludge, Space, Emissions, CAPEX, OPEX

-“3 R” Innovation in WW Treatment



New conceptions

New flowsheets

Include new units

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-New opportunities for AD

- Sewage treatment
  (Retrofit) (Re-think)
- Sewage treatment
  (Re-think)
- BioMethane
- Biorefinery
  (Re-imagine)

Reduce

Reuse

Recover

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Reduce

Sewage Anaerobic Treatment

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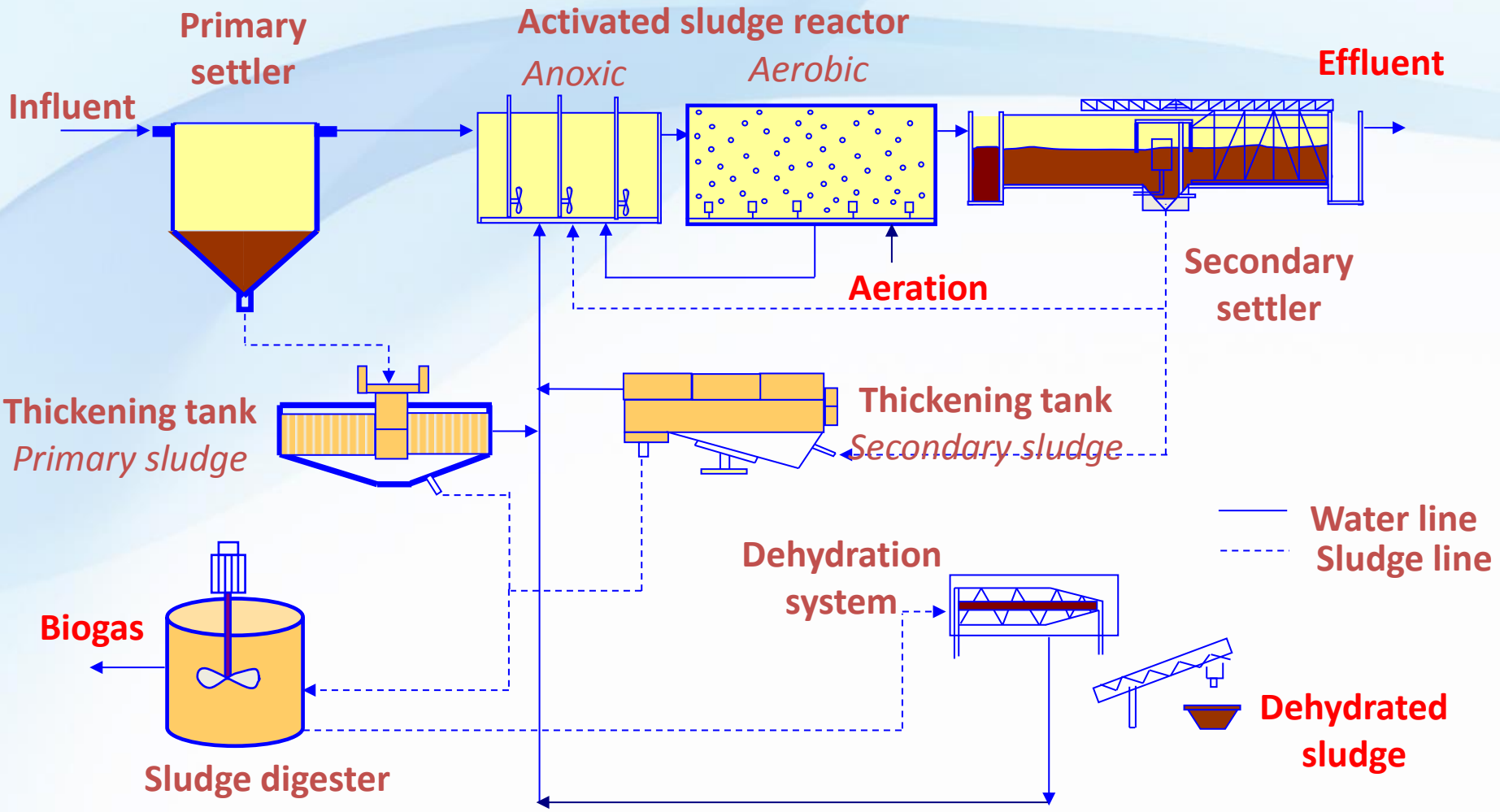
-Retrofit



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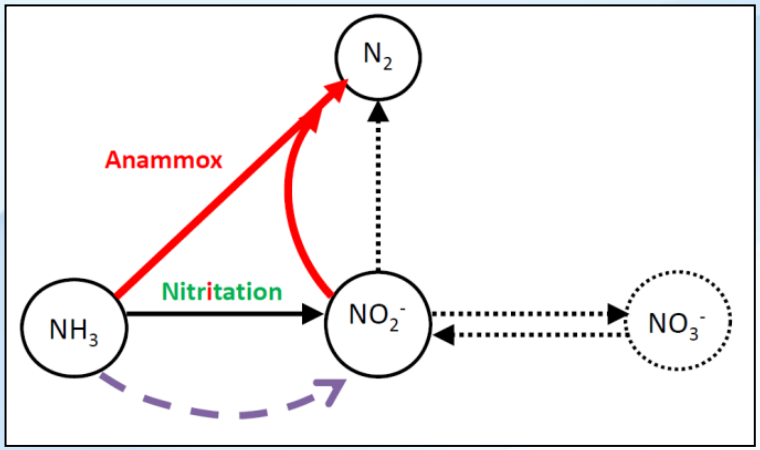
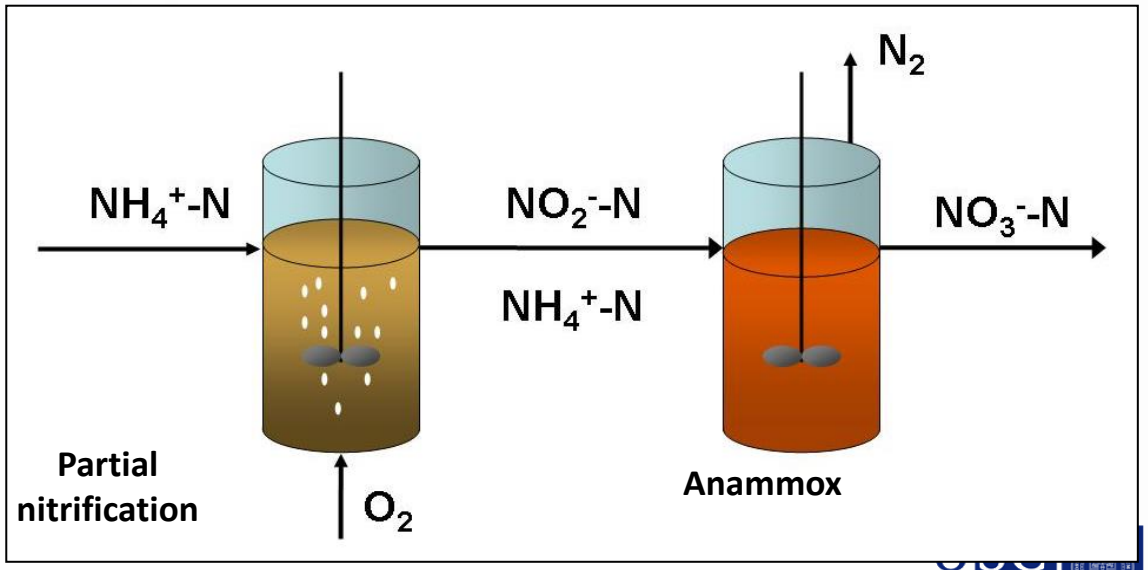
-Anammox





Two steps

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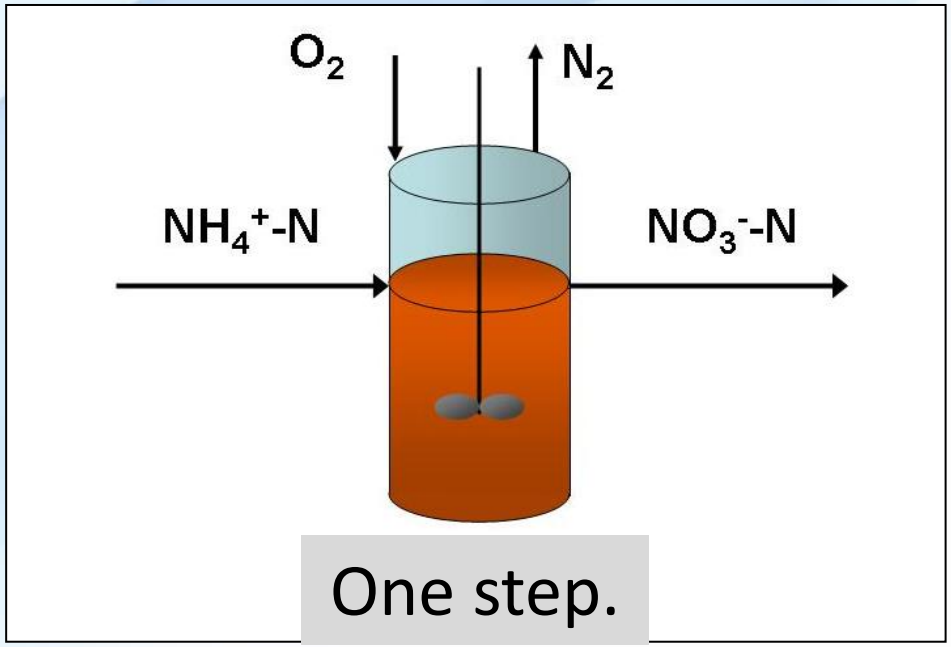
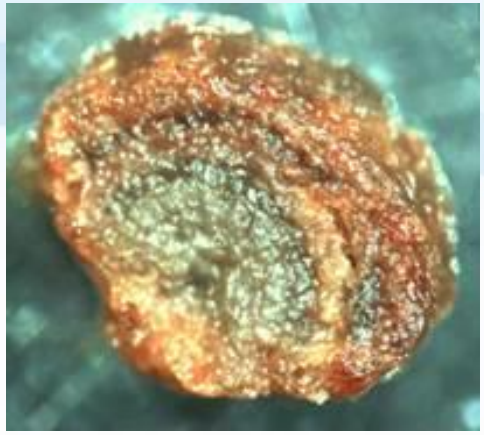
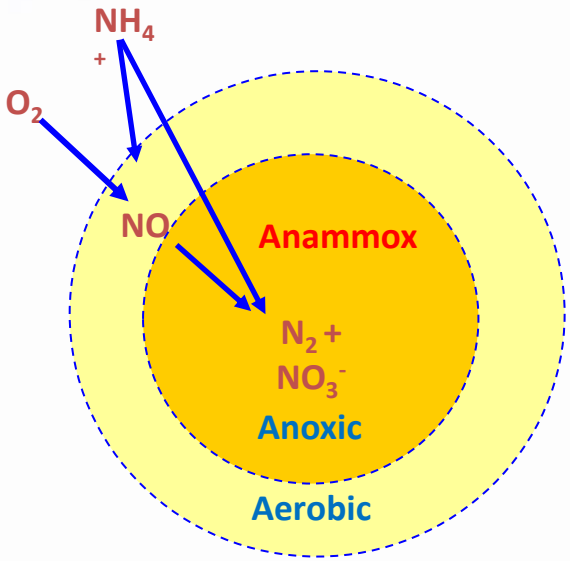
-Nitrogen removal by Anammox



One step.





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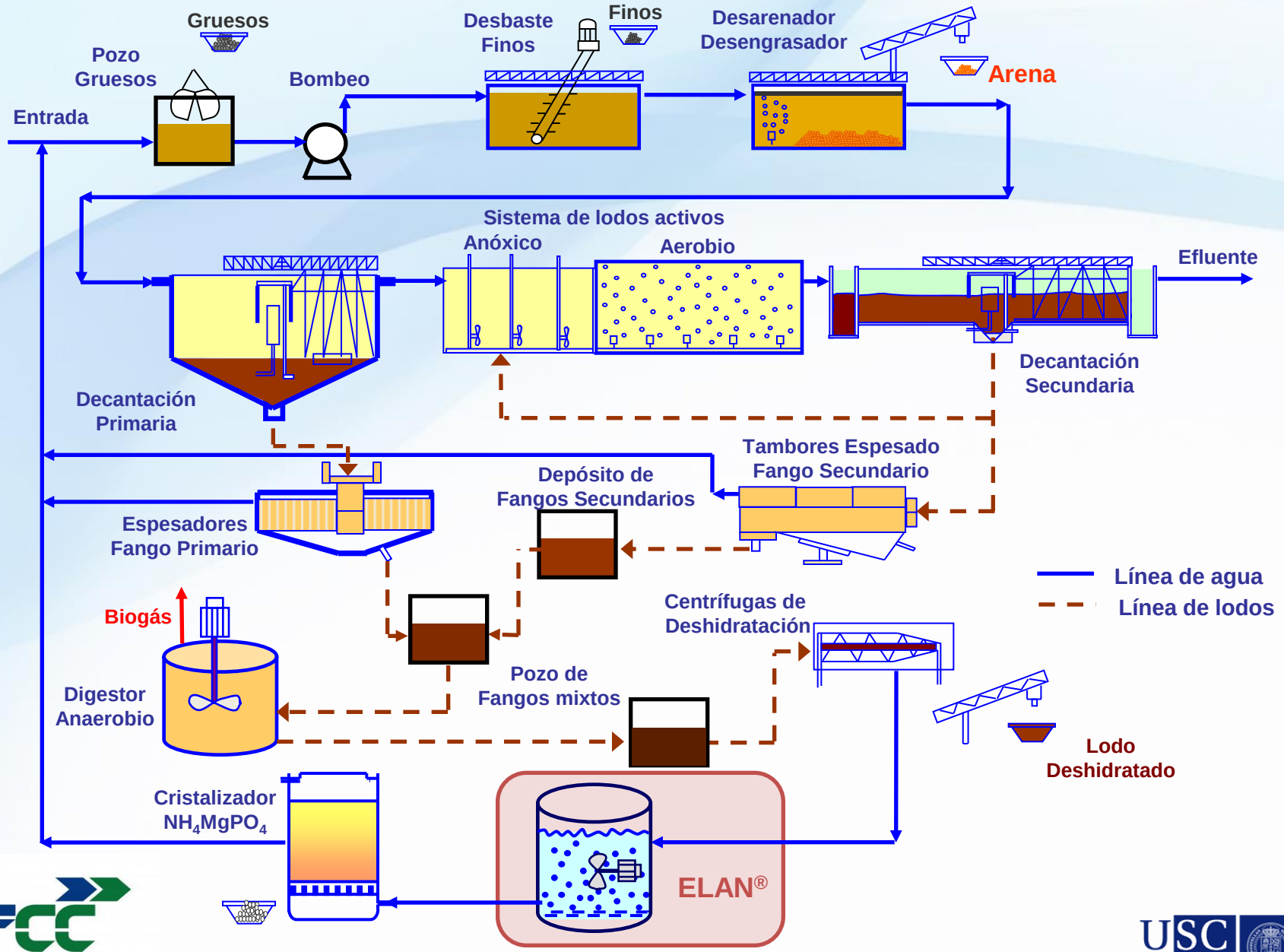
- STP Guillarei- Tui



Aqualia

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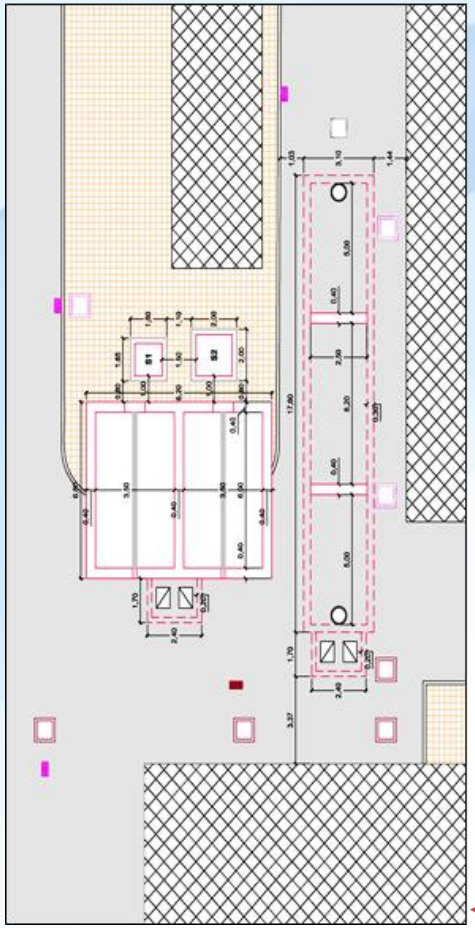
-ELAN®. Guillarei-TUI (Spain)



BioGrou aqualia

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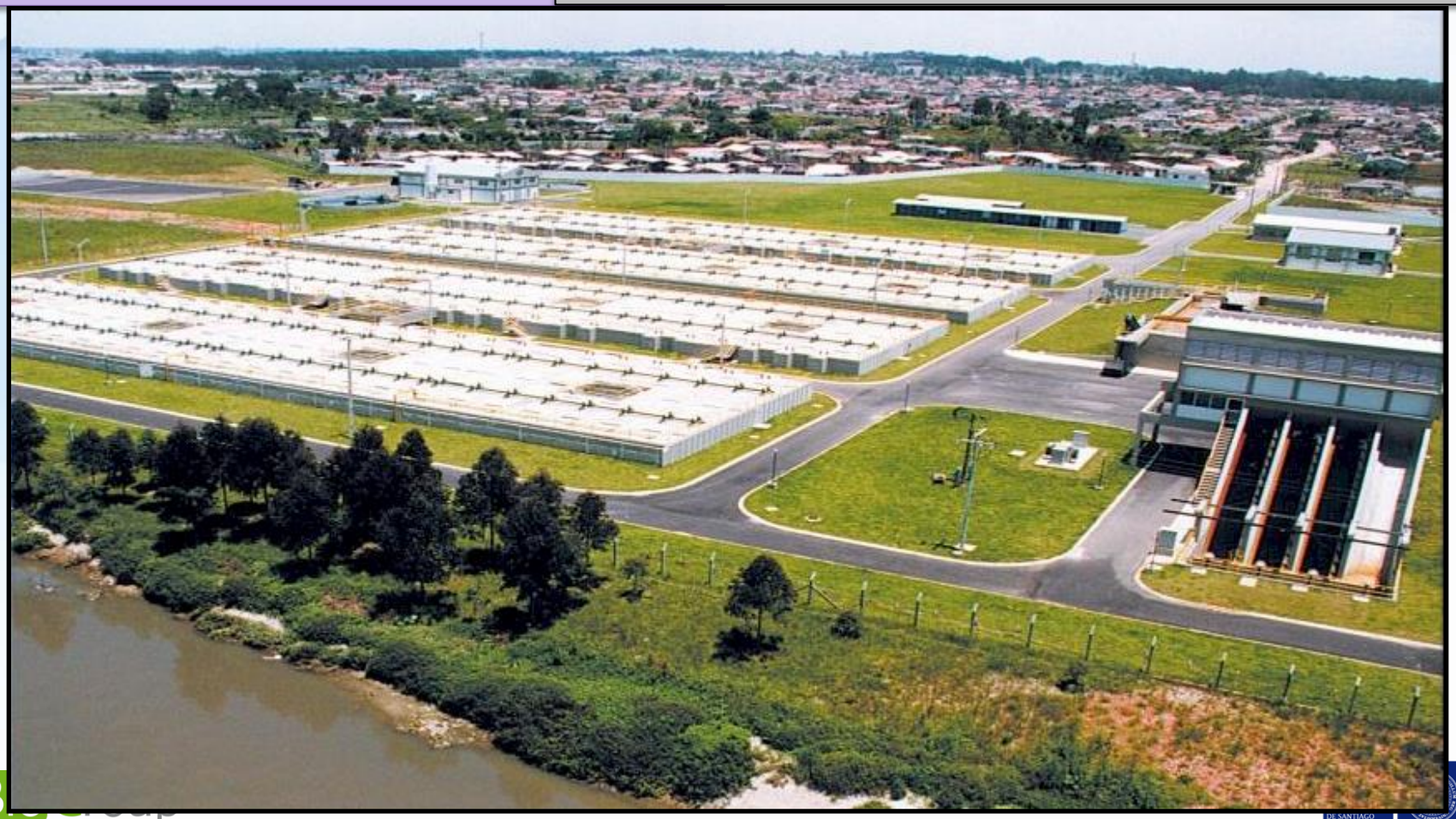
-Anaerobic treatment of Sewage

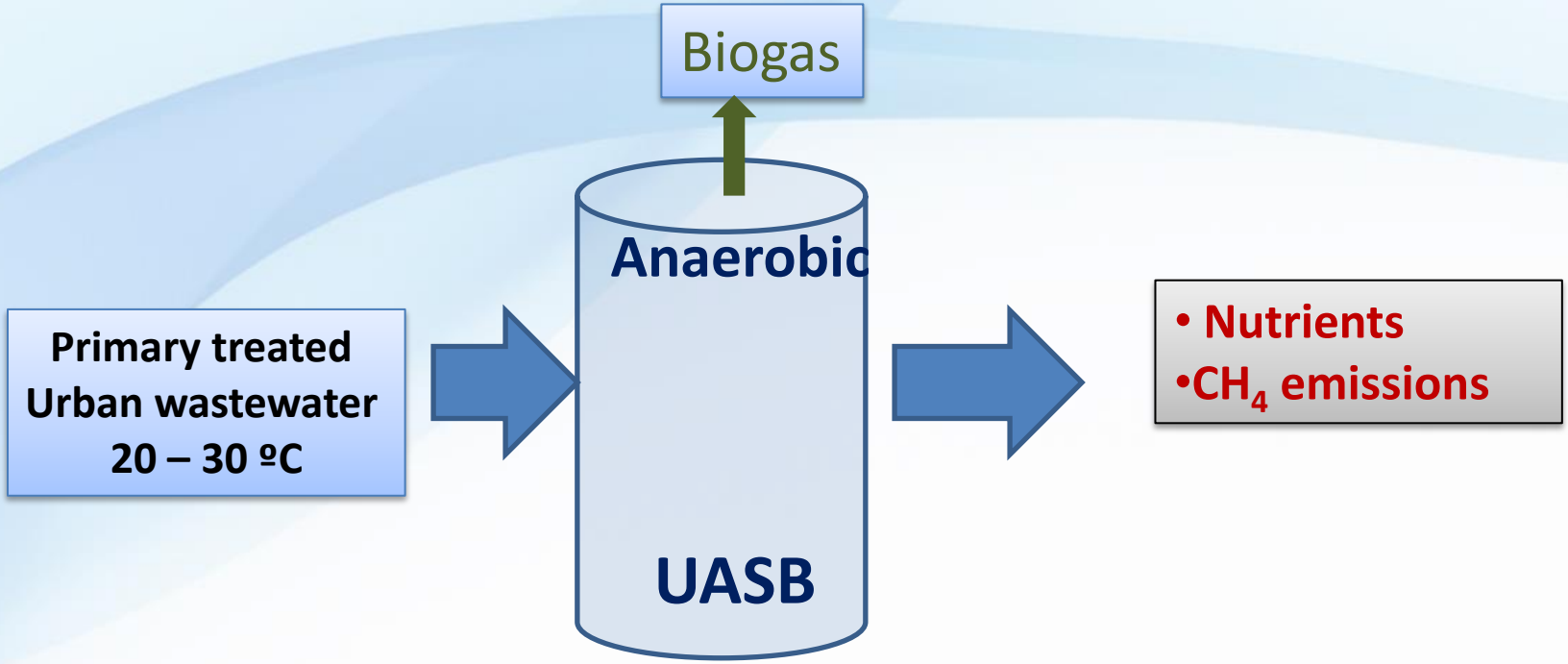
Curitiba – Brazil

UASB reactors + DAF

- Design population: 600,000 inhabitants
- Flowrate: 1,100 L/s



-Anaerobic treatment of Sewage at moderate T



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-Pilot Plant in Rotterdam (main stream)

-Anammox on main stream at low T

Temp.	$Rate_{Tot-N}$	$Rate_{Tot-N}^{max}$	q^{max}
° C	g-N L^{-1} d^{-1}	g-N L^{-1} d^{-1}	g-N_2 g-VSS^{-1} d^{-1}
20	1.85	2.38	0.60
15	1.19	1.58	0.30
13	0.51	0.69	0.12
10	0.34	0.34	0.06

Direct growth on wastewater possible until 10 C
No direct negative influence of BOD

Lotti et al. ES&T 2014

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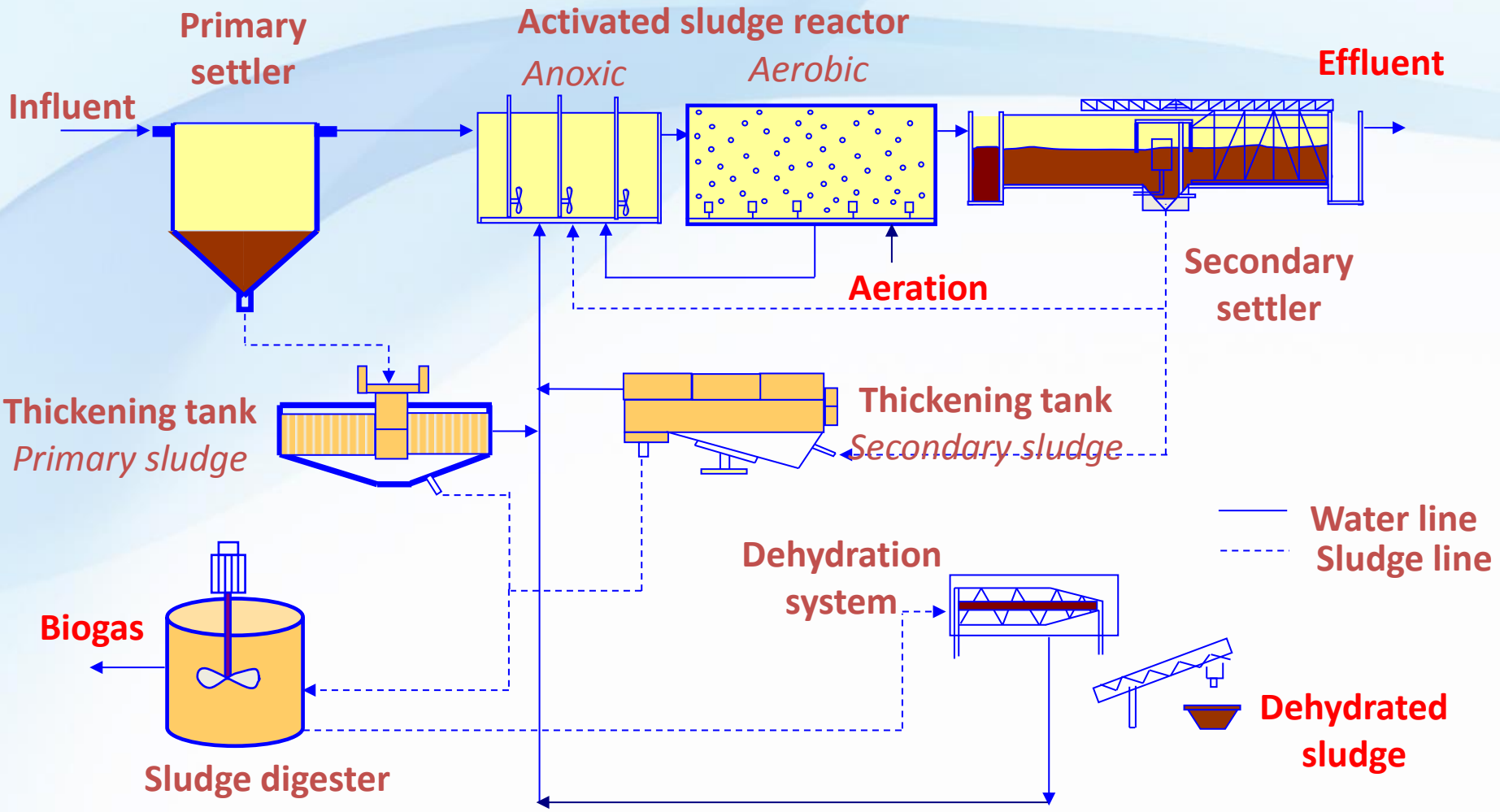
-Rethinking STPs



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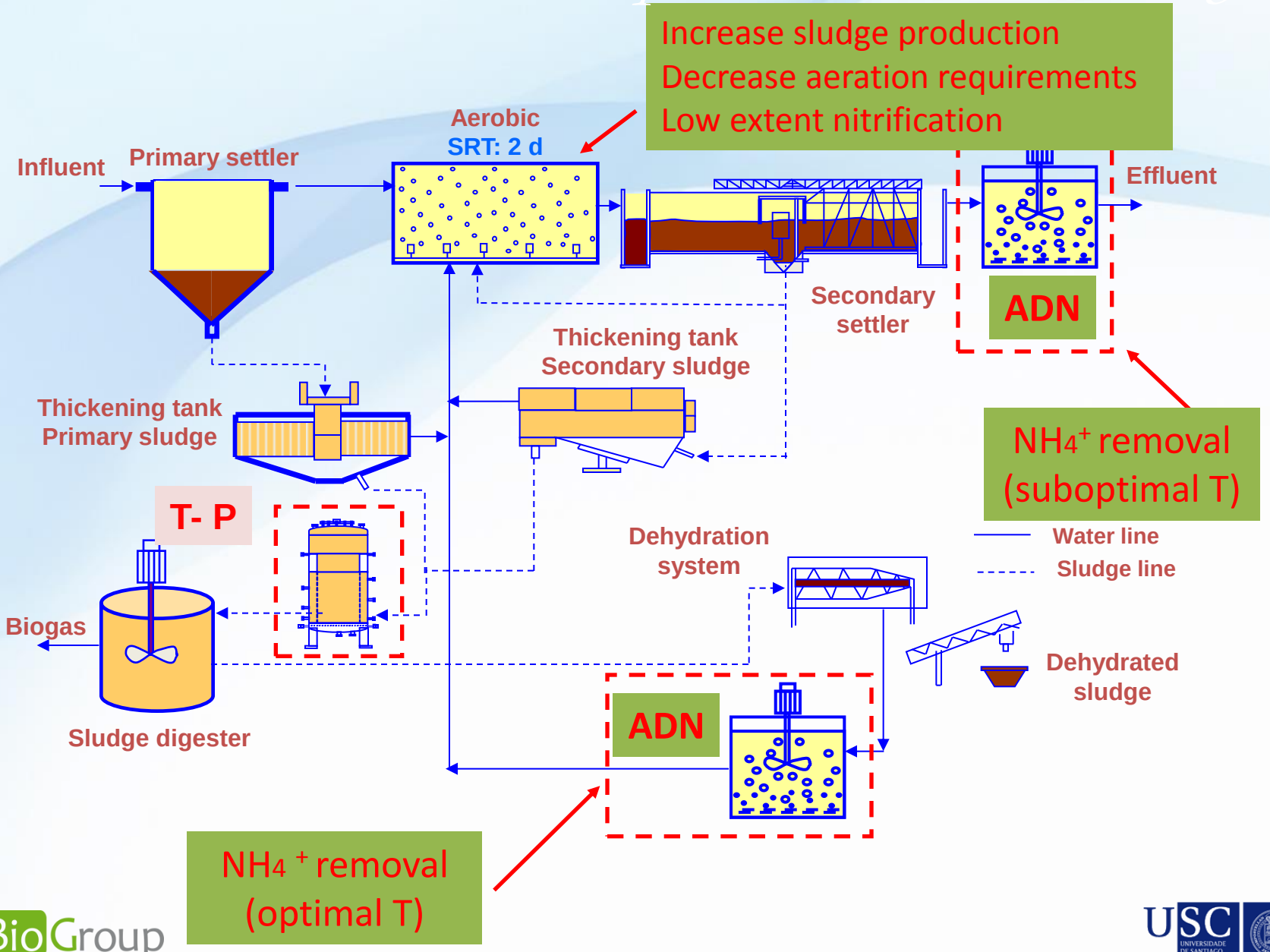
-High Rate (Low SRT) reactor + Anammox



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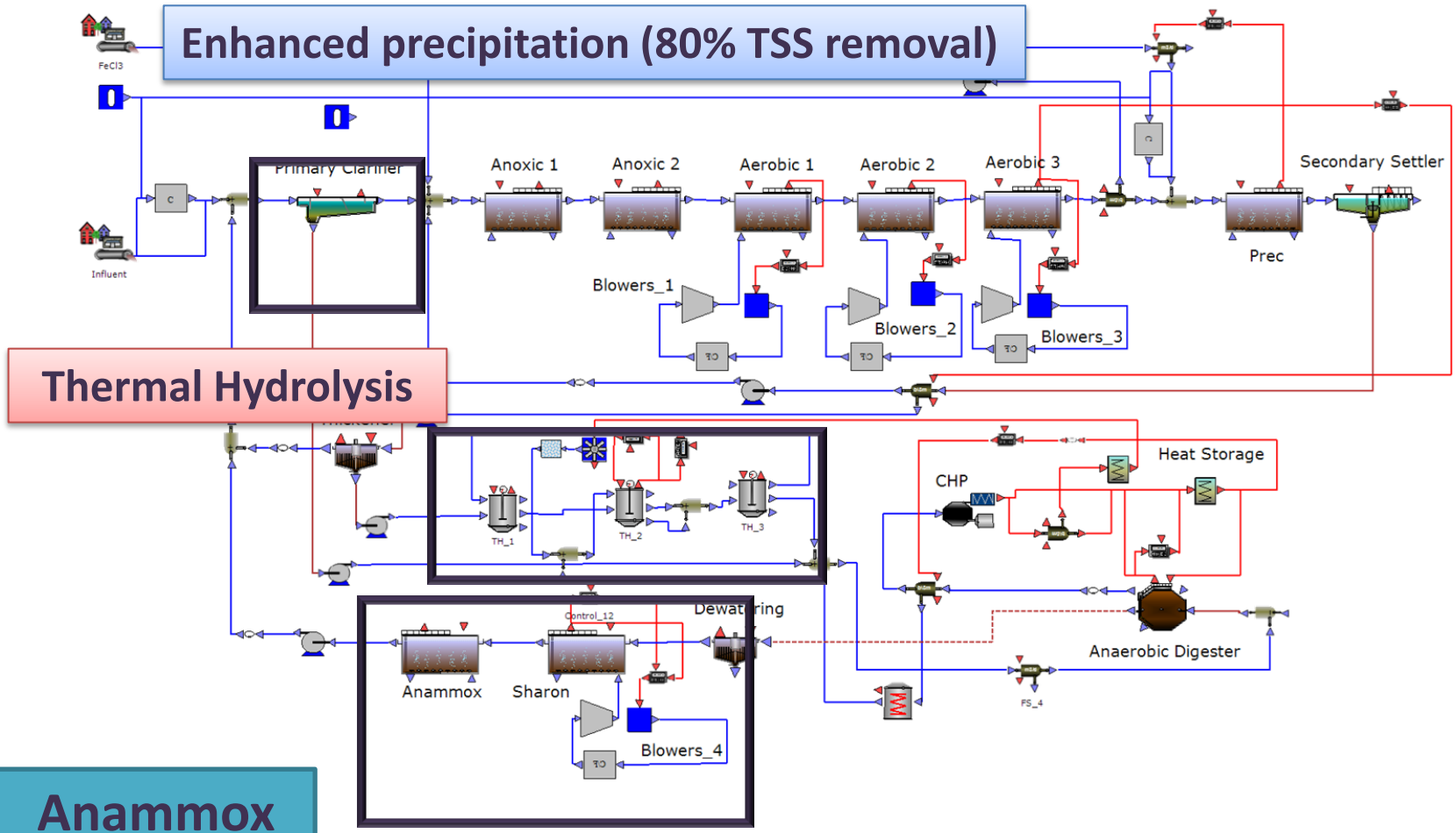
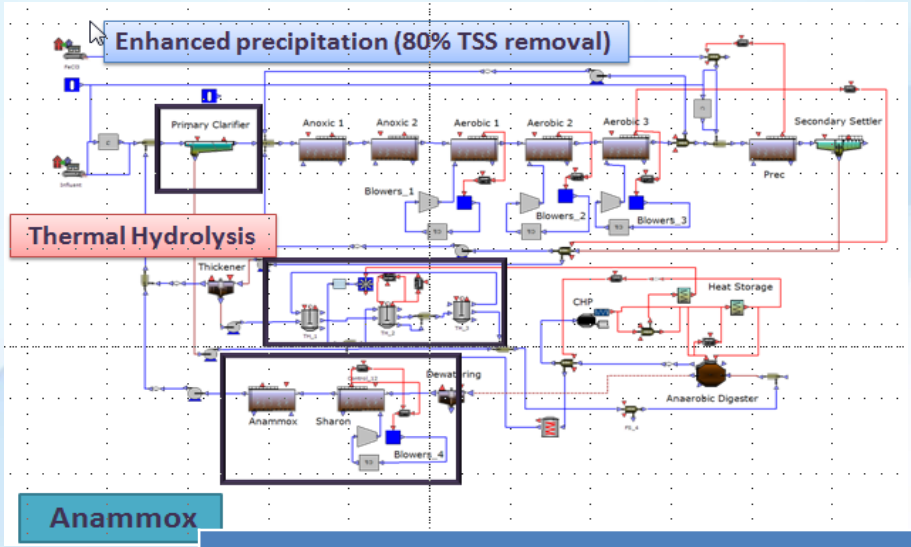
-Enhanced precipitation (EP)

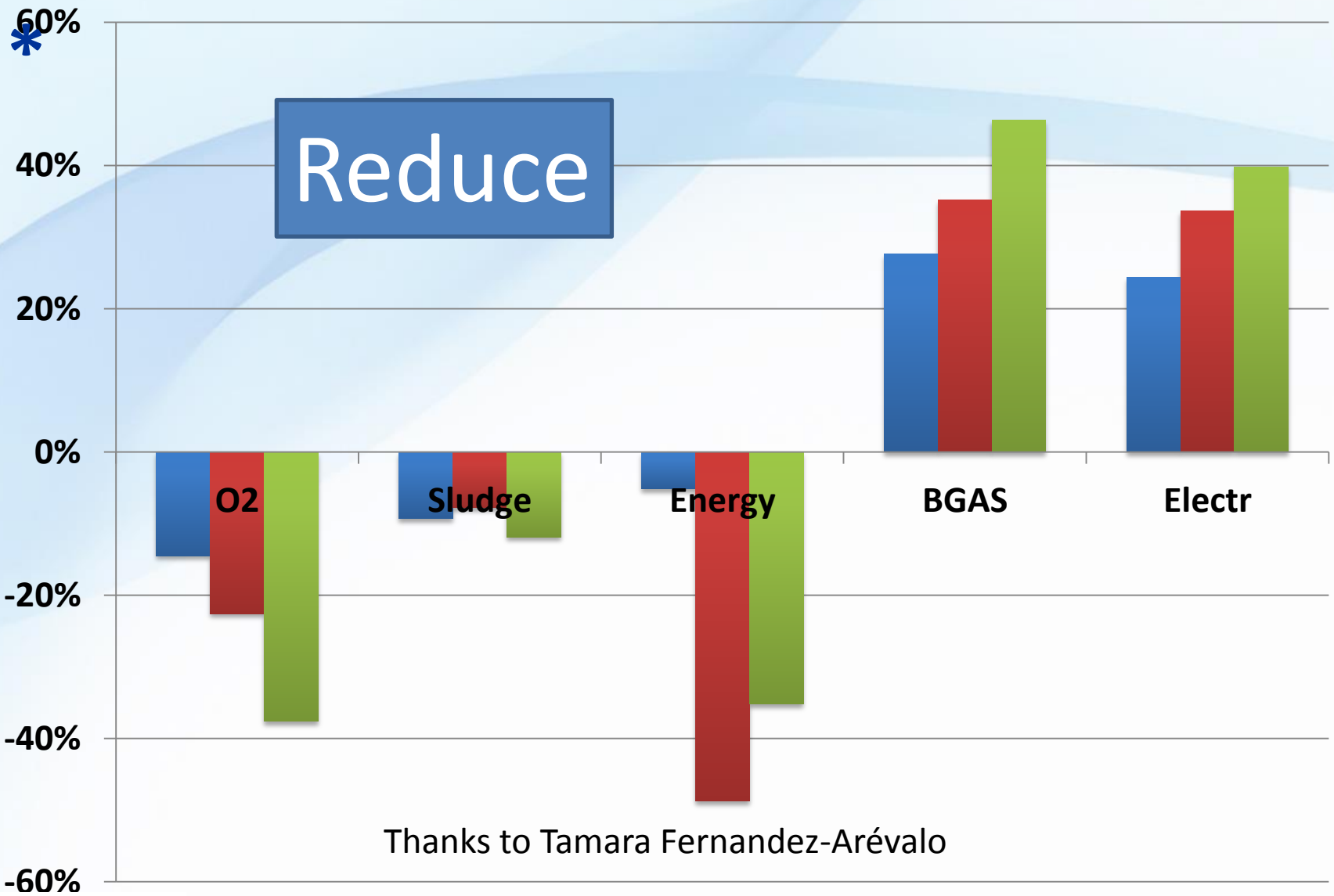


-EP. Plant Wide Modeling Simulation *

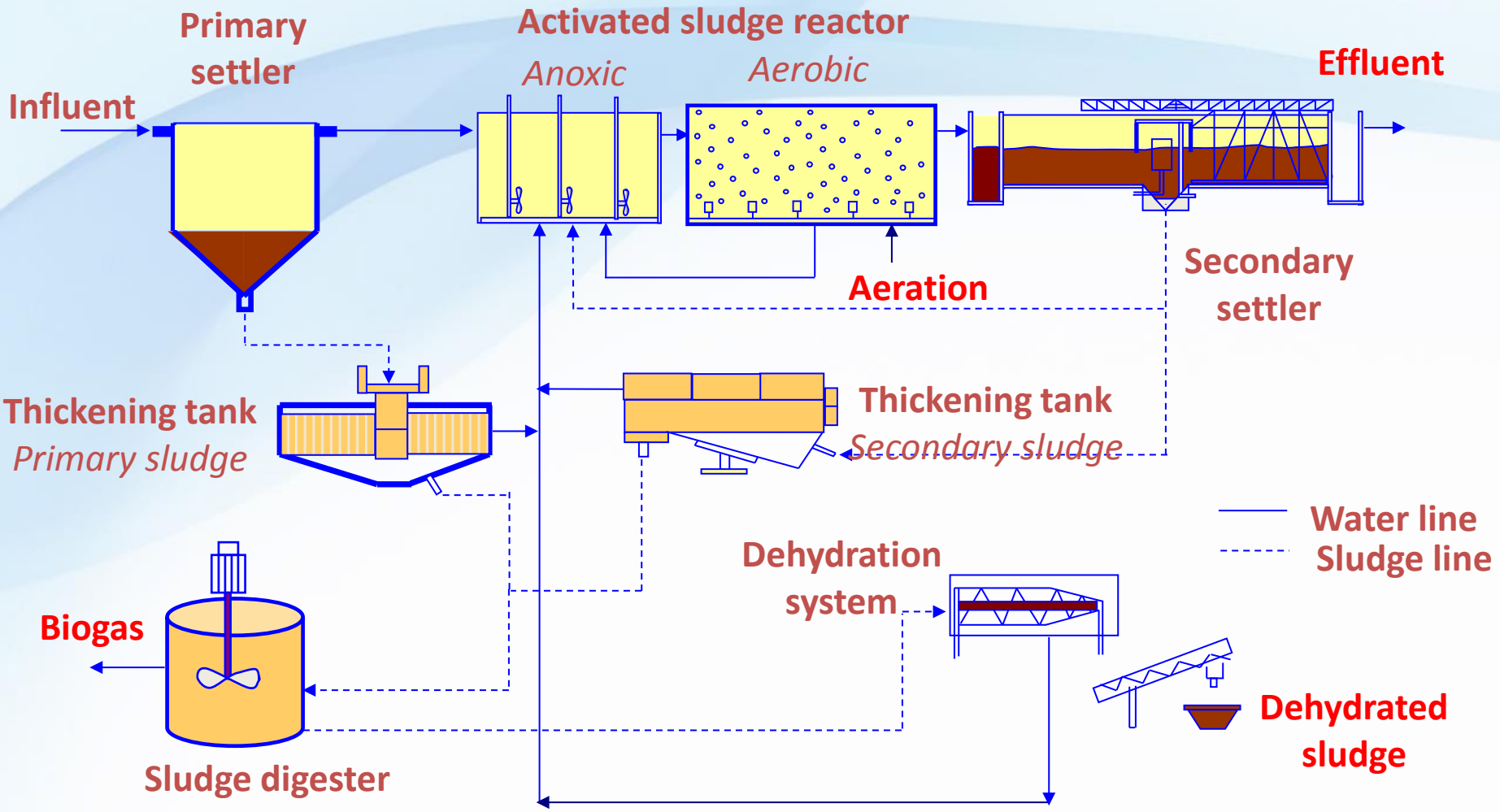


Variable	Increase/Decrease
Oxygen	- 22%
Electricity production	+33,6 %
Biogas Production	+ 35 %
Sludge production	- 8%

-Plant Wide Modeling Simulation



-Re imagining



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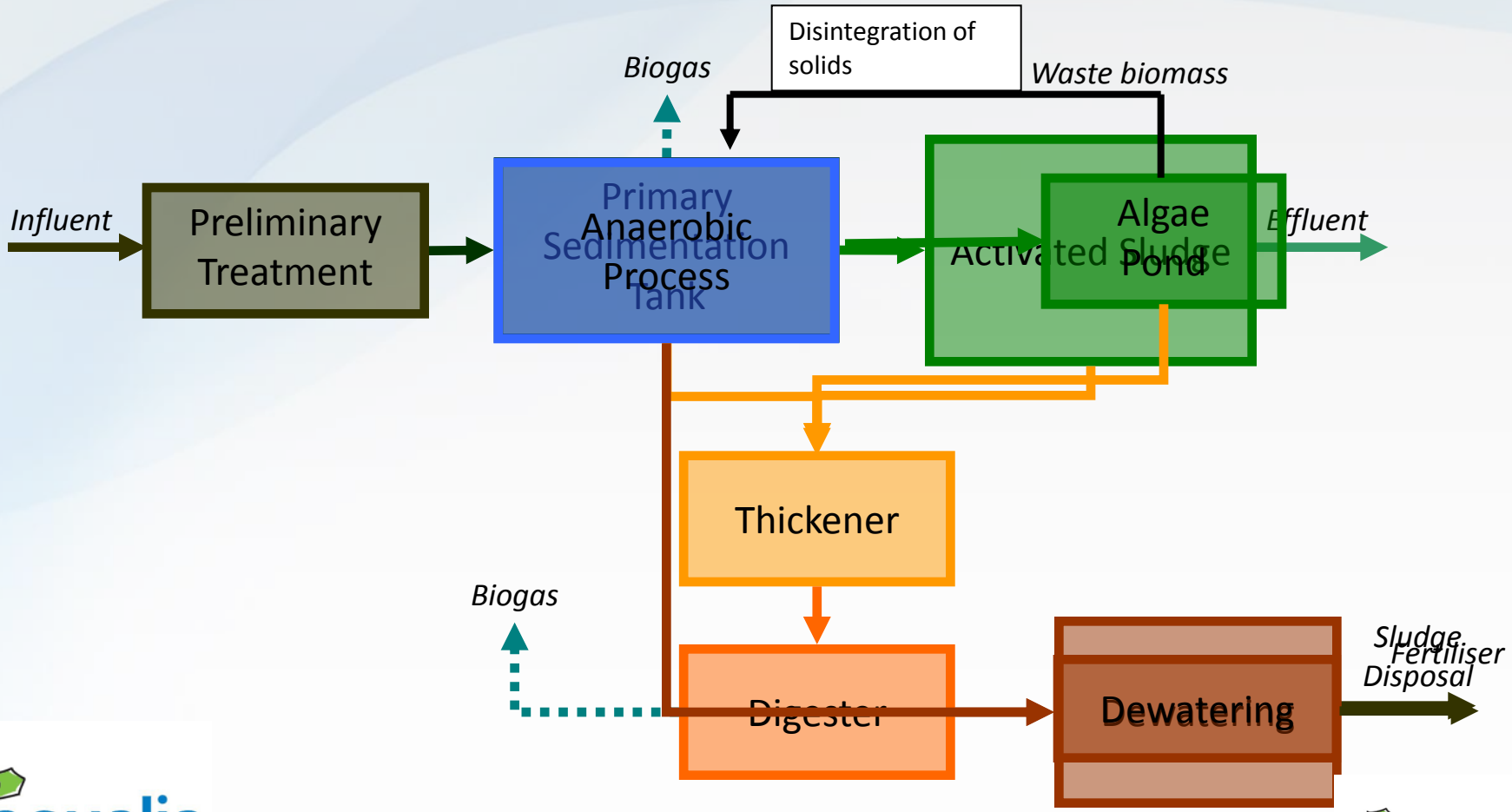
-ALL GAS Project



aqualia

aqualia

-Raceway

Aqualia

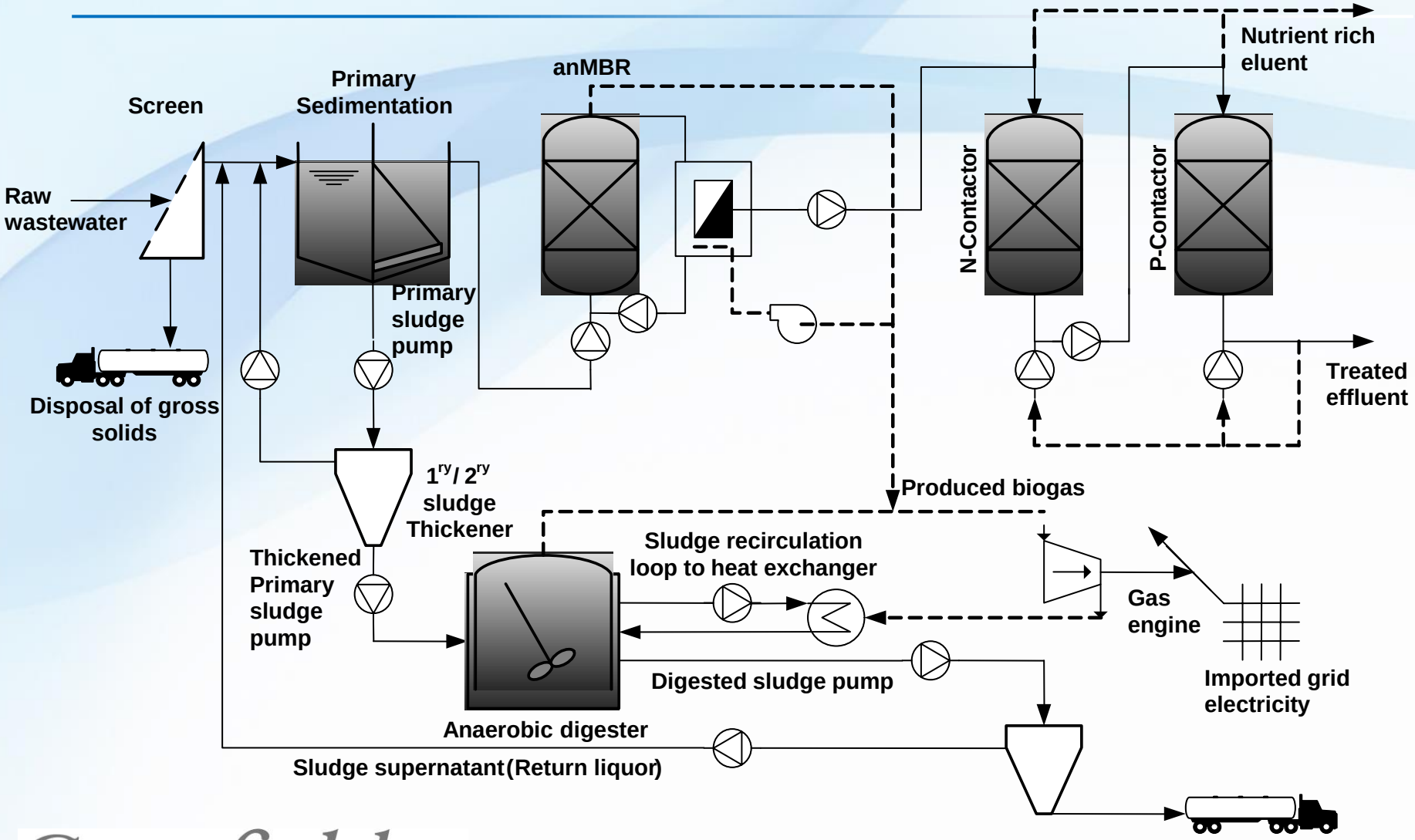
aqualia

-Extension to 4 Ha. 2500 m^3/d = 25 % of STP flow

Aqualia

aqualia

- Granular anaerobic MBR and nutrient absorbers.



Cranfield UNIVERSITY

Reuse

Sewage Anaerobic Treatment

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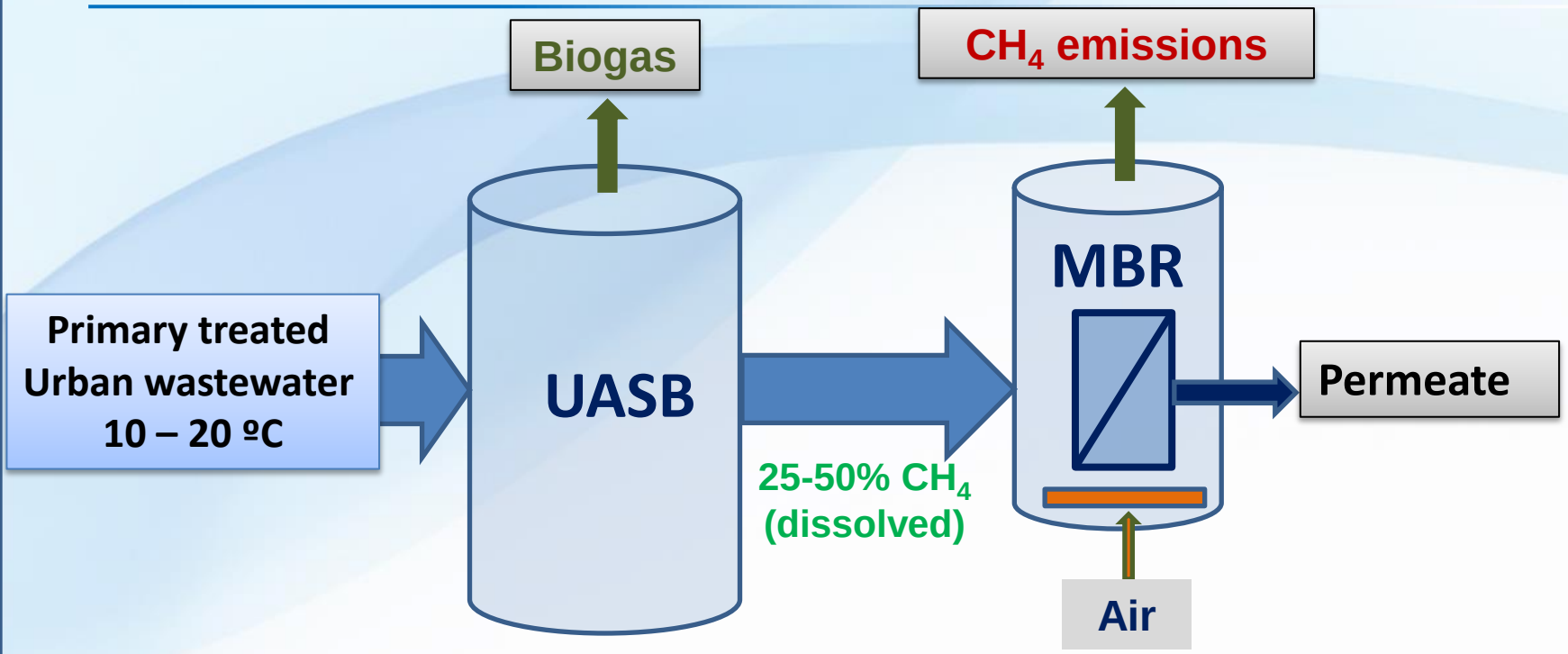
-Anaerobic + Aerobic MBR (for water reuse)



- Low-strength
- Ambient temperature

- Energy savings
- Low biomass production

High quality effluent
(COD, SS, microbiology)

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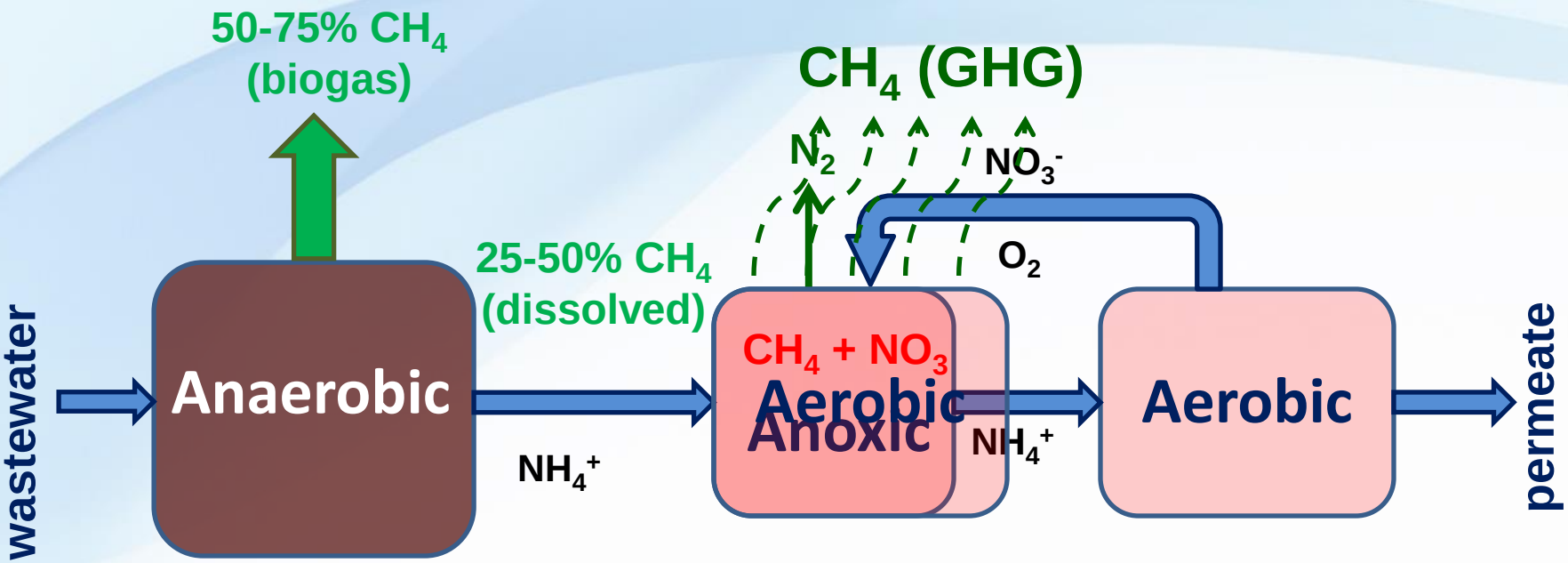
-SIAM ® Concept



CH_4 global warming potential of 25

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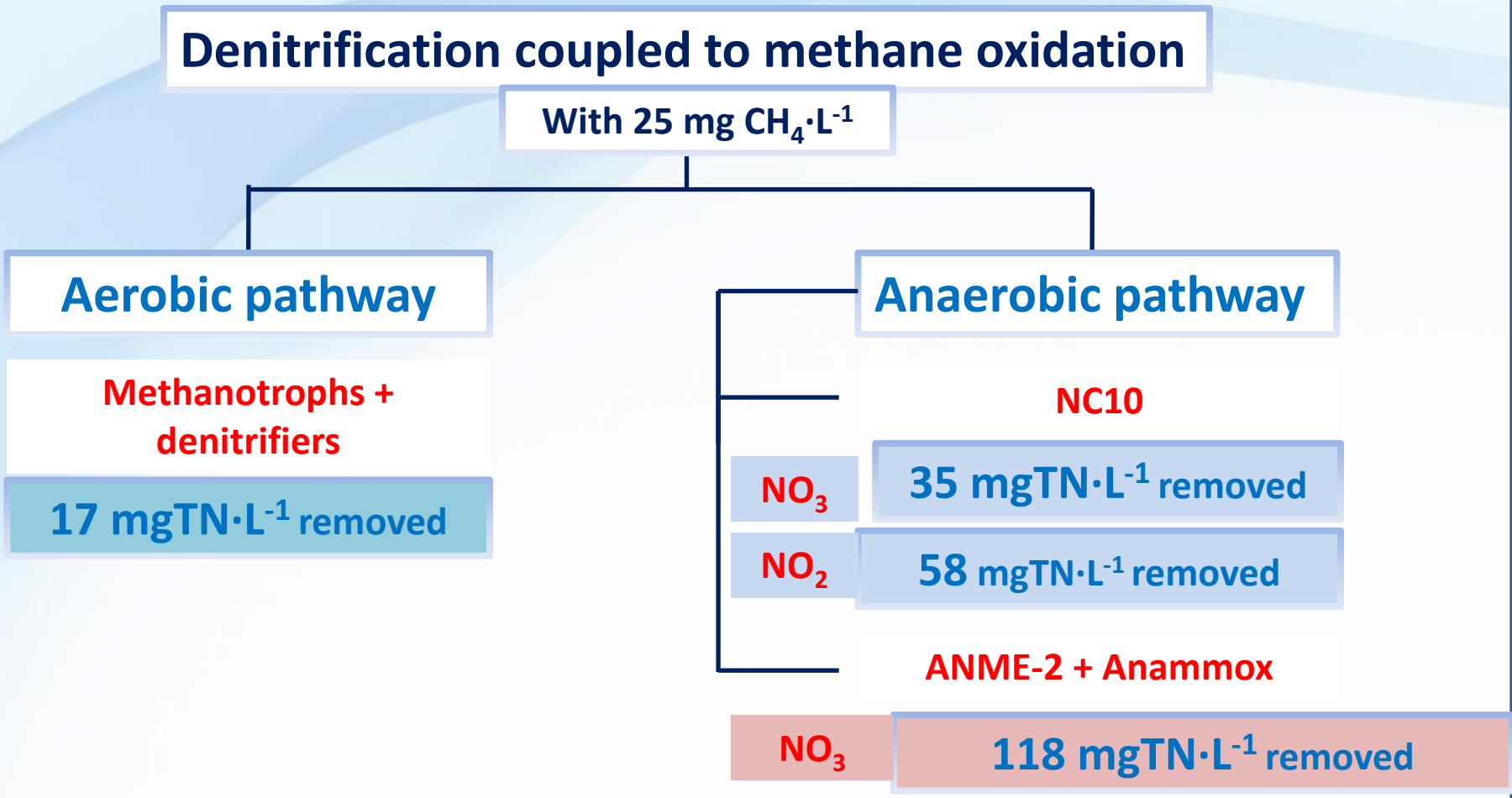
-Background: CH_4 & N removal



-Pilot plant (SIAM)

Supplier	Zenon
Type	Hollow fiber
Matherial	PVDF
Pore size	0.04 µm
Area	0.9 m^2

1 UASB reactor (141 L)
2 Anoxic Chamber (42 L)
3 Aerobic Membrane Chamber (22 L)

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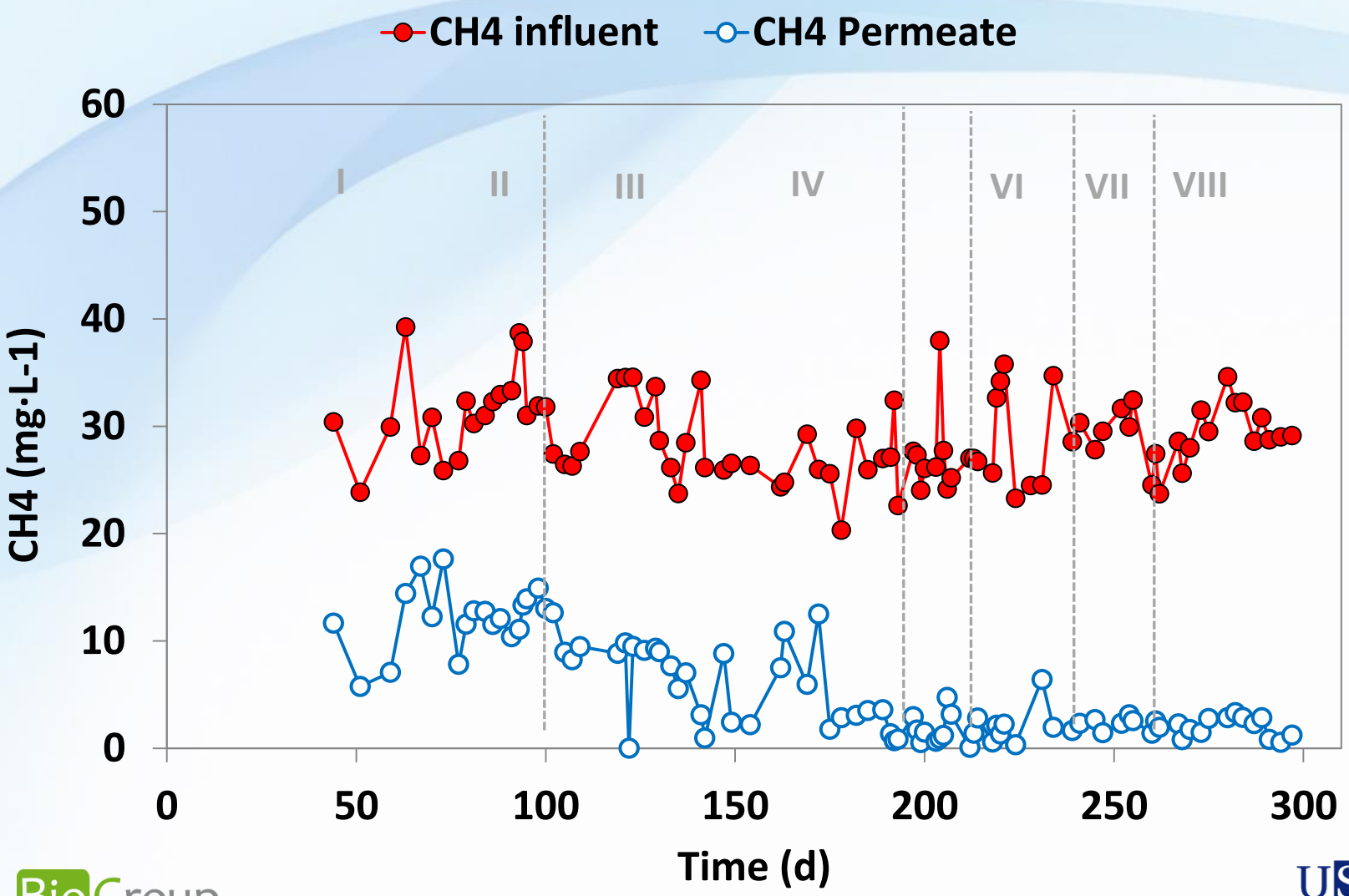
-CH_4 released



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-SIAM- MBR Comparison

	AnMBR	MBR	SIAM
Flux ($L/m^2 \cdot h$)	5-10	16-24	12-17
Energy (kWh/m^3)	-0.5/-0.7	0.2/0.4	-0.5/-0.7
Energy membrane	0.8/ 1.2	0.4/0.6	0.5/ 0.7
Total Energy	0.3/ 0.5	**0.6/1.0**	**-0.2/ 0.2**
CH_4 emissions	**Yes**	**Yes**	**No**
Denitrification	**No**	Yes	**Yes**
Sludge surplus ($kg\ SST/m^3$)	0.08/0.16	**0.2/0.3**	**0.08/0.16**

J. Garrido et al, 2015)

-Pilot plant (SIAM)

(STP Cartagena, Murcia, Spain)

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Recover

1.- Biomethane

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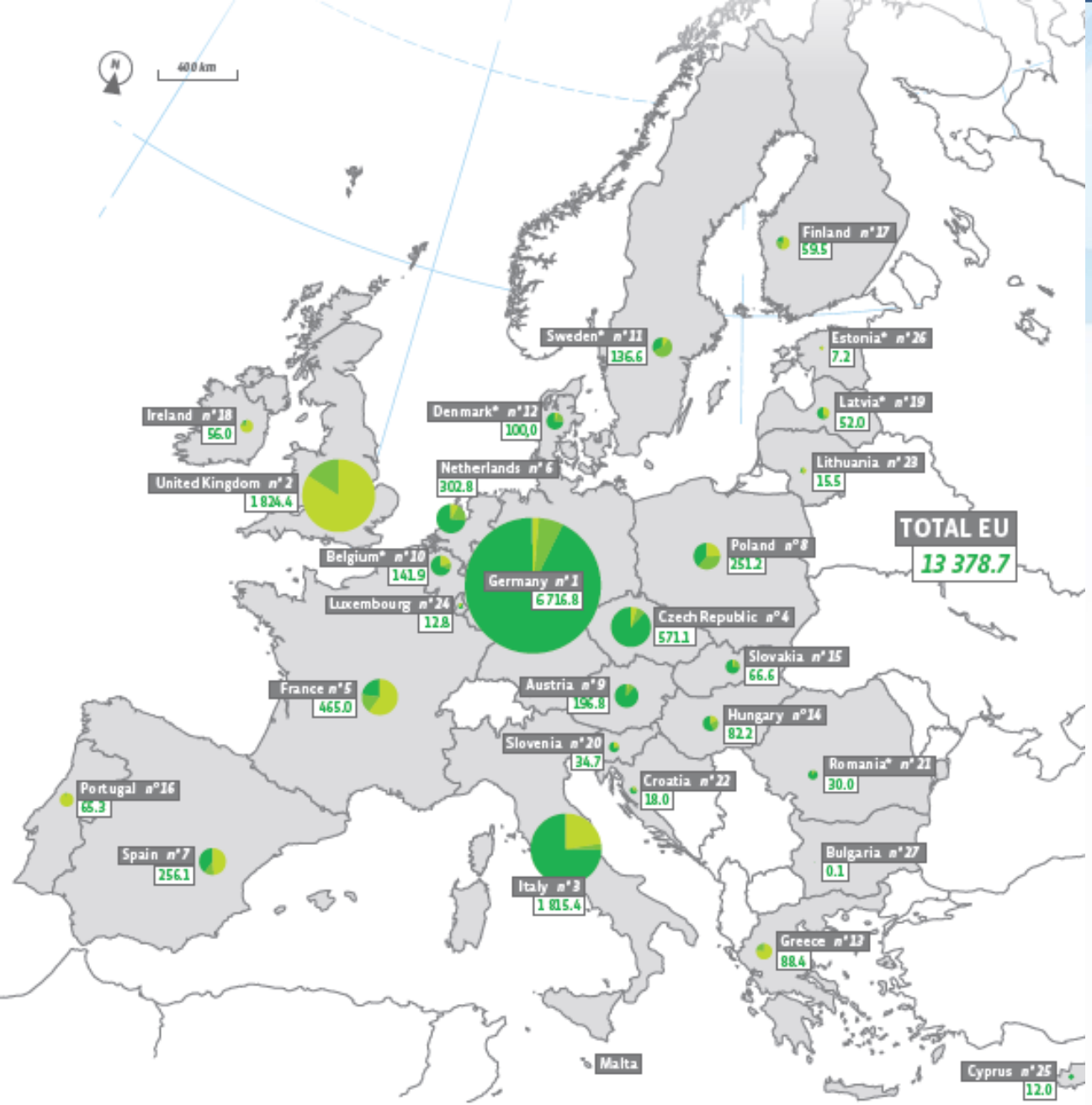

Biogas production in Europe (2014)

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Anaerobic (co) Digestion

Quality?

Maximum production?

ENERGY CROPS

DIGESTATE

DIGESTATE STORAGE

BIOGAS

BIOGÁS

ENGINE

GENERATOR

ELECTRICIT

HEATING SYSTEM

COGENERATION

DIGESTER

Proportions?

Loading rate?

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-Co-substrates blending... Let's try!

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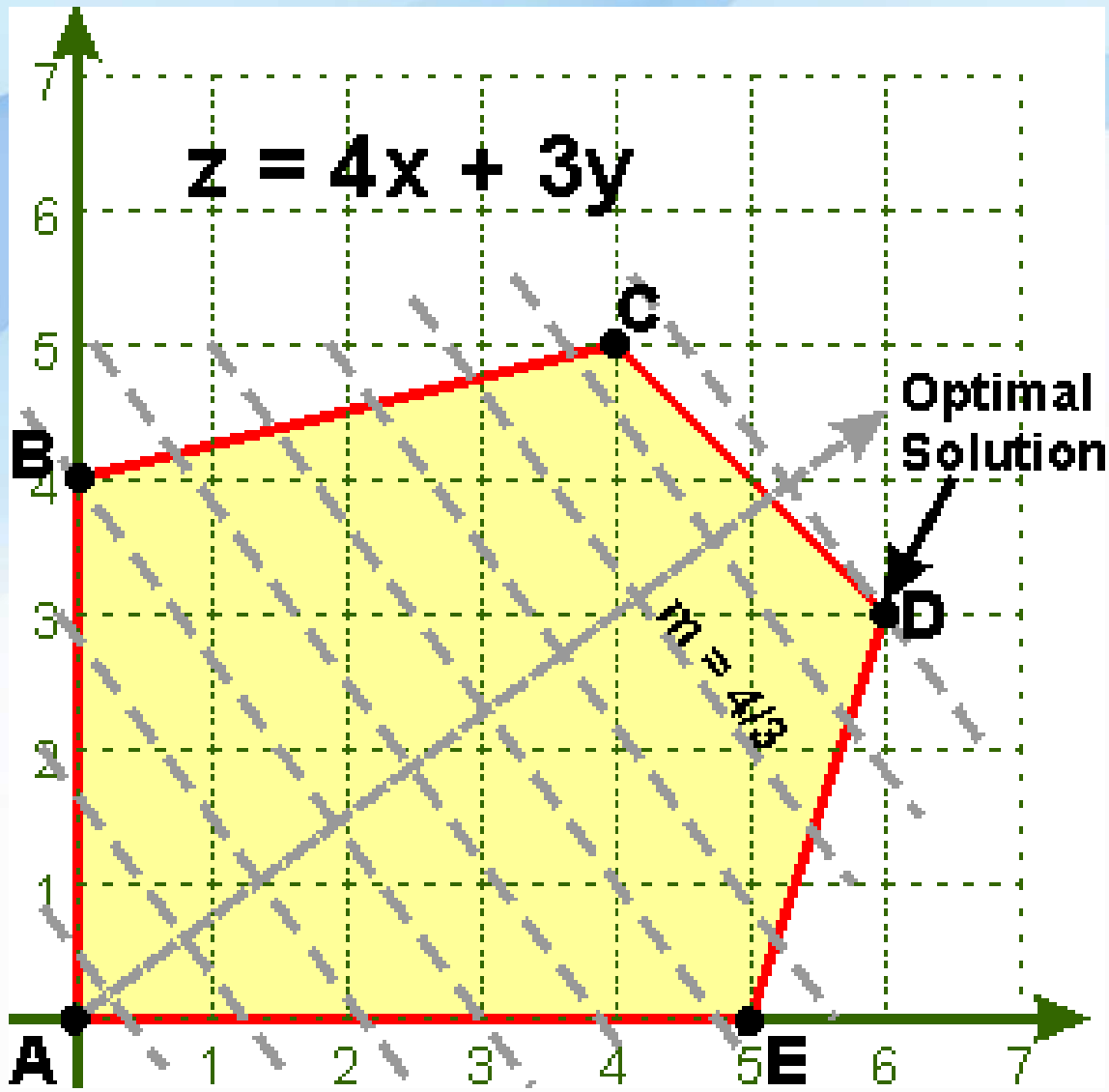
-A more rational approach



-Closed-loop control strategy

Control cycle = ¼ HRT

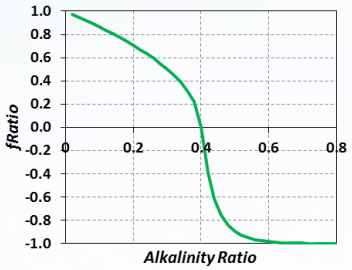
QCH_4^* Ratio* *(Set Points)*

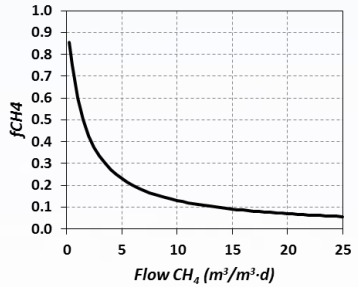
Indicator C | CONTROLLER | fCH4, fRatio | DIAGNOSIS | $\overline{QCH4}$, $\overline{Ratio}$

Modification of operational restrictions

$$Indicator\ C = \begin{cases} f_{Ratio} \cdot f_{CH4} & if \quad f_{Ratio} > 0 \\ f_{Ratio} & if \quad f_{Ratio} \le 0 \end{cases}$$

$$Limit_{NEW} = Limit_{CURRENT} + C \cdot (Limit_{HIGH} - Limit_{LOW})$$





Linear restriction	LOW	HIGH
OLR (g COD/L·d)	0	5
N-TKN (g N/L)	0.2	4
Moisture (kg H_2O/kg)	0.85	1.0
Lipids (g/L)	0	10
Alkalinity (g $CaCO_3$/L)	2	8
Na+ (g/L)	0	3
Biogas quality (ppm H_2S)	0	10,000
Digestate quality (g COD/L)	0	6

Apply to most active restriction

$$\overline{Ratio} = \frac{\int Ratio(t)\,dt}{\int dt} \qquad \overline{Q_{CH4}} = \frac{\int Q_{CH4}(t)\,dt}{\int dt}$$

BLENDER → xi (% vol.), HRT → ANAEROBIC DIGESTER → Flow CH4, Alkalinity Ratio → FILTER

Linear Programming Optimisation method

(García-Gen et al , Water Research, 2015)

-Operational strategy: Industrial pilot plant

(EDAR de BENS. A Coruña, Spain

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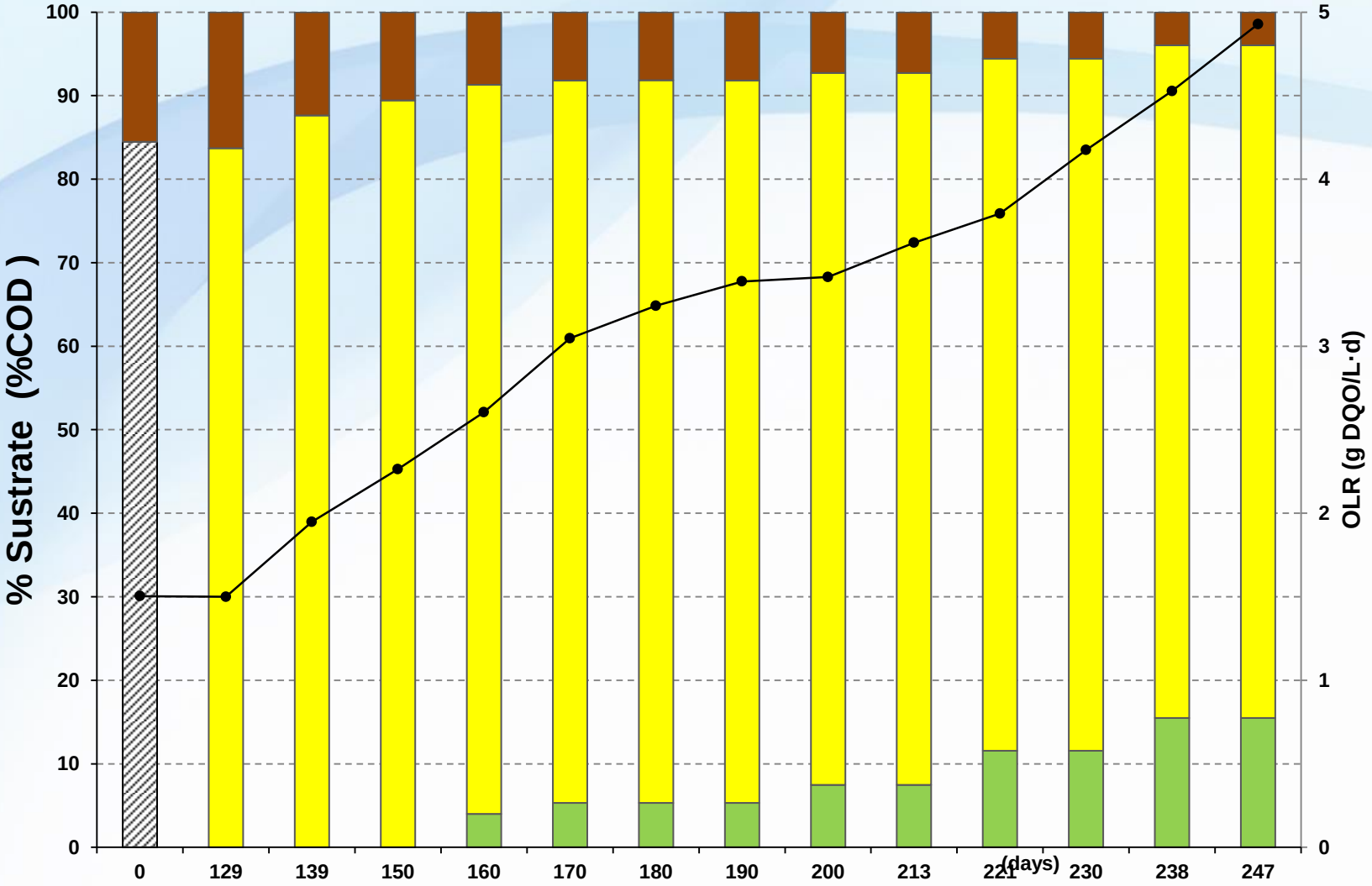
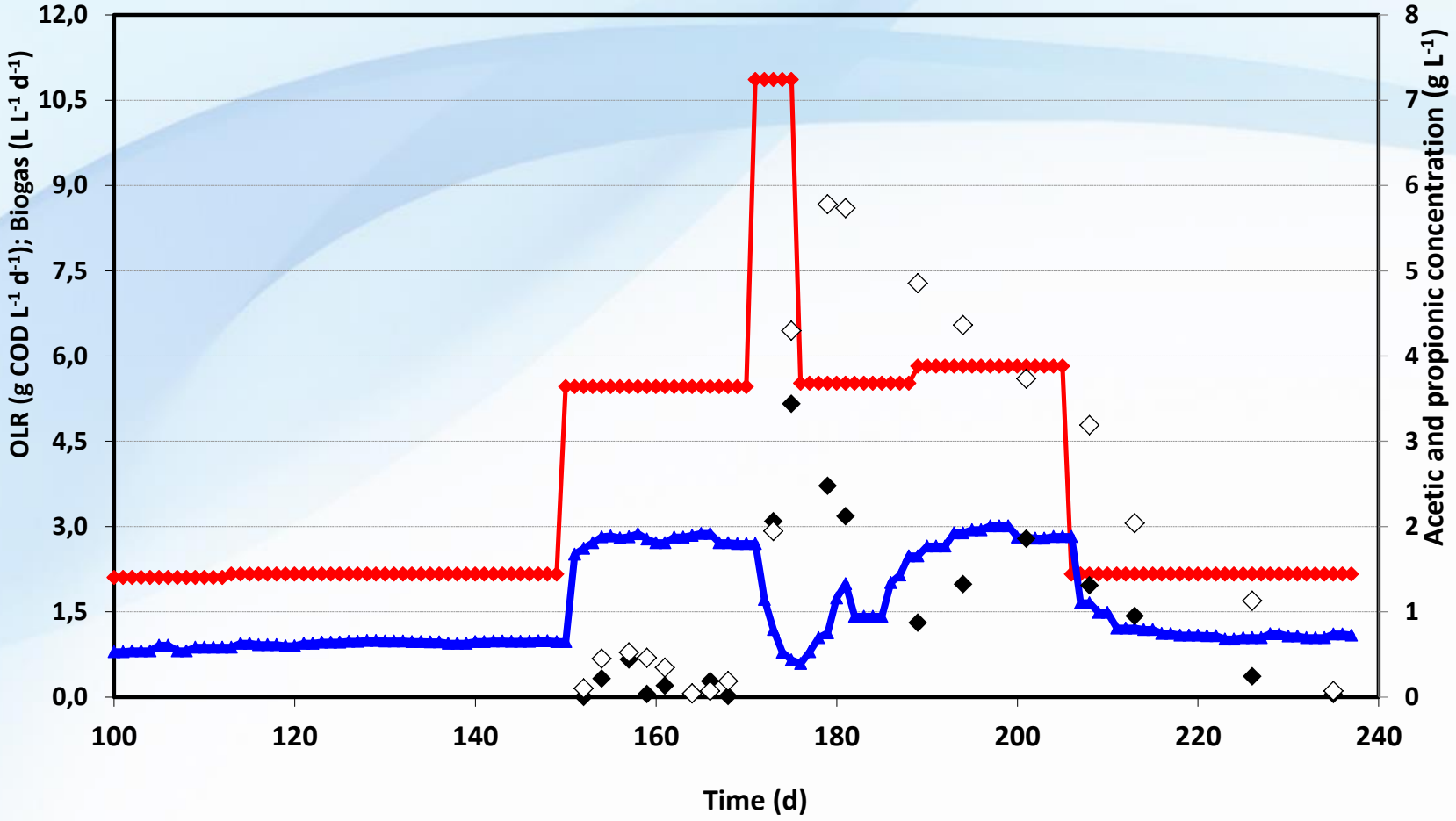
-Change of substrates fraction and OLR optimization



(García-Gen et al, 2015)

-OLR perturbations



Regueiro et al. Biores.Technol. (2015)

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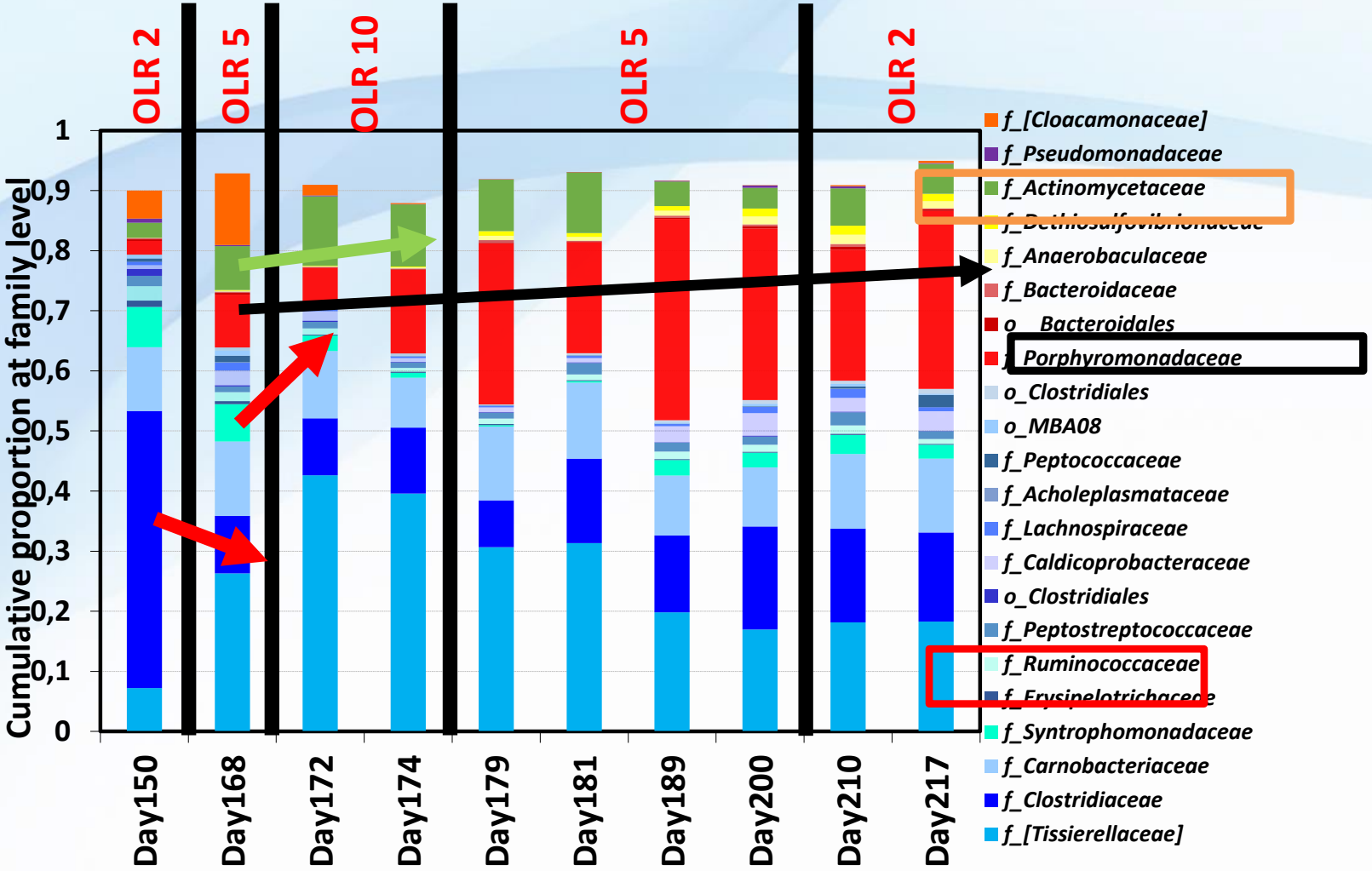
-Microbiome as an “early indicator”?



(Regueiro et al. Biores.Technol. 2015)

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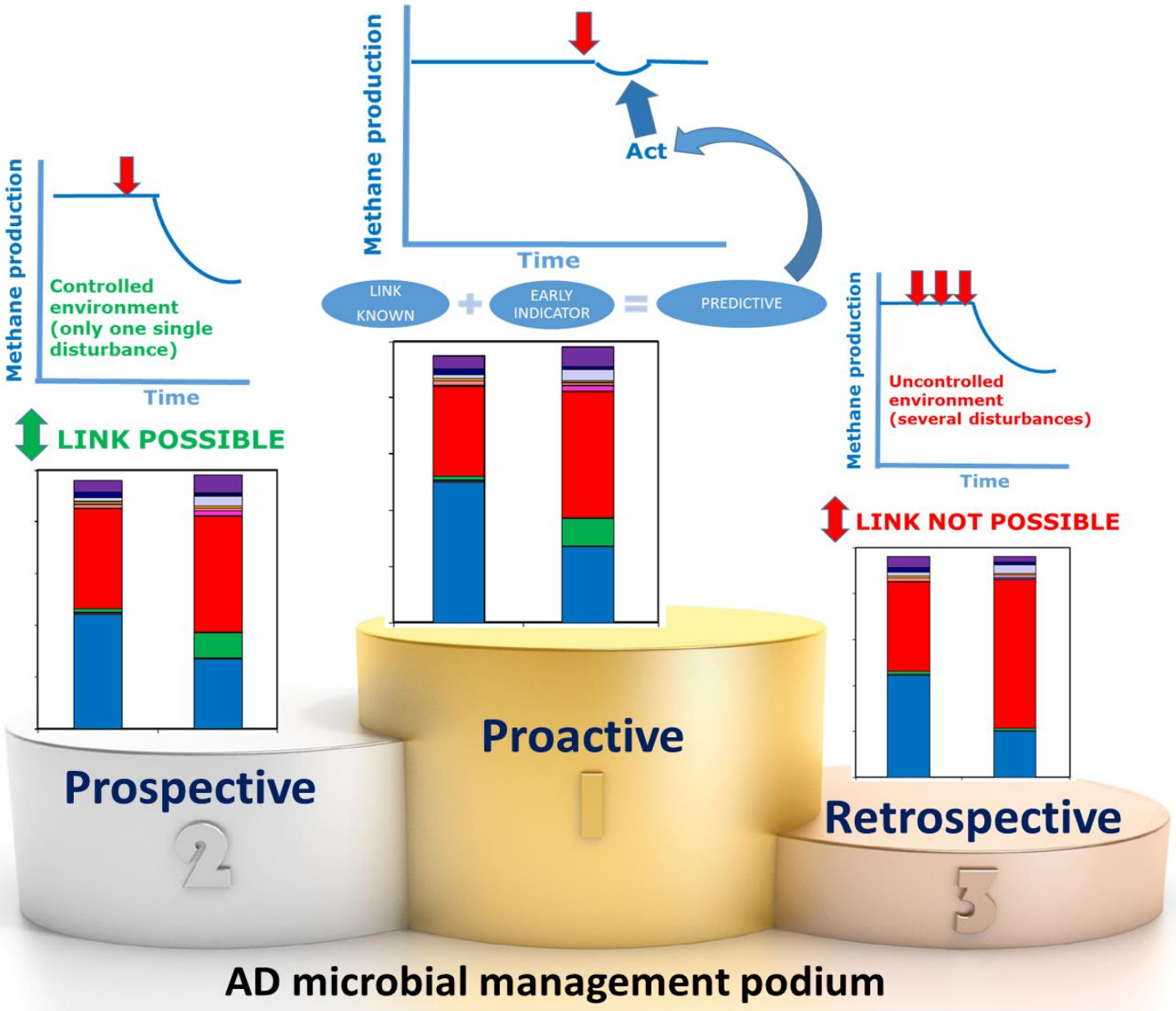
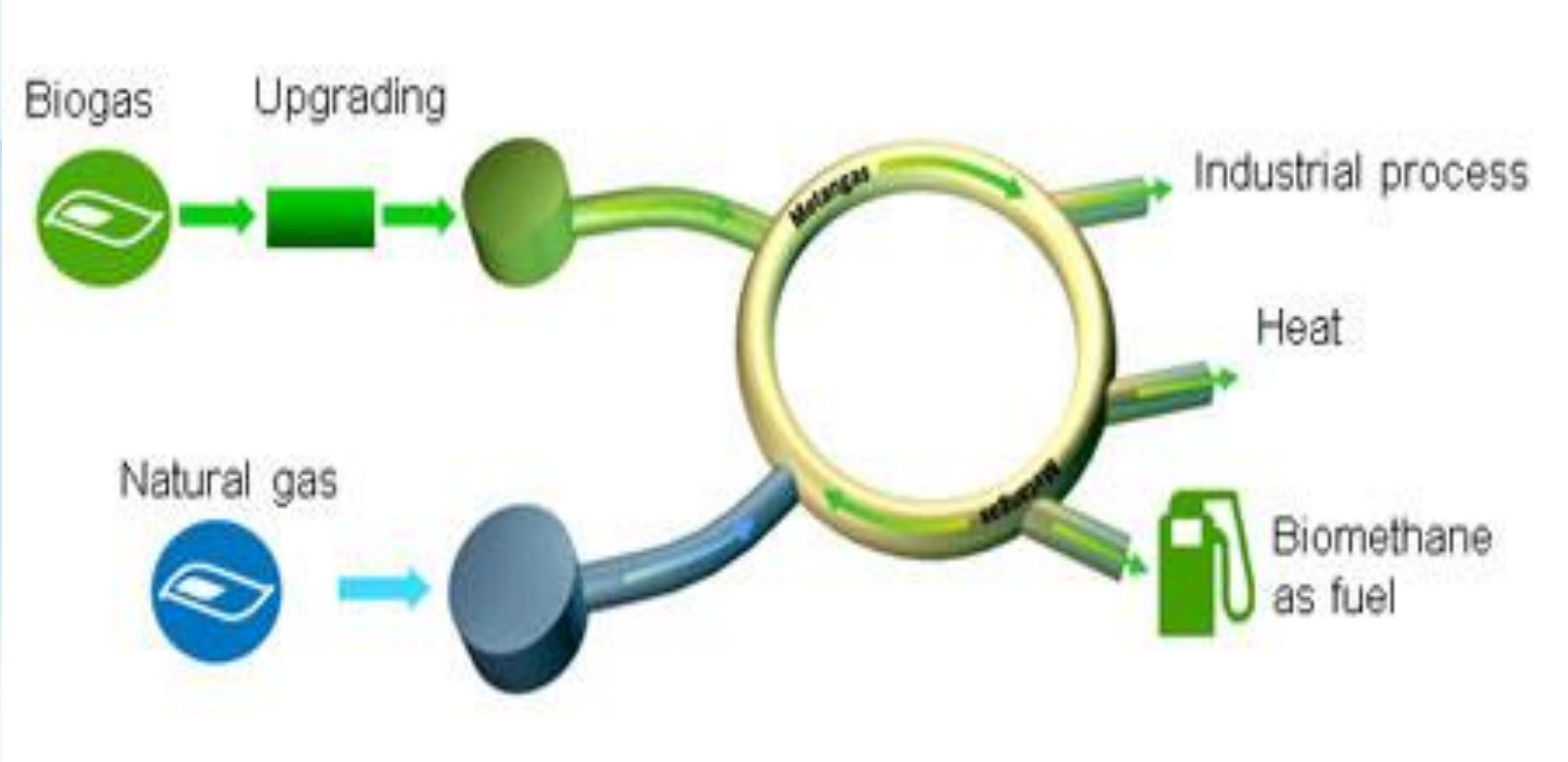


(Carballa et al. Current Opinion Biotechnol. 2015)

-Biogas upgrading to Biomethane



-Biomethane plant

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-Biogas upgrading plants (2012)

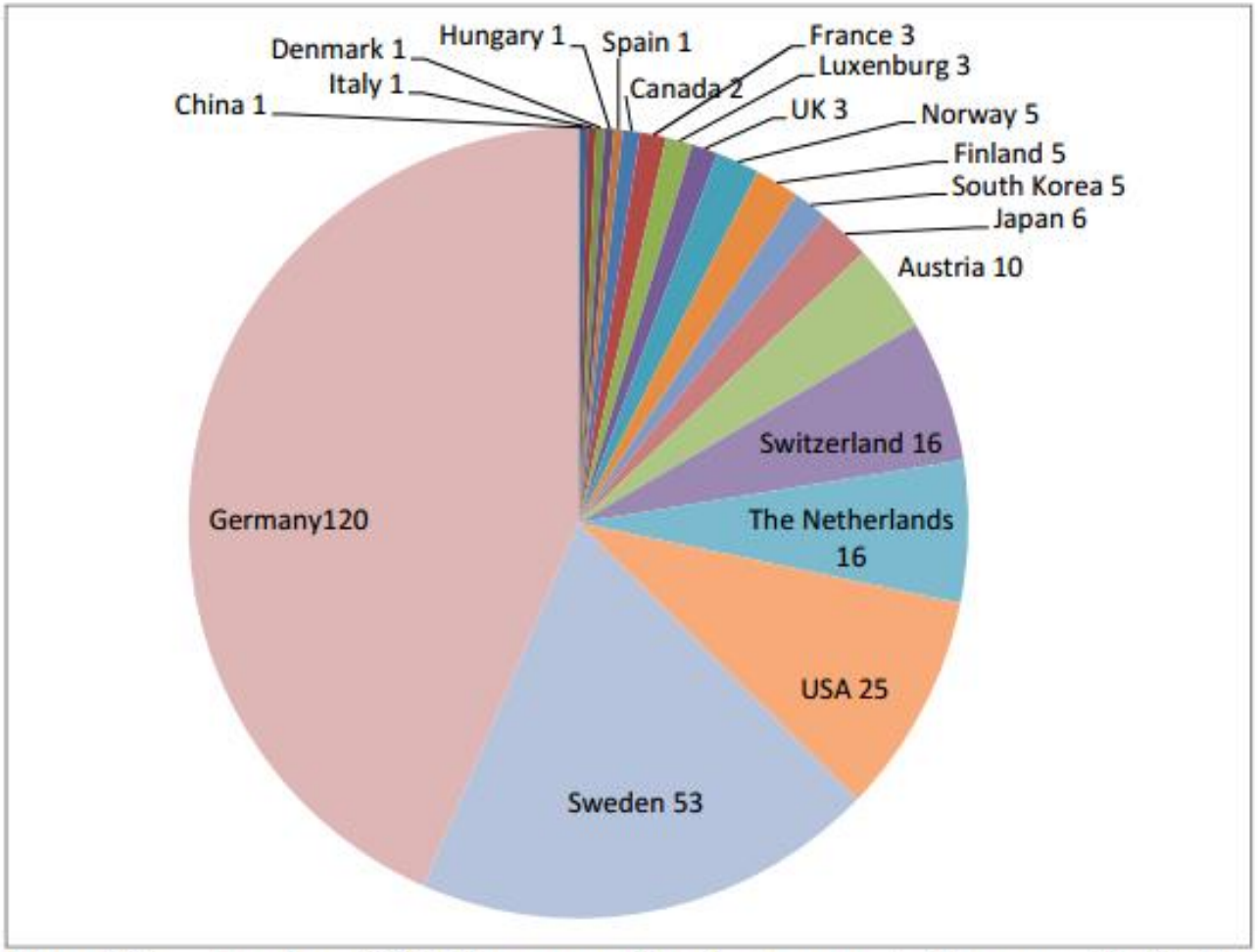

Figure 2-2. Location of 277 biogas upgrading plants, connected to anaerobic digesters, in operation at the end of 2012.

277 plants

http://www.iea-biogas.net/files/daten-redaktion/download/Technical%20Brochures/biomethane-status-2014.pdf

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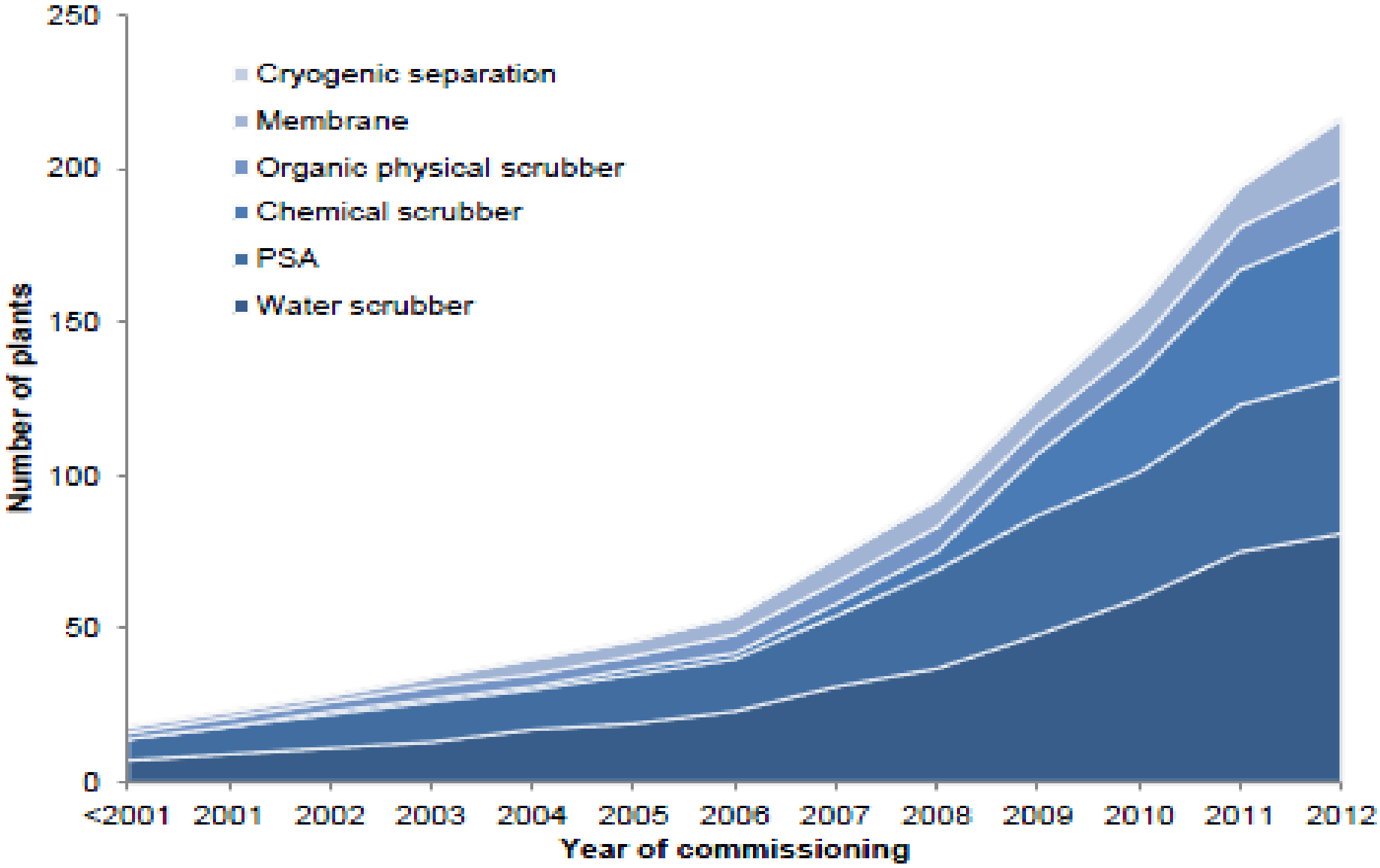
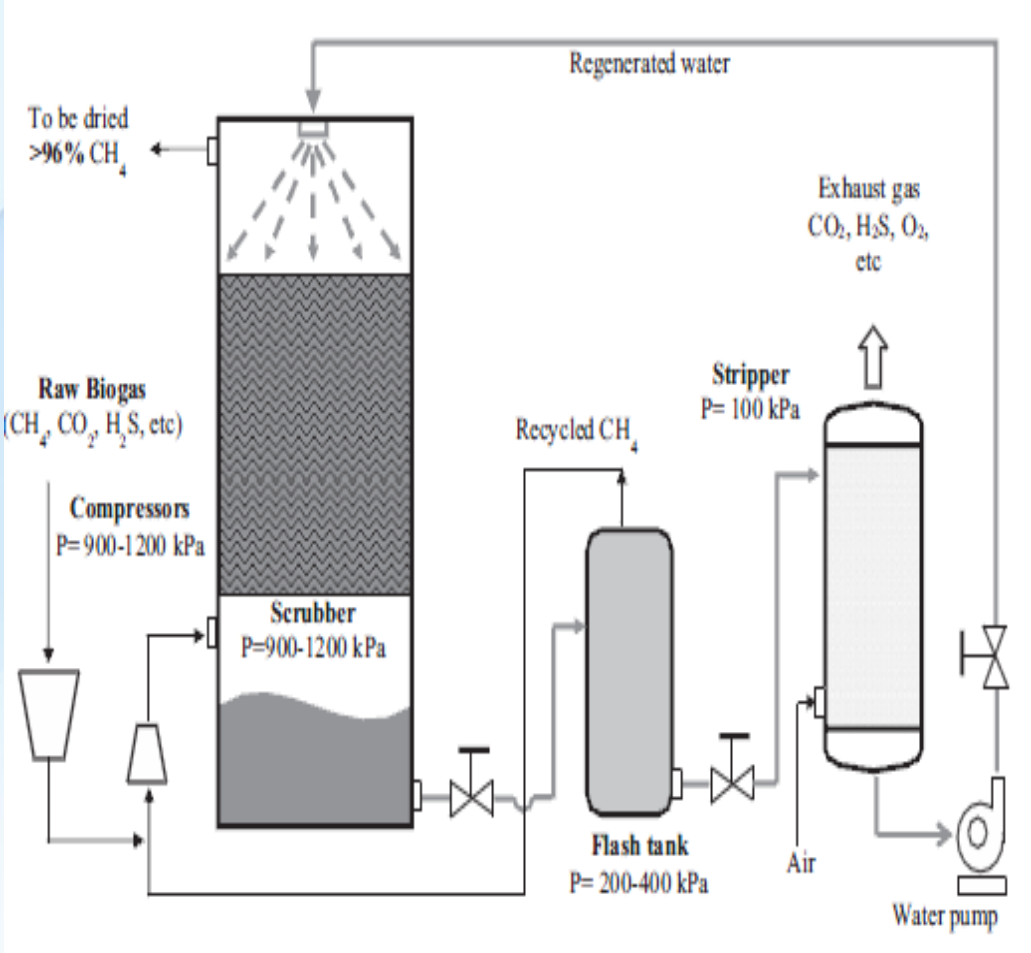
-Commercial Technologies

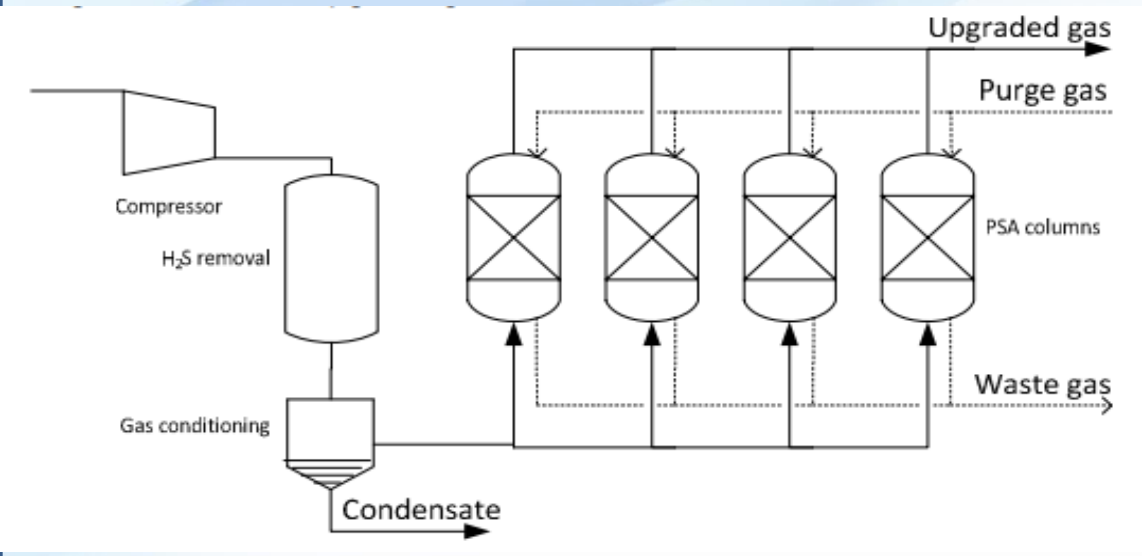


- Scrubbing (Water or Organic solvents)



(Yang, Ge et al. 2014)

-Pressure Swing Adsorption



Biogas upgrading plant Mühlacker, GE (1000m³/h)

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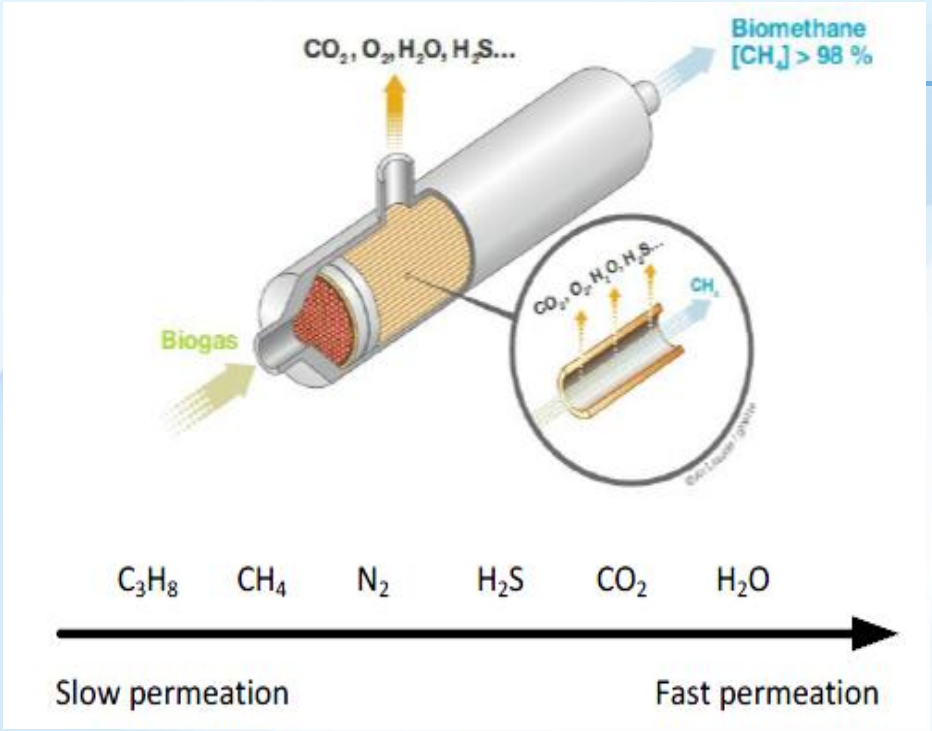
CarboTech AC GmbH

-Membrane separation



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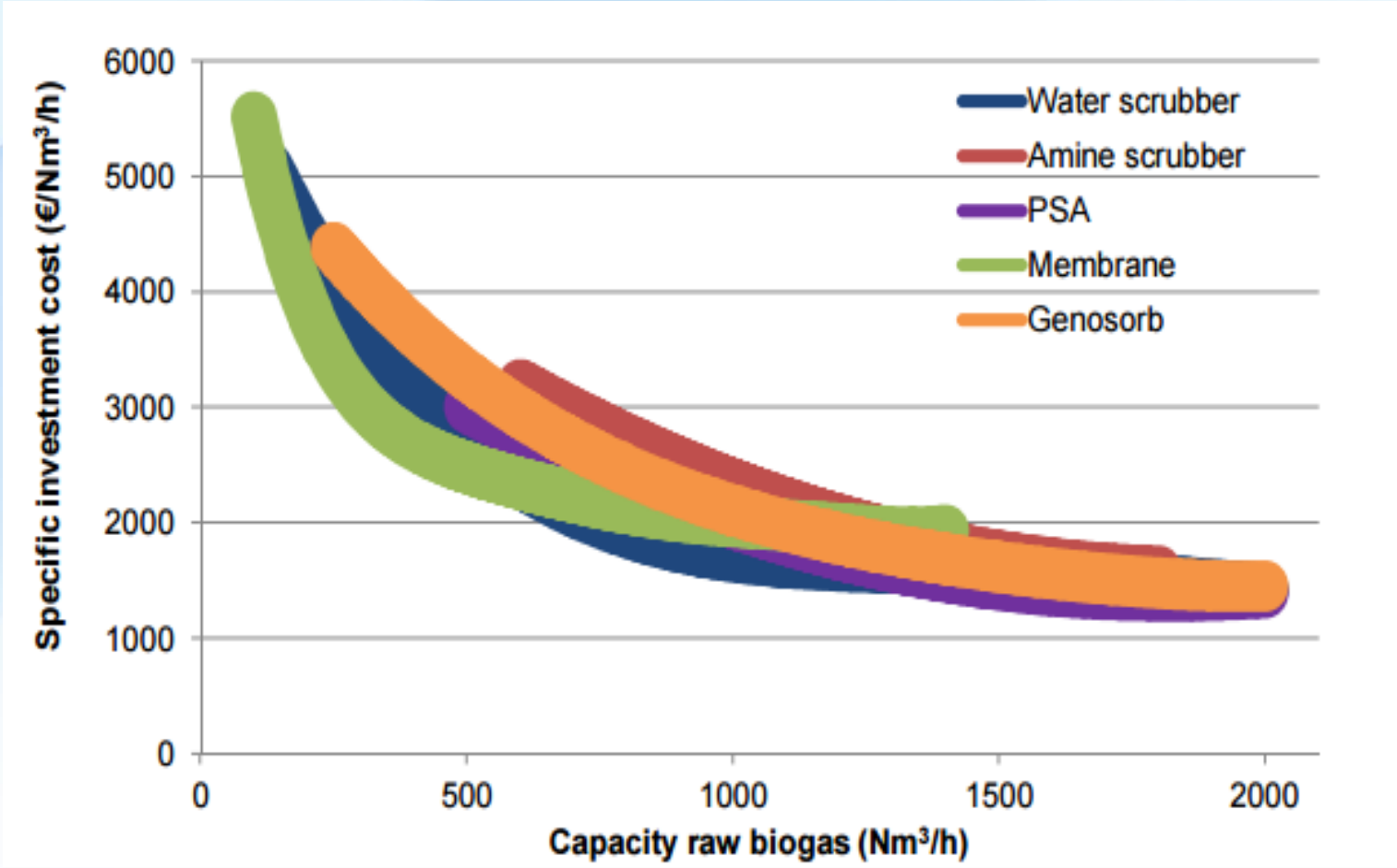
AIR PRODUCTS

-CAPEX



Sun Li et al Renewable and Sustainable Energy Reviews, 2015

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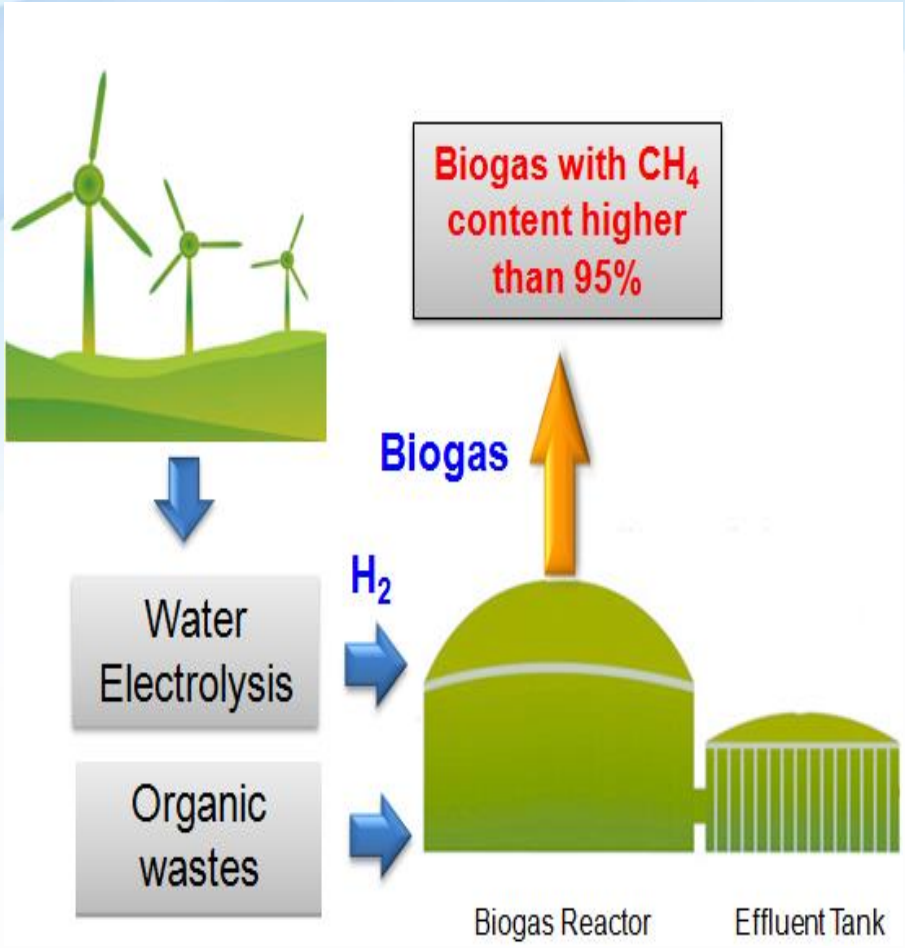
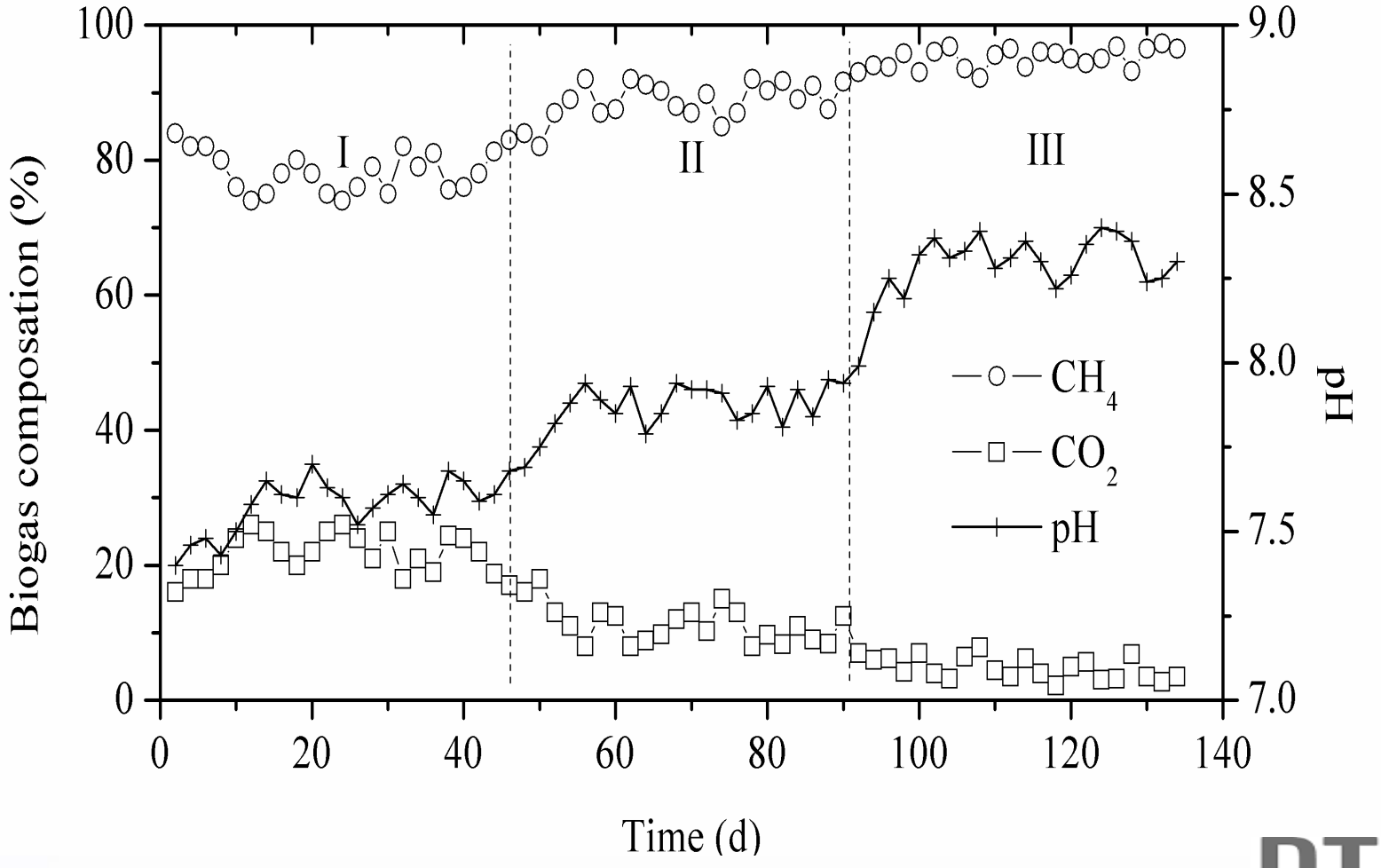
-Biological Biogas Upgrade. *In situ*"

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



- **More info: www.biogasupgrade.dk**

-In situ application



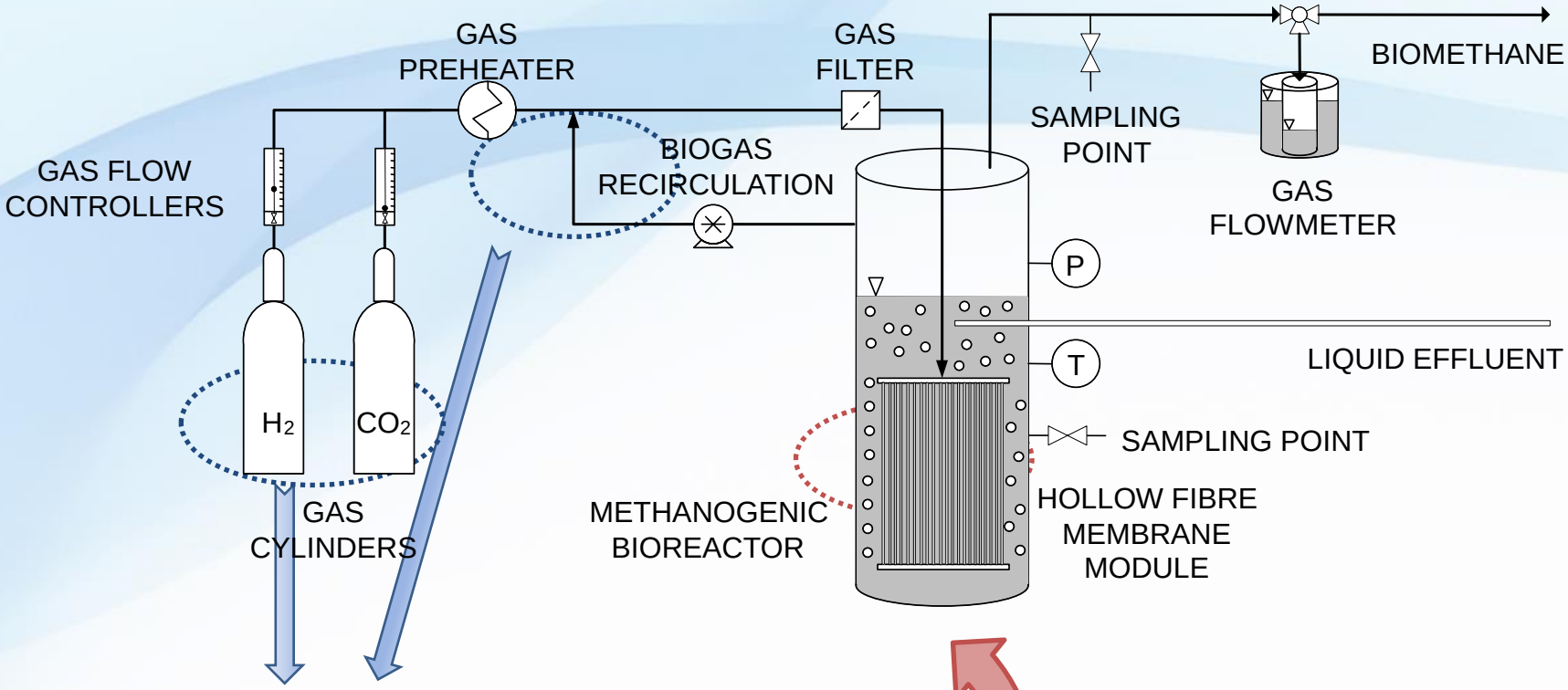
PATENT
PA: 61/563,247

Electrochaea

Pilot at Foulum, Denmark 2013

- Biogas from the anaerobic digestion of manure
- 10 m^3 continuous stirred-tank reactor (CSTR).
- Thermophilic conditions. 60-65°C
- Hydrogen supplied from a storage truck
- 3,200 hours of operation

-Lab-Scale Biological Upgrading



Feed and produced CH_4 are sparged through the membrane module to create fine bubbles

Díaz, I et al . *Biores.Technol.*. (2015)

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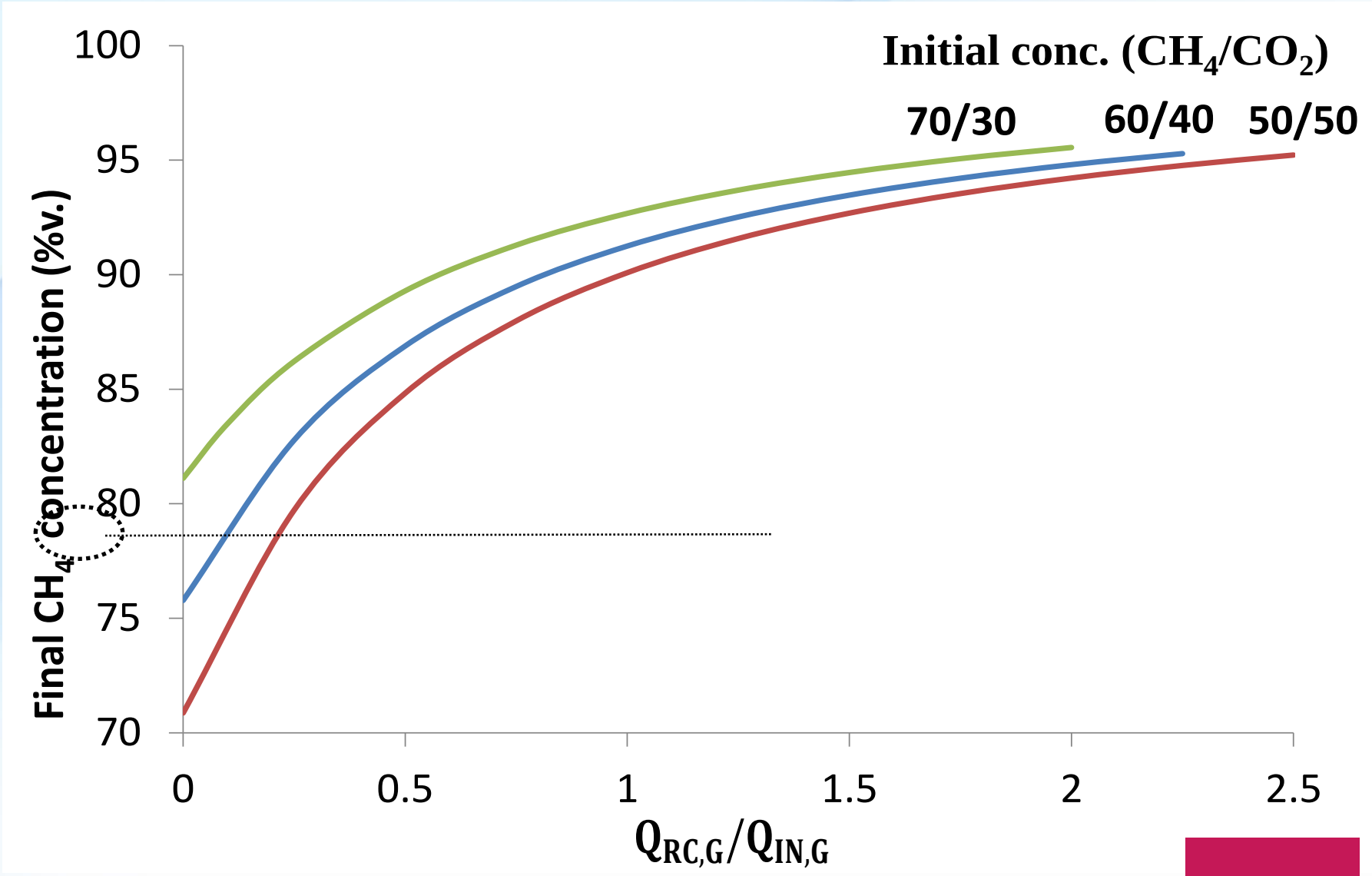
UVa



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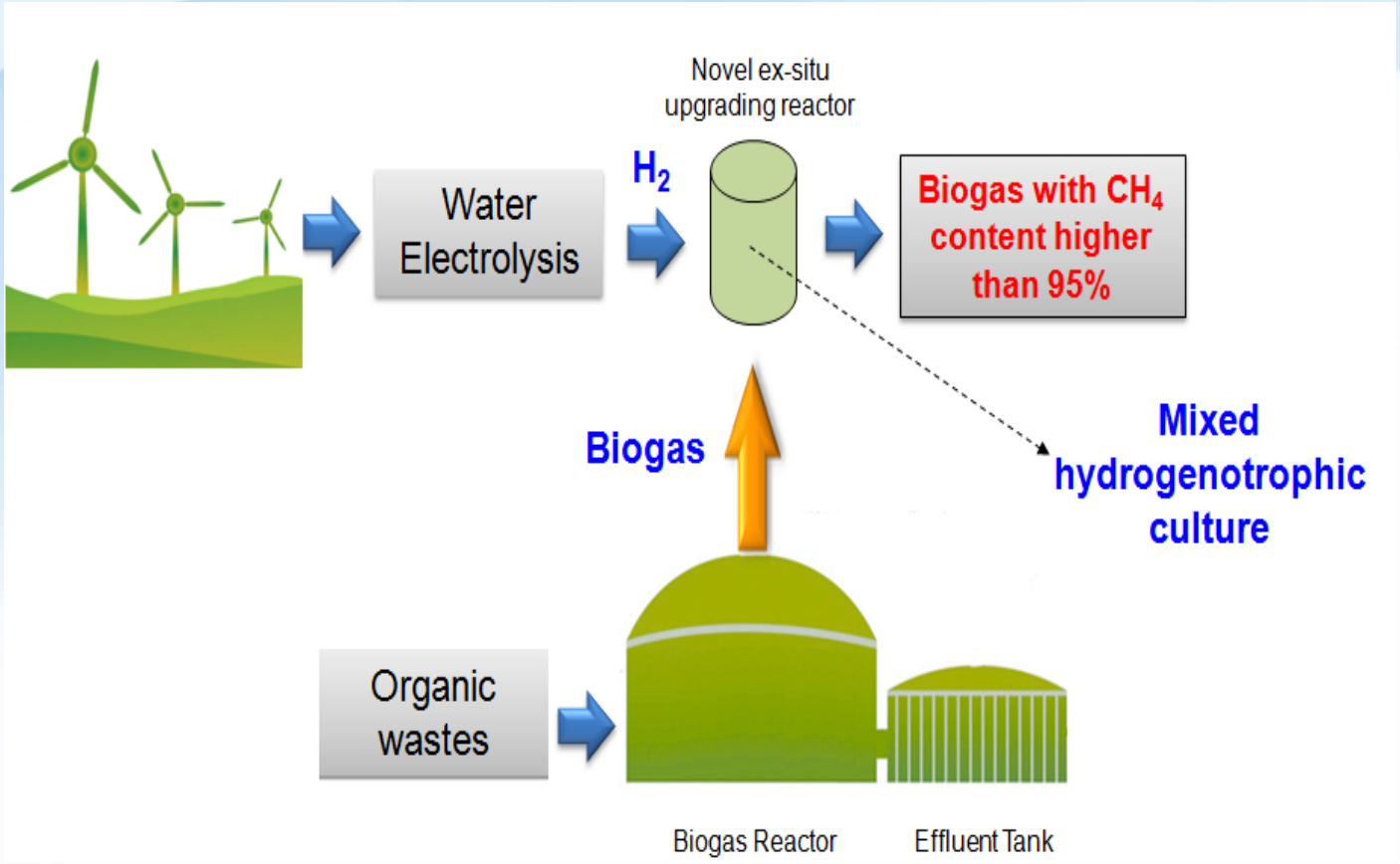
UVa

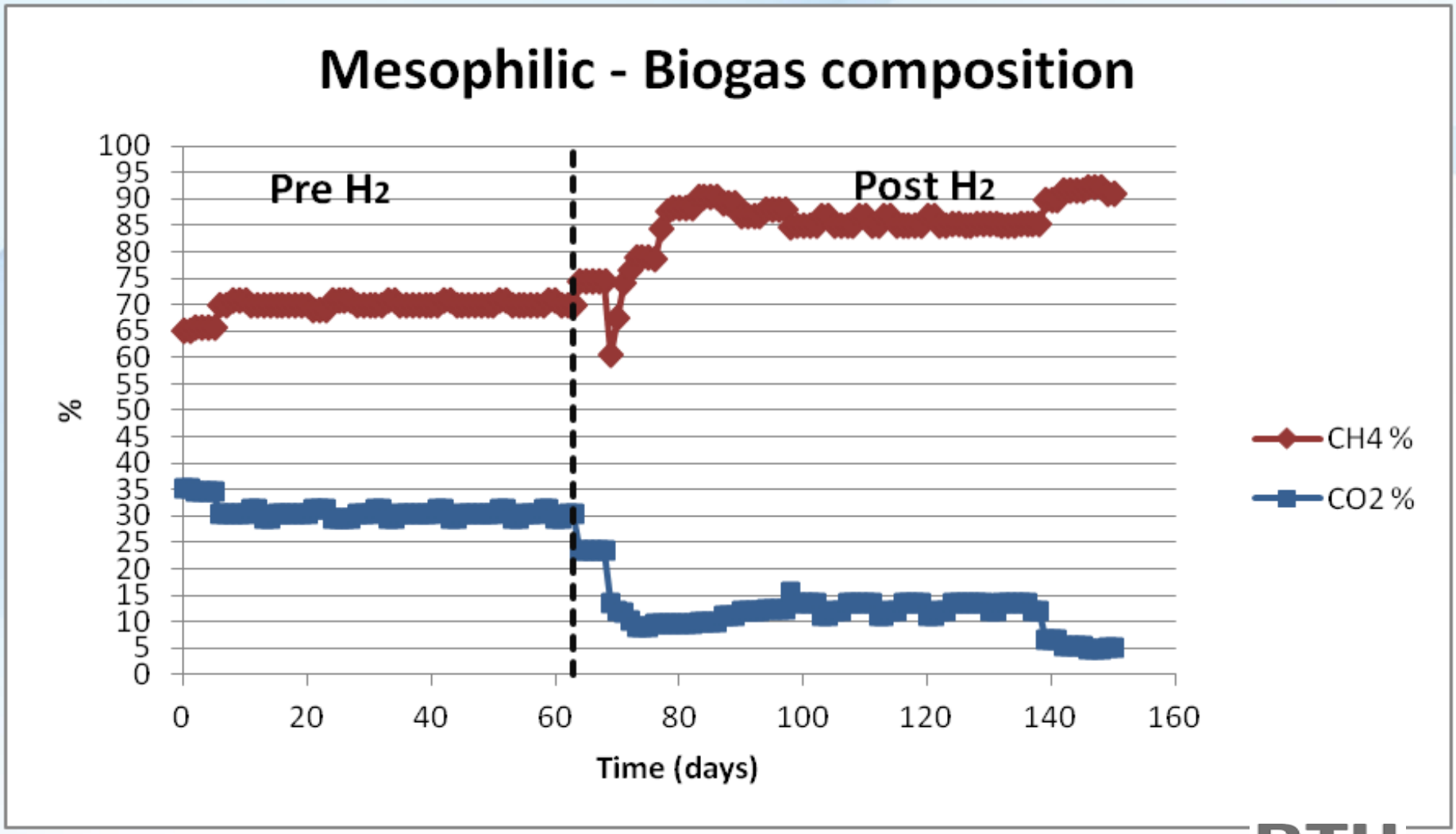
-Biological Biogas Upgrade. *Ex situ*

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

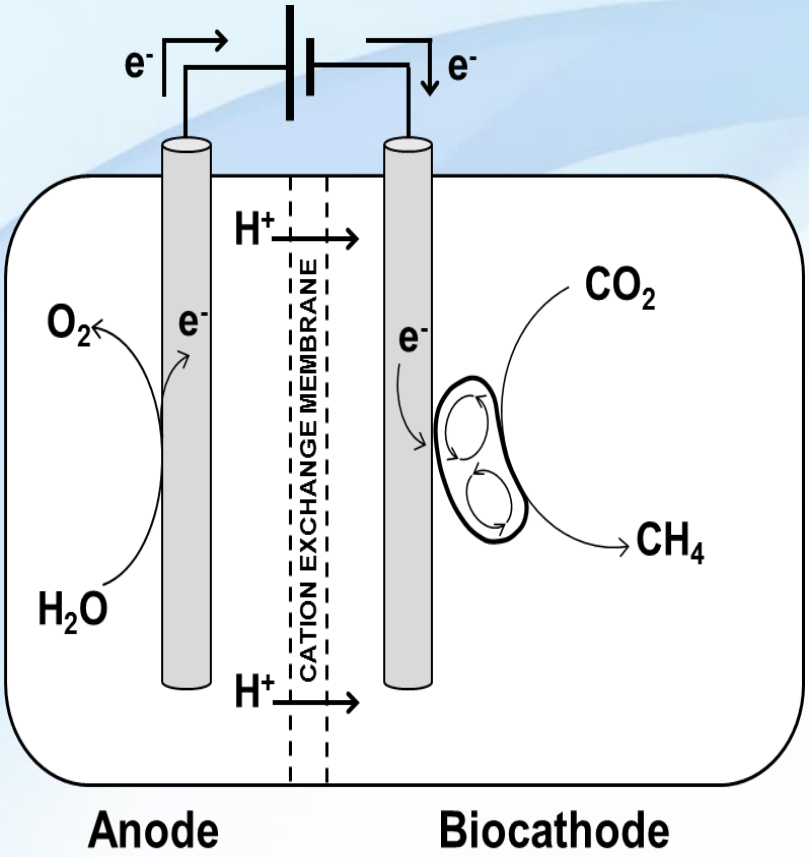


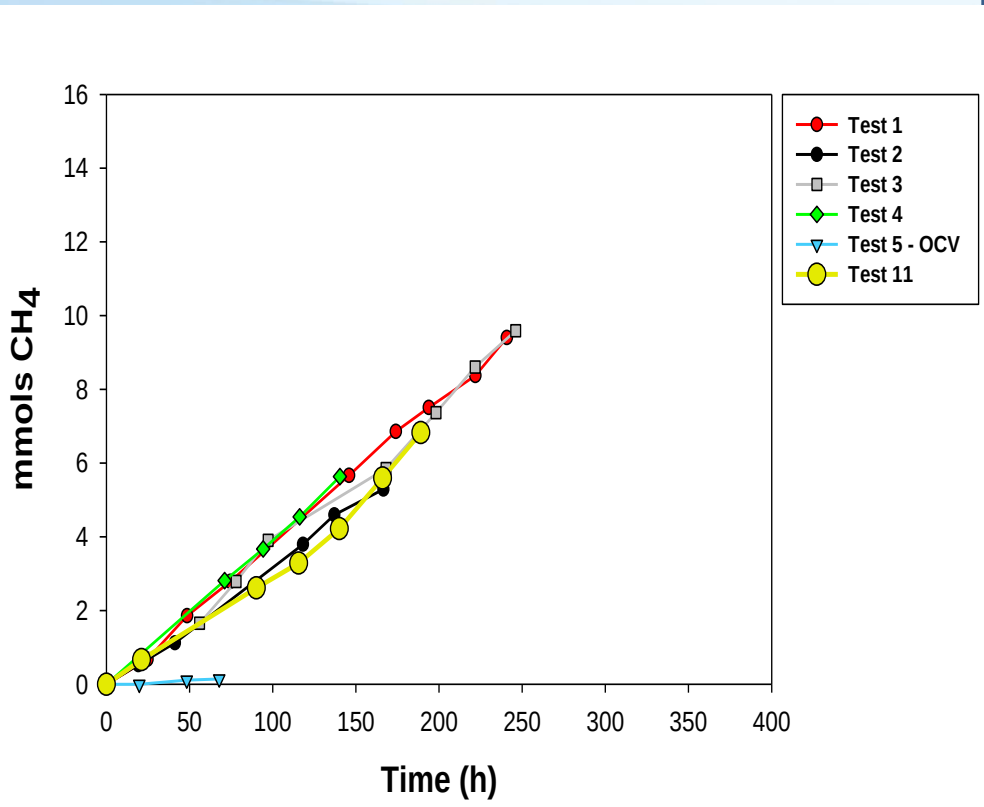
- **More info**: www.biogasupgrade.dk

-Ex situ application



-Microbial electrosynthesis (MES)





(Colprim et al. 2015)

RECOVER

2. Biorefinery

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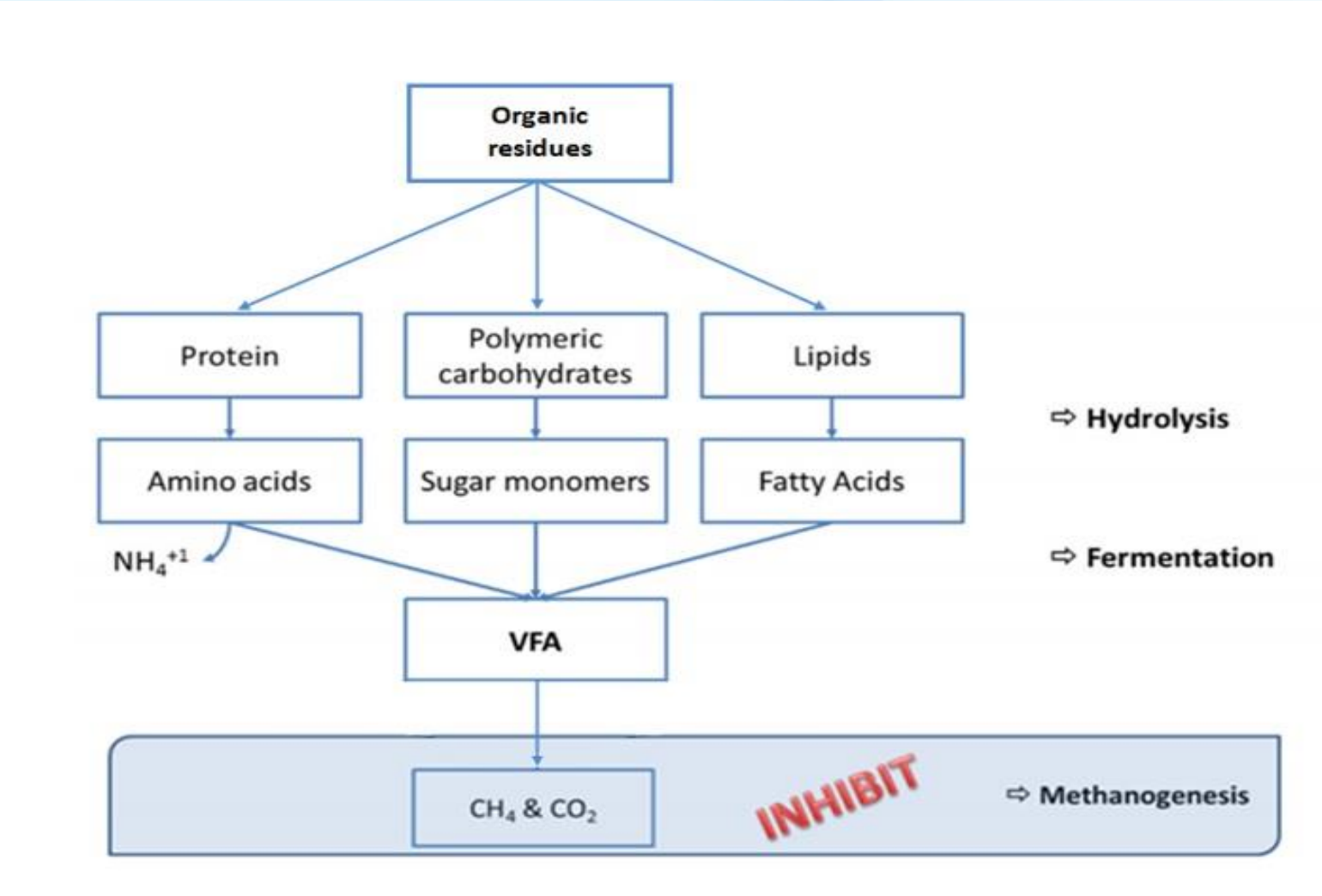
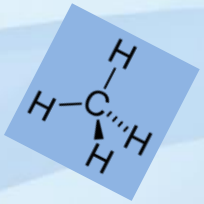
-Biorefinery

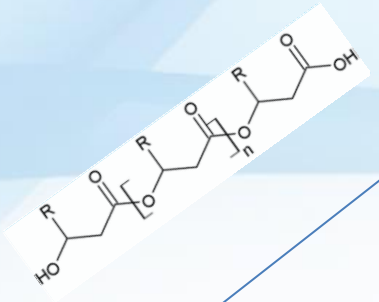


R. Kleerebezem et al. Reviews in Environmental Science and Bio/Technology. (2015)

-Biorefinery

Energy



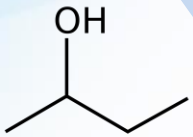


Bioplastics

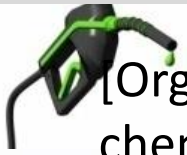
VFA

[Fermentation/ Thermal conversion]

[Organic chemistry]



Fuels (e.g. butanol)



[Organic chemistry]

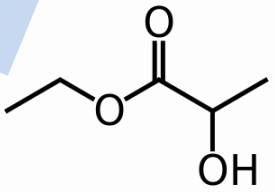
Chain elongation

[Reverse β oxidation]

[Electrosynthesis]

n-Caproate, n-Caprylic acid, etc

[Organic chemistry]



Raw chemicals (e.g. VFA, esters, etc)

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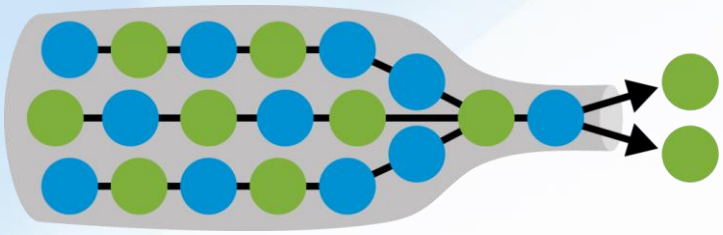
-Bottlenecks



Selectivity: Obtain certain VFAs and the desired amount of each one.

Product inhibition: Extract the product to let the fermentation keep going.

-VFA: Why is selectivity important?

Acetate | Butyrate | Propionate | Valerate

PHB | PHV

Brittle and stiff ✗

P(3HB-co-3HV)

More flexible and tougher ✓

Lee et al.: Chemical Engineering Journal (2013)

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-Increasing selectivity

pH

Temp

HRT

Feeding pattern

Substrate concentration

(co) Substrate

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-Influence of pH on selectivity

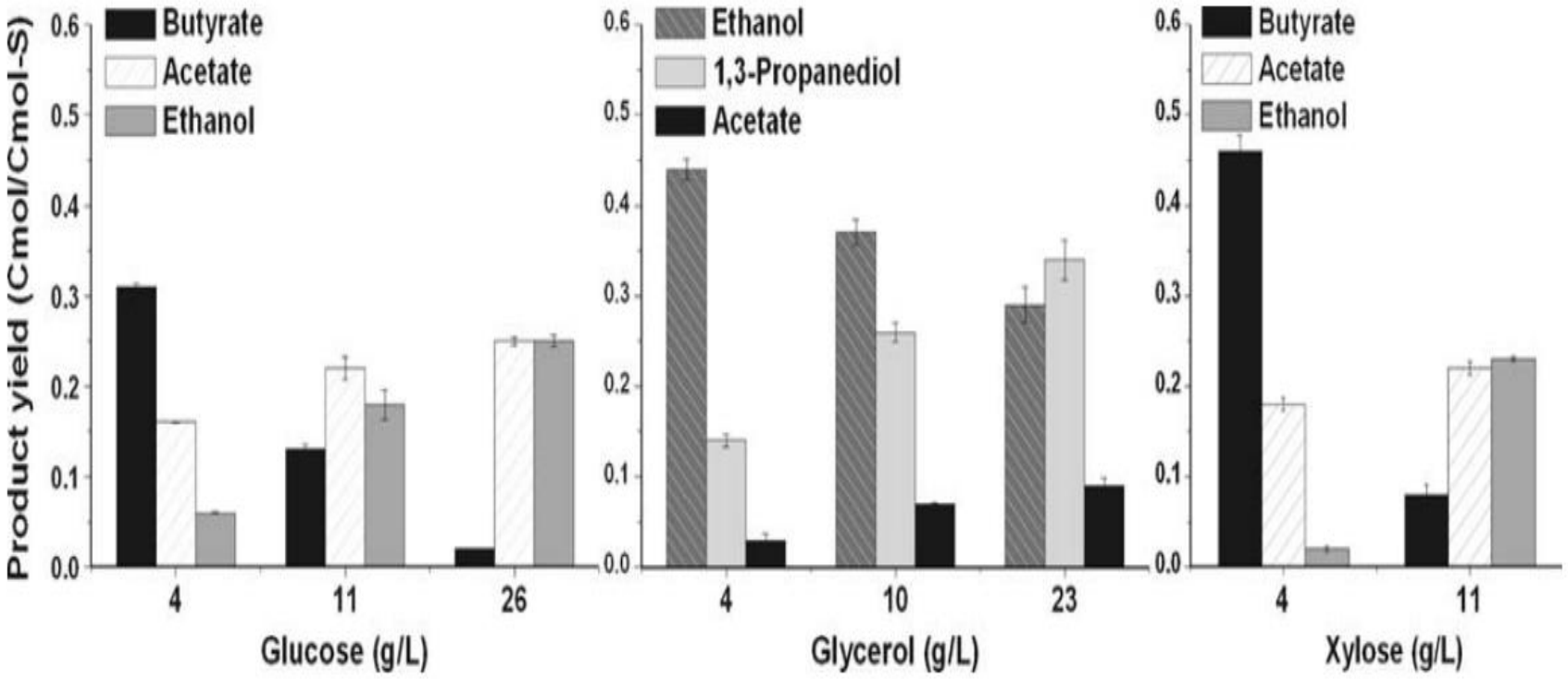
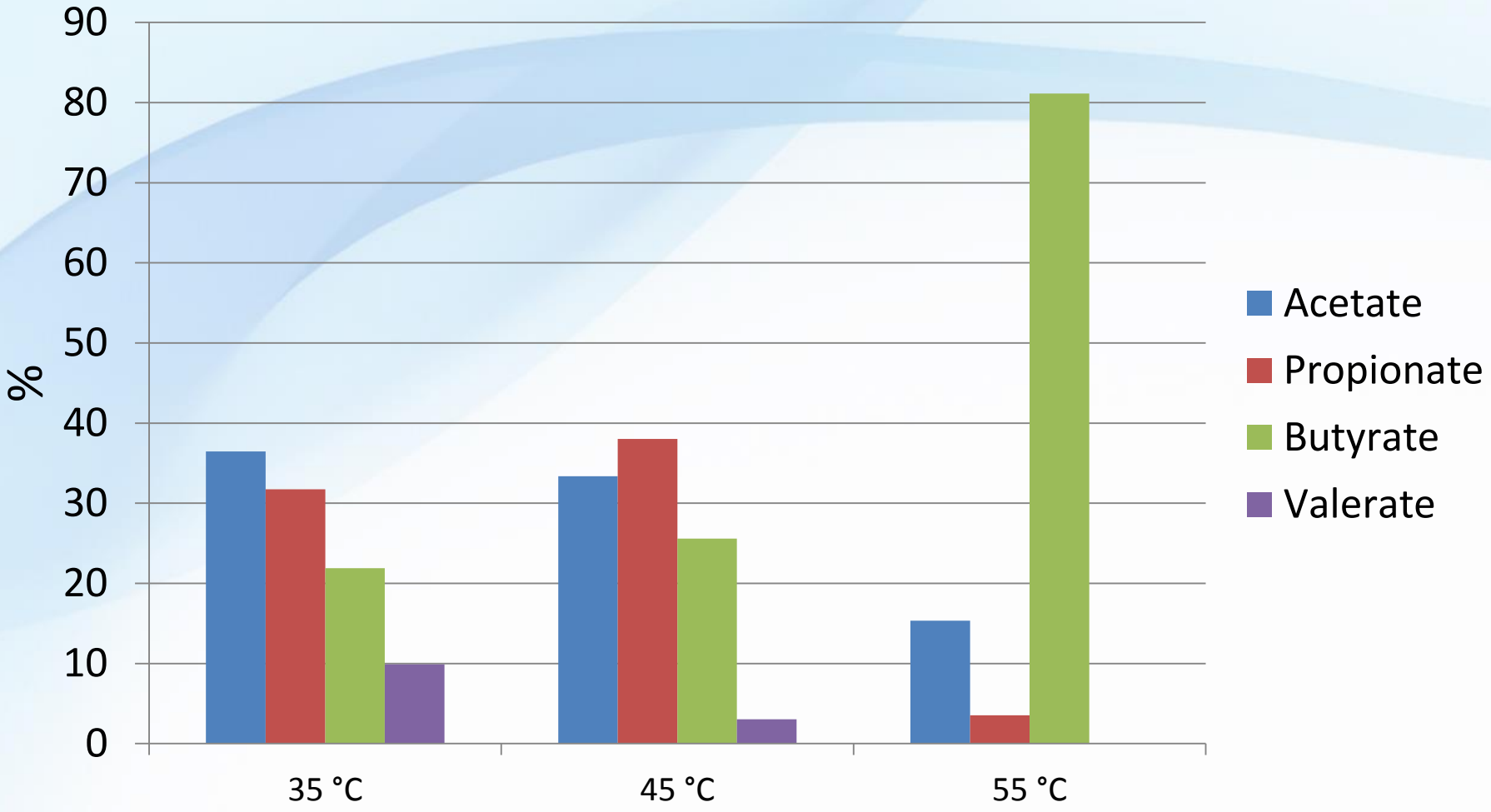


Fig. 3 Main catabolic products of glucose, glycerol and xylose fermentation by open mixed culture at increasing substrate concentration in a chemostat at pH 8, dilution rate 0.12 h^{-1} and 30°C. The main other products were biomass, CO_2, H_2 and formate

Temudo, M.: Appl. Microbiol. Biotechnol. (2008)

TU Delft

-Influence of T on selectivity



Jiang et al. Bioresource Technology 2013)

-Effect of Electrochemical coupling and HRT

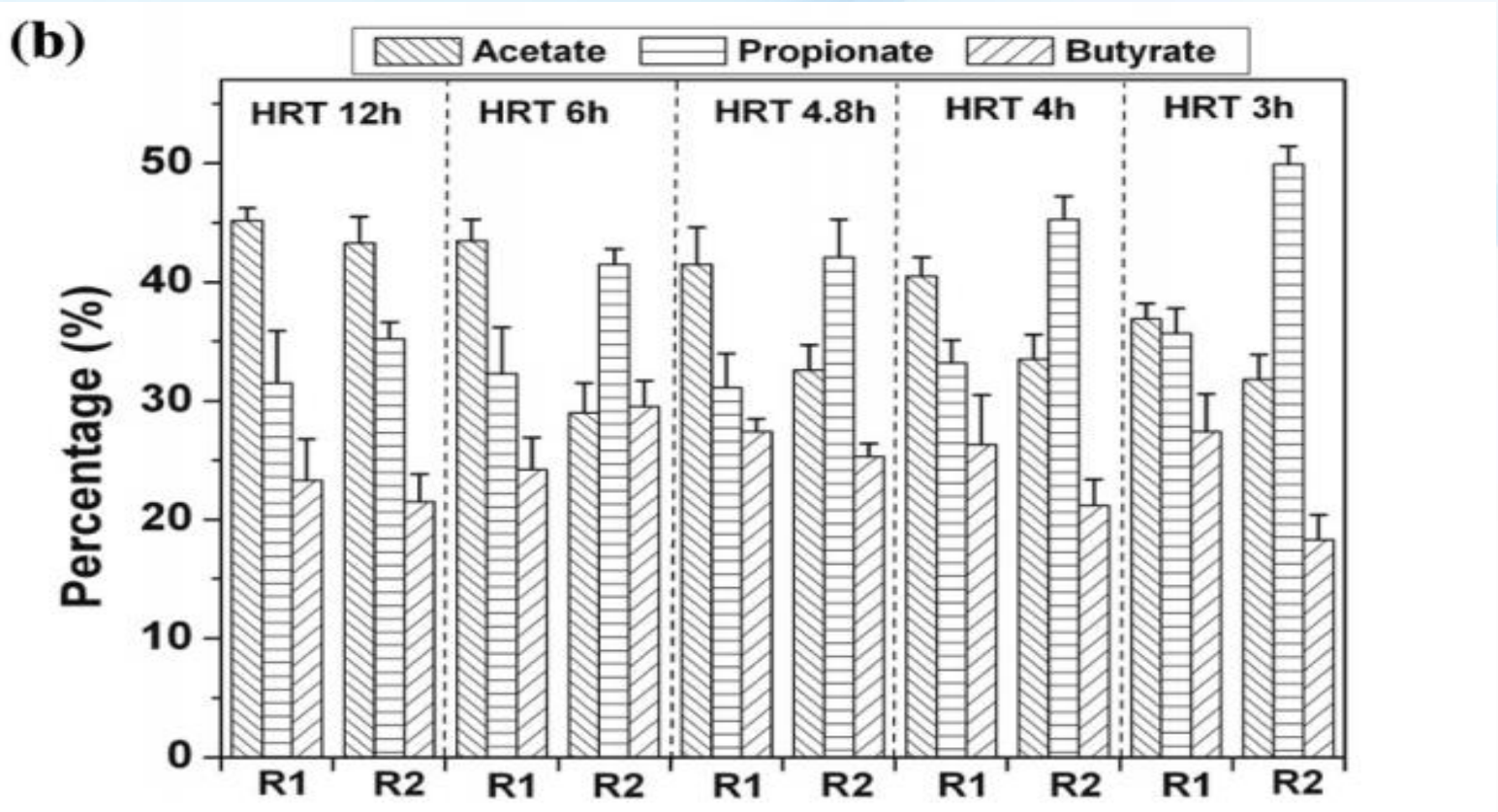
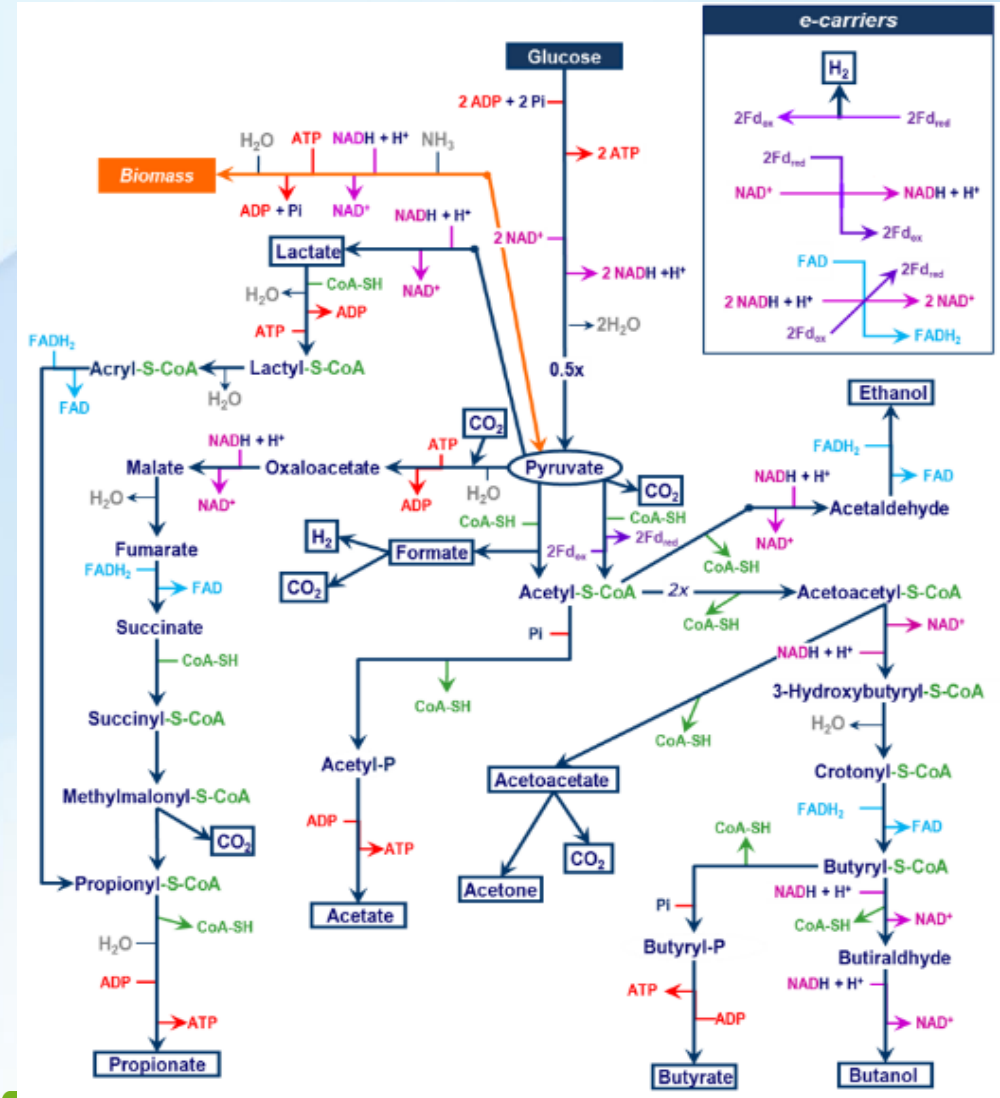


Fig. 2. TVFA yields (a) and the percentage of main VFA composition (b) in R1 and R2. R1: an acidogenic reactor with bio-electrochemical system. R2: common acidogenic reactor without bio-electrochemical system. Error bars represent standard deviation of statistical analysis. The measurement times for HRT 12, 6, 4.8, 4 and 3 h were 18, 15, 18, 12 and 21 times, respectively.

Zhang et al.: Bioresource Technology *(2015)*

DTU

-Thermodynamic-based Model for Products Yielding Prediction



Hypothesis:

The species able to harvest more energy in the imposed conditions will dominate the process.

Gonzalez-Cabaleiro et al. Plos One (2015)

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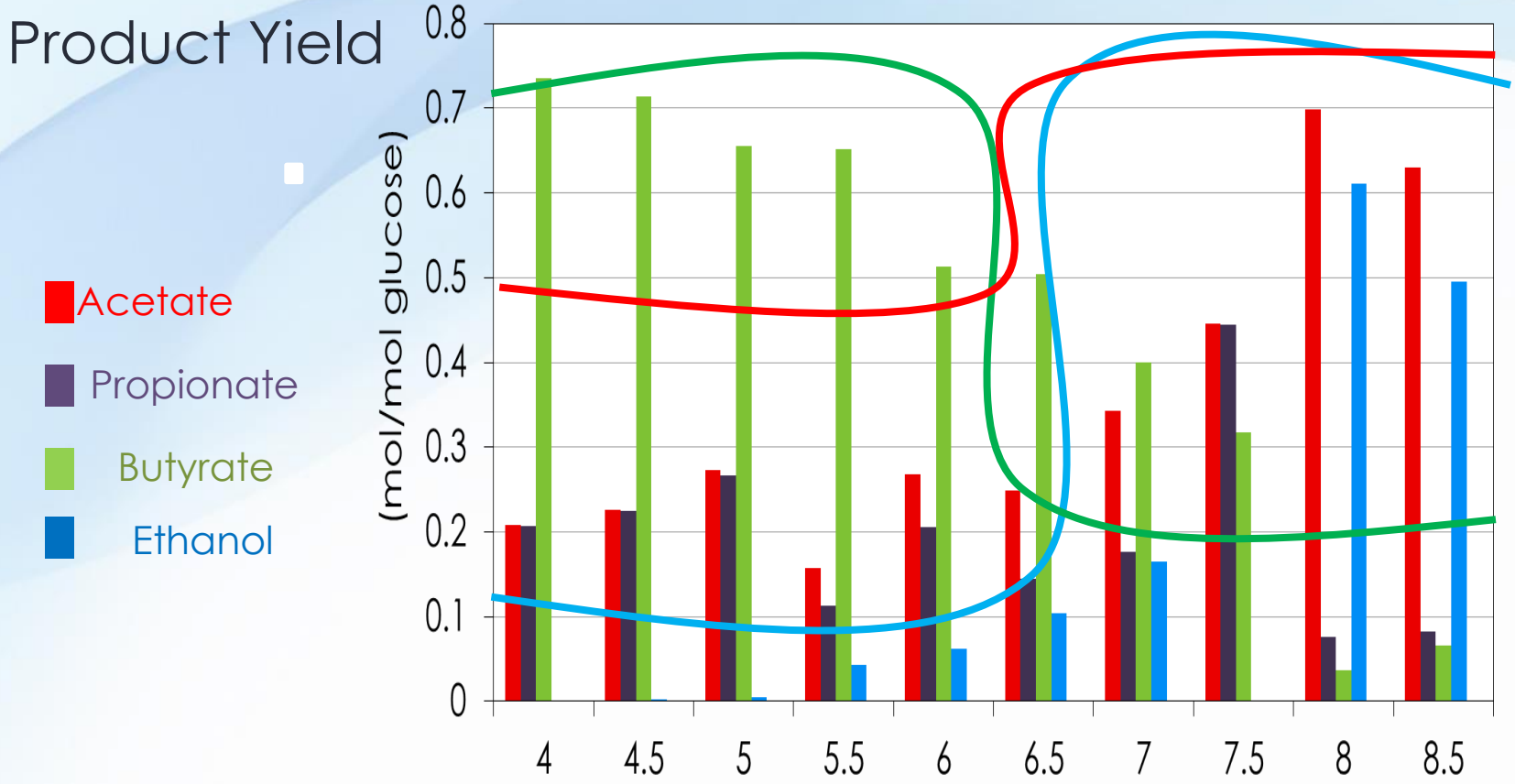
-Acidogenic Fermentation.



Gonzalez-Cabaleiro et al. Plos One (2015)

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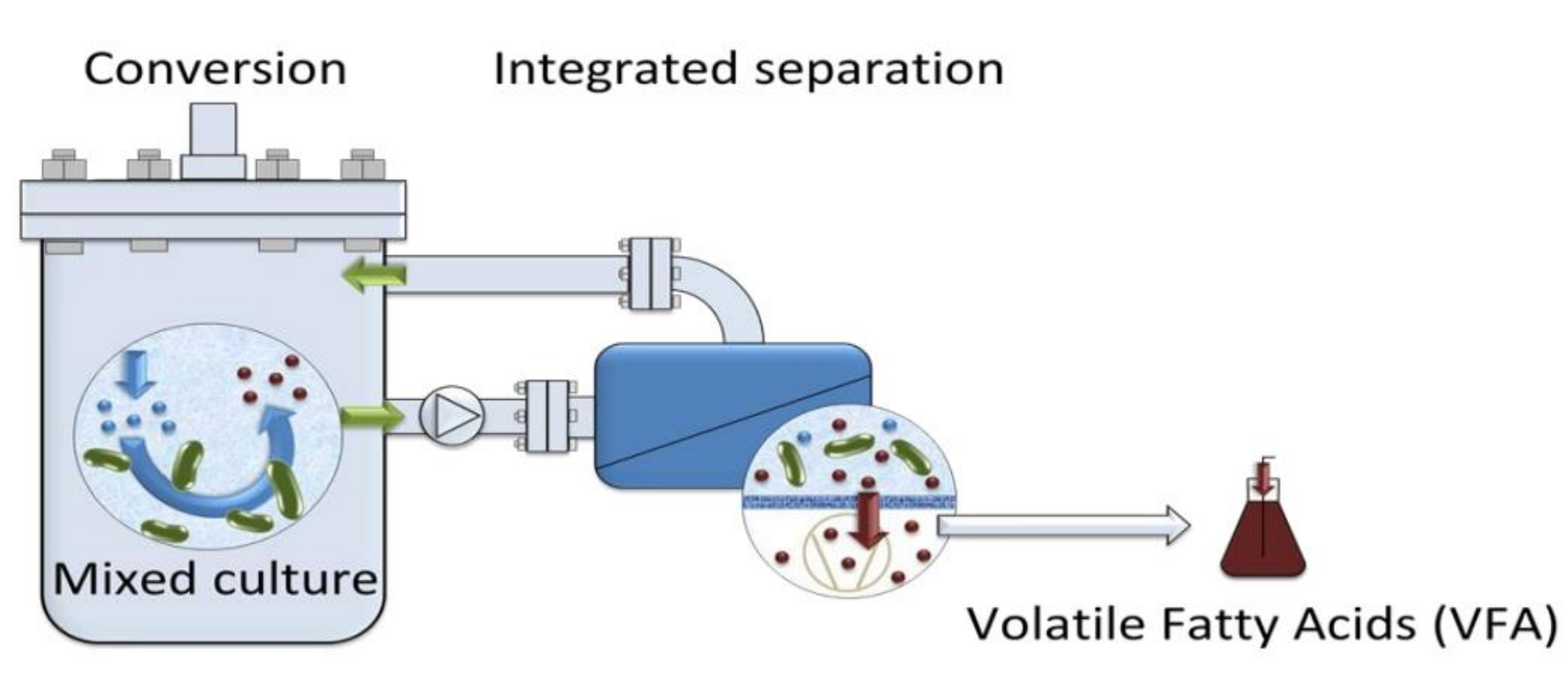
- VFA continuous removal



Ludo Diels (VITO, Belgiumi. http://www.water4crops.org

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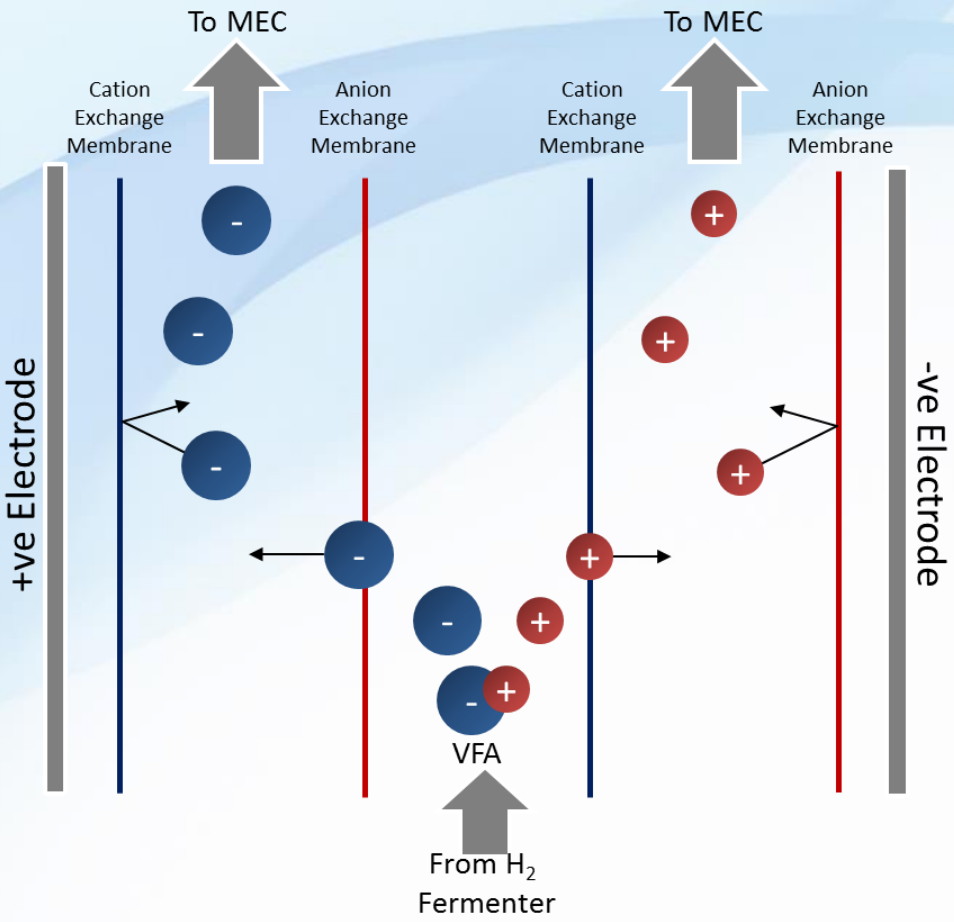
-VFA Removal Technology: Electrodialysis

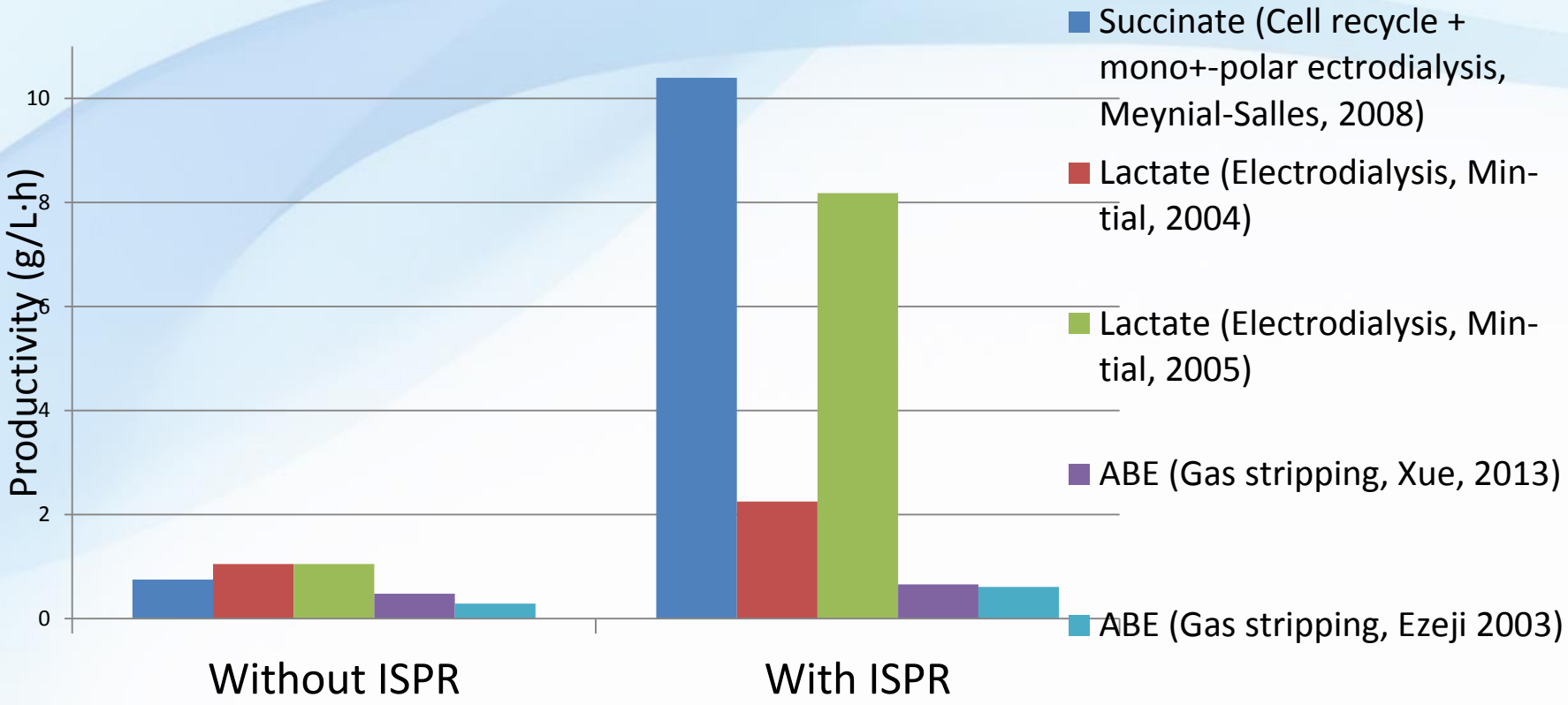


Reduced 1500 mg/l VFA (acetic, propionic, butyric & valeric) by up to 99% in 60 minutes.

Jones et a. Bioresource Technol. (2015)

University of South Wales
Prifysgol De Cymru

-In Situ Product Recovery (ISPR)



Van Hecke et al.: *Biotechnology advances 2014*

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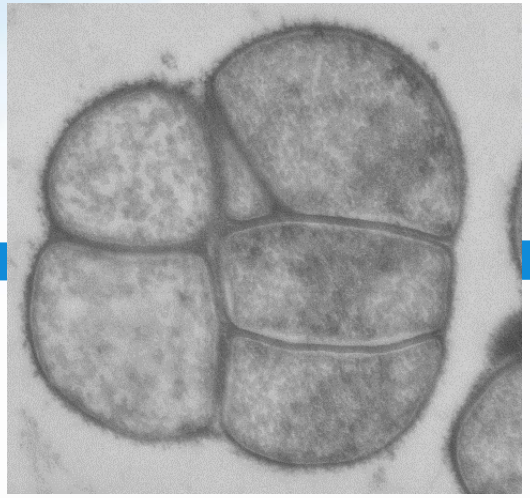
- Wastewater to Bioplastics



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Step 1. Natural Selection

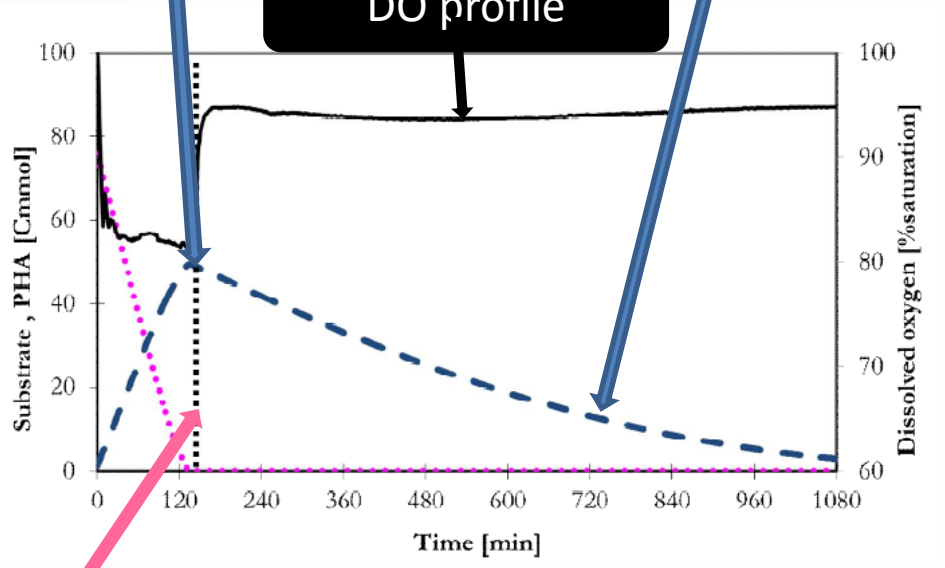
Enrichment reactor

STRATEGY: Feast-Famine regime

PHA production during the feast phase

PHA consumption during the famine phase

DO profile



Very fast substrate uptake

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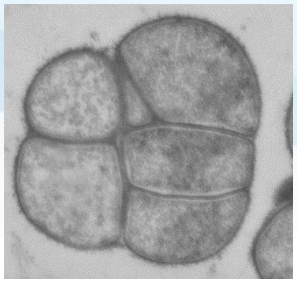
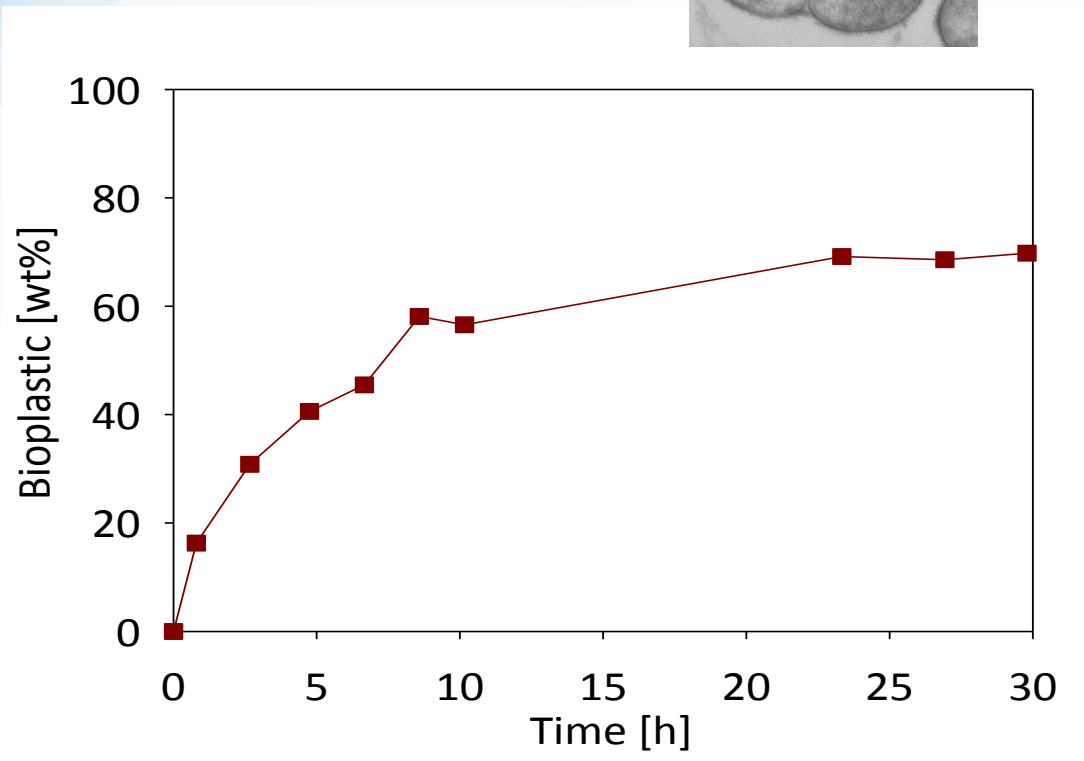
Step 2. PHA production

80 wt% Bioplastic





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-Wastewater to Bioplastics

-Pilot plant of PHA (Aquiris. Brussels)

VEOLIA
ENVIRONNEMENT

-Pilot plant at Mars chocolate. Veghel (NL)

- Production at industrial location at 1 kg/day scale
- Reactor volumen: 300 L.
- The production has to be optimized to bring down the production costs of currently about 8 euro/kilogram to 2 euro/kilogram.

PAQUES


Once upon A time

Princess Aurora

Maleficent

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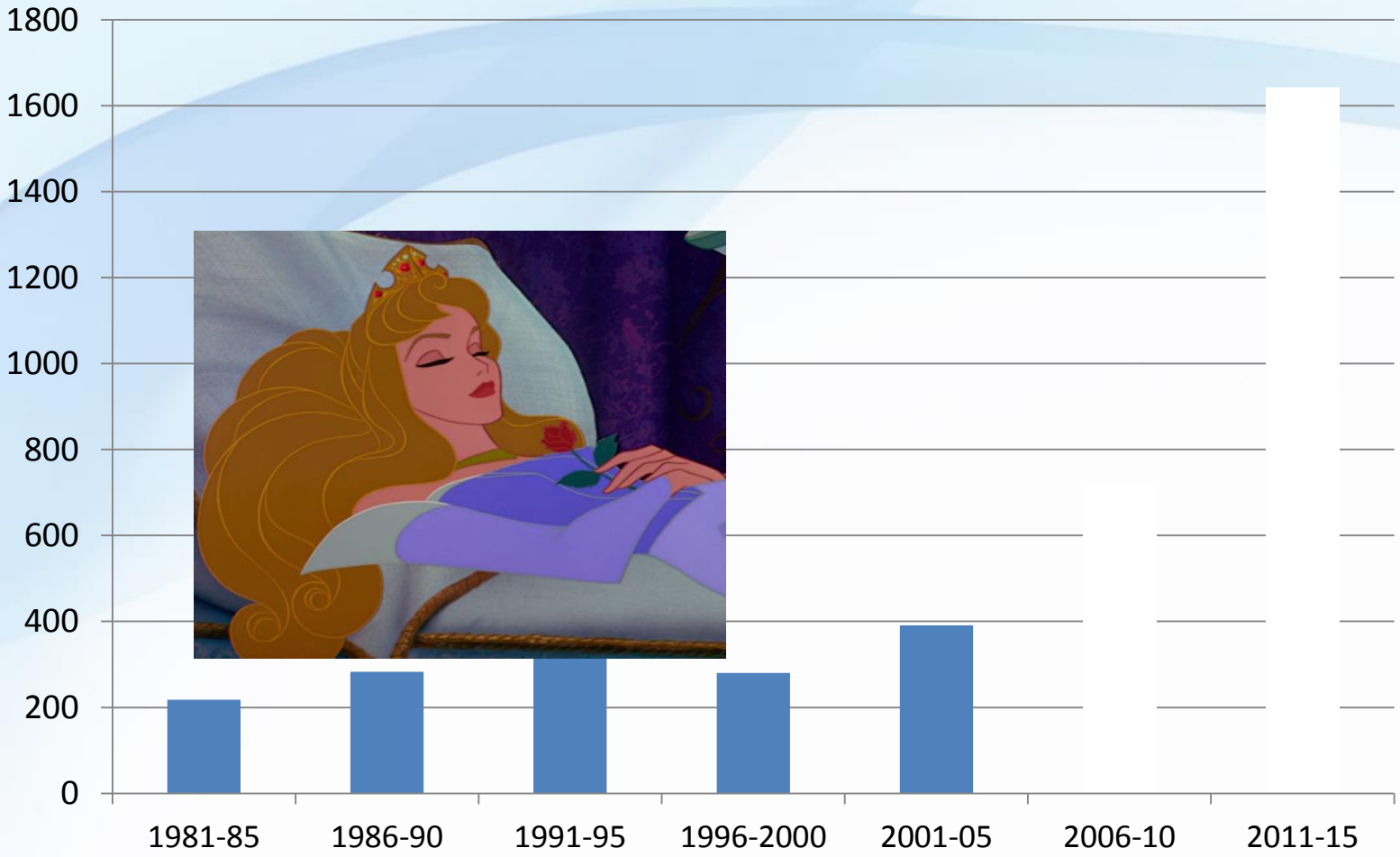
-The sleeping beauty…



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… and the Prince

1800
1600
1400
1200
1000
800
600
400
200
0

1981-85
1986-90
1991-95
1996-2000
2001-05
2006-10
2011-15

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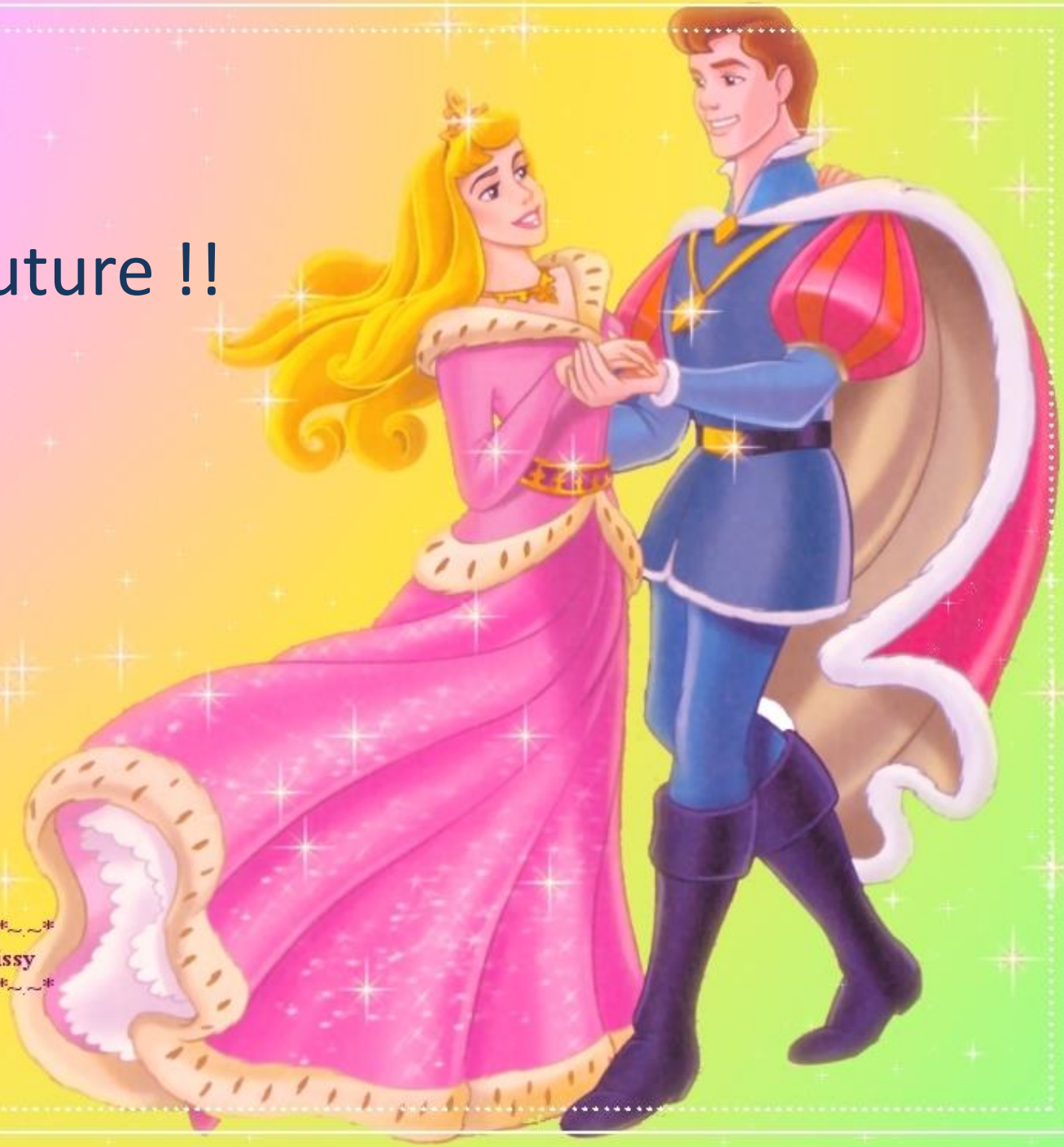
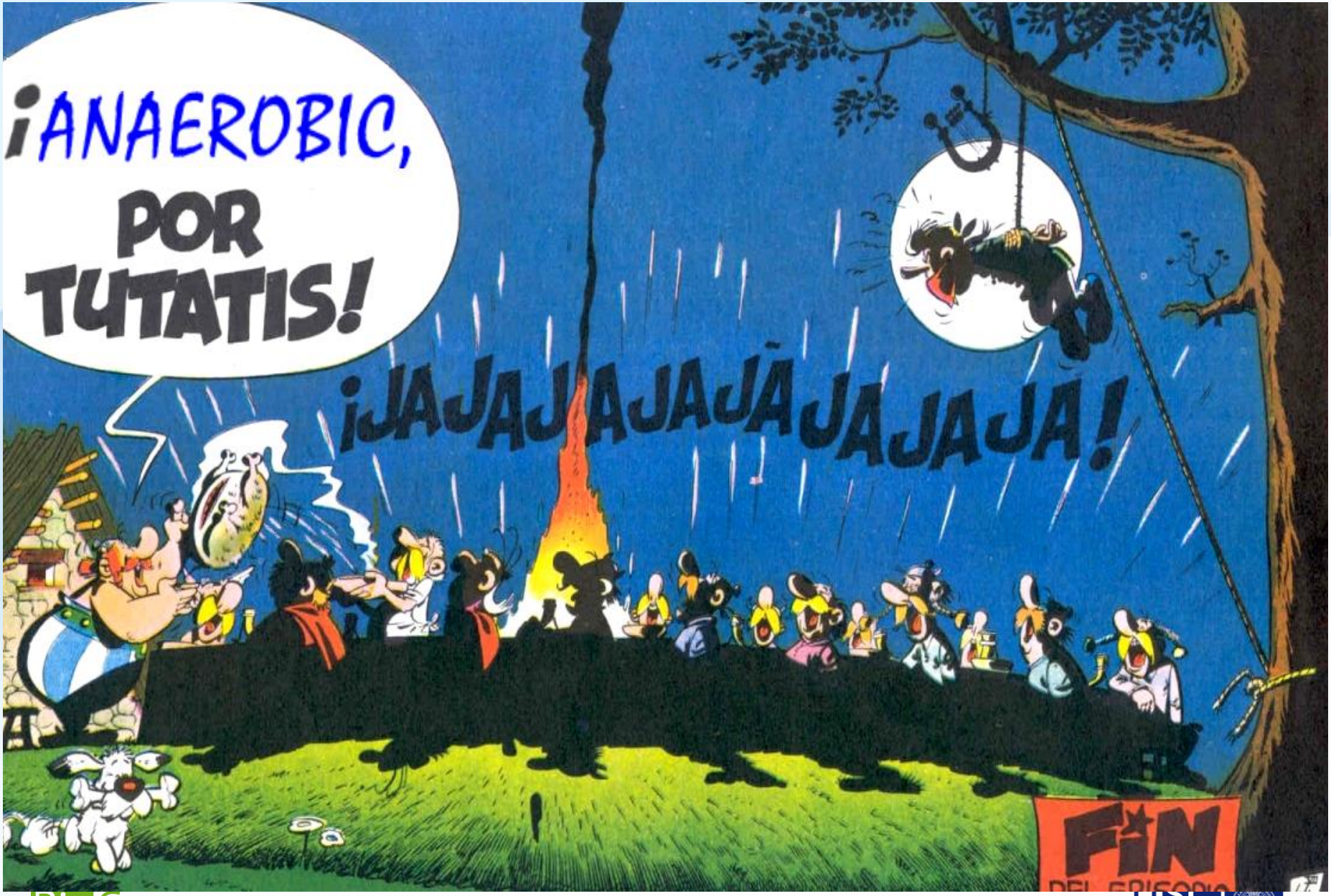
Who is the Prince?

- Sustainability
- Resource recovery
- Anammox
- .....

Brilliant future !!




¡ANAEROBIC, POR TUTATIS!
¡JAJAJAJAJAJAJAJA!
FIN

-The A(co)D team

Juan M. Lema

Marta Carballa

Jorge Rodríguez

Santiago García

Leticia Regueiro

Rebeca González

Iván Rodríguez

Chiara Pedizzi

Lorena González

Alberte Regueira

Antón Taboada

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-The (bio) Group USC

Great Opportunities for Anaerobic Digestion

Juan M. Lema

Department of Chemical Engineering

University of Santiago de Compostela, Spain

BioGroup

Castelló, 7 de julio de 2016

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA