Bioreactors for a sustainable management of gaseous emissions in waste and wastewater treatment plants

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Challenges in gaseous emissions from waste and WWTPs

- Volatile Organic compounds: VOCs
  - Ketones, aldehydes, acids, etc.
- Volatile Inorganic Compounds (VICs)
  - Sulphur: SO_2, SO_3, H_2SO_4, H_2S, R-SH
  - Nitrogen: NO_x, NH_3, R-NH_2
- Odours
  - H2S, mercaptanes, VFAs, etc.
- Biological micropollutants
  - Endotoxins
- Non CO_2 – Greenhouse Gases (GHGs)
  - CH_4, N_2O

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Odours

- Odorants
  - Chemicals that stimulate the olfactory sense
- Characterisation
  - Threshold, intensity, character, and hedonic tone.
  - Threshold: minimum concentration of odorant stimulus necessary for perception
- Types of odorants
  - Wide range of VOCs and VICs
  - Complex mixtures at trace level conc. (ppm, ppb)
- Sources
  - Industry, agriculture, food production, waste management, etc.
- Complaints and Policies
  - 13-20% people affected in EU
  - New regulations are being implemented in many countries

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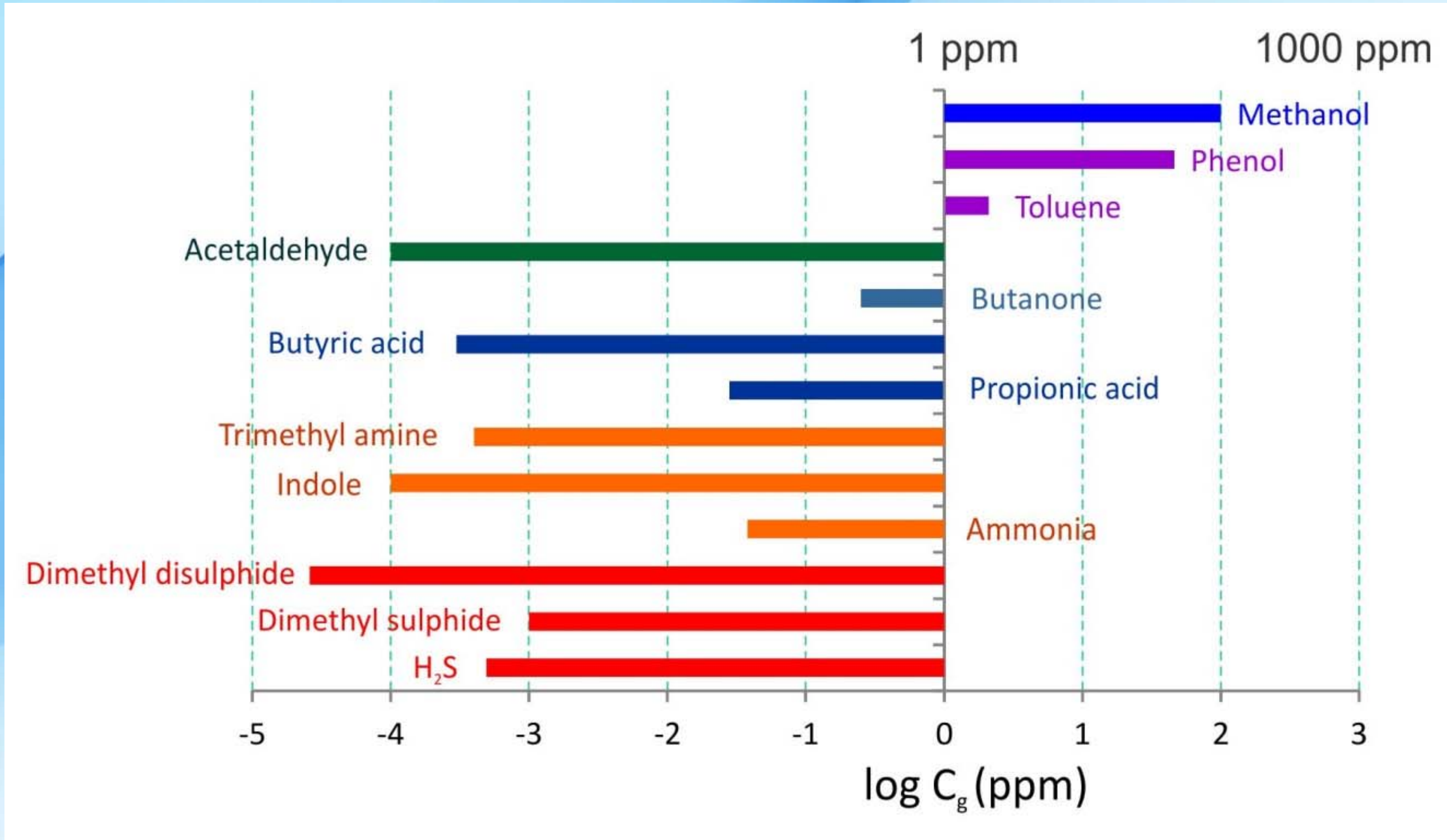
Odor Threshold values



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Odour compounds emitted by environmental plants

(Belgiorno et al., 2013)

	WWTPs	Landfills	Composting	SW Incinerators
Sulphur compounds	H_2S Mercaptans	H_2S Mercaptans	H_2S Mercaptans	H_2S Mercaptans
Nitrogen compounds	NH_3 Amines Indole	NH_3 Amines	NH_3 Amines Cadaverine Putrescine	NH_3
VFAs Aldehydes Ketones	VFAs Aldehydes Ketones	VFAs Aldehydes Ketones	VFAs Aldehydes	VFAs Acetone
Alcohols		Alcohols	Ethanol	
Aromatic HCs		Ar-HCs		Toluene

Odor measurement

UNE-EN 13725
Reference gas: n-butanol

1 OU_E = 123 μg n-BuOH/m^3

Case study: Full scale bioreactors treating 1200 m3/h waste gases from anaerobic WWTP in a brewery

(van Groenestijn et al., 2005)

		Inlet	Outlet	Removal	
H_2S	ppm	**800**	1,7	99,8%	
Other S-comp	ppb	**2780**	399	85,6%	
Odor	OU_E/h	**7000**	200	97,1%	*start-up*
		5000	30	99,4%	*Half year later*

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Non-CO_2 Greenhouse Gases (GHGs)

- GHGs: Methane
  - CH_4 has 25 times more impact on global warming than CO_2
  - Wastewater treatment: 2.5% US emissions (2012)
  - Dumps, WWTPs and other wastes: up to 31% of CH_4 emissions (Spain, 2007)

- GHGs: Nitrous oxide
  - N_2O has 310 times more impact on global warming than CO_2
  - Wastewater treatment: 1.6% US emissions (2012)
  - Around 0.4% of the oxidized NH_3 during nitrification and 0.2% of reduced nitrate during denitrification is emitted as N_2O

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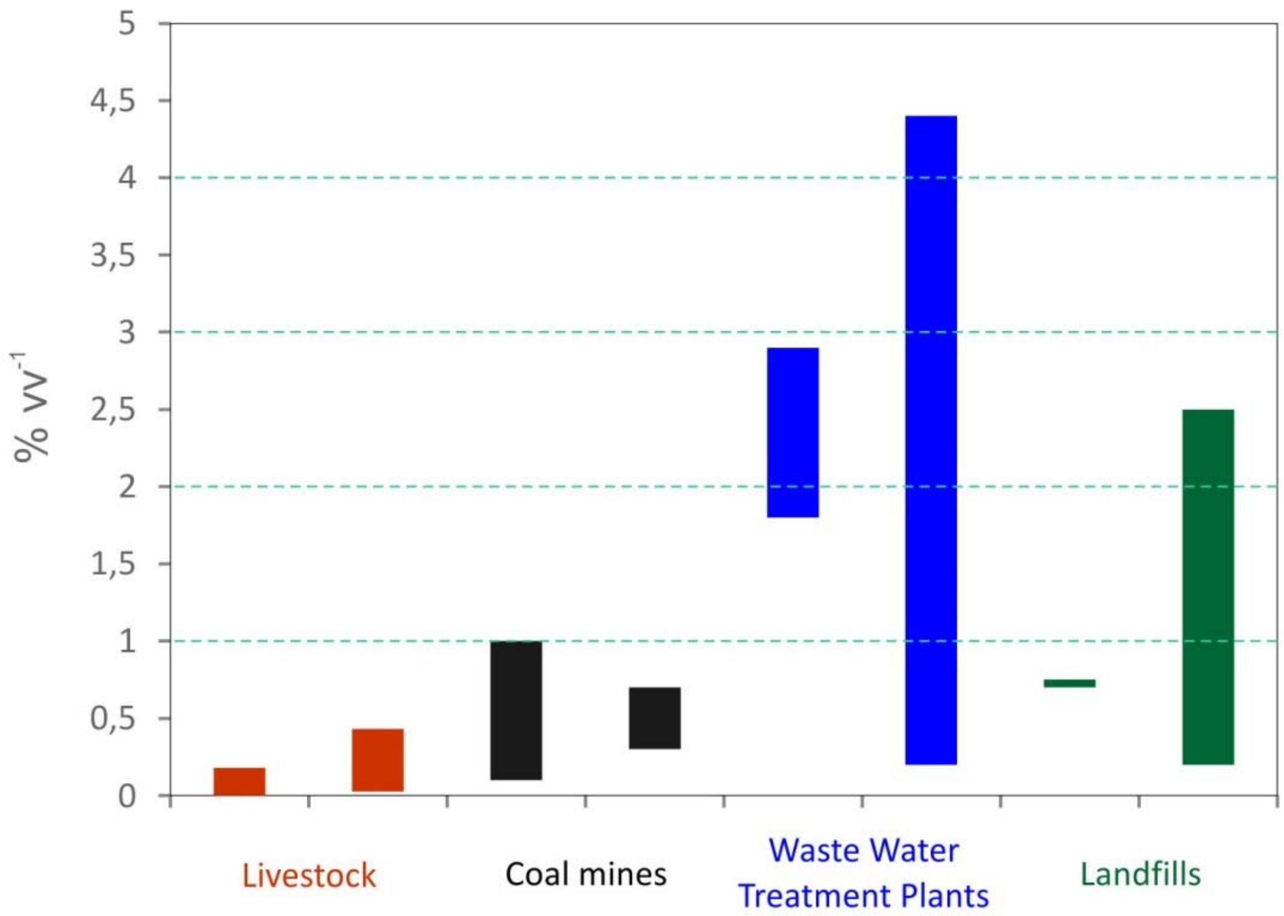
Range of methane diffuse concentrations found in different processes



Yasuda et al. (2009)
Girard et al. (2011)
Su et al (2008)
Carothers & Deo (2000)
Souza et al (2011)
Hartley & Lant (2006)
Nikiema et al (2004)
Streese & Stegmann (2003)

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GHG Emissions in WWTPs

Mt CO_2 eq	1990	2000	2005	2010	2020
Landfill CH_4 (average a & b)	550	590	635	700	910
Wastewater CH_4 [a]	450	520	590	630	670
Wastewater N_2O[a]	80	90	100	100	100
Incinerator CO_2[b]	40	50	50	60	60
Total	1120	1250	1345	1460	1660

[a] Based on reported emissions from national inventories and national communications, and (for non-reporting countries) on 1996 inventory guidelines and extrapolations (US EPA, 2006).

[b] Based on 2006 inventory guidelines and BAU projection (Monni et al., 2006).

Total includes landfill CH_4 (average), wastewater CH_4, wastewater N_2O and incineration CO_2.

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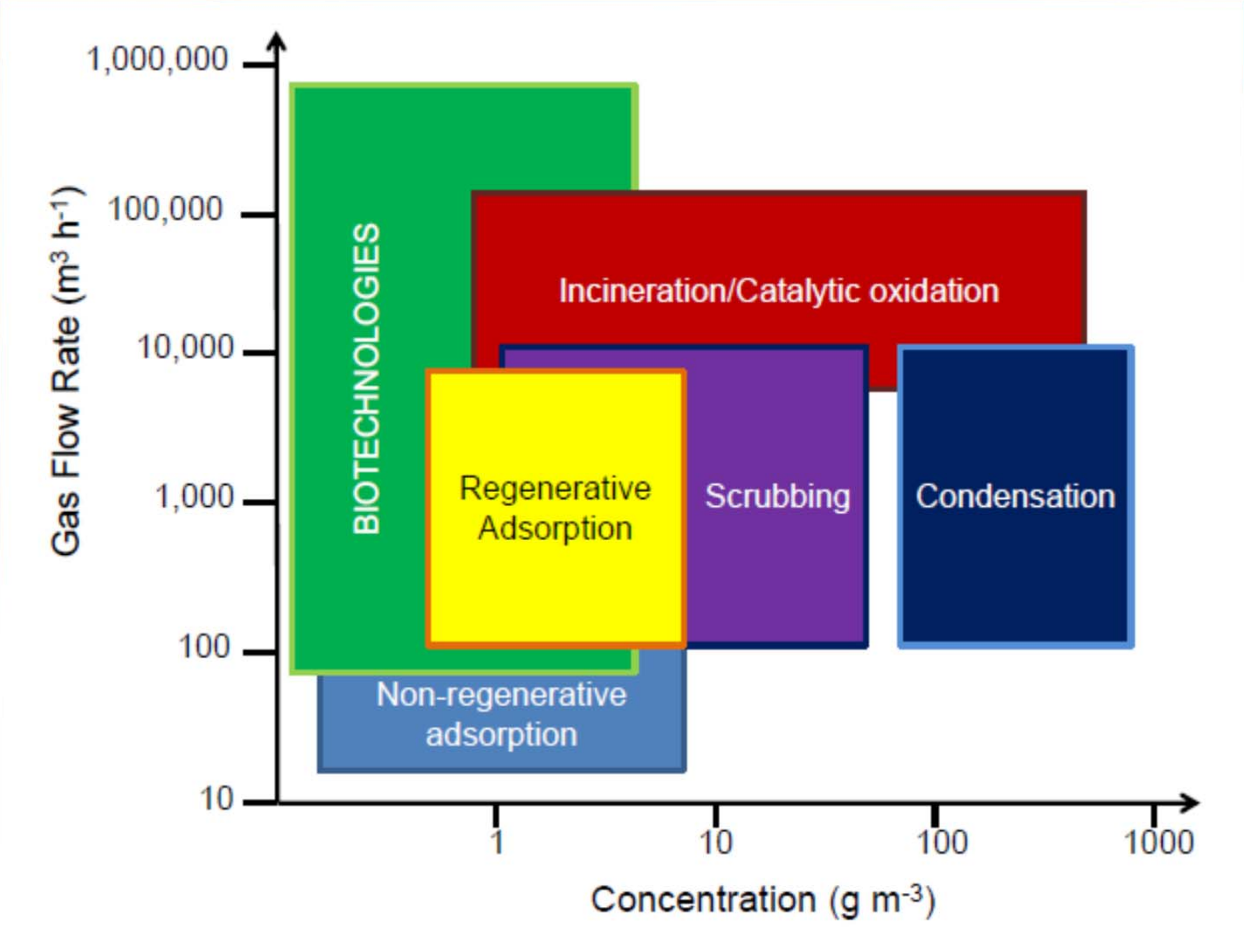
Biological treatment technologies

Gaseous effluents treatment technologies



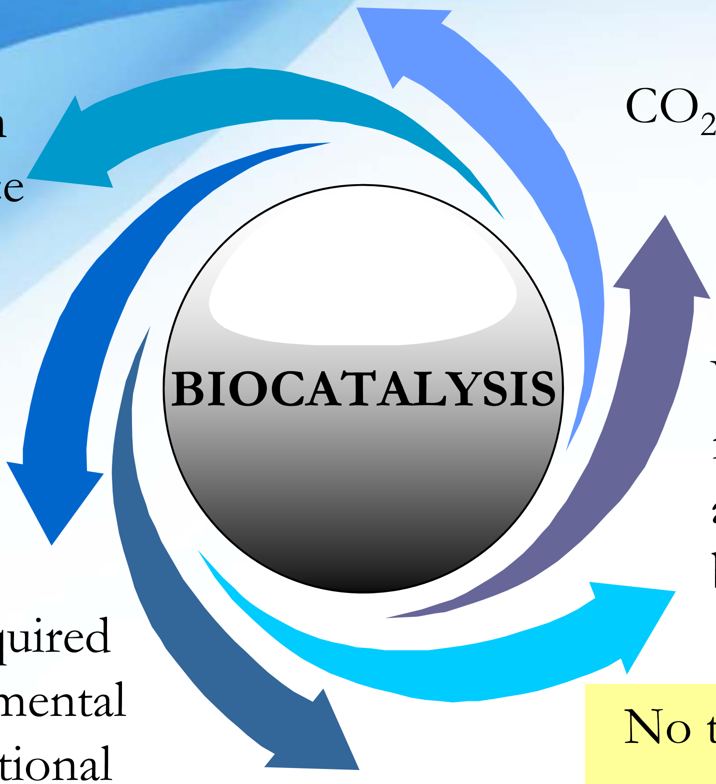
Biological treatment

$$COV + O_2 + \text{Nutrients (N,P,S, trace elements)} \xrightarrow{\text{Microorganisms}} CO_2 + H_2O + \text{Microorganisms} + \text{Energy}$$

VOCs as carbon and energy source

CO_2 footprint is much lower than incineration

No fuel is required



Ambient T and P conditions

VOCs are transferred from gas phase to aqueous phase prior to biodegradation

Less energy is required (thus less environmental impact and operational costs)

No toxic byproducts are used/generated

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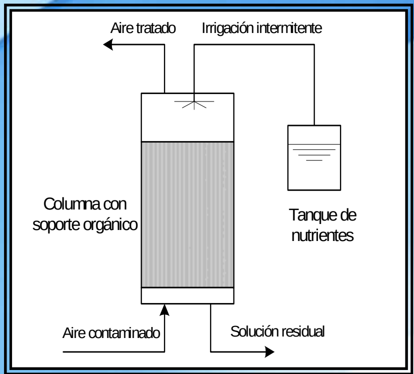
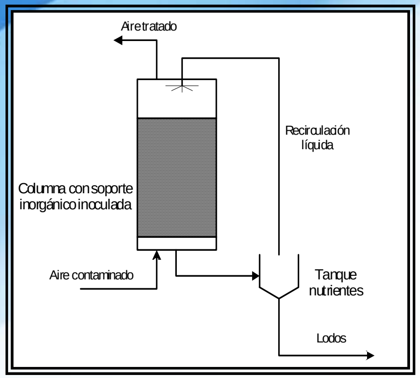
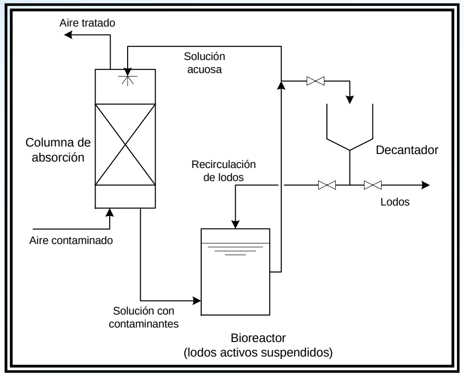
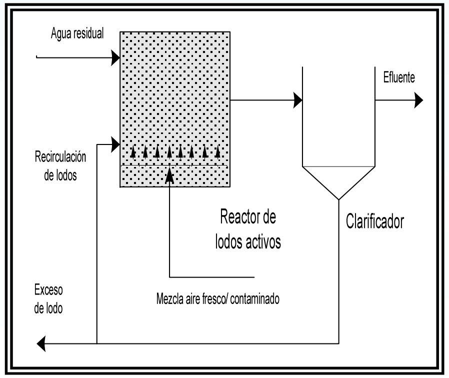
Biotechnologies

Biofilter (BF)	Biotrickling filter (BTF)	BioScrubber (BS)	Activated Sludge Diffusion (ASD)









Stationary aqueous phase	Mobile aqueous phase	Mobile aqueous phase	Stationary aqueous phase

Biomass in biofilm | **Suspended biomass**

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20 s - 2 min
H_2S > 90 %
COVs > 90 %

1-10 s
H_2S > 90%
COVs < 40 %

H_2S > 99%
Odor > 99 %

Advantages		
Easy start-up and operation	Easy control of the operation parameters	Easy control of the operation parameters
Low operation costs	Low EBRT	Existing biological reactor
Disadvantages		
Poor control of operating parameters	Lower transfer area	Possible corrosion
High footprint (medium EBRT)	Lower efficiency for hydrophobic compounds	Sludge bulking / Lack of knowledge on VOCs removal
Costs		
Inv: 5 – 68	5 - 20	0
Op: 2 – 8	2 - 8	2 - 8

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> 7500 biofilters in Europe and half aprox. are located in **WWTP and composting plants**

Van Groenestijn and Kraakman, 2005

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Iranpour et al., 2005

BF

Case studies

	EBRT	Removal of VOCs			Removal of S and N		
	EBRT (s)	Pollutant	Concentration (mg/m3)	RE (%)	Pollutant	Concentration (mg/m3)	RE (%)
Sewage treatment plants:	14 - 69	**Benzene**	0,002-0,003	0	**H2S**	10-50	>99
		Xylenes	0,18-0,66	0-23	**Carbon disulfide**	0,02-0,03	32-36
		Toluene	0,077-0,23	0-17	**MM**	0,3-0,33	91-94
		Dichlorobenze	0,024-0,049	0-6	**DMS**	0,02-0,03	0-21
		Chloroform	0,25-0,40	0	**Carbonyl sulfide**	0,05-0,13	30-35
		PCE	0,35-0,97	0	**Odor (D/T)**	35000-46360	> 99
		PCE	0,35-0,97	0			
	18 - 54	**MTBE**	1,8	20	**H2S**	0,01 - 42	>99
		Acetone	1,6	80			
		Toluene	2,3	60			
		Xylenes	1,3	40			
		DCM	3,5	30			
		Chloroform	0,3	15			
	45 - 180	**Benzene**	3	83-93	**H2S**	13,9	>99
		Toluene	4	88-97	**Odor**	1,20E+06	> 99
		Xylene	0,4-1,1	88-93			
	45	**α-pinene**	675 ppb	100	**H2S**	7-120	100
		β-pinene	345 ppb	100	**DMS**	0,02	100
		limonene	70 ppb	97	**DMDS**	0,16	100
					CS2	0,01	100
					Odor (D/T)	214	94
	36	**Benzene**	0,03	59	**H2S**	0-2	>99
		Xylenes	3,5	92			
		Toluene	0,7	85			
		MTBE	0,09	60			
		Chloroform	0,01	3			
		DCM	1,2	11			

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BF Case studies: VOCs, VICs and odours *(cont.)*

Iranpour et al., 2005

	Removal of VOCs				Removal of S and N		
	EBRT	Pollutant	Concentration	RE	Pollutant	Concentration	RE
	s		mg/m3	%		mg/m3	%
Compost:	55-95				**DMS**	0,08	55
					DMDS	1,1	83
					MM	0,034	>90
					NH3	34-106	98-99
					Odor (D/T)	500-970	> 80
	90	THC (methane)	31	15	**DMS**	0,38	25-36
					DMDS	0,56	19-28
					MM	0,1	20-49
					NH3		59-79
					Odor (D/T)	394	64
Livestock *cow dairy*	5				**H2S**	0,01-0,27	75-100
					NH3	1,4-8,2	60-100
					Odor (OU/m3)	320-1450	57-95
swine facility	5				**H2S**	0,17-1,1	74-98
					NH3	0,36-8,2	0-75
					Odor (OU/m3)	199-862	50-86

The abatement of methane

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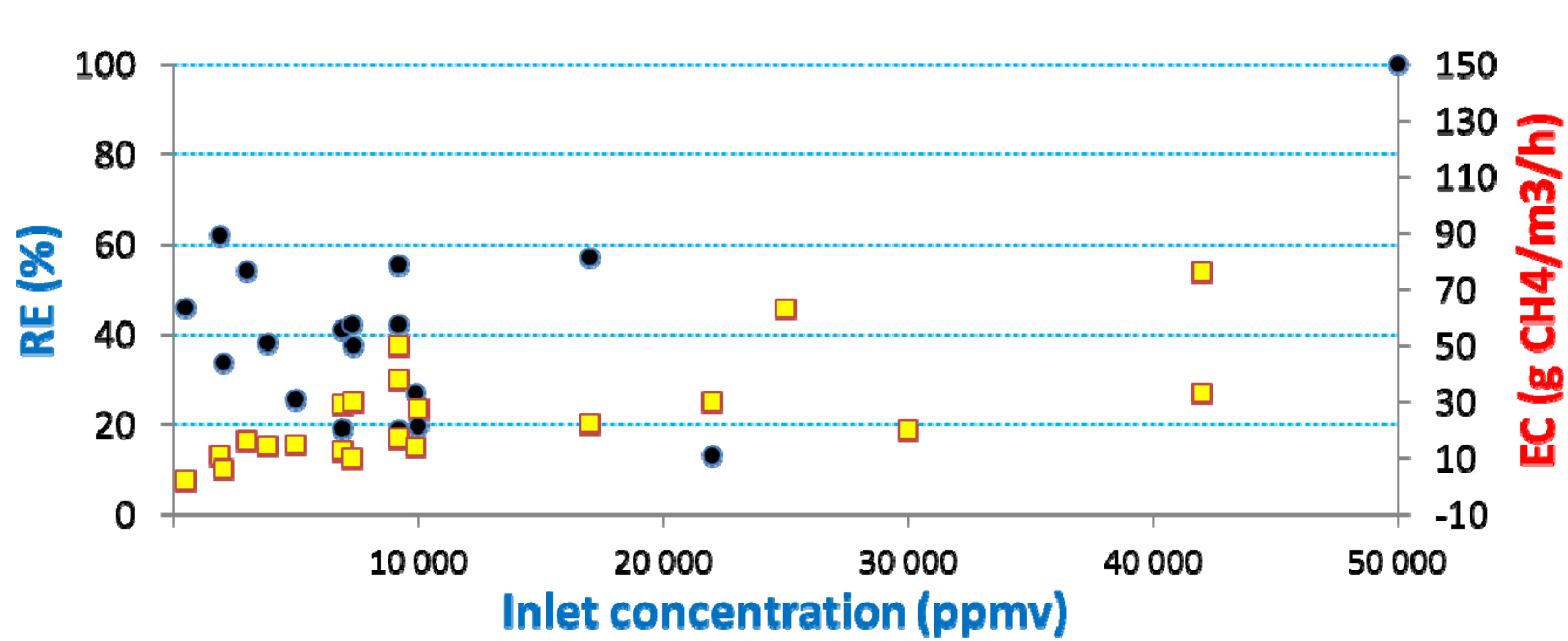
Managing CH_4 (diffuse) emissions from WWTPs

- Physico chemical abatement: Catalytic processes
  - Nano catalysts based on precious metals (Au, etc.)
- Biological abatement: Biofiltration
  - Advantages:
    microbiologically favorable process, simple systems, gained experience in last decade
  - Drawbacks/Limitations:



Environmental and economic indicators

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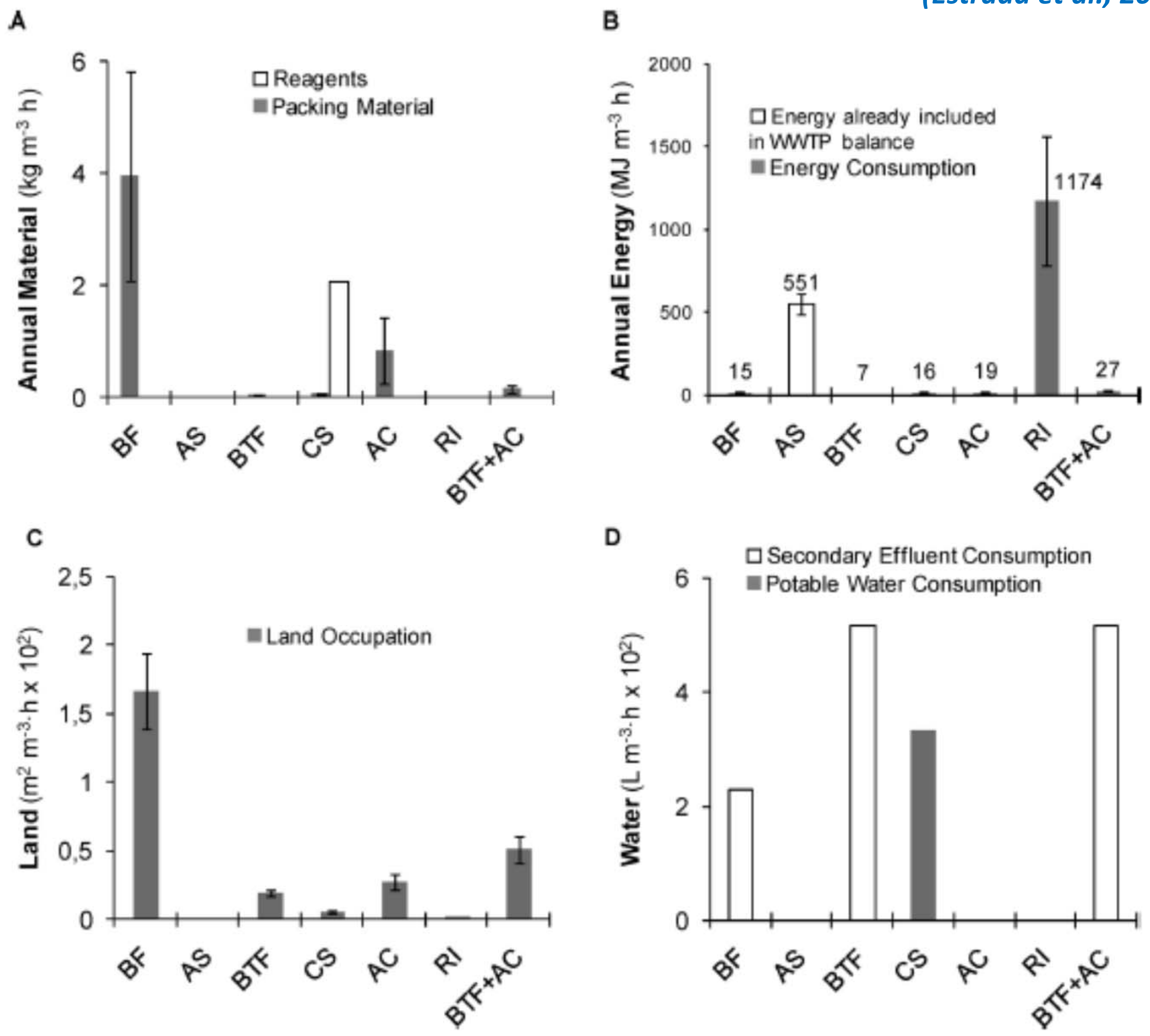
Environmental performance

(*Estrada et al., 2011*)



- Removal of odors in STPs (H_2S)
- Physico-chemical vs. biological technologies

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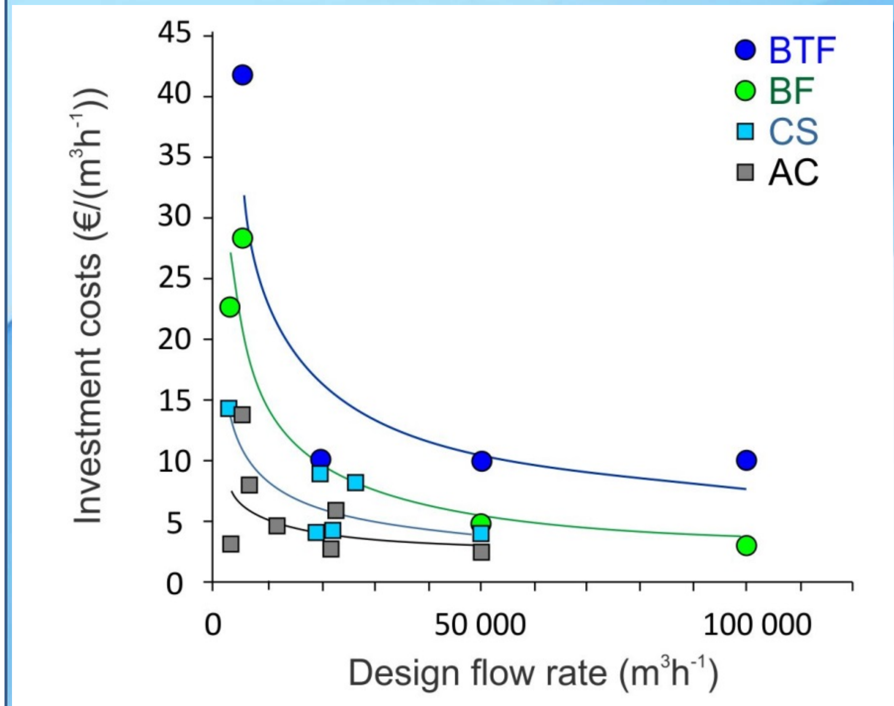
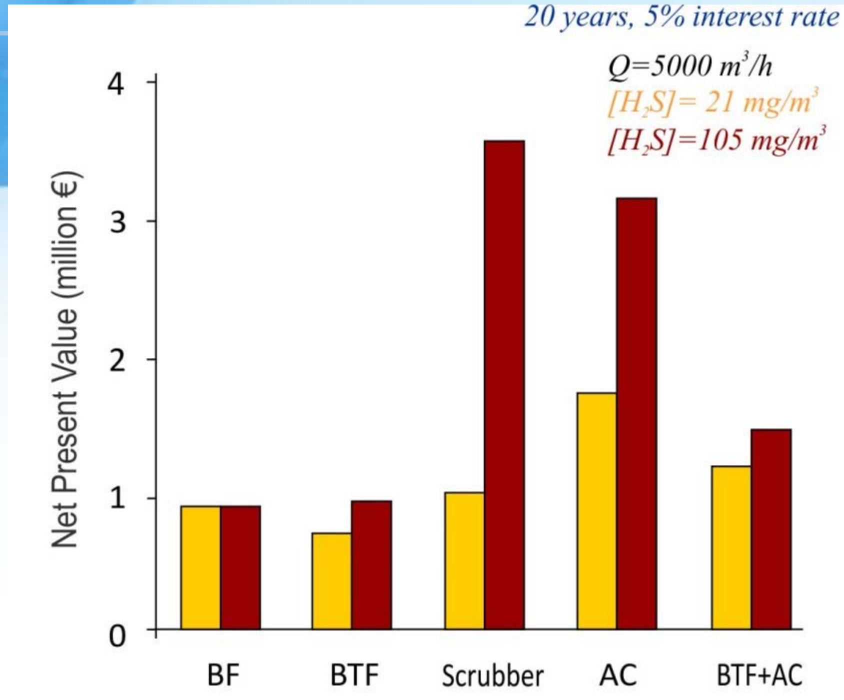
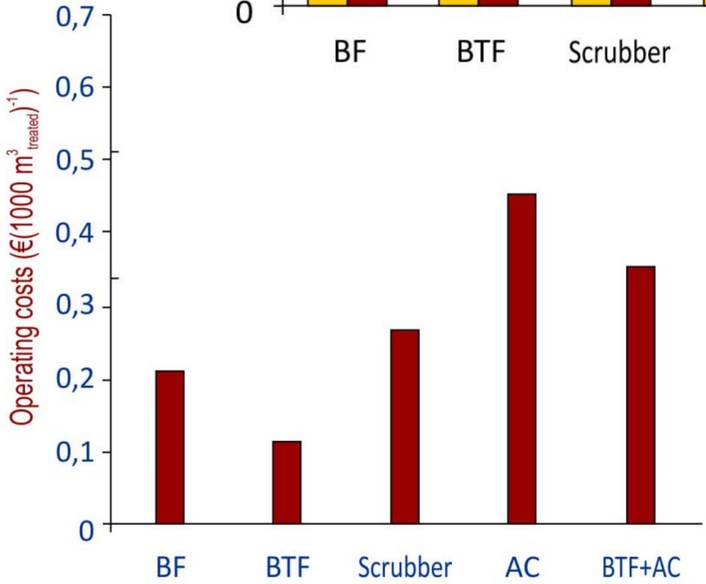
(Estrada et al., 2011)

Economic indicators







- Net Present Value the most convenient analysis
- Senstivity to pollutant concentration

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The LiveWaste approach

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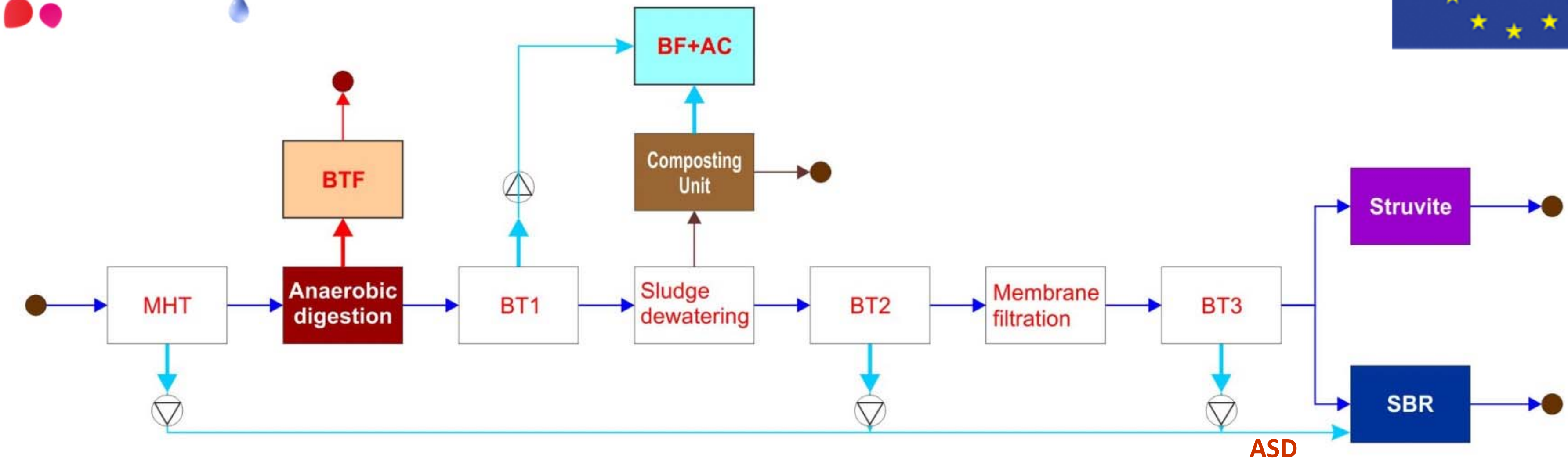
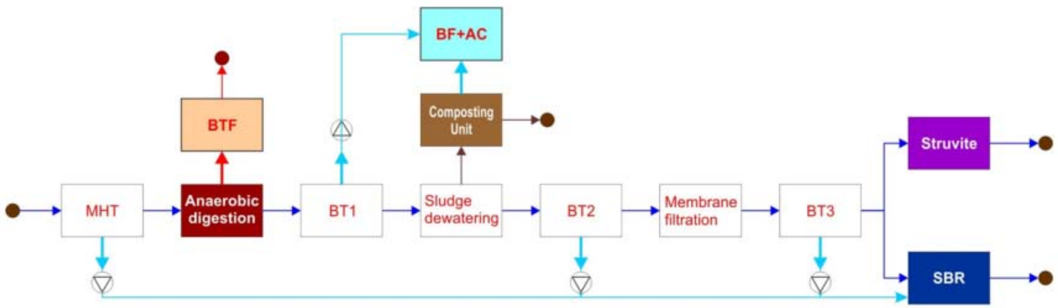
LiveWaste project strategy (LIFE+ programme)

- To develop an innovative integrated scheme for the complete treatment of livestock effluents in Cyprus
  - **optimize the post-treatment of the generated anaerobic digestate**
  - **Recovery of nutrients (struvite)**
  - **Biotechnologies for gas treatment (odours, VOCs, H2S)**



LiveWaste

- Anaerobic digestion (CUT)
  - Livestock wastes (pig, horse, cow manure, etc.)
- Biological nutrient removal via nitrite by SBR (UV)
  - Treatment of the digestate
- Struvite crystallization unit (UV)
  - Recovery of N and P
- In vessel composting reactor (NTUA)
  - Mix of wheat straw and digested material
- Gaseous streams treatment scheme (USC)
  - Odours, GHGs, VOCs and H2S



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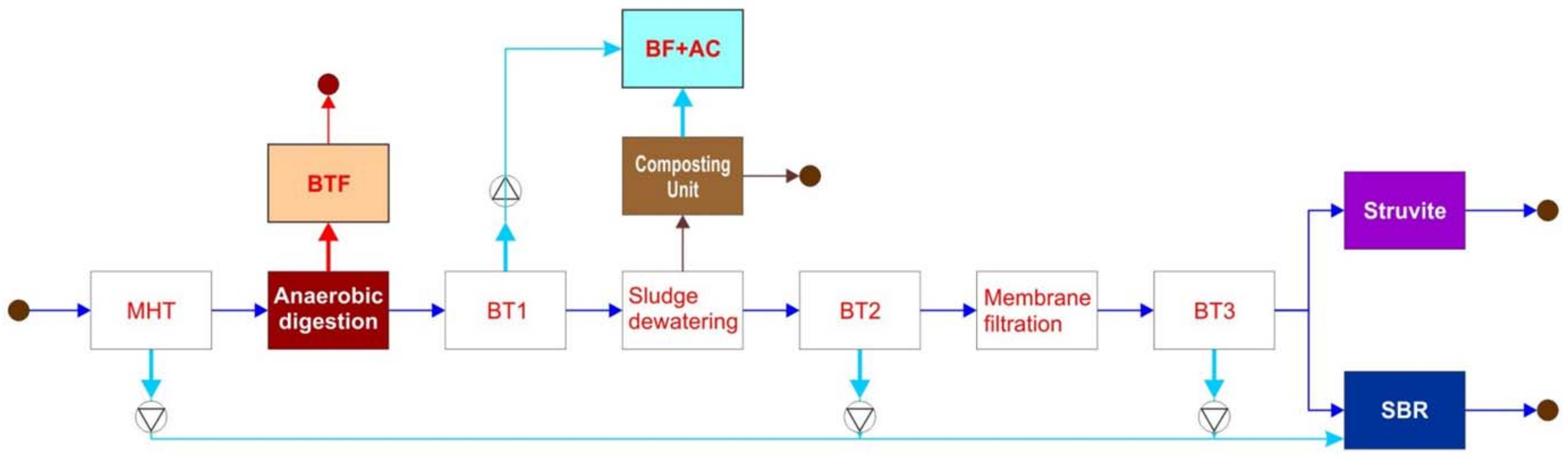
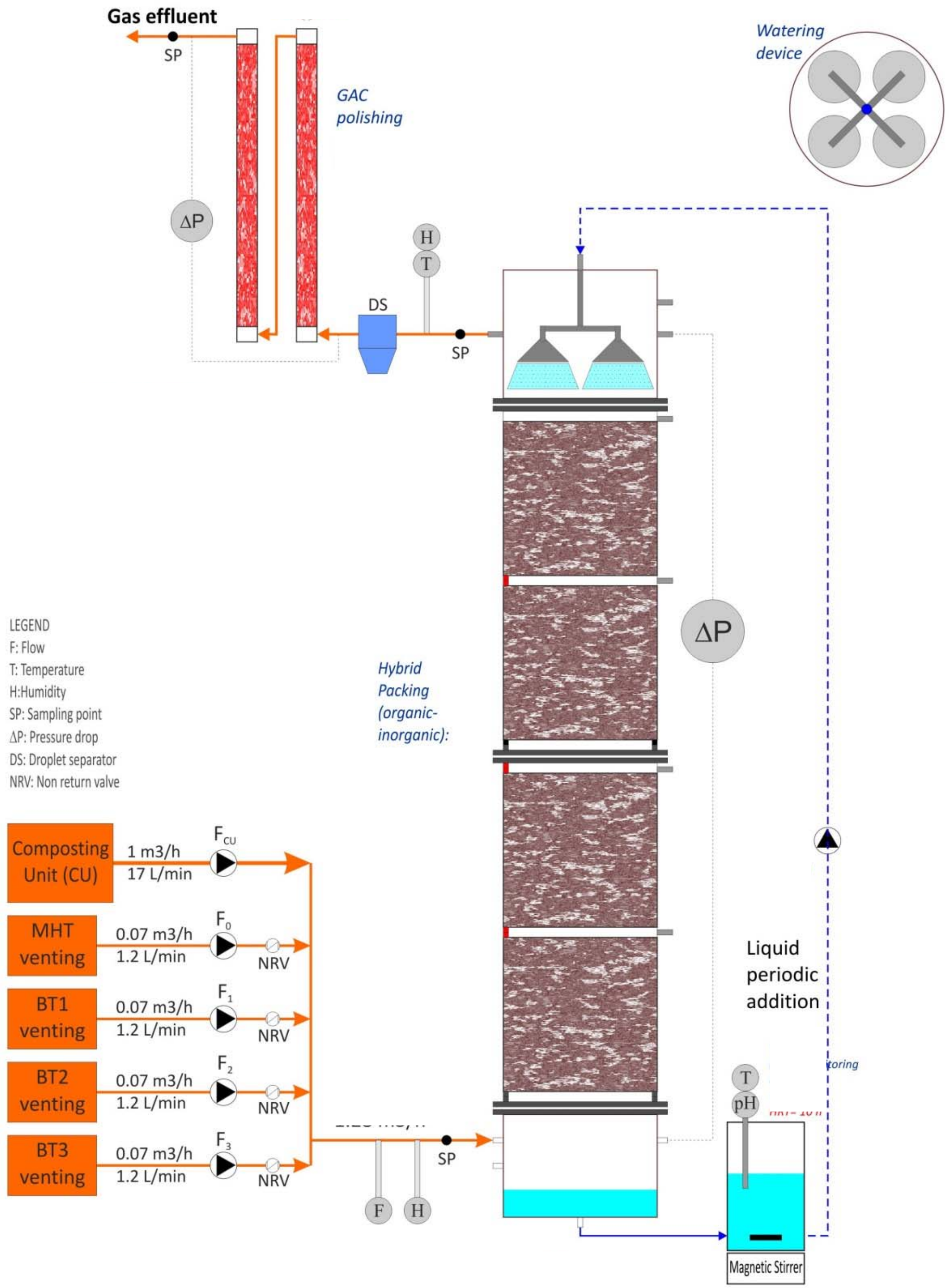
LiveWaste: gaseous treatment scheme

- Hybrid Biofiltration unit
  - Treatment of odour and GHGs from composting unit and venting tanks
- Biotrickling filtration unit
  - Treatment of the biogas for H2S removal
- ASD approach
  - Optimisation of the system by feeding various gaseous streams directly into the SBR



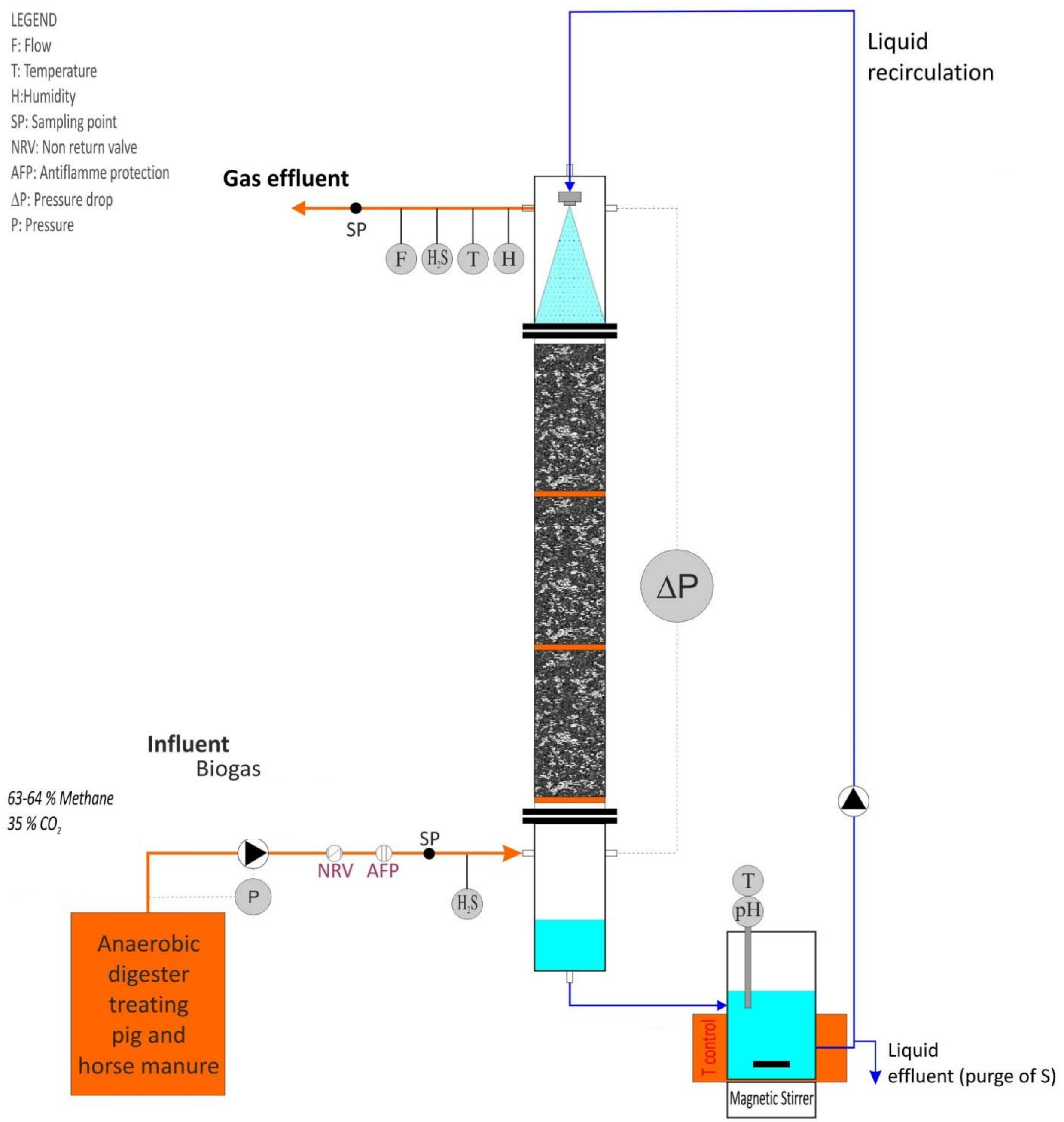
LiveWaste:
BF + GAC

- Biofiltration unit
  - Treatment of odour and GHGs from composting unit and venting tanks



LiveWaste: BTF

- Biotrickling filter unit
  - Removal of H2S



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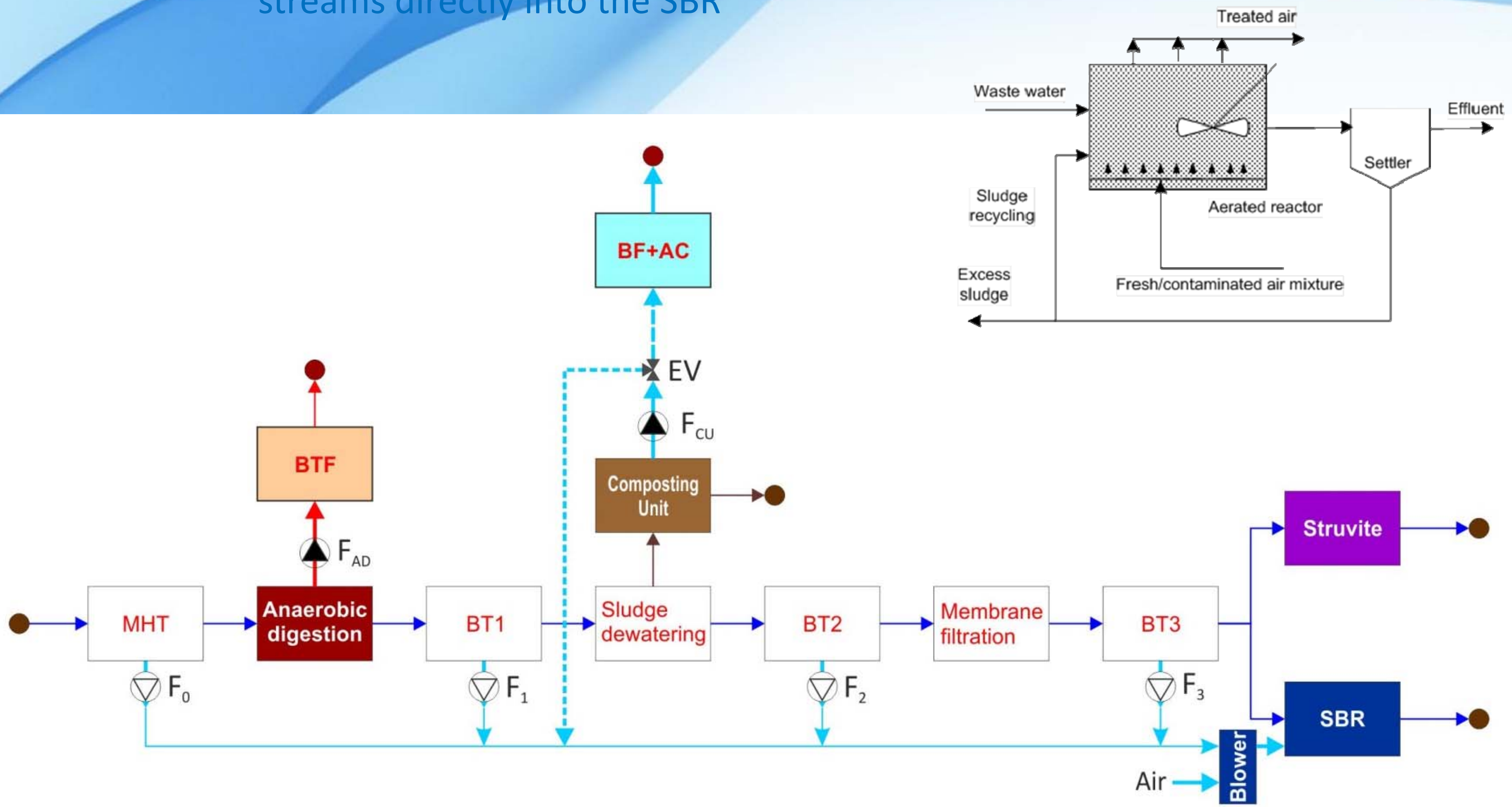
LiveWaste: gaseous treatment scheme

- ASD approach
  - Malodorous air is treated in the activated sludge tank
  - Optimisation of the system by feeding various gaseous streams directly into the SBR



LiveWaste

- Prototype construction

Conclusions and future challenges

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Conclusions and challenges

- **Biological technologies** for gaseous emissions constitute nowadays a **demonstrated alternative**, in terms of **economics and sustainability**, especially interesting for low pollutant concentrations.
- Economic analysis: these technologies imply the **lowest operating costs** being **less sensitive** to design parameters or commodity prices.
- It is necessary to **study and overcome their main limitations** (long-term operation, clogging, inocula, mass-transfer limitations, hydrophobic pollutants, etc.) and promote their applicability.
- **New technological or microbiological approaches** are being evaluated in order to improve mass transfer when treating highly hydrophobic pollutants.

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