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Purple phototrophic bacteria for nutrient recovery from domestic wastewater treatment

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Wastewater and Biosolids Treatment and Reuse:
Bridging Modeling and Experimental Studies

Otranto, Italy

Tim Hülsen, Prof. Jürg Keller, A. prof Damien Batstone

10 June 2014

Domestic wastewater Treatment

- Traditionally, WWTPs aimed to protect downstream users and to remove organics COD, SS and nutrients P and N instead to recover them.
- View changed in the last decades with the implementation of environmental protection and more stringent discharge limits.

- **The term wastewater however is out-dated!**

- Currently, industrial and domestic wastewater is no longer regarded as a waste stream that needs to be dealt with, but as a valuable resource for energy, nutrients (N and P) as well as a resource for the production of potable water.
- Waste treatment should be seen as an integral process which aims for the maximisation of resource recovery.



Nutrients

The world fertilizer consumption (2011/2012 projection) is 139 million tonnes (MT) nitrogen as N and 18 MT phosphorous.

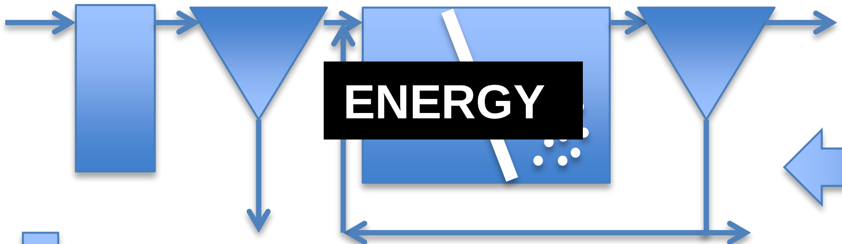
Phosphorous

- Approximately 20% of the mineral phosphorous consumed are excreted by humans.
- The mineral phosphorous market could be fully supplied from human and animal excreta streams (depending on national circumstances)

Nitrogen

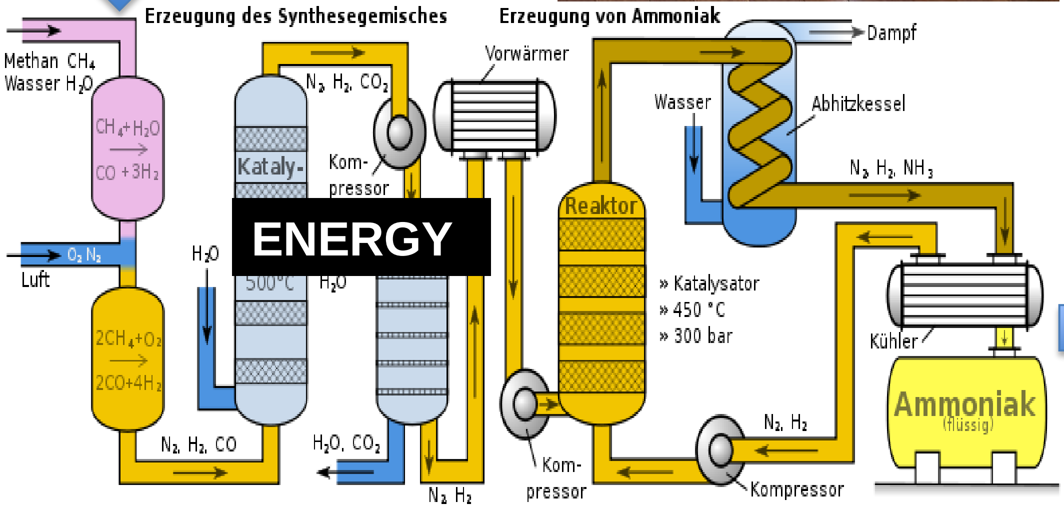
- Approximately 50% of the nitrogen market could be serviced from domestic and industrial waste streams (assuming 4:1 N:P average concentration)
- Ammonia is manufactured using the Haber-Bosch process using **12.36 kWh/kg N**. Nitrogen manufacturing utilises 1-2% of the world's energy supply.

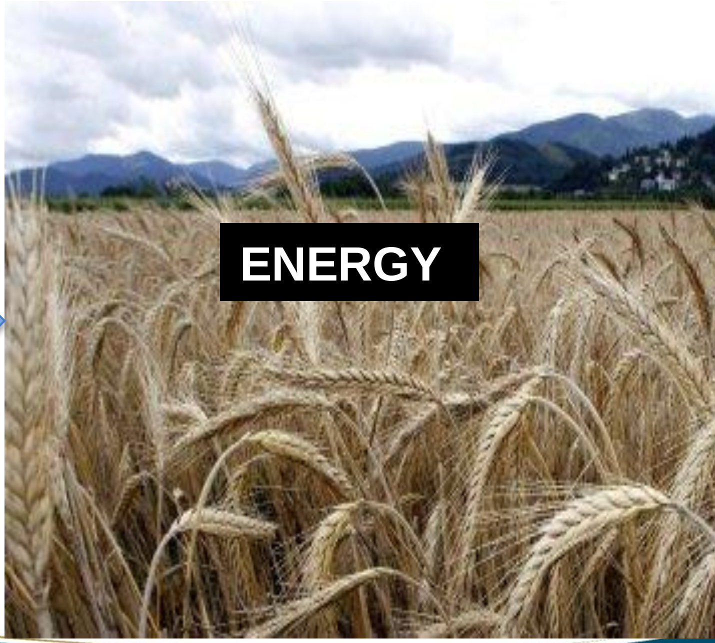
Batstone et al. submitted


ENERGY


ENERGY

N_2


Erzeugung des Synthesegemisches
Erzeugung von Ammoniak
Methan CH_4
Wasser H_2O
$CH_4+H_2O \rightarrow CO+3H_2$
O_2 N_2
Luft
$2CH_4+O_2 \rightarrow 2CO+4H_2$
N_2, H_2, CO_2
Kataly-
Kom-
pressor
H_2O
500°C
N_2, H_2, CO
H_2O, CO_2
N_2 H_2
Vorwärmer
Kom-
pressor
Reaktor
» Katalysator
» 450 °C
» 300 bar
Wasser
Abhitzkessel
Dampf
N_2, H_2, NH_3
Kühler
Ammoniak
(flüssig)
N_2, H_2
Kompressor
ENERGY


ENERGY

Domestic wastewater characteristics

Potential product recovery from municipal "used water".

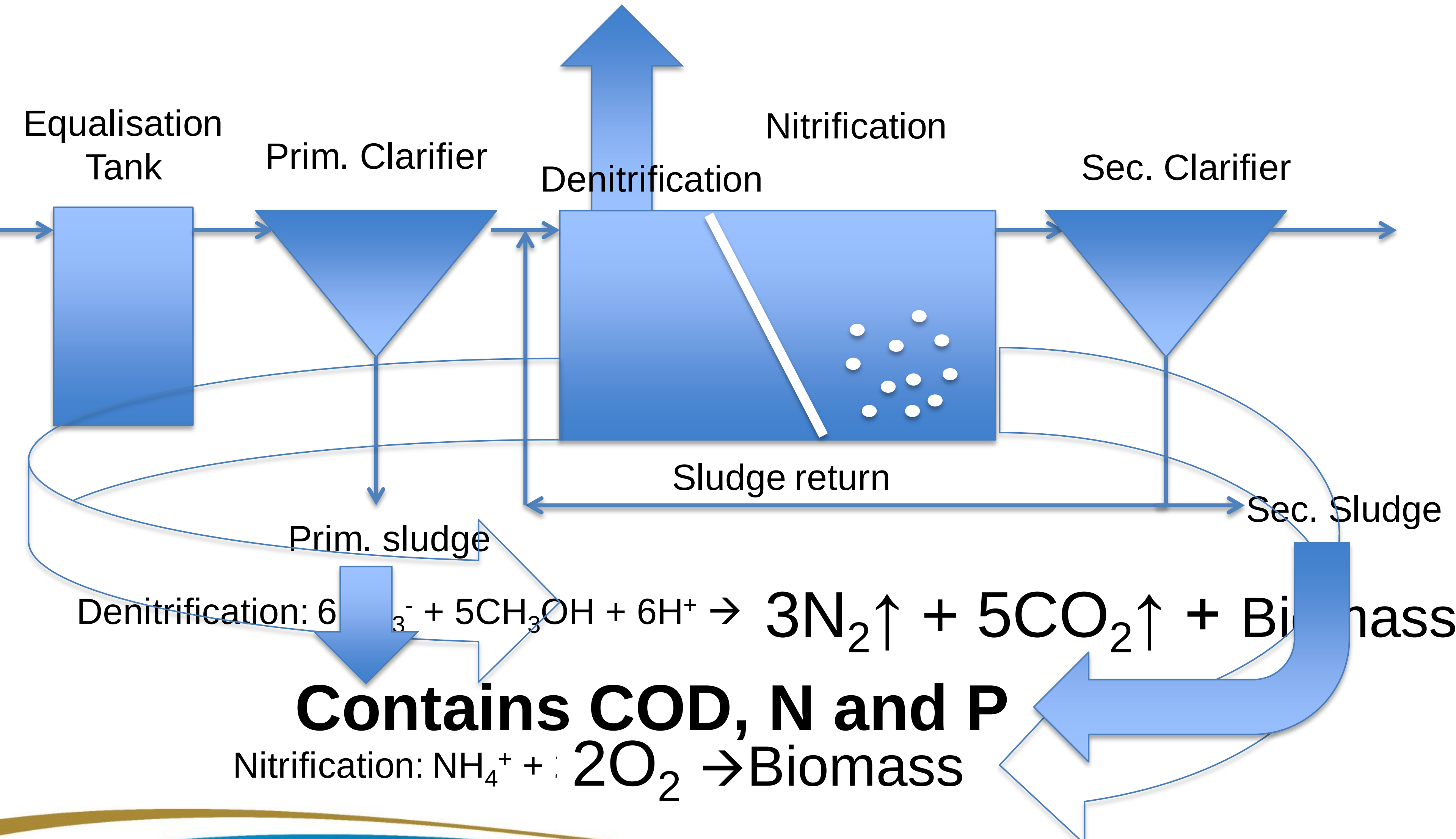
Potential recovery	Per m^3 sewage	Current market prices	Total per m^3 sewage (€)
Water	1 m^3	€0.250/m^3	0.25
Nitrogen	0.05 kg	€0.215/kg	0.01

- → valuable product!? saving for NH_4-N production (100000 p.e. ~500000€ @ 0.12cent/kWh per year (cost of Haber-Bosch for 1000kgN) + 80000 €/year for N

[b] Organic fertilizer was calculated on the basis of 20% organic matter remaining after anaerobic digestion and the price is based on the agricultural value of organics.

(from Verstraete et al, 2009)

$N_2\uparrow$ (~70 - 90% of N) + $CO_2\uparrow$ (~45% of COD)

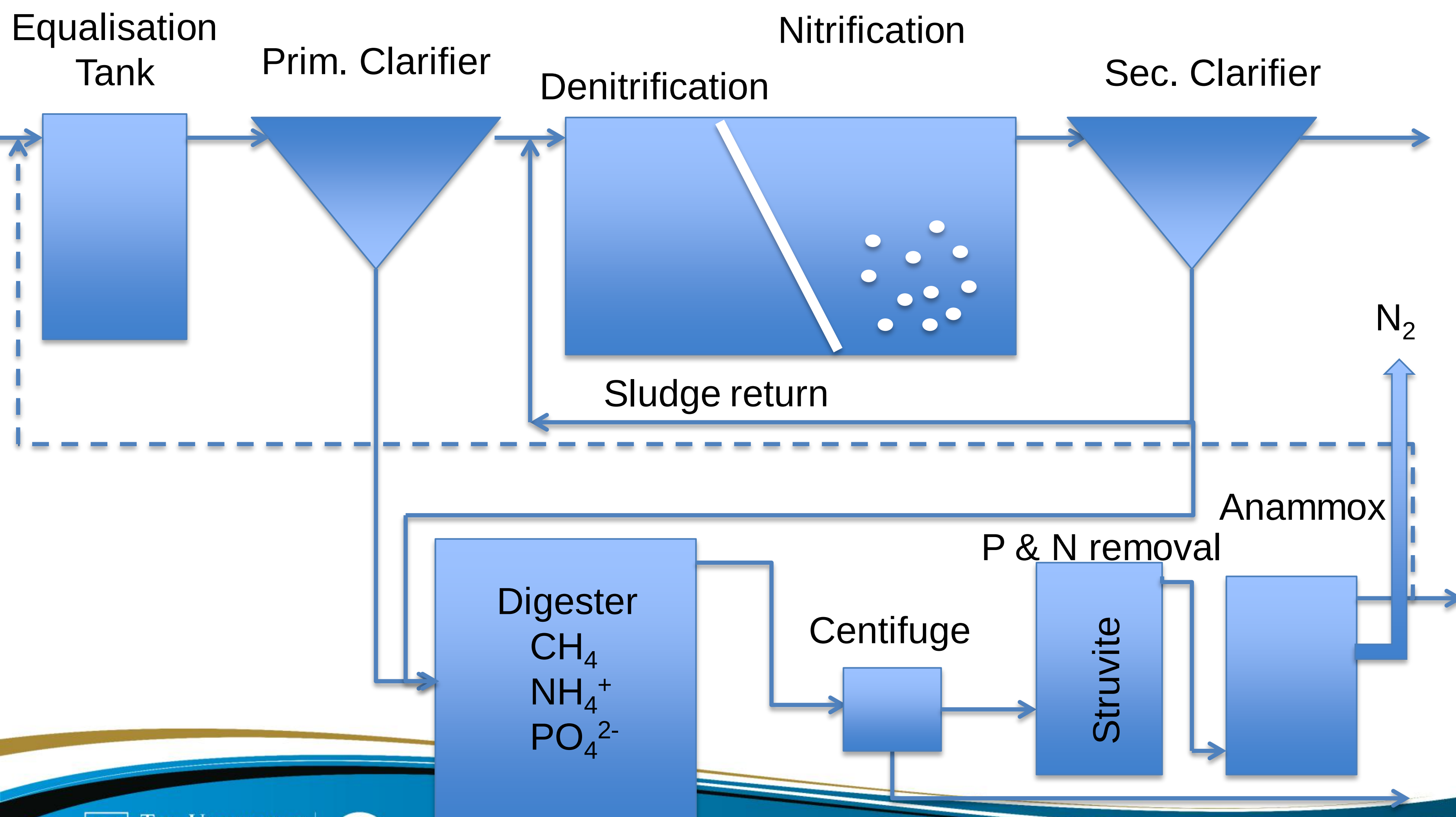


Denitrification: 6 ... $_3^-$ + 5CH_3OH + 6H^+ → $3N_2\uparrow + 5CO_2\uparrow$ + Bi...mass

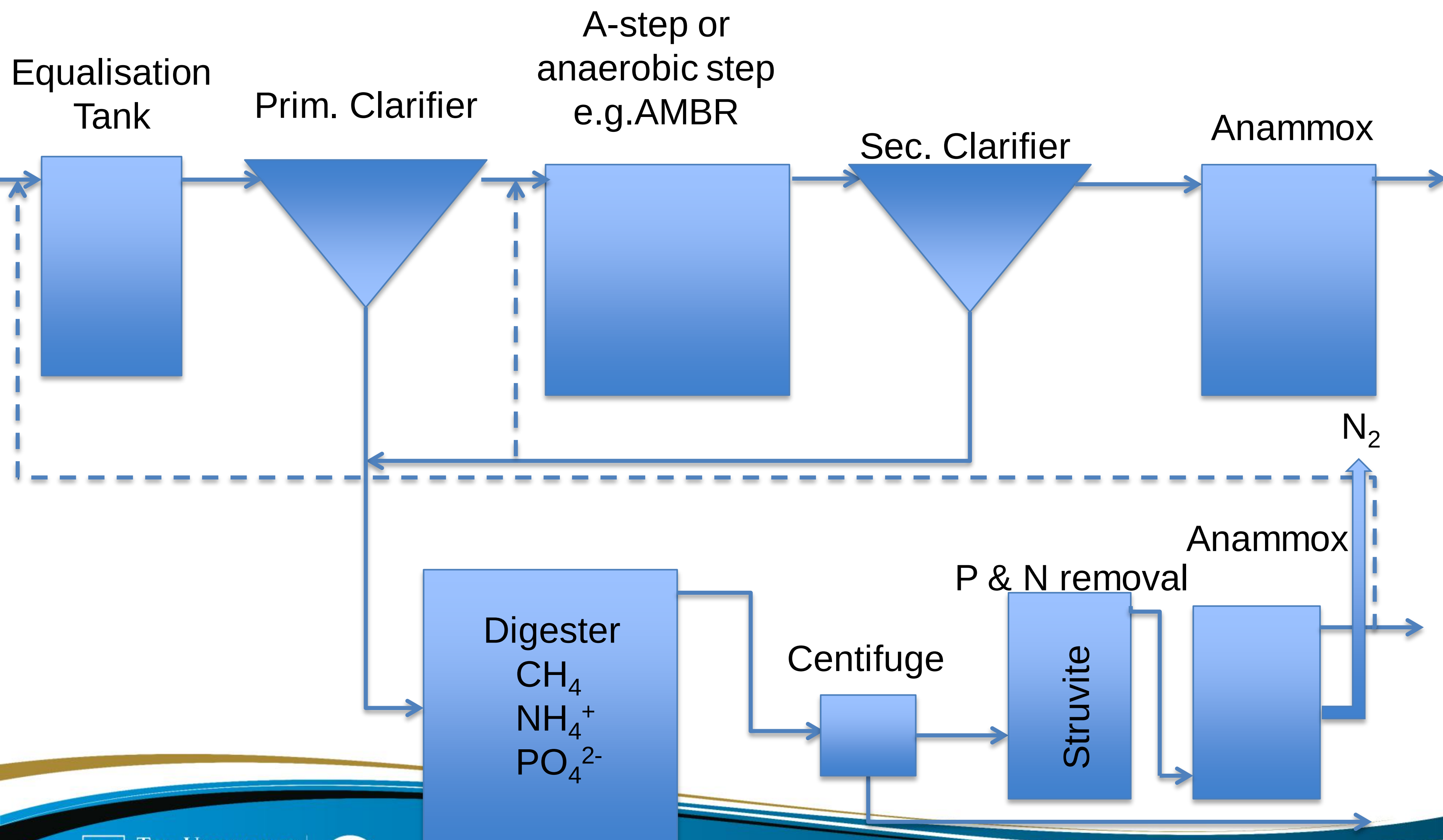
Contains COD, N and P

Nitrification: NH_4^+ + ... $2O_2$ → Biomass

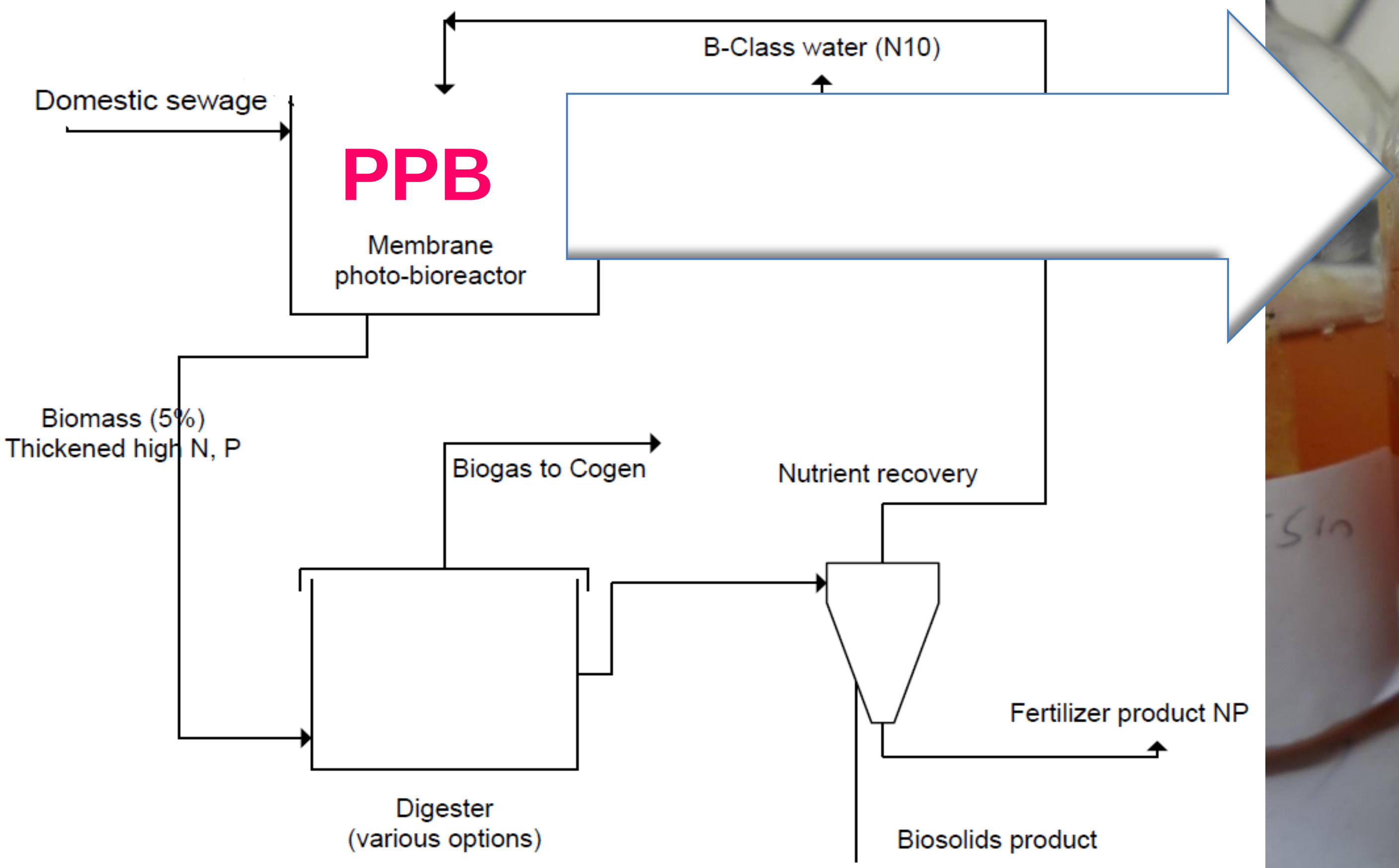
Conventional Wastewater Treatment



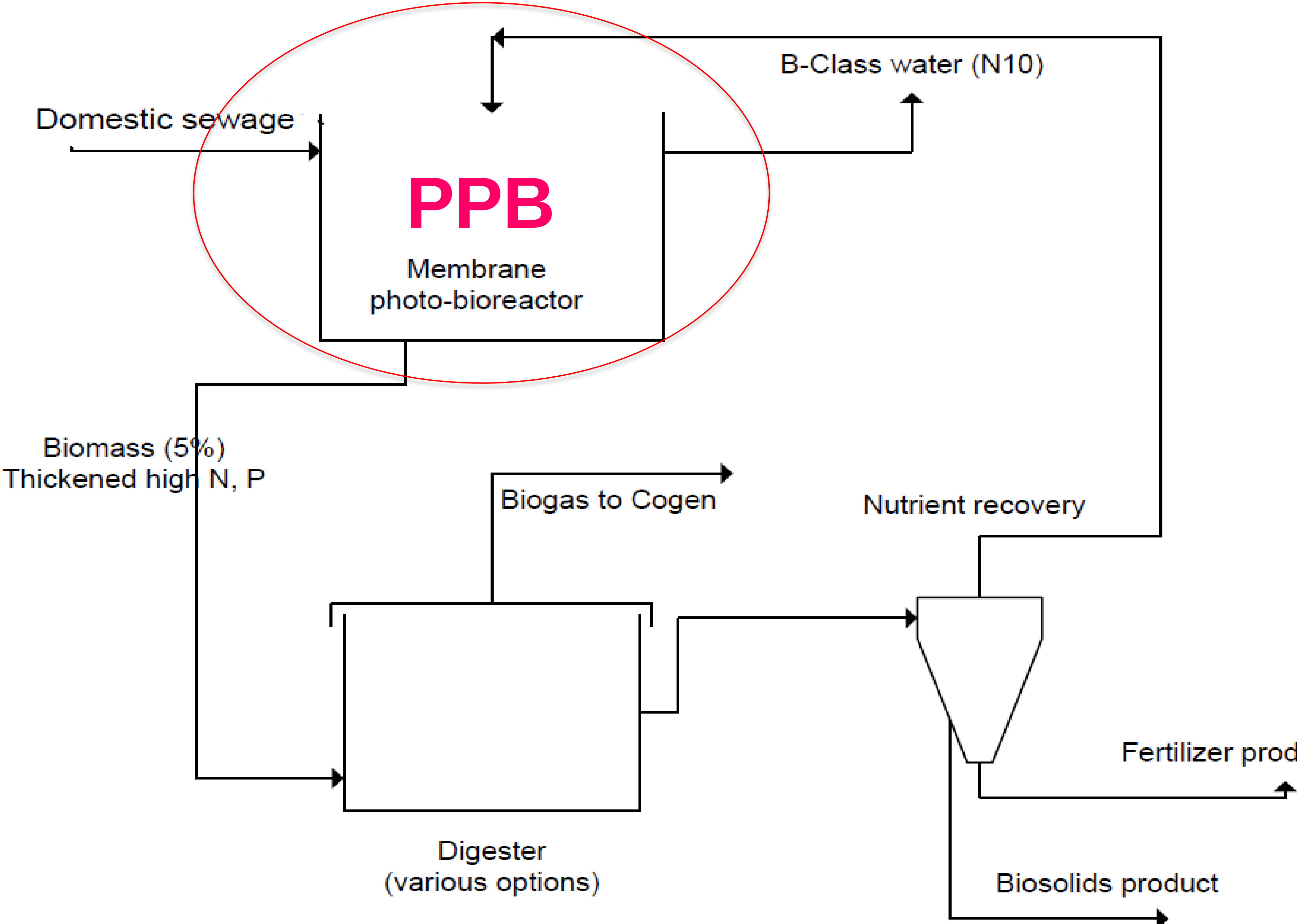
A-step/AMBR-Anammox



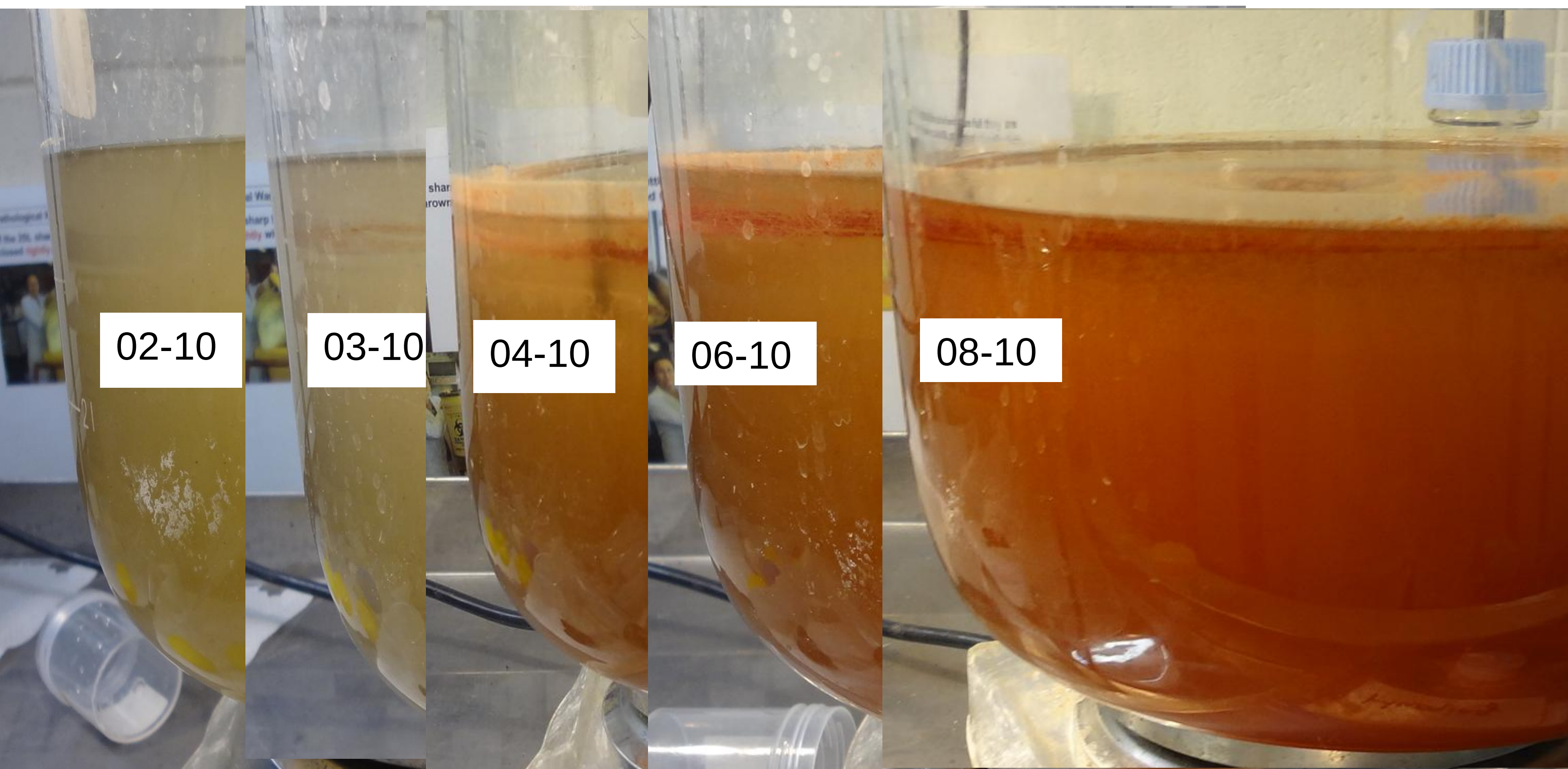
Alternative concept

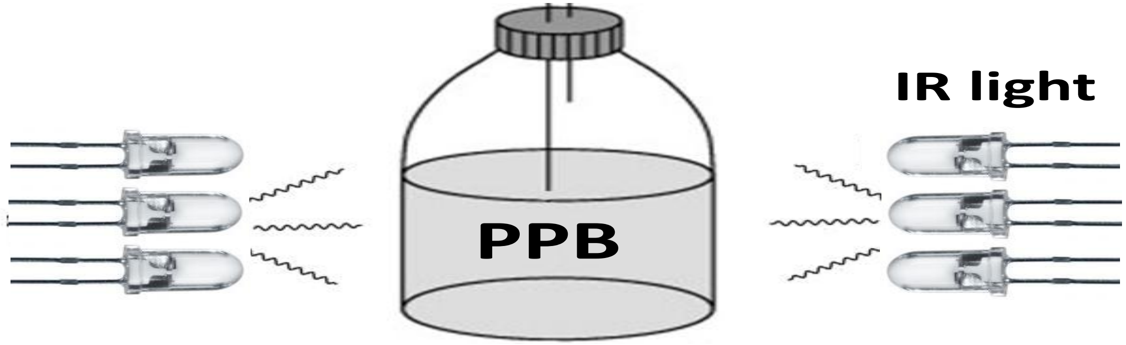


Partitioning-Release-Recovery

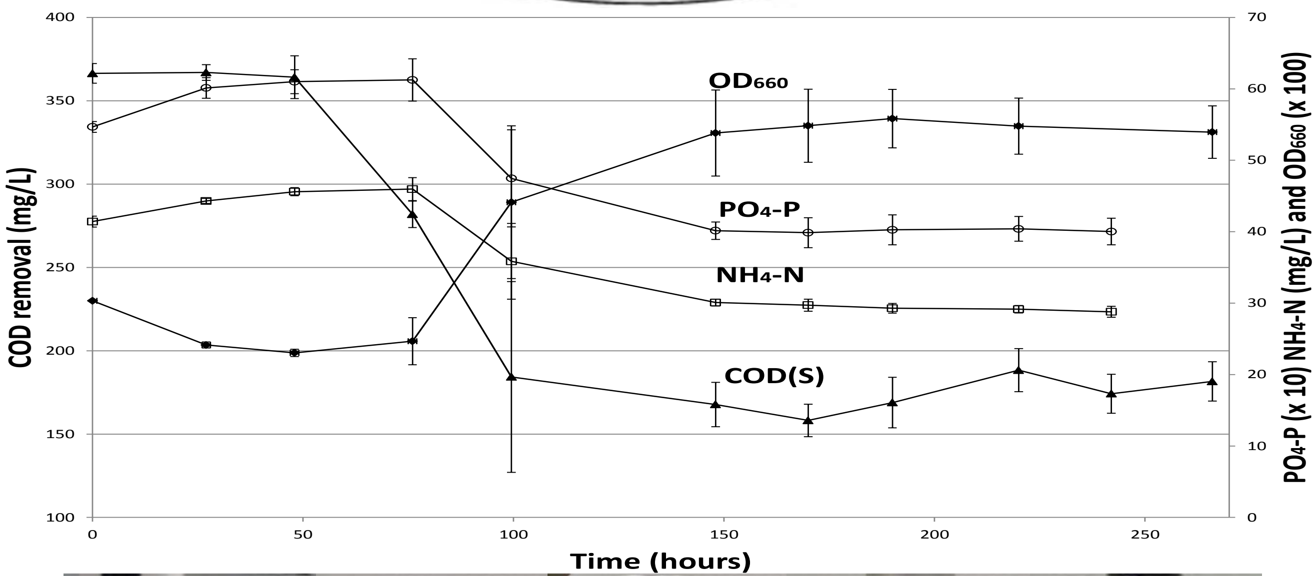

B-Class water (N10)
Domestic sewage
PPB
Membrane
photo-bioreactor
Biomass (5%)
Thickened high N, P
Biogas to Cogen
Nutrient recovery
Fertilizer prod
Digester
(various options)
Biosolids product

Enrichment-RWW anaerobically with UV-VIS absorbing foil

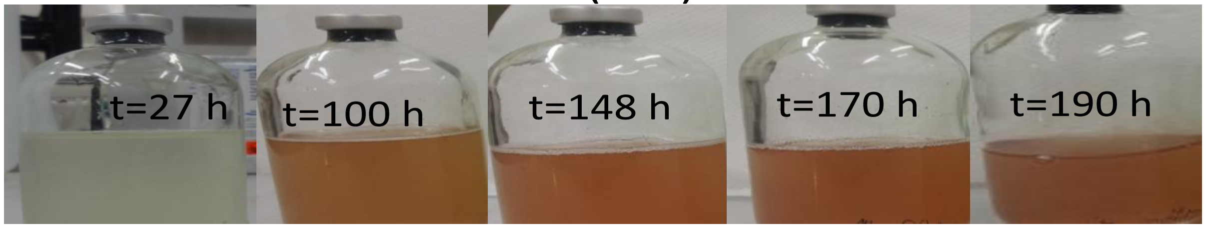




IR light
PPB



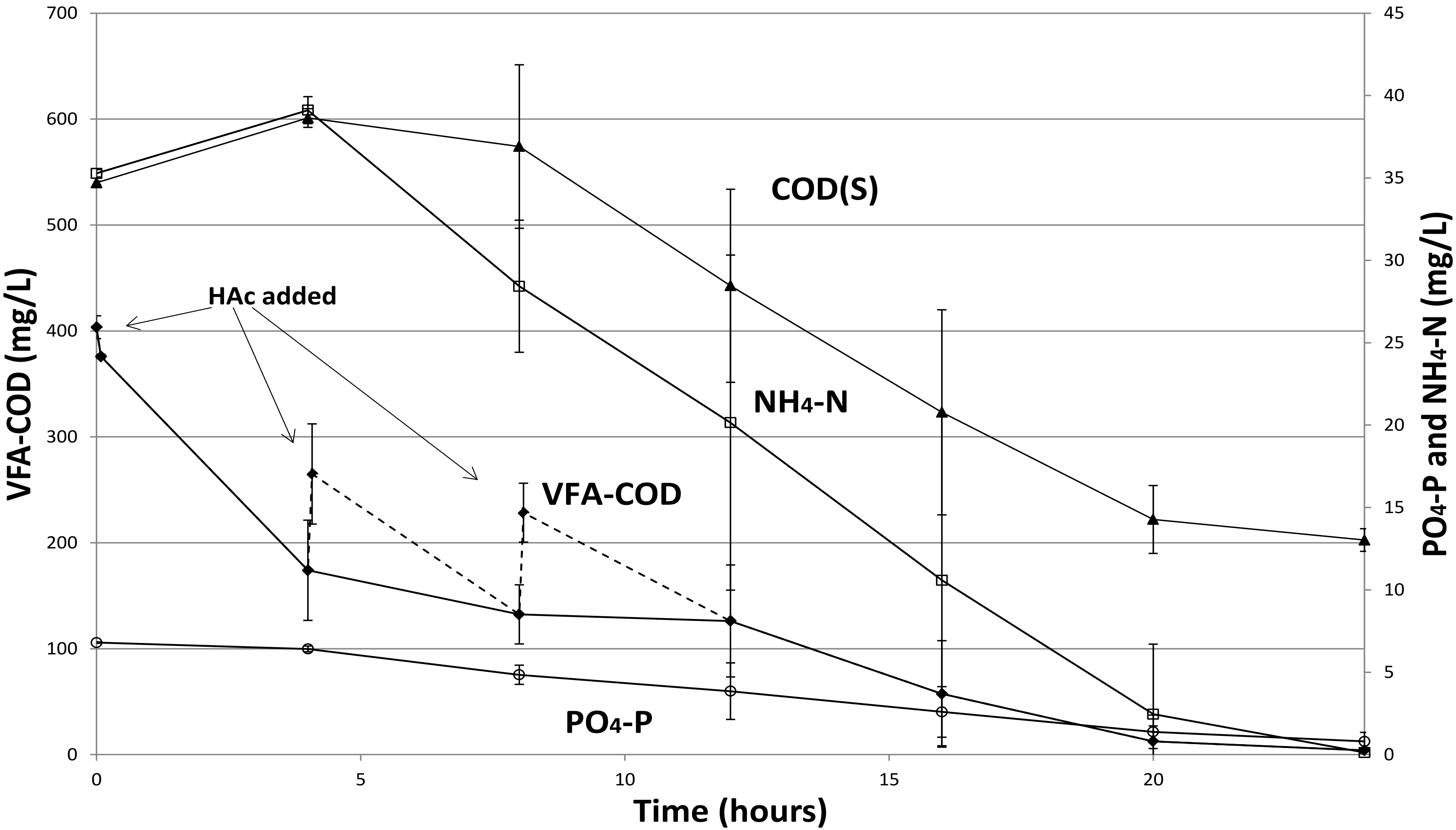
COD removal (mg/L)
PO4-P (x 10) NH4-N (mg/L) and OD660 (x 100)
Time (hours)
OD660
PO4-P
NH4-N
COD(S)
400
350
300
250
200
150
100
70
60
50
40
30
20
10
0
0
50
100
150
200
250



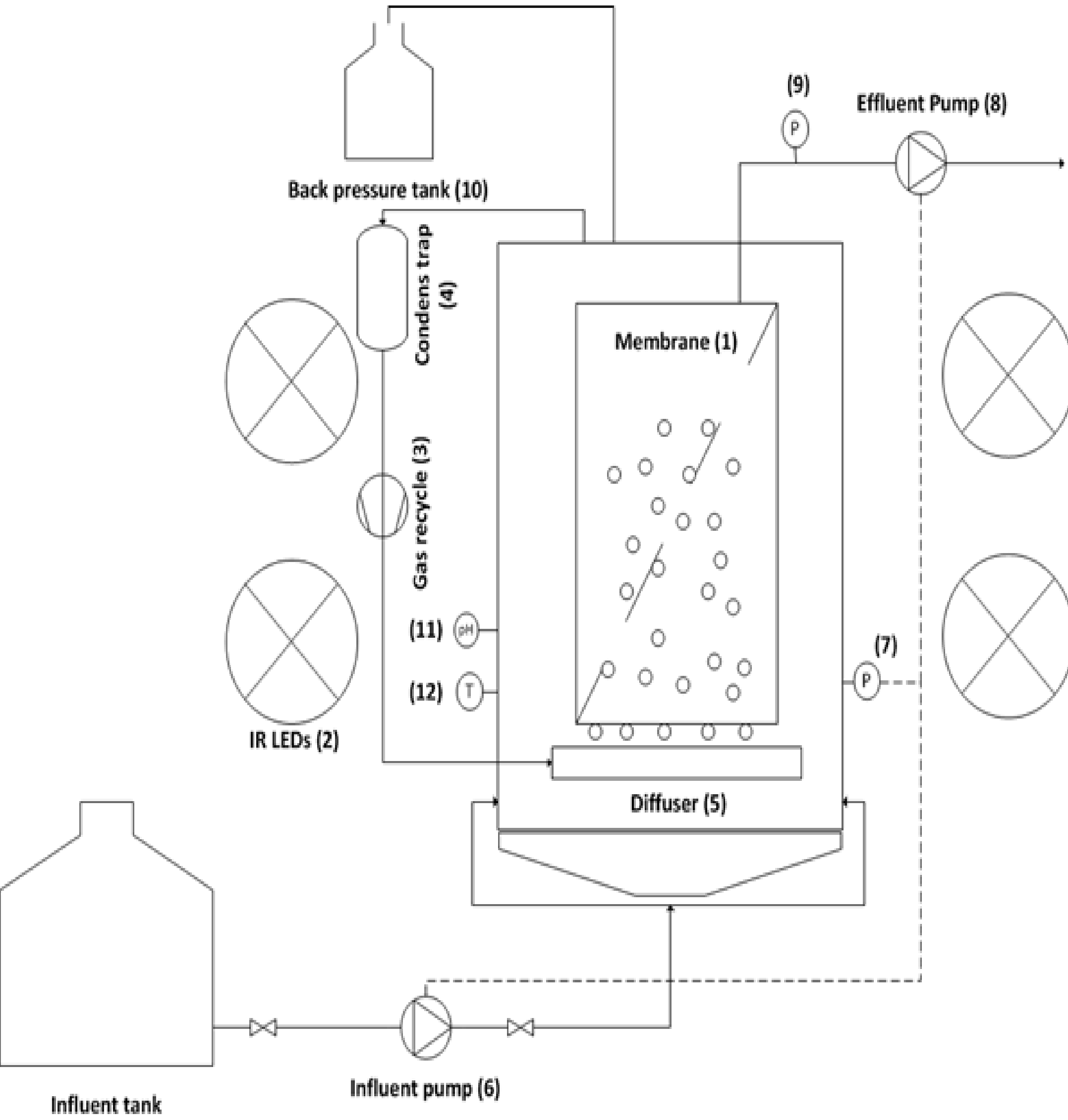
t=27 h
t=100 h
t=148 h
t=170 h
t=190 h

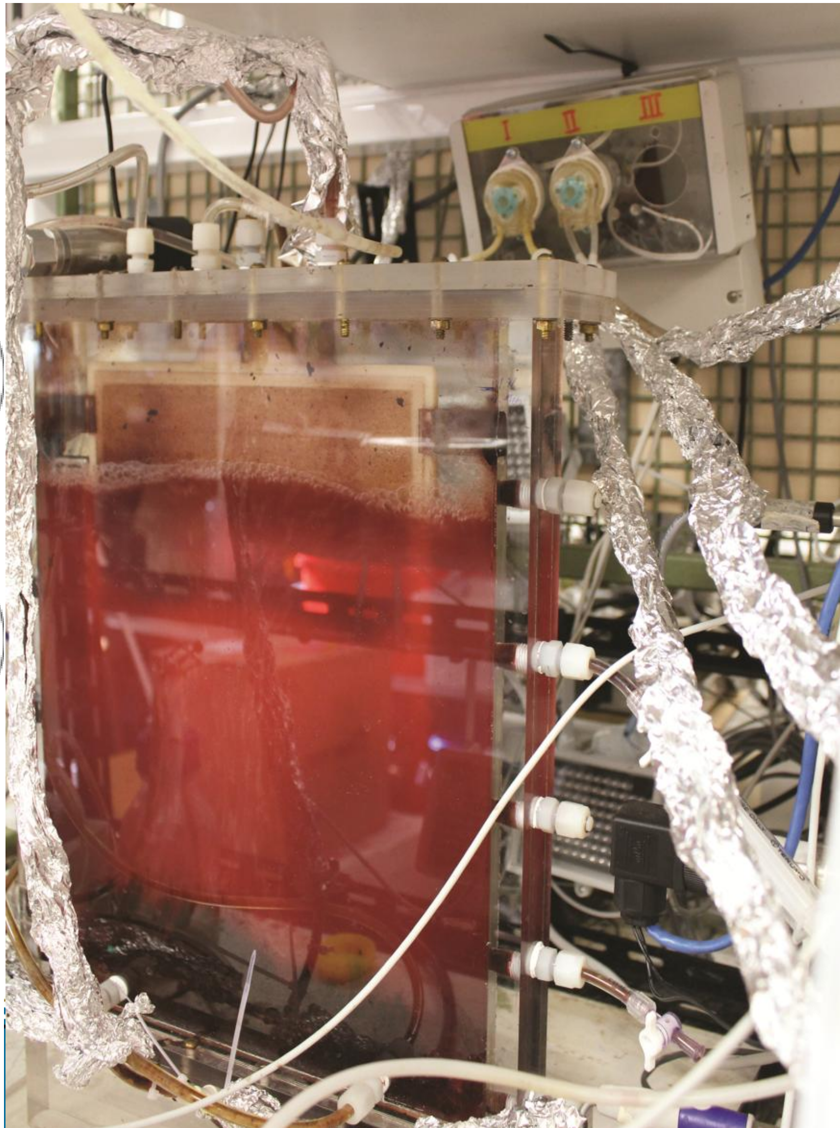
COD, NH_4-N and PO_4-P removal

SCOD/N/P ratio: 100/8.6/1.5

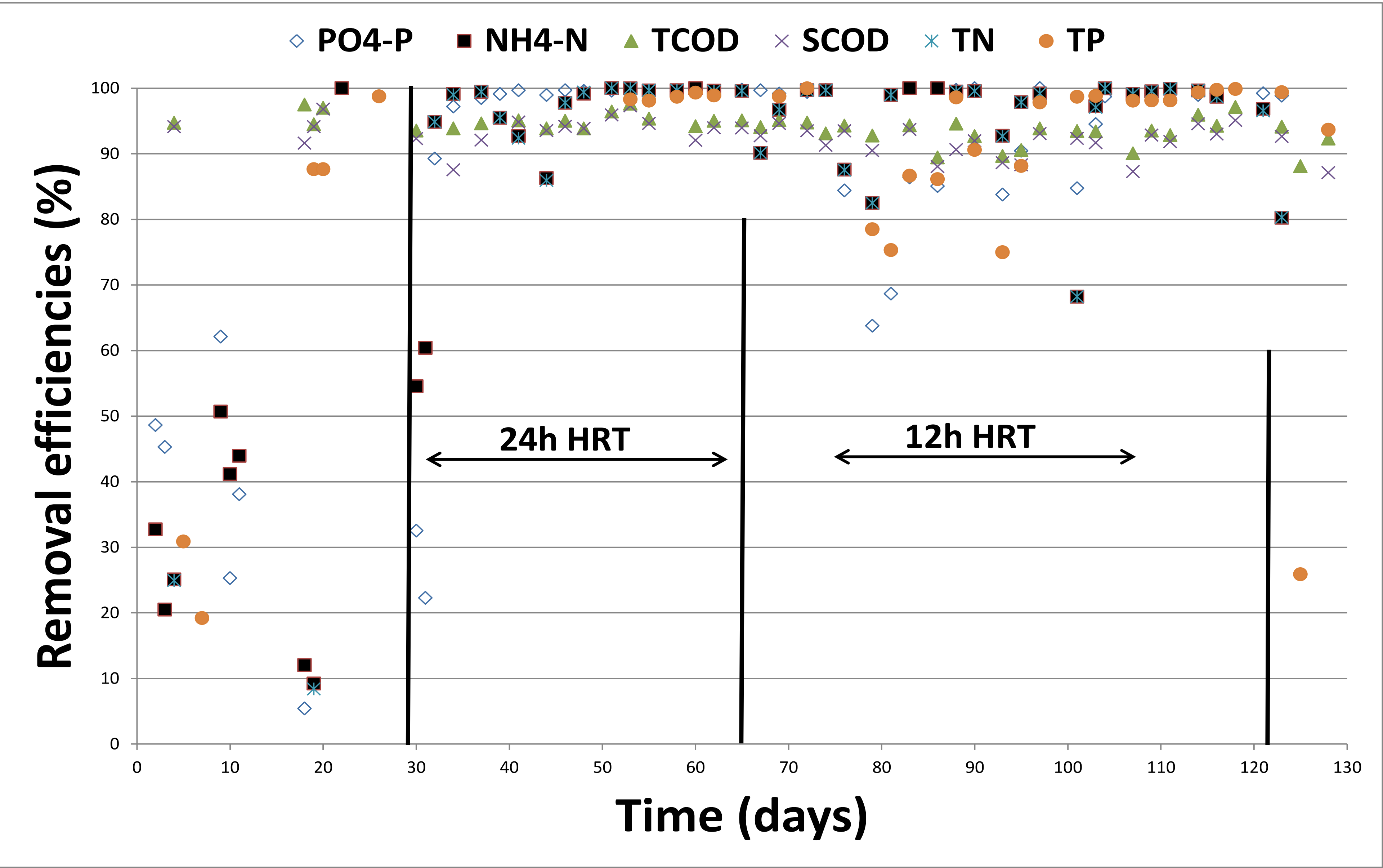


Domestic wastewater treatment with purple phototrophic bacteria using a novel continuous photo anaerobic membrane bioreactor



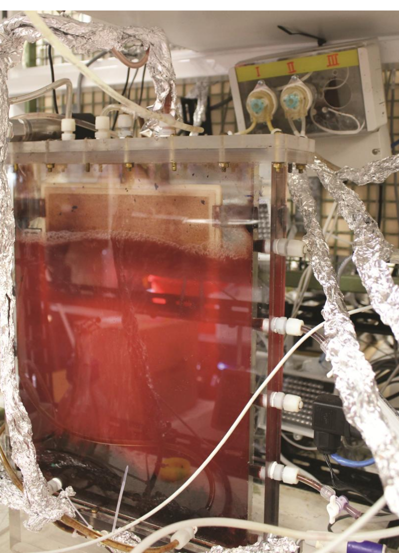


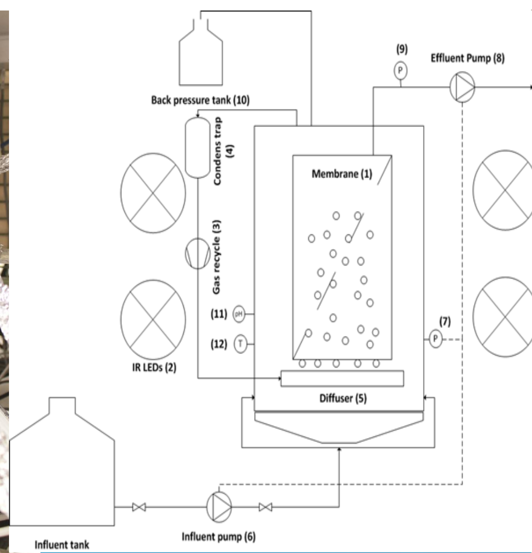
Continuous photo anaerobic membrane bioreactor operation



Performance data

	24 hours HRT, 3.4 days SRT			12 hours HRT, 2.1 days SRT		
Parameter	AVG effluent		STDEV	AVG effluent		STDEV
	mg L^{-1}	%	%	mg L^{-1}	%	%
NH_4-N	1.2	97.3	4.4	1.7	97.2	4.7
TN	4.8	93	6.5	4.1	96.9	4.9
PO_4-P	0.1	98.4	2.7	0.4	93.1	10
TP	0.2	98.7	0.5	0.47	93	9.4
TCOD	65	95	1.3	74	93.4	2.1



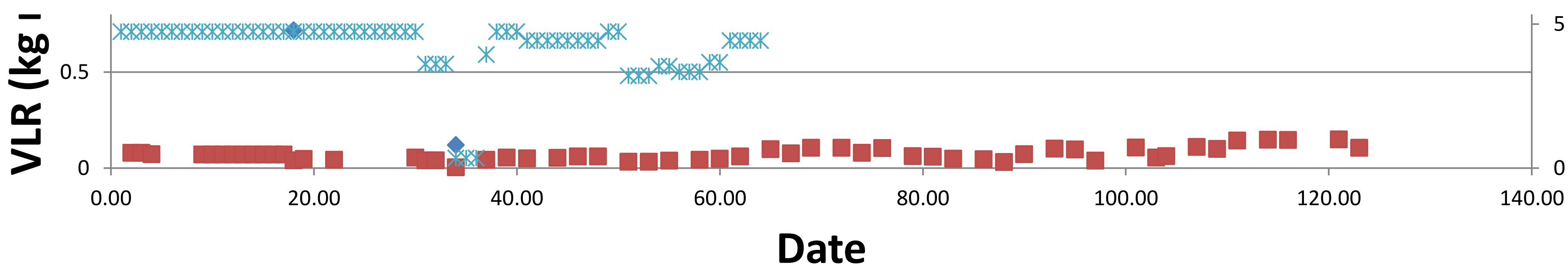


Process parameter

SLR of activated sludge process: **0.2 – 1.0** gCOD/gVSS/d
and of **0.05 – 0.1** kgN/kgVSS/d → **PPB ~ 1.0 gCOD/gVSS/d and 0.03 kgN/kgVSS/d**

VLR of extended aeration reactors, oxidation ditches or anaerobic ponds
0.2 – 0.6 kgCOD/m^3/d

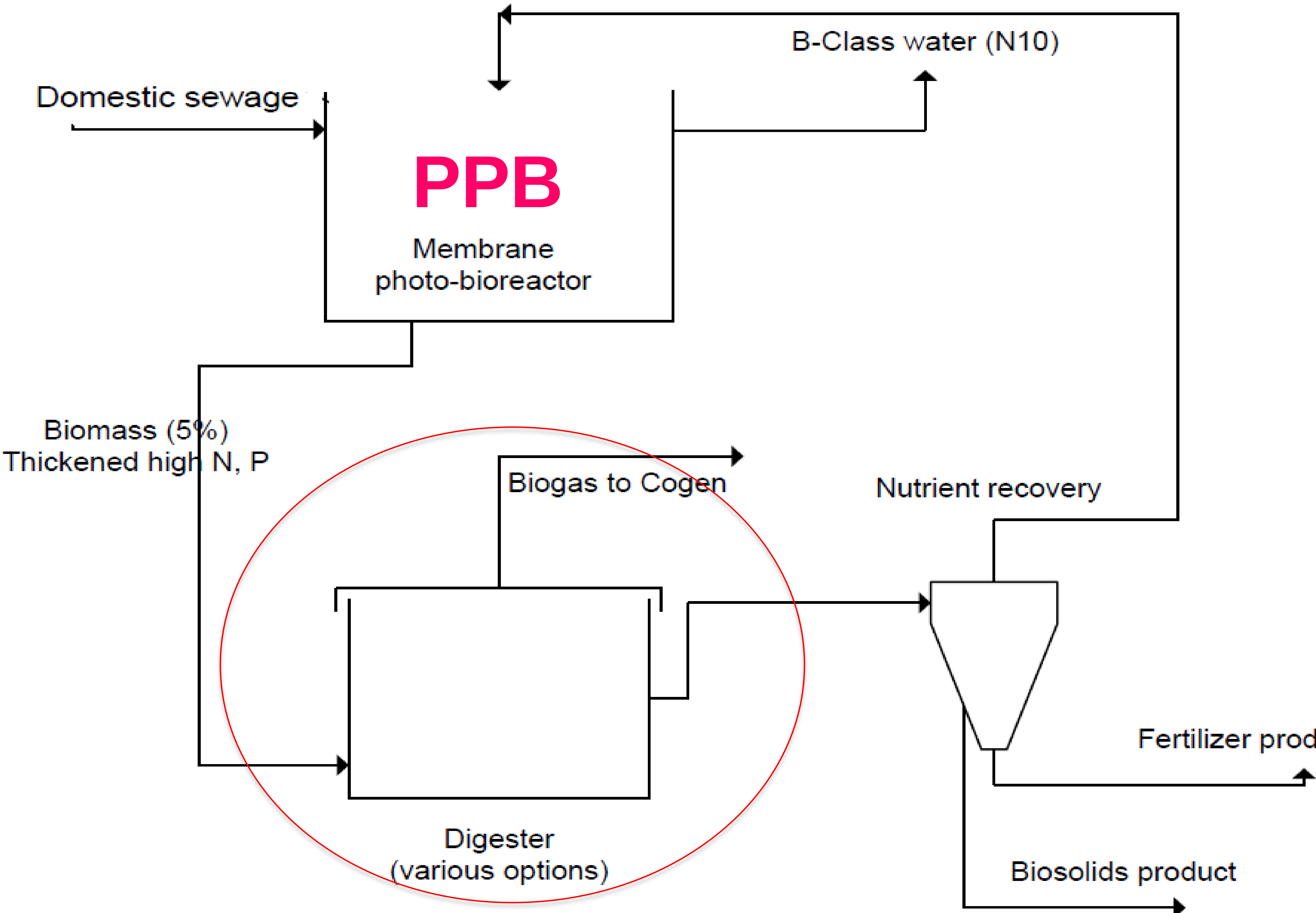
VLR of conventional activated sludge and membrane bioreactor processes
1.2 – 3.2 kgCOD/m^3/d



SCOD/N/P ratios

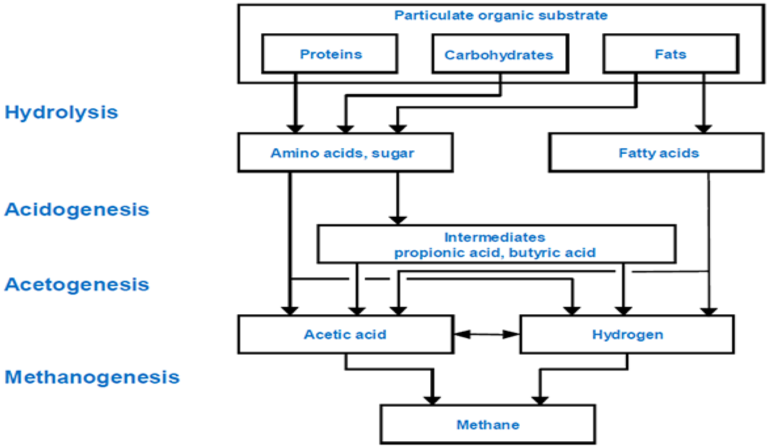
	SCOD/N	SCOD/P
Aerobic*	4.2	0.9
Anaerobic**	1.8	0.4
Anaerobic ***	0.5	0.1
PPB		
24h HRT	5.1	0.8
12h HRT	5.6	0.8

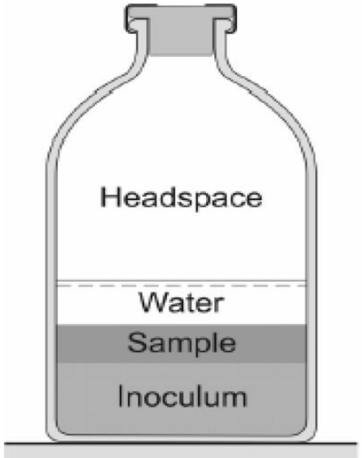
*(assuming 49% growth in terms of COD)
**non acidified WW (assuming 21% growth based on $COD_{removed}$)
***acidified WWT (assuming 6%)



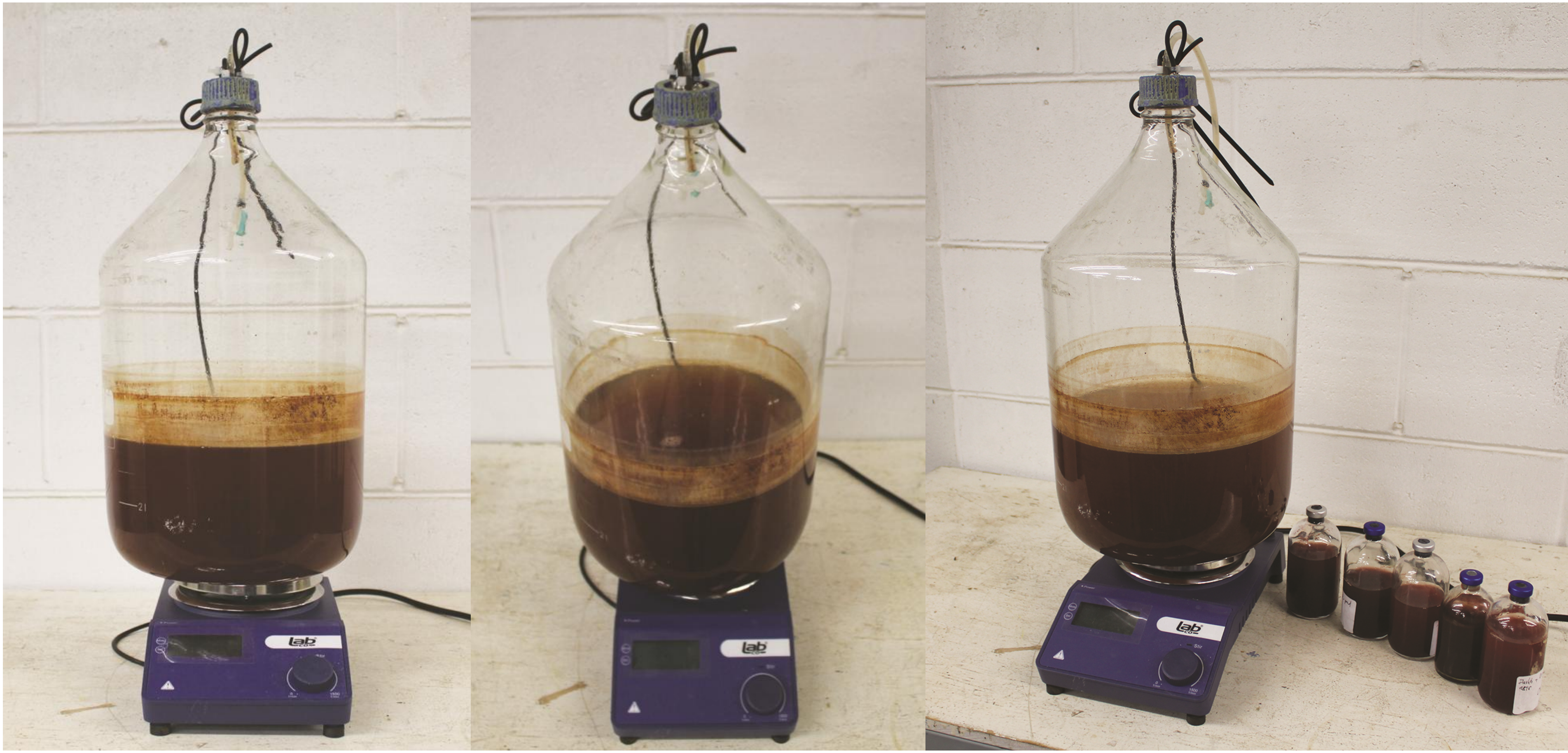
B-Class water (N10)
Domestic sewage
PPB
Membrane
photo-bioreactor
Biomass (5%)
Thickened high N, P
Biogas to Cogen
Nutrient recovery
Fertilizer prod
Digester
(various options)
Biosolids product

Full energy and nutrient recovery from domestic wastewater by purple phototrophic bacteria – anaerobic release potential



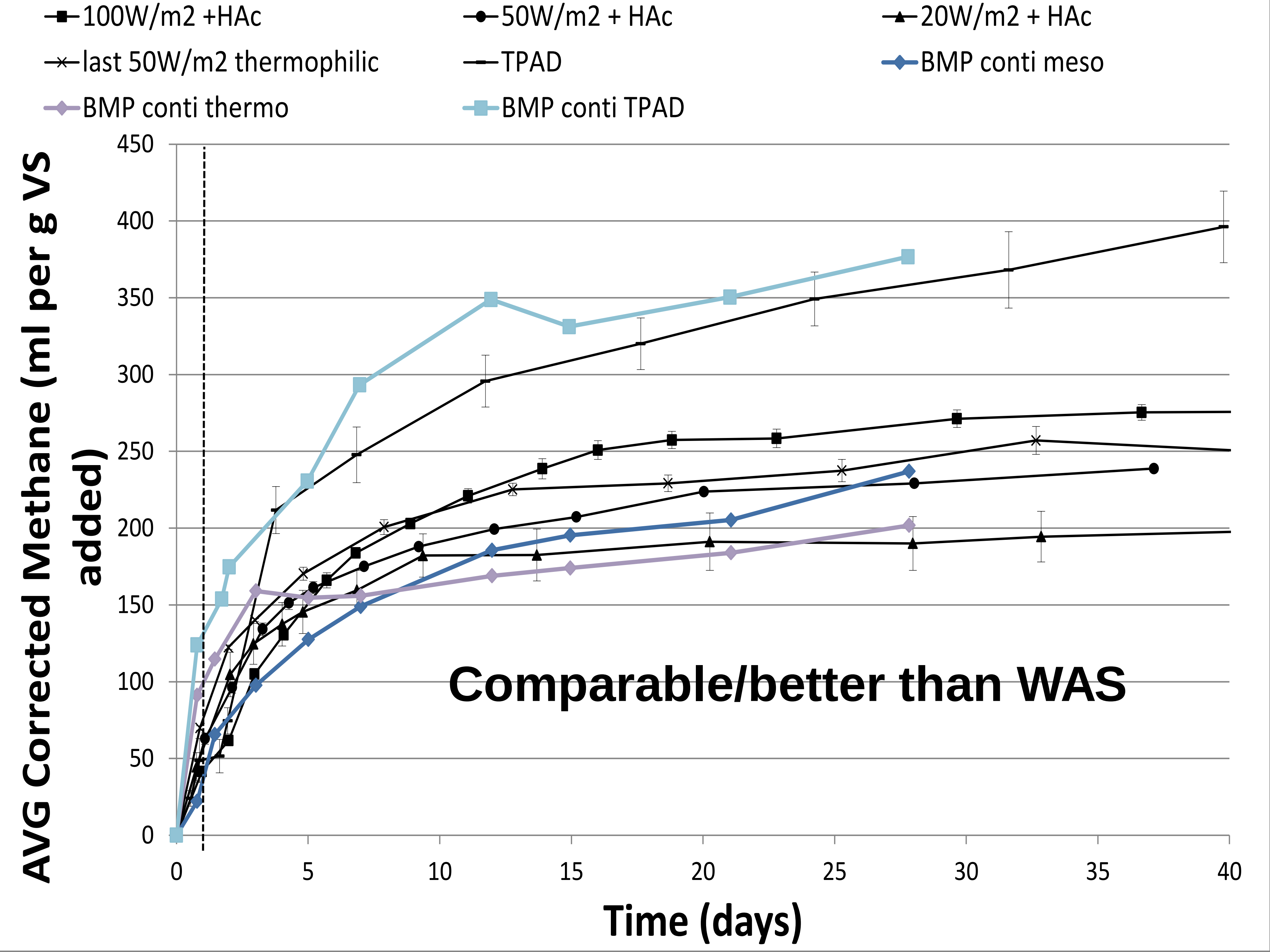


Enrichent for BMP test



Enrichent for BMP test

Bottle	AVG SCOD/N/P
Bottle 1	100/9.73/1.29
Bottle 2	100/7.71/1.03
Bottle 3	100/9.31/1.09
Bottle 4	100/8.89/1.15
Bottle 5	100/8.77/1.15
Bottle 6	100/7.89/0.98
AVG Bottle 1-6	100/8.7 (±0.79)*/1.11 (±0.11)


100W/m2 +HAc
50W/m2 + HAc
20W/m2 + HAc
last 50W/m2 thermophilic
TPAD
BMP conti meso
BMP conti thermo
BMP conti TPAD
AVG Corrected Methane (ml per g VS added)
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
Time (days)
Comparable/better than WAS

COD and Nutrient release

COD release

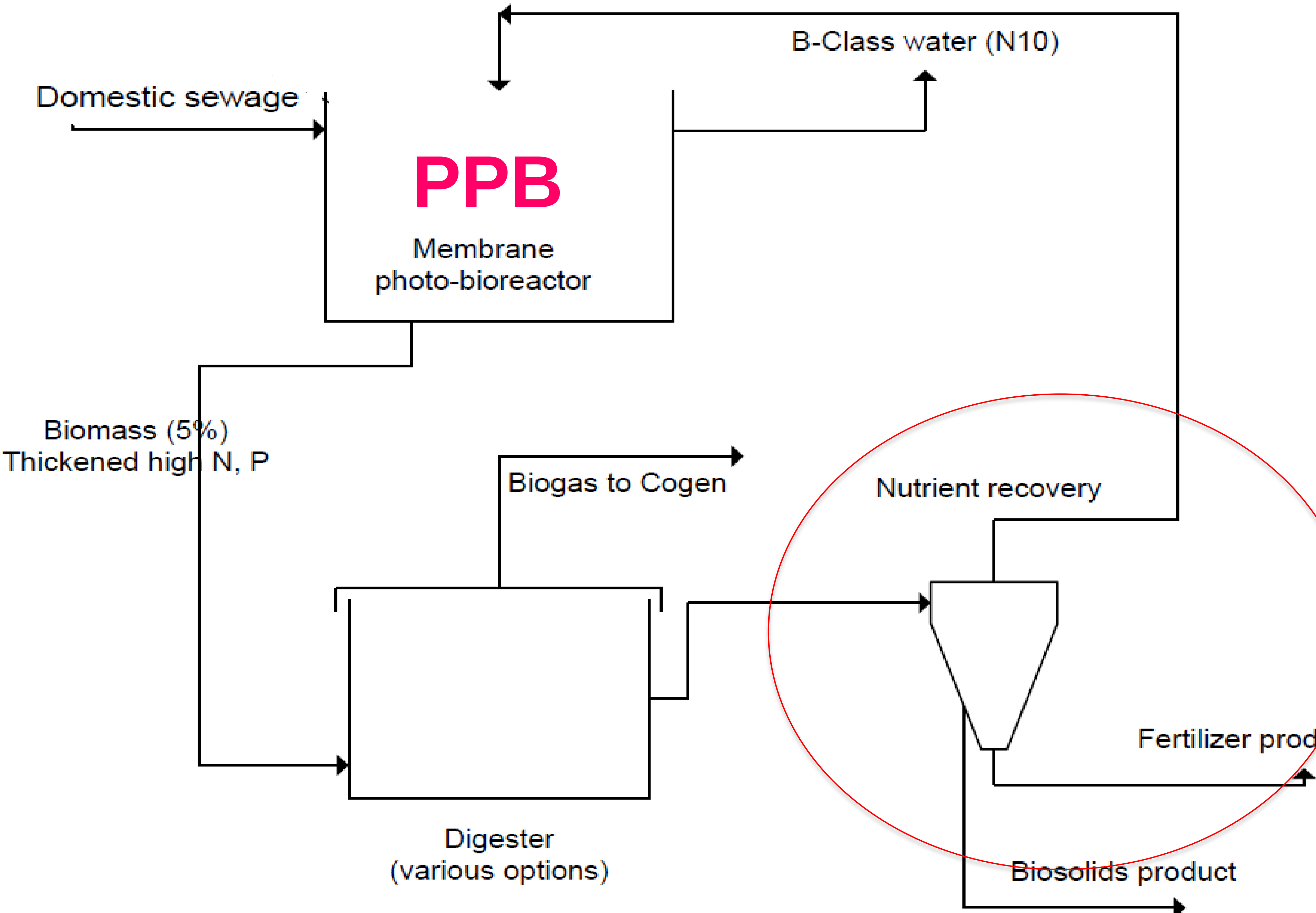
- Mesophilic release: Sludge produced 0.9 $gVS_{produced}$ $gSCOD_{removed}^{-1}$ with TCOD/VS ratio of the sludge around 1.9 (normal is 1.4) → AVG (n = 12) 1.7 $gTCOD_{produced}$ $gSCOD_{removed}^{-1}$
  CH_4-COD release: 0.6 - 0.7 gCH_4-COD gVS_{added}^{-1} → **COD release 67 - 78%**
- TPAD recovery: 0.8 gCH_4-COD gVS_{added}^{-1} → **COD release 89%**

N release

- NH-$_4$-N release ($VS_{removed}$) is between 104 and 135 mg (10.4 and 13.4%) based the SCOD/N ratio of 100/8.7 (± 0.79). Released faster that the VS is degraded!
- NH_4-N release (VS_{added}) is between 47 and 100% of the total NH_4-N assimilated.

P release

- The PO_4-P releasey ranged between 15 and 25 mg g $VS_{removed}^{-1}$ (1.5 and 2.5%). Released faster that the VS is degraded!
- The PO_4-P release (VS_{added}) is between 72 and 91% based the SCOD/P ratio of 100/1.11 (±0.11) measured during the PPB growth.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Biosolids product

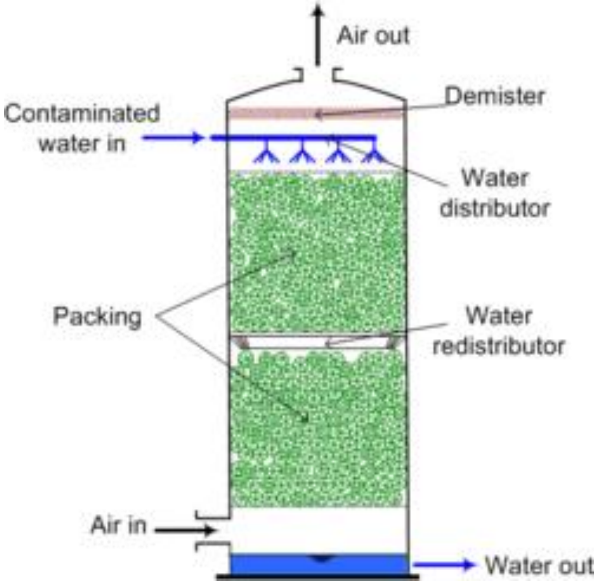
Nutrient recovery technologies

N and P recovery

- Chemical precipitaion
  - struvite
  - Calcium phosphate
- Ion exchange
- Magnetic (magnetite attachment)
- Recovery from sludge ash

N recovery

- AMFER stripping with air
- ARP/CAST (vacuum distillation)
- Evaporation
- Ion exchange
- LGL stripping (rotating discs)
- Nutritec (Turbotec)
- Partial freezing
- RO



Conclusions and future work

- Reliable enrichment of the target microbes from wastewater directly through application of infra-red light, showing that culture can be directed by this method with short start-up times.
- Good reactivity to carbon and nutrients present in wastewater.
- Proof of ability/concept to remove nutrients to discharge limits (N ~ 5 mg L^{-1}; P ~ 0.5 mg L^{-1}).
- Potential one reactor set-up for domestic wastewater treatment
- Nutrients can be partitioned and released → recovered!

Conclusions and future work

- Increased cost due to illumination
- Additional COD dosing required to reach low N and P levels, costs of transport, storage, …
- Thickening of the biomass, centrifuges, filter press, flocculation!?
- SRT control
- NH_4-N toxicity in digester

Conclusions and future work

- Savings of aeration
- One main treatment tank, rest site-stream →Volume saving, cocking in one pan instead of 2 - 3!
- COD and nutrient recovery with products (TPAD potential!?)
  → valuable product!? saving for NH_4-N production (100000 p.e. ~500000€ @ 0.12cent/kWh (cost of Haber-Bosch for 1000kgN)
- Illumination with solar energy – solar panels!?
- Illuminated plates and attached growth → almost no energy for thickening, biomass separation and membranes.
- PPB biomass itself as a product!??? Organic fertilizer, (food chicken or fish farming—LEGISLATION), Carotenoids as vitamins…
- Industrial application e.g. abbatoir….

OPTIONS

Sustainability, energy neutrality and cost neutrality is not always the same

Acknowledgement

CRC for
Water Sensitive Cities

Smart
Water
Fund


Thanks!!!!!
Questions!!??