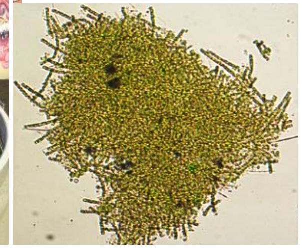



Converting industrial wastewater and sunlight into MaB-flocs, and beyond

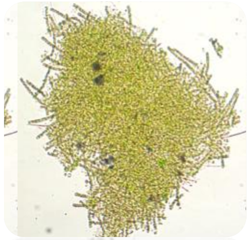
Produktion von Algen-Bakterien-Flocken unter Ausnutzung von Sonnenlicht und Abwasser

Van Den Hende Sofie

Faculty Bioscience Engineering, Ghent University, Belgium

18th June 2015, Eco-innovation Congress, Papenburg, Germany

Outline



1. MaB-floc raceway pond: why and what?

2. Features and challenges

3. Conclusions and future outlook

Microalgal technology: green science fiction or industrial reality?

2005-2015: Renaissance of interest in microalgal technology

Problem: also green microalgae science fiction

Unrealistic translation of lab-scale results to industrial scale

Lab photobioreactor

Microalgal biomass productivity

Aquaculture wastewater

109 mg VSS $L^{-1}_{reactor}$ d^{-1}

= 159 ton **VSS ha^{-1}_{pond} y^{-1}**

Van Den Hende et al., 2014b. Bioresour Technol 161, 245-254.

Outdoor ponds

Microalgal biomass productivity

Aquaculture wastewater

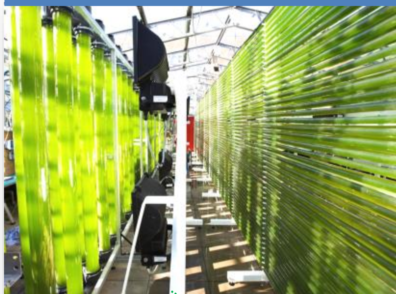
? ton **MaB-floc VSS ha^{-1}_{pond} y^{-1}**

Solution: outdoor pilot-scale experiments

EnAlgae | Pilot Network

Pilot Network

Microalgae

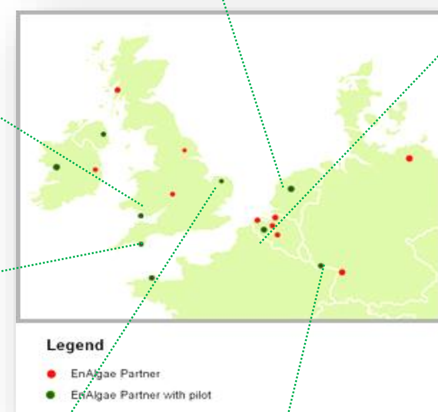


SU, GB

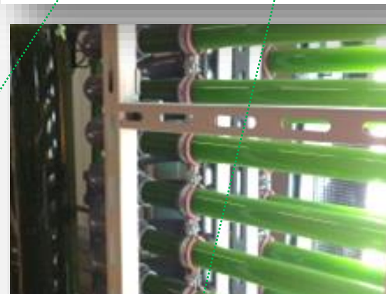
WUR/ACRRES, NL

UGENT, BE

PML, GB



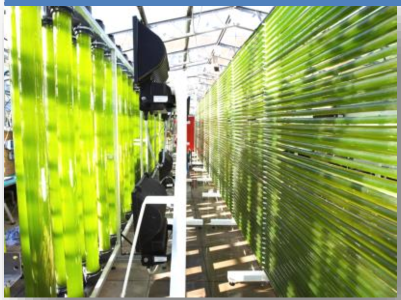
CU/INCROPS, GB



HTW SAAR, DE

Pilot Network

Microalgae



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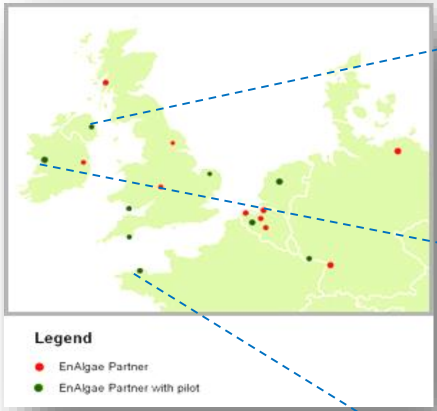


CU/INCROPS, GB

HTW SAAR, DE

Seaweed

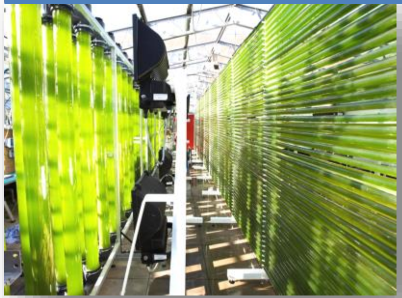
QUB, GB

NUI, IE

CEVA, FR

Pilot Network

Microalgae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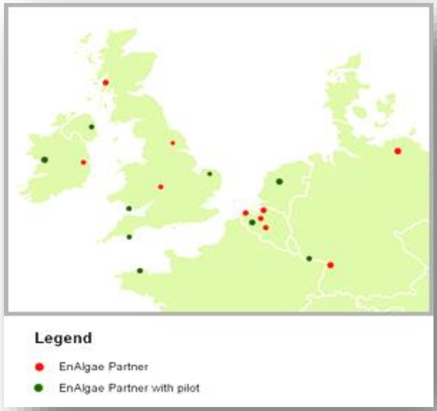



CU/INCROPS, GB


HTW SAAR, DE

Wastewater

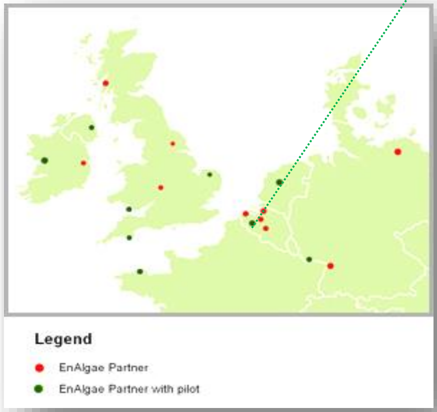
and/or

flue gas

Pilot Network

Microalgae

UGENT, BE



LIWET
=
Lab of
Industrial
Water and
Eco-
Technology

Biosience
Engineering
Faculty

Wastewater

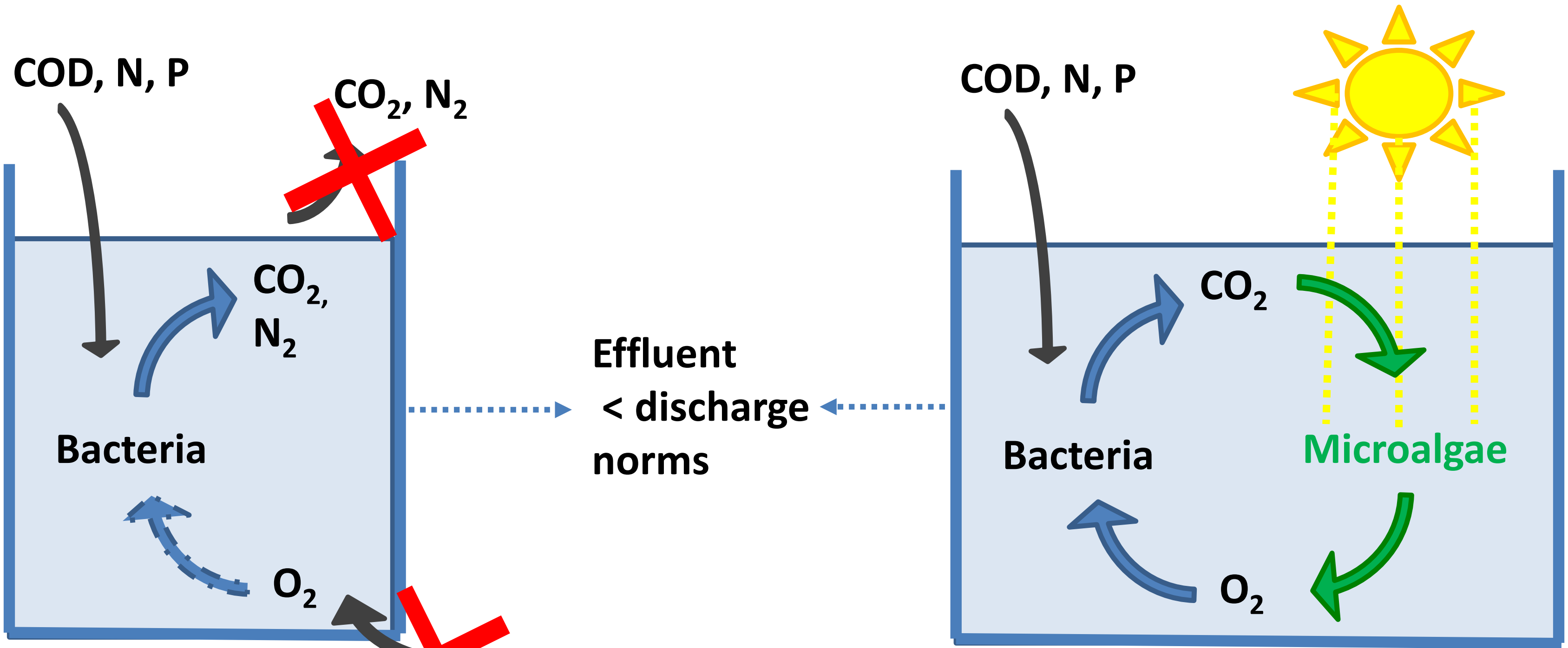
and/or

flue gas

A greener wastewater treatment

Activated sludge system

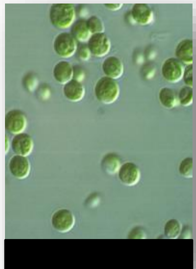
Microalgae bacteria (MaB) system



Mechanical aeration
Nitrification/denitrification
Nutrient removal

Photosynthetic aeration
CO_2 uptake
Solar energy into biomass
Nutrient recovery

Wastewater treatment with microalgae: challenges

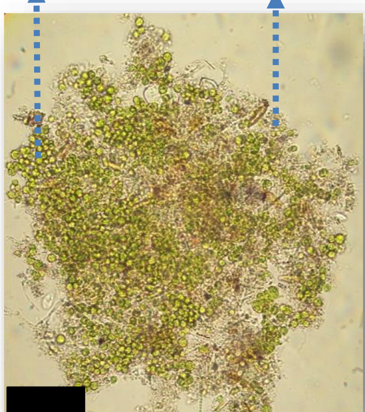


0.05 mm

Problem

Microalgae are expensive to separate from the treated wastewater

Microalgae   Bacteria



0.1 mm

Solution @ Ghent University/Howest

Biomass-free effluent

Bioflocculation of microalgae & bacteria

Microalgal bacterial flocs = **MaB-flocs**

Van Den Hende S., 2014. Microalgal bacterial flocs for wastewater treatment: from concept to pilot scale. PhD dissertation, Ghent University, 324p. Promoters: Prof. dr. Nico Boon (LabMET), dr. Han Vervaeren (LIWET).

The secret recipe of making MaB-flocs

1. Collect microalgae & bacteria (MaB) outdoors

Water tank, Alpro

Sieve, Alpro

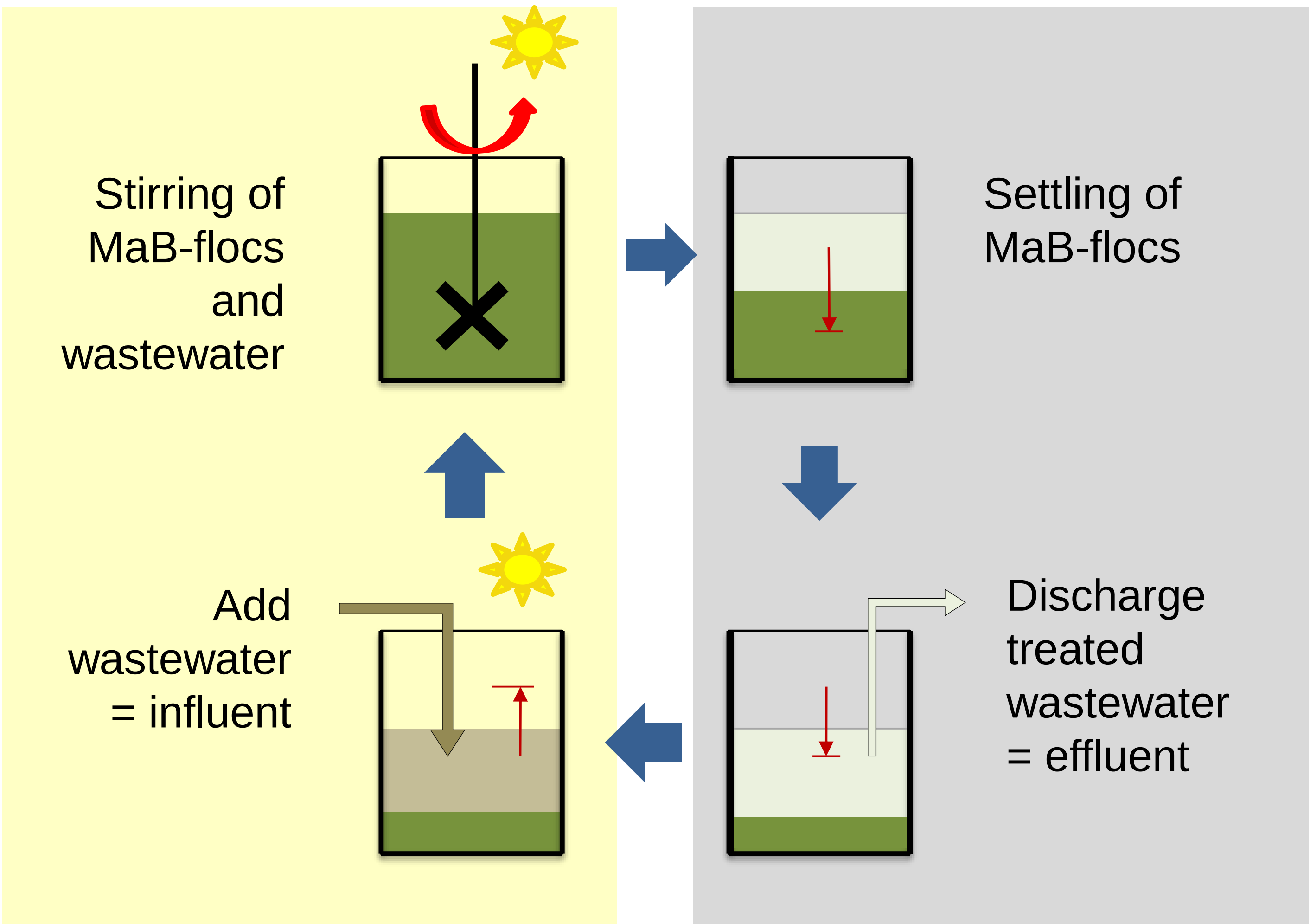
2. Collect wastewater

Wastewater, Alpro

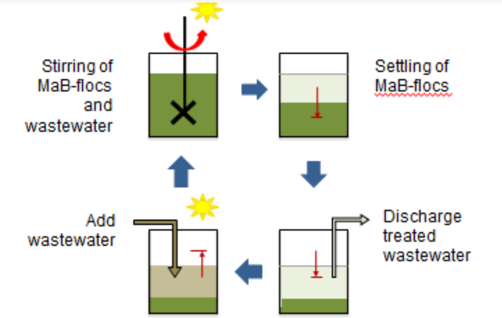
The secret recipe of making MaB-flocs

3. Mix algae and wastewater in <u>s</u>equencing <u>b</u>atch <u>r</u>eactor (<u>SBR</u>)

Selection of fast-settling flocs in 1-2 weeks



Other advantages of the MaB-floc concept



1. Costless separation of the treated wastewater and MaB-flocs

MaB-flocs settle at night in the reactor; no flocculants

2. Hydraulic retention time can be decoupled from MaB-floc retention time

Possible: treatment of low-strength wastewater at a high algal biomass density

3. Flocs are large (200-500 µm) and easy to harvest by filter press (150 µm)

No flocculants needed: cost saving, no chemical contamination

MaB-flocs: for which wastewaters?

- **Problem: wastewaters strongly differ**

- **Solution: screen various industrial wastewaters at lab-scale**

Sewage	(Aquafin)	
Paper mill effluent	(Stora Enso, VPK)	
Pike perch aquaculture	(Inagro)	← **Best !**
Manure treatment	(Innova Manure)	
Food industry	(Alpro)	← **Best !**
Chemical industry	(BASF)	

Van Den Hende et al., 2011b. New Biotechnol 29, 23-31.
Van Den Hende et al., 2012b. Algaeneer Symposium Proceedings.
Van Den Hende et al., 2014b. Bioresour Technol 161, 245-254.

Outline

1. MaB-floc raceway pond: why and what?

2. Features and challenges

2.1. Wastewater & flue gas

2.2. Biomass production & harvest

2.3. Biomass valorization

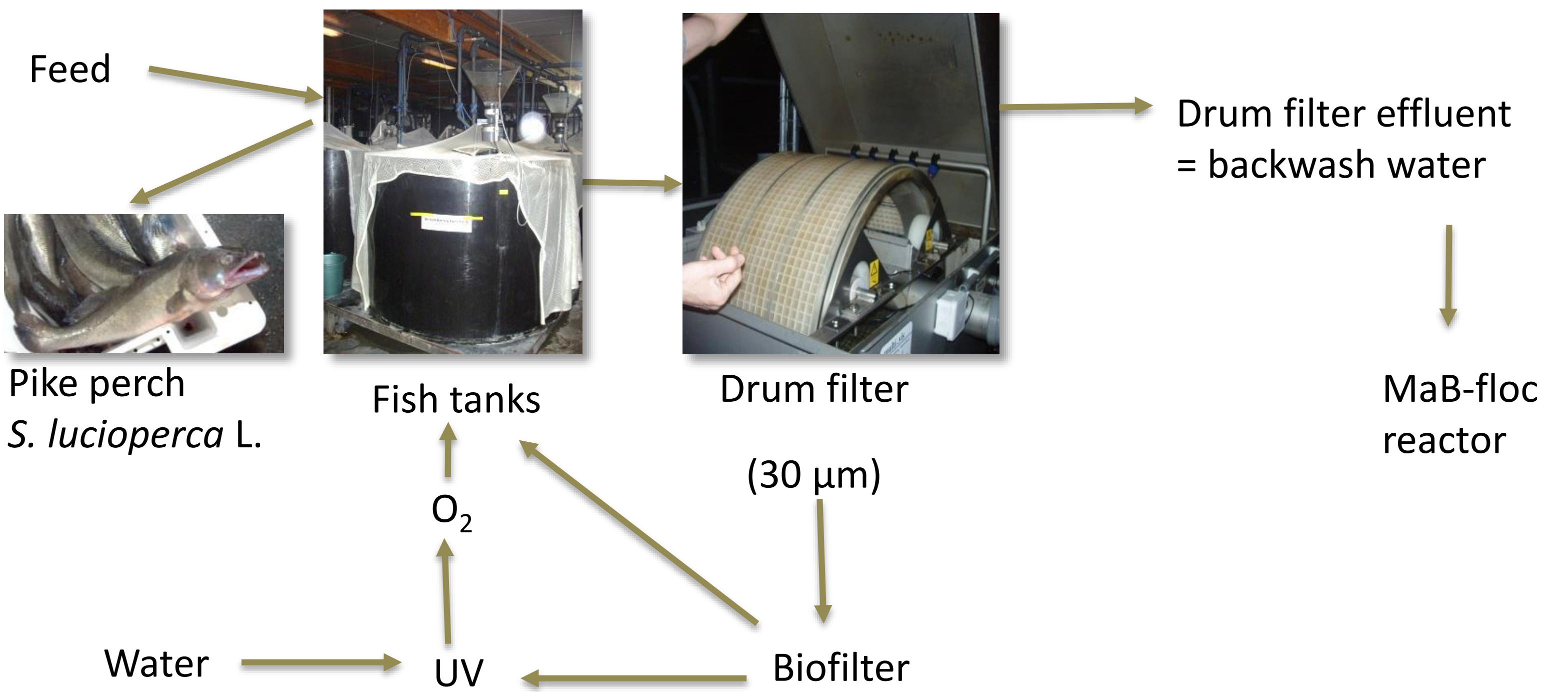
3. Conclusions and future outlook

Aquaculture: wastewater

Wastewater: Drum filter effluent of pikeperch aquaculture (Inagro)

Problem: 45-75 % of energy consumption of WWT is for mechanical aeration of conventional activated sludge (CAS) (Henze et al, 2008)

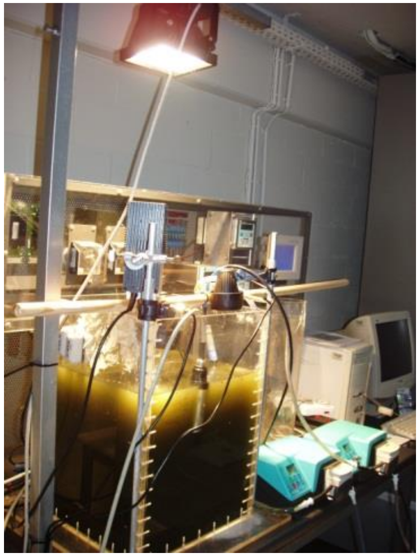
Aim: MaB-floc raceway as an alternative for CAS
Replace mechanical aeration by photosynthetic aeration

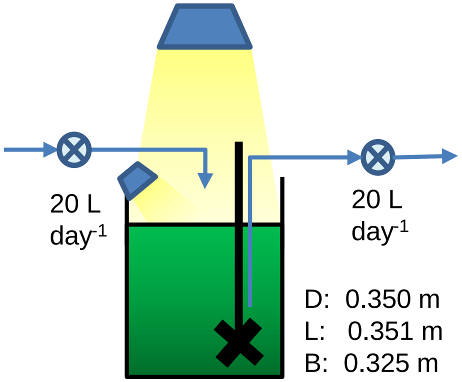


Aquaculture: up-scaling of MaB-floc reactors

4 L indoor
Ugent, Kortrijk

40 L indoor MaB-floc SBR
UGent, Kortrijk

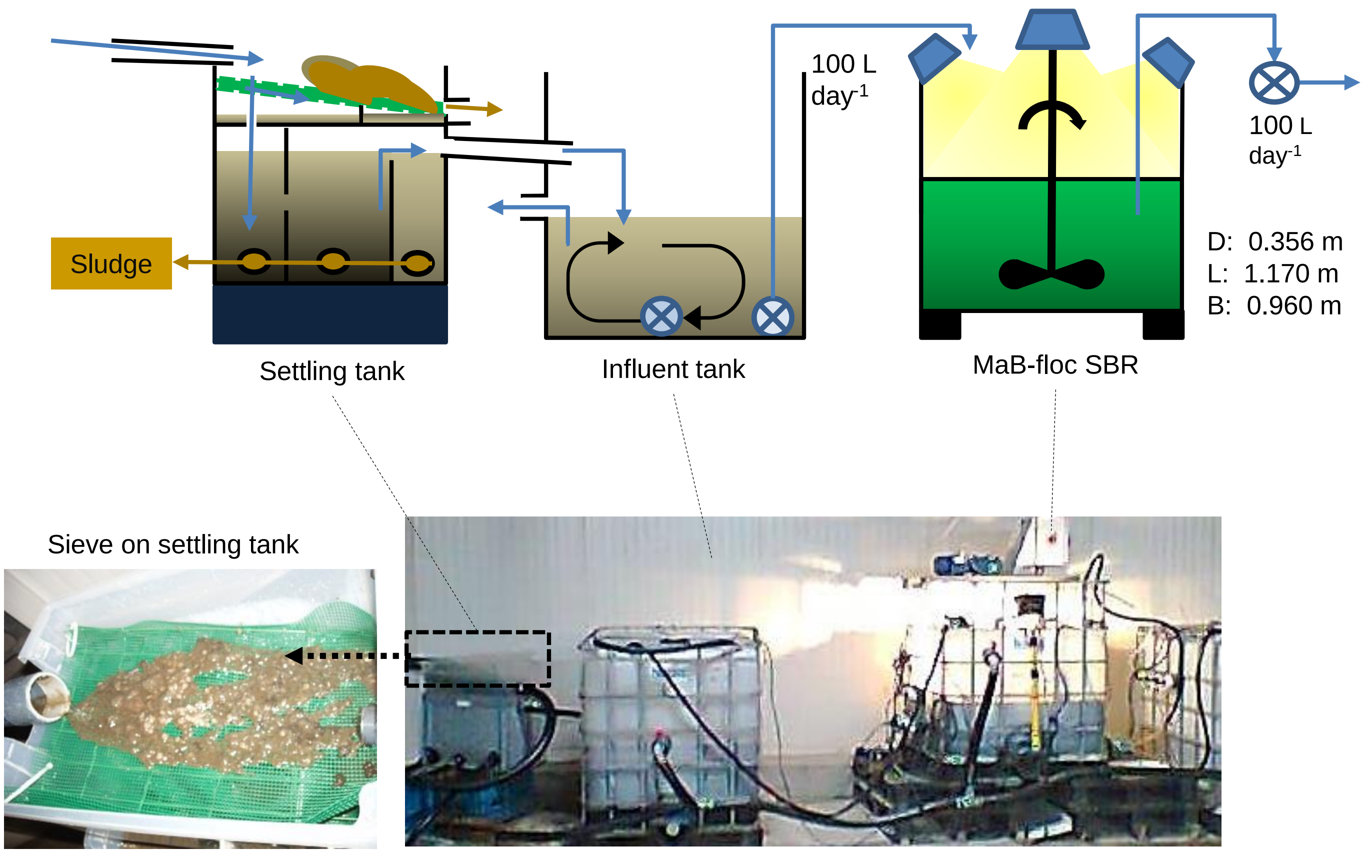




Aquaculture: up-scaling of MaB-floc reactors

400 L indoor MaB-floc SBR of UGent

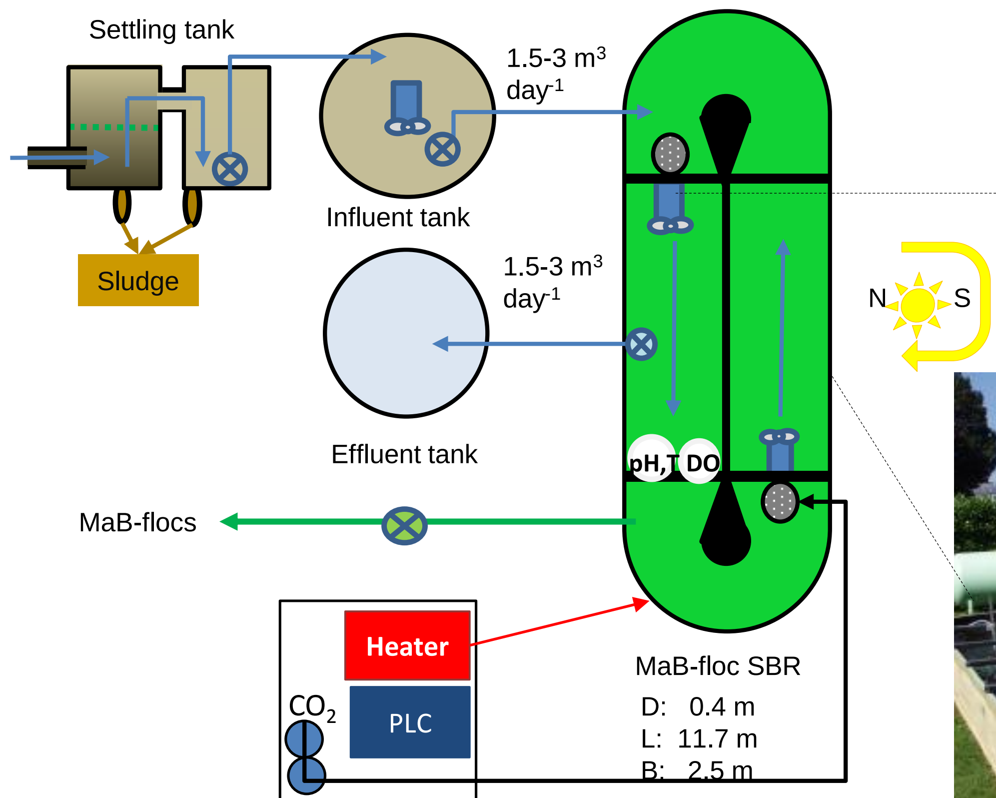
Operation at Inagro, Roeselare



Aquaculture: up-scaling of MaB-floc reactors

12 m³ and 28 m² outdoor MaB-floc raceway pond

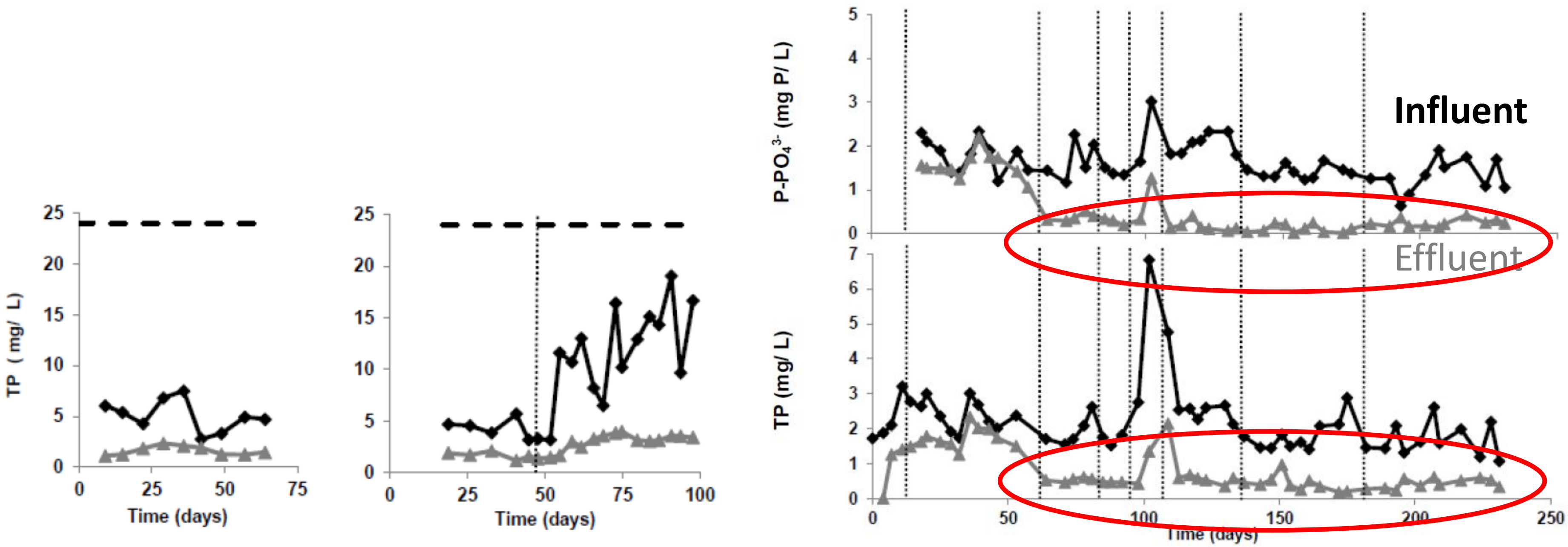
Pilot construction by 2 Belgian SMEs: Bebouwen & Bewaren nv: hardware
CATAEL bvba: 'software' automation



Propellers for stirring

Aquaculture: effluent quality of outdoor pond

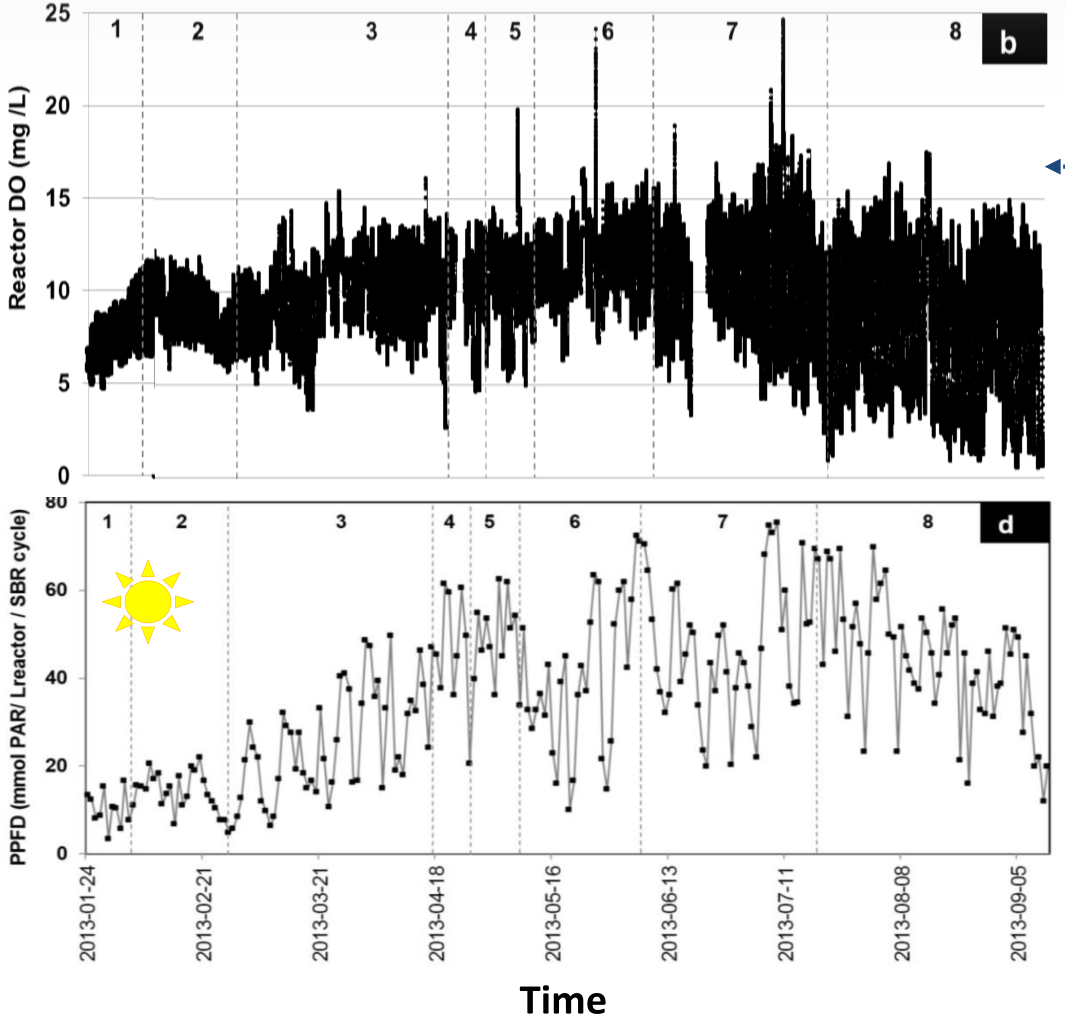
- The COD, BOD_5, TN, NH_4^+, TP, PO_4^{3-} concentrations were below the discharge norms
- Low PO_4^{3-} and TP concentrations in effluent (< 0.8 mg TP L^{-1}; as low as 0.1 mg TP L^{-1})
  -> potential as P-polishing technology



40 L indoor | 400 L indoor | 12 m³ outdoor pond

Van Den Hende et al., 2014a. Bioresour Technol 161, 245-254.

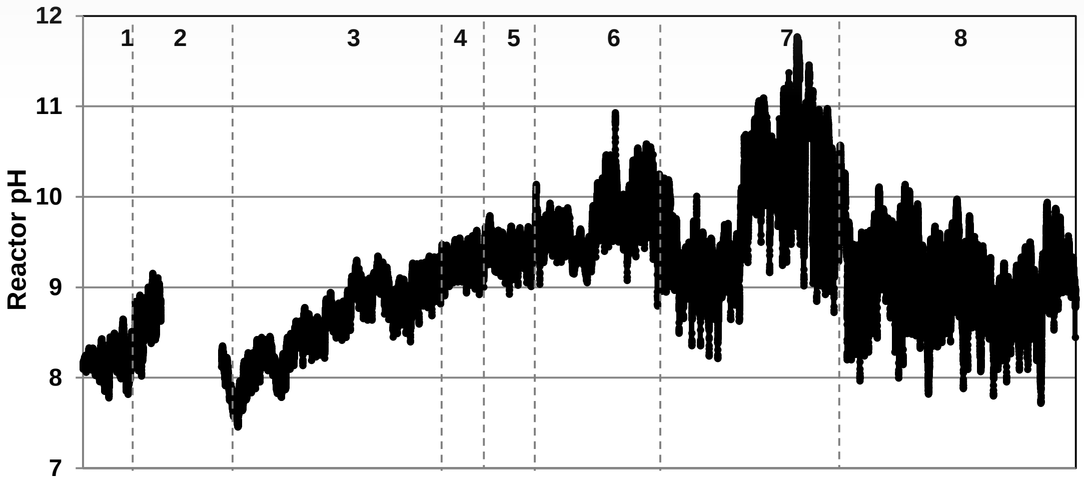
Aquaculture: photosynthetic aeration in outdoor pond



- **Photosynthetic aeration by microalgae was sufficient**
  Oversaturation
  Aerobic, also at night
- **No mechanical aeration needed: cost saving**
  <-> CAS: 45-75 % of working costs
- **10 X more land area needed !**
  MaB-floc ponds: 0.4 m deep
  <-> CAS : 4 m deep

Van Den Hende et al., 2014a. Bioresour Technol 161, 245-254.

Aquaculture: pH problem in outdoor pond



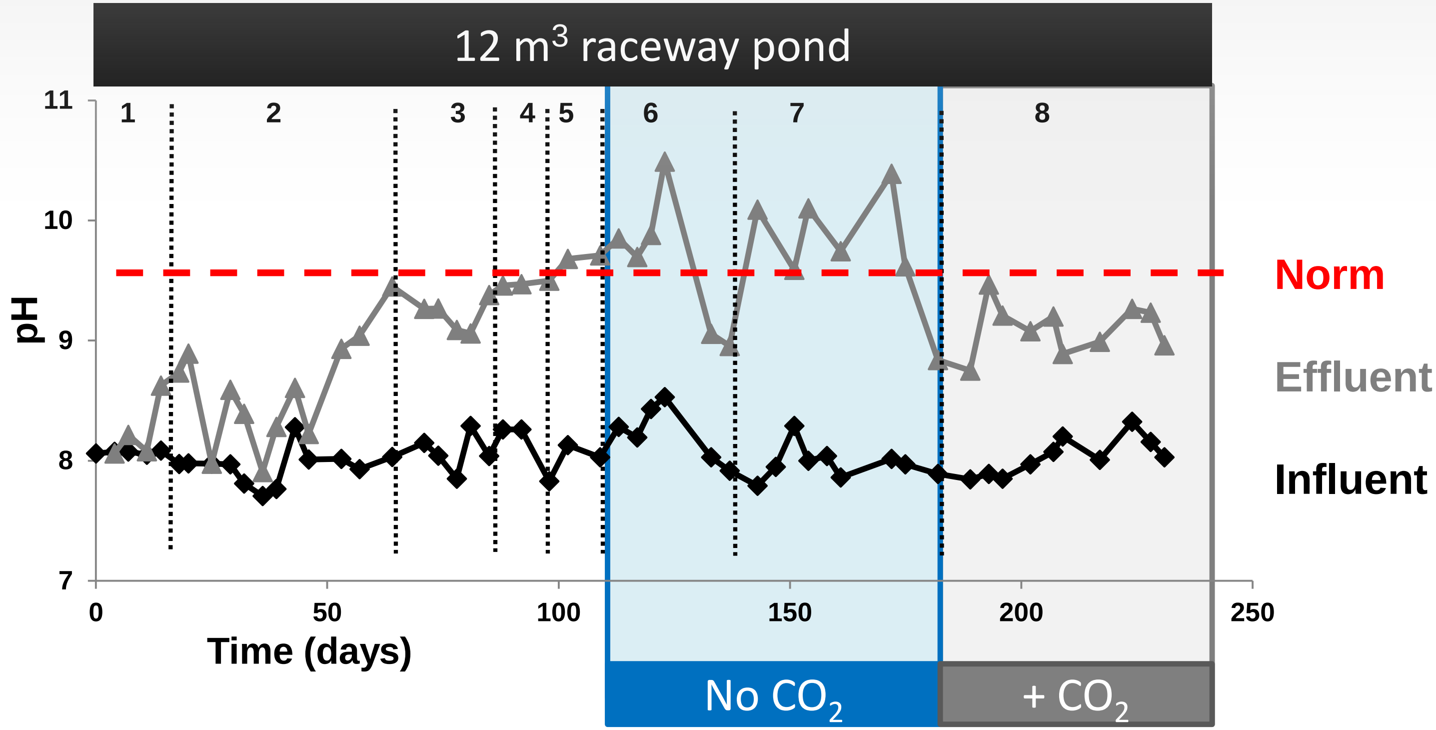
- **Diurnal pH fluctuations**

Photosynthesis
increases pH
during day

Respiration
decreases pH
during night

- **Effluent discharge after night to reach pH discharge norm**
  -> this strategy is not sufficient in summer

Aquaculture: pH problem in outdoor pond



- Outdoors, CO_2 (5%) was needed to lower pH
  Flue gas injection = extra cost ! But, low flue gas flow rates: 0.00004 vvm, so low cost

- MaB-floc SBR is not a flue gas treatment systems -> needed area is huge !
  Flue gas injection in open pond ≠ CO_2 credits !

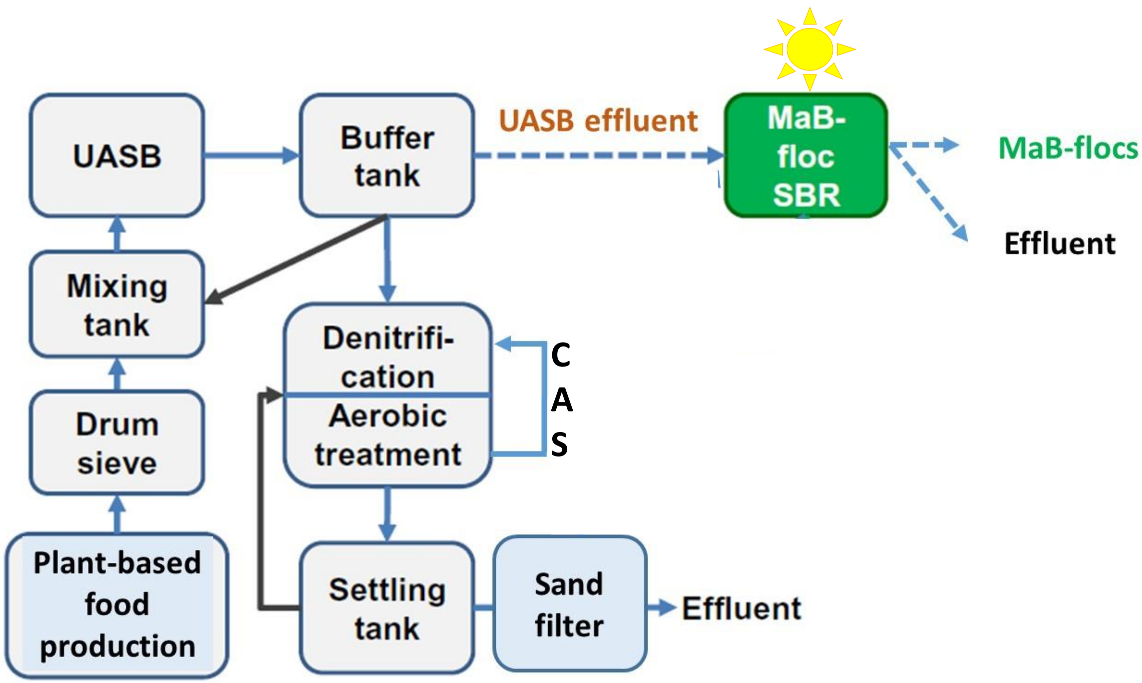
Van Den Hende et al., 2012b. Biotechnol Advanc, 1405-1425.

UASB effluent

Wastewater: Upflow anaerobic sludge blanket (UASB) effluent (Alpro)

Problem: 45-75 % of energy consumption of WWT is for mechanical aeration of conventional activated sludge (CAS) (Henze et al, 2008)

Aim: MaB-floc raceway as an alternative for CAS
Replace mechanical aeration by photosynthetic aeration

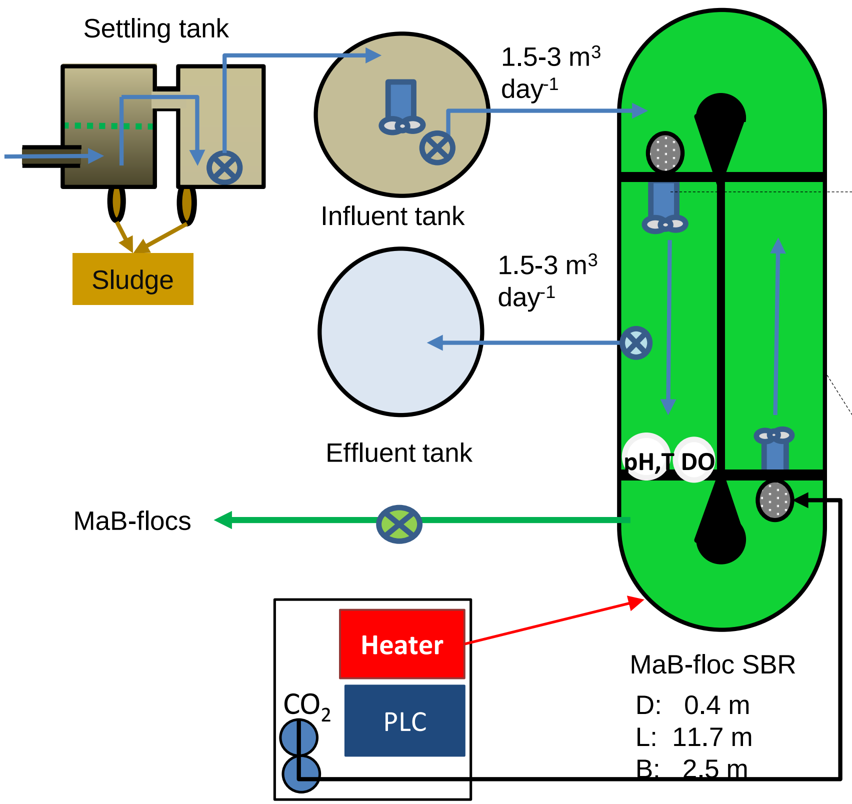


UASB effluent: MaB-floc raceway pond

Mobile pilot: outdoor MaB-floc raceway pond of **28 m²**

Construction by 2 Belgian SMEs: CATAEL bvba (automation)

Bebouwen & Bewaren nv (hardware)



Propeller pump
for raceway stirring

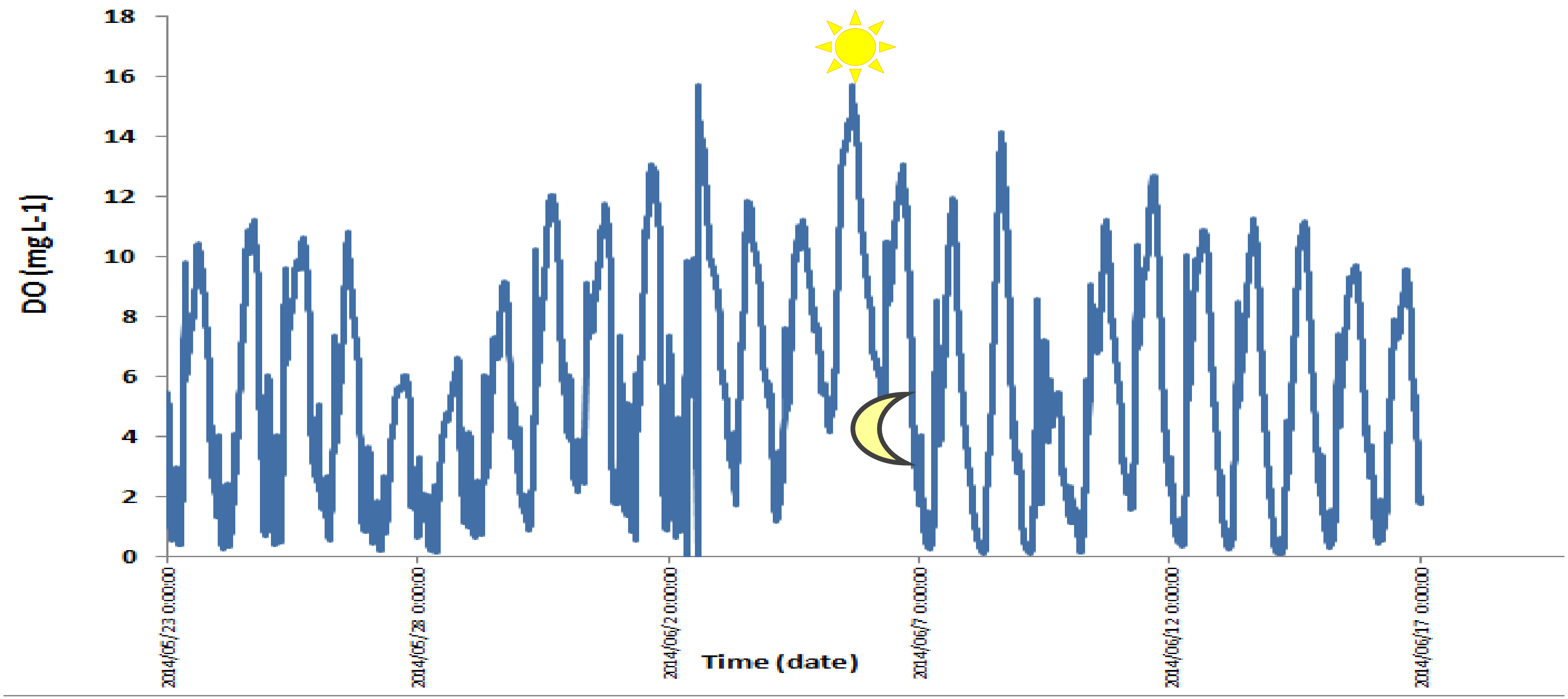
UASB effluent: photosynthetic aeration in outdoor pond

Photosynthetic aeration by microalgae

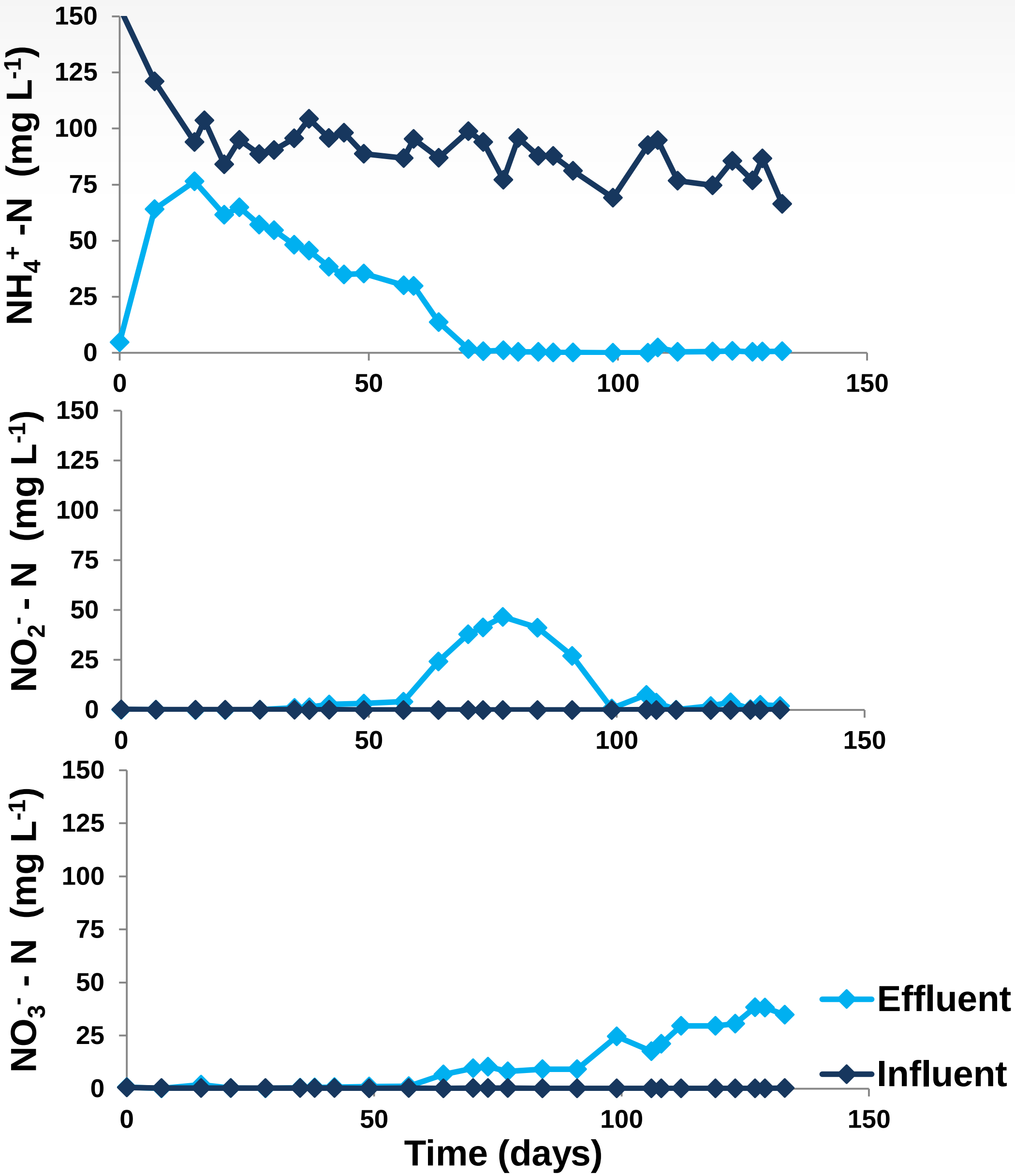
Strong diurnal variations of dissolved oxygen (DO)

Day: aerobic, up to oversaturation of DO

Night: aerobic, but sometimes anoxic



UASB effluent: nitrification



DO adequate for nitrification

Increase in NH_4^+ removal

98 ± 4 % of NH_4^+ removed

Temporary increase of NO_2^-

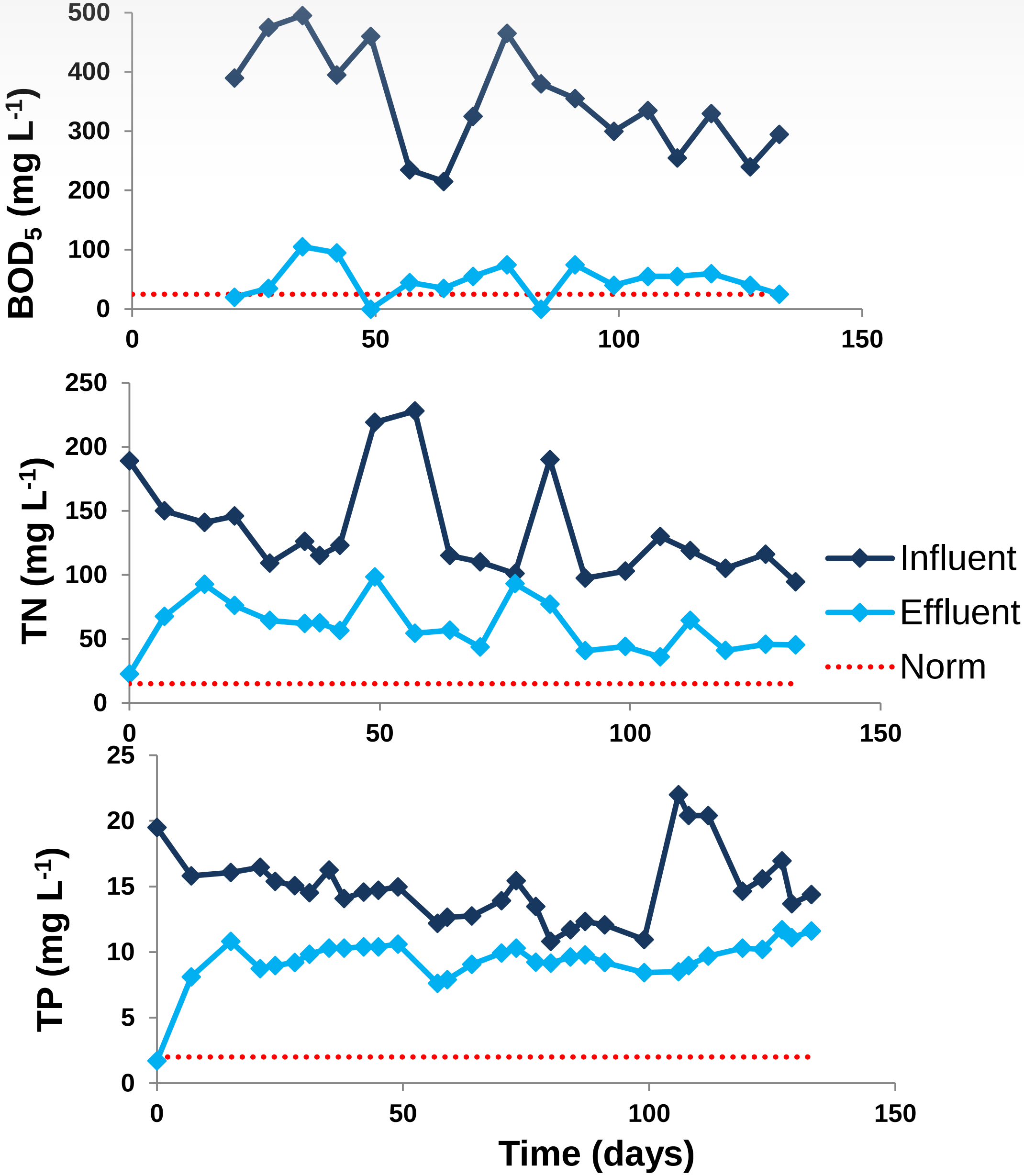
Production of NO_3^-

No mechanical aeration needed: cost saving

<-> 45-75 % of energy consumption in WWT is for mechanical aeration

(Henze et al., 2008)

UASB effluent: effluent quality and land area of outdoor pond



- **Effluent cannot be discharged**

  $BOD_5 > 25$ mg L^{-1}

  TN > 15 mg L^{-1}

  TP > 2 mg L^{-1}

- **MaB-floc raceway pond :**

  35 days HRT and 0.35 m deep

  = 14.6 ha per daily 1,500 m^3 wastewater

  <-> CAS:

  43 hours HRT and 4 m deep

  ~ 0.5 ha per daily 1,500 m^3 wastewater

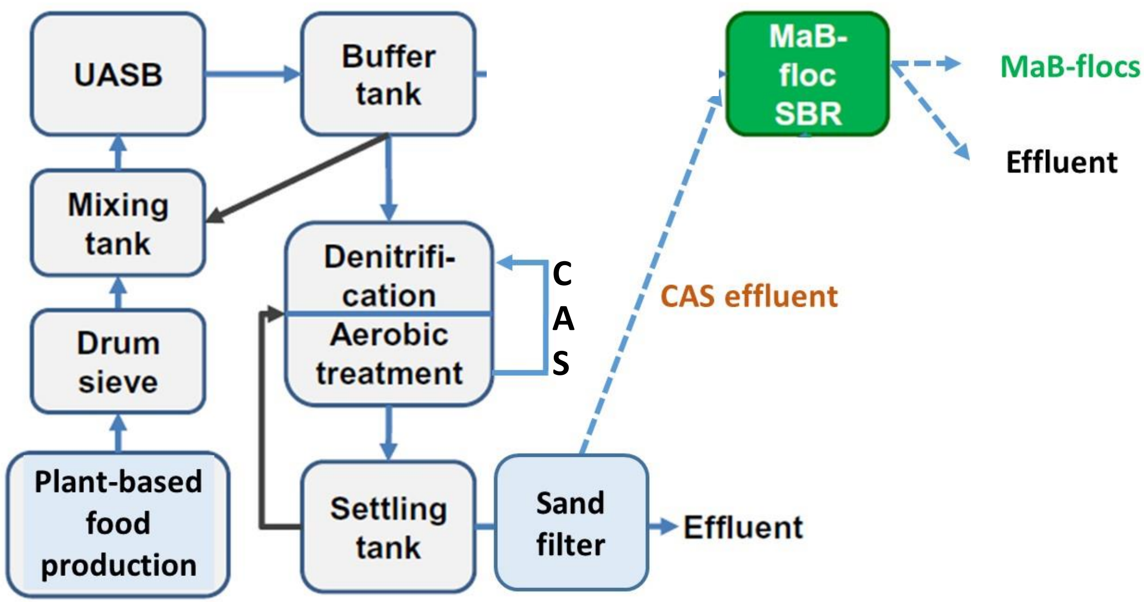
Van Den Hende et al., 2015a. EUBCA.

CAS effluent

Wastewater: Conventional activated sludge (CAS) effluent

Problem: P is becoming scarce, and P-recovery is of strong interest (Shilton 2008)

Aim: MaB-floc raceway pond as additional P-polishing step
HRT of 2 days -> 0.9 ha per daily 1,500 m^3 wastewater



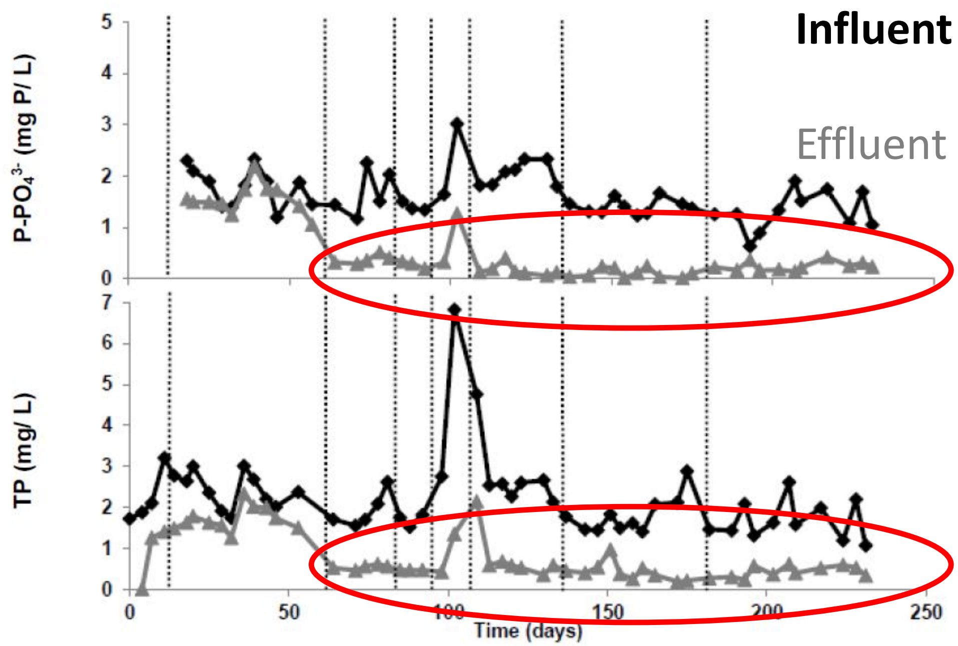
CAS effluent: phosphorous removal in outdoor pond

- CAS effluent :
  20 ± 18 % of TP removed

  Not for P-polishing (yet)

- Aquaculture wastewater:
  64 ± 22 % of TP removed

  -> Potential as P-polishing technology
  0.1-0.8 mg TP L^{-1} in effluent



Van Den Hende et al., 2015a. EUBCA.

Van Den Hende et al., 2014a. Bioresour Technol 161, 245-254.

MaB-floc raceway ponds for wastewater treatment: limitations

1. Large pond area due to undeep ponds and high HRT

Pikeperch farm of 1 ha fish tanks	-> 1 ha for 1,000 m^3 wastewater/day
UASB effluent Alpro	-> 14.6 ha for 1,500 m^3 wastewater/day
CAS effluent Alpro	-> 0.9 ha for 1,500 m^3 wastewater/day

2. Pond heating in winter a problem

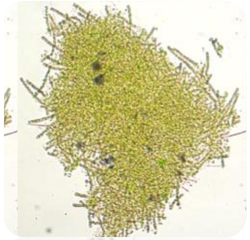
Winter: heating open pond to min. 12°C -> Waste heat?

Opportunities for warmer climates without strong seasonal variations?

3. Effluent quality

Food UASB effluent: optimisation needed

Outline



1. MaB-floc raceway pond: why and what?

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   - 2.1. Wastewater & flue gas
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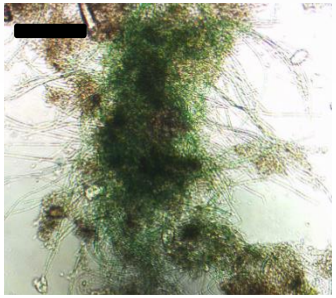
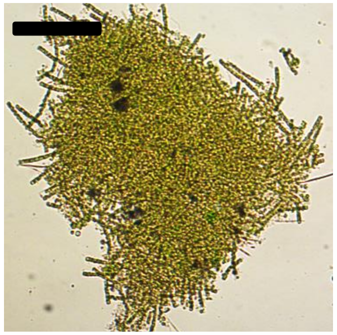
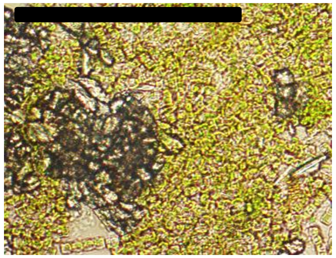
Aquaculture: indoor versus outdoor MaB-flocs

400 L indoor



Raceway outdoor





Up-scaling shifted the dominant algal sp.

Phormidium sp. indoor

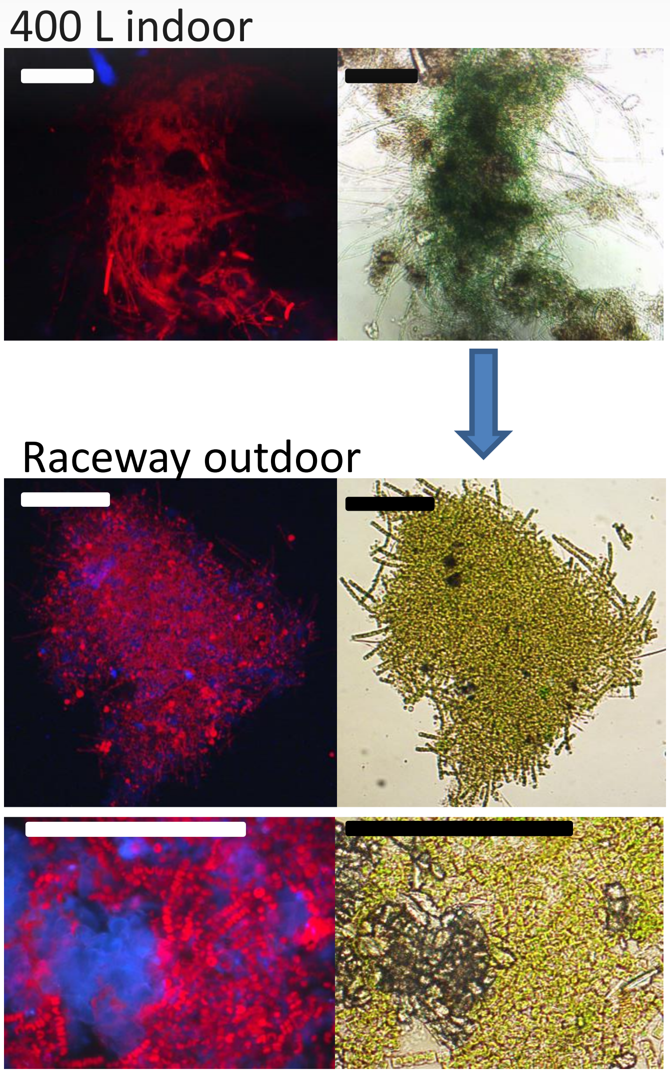
(filamentous cyanobacteria)

to *Ulothrix* or *Klebsormidum* sp. outdoor

(filamentous microalgae)

Van Den Hende et al., 2014a. Bioresour Technol 161, 245-254.

Aquaculture: indoor versus outdoor MaB-flocs



- **Up-scaling increases the crystal content**
  Red = chlorophyl -> algae
  Blue = crystals -> Ash in MaB-flocs -> $CaCO_3$

- **Crystals enhance the settling of MaB-flocs**
  Correlation ash content and dSVI (r_s= 0.935)

- **Negative for biomass valorization?**
  Decreased energy content of biomass
  Unbalanced Ca:P:K ratio

Van Den Hende et al., 2014a. Bioresour Technol 161, 245-254.

Aquaculture: up-scaling & biomass productivity

Scale-up decreased the biomass productivity

10 times less TSS, 13 times less VSS

1.5-4 times lower compared to ww-fed HRAP in New Zealand (Park et al., 2011)

But, no optimisation yet!

Reactor	**TSS productivity (mg TSS $L_{reactor}$ day^{-1})**	**VSS productivity (mg VSS $L_{reactor}$ day^{-1})**
4 L indoor	236 ± 73	109 ± 30
40 L indoor	65 ± 8	45 ± 6
400 L indoor	16 ± 23	12 ± 17
12 m^3 outdoor	23 ± 54	8 ± 18

: 10   **: 13**

TSS: total suspended solids; VSS: volatile suspended solid

Van Den Hende et al., 2014a. Bioresour Technol 161, 245-254.

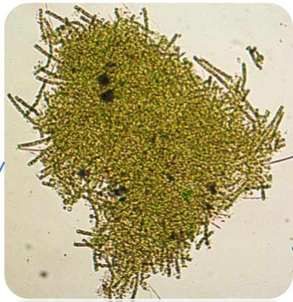
Aquaculture & food: biomass productivity

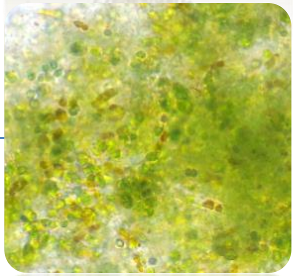
Outdoor pilot scale productivity based on pilot scale results

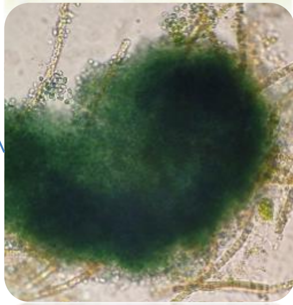
Assuming 1 ha pond = 1.6 ha land

<-> Conventional crops: 12-16 ton DM ha_{land}^{-1} $year^{-1}$ (Peeters., 2010)

Wastewater origin	**TSS productivity (ton TSS ha_{pond} y^{-1})**	**VSS productivity (ton VSS ha_{pond} y^{-1})**	**Chlorophyl *a* in MaB-flocs (% VSS)**
Aquaculture	33	12	1.64
Food - UASB	31	27	0.35
Food – CAS	25	17	1.17







Van Den Hende et al., 2014a. Bioresour Technol 161, 245-254.
Van Den Hende et al., 2015. EUBCIA.

MaB-floc harvesting: 1. settling, 2. filtering

MaB-floc SBR raceway pond

1.
Settling of
MaB-flocs
(1 hour)

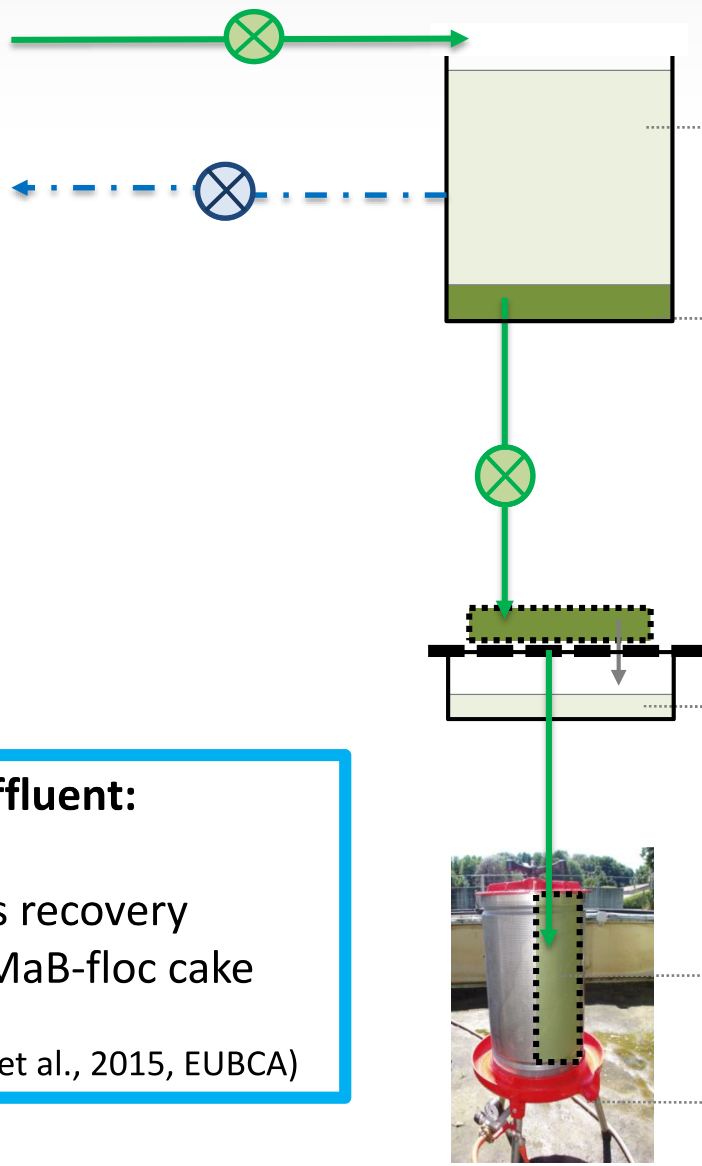
2.1.
Filtering by
gravity

2.2.
Filtering by
hydropress

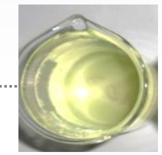
MaB-floc cake

MaB-floc harvesting: 99% biomass recovery for aquaculture !

MaB-flocs in pond



1. Concentrating step: settling



Supernatant:
7.9 ± 5.7 % MaB-floc TSS loss,
pumped back into pond **-> No loss!**

Settled MaB-floc slurry 70 g TSS L^{-1}

2. Dewatering step: filtering 150-250 µm

2.1. Gravity filtering

Gravity filtrate:
1.2 ± 0.9 % MaB-floc TSS loss

2.2. Hydropress filtering

MaB-floc cake**: 43 ± 8 % dry matter**

Press filtrate:
0.05 ± 0.03 % MaB-floc TSS loss

Food - CAS effluent:

89 % biomass recovery
23 % DM of MaB-floc cake

(Van Den Hende et al., 2015, EUBCA)

Biomass production and harvesting: conclusions

Features

1. Biomass productivity

Moderate for microalgae - High, compared to plant crops

2. Very efficient and cost-effective MaB-floc harvesting, for aquaculture

Pilot: water-powered filter press (4 bar water): 0.16 € kg^{-1} MaB-floc TS

Com.: electricity-powered filter press: 0.01 € kg^{-1} MaB-flocs TS

Limitations

1. Harvesting: results are wastewater dependent

2. High cost of stirring

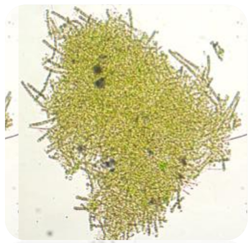
Example: aquaculture wastewater

MaB-flocs at pilot scale: 2 propellers/ pilot -> 10 €/kg MaB-floc TS

MaB-flocs at larger scale: 2 propellers/ 250 m^2 -> 1 €/kg MaB-floc TS

Chiaramonti et al., 2013 propeller stirring at 0.47 W/m^2 pond -> 0.1 €/kg MaB-floc TS

Outline



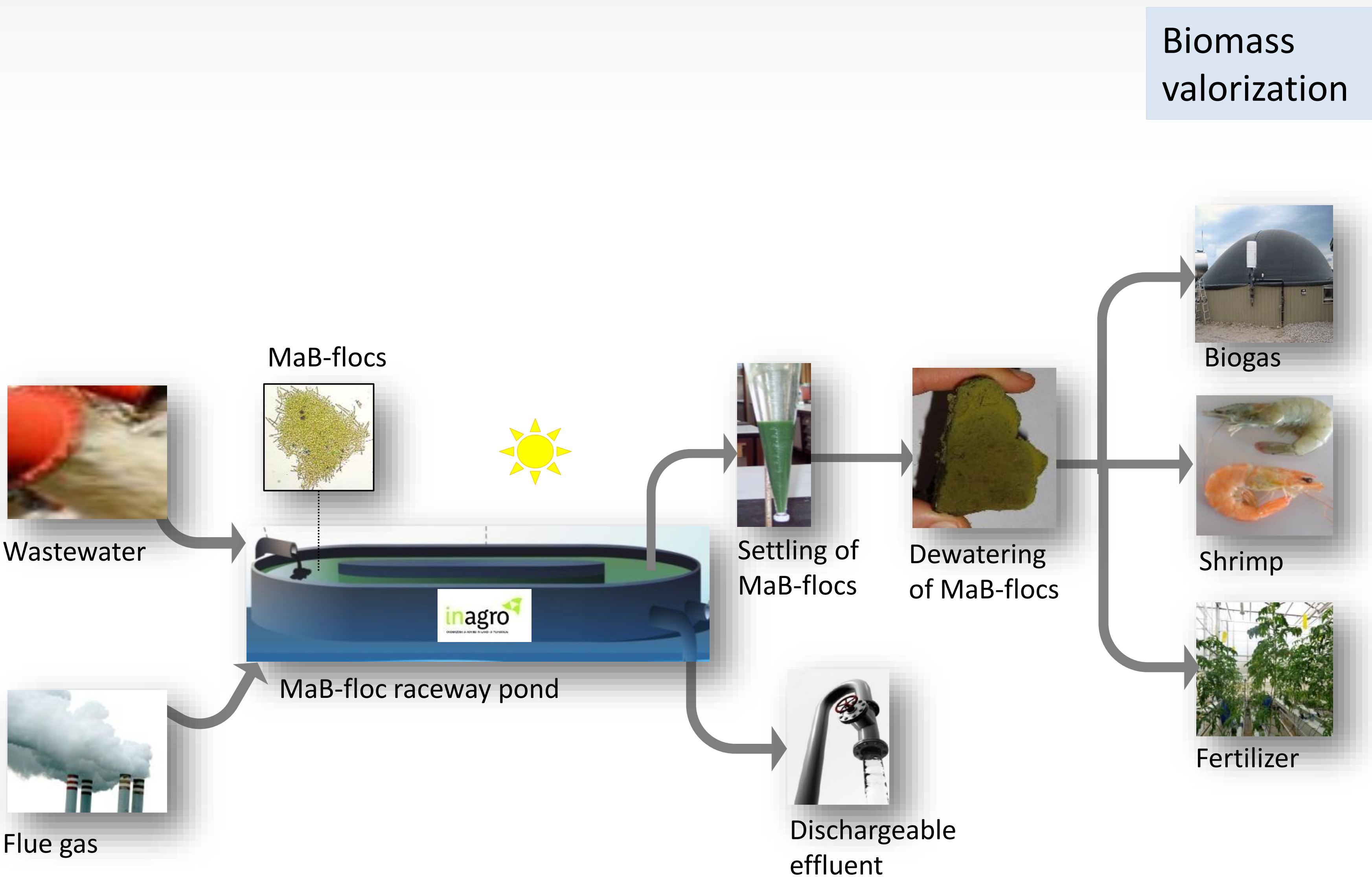
1. MaB-floc raceway pond: why and what?

2. Features and challenges

2.1. Wastewater & flue gas
2.2. Biomass production & harvest
2.3. Biomass valorization

3. Conclusions and future outlook

MaB-floc raceway pond: aquaculture wastewater @ Inagro



Biogas: MaB-flocs as feedstock?

- **Biochemical methane potential (BMP) of MaB-flocs**

  Aquaculture wastewater-fed MaB-flocs

- **Moderate MaB-floc BMP ~ activated sludge < microalgae**

  128-226 NL CH_4 kg^{-1} MaB-flocs VS

  129-380 NL CH_4 kg^{-1} activated sludge VS (Mahdy et al., 2015)

  50-510 NL CH_4 kg^{-1} microalgae VS (Mehrabadi et al., 2015)

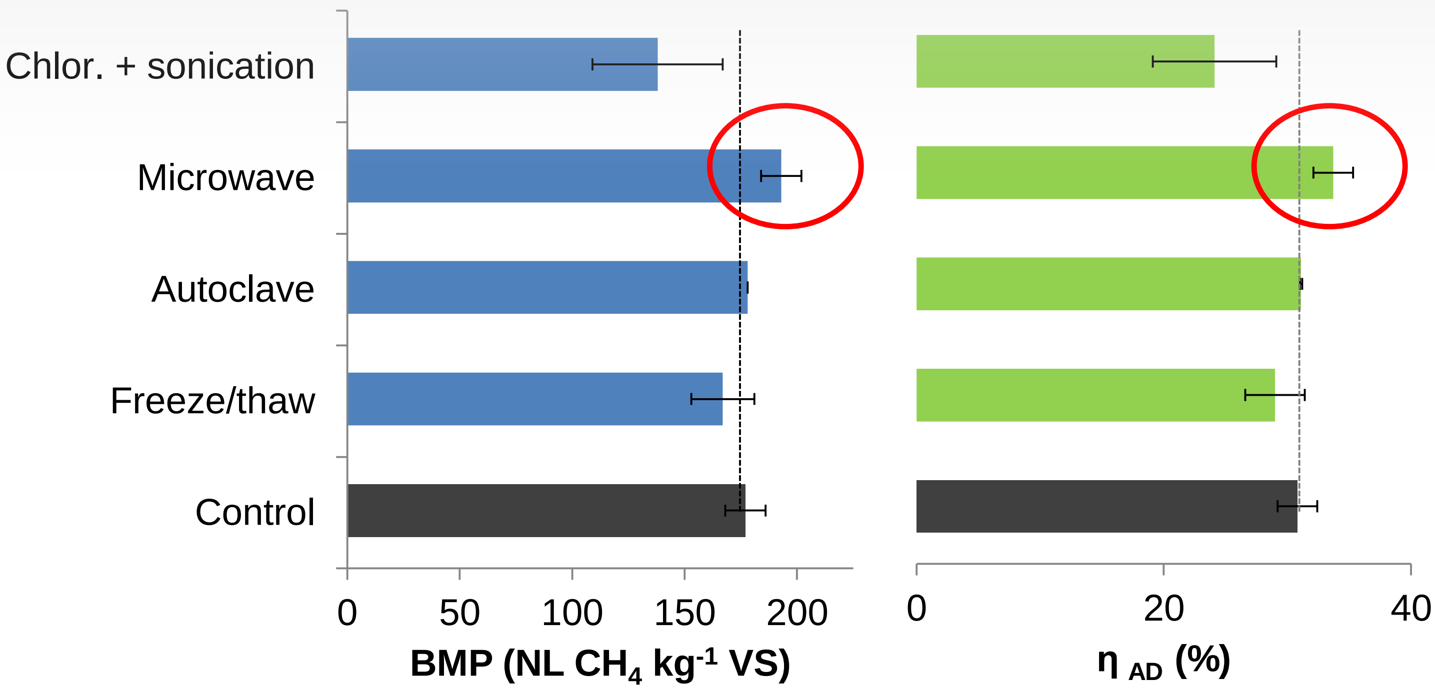
- **Low biomass-to-biogas-conversion efficiency**

  η_{AD} 25 - 36 %

  Only 52-87 % of chlorophyl *a* was removed during AD batch

- **Needed: pretreatment of MaB-flocs**

Biogas: pretreated MaB-flocs?



- **Only improved BMP by a microwave pretreatment (870 s, 700W)**

  9.4 ± 5.2 % increase of BMP, but $E_{input} : E_{output} = 14$

  Compared to 12-78 % increase of BMP, but $E_{input} : E_{output} = 33\text{-}70$ (Passos et al., 2013)

-> Energetically not interesting

Biogas: not a good idea!

- **AD to biogas is not economically interesting for MaB-flocs originating from aquaculture wastewater**

  Biogas revenues are low: < 0.01 € $m^{-3}_{wastewater}$

  Low compared to wastewater treatment cost of 0.30-0.60 € m^{-3} (Verstraete et al., 2009)

- **Practical constraints**

  Scaling ($CaCO_3$) of reactors due to high ash content of MaB-flocs

- **Needed: biomass valorization pathways with €**

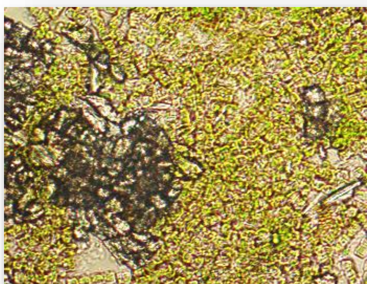
  If MaB-floc market price of 2.5 € kg^{-1} DM -> 0.32 € m^{-3} wastewater

Van Den Hende et al., 2014d. XI Simposio Latinoamericano de Digestion Anaerobia, 11/24-27, La Havana.

Shrimp feed: MaB-floc inclusion ?

Problem:

What to do with these low-energy MaB-flocs ?



Compound	Content (%)
Ash	62
Calcium	17
Protein	21
Lipid	4

Research question:

Can MaB-flocs be included in diets of white Pacific shrimp?

*Litopenaeus vannamei (*Boone 1931)

CreveTec

AQUACULTURE farming technology

0 - 2 - 4 - 6 - 8 % inclusion

Mainly wheat was replaced

1. Shrimp quantity?
2. Shrimp quality?

Shrimp feed: no effect on production

0-2-4-6-8 % MaB-floc inclusion did NOT lead to significant differences of:

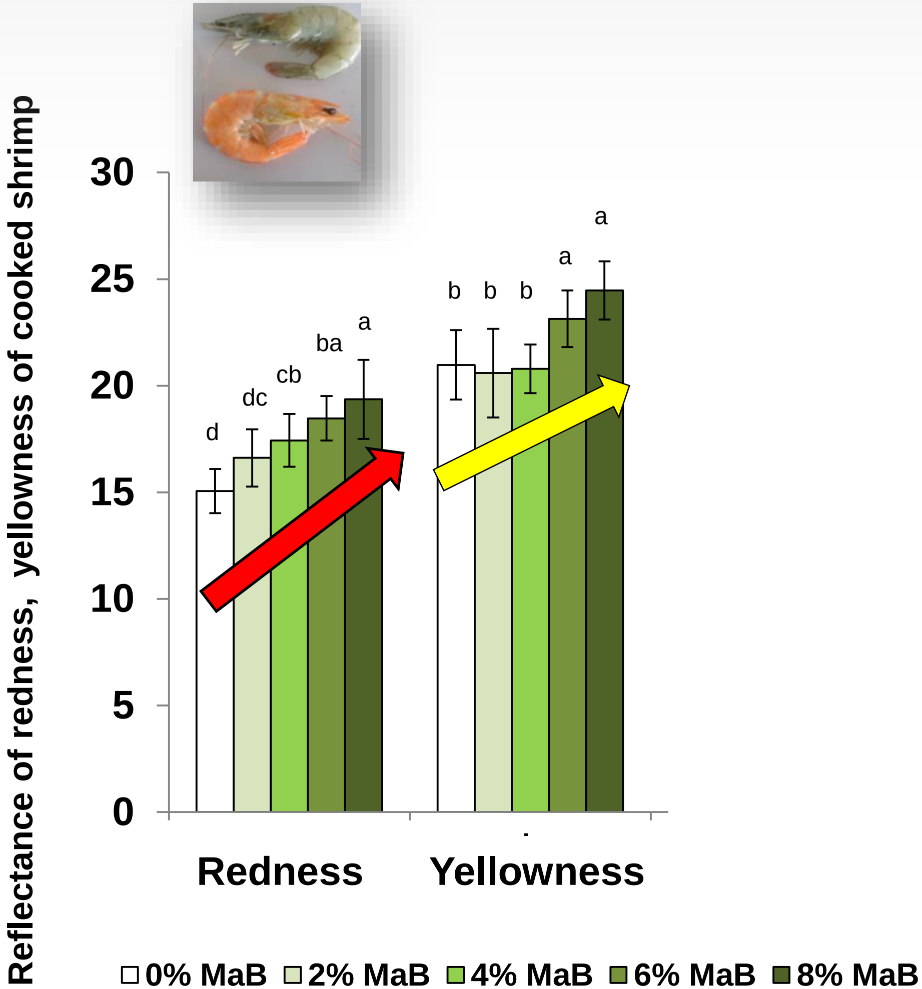
Shrimp quantity	**Range of averages of all trials**
Survival	93 - 97 %
Weight gain	0.32 - 0.34 g day^{-1}
Feed conversion ratio	1.17 - 1.27

Shrimp quality of shrimp tails

Proximate composition

Fatty acid profile

Shrimp feed: significant effect on pigmentation



- **MaB-flocs effect pigmentation of cooked shrimp tails**
  Enhanced redness and yellowness
- **MaB-flocs contain 0.25 %m carotenoids**
- **Increased market value of shrimp ?**

Van Den Hende et al., 2014c. Aquaculture Research, DOI:10.1111/are.12564.

Shrimp feed: EU market regulations – is it legal?

Regulation EC No 767/2009: NO!

Restricts the use of faeces and urine including of fish (aquaculture) in feed that enters the EU market

Restricts the use of waste from treatment of industrial wastewater in animal feed

Directive 91/271/EEC: BUT…

Industrial wastewater is 'wastewater which is discharged'

e.g. aquaculture wastewater in closed RAS = process water ?

Opportunities: YES?

Don't bring it on the market -> use it where it is produced -> integrated system

Process water free of urine and manure particles

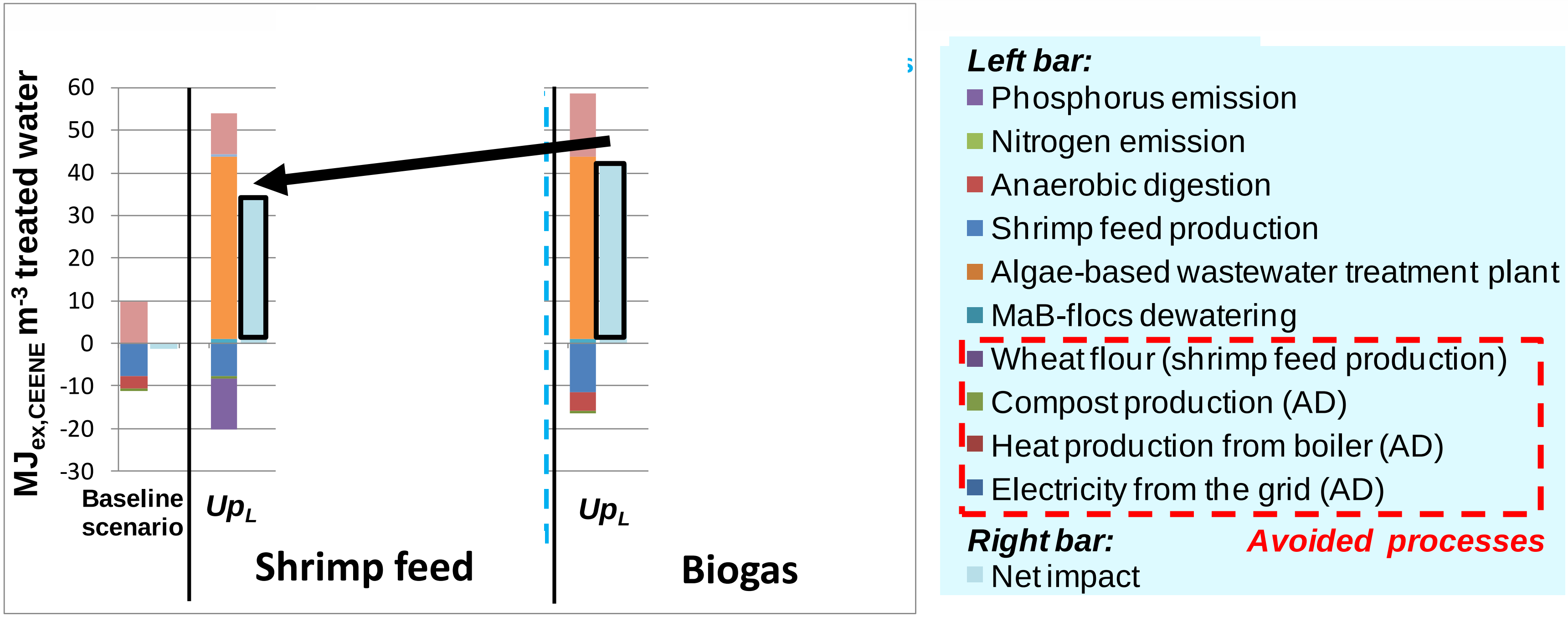
But, more research is needed

Health of shrimp and consumers

Environmental sustainability: LCA

Environmental sustainability: biogas vs shrimp

Resource footprint of shrimp feed is lower than for biogas



CEENE 2014: Cumulative Exergy Extraction from the Natural Environment (Dewulf et al., 2007)

UP$_L$: 1 ha linear up-scaled 40 ponds of 250 m^2

More info: sophie.sfez@ugent.be

Sfez et al., 2015. Bioresour Technol 190, 321-331.

Shrimp feed: conclusions

- **Low inclusion of MaB-flocs in shrimp diets enhances shrimp pigmentation**

- **LCA: shrimp feed preferred above biogas**

- **Implementation potential in EU is limited**

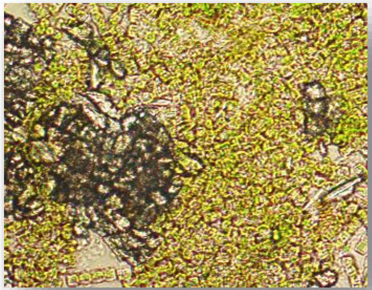
  In EU: integrated systems, manure-free process water

  Tropical regions with a large shrimp industry -> New green water technology

Fertilizer: MaB-flocs?

Problem:

What to do with these low-energy MaB-flocs ?



Research question:

MaB-flocs as slow-release fertilizer?

Mix with substrate for tomato hydroculture

4 fertilizers:

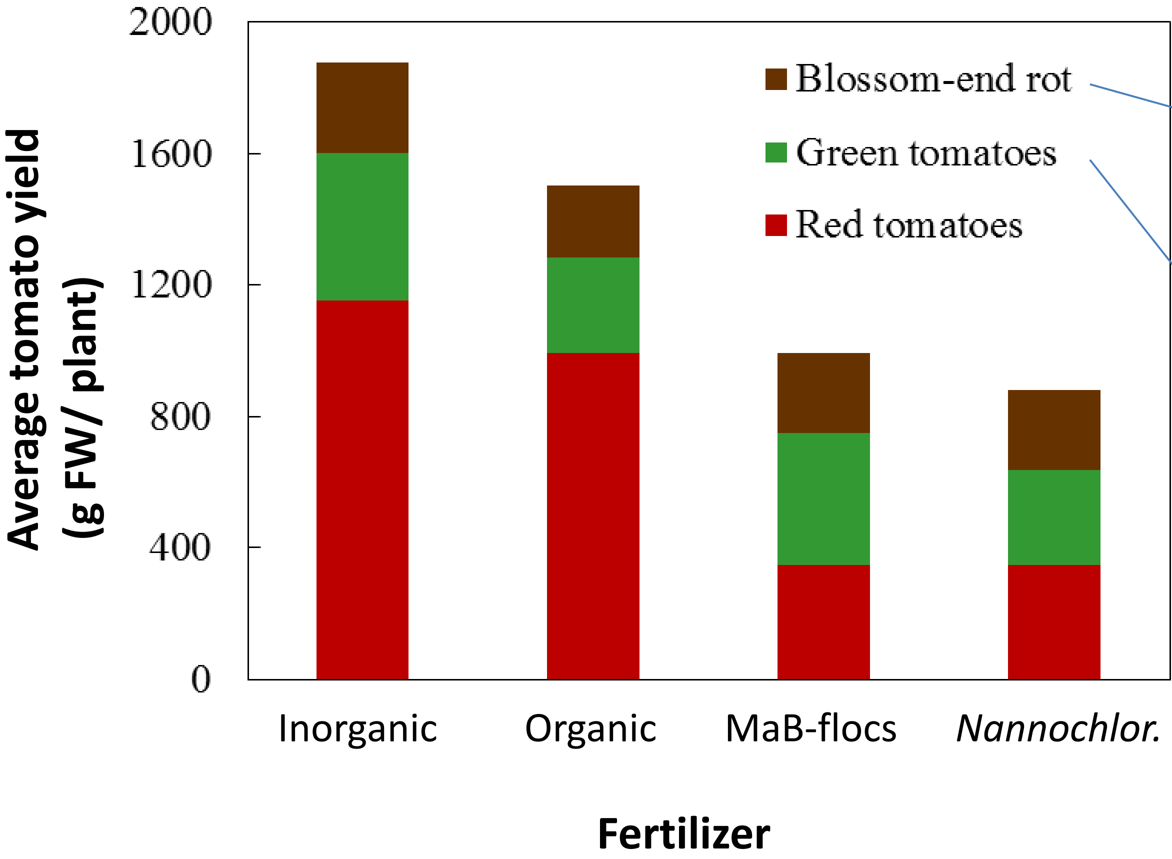
- Inorganic fertilizer
- Organic fertilizer
- MaB-flocs
- *Nannochloropsis*

Differences in:

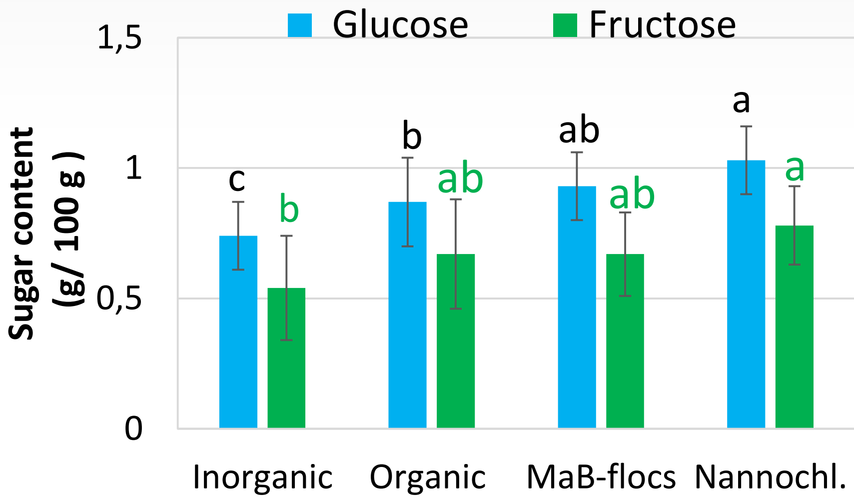
1. Plant growth?
2. Mineralisation rate?
3. Leaf and fruit composition?

Fertilizer: tomato yield

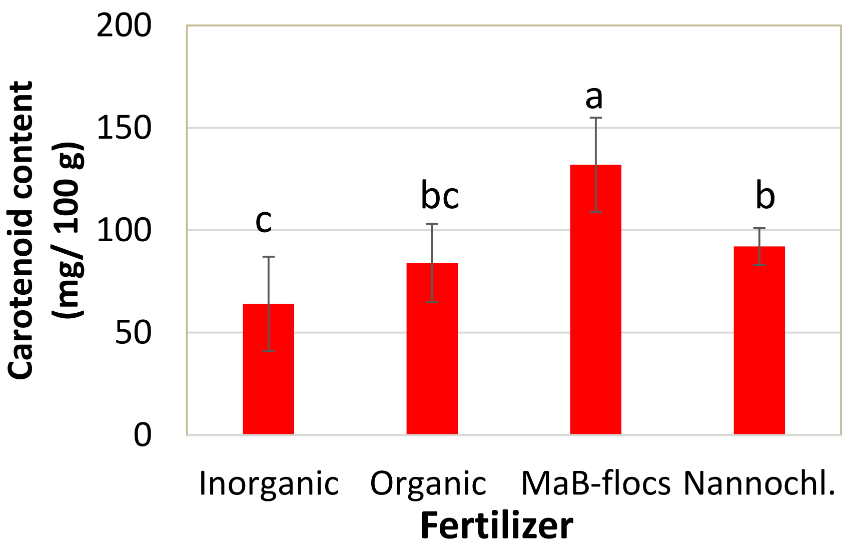
MaB-flocs (and *Nannochloropsis*) decrease the yield of red tomatoes



Fertilizer: tomato composition



- **MaB-flocs significantly increase the glucose content** compared to the inorganic fertilizer



- **MaB-flocs significantly increase the total carotenoid content** compared to all other fertilizers

Fertilizer: conclusions

- **MaB-flocs have potential as slow-release fertilizer for tomato hydroculture**
  if the tomato yield can be increased
  if the improved quality (sugar, carotenoids) can be maintained
  if economically feasible

- **More info**
  PhD student Joeri Coppens, LabMET, Ghent University
  Joeri.coppens@ugent.be

Coppens et al., 2015. Proceedings UNESCO-IHE, Delft, NL.

MaB-flocs

1. Why and what?

2. Features and challenges

3. Conclusions and future outlook

MaB-floc SBR ponds: conclusions

Features

Proof-of-principle of photosynthetic aeration in NW Europe

Promising results on bioflocculation

Moderate to high biomass productivities, compared to plant crops

Cost-effective harvesting: < 0.01 € kg^{-1} MaB-flocs TS

Limitations

UASB effluent treatment -> huge areas, and no dischargeable effluent (yet)

CAS effluent treatment -> moderate area, but low P removal efficiency

Heat during winter

Changing wastewater treatment into biomass production in undeep ponds is a radical change for industries in EU

Research needed to turn this green science into an industrial reality

Biomass valorization -> Key to unlock the potential of MaB-floc SBR technology

All it takes to unlock the potential of MaB-flocs is an unlocked door…

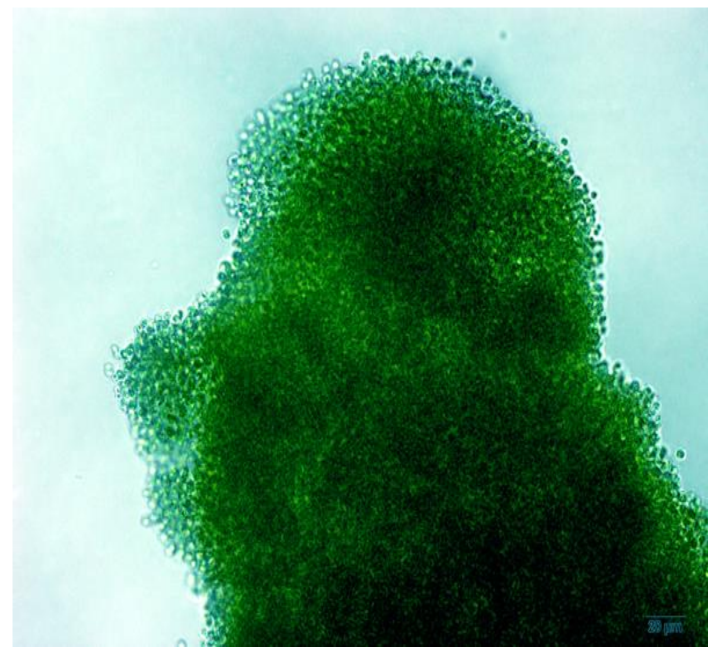
All it takes to unlock the potential of MaB-flocs is an unlocked door…

Liquid fraction of dewatered MaB-flocs after (accidently) thawing

MaB-floc SBR ponds: current EnAlgae research

- **Valorization of MaB-flocs grown on wastewater of food company Alpro**

- **Interested in blue and red pigments ?**
  sofie.vandenhende@ugent.be

The truth about MaB-flocs :

Thank you

The truth about MaB-flocs :
a work of many people,   and many more to come

Alpro: Coolsaet Carlos, Vanhoucke Thomas
Aquaculture Farming Technology: Claessens Leon
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sofie.vandenhende@ugent.be

www.enalgae.eu info@enalgae.eu

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