Microbial cleantech
for a sustainable water cycle and food production chain

(Wordle of Verstraete et al., 2016)
1. The sustainability challenge at hand
2. Microbial cleantech
3. Removal solutions
4. Recovery solutions
5. Reduction solutions
6. Conclusions
7. Acknowledgments
Sustainable development: a hype?

“Meeting the needs of the present without compromising the ability of future generations to meet their own needs.”

(Brundtland commission, Our Common Future, 1987)

Sustainable development is prerequisite to sustain human life on this planet:

- Mental needs
- Physical needs:
  - Few diseases
  - Breath (clean air)
  - Drink (clean H₂O)
  - Eat (healthy food)

(Protos NGO; Arcimboldo)
Needs: a demanding global population

50% higher demand in dietary protein by 2050

(www.live.worldbank.org)

(Boland et al., 2013)
Fertilizer – Feed – Food – Fork: Many inefficiencies & losses

Fertilizers

- Crop production
  - N:100
  - P:100

Feed

- Food industry
  - N:6
  - P:10
  - Crops

- Animal production
  - N:72
  - P:76
  - Fodder

  - N:36
  - P:38
  - Animal products

Food industry

- Distribution and preparation
  - N:27
  - P:24
  - Food

Consumer

- N:14
  - P:14
  - Consumption

Losses and waste

- Animal slurry, manure
  - N:22
  - P:14

- Industrial wastewater, organic waste
  - N:12
  - P:14

- Sewage, faeces, urine, organic waste
  - N:3
  - P:10

Diffuse emissions

(Coppens et al., 2016)
The result...
Nutrient flows by far exceed planetary safety boundaries

(Steffen et al, 2015, Science)
Do we have enough water in Belgium?
1. Not at all
2. Medium
3. Yes!
Water stress in Europe (Sofroinou & Bishop, 2014)

"Did you know that your daily water footprint is 7400 l?"

Dries Seuntjens
The food/water sustainability challenge: A double-edged sword

→ We need more product

→ We need less impact on environment and natural resources

The future of humankind depends on sustainable development
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The definition of our solution

**engineering** | ˌendʒəˈmərn|  
the branch of science and technology concerned with the design, building, and use of engines, machines, and structures.

**bio**- | ˈbaɪə |  
relating to life  
• biological; relating to biology  
• of living beings

**microorganism** | ˌməɪkrəˈɔːɡ(ə)nɪz(ə)m|  
a microscopic organism, especially a bacterium, virus, or fungus.

**sustainable** | ˌsəˈsteɪnəb(ə)l|  

= bioscience engineering  
= microbial technology  
= microbial cleantech

(Oxford Dictionary of English)
Our ‘3R Strategy’ for nutrient/water management

1. **Reduce**: Improve efficiency, prevent losses, conservation if possible

Choose ‘1, 2 and/or 3’ based on:

1. **Lowest environmental impact**:
   - Efficient in use of natural/depletable resources
   - Poor in harmful emissions

2. **Minimal cost**

2. **Recycle** (reuse) from waste streams: resource recovery

3. **Remove**: clean waste streams to discharge into the environment
Questing for **microbial cleantech** solutions

(colouring by Kasper, 4 years old)
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PhD thesis:
Biofilm and granule applications for one-stage autotrophic nitrogen removal
(prof. Willy Verstraete)

- Process: Partial nitritation/anammox
- Cost reduction and environmental benefits:
  - Consumes less energy
  - Consumes less chemicals (organic carbon)
  - Produces less waste (sludge)
Exercising the boundaries of biological nitrogen removal:

Development strategies for thermophilic nitrification and denitrification

ir. Emilie Courtens

Succession guaranteed

PhD #1: Dr. ir. Emilie Courtens

‘Founding mother of thermophilic nitrification’

Developed for the first time nitrification in a bioreactor around 50°C, with potential for cost savings
A pilot installation (7 m³) for ‘mainstream’ partial nitritation/anammox: towards energy self-sufficient sewage treatment

(Seuntjens et al., 2016)
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Nutrient recovery options

Inorganic, e.g.
- Stripped,
- e.g. $(\text{NH}_4)_2\text{SO}_4$
- Struvite
- Nitrified $(\text{NO}_3^-)$

Organic, e.g.
- Microbial biomass

Fertilizer
- Mineral: fast
- Organic: slow

Nutritional protein (single cell protein)
- Very high protein content
- Highly resource-efficient production (land, water, chemicals)

Green: microbial cleantech
PhD #2: Dr. ing. Joeri Coppens

- Quantified for first time nutrient flows throughout Flanders
- Developed a nitrification strategy for undiluted human urine

Succession guaranteed
Integrated pilot plant (136 L/d): Energy self-sufficient nutrient refining from animal slurries

(Pintucci et al., Water Science and Technology, in press)
Are you prepared to eat microorganisms grown on wastewater?

1. Yes
2. No
Prepared to eat microorganisms cultivated on wastewater

- Yes: 32%
- Maybe: 14%
- No: 9%
- No opinion: 45%

About 50% extra after re-assuring quality

Opinion after explaining that food safety is guaranteed

- No: 30%
- Yes: 47%
- Maybe: 20%
- No opinion: 3%

Consumer acceptance
(45 people in the streets of Antwerp)
Production of purple bacteria on fermented wastewater: infrared light as steering tool

- Purple non-sulfur bacteria
- Volatile fatty acids
- Light (VIS + IR)

-> High growth rates and protein productivity
Struvite as ‘SCP nutrient hub’

Clarebout potatoes; BE NuReSys

**No growth limitation** if synthetic P in growth media is replaced by **struvite** for:
- Microalgae
- Purple non-sulfur bacteria
- Aerobic heterotrophic bacteria

Rapid solubilisation -> **Direct addition** into the bioreactor is **feasible**

-> Struvite can be a **sustainable nutrient source for SCP** production
PhD #3: Dr. Francis Meerburg

‘Founding father of HiCS’

Developed a high-rate version of the contact/stabilization (HiCS) activated sludge process, a better process for energy recovery from wastewater.

Succession guaranteed
Prototype installation for Space missions: Up to 90% water recovery, for the treatment of urine and shower water produced by 1 person
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Microalgae for human consumption

*Spirulina platensis*  
*Chlorella vulgaris*

Microalgae

Light (VIS)

CO₂  
O₂

How can cultivation conditions improve the nutritional value?
± 100 customers of Bio-Planet (organic supermarket)

60% of the customers do NOT eat microalgae, why?

-> Commercially interesting to inform people about microalgae
Awareness campaign:
Cooking with Spirulina
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A professorial view and ambition for impact

1. Prioritize: if anything, society needs sustainable development
2. Scientists and engineers have a moral responsibility to develop cleantech
3. Appreciate the small: microbes are versatile and can be very powerful
4. ‘Reduce – Recycle – Remove strategies’ for microbial cleantech for water and food management: base choice on environmental impact and costs
5. Collaborate: complex challenges require interdisciplinary solutions (and it’s fun)
6. Valorize: from the test tube to industrial scale

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- European Community’s Seventh Framework Programme (FP7)
- > 10 Companies and public utilities
Applied research involves non-academic partners
Global applicability of partial nitritation/anammox (OLAND)

1995: °AnAOB (anammox bacteria)

1998: OLAND

2003: AnAOB in Black Sea

2009: OLAND in Black Water (Vlaeminck et al., 2009)

2020: OLAND in Space?
Let’s fly with anammox bacteria (and geckos)

Launching site in Baikonur (Kazakhstan)
The geckos did not make it

The ‘Space Sex Geckos’ Are Okay! (4/8/2014)

Geckos of the Lost Ark (25/7/2014)

Russian Geckos Die Before They Can Have Sex In Space (2/9/2014)

But anammox bacteria could be reactivated upon their first Space exposure!

(imgur.com/gallery; themadspaceball.com; www.giantfreakinrobot.com; www.davidreneke.com)
• Young open access journal (volume 1 in 2008)
• Editors: Kenneth N. Timmis, Juan Luis Ramos, Willem de Vos, Siegfried E. Vlaeminck, Auxiliadora Prieto
• 2015 impact factor: 3.991 (2014: 3.081)
• 2015 ranking: Top 25% (Q1) in Microbiology (28/123) and Biotechnology & Applied Microbiology (29/161)

Environmental biotechnology - Green chemistry - Food, beverages and supplements - Bioenergy - Agriculture - Bioremediation - Biopolymers, biomaterials - Technology development - Process engineering

– AND MUCH MORE

Looking forward to receive your best work!