2nd Xiamen International Forum on Urban Environment:

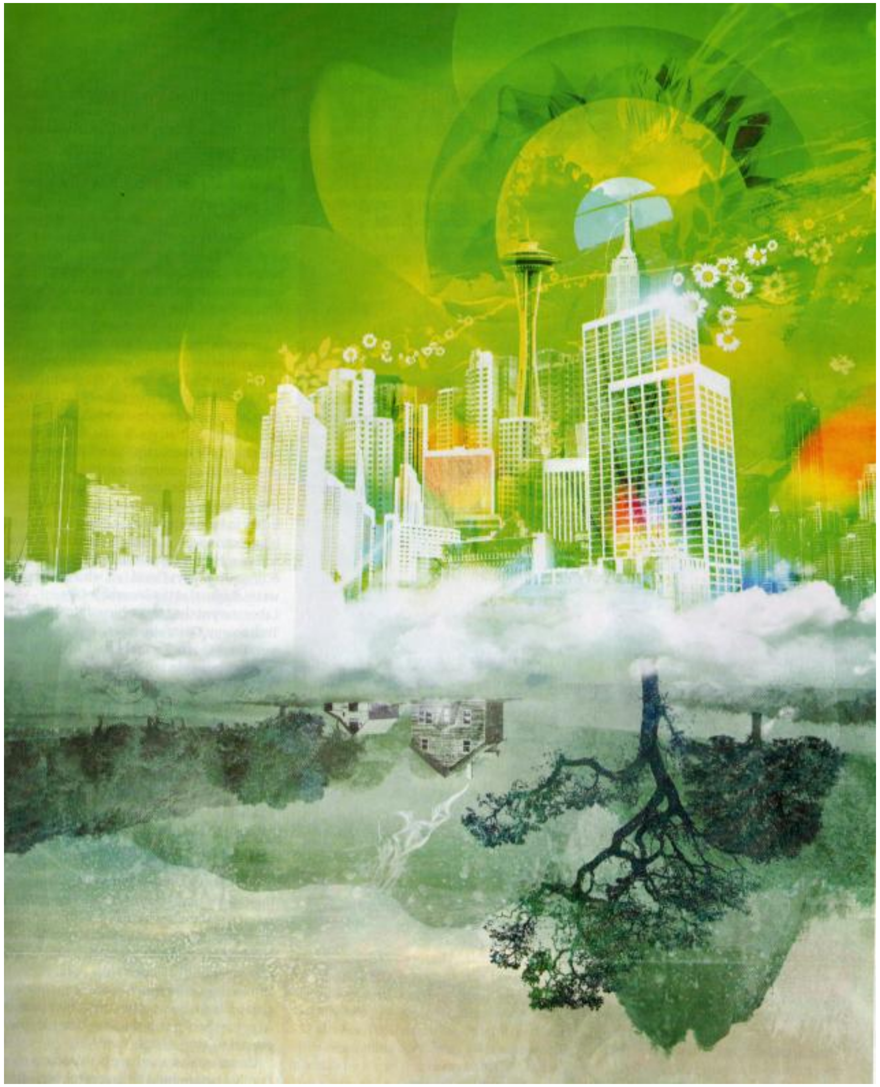
ZeroWasteWater: Short-cycling of Wastewater Resources for Sustainable Cities of the Future

---

W. Verstraete, B. Bundervoet & B. Eggermont

Lab. Microbial Ecology and Technology (LabMET)
Faculty of Bioscience Engineering,
Ghent University
Coupure L 653, B-9000 Gent, Belgium
www.LabMET.UGent.be

1. Escape to the city: a urban utopia

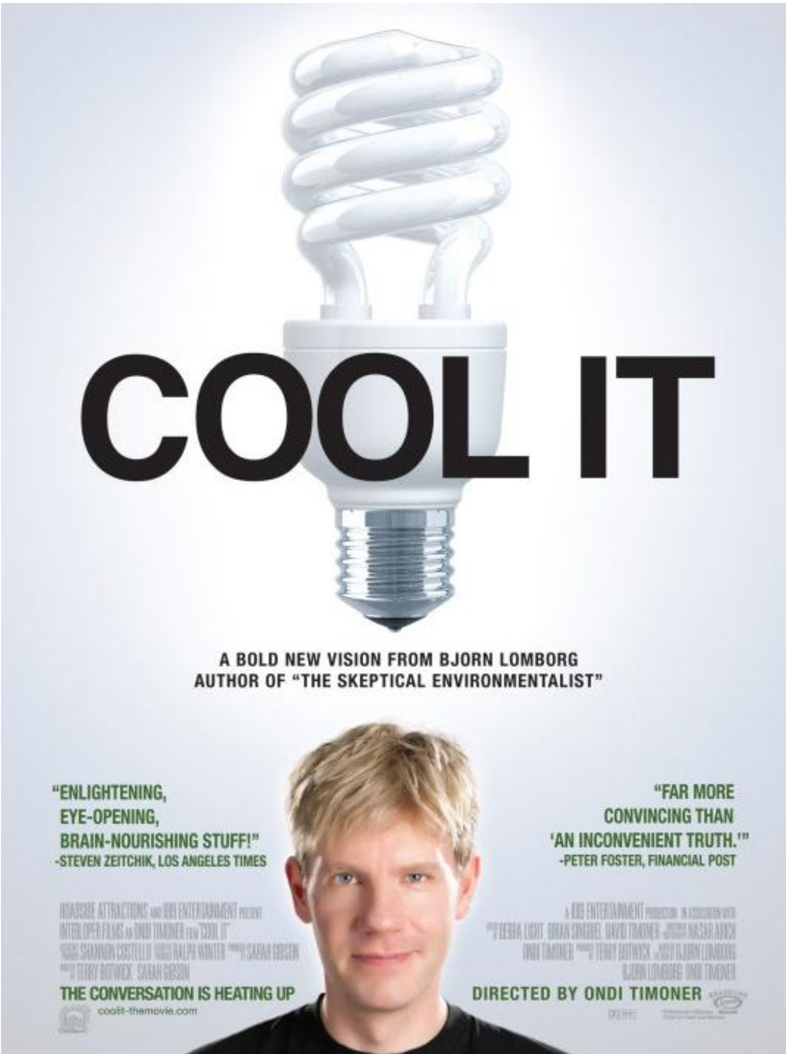


"Urbanites now outnumber their rural cousins – and that's surprisingly **good news** for the environment"

"The average New Yorker produces just 30 per cent of the greenhouse emissions of the average US citizen"

(Barley 2010; *New Scientist* 2785, 32-37)

2. Panic won’t save the world



Positive and <u>effective</u> remedies:

- promote basic sanitation
- implement green roofs

(Bjorn Lomborg)

3. Myth: Sanitation worldwide is resolved

The WC with a water footprint of some 130 L water per capita per day is “unsustainable”

Currently 2.6 billion people have no decent sanitation

Sanitation is taboo in
many cultures, religions, science, … !

Result of the taboo:

4. New approaches for sanitation are needed

The NoMix - NoTaboo toilet

→ Excrements are separated

→ Acceptable and respectable in all cultures and religions

→ Costs are reasonable

NEW

Feces
* Dry by air or lime

Urine
* Oxidation pond ($NH_4 \rightarrow NO_3^-$)

→ Use as a Natural Stable Fertiliser (NSF)

Key issues :

- The “Urban Metabolism” of the “Cities, towns and villages of the Future”

  ➔ it must be redesigned drastically

- Rich countries must give the example

4. New approaches for sanitation are needed

Durban (South Africa) pays inhabitants for urine

- Dry toilets (water is scarce in Africa)
- Family can earn about 3 €/week by delivering urine

World Toilet Day - 19 November 2010

Poor access to water, sanitation and hygiene has a particularly acute impact on women and girls, affecting their health, dignity and life chances. (http://www.wateraid.org/uk)

4. New approaches for sanitation are needed

Pure urine as liquid NSF is interesting for agricultural applications in developing countries

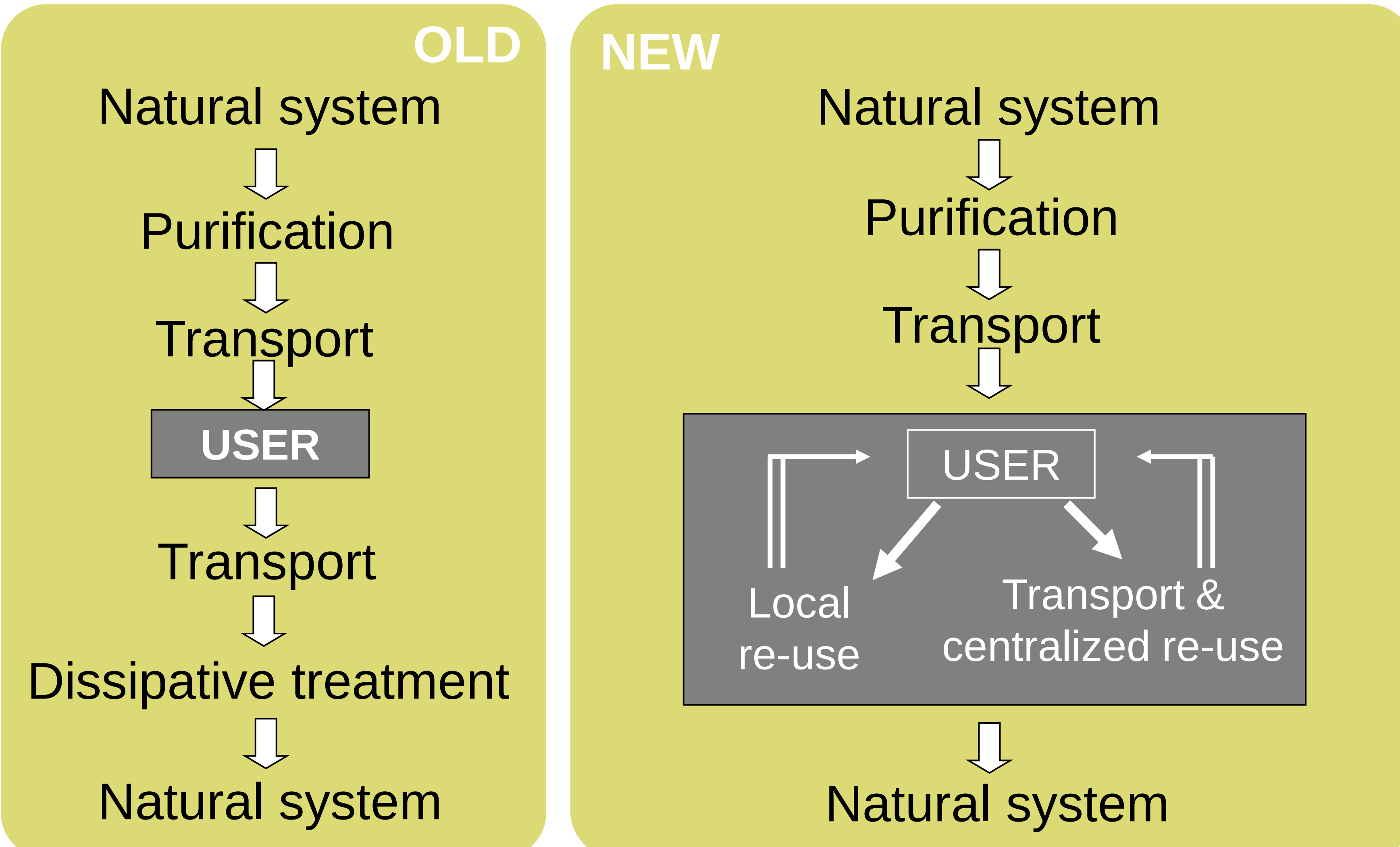
BUT can contain some hazardous components (e.g. pharmaceuticals)

➡ Possible treatments:

- Electrodialysis
- Struvite
- Sand filtration + solar drying

(Pronk and Kone 2009; *Desalination* 248, 360-368)

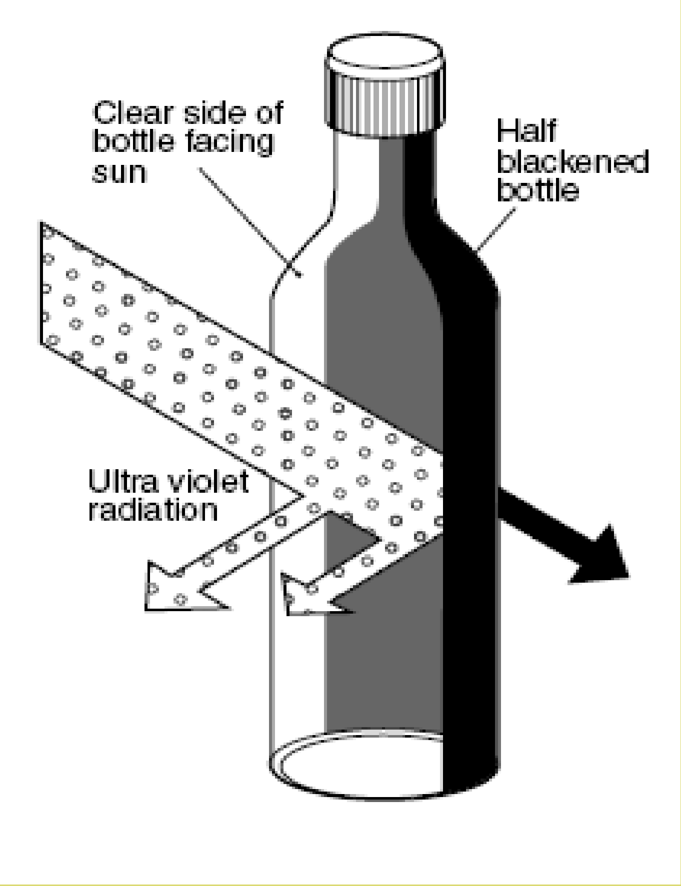
5. The old and the new water cycle



5. The old and the new water cycle

Production of drinking water in developing countries: **SODIS**

- A PET bottle in the sun !
- The diarrhoea decreases by a factor 3
  (SandecNews, EAWAG Aquatic Res., Aug. 2010)
- The costs are affordable because below 0.1 €/m^3



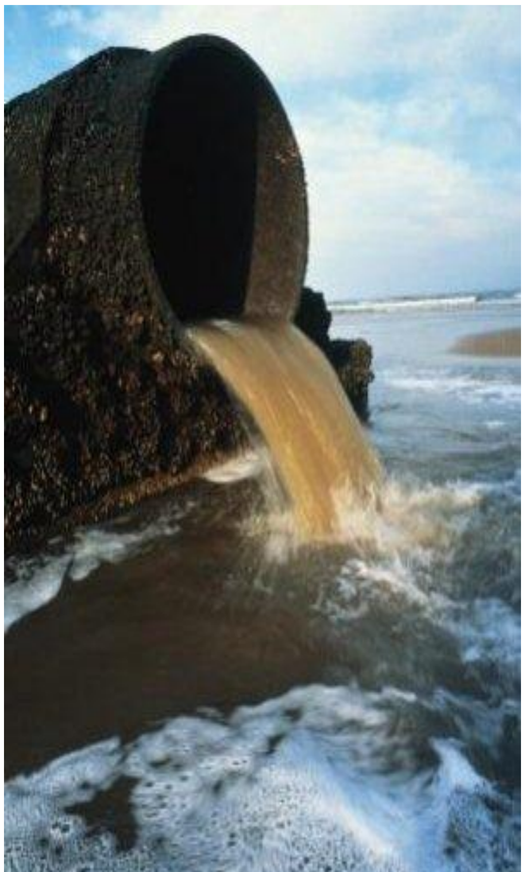
Key issues are :
We should be humble enough to upgrade SODIS and propagate its use.

5. The old and the new water cycle

Production of drinking water in developing countries: **SODIS**

5. The old and the new water cycle

A. Decentralized: Maximum storage



Black water

↓

+ Stabilizer → Storage → No GHG (otherwise 7-14 kg CH_4 IE^{-1} yr^{-1})

↓

Transport to centralized plant

Question: What type of reversible stabilizer?

5. The old and the new water cycle

A. Decentralized: Elegant integration in the street

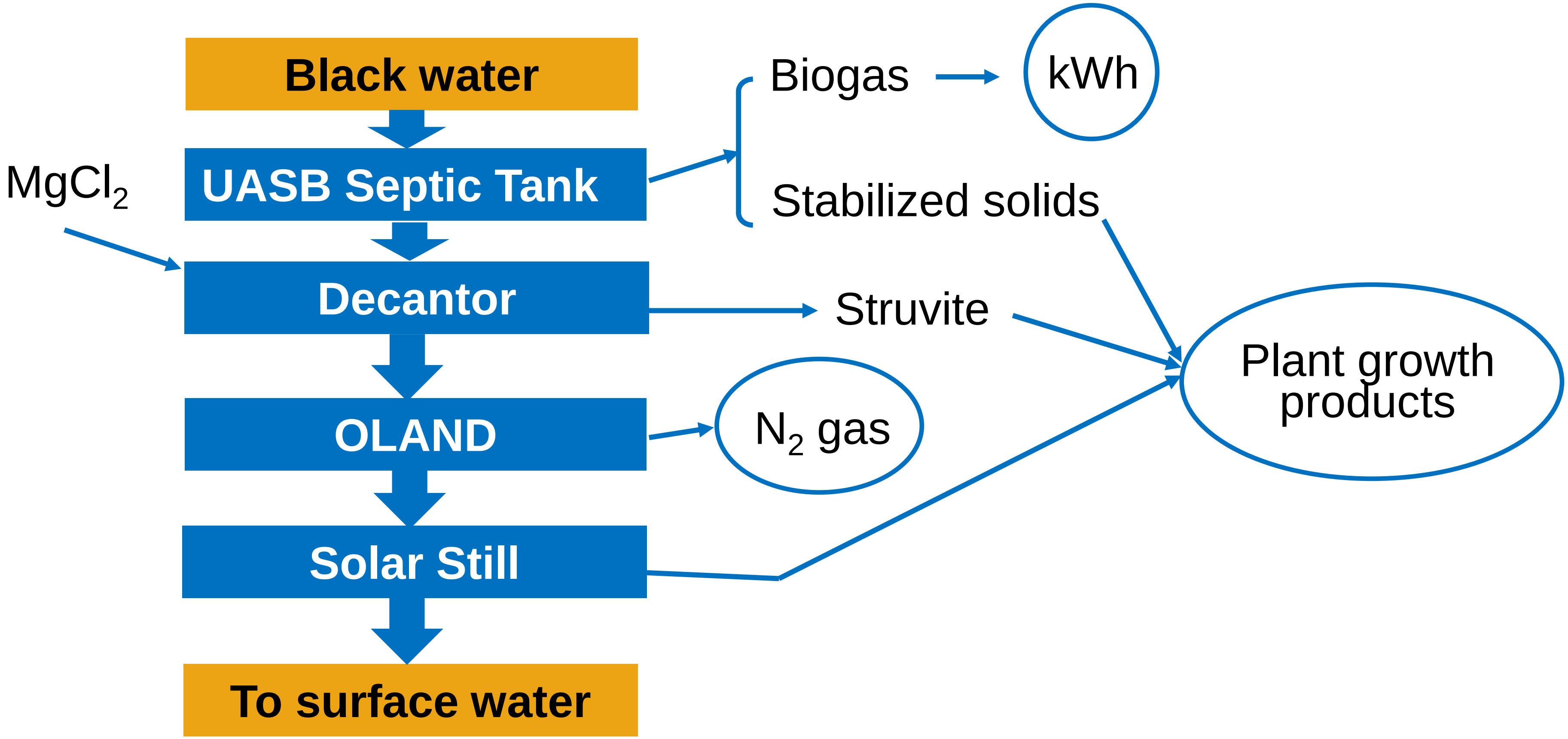
Multilayer Combined Bio-Trickling Filter (MC-BTF); Shangai

→ Unit for 100 families!

(Kuai Linping, Shanghai Jiao Tong University, China)

5. The old and the new water cycle

A. Decentralized: Autonomic treatment



(Vlaeminck et al. 2007; *Appl. Microbiol. Biotechnol.* 74: 1376-1384; LabMET)

5. The old and the new water cycle

A. Decentralized: Autonomic treatment

UASB (ST)	**SRT** = 75 d **HRT_{min}** = 10 d **T** = 30 ºC
Decantor	**HRT** = 30 min
OLAND	**HRT_{min}** = 3 d
Solar still	**HRT** = months

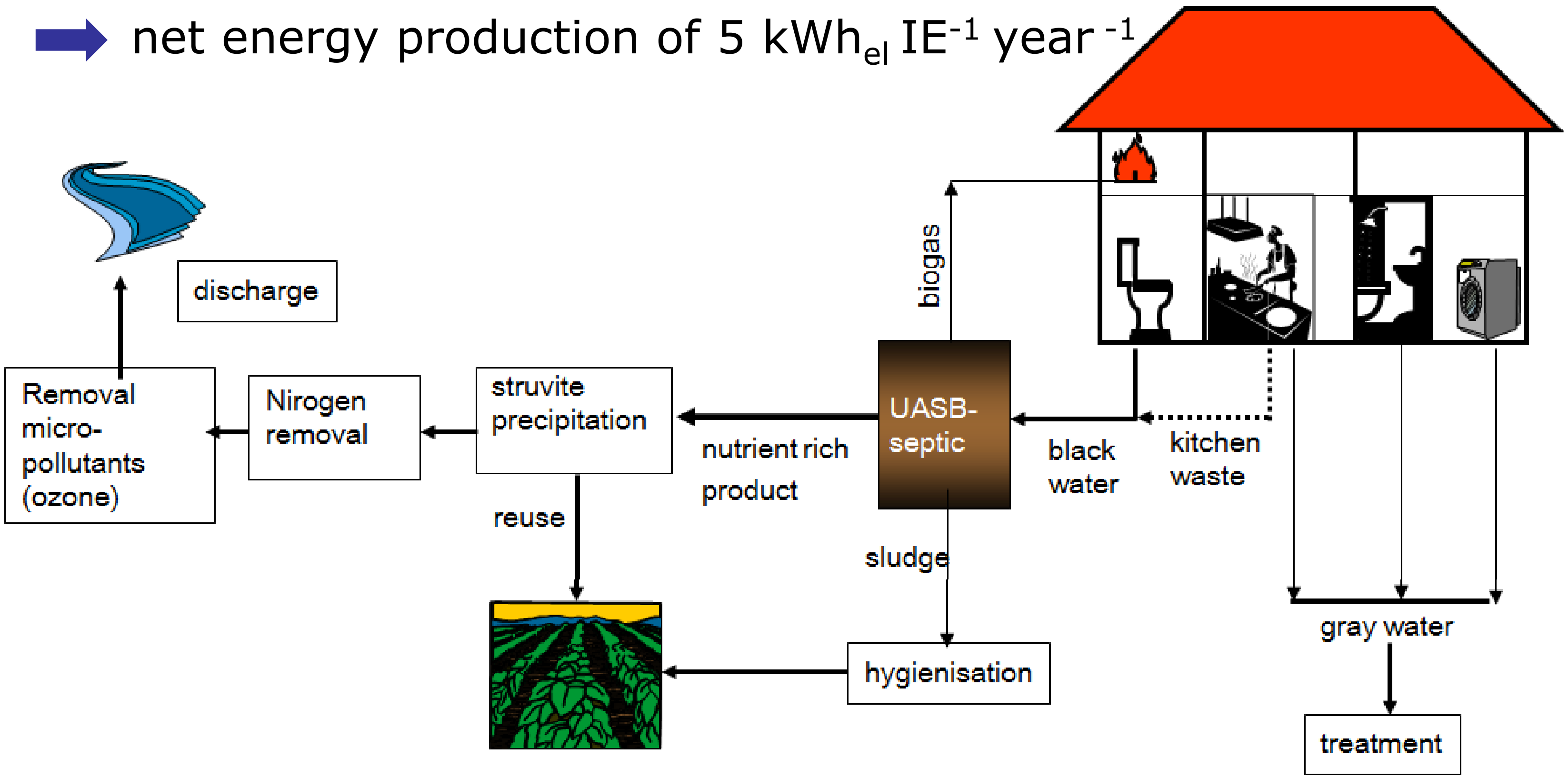
(Zeeman et al. 2008; *Water Sci. & Techn.* 57, 1207-1212)

5. The old and the new water cycle

A. Decentralized: Autonomic treatment

Case study (Sneek, Netherland): Pioneer project of 32 houses with vacuum toilets (flushing with 1L in stead of 7L)

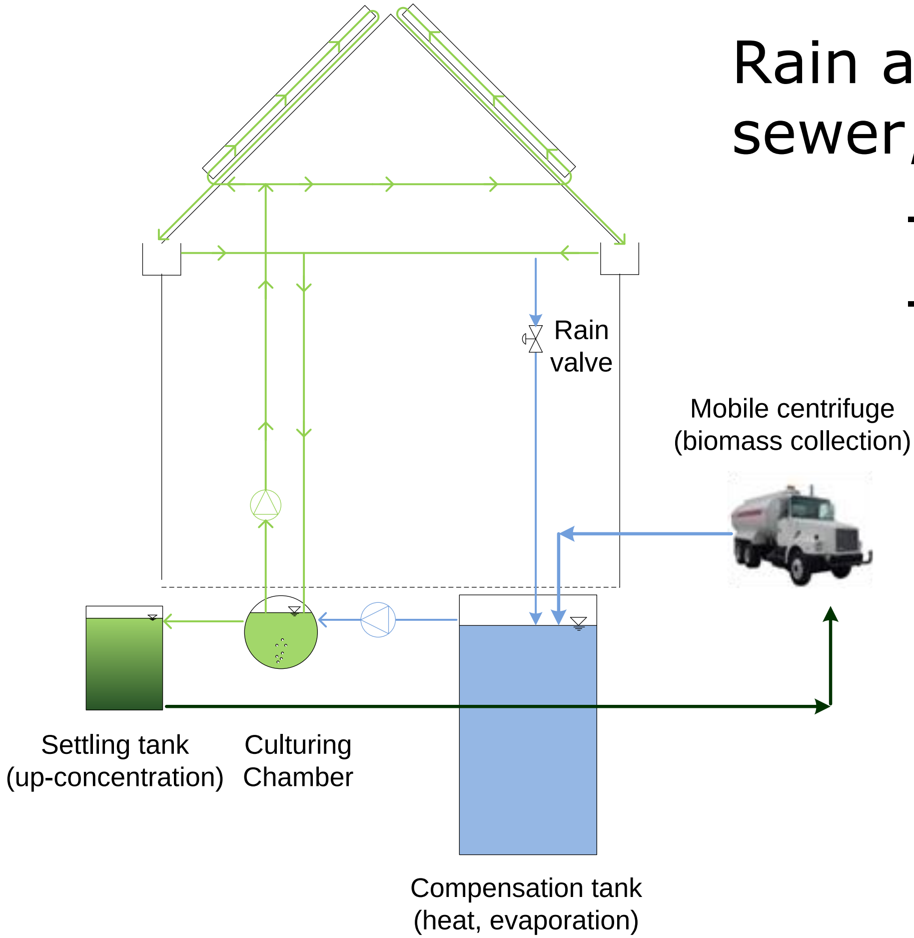
➡ net energy production of 5 kWh_{el} IE^{-1} $year^{-1}$



(Zeeman et al. 2008; *Water Sci. & Techn.* 57, 1207-1212)

5. The old and the new water cycle

A. Decentralized: Green roofs



Rain and pretreated sewage not in sewer; it can be used to maintain:

- Green rooftops
- Algae cultivation

(Zamolla et al. In prep.; LabMET)

5. The old and the new water cycle

A. Decentralized: Algae cultivation on domestic roofs

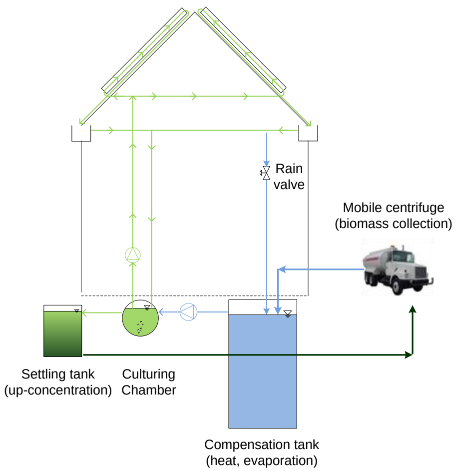
production of 20 g dry mater m^{-2} d^{-1}

➔ gross energy recovery of 8.7 kWh_{el} m^{-2} $year^{-1}$

or 1000 kWh_{el} $home^{-1}$ $year^{-1}$

⬍

photovoltaic panels: 100 kWh_{el} m^{-2} $year^{-1}$



Other advantages:

- Recycle grey water nutrients
- Uptake of CO_2
- Management of storm water
- Cooling of the house

(Zamolla et al. In prep.; LabMET)

(Verstraete & Vlaeminck, 2010; Keynote Paper 2nd Xiamen International Forum on Urban Environment; LabMET)

5. The old and the new water cycle

B. Centralized: Conventional activated sludge (CAS) design

- Capex + Opex: 17 - 40 EUR IE^{-1} $year^{-1}$
- Energy use: **20-35 kWh_{el} IE^{-1} $year^{-1}$**
- Energy recovery via sludge digestion is limited
  - ◊ Theor.: 30-40 kWh IE^{-1} $year^{-1}$
  - ◊ Pract.: 15-20 kWh IE^{-1} $year^{-1}$
- N, P, K → no recovery
- All organic C via biology + sludge incineration to CO_2
- Water → hardly re-used

Take home: The centralized wastewater treatment must be redesigned entirely!

5. The old and the new water cycle

B. Centralized: Retrofitting of CAS-design

Macao (Egypt): sewage treatment plant

INESS® Integrated New Energy Solutions & Services wastewater treatment plant powered by the sun

Wind turbine

Anaerobic digester

Photovoltaic roof

Towards minimal external power consumption

WATERLEAU water · air · waste · new energy

6. New Urban Metabolism

<u>Food wastes are properly re-used</u>

- Food consumes 15% of the US overall energy budget
- About 20% of food is wasted, i.e. 2-3% of the total energy budget *(Webber & Cuellar, 2010; EST; DOI 10:1021)*

<u>Take home:</u>

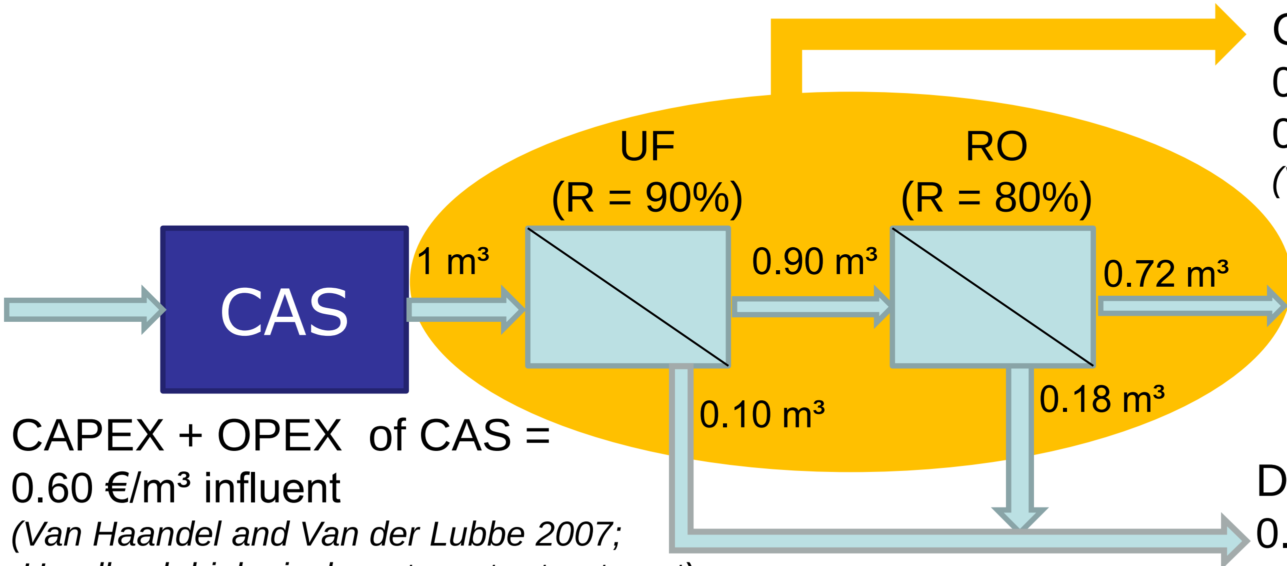
- Co-digestion can recover a major part of this energy
- Food and kitchen wastes can be the driver of a new type of wastewater treatment

7. Sewage as a resource

Resources	Production IE^{-1} year^{-1}		Market price	Value (EUR IE^{-1} year^{-1})	
	Sewage	Kitchen waste		Sewage	Sewage + Kitchen waste
Potable water	54 m^3		1.2 EUR m^{-3}	65.4	65.4
Heat recovered (5°cooling)				6.9	6.9
• Electricity consumption	-179 kWh_{el}		0.10 EUR kWh_{el}^{-1}		
• Heat recovered	496 kWh_{th}		0.05 EUR kWh_{th}^{-1}		
Anaerobic digestion				3.5	5.9
• Electricity produced	23 kWh_{el}	16 kWh_{el}	0.10 EUR kWh_{el}^{-1}		
• Heat generated	24 kWh_{th}	17 kWh_{th}	0.05 EUR kWh_{th}^{-1}		
Biochar production	5.7 kg	3.9 kg	0.14 EUR kg^{-1}	0.8	1.3
Recovered nitrogen	2.4 kg	0.2 kg	1.15 EUR kg^{-1} N	2.7	2.9
Recovered phosphorus	0.82 kg	0.66 kg	1.35 EUR kg^{-1} P	1.1	2.0
			Overall	**80.4**	**84.5**

(Verstraete & Vlaeminck, 2010; Keynote Paper 2nd Xiamen International Forum on Urban Environment; LabMET)

8. Sewage as a resource of water



CAPEX + OPEX =
0.46 €/m³ RO permeate
0.33 €/m³ influent
(Van Houtte and Verbauwhede 2008; Desalination 218, 198-207)

Benefit = reusable water
1.20 €/m³ RO permeate
0.86 €/m³ influent

CAPEX + OPEX of CAS =
0.60 €/m³ influent
(Van Haandel and Van der Lubbe 2007; Handbook biological waste water treatment)

Discharge in the sea
0.060 €/m³ RO concentrate
0.017 €/m³ influent

<u>Balance (m³ influent):</u>
- 0.600 for CAS
- 0.330 for UF/RO polishing
- 0.017 for concentrate discharge
+ 0.860 for water valorization

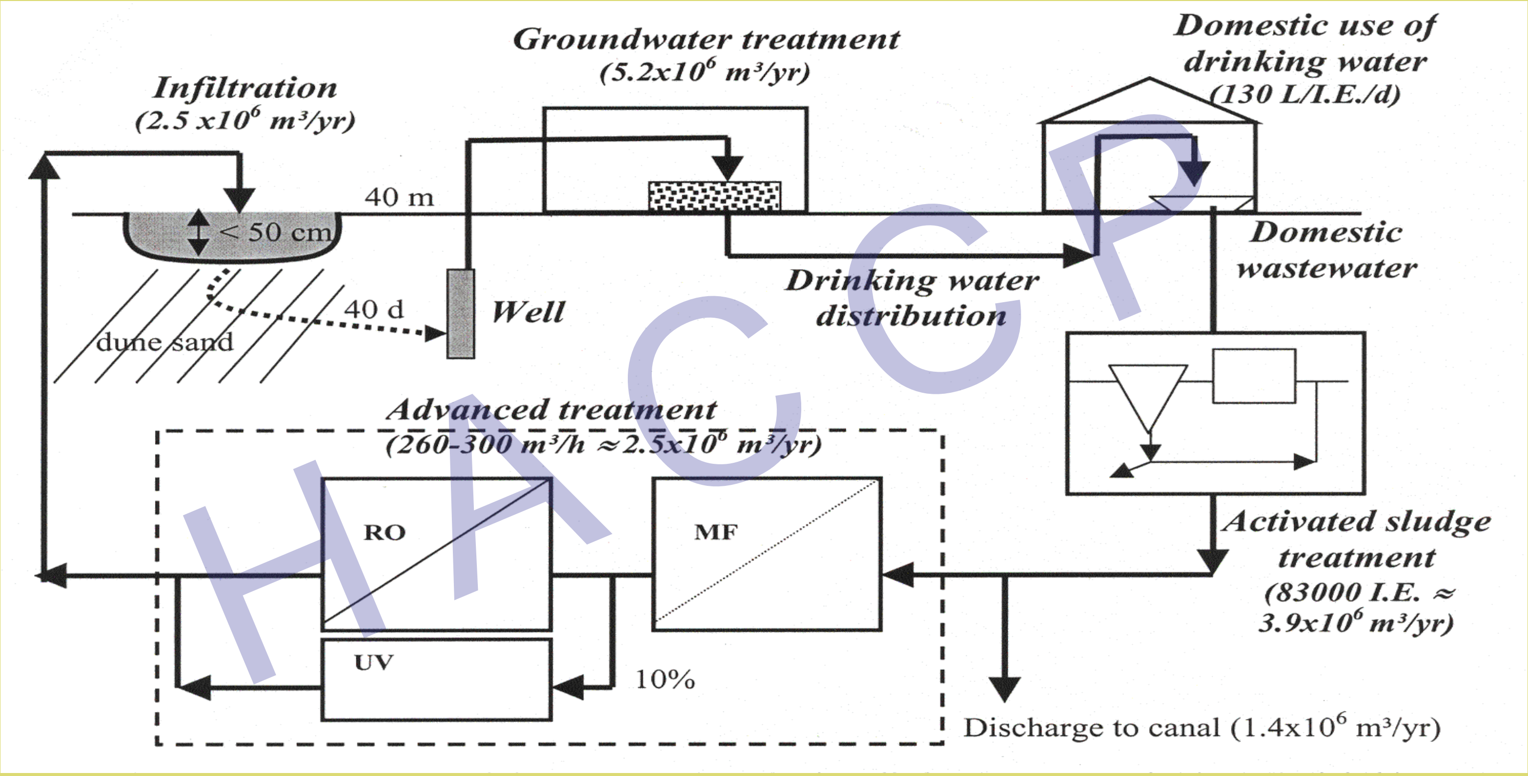
→ -0.087 €/m³ influent

(Verstraete et al. 2009; Bioresource Techn. 100, 5537-5545; LabMET)

<u>Take home</u>: If RO-permeate is used at value, CAS + UF + RO pays already for itself !

8. Sewage as a resource of water

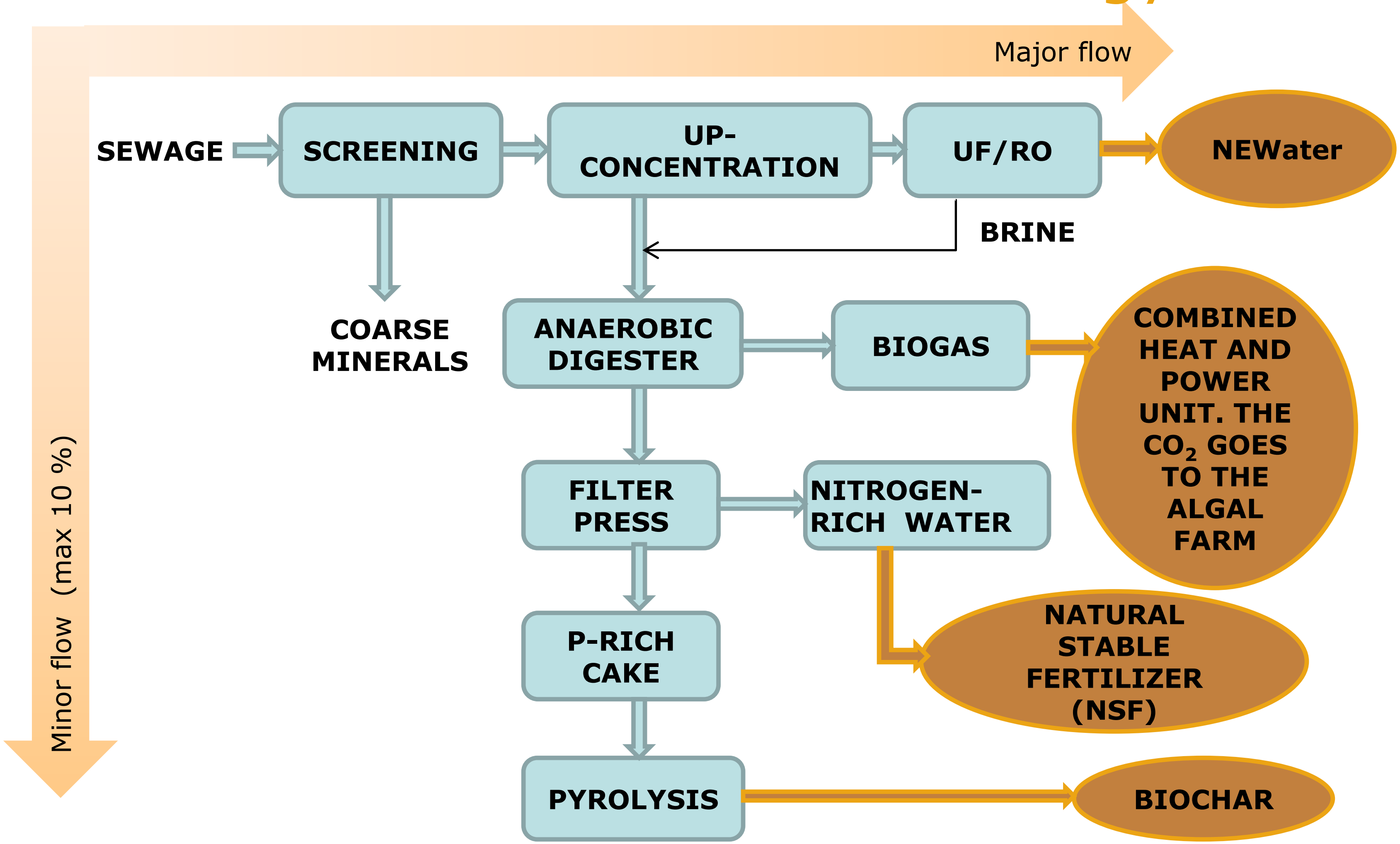
Case study: Koksijde, Belgium (IWVA)



(Dewettinck et al., 2001; Water Sci. Technol. 43: 31-38; LabMET)

<u>Take home:</u> this technology was upscaled in Singapore ➔ NEWater

9. The "Zero-Waste" Water Technology



(Verstraete et al. 2009; Bioresource Techn. 100, 5537-5545; LabMET)

10. Sewage as a multi-resource

Crucial step = up-concentration

(creating a pre-effluent easy cleanable with UF/RO
+ concentrate waste load with 10 – 20 times more COD/m³)

Examples of up-concentration (prevention of sewage dilution)

- Separate sewer system (rain water and waste water)
- 50 % less infiltration of ground water in sewer
- Domestic water conservation
- Use of kitchen waste
- Control microbial degradation

➔ **Already (5 – 10 times) upconcentration possible**

(Verstraete & Vlaeminck, 2010; Keynote Paper 2nd Xiamen International Forum on Urban Environment; LabMET)

UNIVERSITEIT GENT

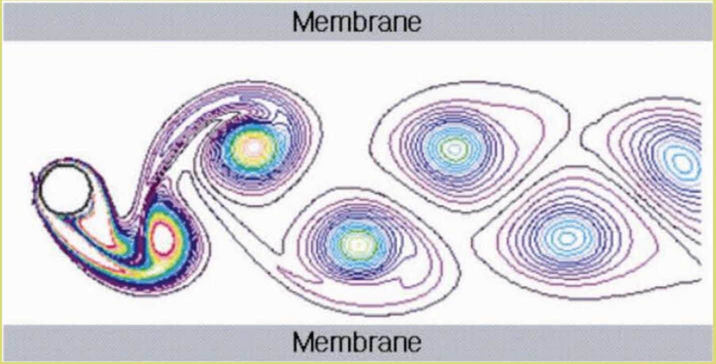
10. Sewage as a multi-resource

Crucial step = up-concentration

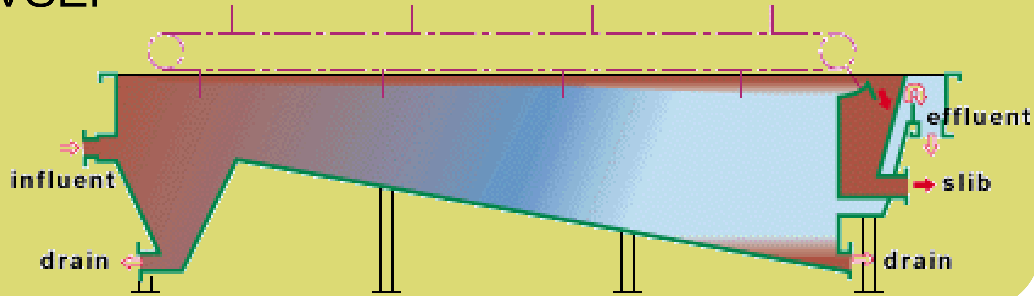
(creating a pre-effluent easy cleanable with UF/RO
+ concentrate waste load with 10 – 20 times more COD/m³)

Examples for up-concentration (Physical/Chemical)

- (Direct) filtration
  = filtration with or without coagulant
  e.g. - Dynamic sand filtration (DSF)
  - Membrane filtration
  e.g. FMX and VSEP



- Dissolved Air Flotation (DAF)



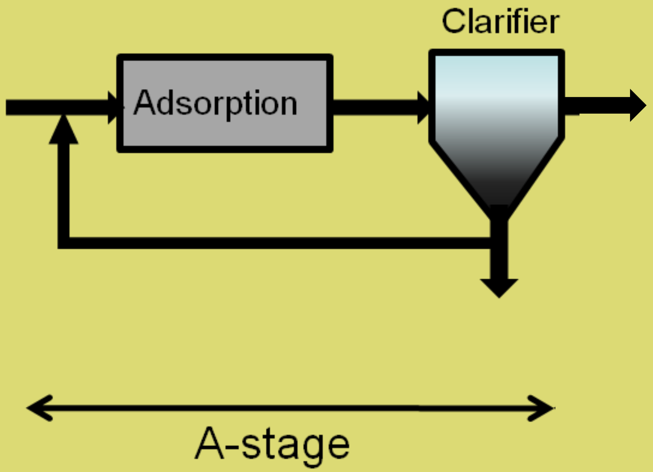
10. Sewage as a multi-resource

Crucial step = up-concentration

(creating a pre-effluent easy cleanable with UF/RO
+ concentrate waste load with 10 – 20 times more COD/m³)

Examples for up-concentration (Biological)

- Adsorption Bio-Aeration or A/B-Boehnke concept



(Boehnke et al. 1998; Water-Engineering & Management 145, 31-34)

UNIVERSITEIT GENT

10. Sewage as a multi-resource

Cost consideration for the proposed sewage recycling technology (according to C2C)

➔ **the major flow**: directly to reuse

➔ **the minor flow** (= a concentrate): produced at the entry of the plant, subjected to advanced recovery for energy and fertilizers

Major flow		
Dissolved air flotation	0.02-0.03 €/m^3	
Dynamic sand filtration	0.05-0.06 €/m^3	0.53-1.15 €/m^3
Ultra filtration and Reverse Osmosis	0.46-1.06 €/m^3	
Minor flow		
Anaerobic digestion	Break even	
Mechanical separation	0.08-0.10 €/m^3	0.08-0.10 €/m^3
Pyrolysis	Break-even	
	Total costs*:	**0.61-1.25 €/m^3**

** this is the estimated total cost*

(Verstraete et al. 2009; Bioresource Techn. 100, 5537-5545; LabMET)

Take home: Total costs of about 1 €/m^3 are comparable with CAS + UF + RO

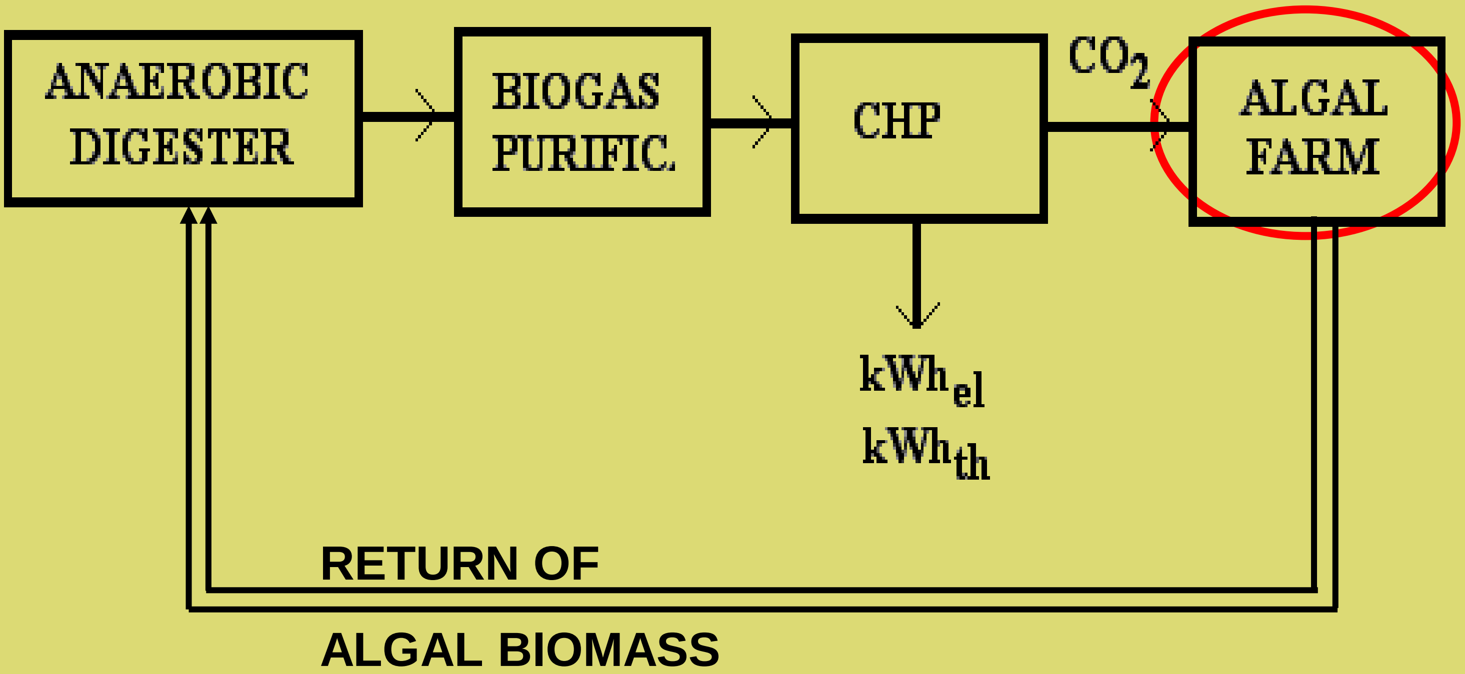
10. Sewage as a multi-resource

- **AD of the "concentrate-line"**
  - Add organics from 0.5 g COD/L to 5.0 g COD/L to 50 g COD/L
  - The burned biogas, i.e. CO_2 can be used to grow algae
- **After AD → Separator: Decantor centrifuge with(out) PE**
- **Pyrolysis to biochar** *(Lehmann et al. 2007; Nature 447, 143-144)*
  - Development needed in terms of
    - Pyrolysis of dry solids
    - Quality & optimal use of biochar
  - Economically feasible?
    - Improves soil fertility (= economic value)
    - 1 ton C ≈ 3 ton CO_2 ≈ 39 € with 13 €/tCO_2 *(IETA, greenhouse gas market 2010)*

10. Sewage as a multi-resource: CO_2

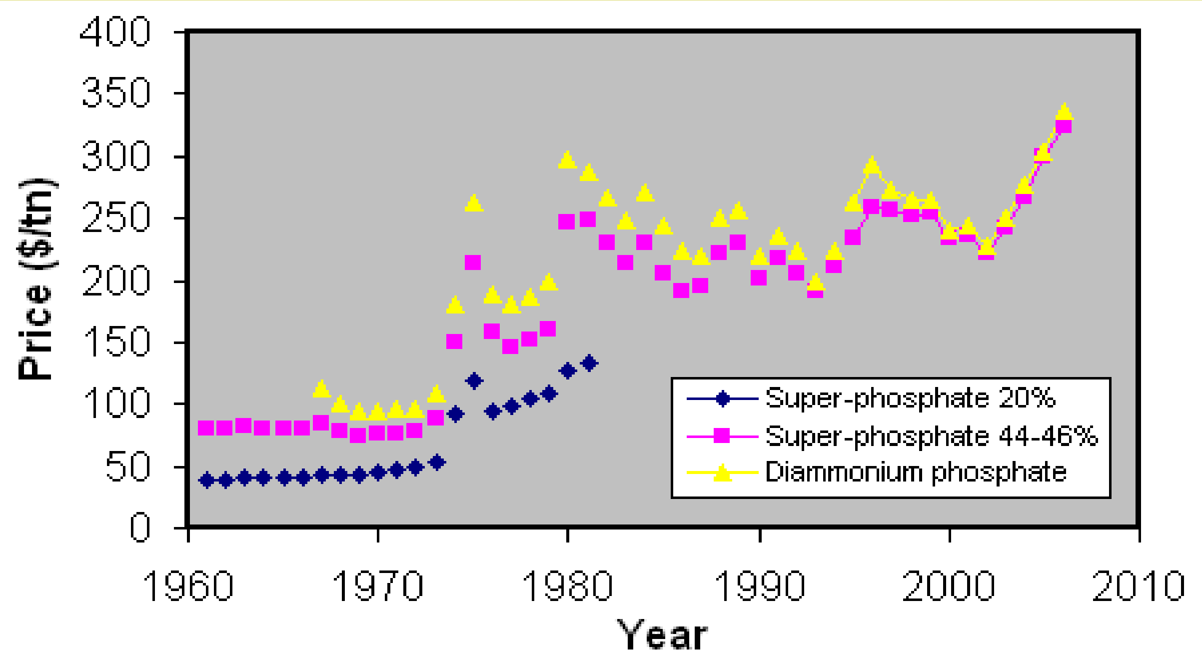
CO2 use by algal forestry:

Digester gas treatment and energy production



(De Schamphelaire & Verstraete 2009; *Biotechn. Bioeng.* 103, 296-304; LabMET)

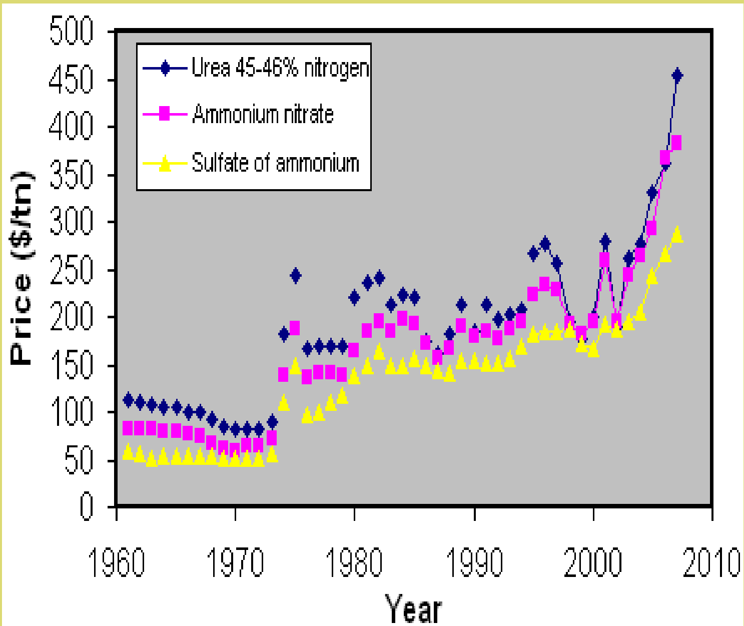
10. Sewage as a multi-resource: Phosphorus

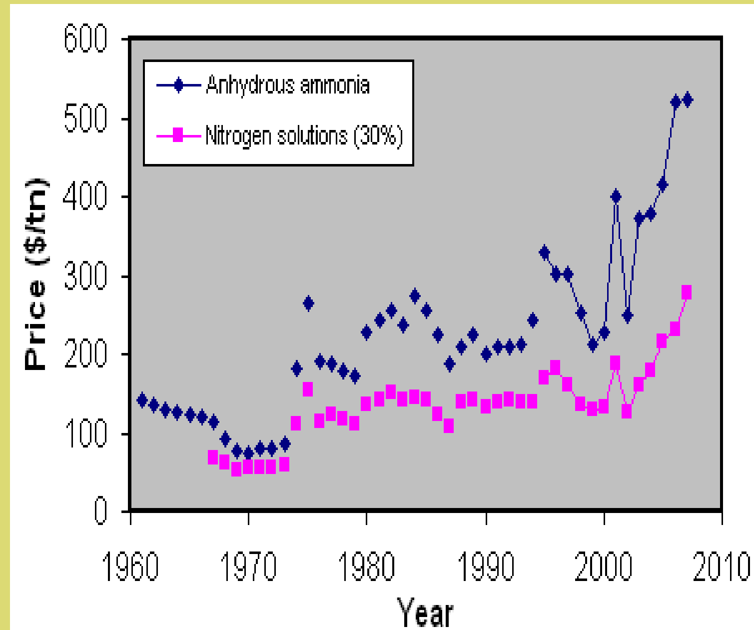


Phosphate rock (2010):	119.6 $/mt
Diammonium phosphate (2010):	482.6 $/mt
Currently (2010):	**1.1 – 1.6 $/kg-P**

(Sources: US Geological Survey Minerals Yearbook 2006 and the World Bank commodity data 2010)

10. Sewage as a multi-resource:Nitrogen



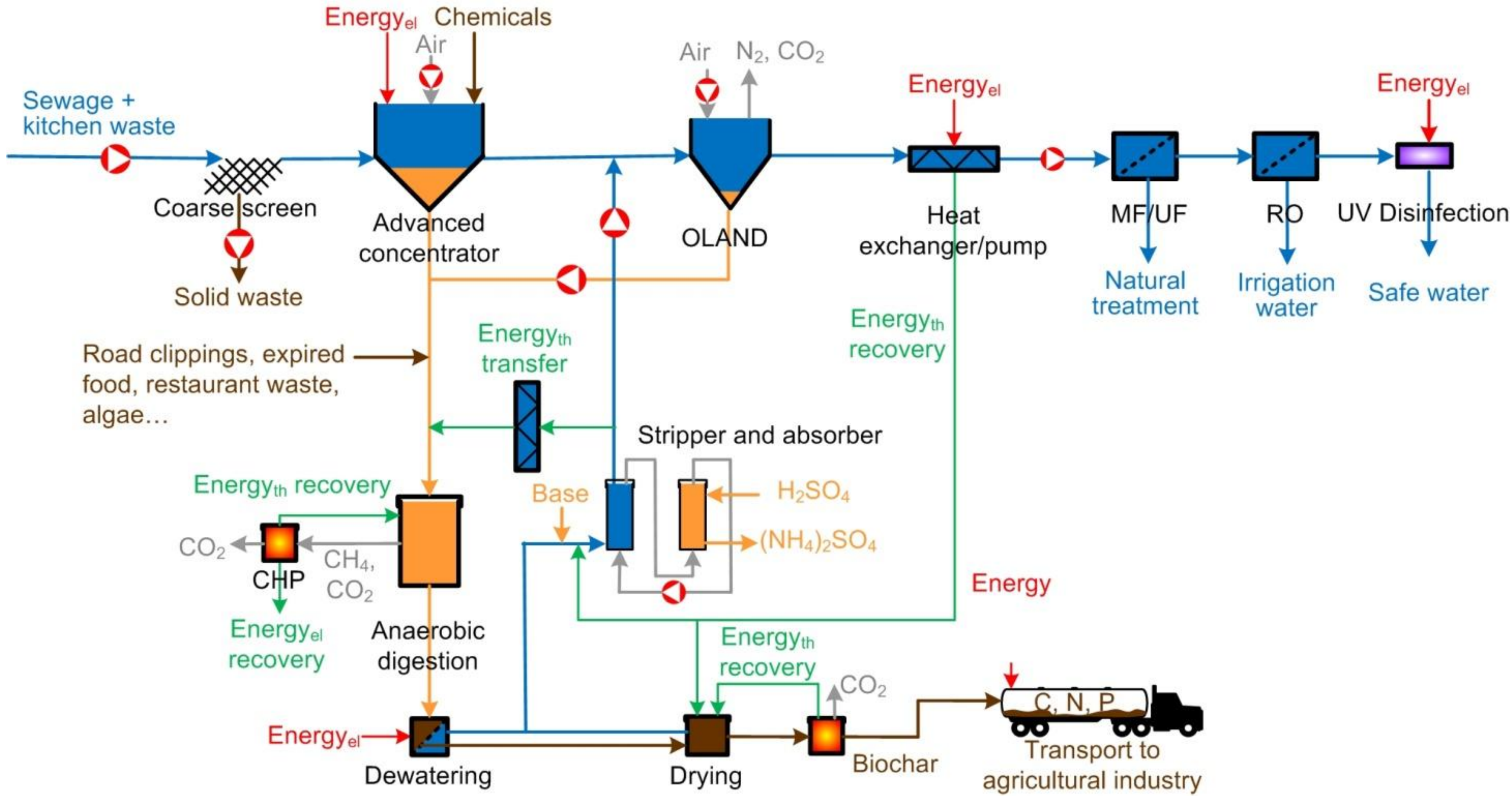


Ammonium nitrate (2008):	300 - 330 $/mt
Ammonium sulfate (2008):	200 - 210 $/mt
Anhydrous ammonia (2008):	450 - 650 $/mt
Currently (2010):	**1.15 – 1.48 $/kg-N**

(Sources: US Geological Survey Minerals Yearbook 2006, 2008 and the World Bank commodity data 2010)

10. Sewage as a multi-resource

The overall system:



(Verstraete & Vlaeminck, 2010; Keynote Paper 2nd Xiamen International Forum on Urban Environment; LabMET)

10. Sewage as a multi-resource

	Energy gain (kWh IE^{-1} $year^{-1}$) Electricity	Heat	Avoided CO2 emission (kg CO_2 IE^{-1} $year^{-1}$)
Kitchen grinder	-1.4		-0.9
Advanced concentrator	-6.0		-3.6
OLAND	12.8		6.6
Heat recovery	-179	496	41.7
Anaerobic digestion	38.9		23.3
Sludge dewatering	1.8		1.1
N recovery	-9.6	40.8	4.5
P recovery	1.2		2.0
Biochar			13.3
sum	**-141**	**537**	**88**

Take home: Zero WasteWater prevents 1-4 % of the CO_2 emissions per IE

(Verstraete & Vlaeminck, 2010; Keynote Paper 2nd Xiamen Intern. Forum on Urban Environment; LabMET)

10. Sewage as a multi-resource: Economically

CAS design: - Total cost with water recovery ≈ 1.0 €/m³
- Net costs upon sale of RO-permeate = 0.0 €/m³

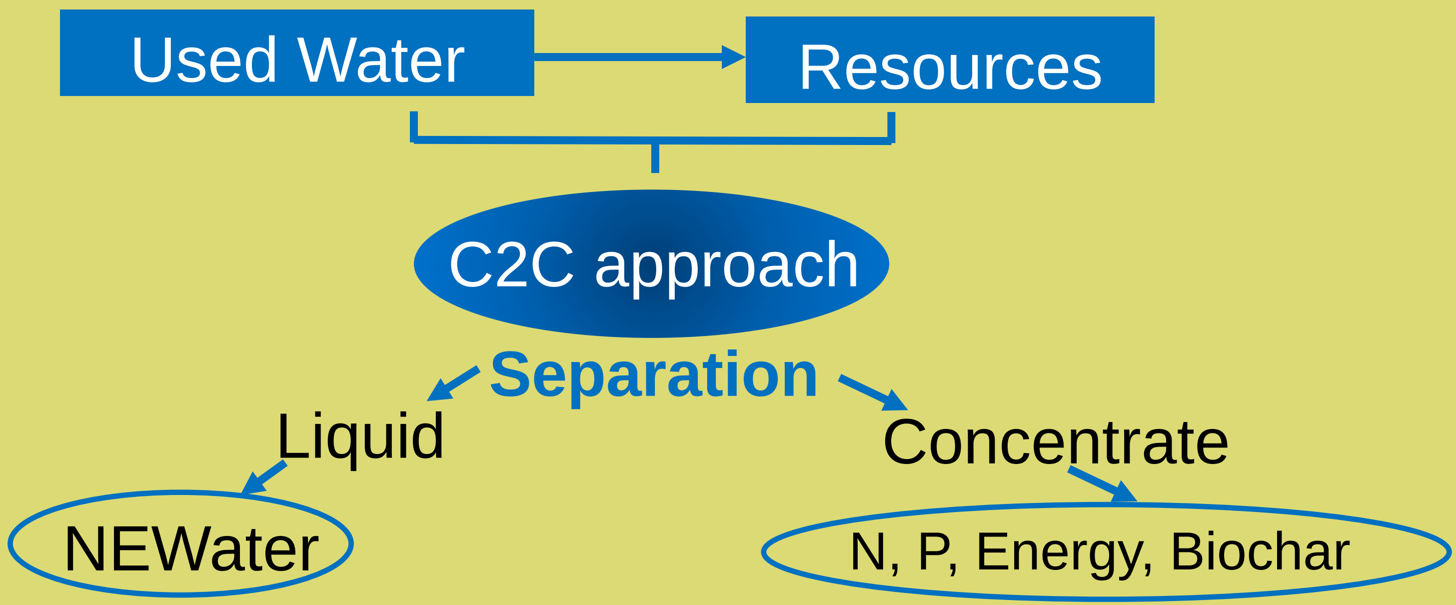
C2C design - Total cost with up-recycling of water, energy & nutrients ≈ 1.0 €/m³
- Net costs upon sale of RO-permeate = 0.0 €/m³

→ **Perspective**:
- CO_2 recycling via algae
- Recovery of struvite
- C-storage as biochar

Take home:

The C2C design can already be achieved at equal costs of the CAS + it holds plenty of extra potentials

10. Sewage as a multi-resource: Economically

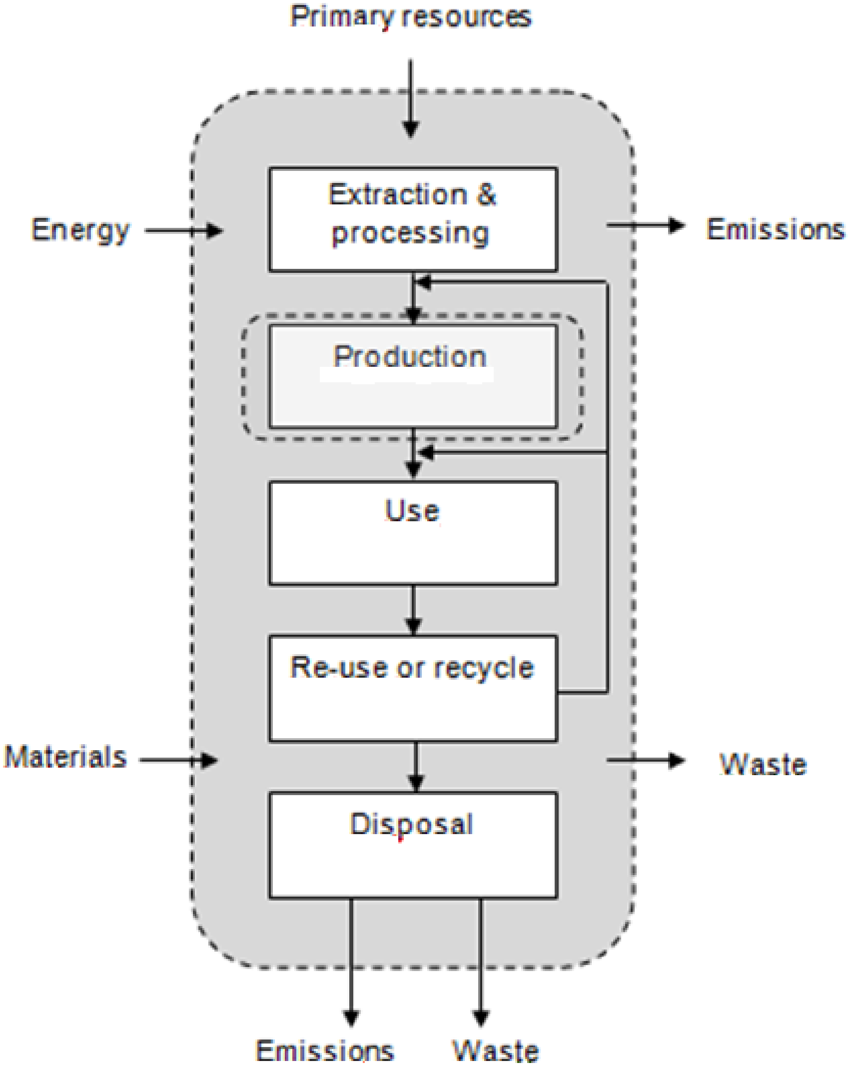


Note: • No activated sludge with biosolids production, no denitrification, no biol. P-removal, no explicit disinfection !!!

• Still problematic: micropollutants

Take home: To have a set of advanced case-specific processes available, can be useful

11. Evaluate sewage treatment plant with LCA



Life Cycle Assessment or LCA is a process to evaluate the environmental burdens associated with a product, process or activity by identifying, quantifying and assessing energy and materials used and wastes released to the environment

11. Evaluate sewage treatment plant with LCA

LCA : Identify and evaluate opportunities to effect environmental improvements for policy makers, product developers, …

❖ **standard units** to compare technologies (e.g. CO_2-equivalents IE^{-1})

❖ Use of **mili Persons Equivalent or mPE** to evaluate the impact of a certain product/process

➢ 1000 mPE = 100% of the yearly pollution of a specific kind (e.g. eutrofication, acidification, global warming, …)

e.g. - 58 kg NO_3-equivalents = 1000 $mPE_{eutrofication}$
- 8700 kg CO_2-equivalents = 1000 mPE_{CO2}

11. Evaluate sewage treatment plant with LCA

Some mPE's of waste water treatment

	Conventional	Zero waste water
Eutrofication	115 mPE	↘↘↘
Ecotoxicity	85 mPE	↘↘
Acidification	30 mPE	↘
Global warming potential	18 mPE	↘

(Clauwaert et al 2010; WT-Afvalwater 10, 186-195; Aquafin)

<u>Take home</u>: wastewater treatment still has a relatively large share in the environmental pollution; this can be decreased significantly!

12. Conclusions

- We have to redesign the sewage System entirely
  - Separation at source (NoMix)
  - Separation at STP
- Up-concentration is a crucial step

  Several lines of up-concentration are under development
  - Management
  - Physical/chemical
  - Biological
- AD is a key process in the recovery of Energy and Nutrients
- We must work towards a “Zero Waste”-Water Technology both at decentralized as centralized level
- Thus we can truly deal with the environmental burdens of the water cycle