Source separation; the future for efficient resource recovery

Grietje Zeeman

Uppsala, 25 October 2017

Barrel system

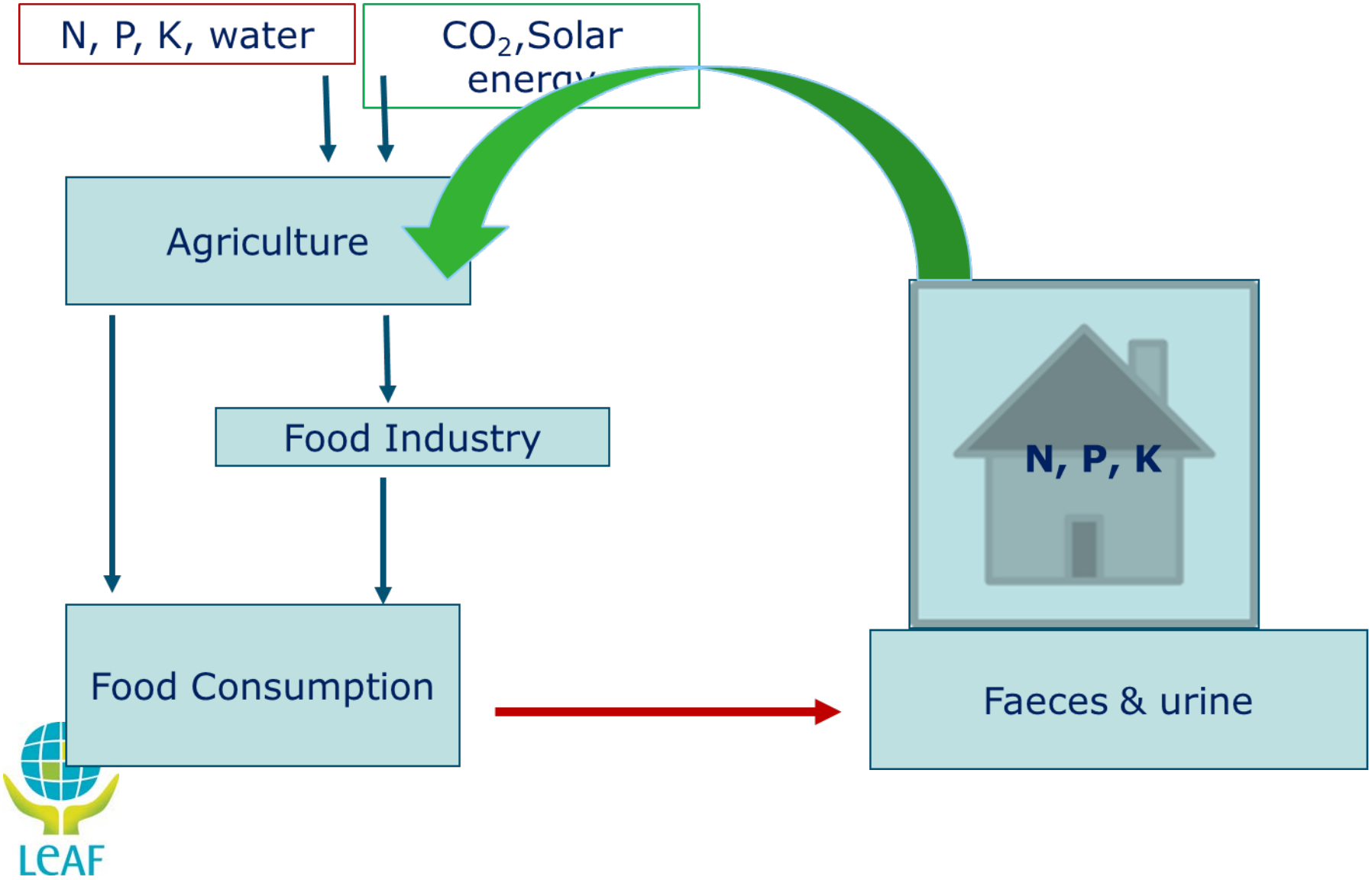
End of the 19th century:

faeces & urine collected in barrels

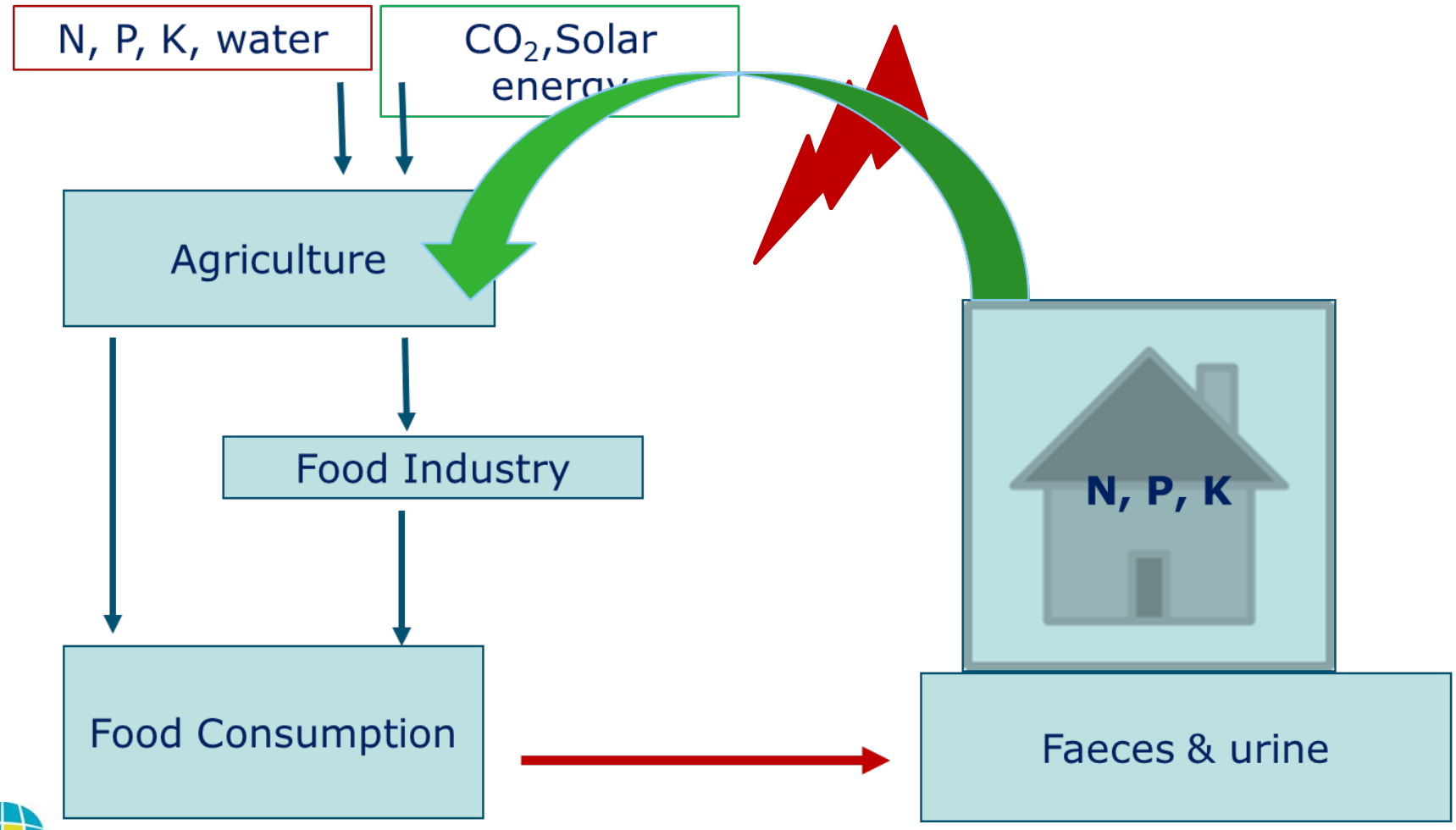
Barrel system

Transported to Agriculture

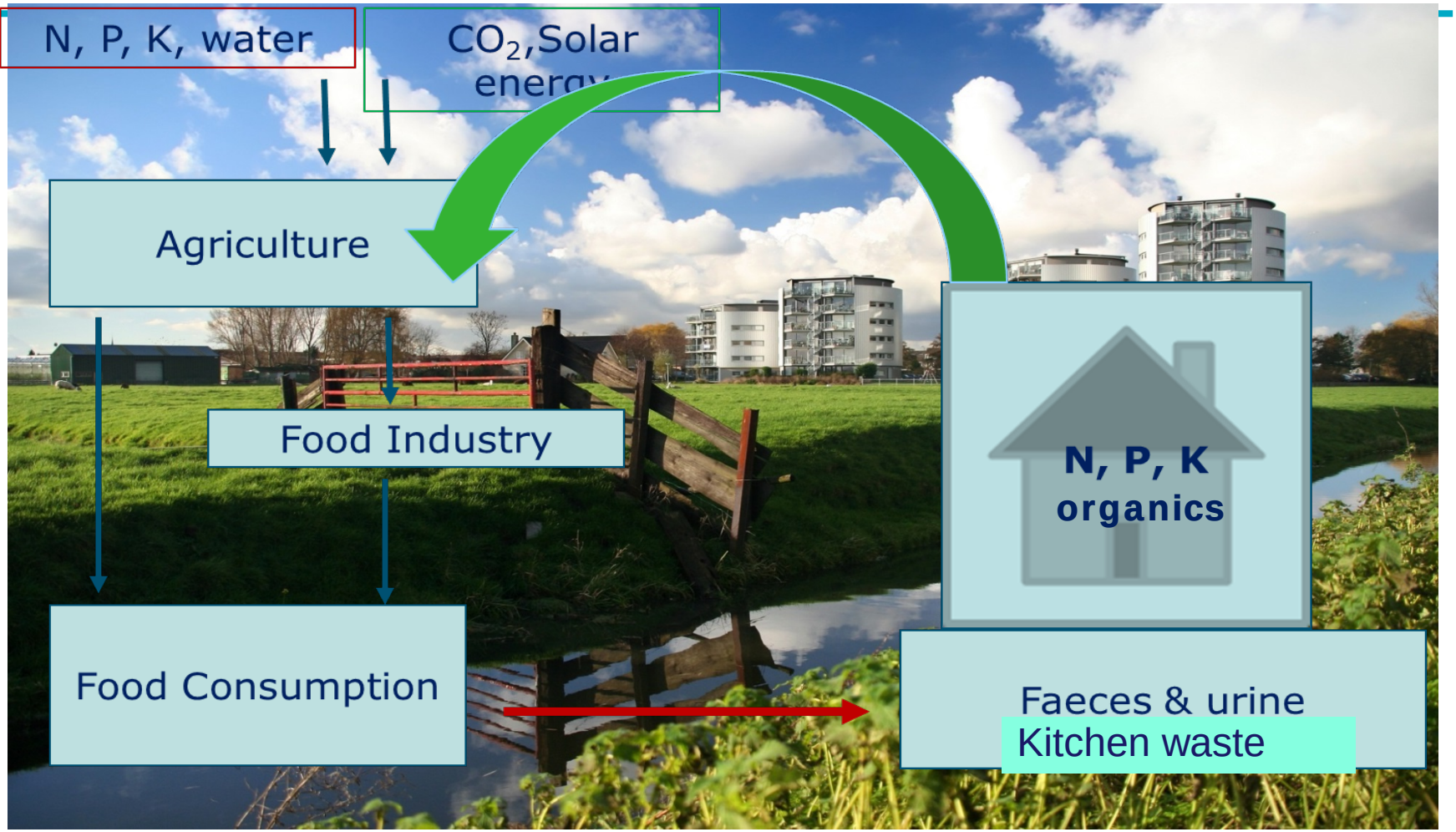
Raw material in faeces and urine recycled



Flush toilet & artificial fertilizers



Objective ‘NS’: restore the resource cycle



Raw materials

	Black water & **Kitchen waste** ($g\ p^{-1}d^{-1}$)	% of total domestic **Wastewater & Kitchen waste**
N	12.3 g	92
P	1.6 g	80
K	3.9 g	84
organics	111 g COD	69

adapted from Zeeman & Kujawa-Roeleveld, 2011

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The potential for recovery

	BW + KW (tons per year)	Fertilizer production (tons per year)	% coverage	Energy equivalent
P	$3.9*10^6$	$^{\#}14.9*10^6$	27	
N	$^{*}30.9*10^6$	$^{\#\#}121*10^6$	25	$1.1*10^3$ PJ/y

World Population:6,911,750,810 people (http://www.census.gov/main/www/popclock.html). #Cordell, D., Drangert, J.-O., and White, S. , (2009). ##J. N. Galloway et al, (2008); $^{+}$ Haber-Bosch:35kJ/gN; $^{++}$anaerobic treatment: 70% conversion; 0.0378 MJ/LCH_4 .

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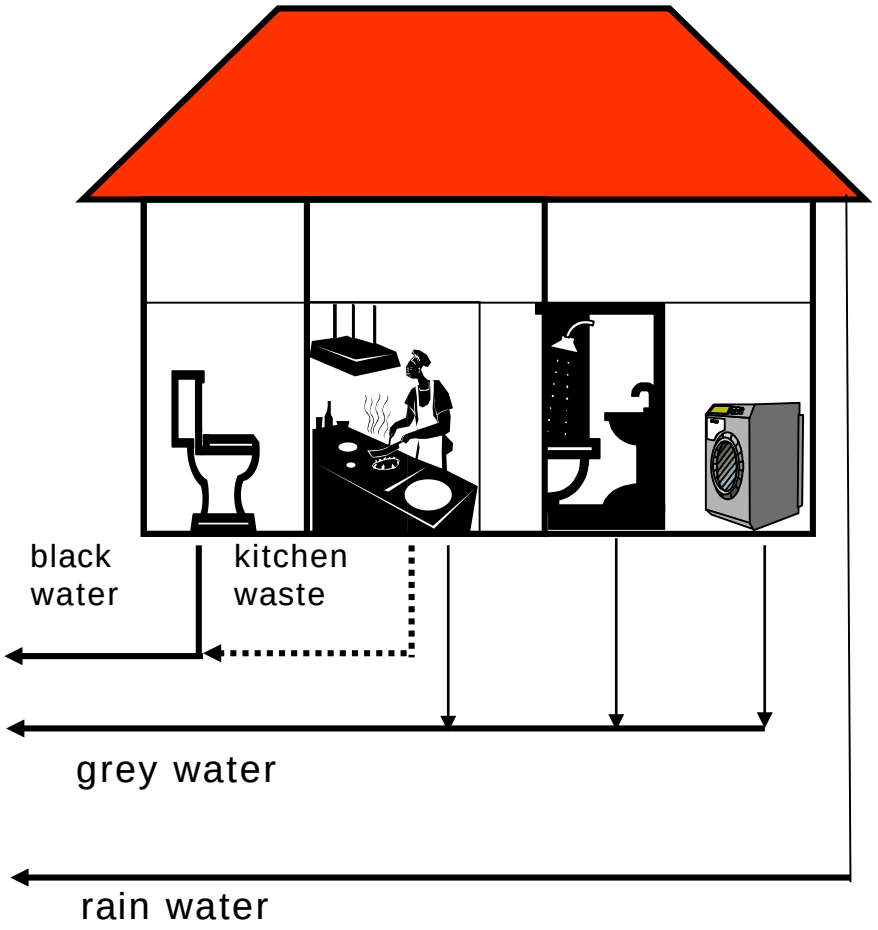
'New Sanitation’

Collection

Transport

Treatment & recovery

Reuse



Vacuum kitchen grinder

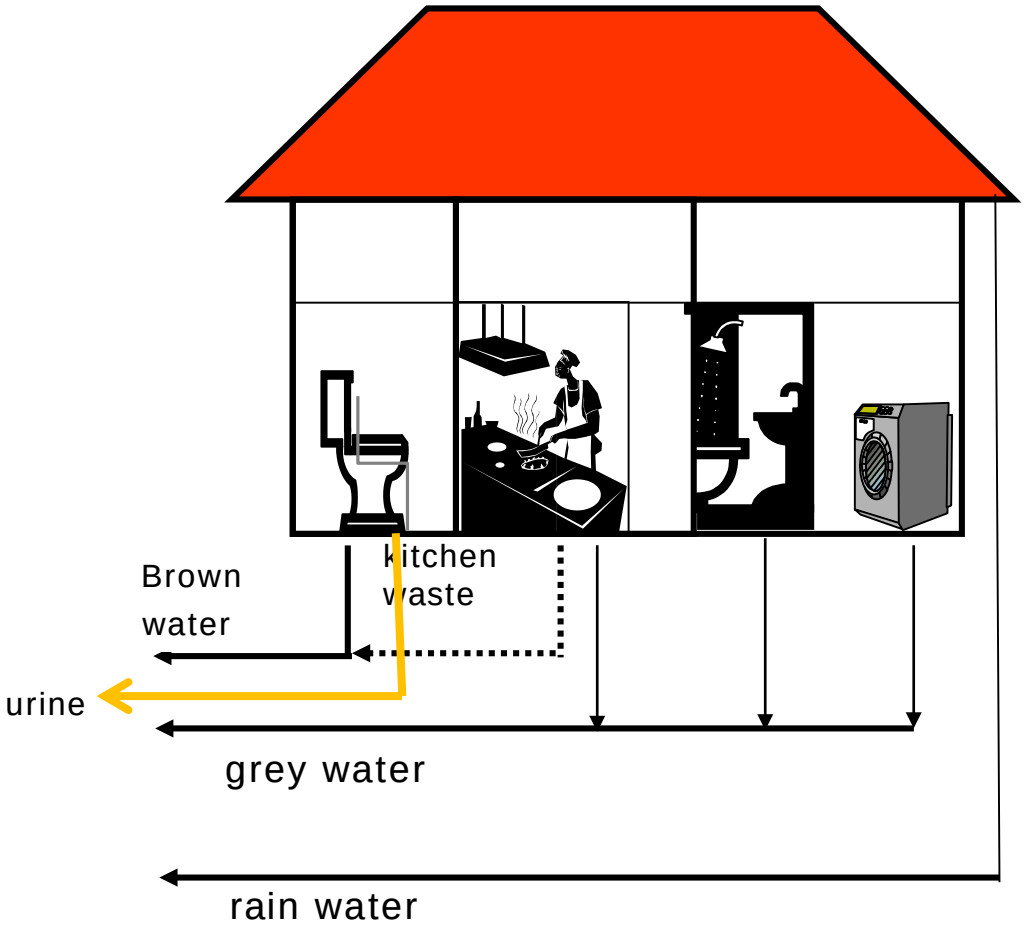
'New Sanitation' ; source separation

Collection

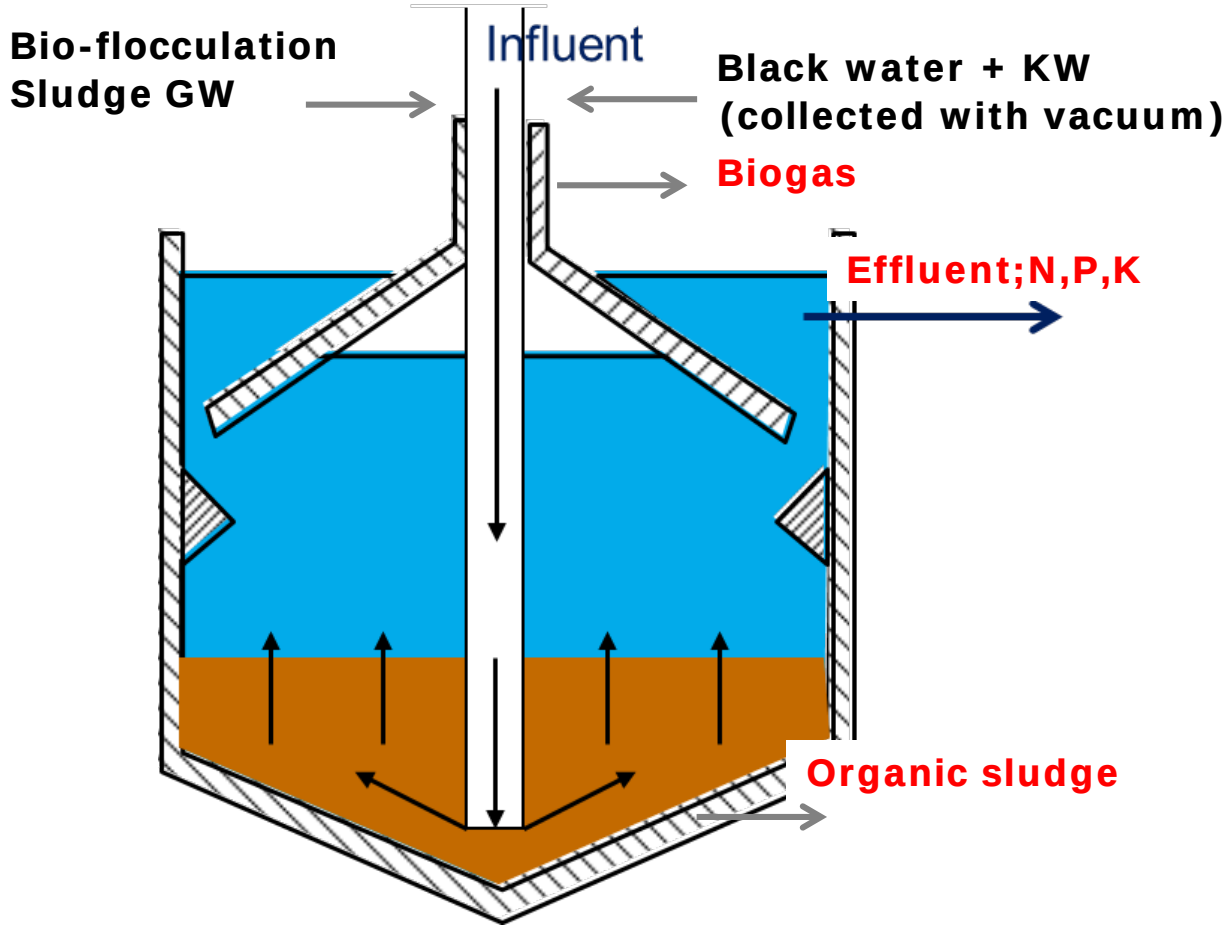
Transport

Treatment & recovery

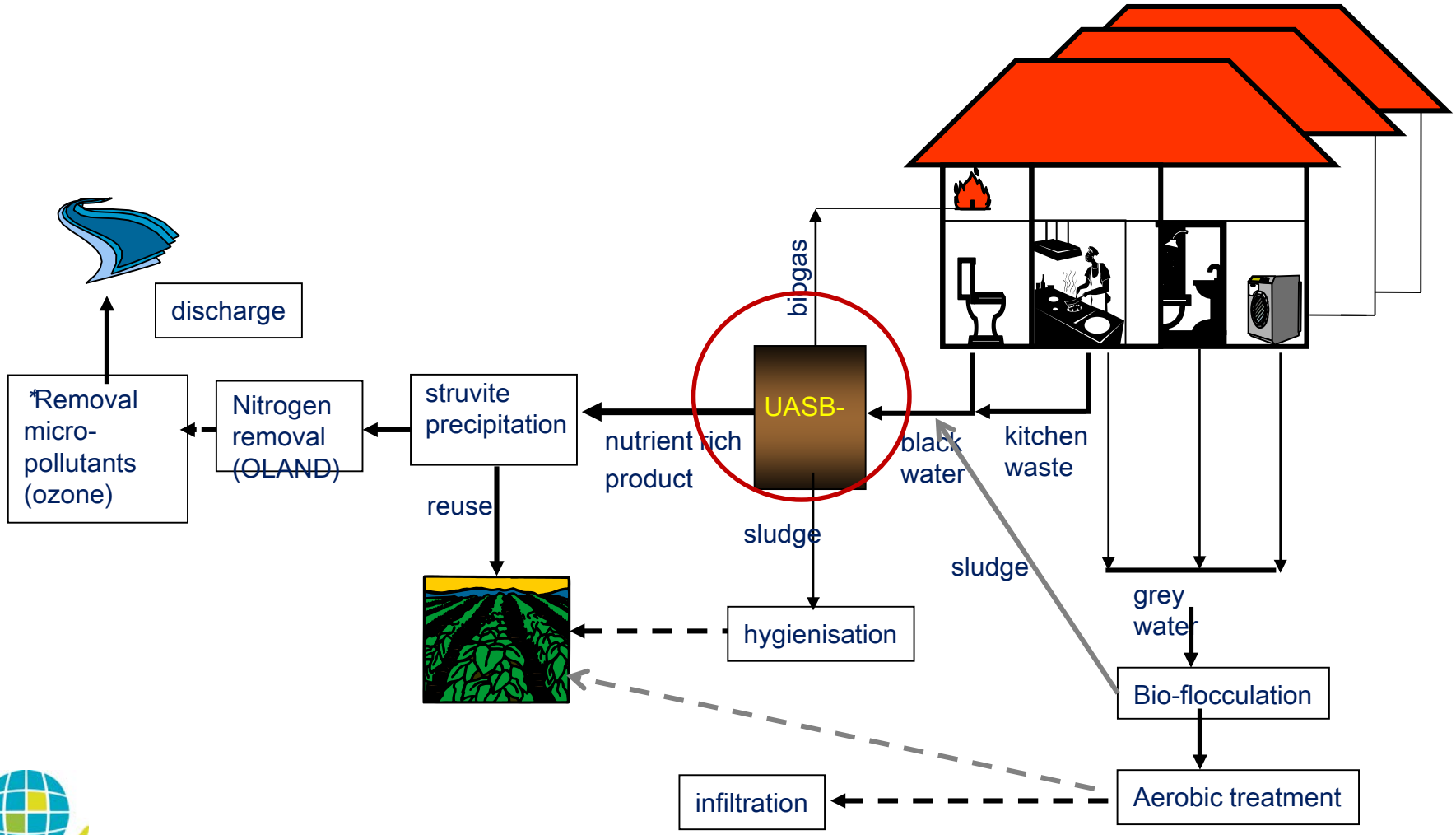
Reuse



Developed ‘New Sanitation’ concept; UASB core technology

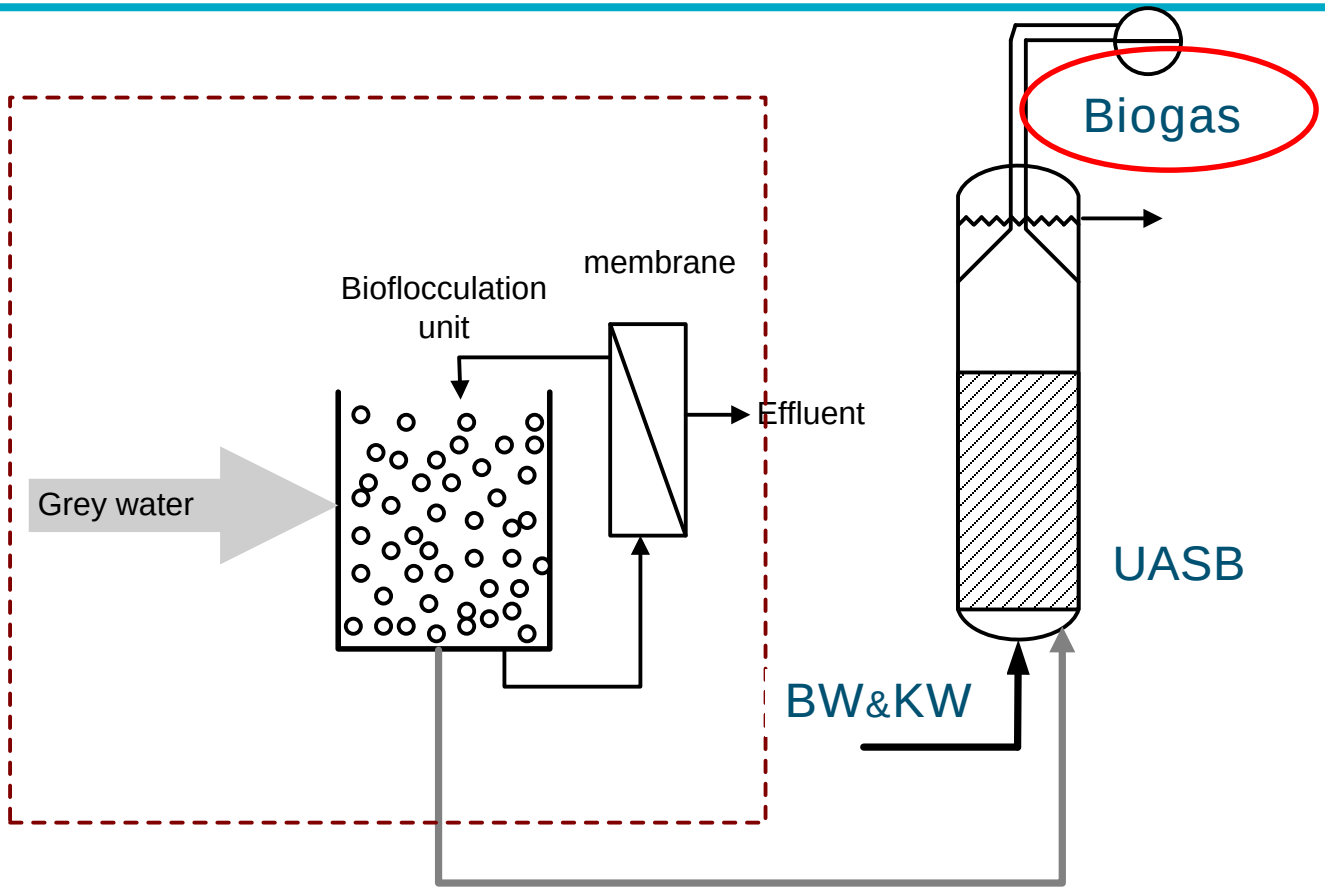


'New Sanitation' concept



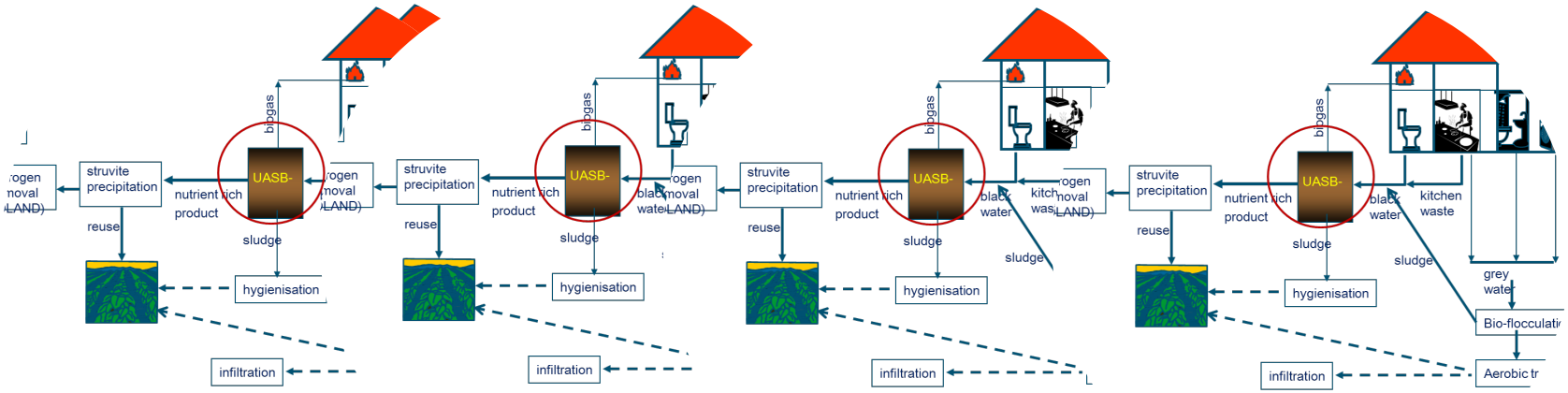
Bio-flocculation of grey water (GW)

Hernandez Leal L., Temmink H., Zeeman G., Buisman C.J.N. (2010b). Bioflocculation of Grey Water for improved energy recovery within decentralized sanitation concepts. Bioresource Technology, Volume 101, Issue 23, 9065-9070



What did we achieve so far in practice?

Full scale applications in Sneek, Venlo, Wageningen, The Hague



Sneek; Waterschoon

250 houses;

Opening in 2011

Venlo, Villa Flora

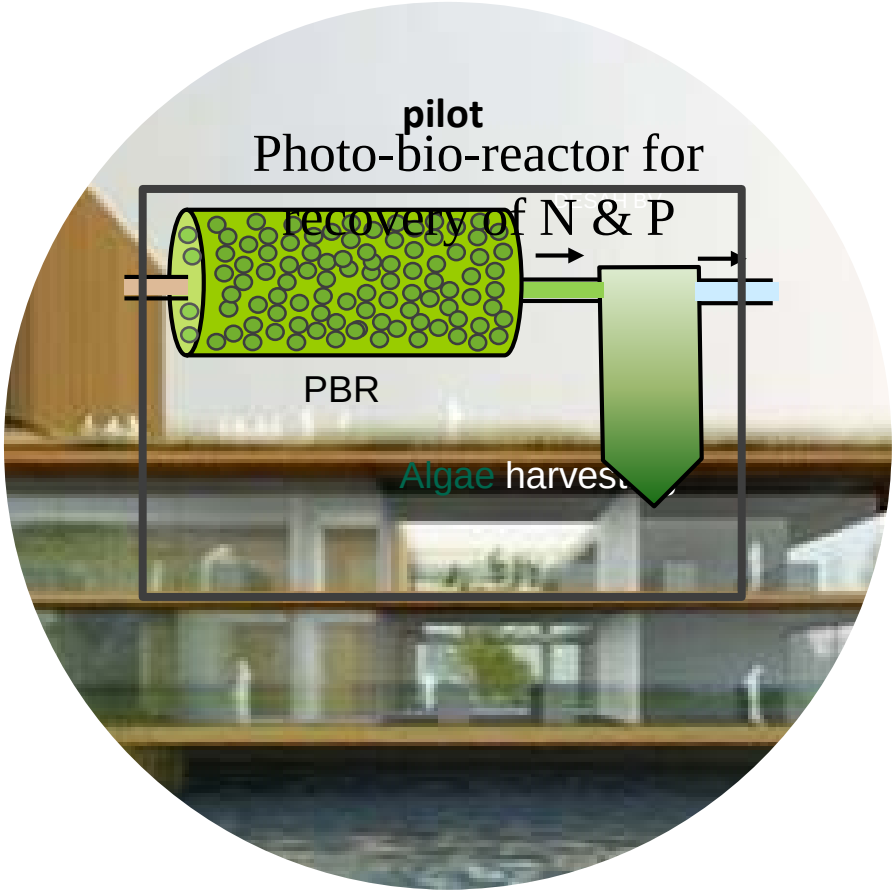
Office building

Opening in 2012

Wageningen, NIOO

Office building

Opening in 2012



NEDERLANDS INSTITUUT VOOR ECOLOGIE
NETHERLANDS INSTITUTE OF ECOLOGY

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The Hague, Ministry of Infrastructure & Environment

Office building

Opening in 2016

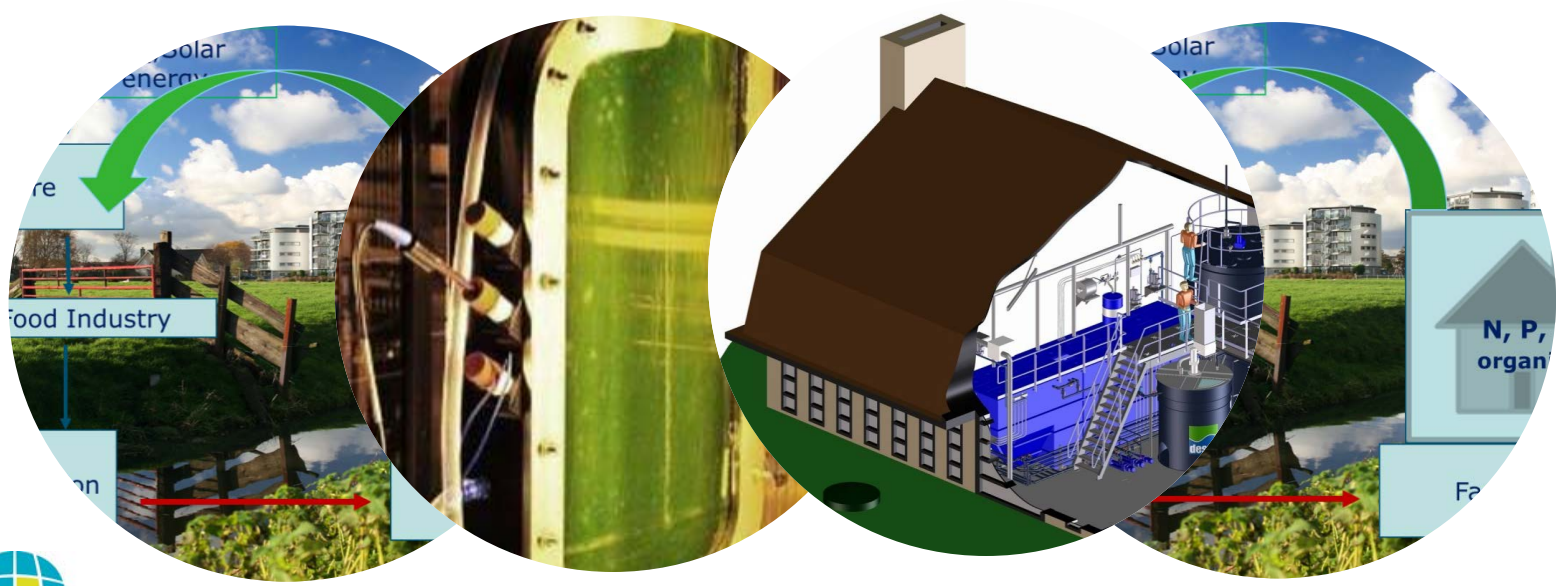
Vacuum toilets & **water free urinals**

UASB-septic tank at Brouwershuis, Wageningen

Since May 2013

Under development

i.e. Amsterdam (450 houses), Nijkerk, Kerkrade, Boekel (The Netherlands), Gent (Belgium), Helsingborg (Sweden), Vigo (Spain), Hamburg (Germany), Edmonton (Canada) and, ...



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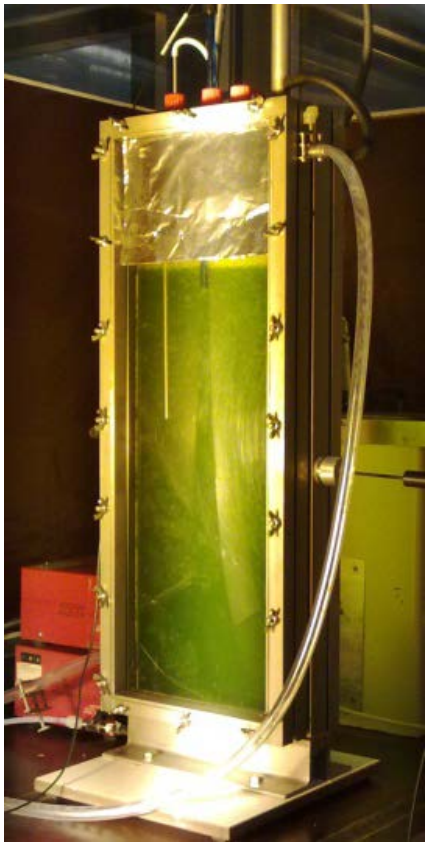
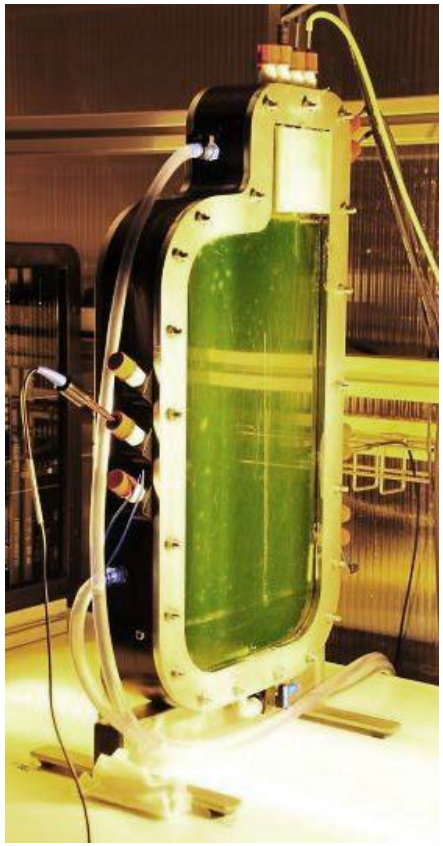
Nitrogen removal or recovery?

Urine separation

N & P recovery; microalgae growth on urine





Kanjana Tuantet, Marcel Janssen, Hardy Temmink, Grietje Zeeman, René H. Wijffels, and Cees J.N. Buisman (2013). Nutrient removal and microalgal biomass production on urine in a short light-path photobioreactor. Water R e search 5 5, 1 6 2 -1 7 4

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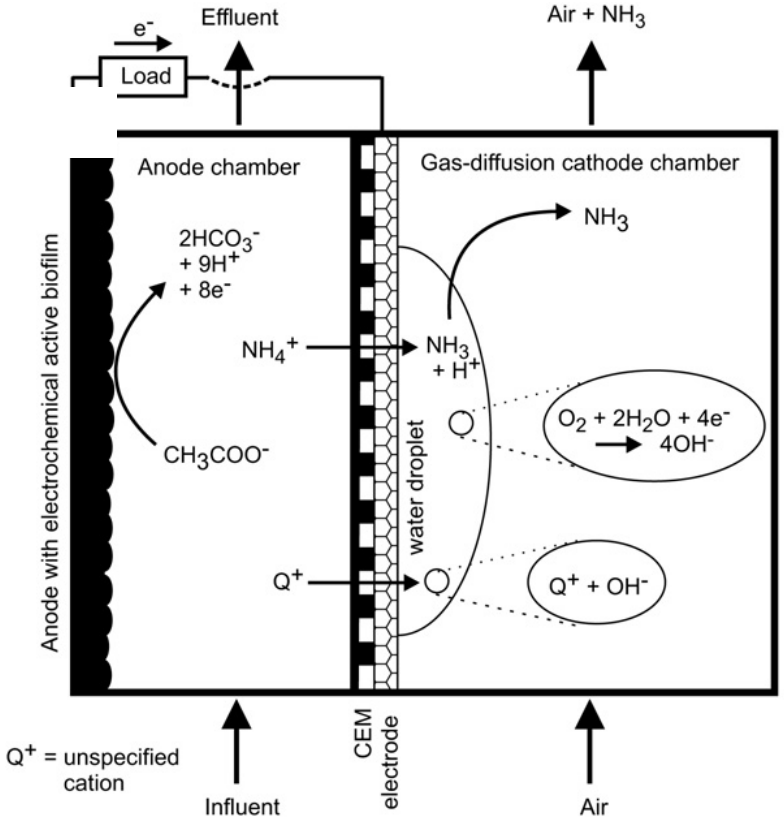
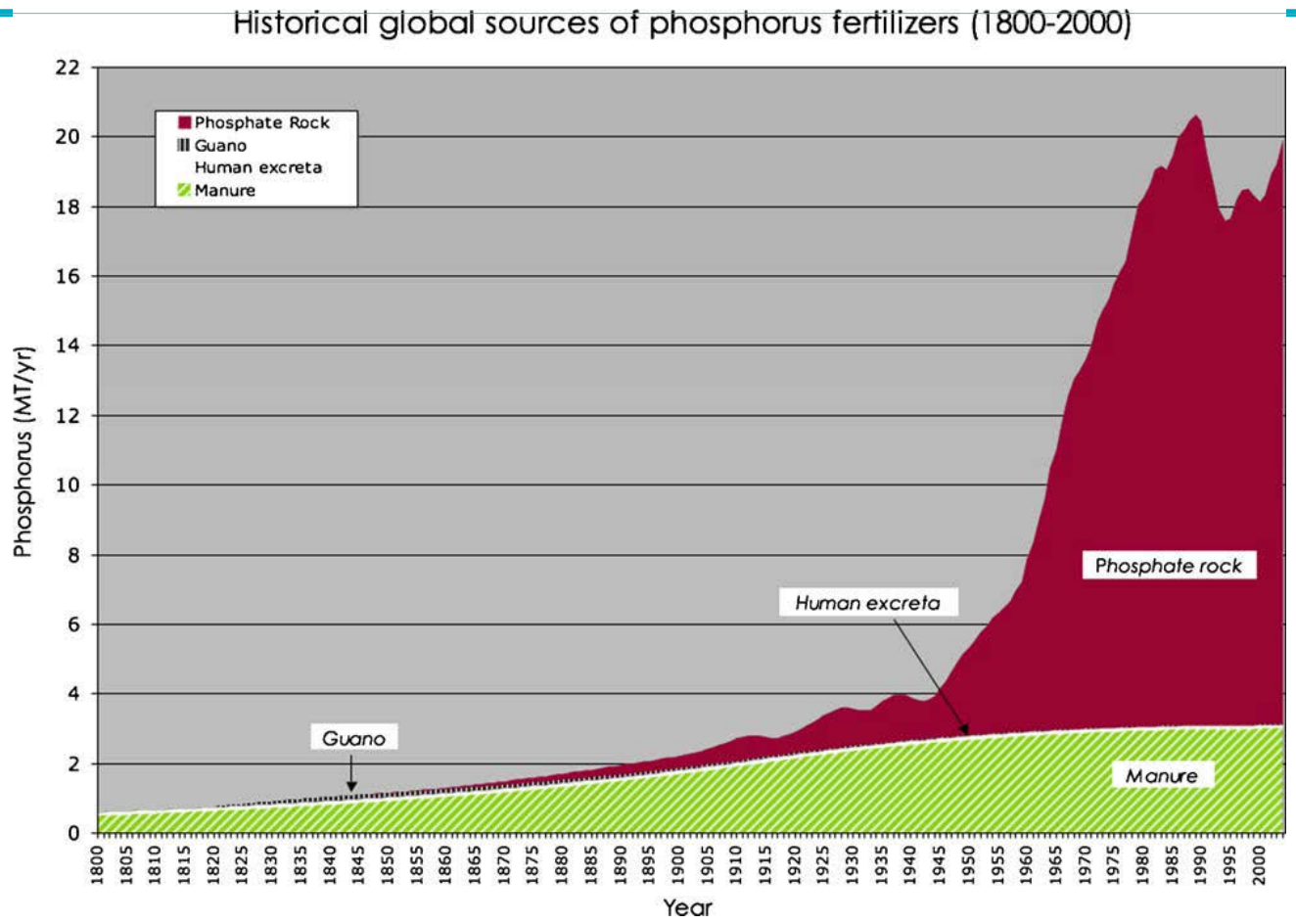
NH_3-recovery; microbial fuel cell

- migrational ion flux to the cathode
- driven by electron production
- anaerobic degradation of organic matter in urine.



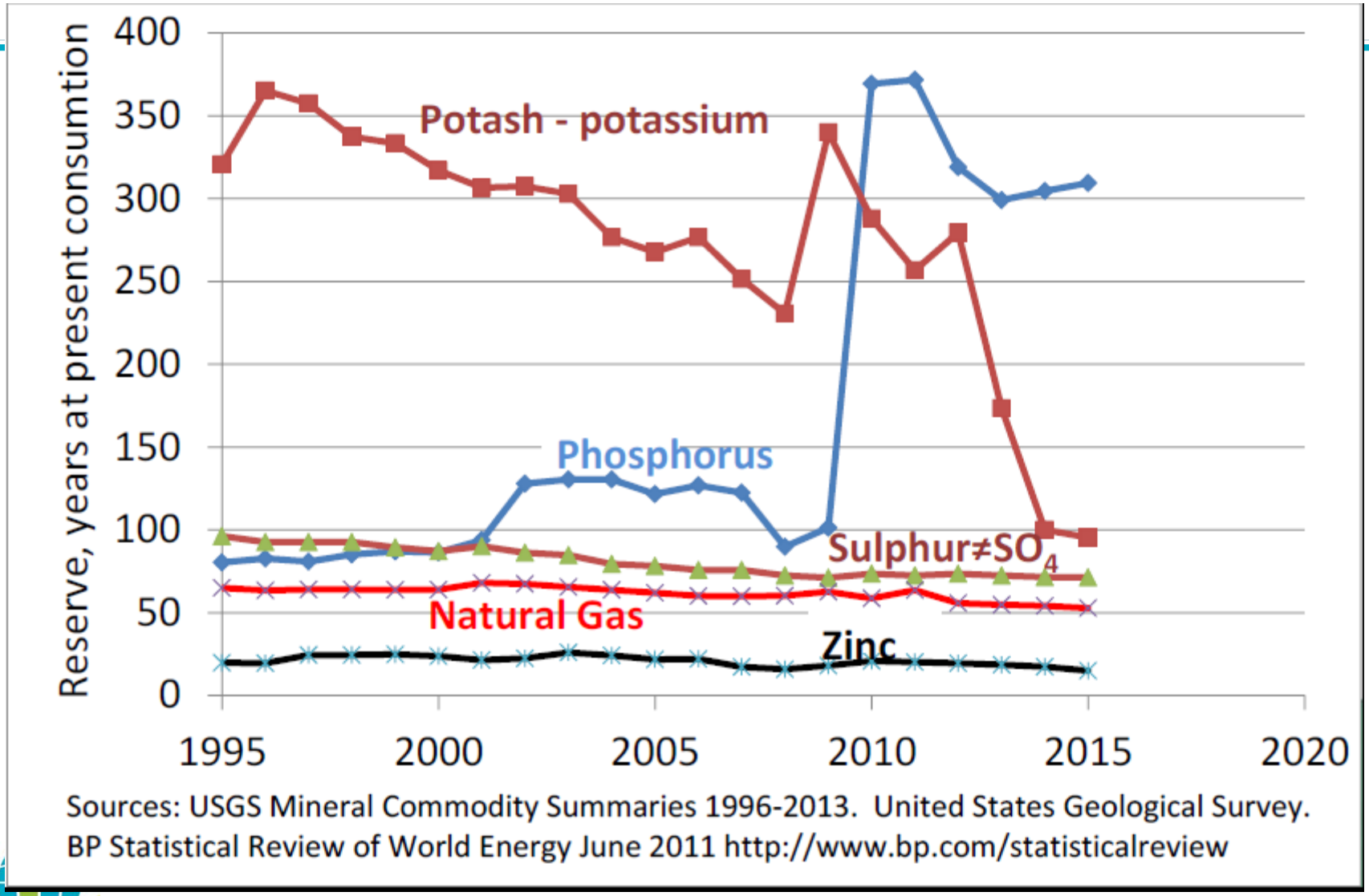
Kuntke, P., Śmiech, K.M. , Bruning, H., Zeeman, G., Saakes, M. , Sleutels, T.H.J.A. , Hamelers, H.V.M., Buisman, C.J.N. (2012). Ammonium recovery and energy production from urine by a microbial fuel cell. Water Research, 46-8, 2627-2636

Phosphorus is a finite resource



Cordell, D., Drangert, J.-O., and White, S. (2009). The story of phosphorus: Global food security and food for thought. Global Environmental Change, 19, 292-305.

Supply/scarcity of different resources



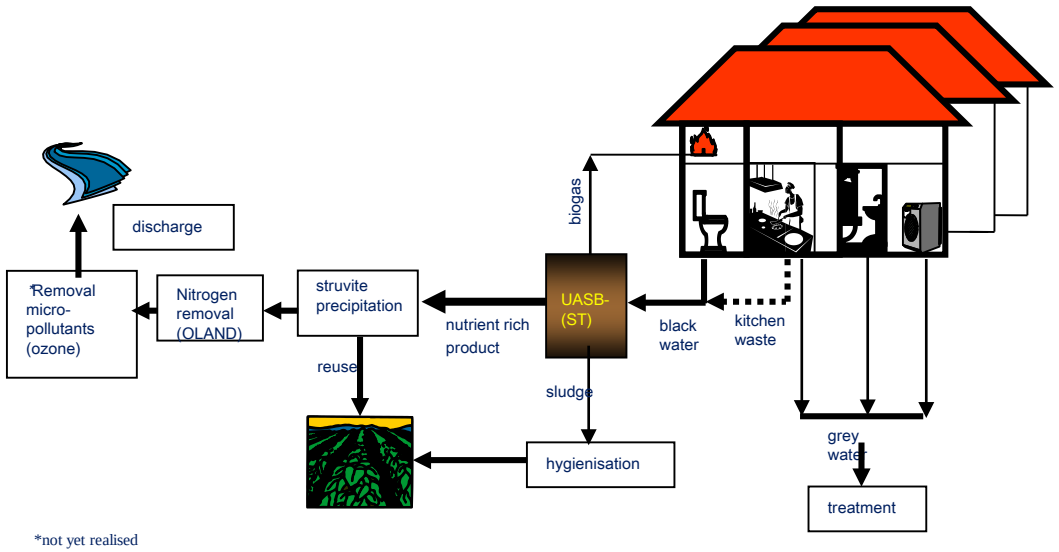
Sources: USGS Mineral Commodity Summaries 1996-2013. United States Geological Survey.
BP Statistical Review of World Energy June 2011 http://www.bp.com/statisticalreview

Håkan **Jönsson**,
(Wageningen, 7-10-2016)

'New Sanitation' concept

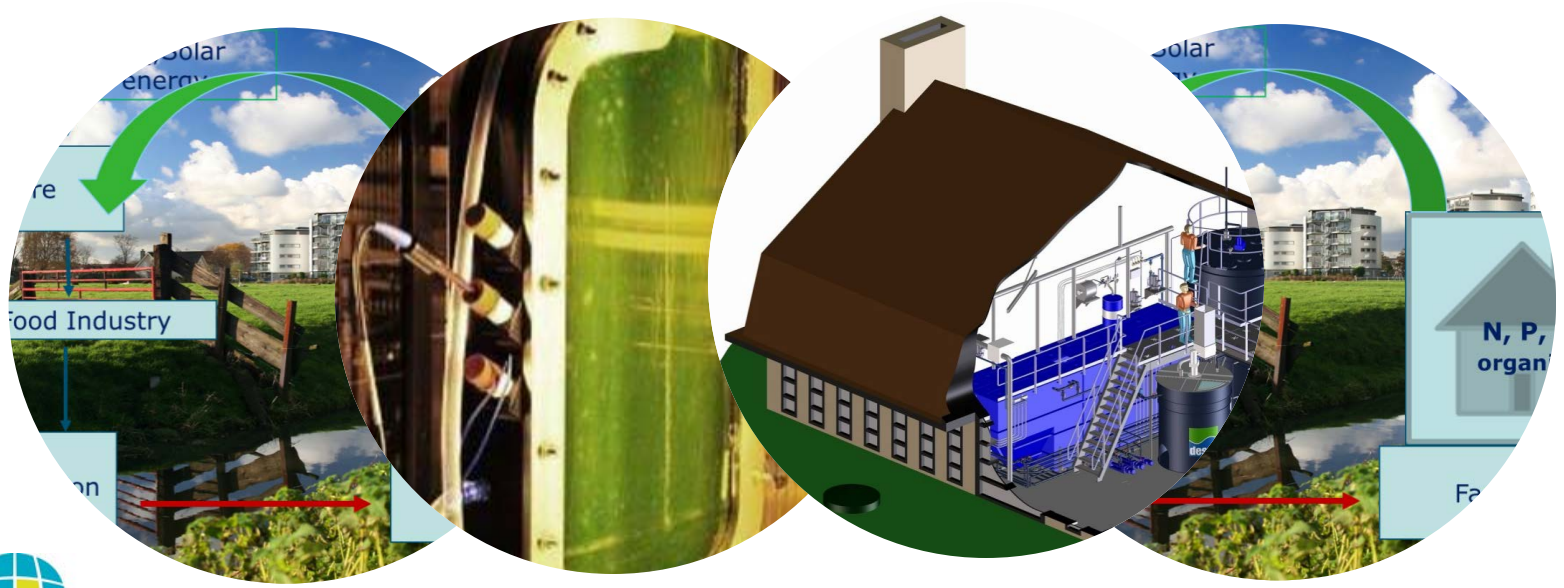
Local recovery and reuse of:

- Energy
  - **Biogas**
  - **Heat**
- Nutrients
  - **Struvite**
- Organic fertiliser
- Water



New developments

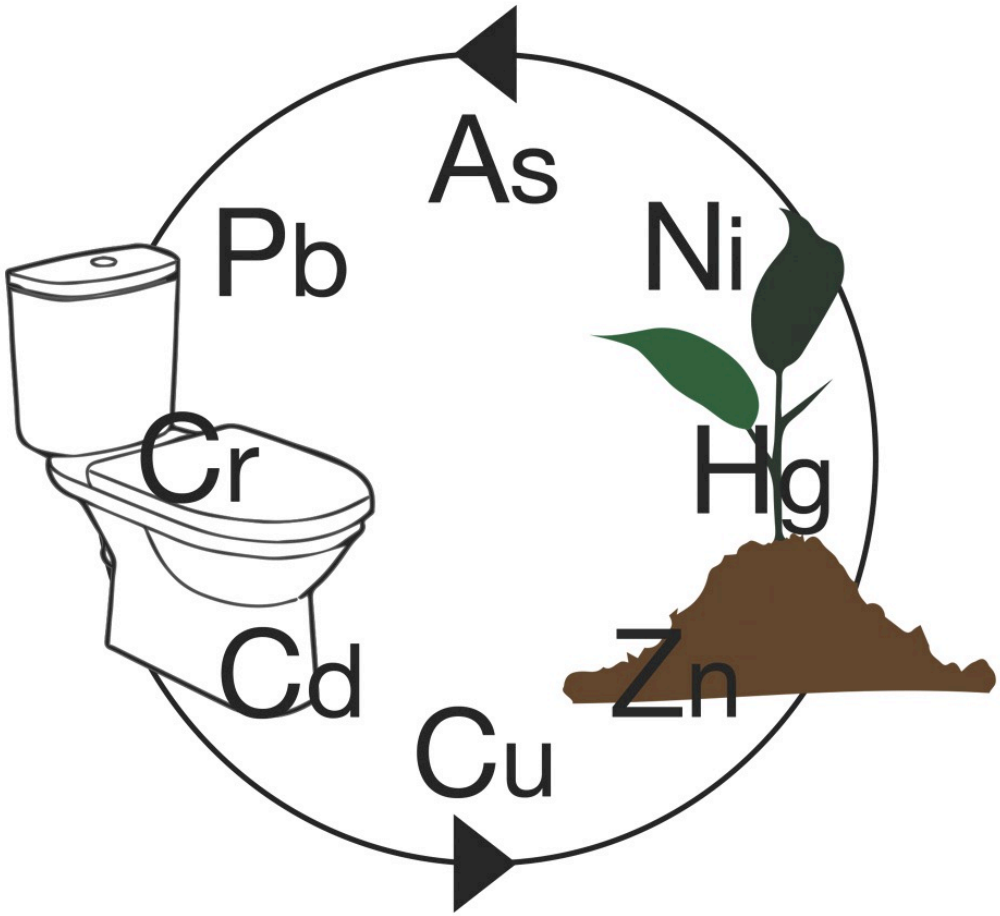
BW sludge quality; CaP recovery; hyper-thermophilic anaerobic treatment



Quality of BW organic sludge

Improving soil quality

Heavy metals in black water sludge



Tervahauta, T.; Rani, S.; Hernández Leal, L.; Buisman, C.J.N.; Zeeman, G. Black water sludge reuse in agriculture: Are heavy metals a problem? J. Hazard. Mater. 2014, 274, 229–236.

Heavy metals in black water sludge

Heavy metal content of black water sludge, sewage sludge, cow manure and phosphate fertilizer (unit mg/kg P).

Element	BW sludge[a]	Sewage sludge[b]	Cow manure[c]	P-fertilizer[d]
As	12	300	nd	33
Cd	13	39	33	91
Cr	731	1268	1145	1245
Cu	3720	12701	14397	207
Hg	0.12	23	nd	0.7
Ni	466	1025	1472	202
Pb	69	3519	695	154
Zn	13919	31166	25947	1923

nd, not detected.

[a] Measured in this study.
[b] CBS
[c] van Dooren et al.
[d] Remy and Ruhland

Tervahauta, T.; Rani, S.; Hernández Leal, L.; Buisman, C.J.N.; Zeeman, G. Black water sludge reuse in agriculture: Are heavy metals a problem? J. Hazard. Mater. 2014, 274, 229–236.

Heavy metals in black water sludge

The heavy metals in faeces and urine are primarily from dietary sources

Promotion of the soil application of black water sludge over livestock manure and artificial fertilizers could further reduce the heavy metal content in the soil/food cycle.

Tervahauta, T.; Rani, S.; Hernández Leal, L.; Buisman, C.J.N.; Zeeman, G. Black water sludge reuse in agriculture: Are heavy metals a problem? J. Hazard. Mater. 2014, 274, 229–236.

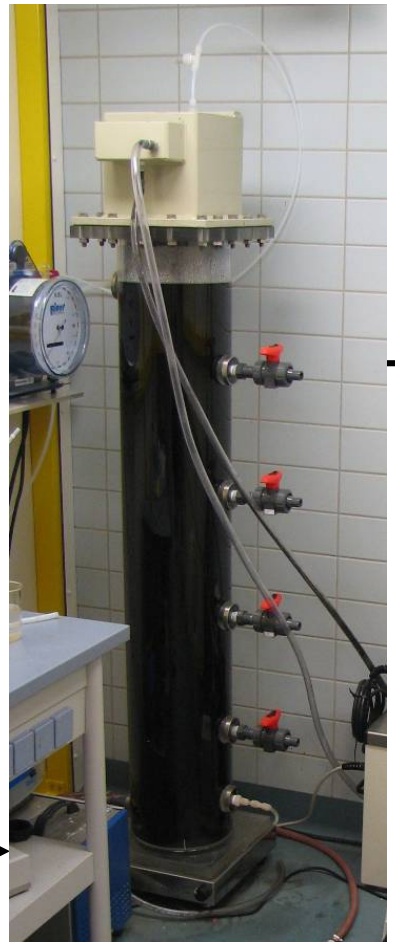
Micro-pollutants in black water sludge; Composting

Compound	Micropollutants reduction by weight, %	
	at 35ºC	at 50ºC
Estrone	99.9	99.8
Diclofenac	99.9	99.9
Ibuprofen	99.8	99.9
Carbamazepine	88.1	87.8
Metoprolol	95.1	94.2
Galaxolide	97.8	97.0
Triclosan	96.6	92.9

Butkovskyi, A. G. N, Hernandez Leal, L., Rijnaarts, H.H.M. , Zeeman, G. (2016). Mitigation of micropollutants for black water application in agriculture via composting of anaerobic sludge. Journal of Hazardous Materials 303, 41–47

Phosphorus balance UASB; 900 days

HRT 9 days; 25°C



100%

61%

Struvite ($MgNH_4PO_4$)
0.22 kg P $p^{-1}y^{-1}$

De Graaff et al., (2011), WS&T

Recovery of Ca-Phosphate in a UASB

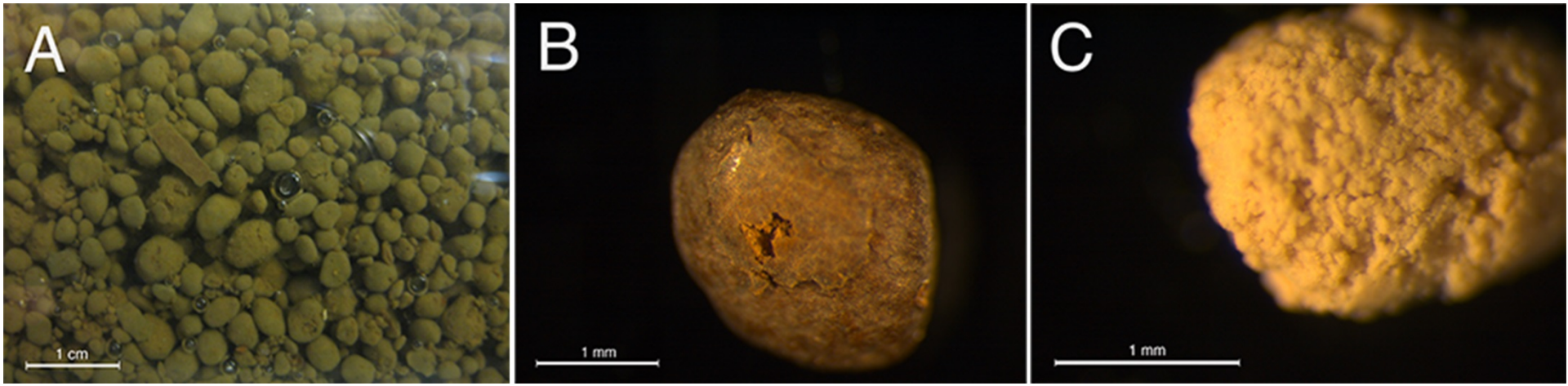
P-free effluent;

CaP granules

Organic sludge

influent

Calcium phosphate granulation in anaerobic treatment of black water

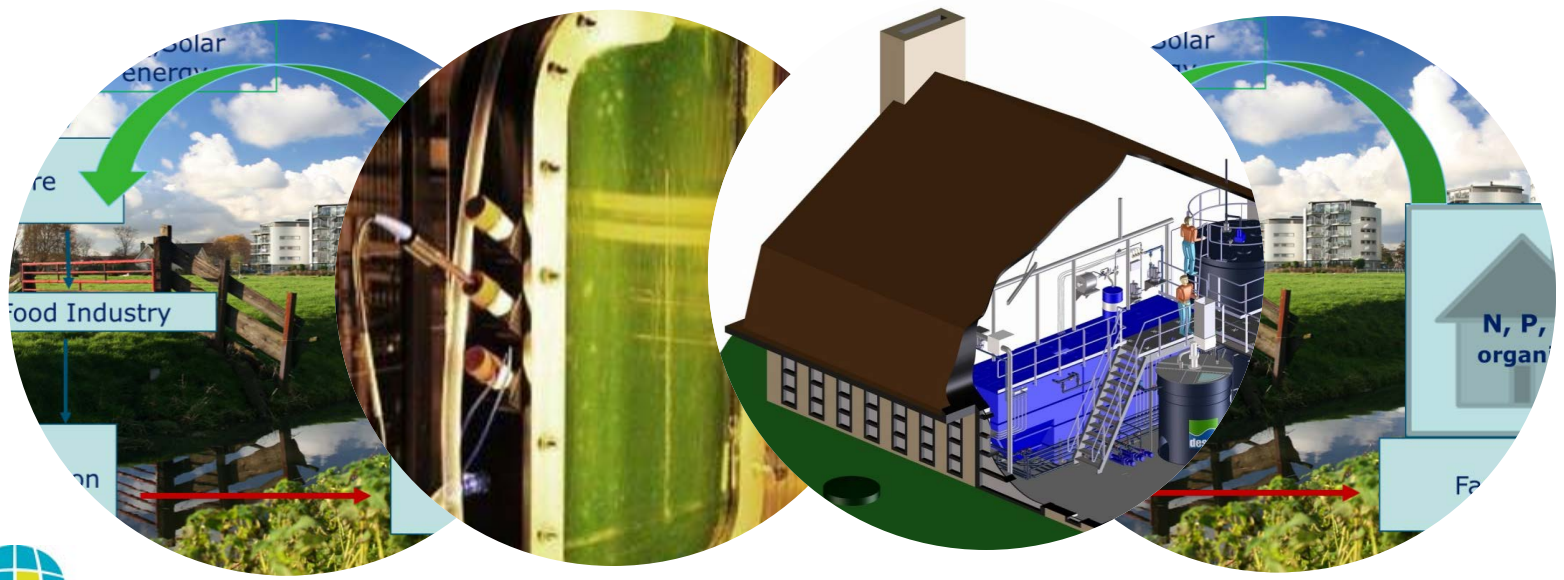


Tervahauta, T., van der Weijden, R. D., Flemming, R. L., Herna´ndez Leal, L., Zeeman, G., Buisman, C. J., 2014. Calcium phosphate granulation in anaerobic treatment of black water: A new approach to phosphorus recovery. ***Water Research*** *48, 632–642.*

Future

Much higher BW concentration

Very low flush toilets (≤ $1lp^{-1}d^{-1}$)



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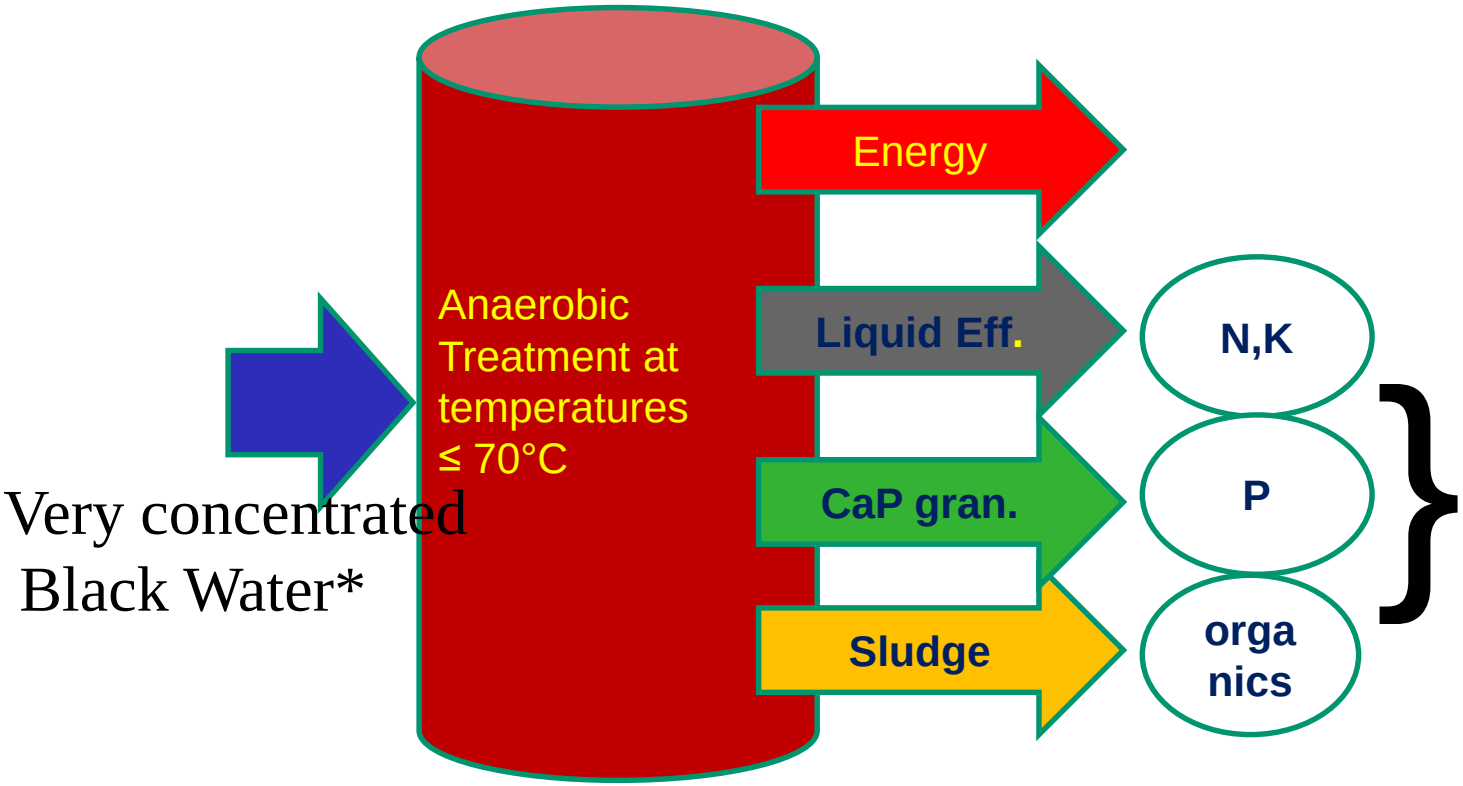
(Vacuum) toilet

Maximum 1 liter per person **per day**

One step treatment of BW



*Collected with **improved** vacuum toilets

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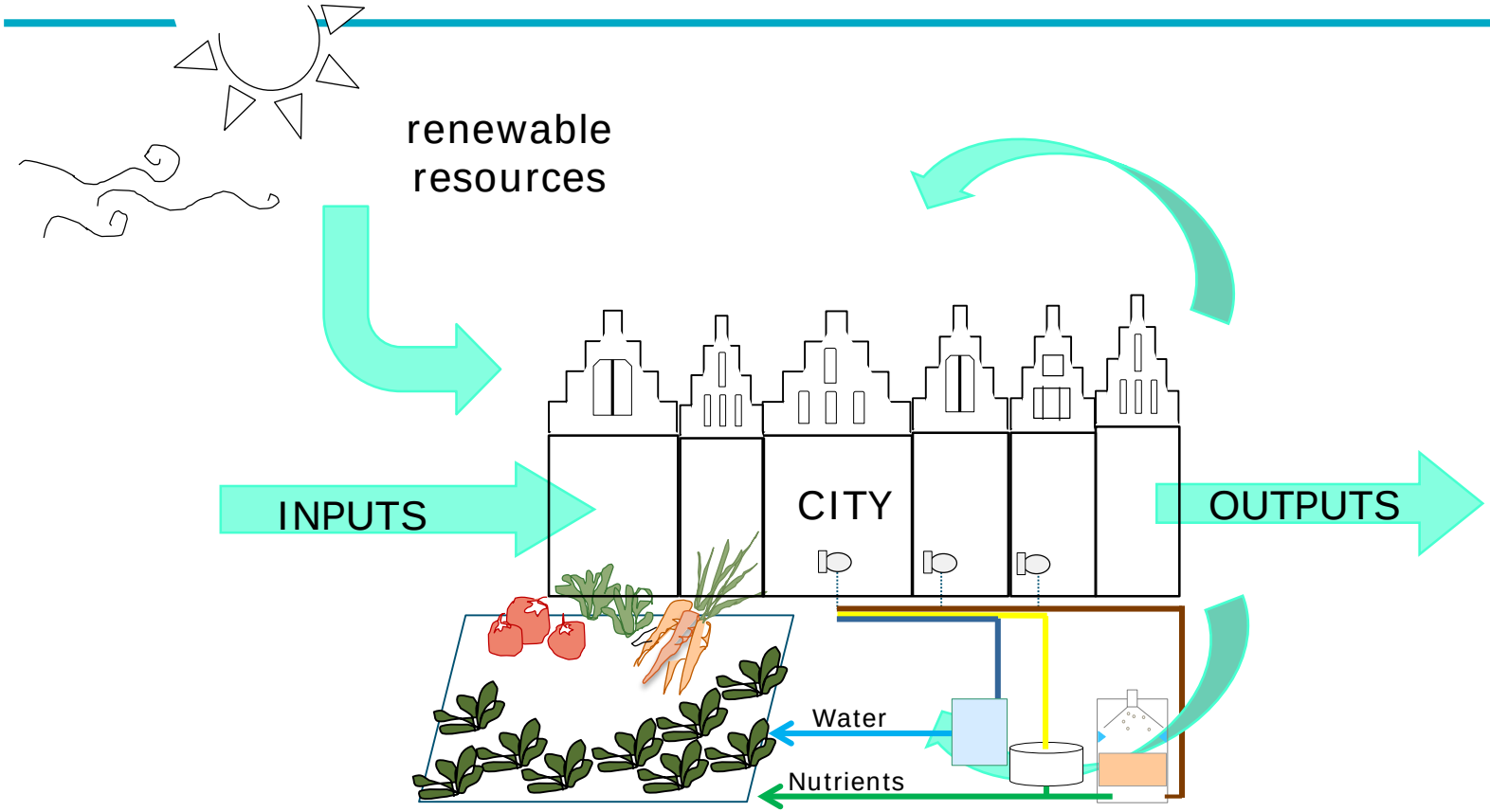
Urban Agriculture & New Sanitation



Website: www.wageningenur.nl/ete; rosanne.wielemaker@wur.nl

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Urban Agriculture Typologies

- Ground-based

- Rooftop

(De DakAkker, 2014)

rosanne.wielemaker@wur.nl

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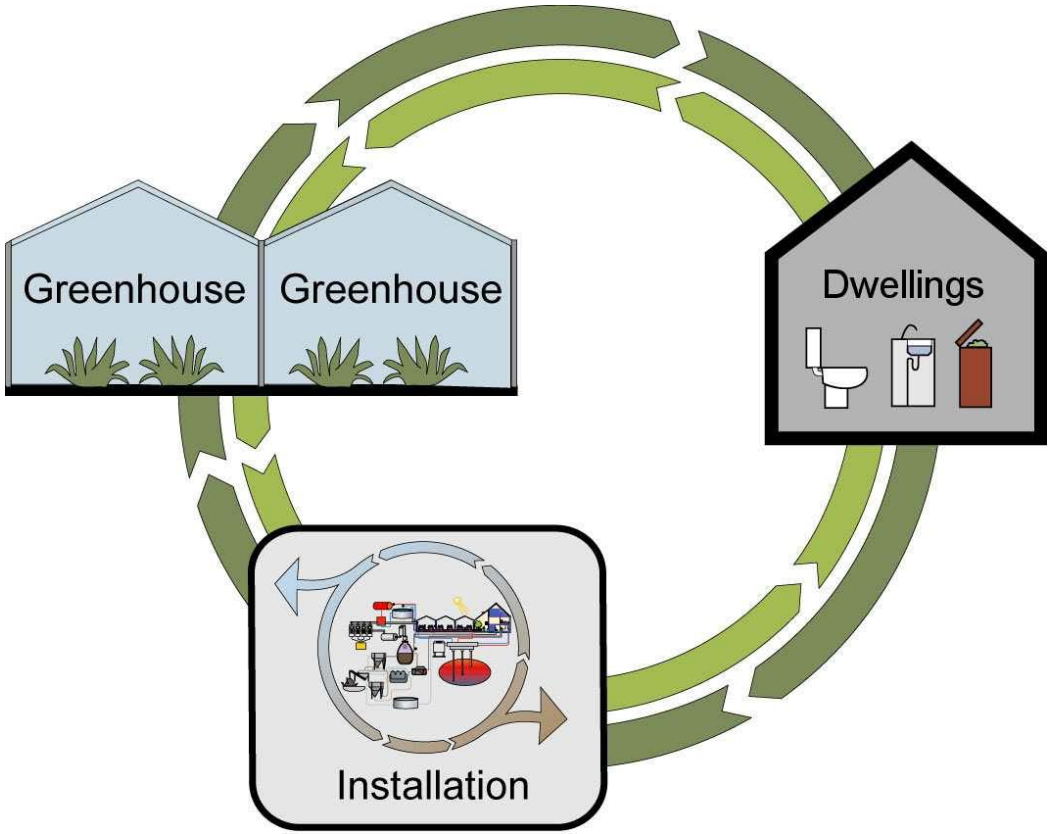
Greenhouse Village

Mels *et al*, (2007); www.zonneterp.nl

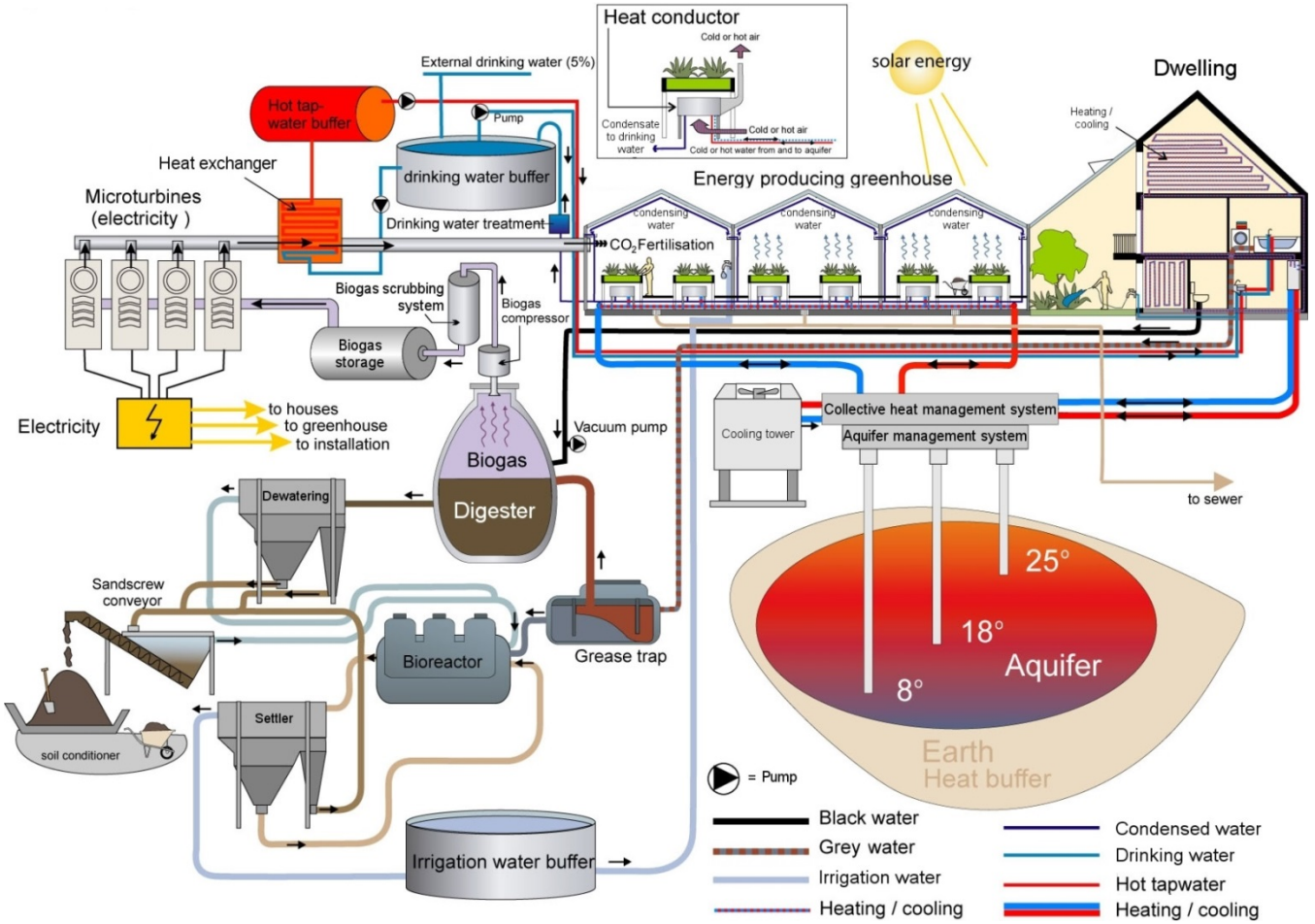


Exchange of resources

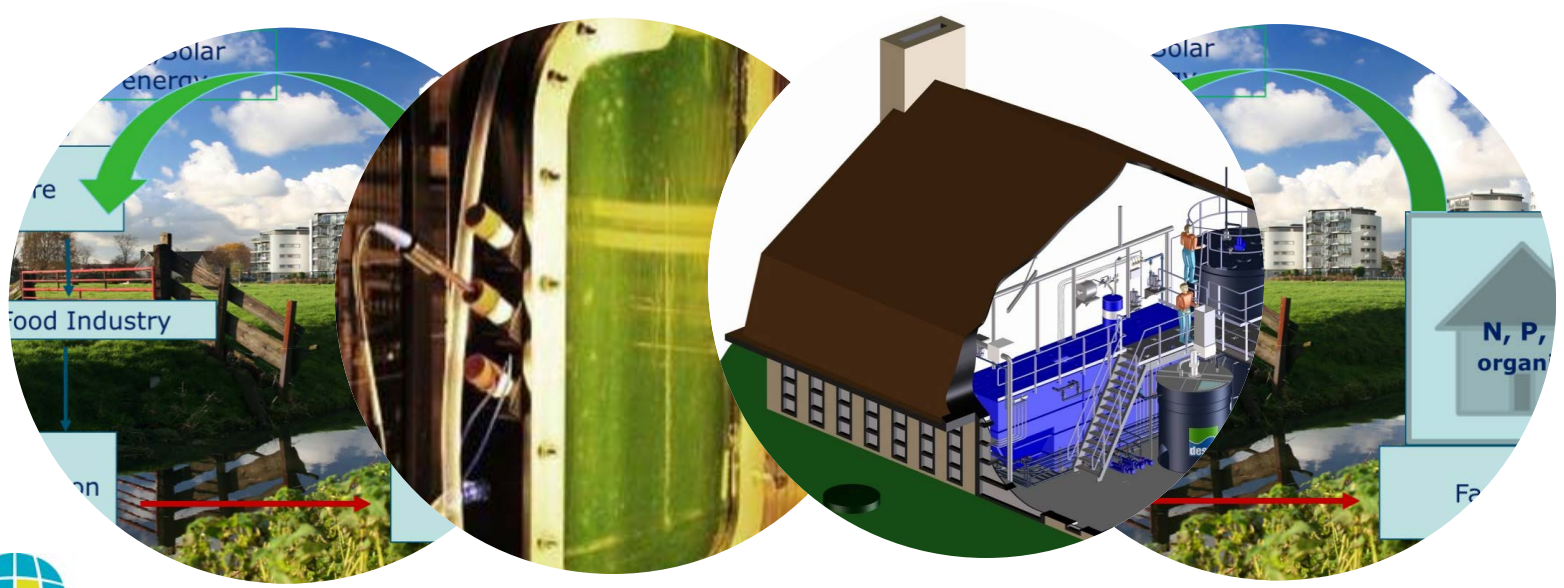
Closed resource cycles

- Integration of functions
- Implementation of technologies

Greenhouse Village
Mels *et al*, (2007); www.zonneterp.nl



Costs;
based on monitoring results Waterschoon



Comparison ‘New’ and ‘conventional’ sanitation

‘New sanitation’ at 1200 p.e. ca. 11 % more expensive than conventional at 100.000 p.e

Incl. price volatility calculation & uncertainty range:

At a scale between 1.000 en 1.500 inhabitants, ‘New sanitation’ has similar costs as compared to ‘conventional sanitation’ (100.000 p.e.)

*de Graaf, R. and A. J. van Hell (2014). New Sanitation Noorderhoek, Sneek. P. Hermans. Amersfoort, STOWA (Dutch Foundation for Applied Water Research): 304

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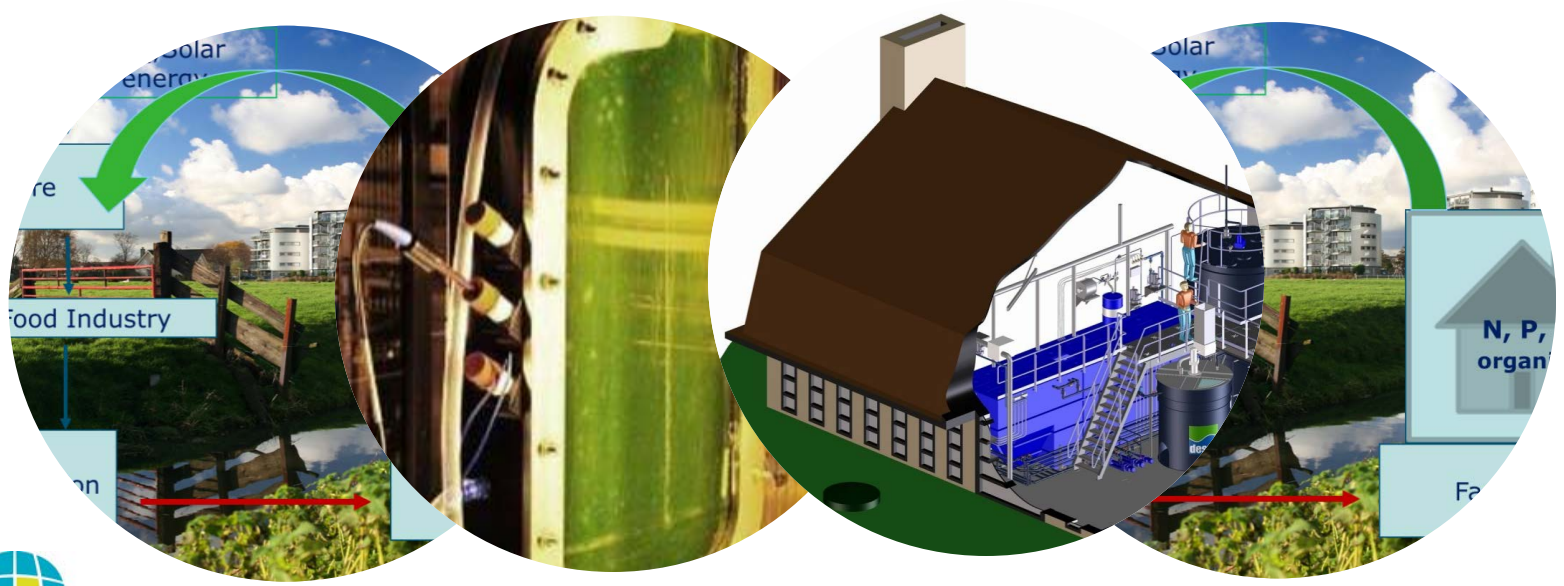
Conclusions

4 ‘New Sanitation’ applications in The Netherlands &

Several in preparation also elsewhere in Europe and Canada;

Improved concepts under development.

Ready for further application!!



Thank you Håkan !!!!!!!!!!!!!!!!!

Source separation; the future for efficient resource recovery

Questions?

Grietje Zeeman

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