Water sensitive sanitation

The waste(water) biorefinery.

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LEED certification in the peri-urban space

The U.S. Green Building Council's LEED Green Building Rating System establishes "best practice" criteria for water and energy usage that can be applied to any type of construction, even if certification is not the goal. The Water Use Reduction section of LEED-NC identifies a baseline for water use and awards one or two credits for surpassing requirements, in aggregate by 20 percent or 30 percent, respectively, beyond the Energy Policy Act of 1992 fixture performance requirements.

- WE 2: Innovative Wastewater Technologies. The intent is to reduce generation of wastewater and potable water demand, while increasing the local aquifer recharge.
- WE 3.1: Water Use Reduction 20%. The intent is to maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.
- WE 3.2: Water Use Reduction 30% has same intent as 3.1.

Structure

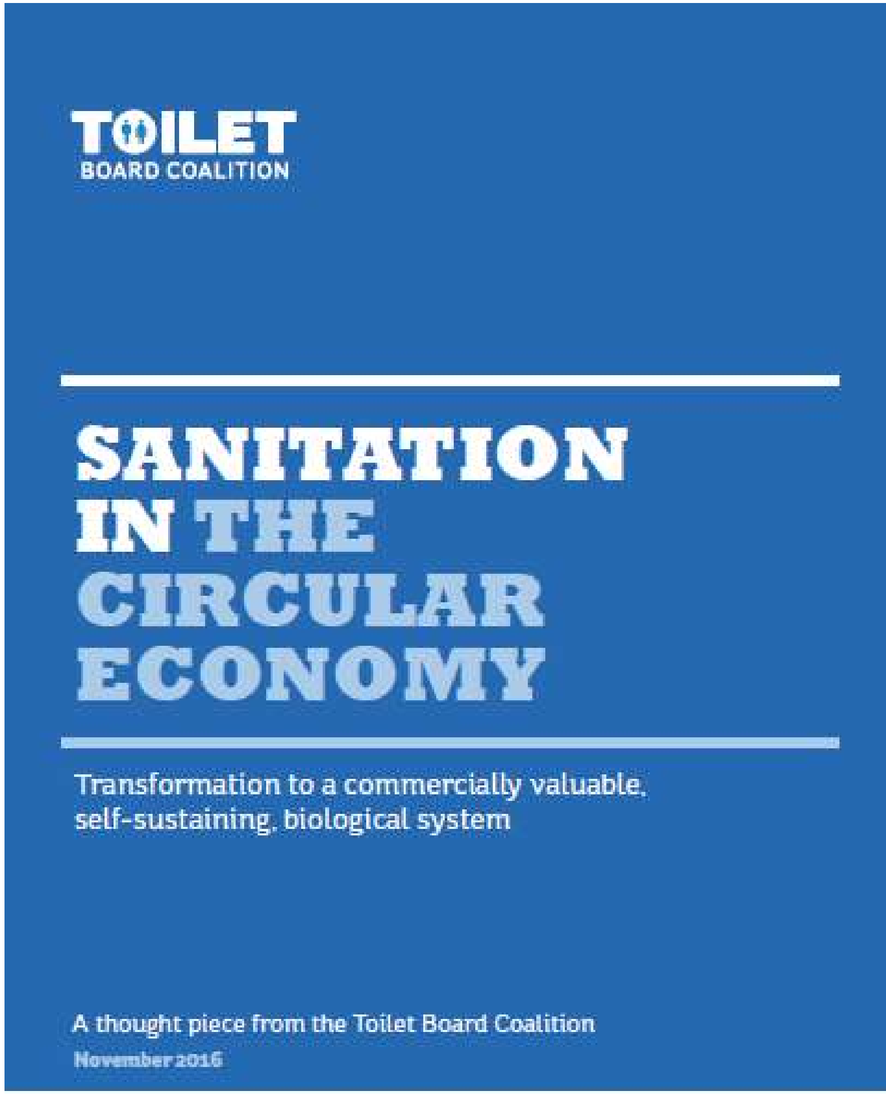
1. Size of the opportunity: some findings of WRC Report 2380-1-17 "Towards Wastewater Biorefineries: integrated bioreactor and process design for combined water treatment and resource productivity"
2. Why sanitation: The challenge
    1. P
    2. N
    3. Environmental buffers
3. Products suitable from sanitation – focus on (very) high value
4. Flush or dry?

TL;DR:

The nutrients in waste is profoundly valuable and needed to grow the economy.

The best way to get these nutrients is through dry sanitation.

We are all peri-urban; We should ALL use dry toilets.



http://www.toiletboard.org/media/17-Sanitation_in_the_Circular_Economy.pdf

Water sensitive sanitation: Two options

1. Quantity: Use less water and/or;
2. Quality: Recover the water used, better

In addition, recover nutrients and energy.

-> Water consciousness in the big picture

Peri-urban?

“Peri-urban areas (also called rurban space, outskirts or the hinterland) are defined by the structure resulting from the process of peri-urbanisation. It can be described as the landscape interface between town and country, or also as the rural—urban transition zone where urban and rural uses mix and often clash. It can thus be viewed as a landscape type in its own right, one forged from an interaction of urban and rural land use.”

So, urban sprawl? Having a garden?

We are all peri-urban.

https://en.wikipedia.org/wiki/Peri-urbanisation

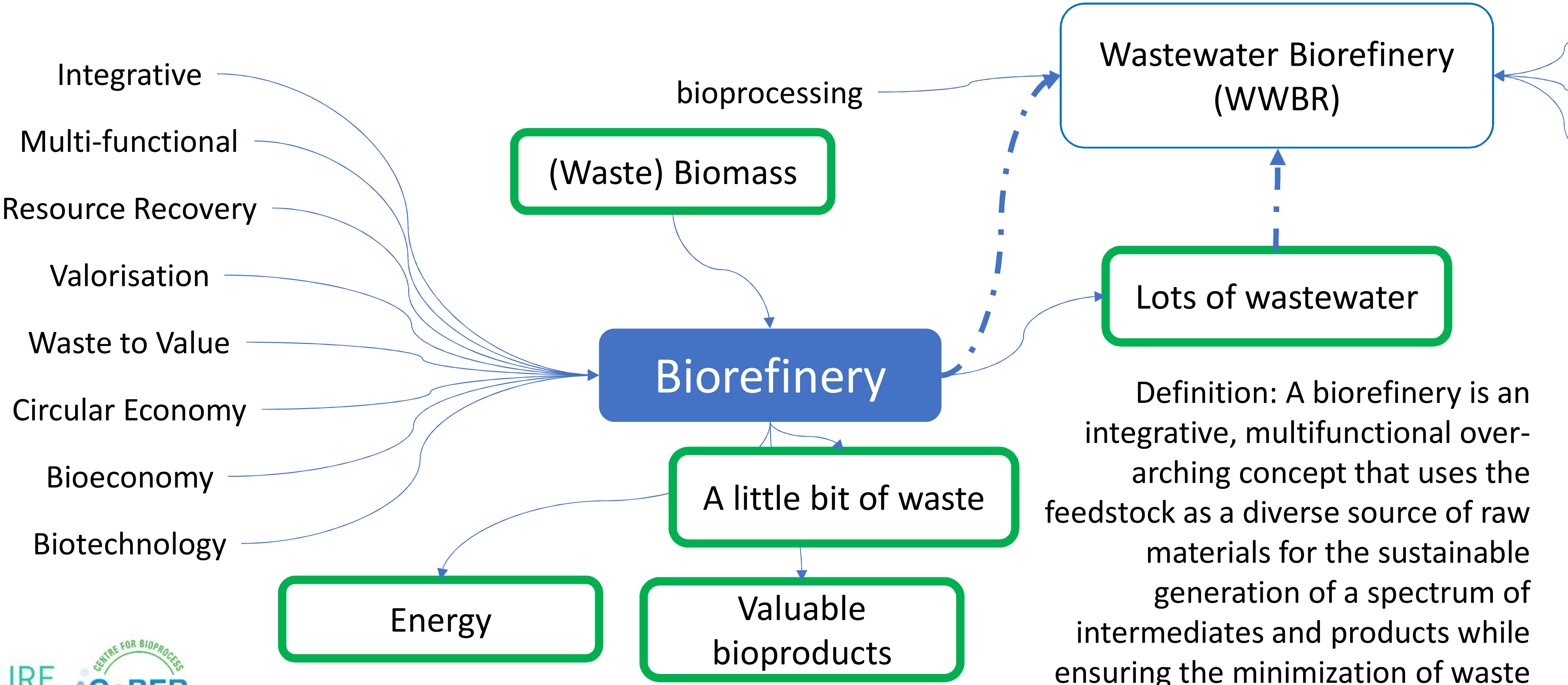
Resource Efficiency

Using less, living better

Using the Earth's limited resources in a sustainable manner while minimizing the impacts on the environment

$$\text{Resource Efficiency} = \frac{\text{Benefits (useful outputs)}}{\text{Adverse environmental impact}}$$

WWBR = Biorefinery + Water?



Definition: A biorefinery is an integrative, multifunctional over-arching concept that uses the feedstock as a diverse source of raw materials for the sustainable generation of a spectrum of intermediates and products while ensuring the minimization of waste products.

ACTIVE Biotransformation

not just (passive) Bioremediation

It's all about reactor design

wastewater

waste nutrients

biotechnology

bioprocessing

biorefinery

bioeconomy

Wastewater Biorefinery (WWBR)

wastewater treatment

environmental protection

human health?

environmental engineering

products of value

fit for purpose water

… A wastewater biorefinery expands this application to include wastewater as a source of raw materials, operating in the wastewater arena and designed to, simultaneously, generate products of value from waste nutrients and produce clean or 'fit for purpose' water as the non-negotiable product (using De la Fuente, 2014)

What is a Wastewater Biorefinery?

- Emphasis is on ACTIVE Biotransformation, not just (passive) Bioremediation.
- Definition: A biorefinery is an integrative, multifunctional over-arching concept that uses the feedstock as a diverse source of raw materials for the sustainable generation of a spectrum of intermediates and products while ensuring the minimization of waste products. A wastewater biorefinery expands this application to include **wastewater as a source of raw materials**, operating in the wastewater arena and designed to, simultaneously, generate products of value from waste nutrients and produce clean or 'fit for purpose' water as the non-negotiable product (using De la Fuente, 2014)
- Resource Recovery and valorisation - Circular Economy

  - Water reuse with economic incentive for byproducts

Harrison, Verster, Rumjeet, Raper, Rademeyer, Mostert, Johnstone-Robertson. Towards Wastewater Biorefineries: integrated bioreactor and process design for combined water treatment and resource productivity. Water Research Commission Report 2380/17, 2017.

Benefits and challenges to implementation of WWBR

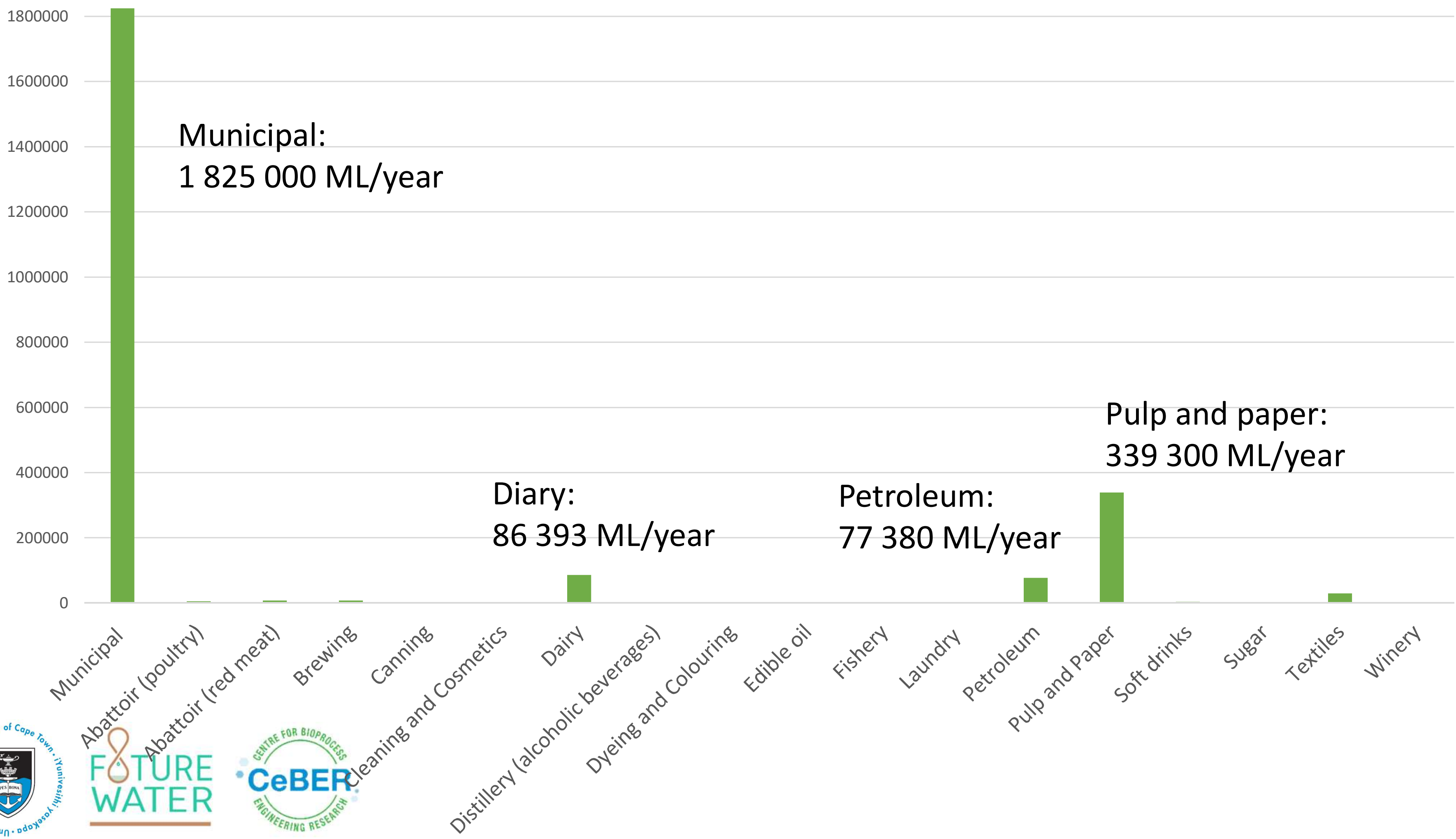
Benefits:

- Addresses the needs of the circular economy
- Places clean water as a product of importance, with economic value
- Potential for the biorefinery to provide the funding for water treatment or the energy requirement or both
- Resource productivity

Challenges:

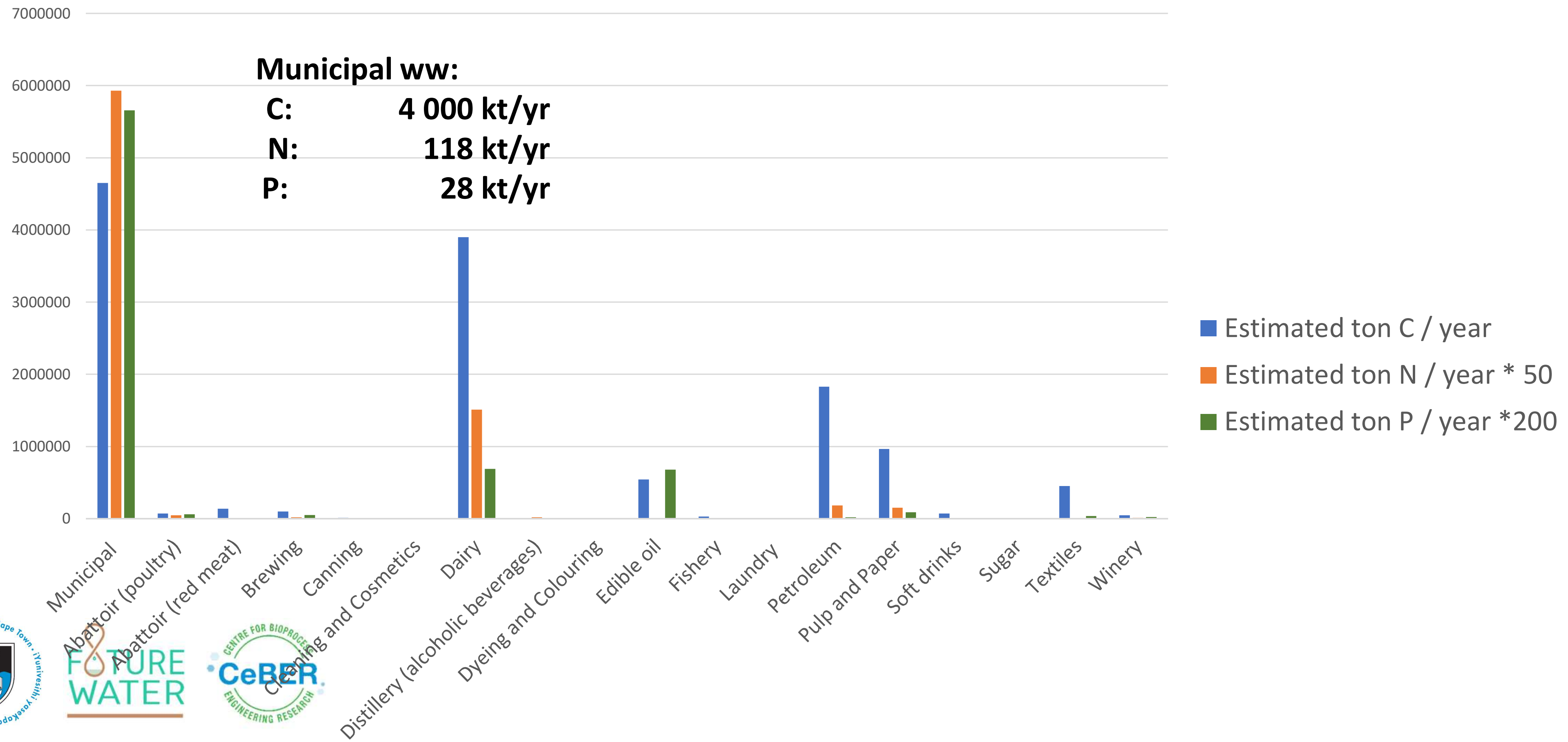
- Integrated process creates inter-dependencies
- Technical skills required for operation are increased
- Need to secure markets for products of the biorefinery, preferably within the sector generating them
- Public perception
- Waste legislation

Potential of Wastewater in South Africa



Industry Sector
Municipal
Abattoir (poultry)
Abattoir (red meat)
Brewing
Canning
Cleaning and Cosmetics
Dairy
Distillery (alcoholic beverages)
Dyeing and Colouring
Edible oil
Fishery
Laundry
Petroleum
Pulp and Paper
Soft drinks
Sugar
Textiles
Winery
Simplified table, refer to

Potential of Wastewater in South Africa
Nutrients available in Wastewaters



Potential of Wastewater in South Africa
Nutrients available in Wastewaters

Industry Sector	ML effluent per year	Estimated ton C / year	Estimated ton N / year	Estimated ton P / year	Comment
Municipal	1 825 000	4 653 750	118 625	28 288	Waste receptable, receiving all sorts.
Abattoir (poultry)	5 400	71 280	945	308	Blood, skin, fat, viscera, faeces, solids
Abattoir (red meat)	8 188	139 057	101	Nl	Blood, skin, fat, viscera, faeces, solids
Brewing	8 334	100 008	438	250	
Canning	1 074	11 599	Nl	Nl	
Dairy	86 393	3 900 000	30 238	3 456	Fats, protein, faeces, grit
Distillery (alcoholic beverages)	387	128	428	Nl	
Edible oil	1 361	543 039	42	3 409	Pollutants incl. fats, oils, grease, sodium, sulphates and phosphates
Fishery	1 760	30 624	62	Nl	Flesh, scales, blood
Petroleum	77 380	1 830 000	3 691	101	Oil and grease, phenols
Pulp and Paper	339 300	967 005	3 068	443	AOX, dioxin, chlorinated organics
Soft drinks	4 070	74 326	nl	nl	
Sugar	411	2 158	nl	nl	Fibres, sand
Textiles	30 000	454 000	15	196	Azo dyes
Winery	2 421	49 388	266	126	Polyphenols, inorganics such as sodium and potassium

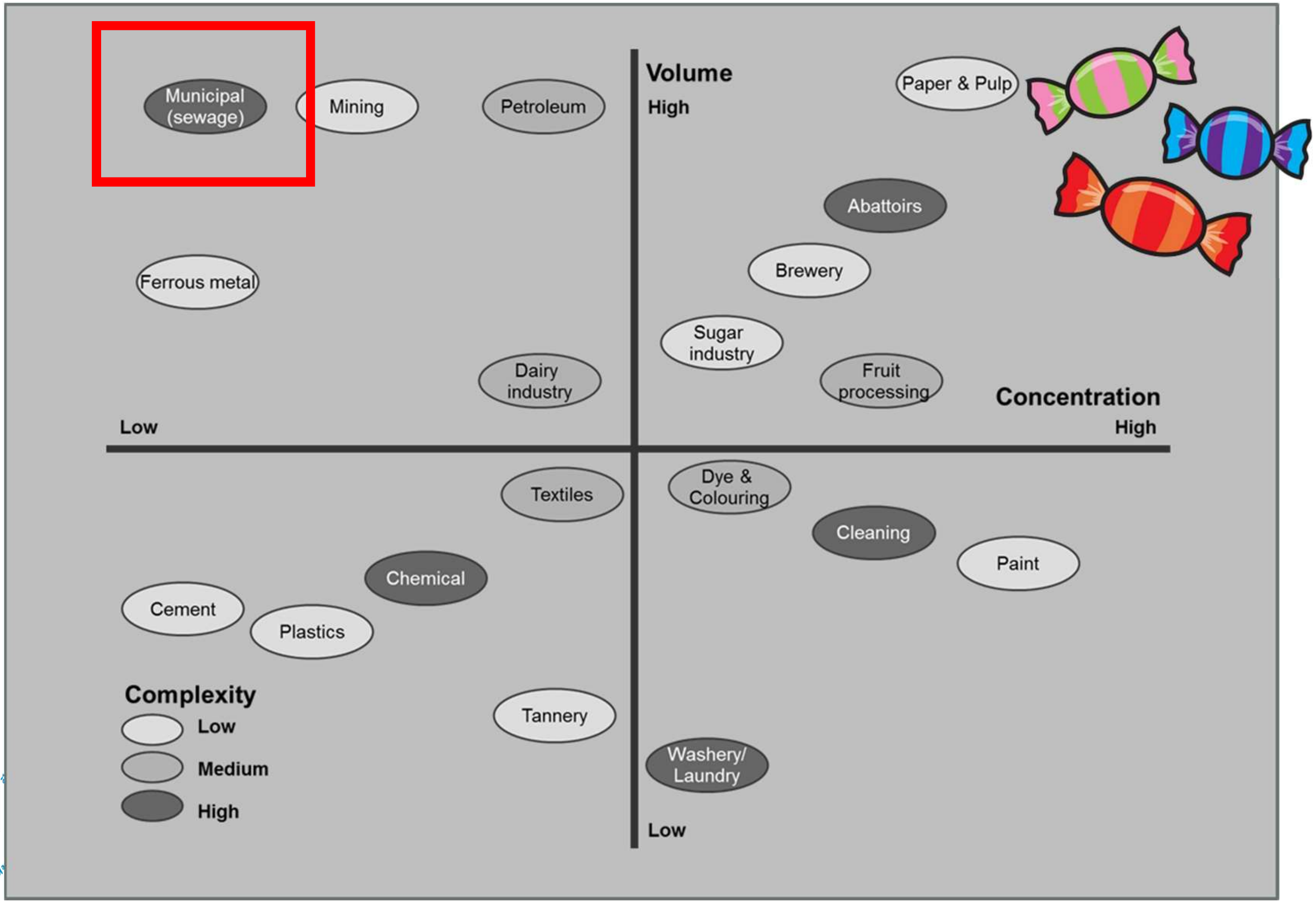
nl not listed

Potential of Wastewater in South Africa
Nutrients available in Wastewaters

Size of the potential

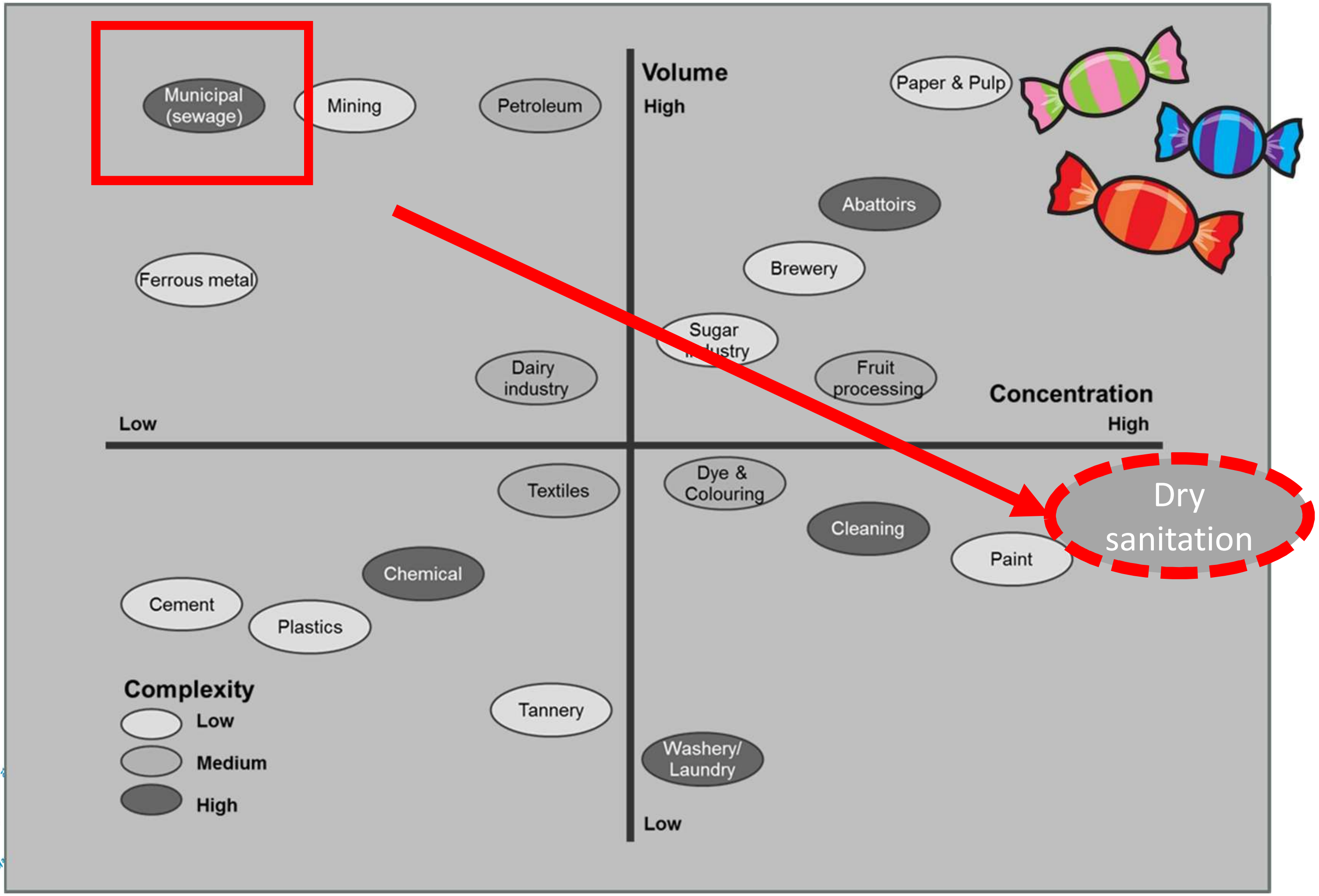
Recorded resources in wastewater in South Africa	Tons produced per DAY
Carbon	**12 750**
Nitrogen	**325**
Phosphorus	**77**

Potential of Wastewater in South Africa
Volume, concentration and complexity



Solids?

Potential of Wastewater in South Africa
Volume, concentration and complexity



Solids?

The Wastewater Biorefinery
Selecting the reactor design

	Criteria	
Most Important	1	Decouples hydraulic and solid retention times
	2	Continuous or semi-continuous (cannot store flows)
	3	Product formation in different phase
	4	Reactor design facilitates the recovery of the product
Less Important	5	Think big! Commodity rather than niche
	6	Influences microbial community, non-sterile
	7	Gives advantage to product: creates ecological niche
	8	Water released into environment eventually
# of criteria that completely comply		

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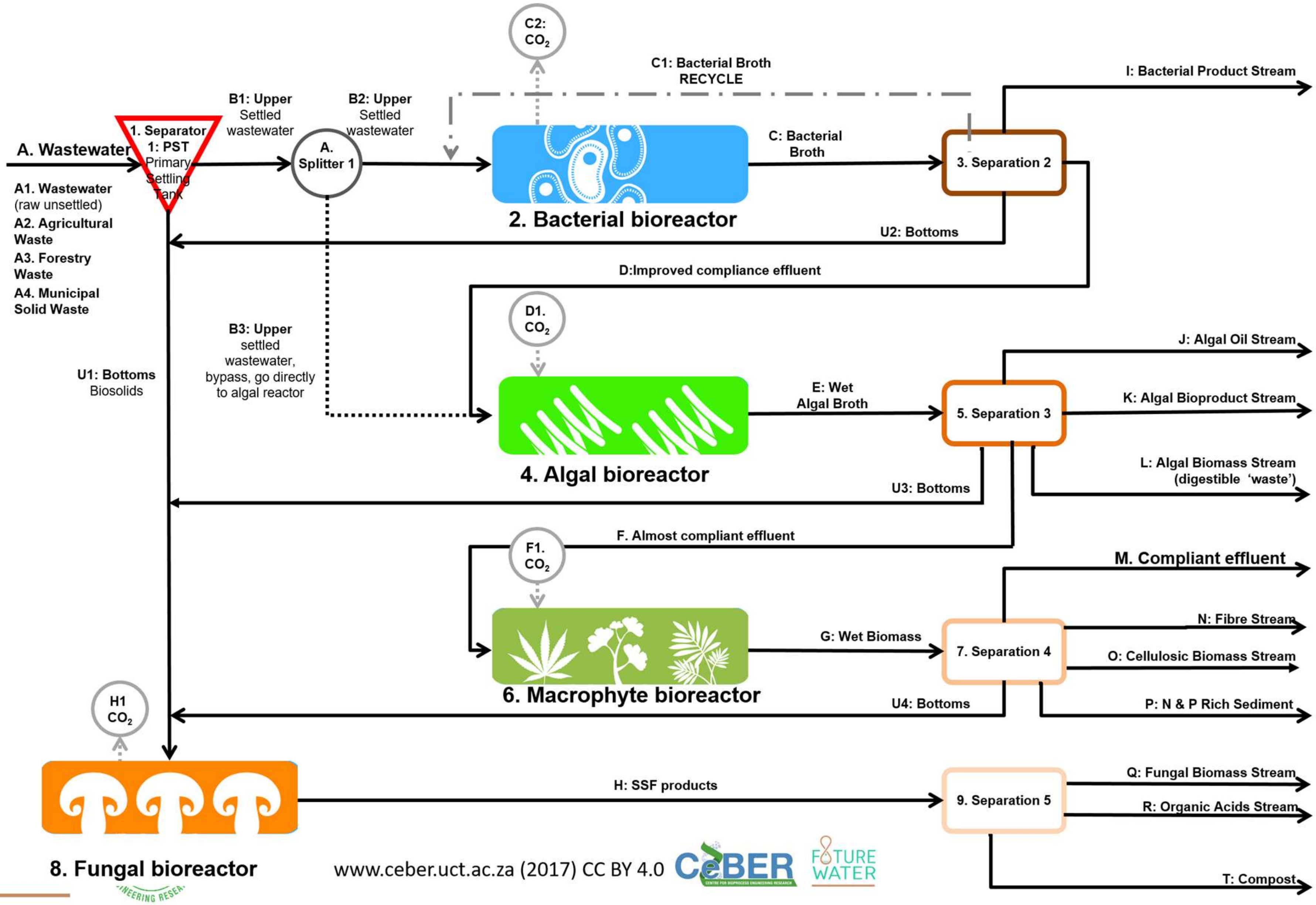


A. Wastewater
A1. Wastewater (raw unsettled)
A2. Agricultural Waste
A3. Forestry Waste
A4. Municipal Solid Waste
1. Separator 1: PST Primary Settling Tank
B1: Upper Settled wastewater
A. Splitter 1
B2: Upper Settled wastewater
C2: CO_2
C1: Bacterial Broth RECYCLE
2. Bacterial bioreactor
C: Bacterial Broth
3. Separation 2
I: Bacterial Product Stream
U2: Bottoms
D:Improved compliance effluent
D1. CO_2
B3: Upper settled wastewater, bypass, go directly to algal reactor
U1: Bottoms Biosolids
4. Algal bioreactor
E: Wet Algal Broth
5. Separation 3
J: Algal Oil Stream
K: Algal Bioproduct Stream
L: Algal Biomass Stream (digestible 'waste')
U3: Bottoms
F. Almost compliant effluent
F1. CO_2
6. Macrophyte bioreactor
G: Wet Biomass
7. Separation 4
M. Compliant effluent
N: Fibre Stream
O: Cellulosic Biomass Stream
P: N & P Rich Sediment
U4: Bottoms
H1 CO_2
8. Fungal bioreactor
H: SSF products
9. Separation 5
Q: Fungal Biomass Stream
R: Organic Acids Stream
T: Compost

Potential for the Wastewater Biorefinery
Product Classes

1. Bioproducts
   i. Biobased building blocks
      - New functionality
      - Drop in products
   ii. Complex, functional macro-molecules
2. Bioenergy
3. Biomass
4. Water

Potential for the Wastewater Biorefinery
Product Classes

Domestic municipal wastewater ‘top 5’

- alginic acid
- phosphorous
- biogas
- cellulose
- polyhydroxyalkanoates (PHA)

http://www.iwa-network.org/groups/resource-recovery-from-water-cluster/

Conclusions so far

Wastewater is a lucrative source of raw materials

Valuable bioproducts are starting to become produced at commercial levels from wastewater – alginate most exciting.

Municipal wastewater is the largest potential opportunity but also one of the most complex.

Wastewater is key to water sensitive living

17 Principles for Water-Wise Cities

4 Levels of Action

1 Regenerative Water Services

- Replenish Waterbodies and their Ecosystems
- Reduce the Amount of Water and Energy Used
- Reuse and Use Diverse Sources of Water
- Apply a Systems Approach for Integration with Other Services
- Increase the Modularity of Systems for Multiple Options

2 Water Sensitive Urban Design

- Enable Regenerative Water Services
- Design Urban Space to Reduce Flood Risk
- Enhance Livability with Visible Water
- Modify and Adapt Urban Materials to Minimise Environmental Impact

3 Basin Connected Cities

- Secure Water Resources and Plan for Drought Mitigation
- Protect the Quality of Water Resources
- Plan for Extreme Events

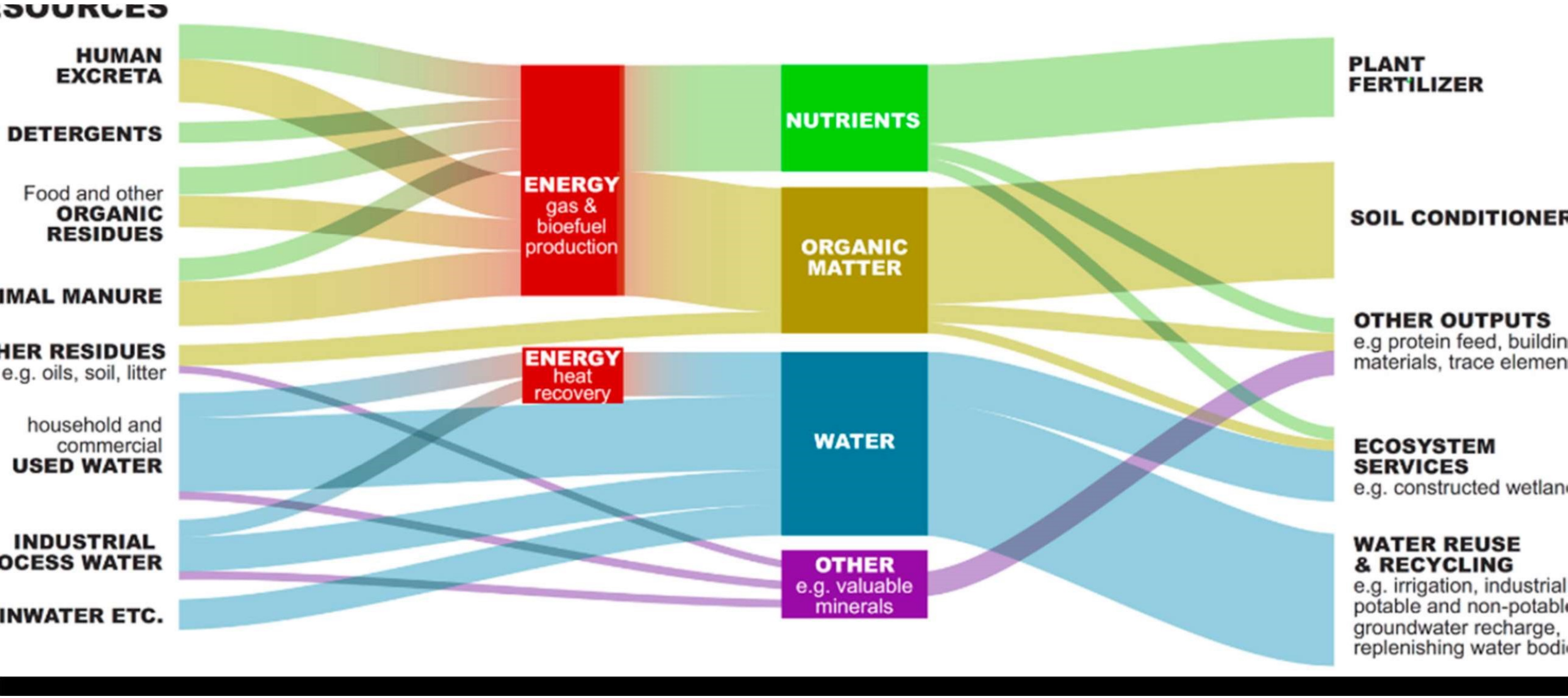
4 Water Wise Communities

- Empowered Citizens
- Incentivized Professionals
- Transdisciplinary Planning Teams
- Progressive Policy Makers
- Leaders that Engage and Engender Trust

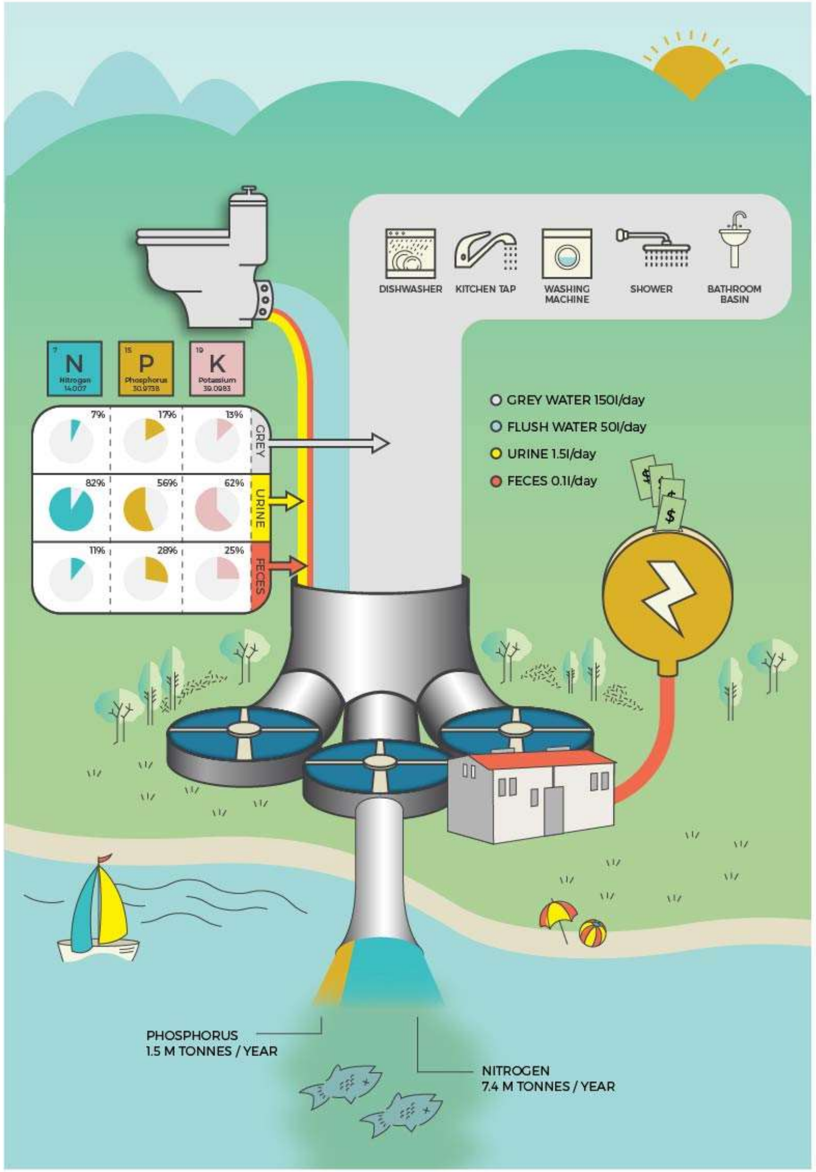
iwa-network.org/projects/water-wise-cities

The potential in sanitation

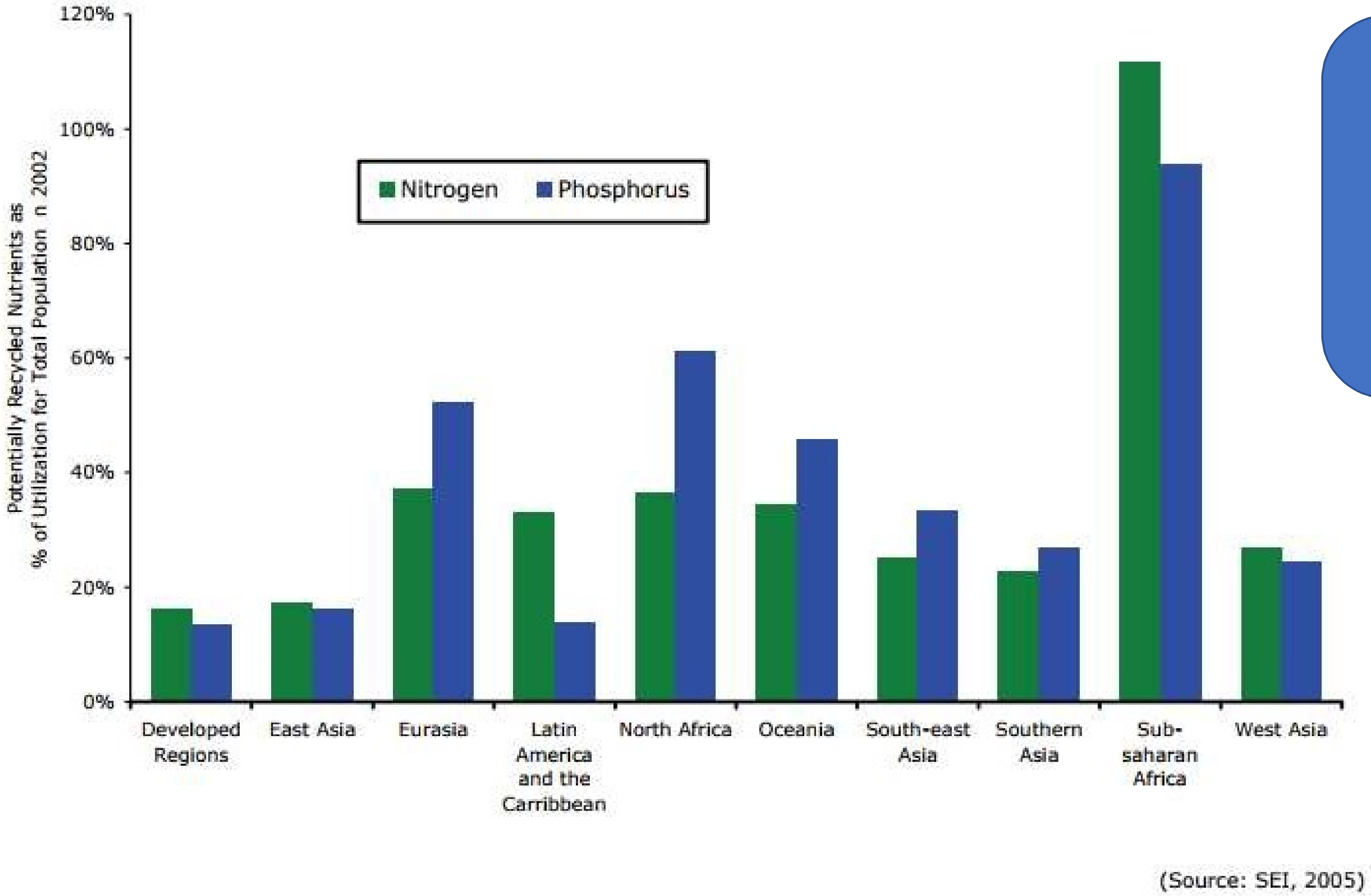
http://www.mdpi.com/2071-1050/8/12/1289/html
Review: Towards "Sustainable" Sanitation: Challenges and Opportunities in Urban Areas
Kim Andersson *, Sarah Dickin and Arno Rosemarin
Sustainability 2016, 8(12), 1289; doi:10.3390/su8121289



Peak Pee!



www.nature.com/scientificamerican/journal/v300/n6/box/scientificamerican0609-54_BX1.html
www.futurewater.uct.ac.za/peakpee



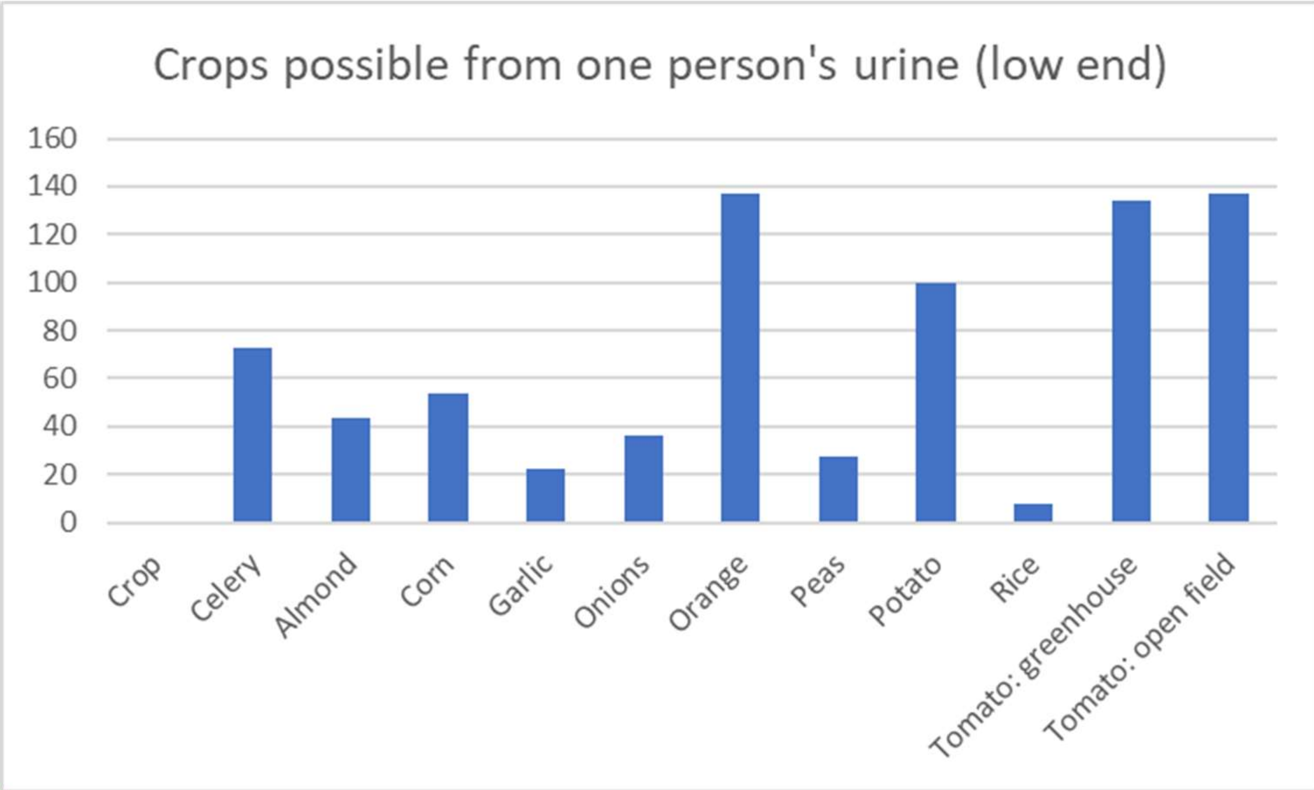
Nutrients in sanitation can replace fertilizer:
20% for Sweden
100% for SS-Africa
60% South Africa
(2002 data)

Figure 23: Potential capacity of ecological sanitation systems to replace chemical fertiliser used in different world regions

https://www.researchgate.net/profile/Arno_Rosemarin/publication/289927835_Pathways_for_Sustainable_Sanitation_Achieving_the_Millennium_Development_Goals/links/569e189908ae950bd7a8b167/Pathways-for-Sustainable-Sanitation-Achieving-the-Millennium-Development-Goals.pdf

The P in your pee

g P	0.15	per day low end
g P	0.75	per day high end



http://www.smart-fertilizer.com/nutrient-requirements

The P in your pee

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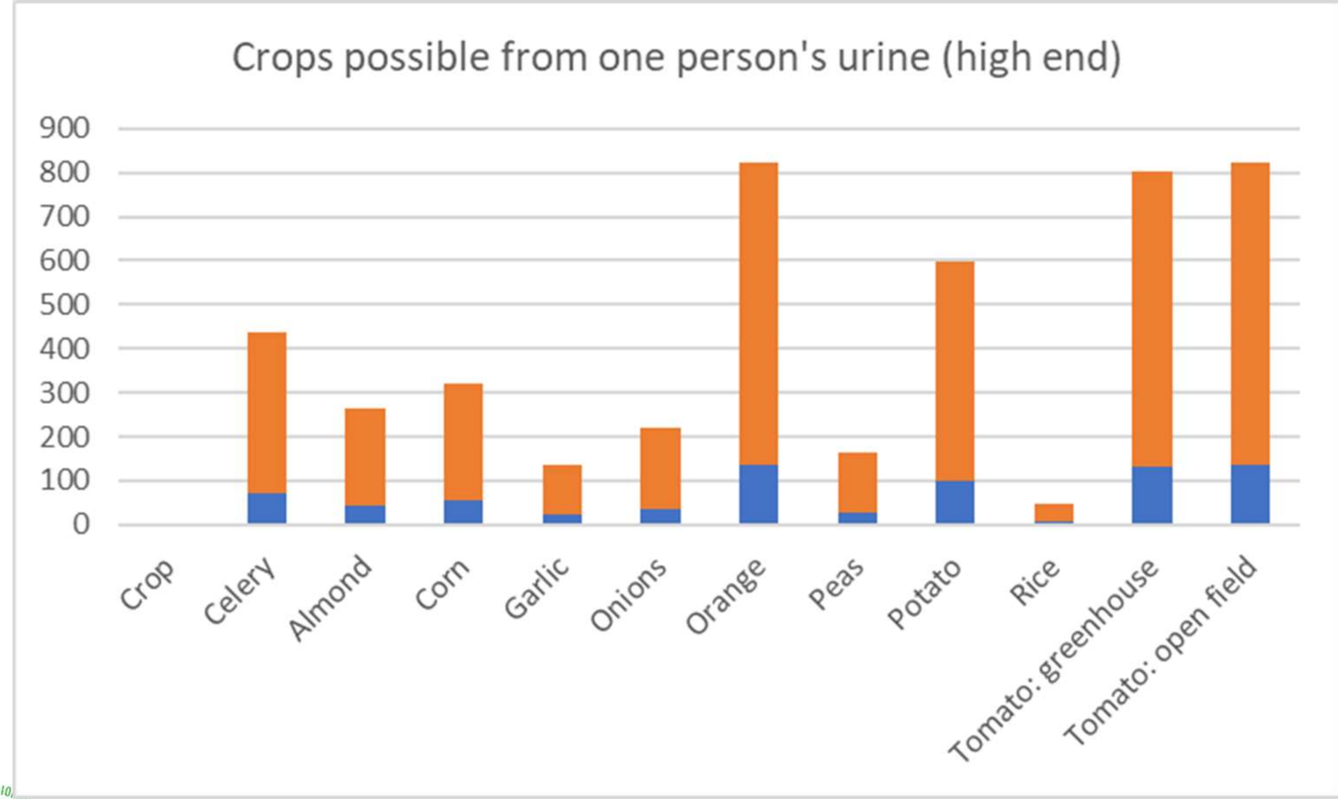
g P	0.75	per day high end

Grow 1kg food per day on your urine!



http://www.smart-fertilizer.com/nutrient-requirements

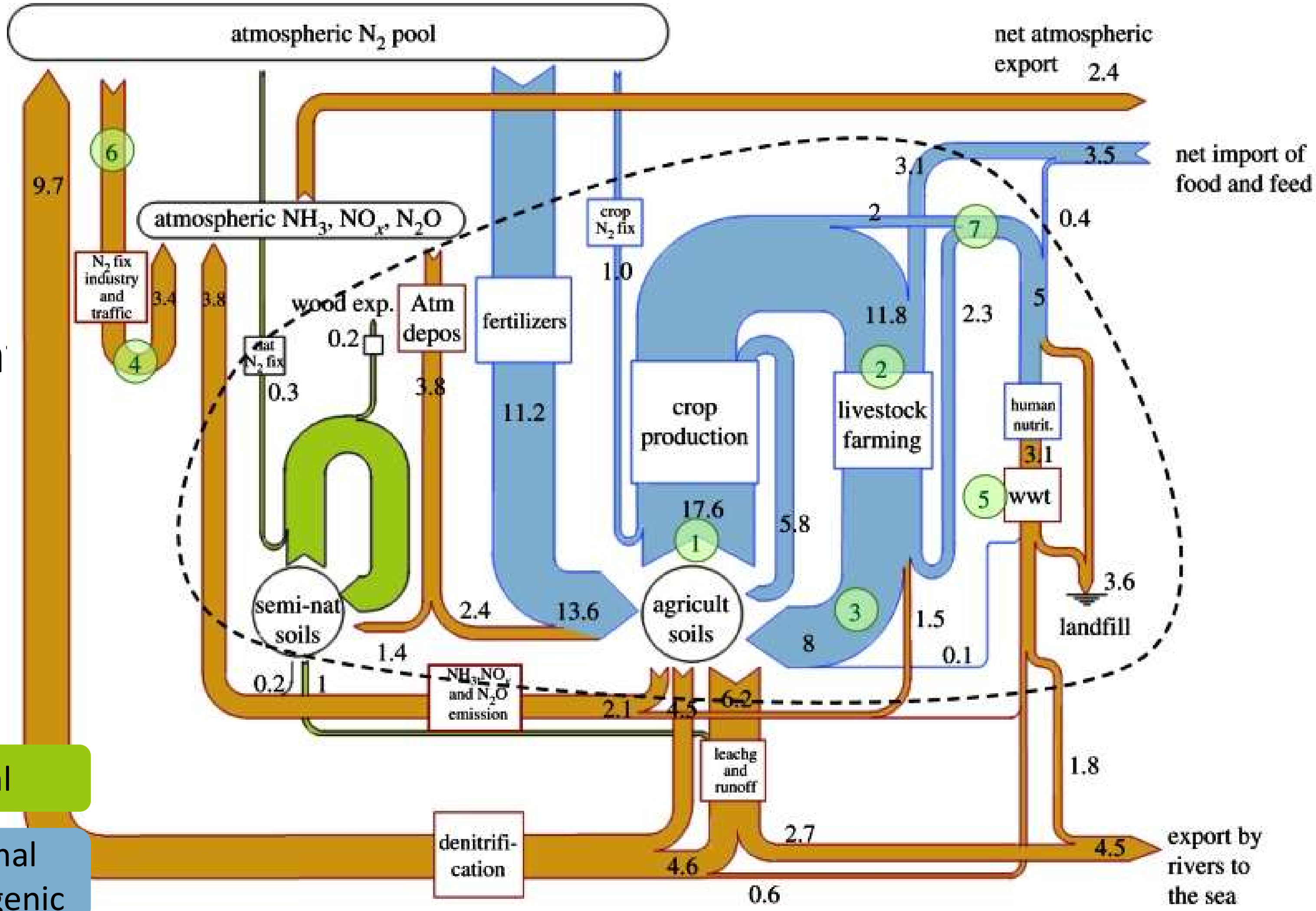
The N cycle

Haber–Bosch

energy requiremen

Greenhouse gases

Global cycle



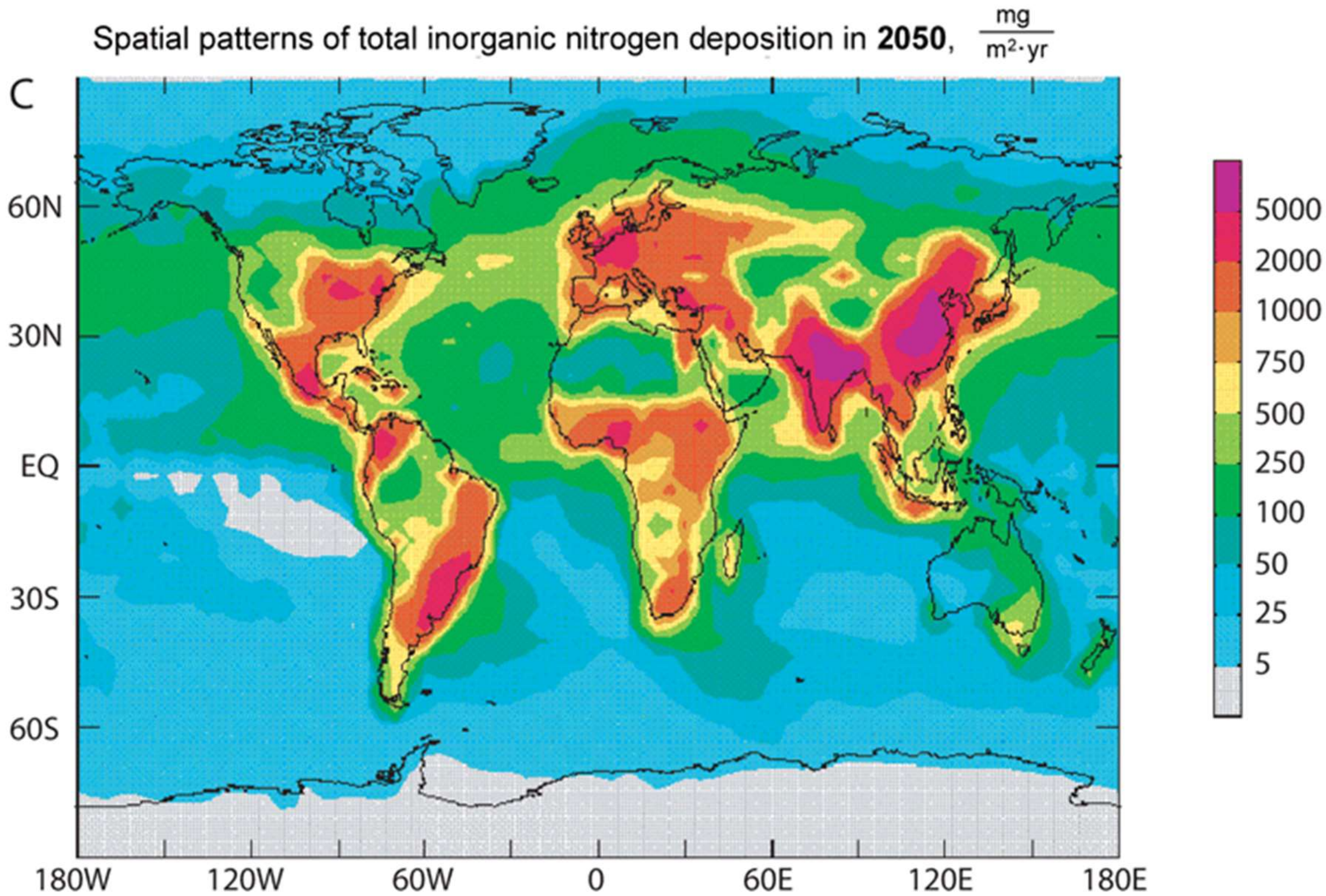
natural

intentional anthropogenic

unintentional

www.ncbi.nlm.nih.gov/pmc/articles/PMC3682748/

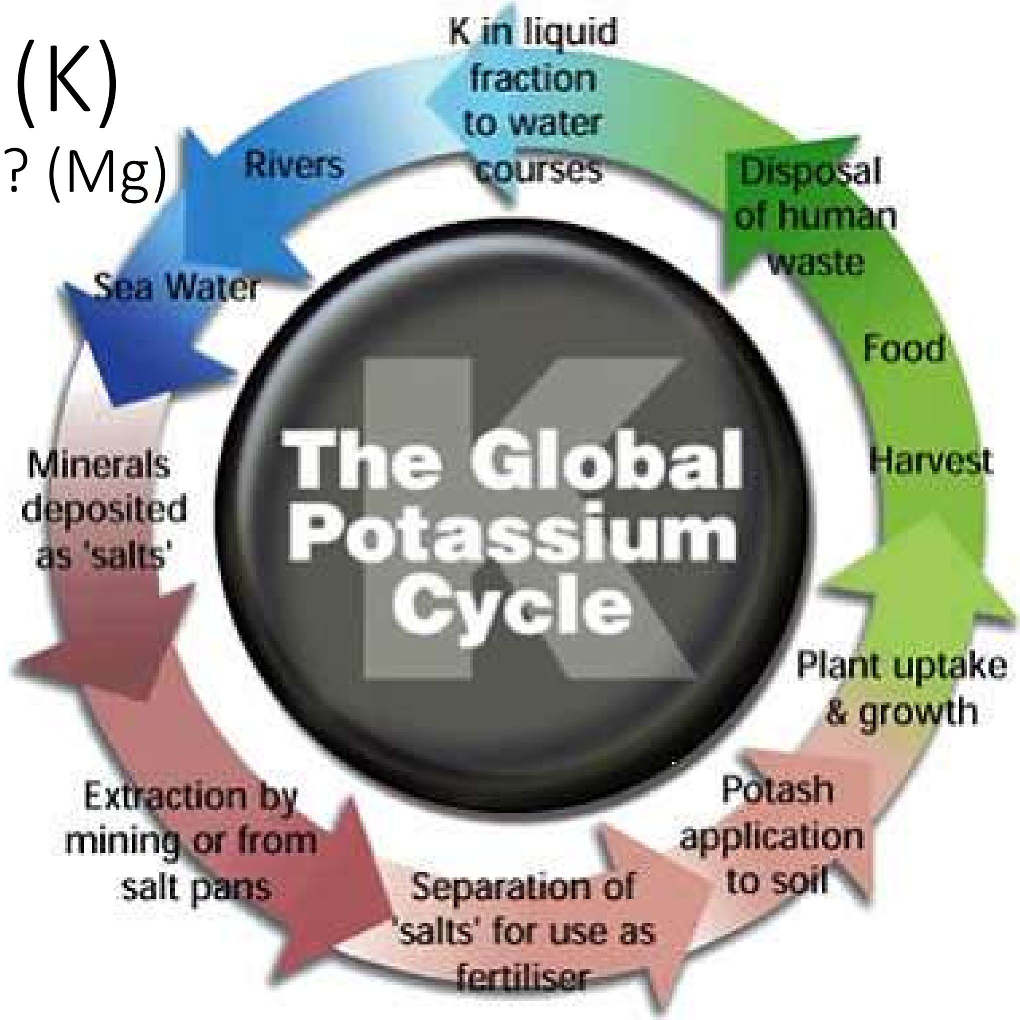
N crisis



It's predicted that by 2050, harmful biologically reactive nitrogen will be dangerously high

Potassium (K)

Also Magnesium? (Mg)



Abundant, convenient to recycle ☺

www.pda.org.uk/what-is-potash/

Effect of compliant discharge on receiving bodies*

Substance/Parameter	General Limit (mg/ℓ)	Special Limit (mg/ℓ)
Chemical Oxygen Demand (COD)	75	30
Ammonia (ionised and un-ionised) as Nitrogen	6	2
Nitrate/Nitrite as Nitrogen	15	1.5
Orthophosphate as phosphorus	10	1 (median), 1.5 (max)

General Authorisation Standards for treated effluent (DWA SA, 2013

1mg/L = 1kg/ML

20ML/day plant = 20 000 000 L / day
Each L has 1mg of P
20 000 000 L/day * 1mg P/L =
20 000 000 mg P/day =
20 kg P per day.

* When things are working well!

EUTROPHICATION

Effect of compliant discharge on receiving bodies*

Substance/Parameter	General Limit (mg/ℓ)	Special Limit (mg/ℓ)
Chemical Oxygen Demand (COD)	75	[illegible]
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1mg/L = 1kg/ML

20ML/day plant = 20 000 000 L/ day
Each L has 1mg of P
20 000 000 L/day x 1mg P/L =
20 000 000 mg P/day =
20 kg P per day.

Conclusions so far: resources in toilets are valuable AND in dire need to be recovered

BUT: Technology based risks, e.g. fertiliser

Perception: choose the right market

Risk: Pathogen, EDC, CECs etc, Metals – depends on market, processing. Can be done – O & M issue (need professional service)

Transport – products produced in (peri)-urban, needed where food is grown… (rural? Peri-urban?)

Overall costs: **Profitable?**

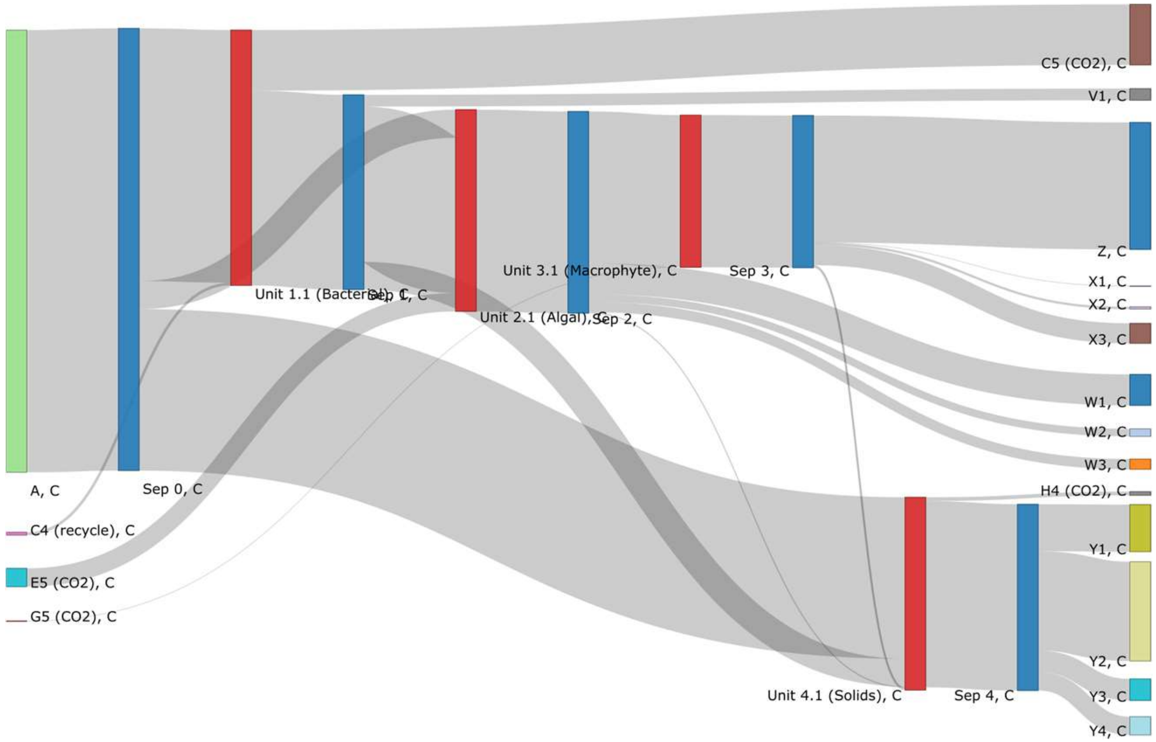
The nutrients need to go to food, but money not great.

Processing for a high value product, remainder still good for soil product; high value product subsidises cost of treatment

What is possible with bioprocess engineering?

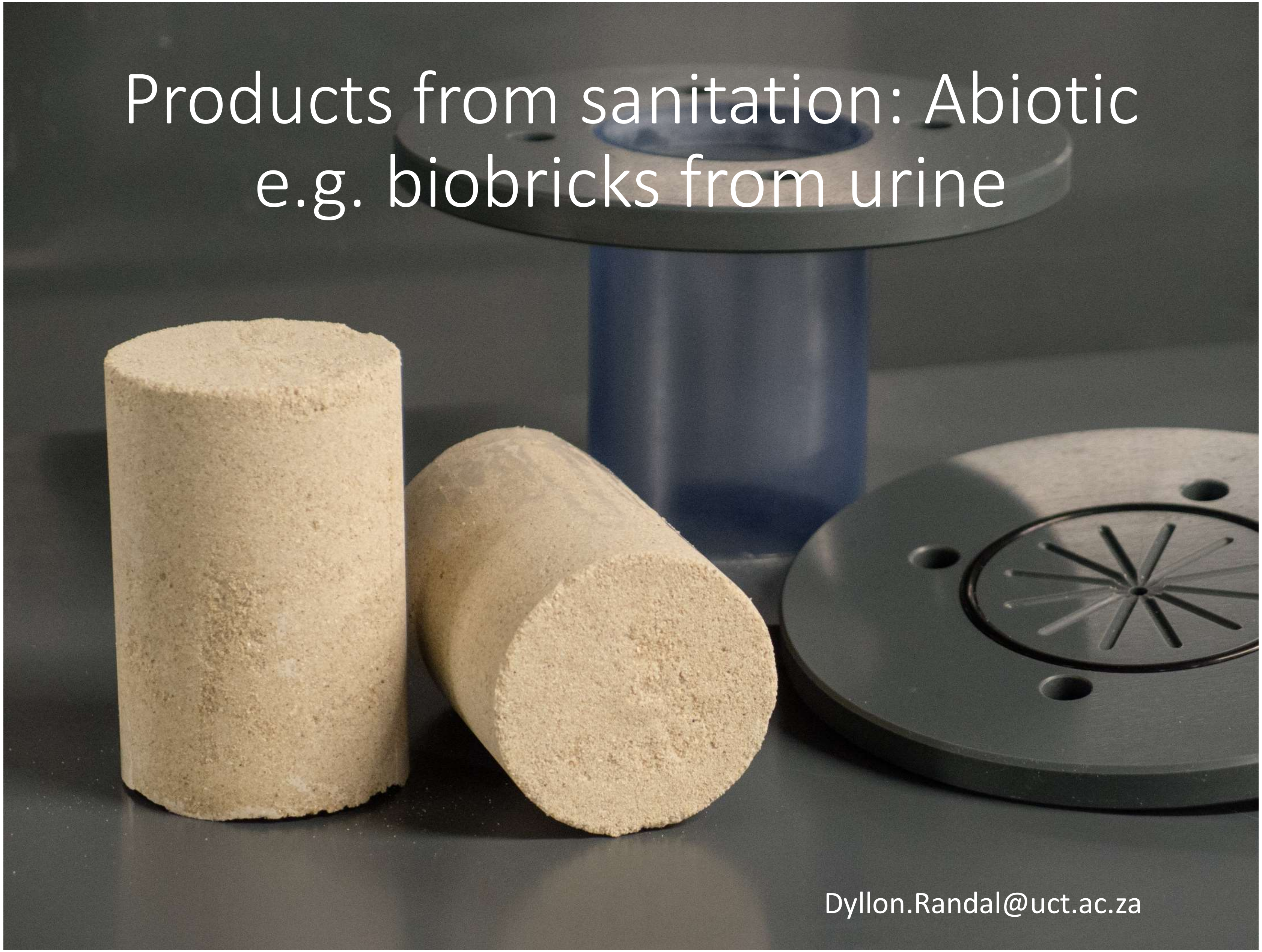
Comparison of total amount of each product produced by three wastewater streams investigated, per 1 000m^3 incoming wastewater

kg/day	Domestic municipal wastewater
Bacterial product V1	33
Algal bioproduct W1	60
Algal oil W2	12
Algal digestible waste W3	26
Cellulosic fibre X1	1
Cellulosic biomass X2	4
N,P rich sediment X3 *	34
Crust/surface related product stream Y1	133
Liquor related product stream Y2	347
Cake-related product stream Y3	81
Compost Y4 *	318
Compliant effluent Z C (mg/L)	0.172
Compliant effluent Z N (mg/L)	0.081
Compliant effluent Z P (mg/L)	0.018



Note:
Yields in table is kg total product
Image is kg C only

Products from sanitation: Abiotic e.g. biobricks from urine



Dyllon.Randal@uct.ac.za

Nutrient recovery from sanitation is important.

What is the best way to do this?

Is nutrient recovery easier from dilute wastewater or ‘dry’ material?

The Wastewater Biorefinery
Selecting the reactor design

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Less Important	5	Think big! Commodity rather than niche
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	7	Gives advantage to product: creates ecological niche
	8	Water released into environment eventually
# of criteria that completely comply		

If the first thing is to decouple the HRT and SRT, and we consider the entire sanitation system as the process flow diagram, then dry toilets may be the most appropriate.

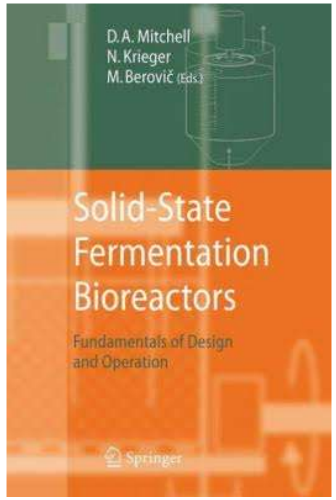
Potential for the Waste(water) Biorefinery

1. Bioproducts
   - i. Biobased building blocks
     - New functionality
     - Drop in products
   - ii. Complex, functional macro-molecules

Citric acid
Glutamic acid
Lysine

Detergents
Industrial Enzymes
Flocculants
Biopolymers (plastics)
Poly-glutamic acid (PGA)

http://www.icsn.cnrs-gif.fr/spip.php?article927&lang=en



Fungi

Scandinavia

“Can we reduce the water footprint of a city to 1/10th without sacrificing comfort?”

http://blogg.slu.se/kretsloppsteknik/files/2017/10/SLU-251017-PD-Jenssen-.pdf

KÄYMÄLÄSEURA HUUSSI RY
GLOBAL DRY TOILET ASSOCIATION OF FINLAND

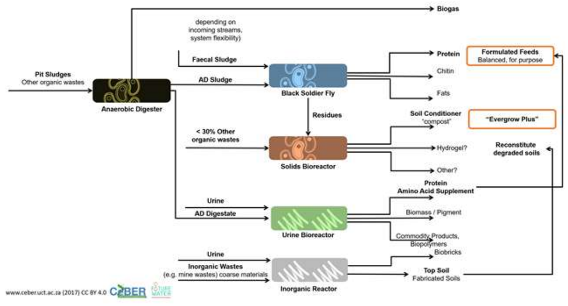
http://www.huussi.net/en/activities/dt-2018/dry-toilet-conference-2018/call-for-papers-2/

EMBRACE THE WATER
a Cities of the Future Conference
12-14th of JUNE, 2017 GOTHENBURG, SWEDEN

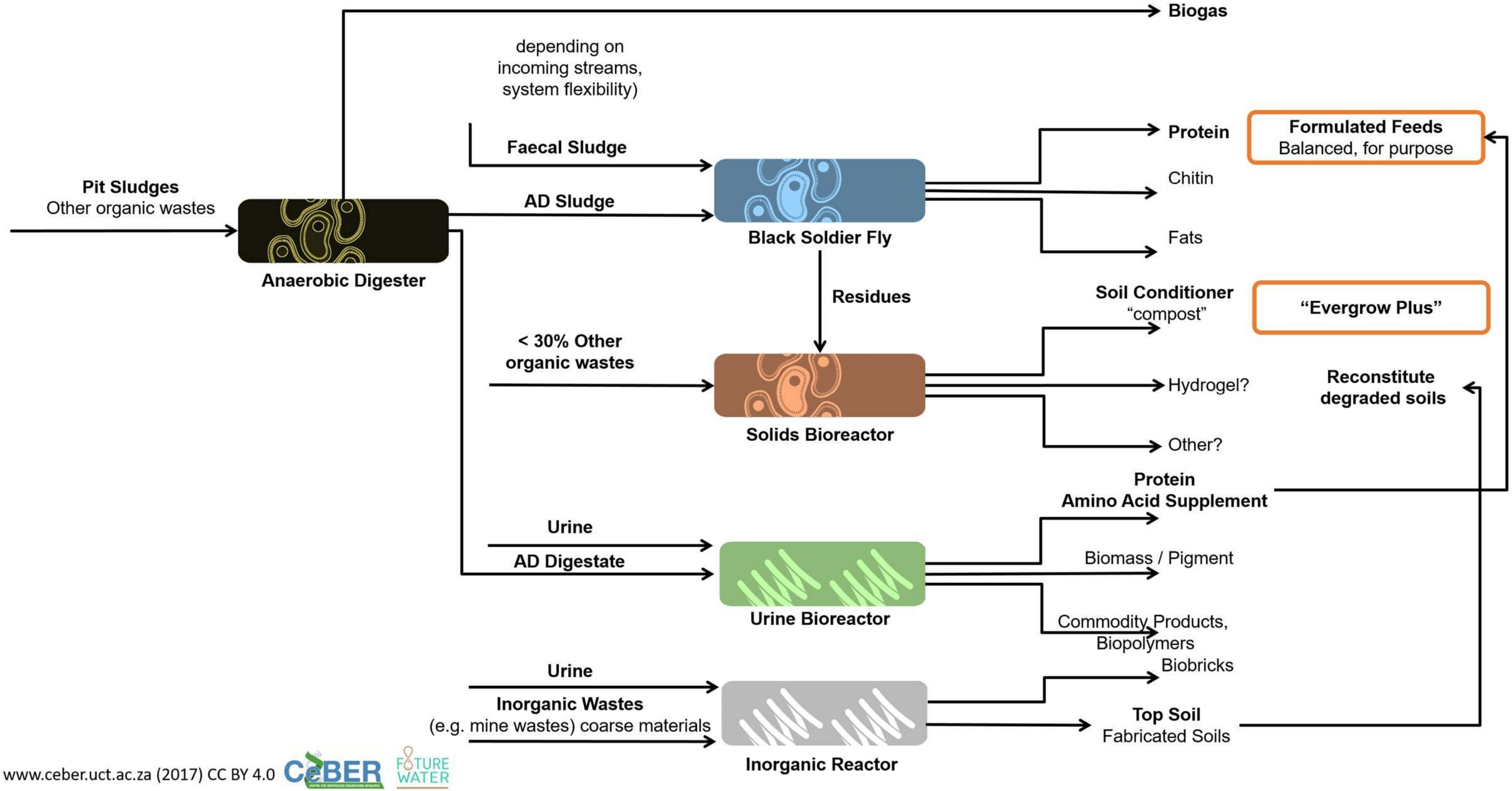
http://www.embracethewater2017.com/

Sanitation as a (bio)engineered process

EUR 3 199



User interface	Storage	Collection	Transport	Processing
Whatever you like ‘the bright red box’ ‘the crème de la crème’ Foam flush	Contained, no seepaway. NOT A PIT	Easy, no sloshing. Small, carried by single person (e.g. 20kg container)	Road vs pipe trade off?	**Waste biorefinery** **Active processing** Skilled and unskilled labour intensive
Urine diversion – no regret measure	Store urine and faeces separately. Urine can be dosed with CaOH.	**Inoculum added**	Neighbourhood level transport (5k – 10k people)	Bioprocessing for high value product also results in Pathogen removal Remainder good for fertilizer / soil conditioner / mulch
	(Bio)processing starts HERE	Effectively solid waste management		


Biogas
depending on
incoming streams,
system flexibility)
Faecal Sludge
Protein
Formulated Feeds
Balanced, for purpose
Chitin
Pit Sludges
Other organic wastes
AD Sludge
Black Soldier Fly
Fats
Anaerobic Digester
Residues
Soil Conditioner
"compost"
"Evergrow Plus"
< 30% Other
organic wastes
Hydrogel?
Reconstitute
degraded soils
Solids Bioreactor
Other?
Protein
Amino Acid Supplement
Urine
AD Digestate
Biomass / Pigment
Urine Bioreactor
Commodity Products,
Biopolymers
Biobricks
Urine
Inorganic Wastes
(e.g. mine wastes) coarse materials
Top Soil
Fabricated Soils
Inorganic Reactor

Darmstadt semi-zentral

as large as necessary, but as small as possible

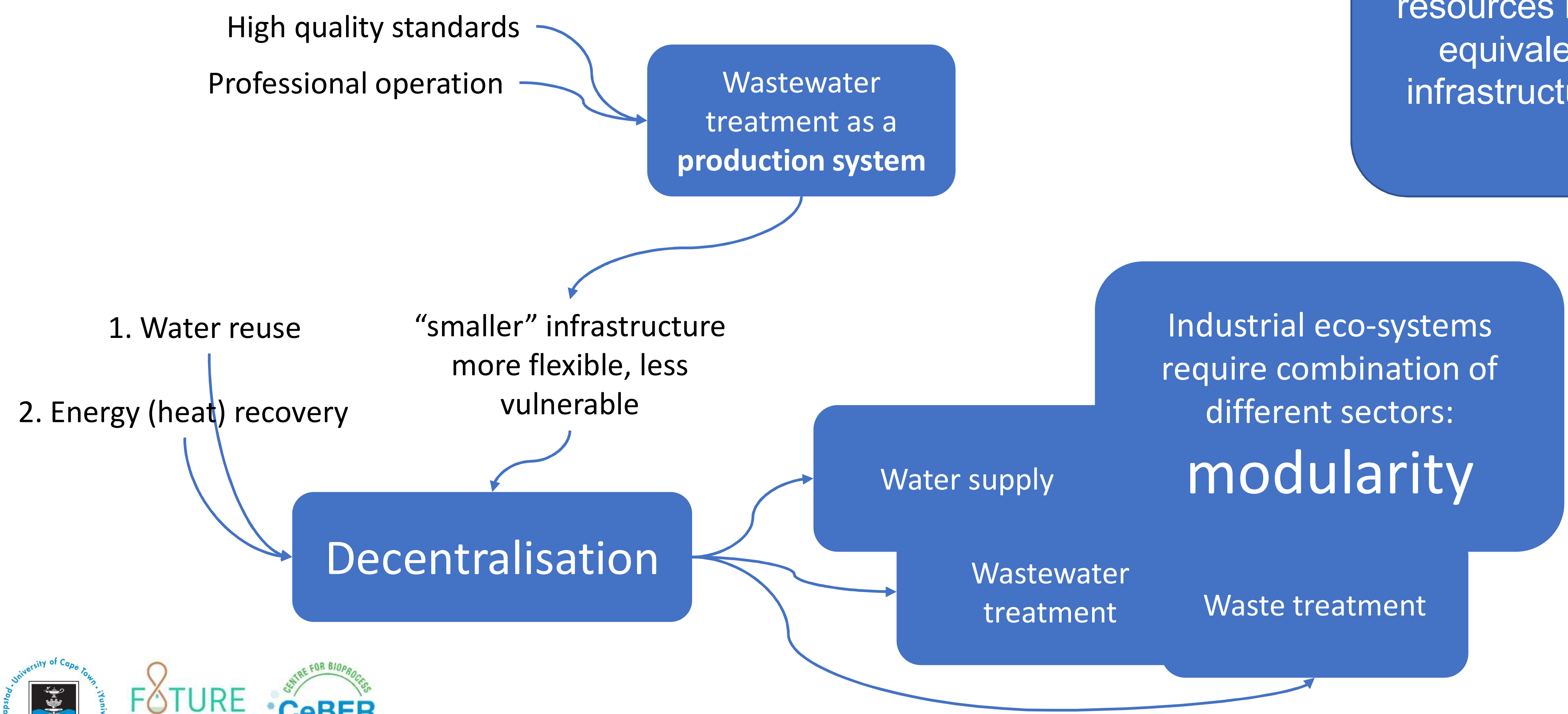
The disadvantages of conventional large (centralized) or small (decentralized) systems can be avoided while utilizing their benefits at the same time

SEMIZENTRAL GERMANY

www.semizentral.de/

Decentralisation? Appropriate scale?

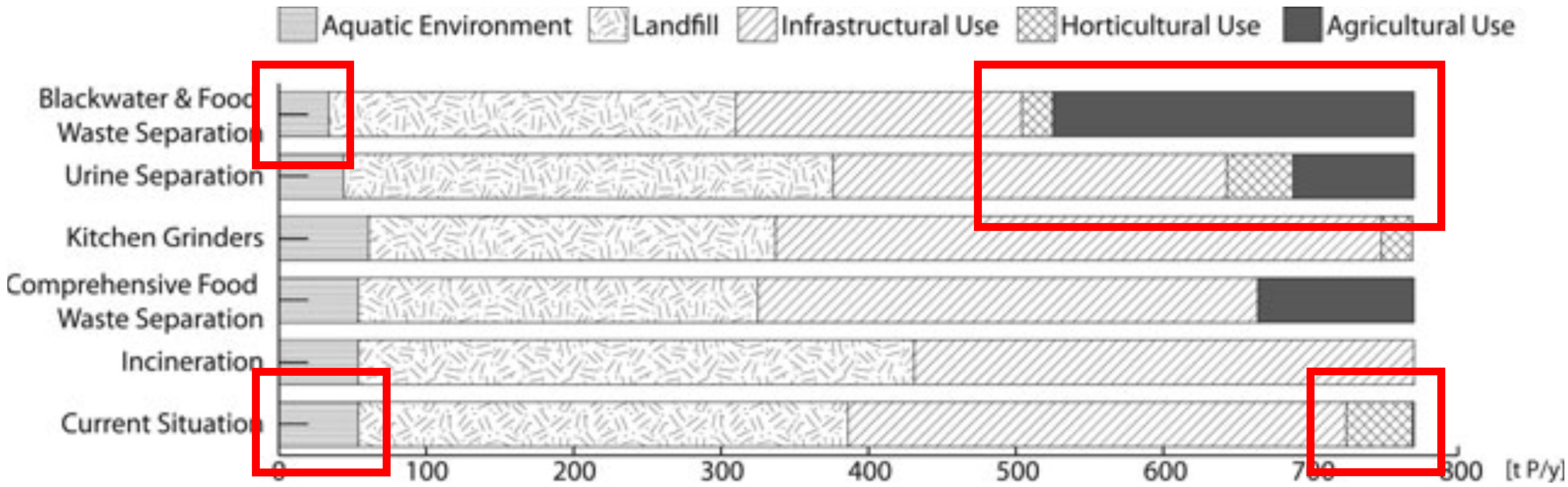
The re-use of resources need equivalent infrastructures



Inspired from www.semizentral.de/en/publications/publications/#dropdown

Gothenburg, Sweden

The major phosphorus flows: **food consumption**
Phosphorus accumulated in two sinks: deposits of **sewage sludge** and incineration ash.
40% of the total output of phosphorus in Gothenburg is found in each of these sinks.

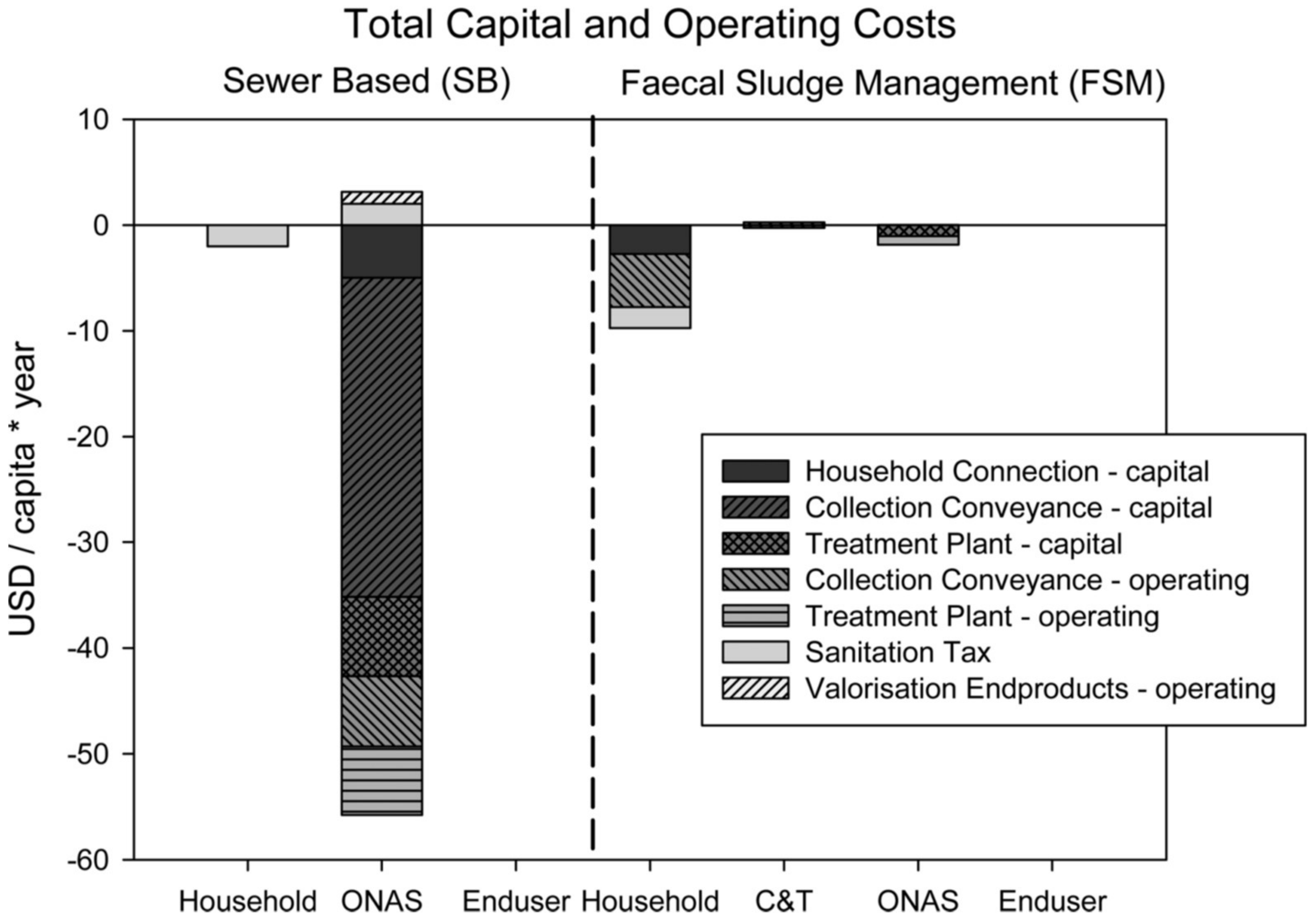


Kalmykova Y, Harder R, Borgestedt H, Svanäng I (2012) Pathways and management of phosphorus in urban areas. Journal of Industrial Ecology 16(6):928-939.
DOI: 10.1111/j.1530-9290.2012.00541.x

Cost: flush vs dry

Assume a well functioning overall system in each case.

"Conventional sewer systems are in most cases the most expensive sanitation options, followed, in order of cost, by sanitation systems comprising septic tanks, ventilated improved pit latrines (VIP), urine diversion dry toilets and pour-flush pit latrines."



http://washdev.iwaponline.com/content/early/2017/10/19/washdev.2017.058

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3317593/

Future work: Not all greener grass… yet

RISK of managing decentralization

Be realistic: Place savings in context - Water quality is most NB.

Be realistic: Recovering energy and nutrients from wastewater will not solve our problems.

(Bio)processing of faecal solids need better understanding – our work @ CeBER

Understand the big picture better – when to recover what

My odd discovery…

What do I consider non-negotiable in a toilet?

Convenience is assumed. As it should be.

Dignity, Convenience, safety, of course.

Assumed that this can be delivered only by white ceramic flush?

- Good natural light
- Indoors
- No flies
- No smell

Nowhere in this list am I bothered by if it’s flush or dry.

Other people: Psychological: Seeing the shit, can’t flush it away. The idea of it.

Other people: The earthy smell is still not good.
I swear people have become addicted to bleach.

Other people: I want what I perceive is the best – a white ceramic flush toilet

Future work

"However, the management of the solids was excluded in this work, in accordance with the scope of the study and corresponding selection of the functional unit." - Chirjiv Kaur Anand thesis (U Toledo) 2013

Understand solid substrate bioprocesses better

Understand how it all fits together – e.g. the road vs pipe trade off.

Develop and market the benefits at the user interface

If rich people are not willing to use the most sustainable sanitation systems, how can we expect poor people to use it?

If we look at the resources available and needed, which is easiest recovered through dry sanitation, at the contribution of wastewater treatment re-releasing N into the atmosphere and hence justifying the unbalanced N cycle, if we look at the cost of flush toilets potentially taking away public funds to provide dignified sanitation to everyone, and at the water savings possible through dry sanitation… then I question the constitutionality of having a flush toilet, especially while others have to use chemical toilets or pit latrines.

Question the constitutionality of having a flush toilet

especially while others have to use chemical toilets or pit latrines

To sewer or not to sewer:
What is appropriate for African Urbanism in the context of the Circular Economy

Bernelle Verster: The best way to integrate sanitation in the circular economy is through **non-sewered** sanitation.

Neil Armitage: The best way to integrate sanitation in the circular economy is through **sewered** sanitation.

Andrew 'Mugsy' Spiegel: **Experimenting** with non-sewered or very locally treated sewered sanitation must be done **in affluent areas** and marketed to their residents, not in less affluent areas

Julia McLachlan: Not to sewer – Exploring **infrastructure as Urban space**

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www.indiebio.co.za/resources

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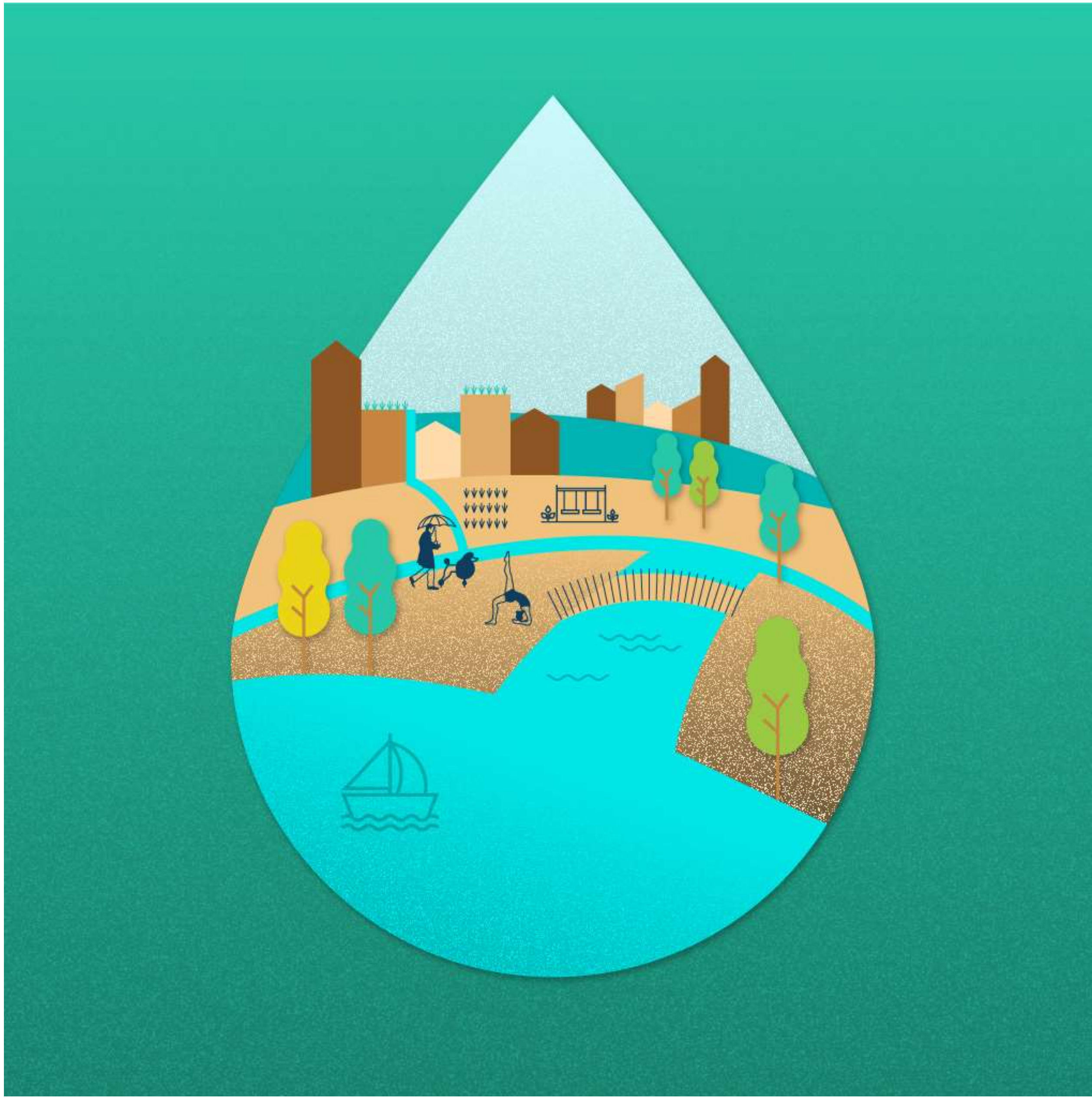

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The Wastewater Biorefinery
Why these unit operations?

- **Heterotrophic microbial:** great control, well understood, good C removal. “bacteria”
- **Photomixotrophic:** nitrogen and phosphorous removal, greater energy contribution from photosynthetic activity “algae”
- **Macrophyte bioreactor:** polishing step, nitrogen and phosphorous removal “plants”
- **Solids:** (dominant group expected to be fungal organisms), bioprocessing of high solids content “sludge”
- **All:** robust, resilient, ecosystem, using many different metabolisms

https://pookkani.com/viewbotany

World Building of the Year 2017
World Architecture Festival, Berlin