The Sanitation Economy

Environmental Sanitation as an Industrial Ecosystem

Bernelle Verster

Joshua Palfreman

Collaborative Africa Budget Reform Initiative (CABRI) masterclass

6 June 2018

Who are we?

Bernelle Verster (indiebio)

Not an environmentalist.
Not a trained water/sanitation person.

Passionate about biotech.
Using biology to make money.

Shit-stirrer since 2011.

Joshua Palfreman

Solid waste management and recycling specialist

integrated solid waste management planning and delivery,

municipal service planning (WASH)

private sector development (market systems and M4P)

geographic specialty in East & Southern Africa (EAC, SADC).

Outline

1. VERY brief overview of sanitation systems
2. Sanitation as an industrial ecosystem
3. Why do I argue for dry?
4. What is needed from a government budget / financial perspective to support this?
5. How to govern responsibly when decentralisation is a feasible option?

1. Environmental Sanitation

Sanitation

- Faeces
- Urine
- Greywater
- Foodwaste
- Other?

Stormwater

Solid waste management

- Organic
- Inorganic

Water sensitive, sustainable sanitation: The options

Sanitation

Greywater
Food waste
Urine
Faeces

Solid waste management

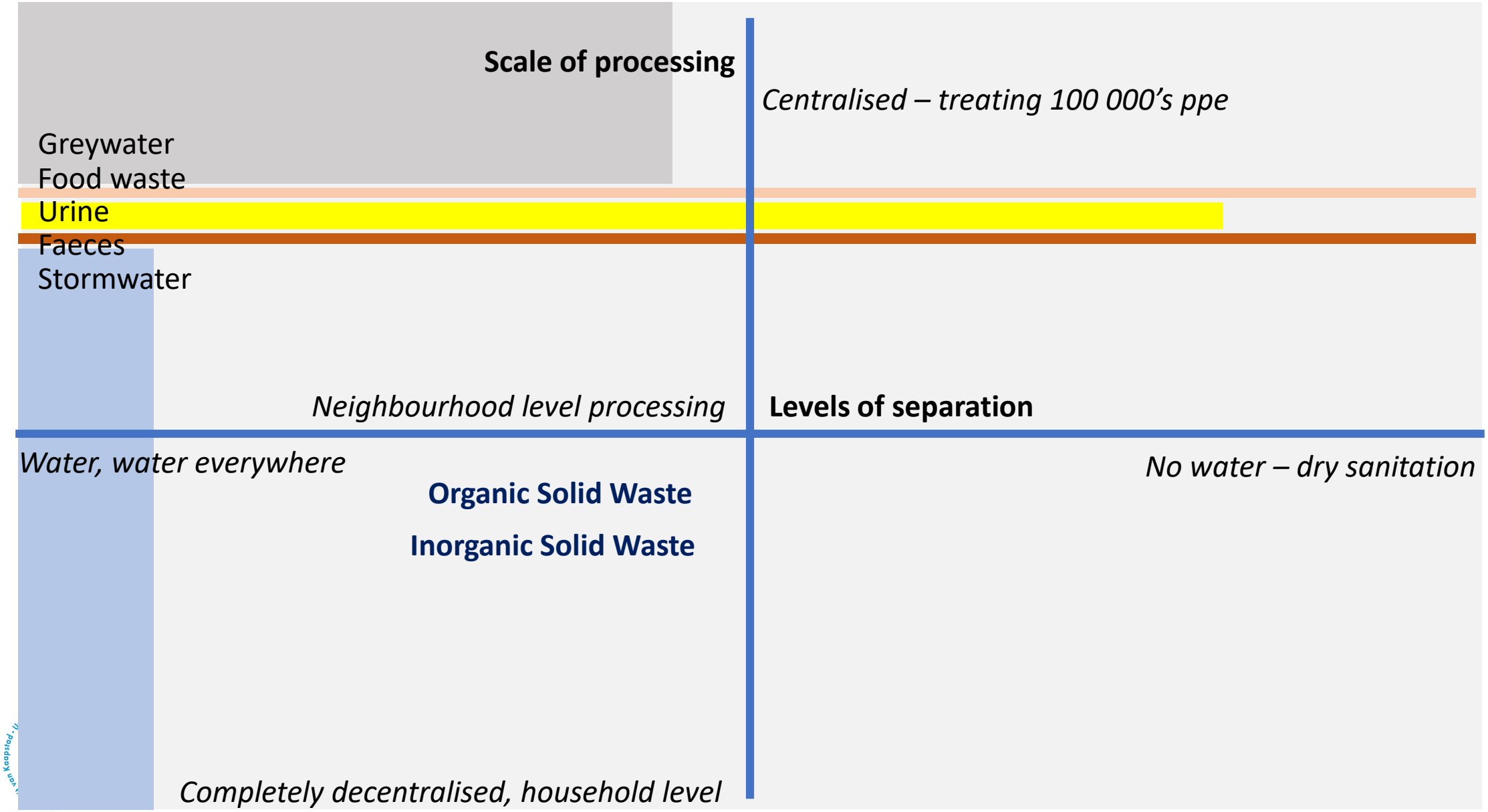
Organic Solid Waste

Inorganic Solid Waste

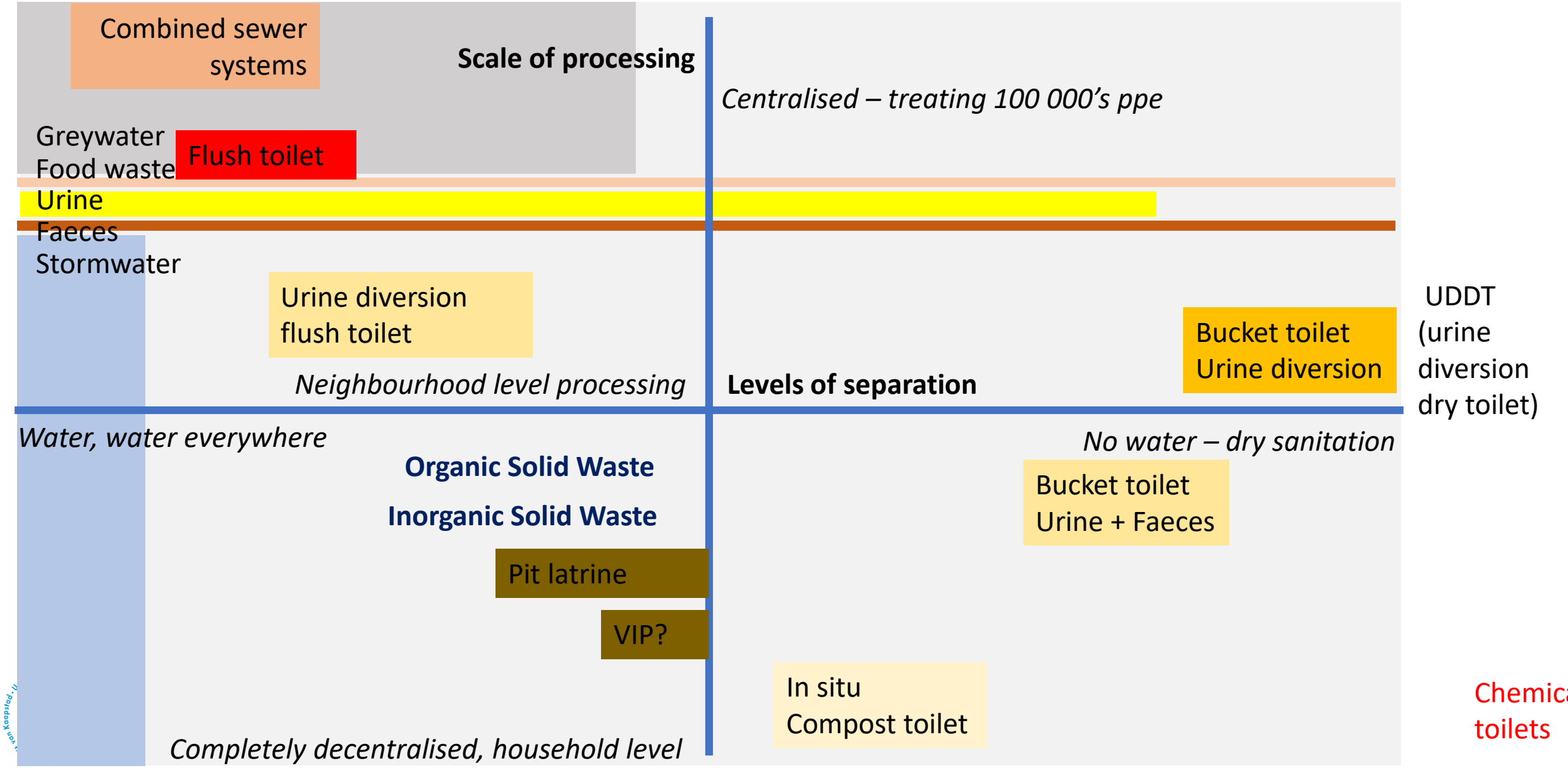
"Toilets are receptacles. Everything goes in there."

Stormwater

Water sensitive, sustainable sanitation: The options

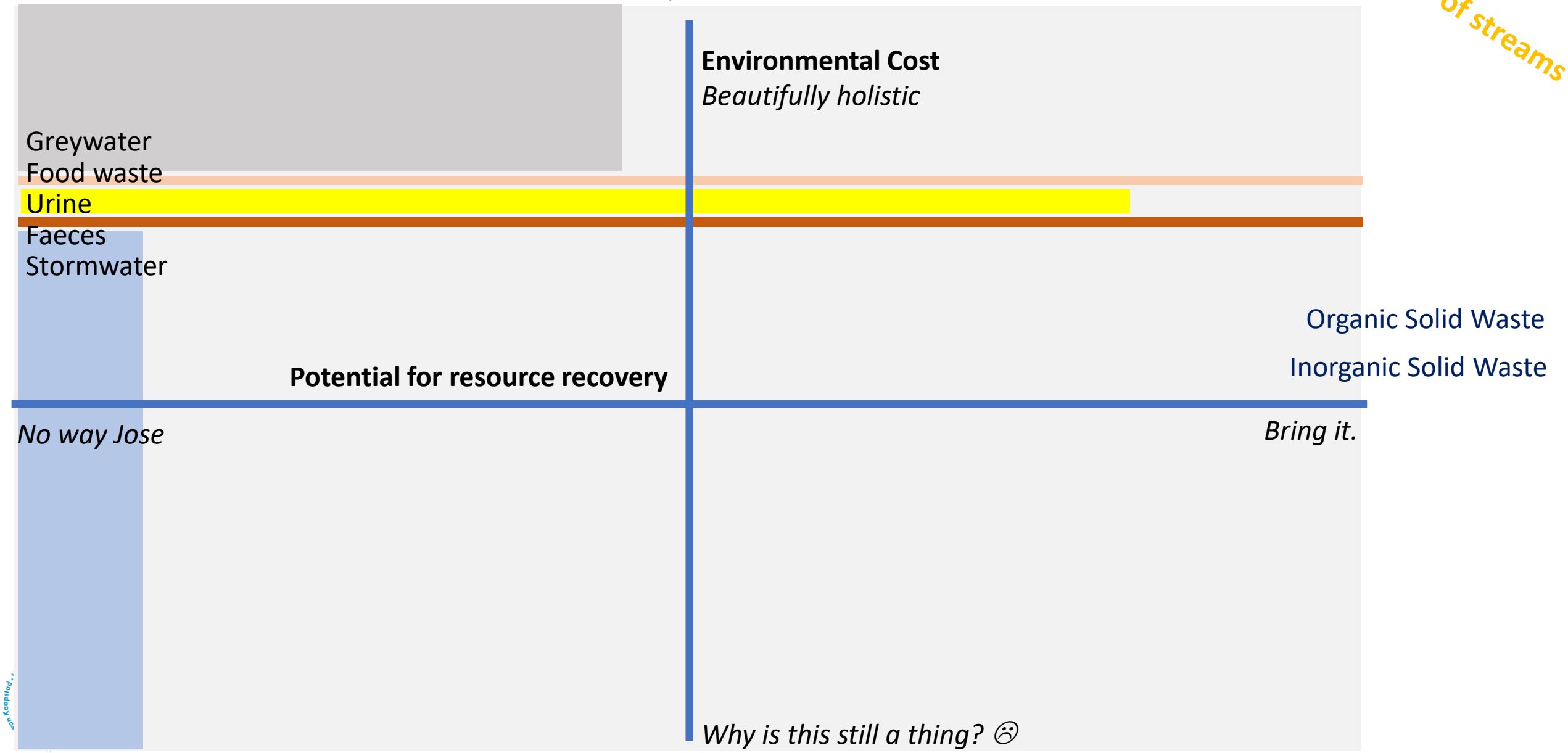


Water sensitive, sustainable sanitation: The options



Comparison of options, considering Potential for resource recovery and Environmental cost

Separation of streams



Comparison of options, considering Potential for resource recovery and Environmental cost

Separation of streams

Environmental Cost

Beautifully holistic

Greywater
Food waste
Urine
Faeces
Stormwater

Organic Solid Waste

Inorganic Solid Waste

Potential for resource recovery

No way Jose

Bring it.

Why is this still a thing? ☹

Comparison of options, considering Potential for resource recovery and Environmental cost

Separation of streams

Environmental Cost
Beautifully holistic

Greywater
Food waste
Urine
Faeces
Stormwater

Bucket toilet
Urine diversion

Urine diversion
flush toilet

Bucket toilet
Urine + Faeces

Organic Solid Waste

Inorganic Solid Waste

Potential for resource recovery

No way Jose

Bring it.

Pit latrine

VIP?

Combined sewer systems

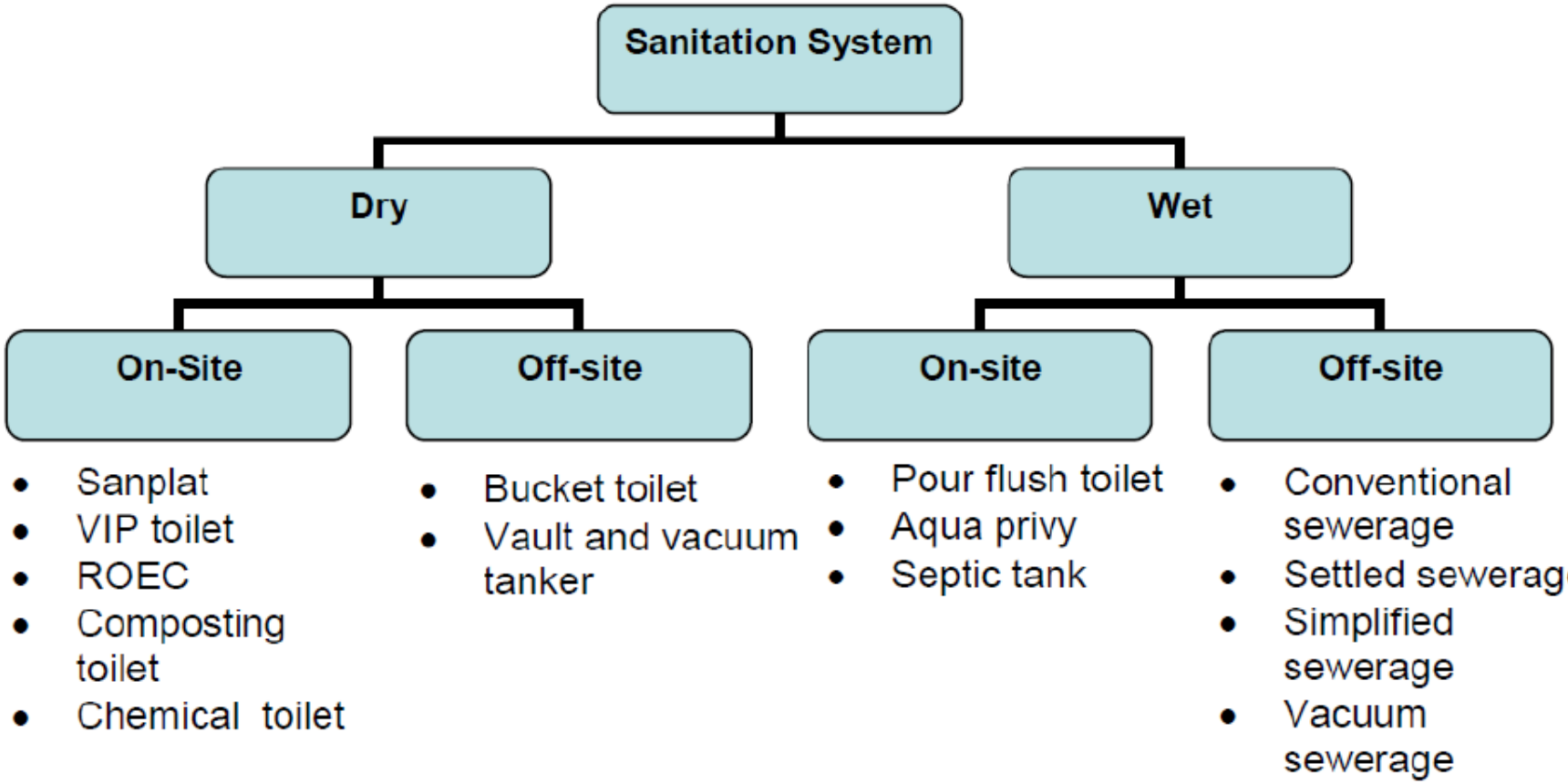
In situ
Compost toilet

Flush toilet

Why is this still a thing? ☹

Chemical toilets

Sanitation classification



Graham (2003)

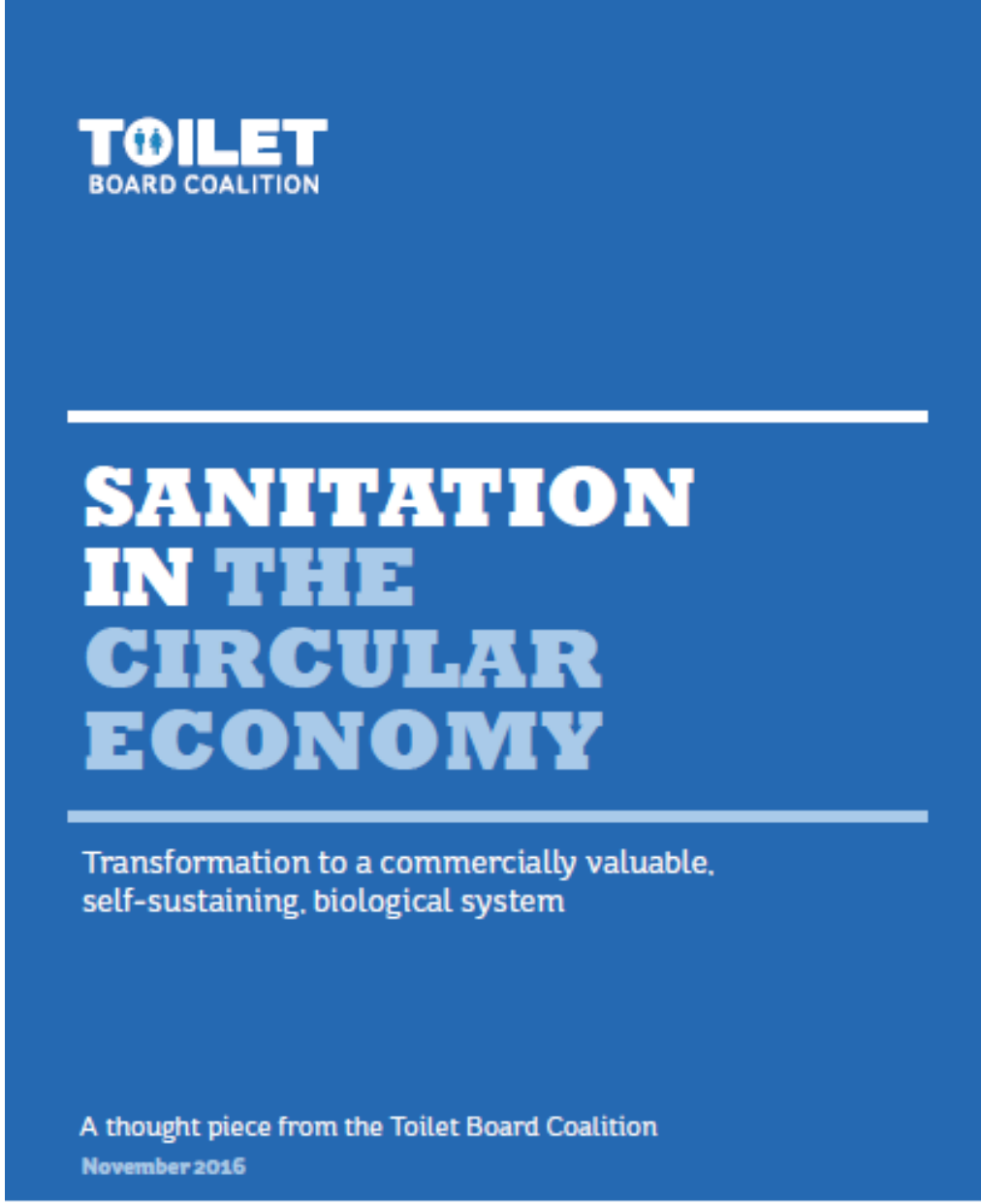
Via Neil Armitage

2. Sanitation as an industrial ecosystem

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.



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

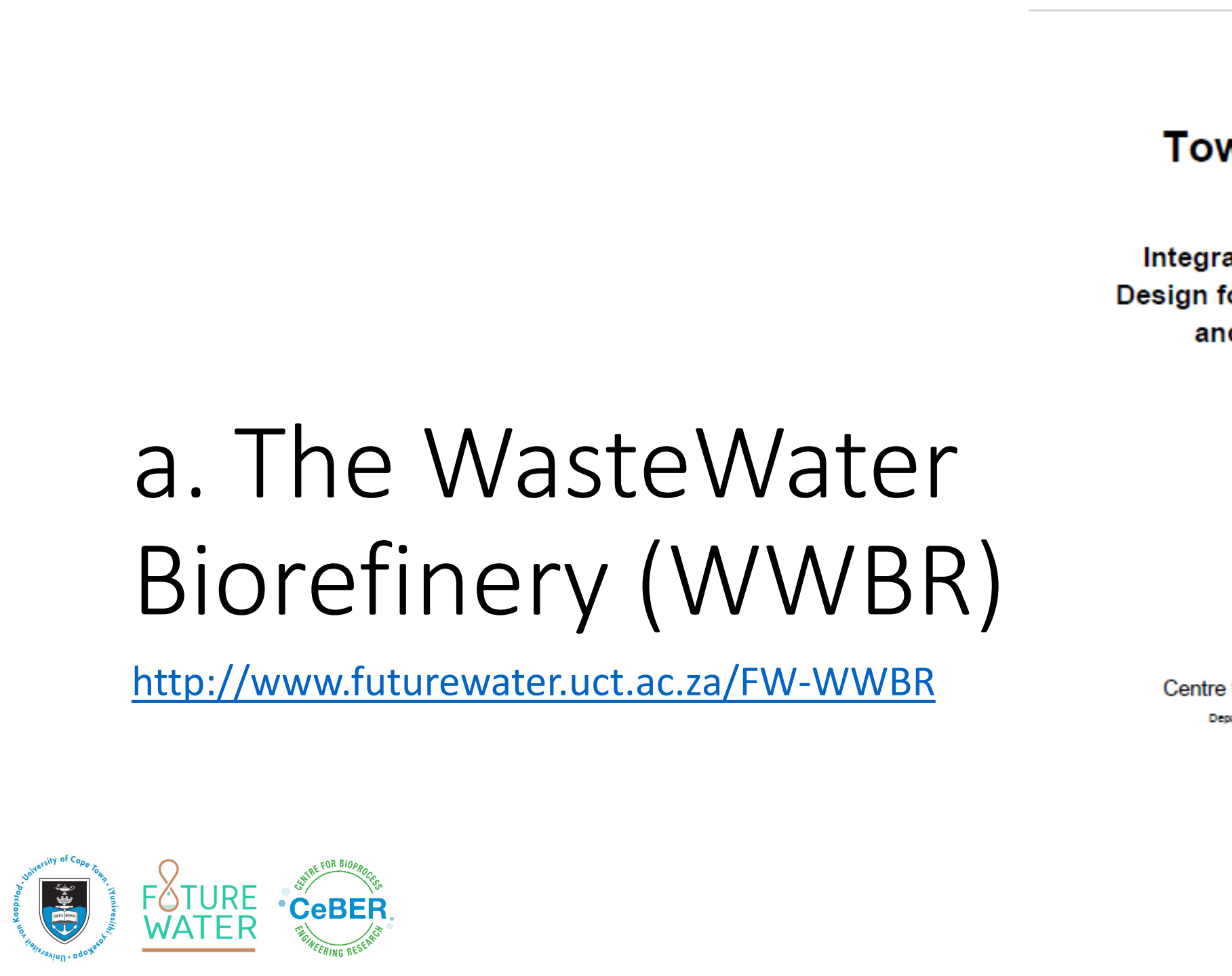
Where sanitation started for me:

Wastewater as an opportunity

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?

a. The WasteWater Biorefinery (WWBR)

http://www.futurewater.uct.ac.za/FW-WWBR



Towards Wastewater Biorefineries:

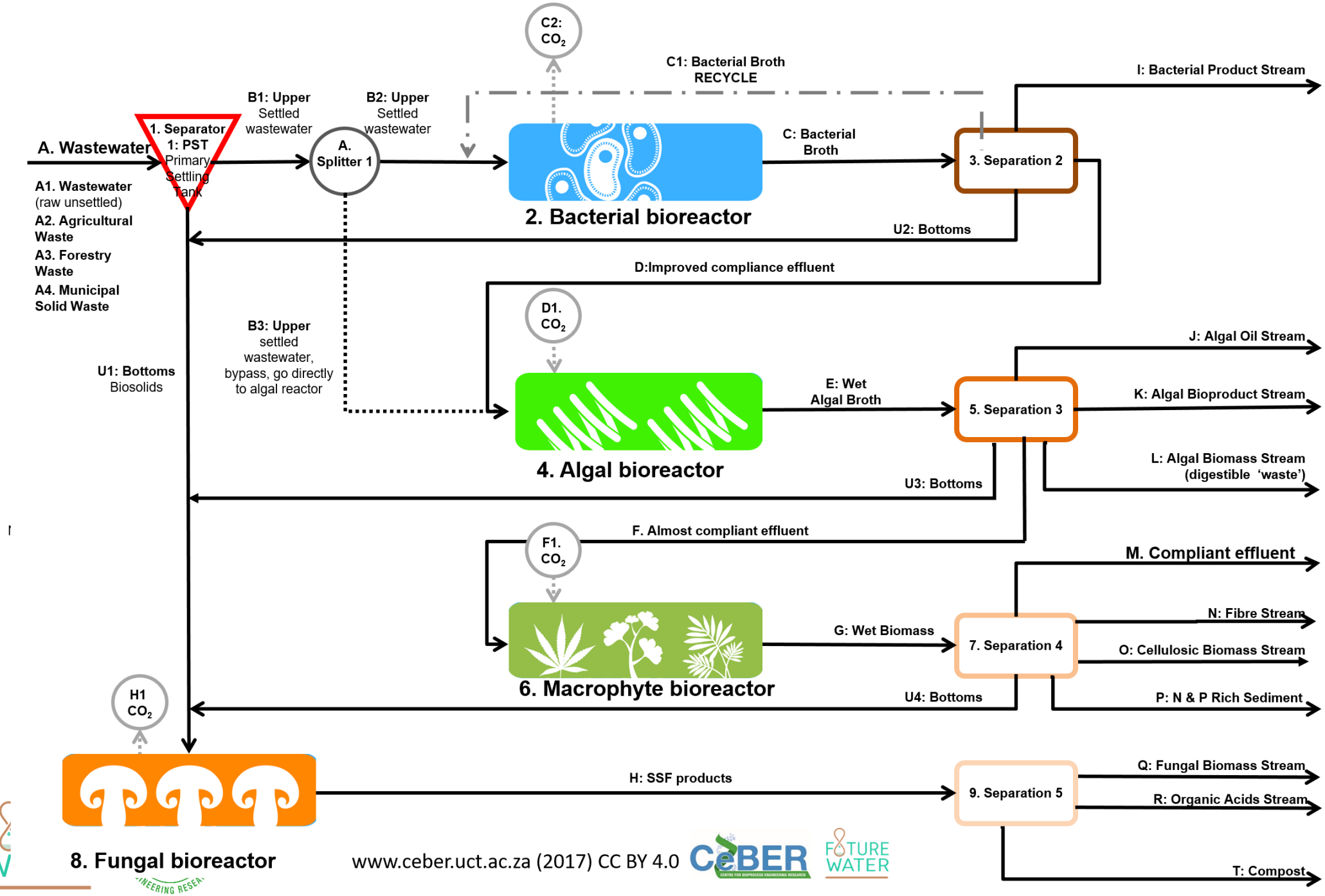
Integrated Bioreactor and Process Design for Combined Water Treatment and Resource Productivity

Final Report

Sucan T.L. Harrison
Bernelle Verster
Lecley Mostert
Shilpa Rumjeet
Tayana Raper
Sharon Rademeyer
Madelyn Johnstone-Robertson

Centre for Bioprocess Engineering Research
Department of Chemical Engineering, University of Cape Town

WRC Project Number: K5/2380
December 2016



www.ceber.uct.ac.za (2017) CC BY 4.0

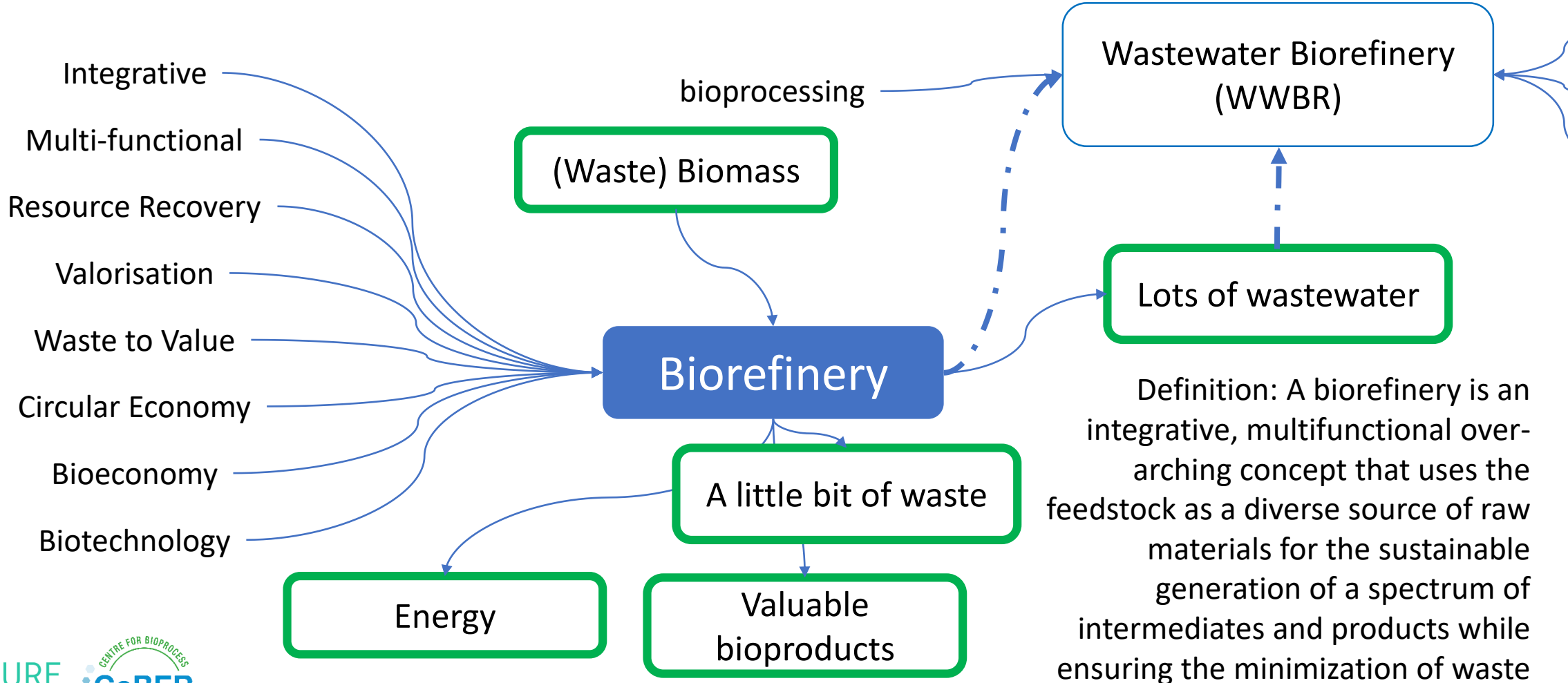
Resource Efficiency

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?

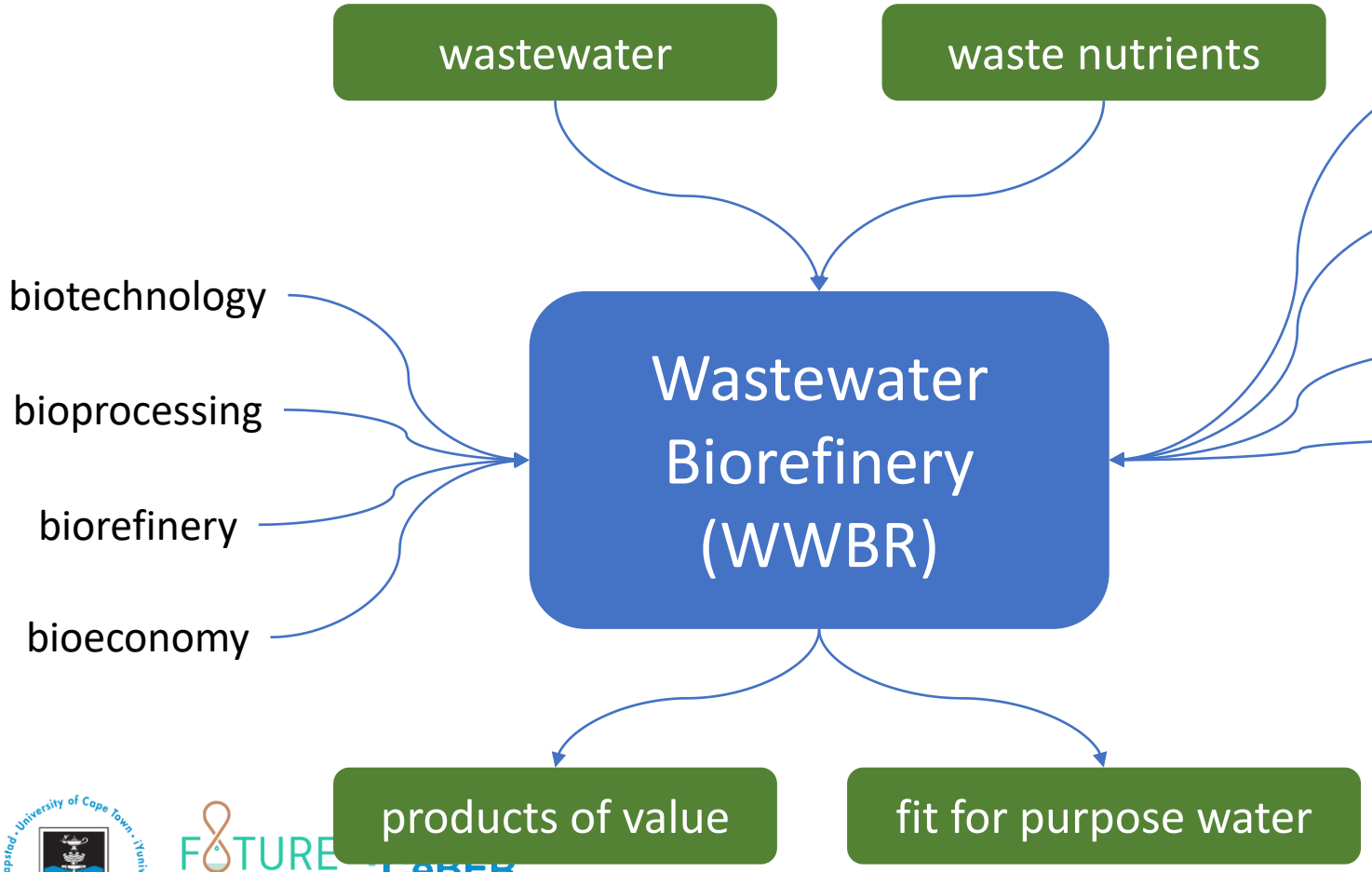


Definition: A biorefinery is an integrative, multifunctional over-arching concept that uses the feedstock as a diverse source of raw materials for the sustainable generation of a spectrum of intermediates and products while ensuring the minimization of waste products.

ACTIVE Biotransformation

not just (passive) Bioremediation

It's all about reactor design



… 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)

Benefits and challenges to implementation of WWBR

Benefits:

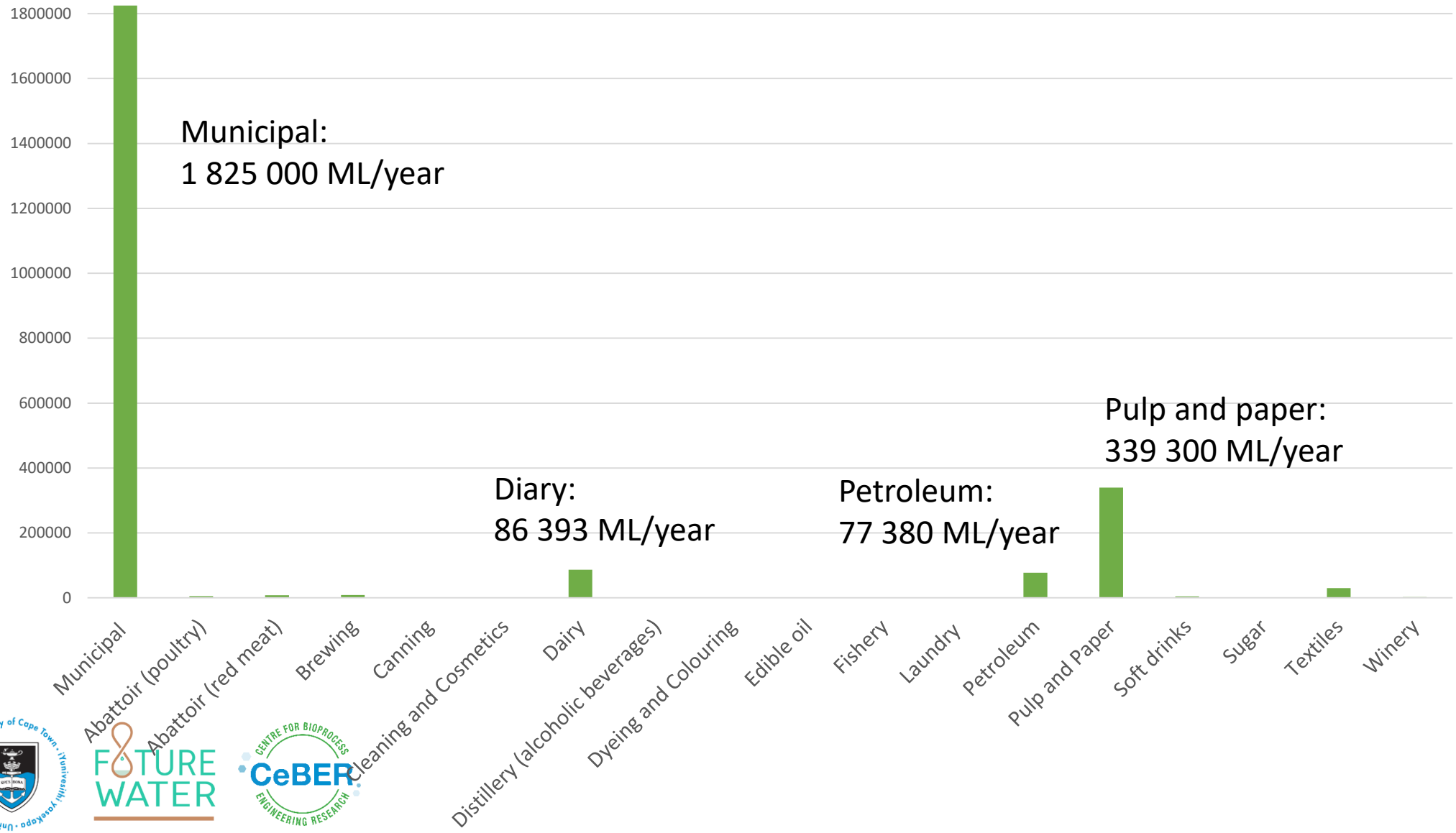
- Addresses the needs of the circular economy
- Places clean water as a product of importance, with economic value
- Potential for the biorefinery to provide the funding for water treatment or the energy requirement or both
- Resource productivity

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

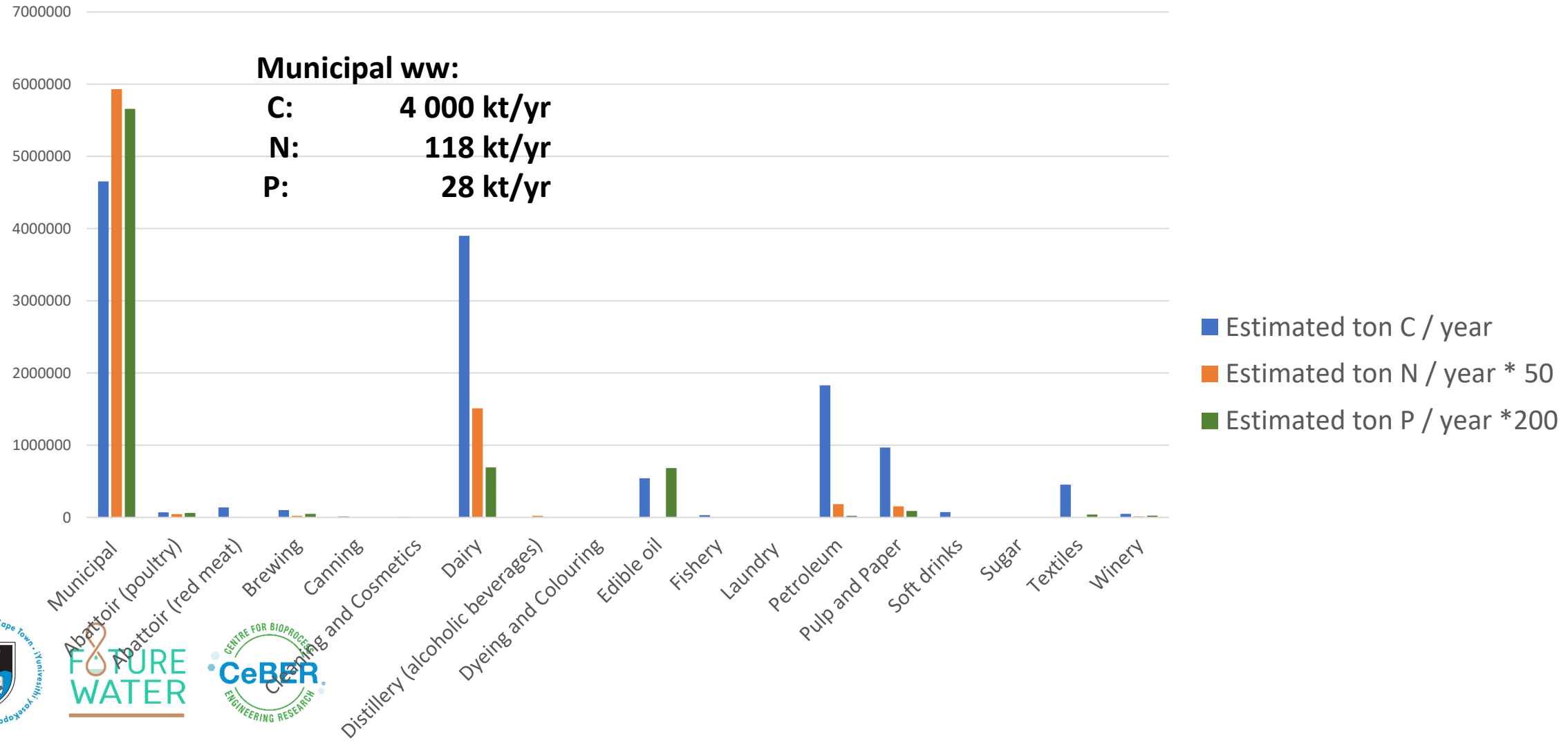
b. Why choose sanitation?

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 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’

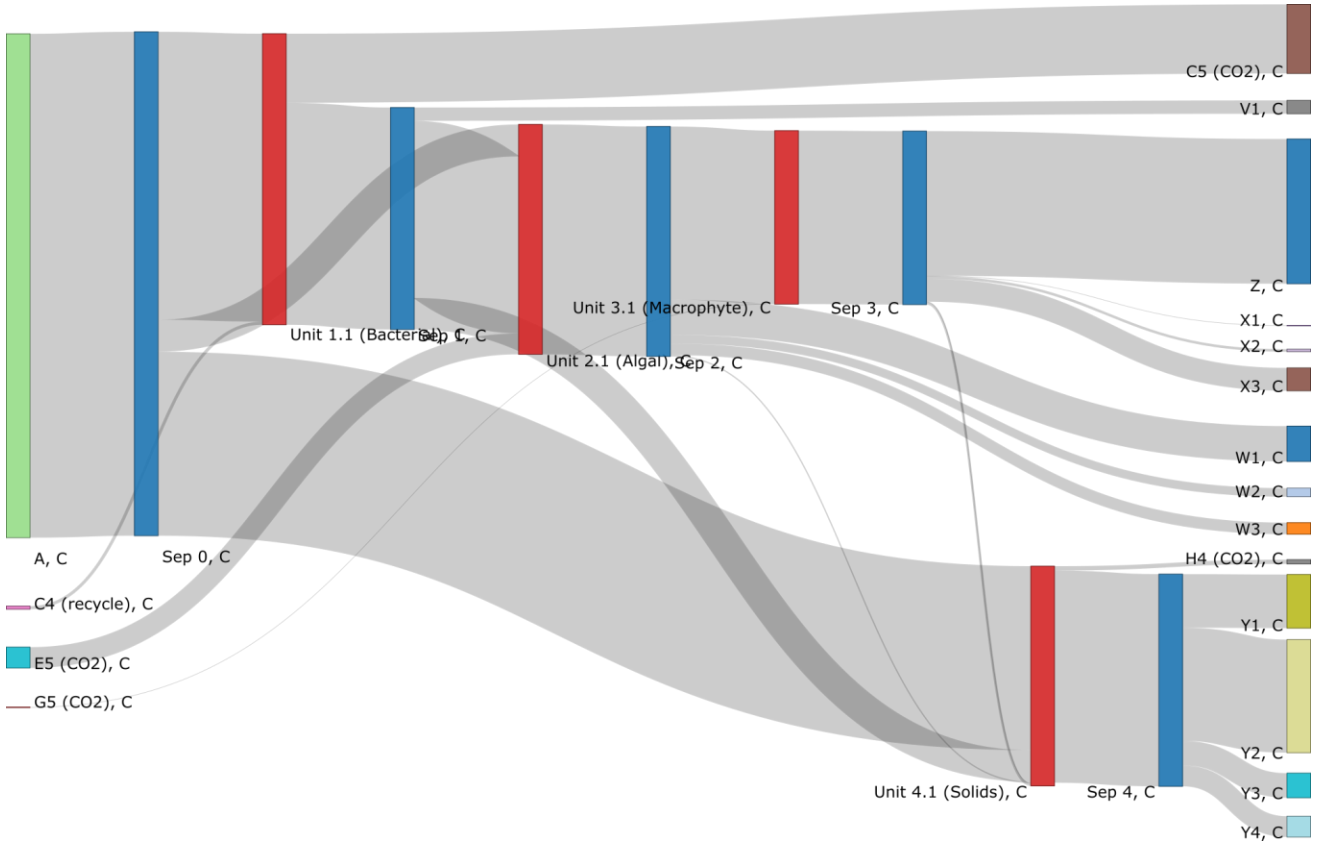
- alginic acid
- phosphorous
- biogas
- cellulose
- polyhydroxyalkanoates (PHA)

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

@UCT: 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

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

Dyllon.Randal@uct.ac.za

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

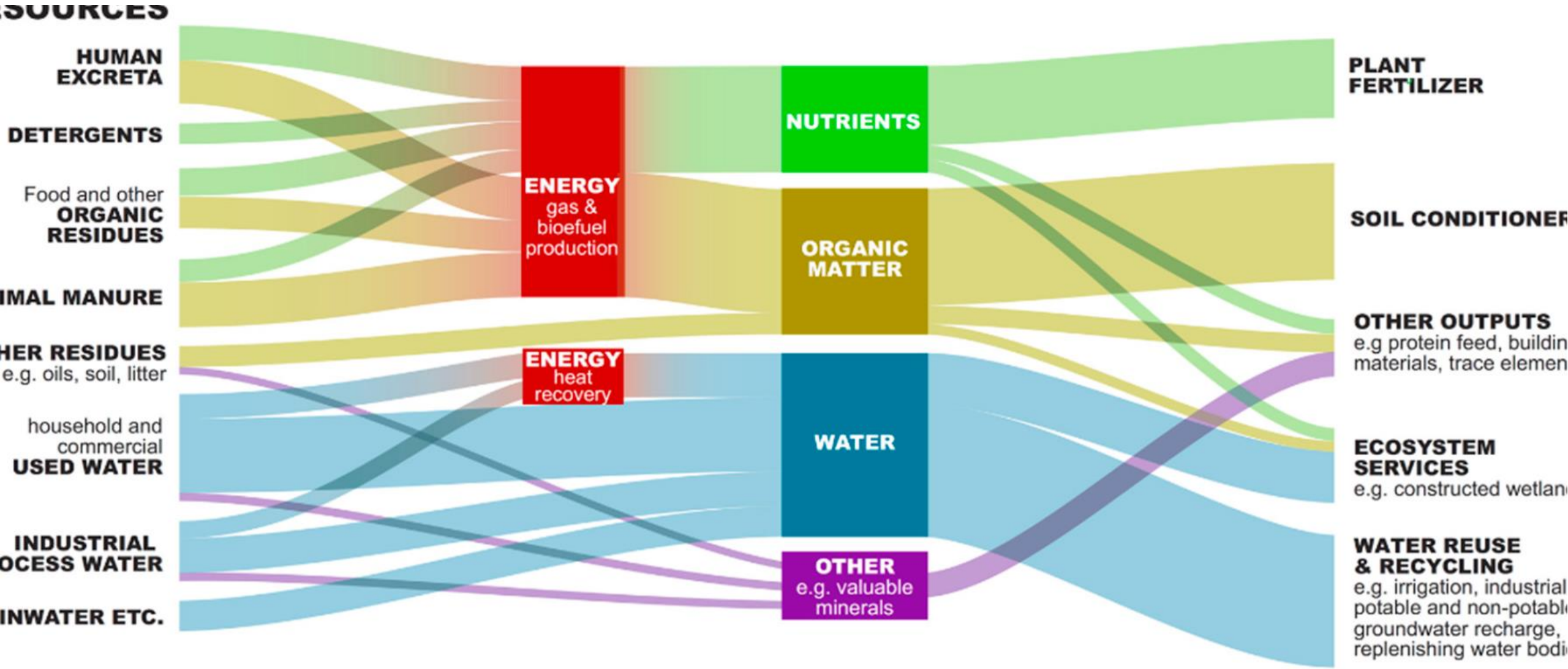
4 Water Wise Communities

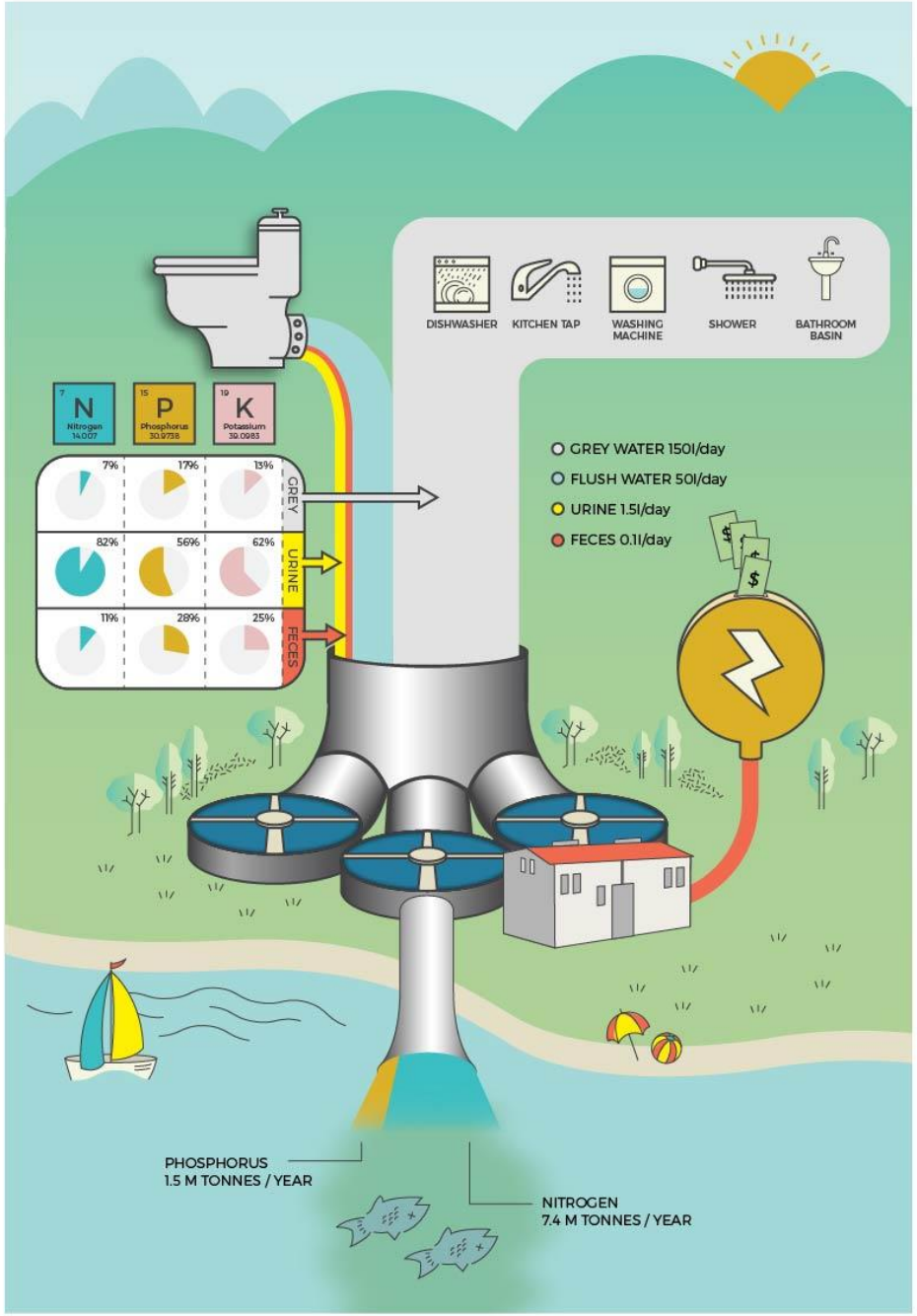
- Empowered Citizens
- Incentivized Professionals
- Transdisciplinary Planning Teams
- Progressive Policy Makers
- Leaders that Engage and Engender Trust

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

The potential in sanitation

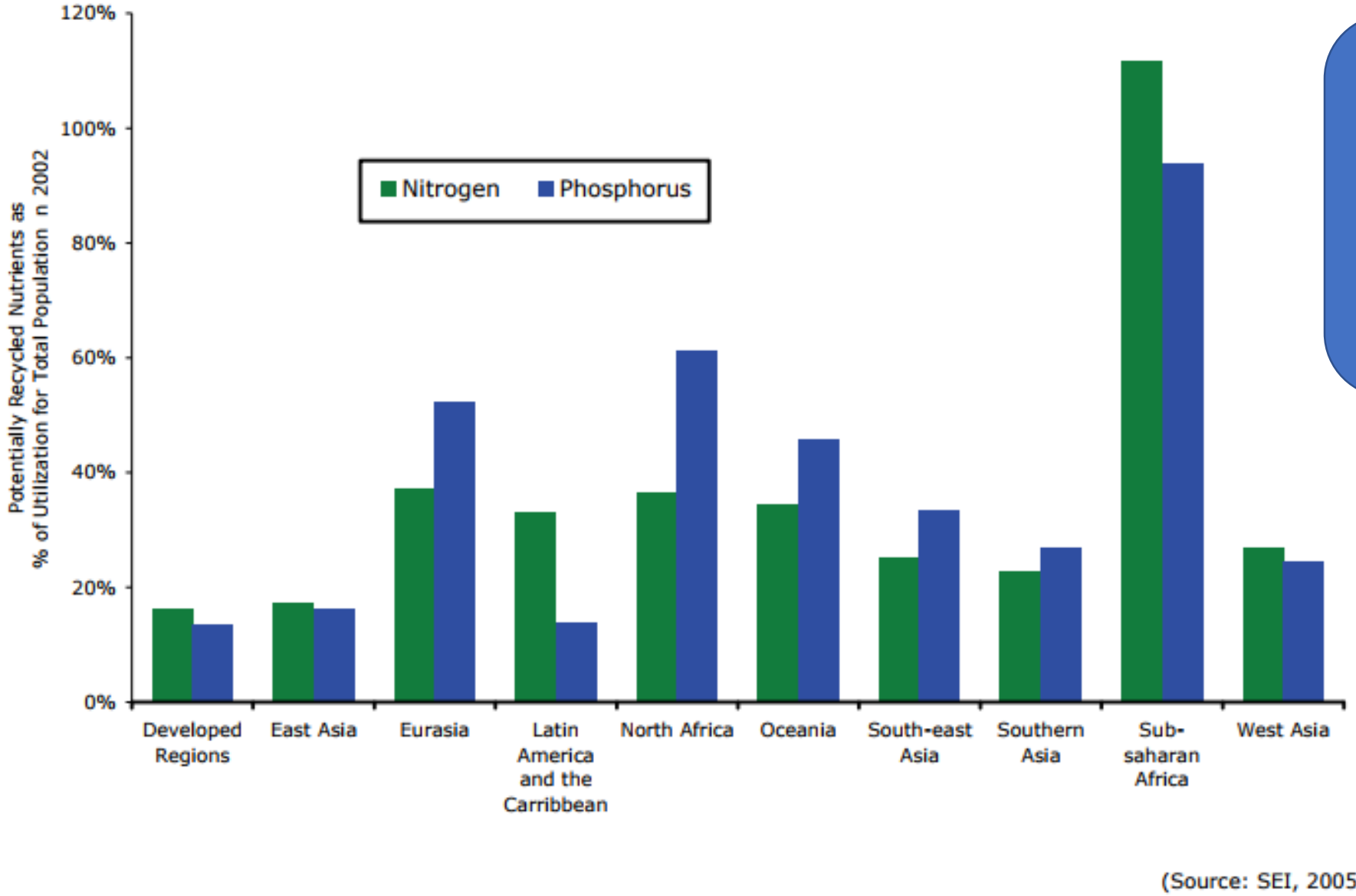
http://www.mdpi.com/2071-1050/8/12/1289/html
Review: Towards “Sustainable” Sanitation: Challenges and Opportunities in Urban Areas
Kim Andersson *, Sarah Dickin and Arno Rosemarin
Sustainability 2016, 8(12), 1289; doi:10.3390/su8121289





Peak Pee!

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



(Source: SEI, 2005)

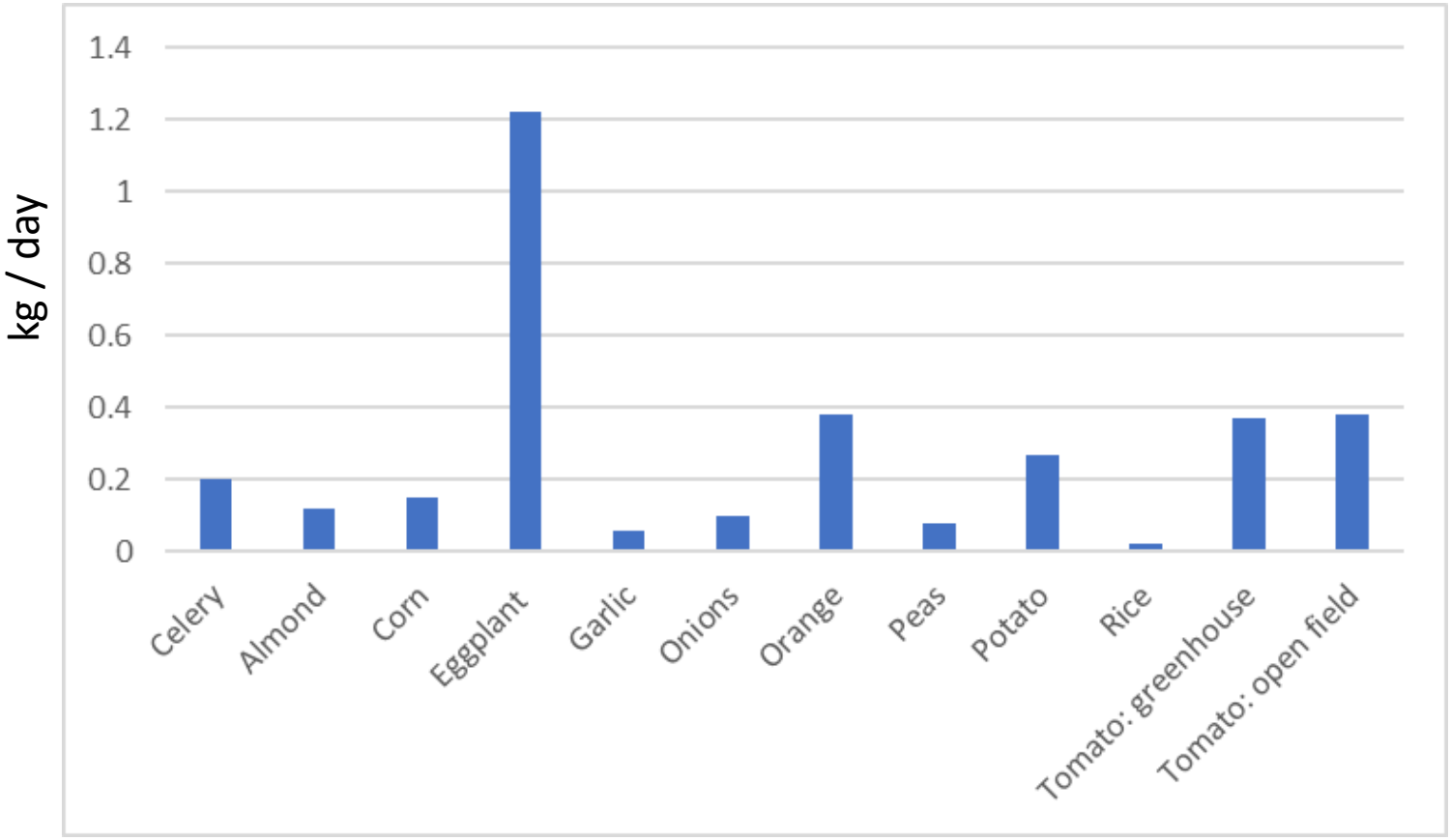
Figure 23: Potential capacity of ecological sanitation systems to replace chemical fertiliser used in different world regions

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

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

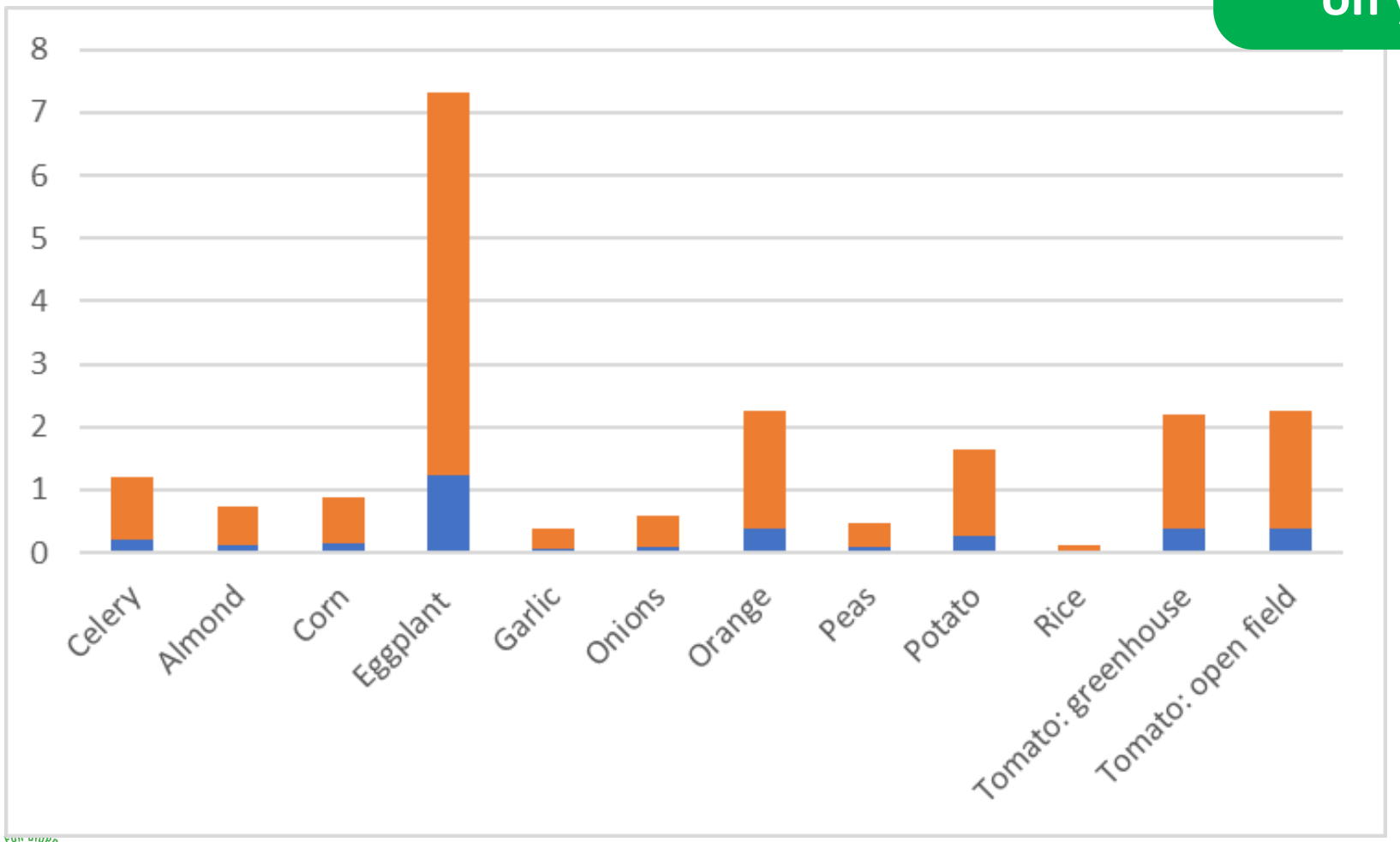


http://www.smart-fertilizer.com/nutrient-requirements

The P in your pee

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

Grow 1kg food per day on your urine!



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

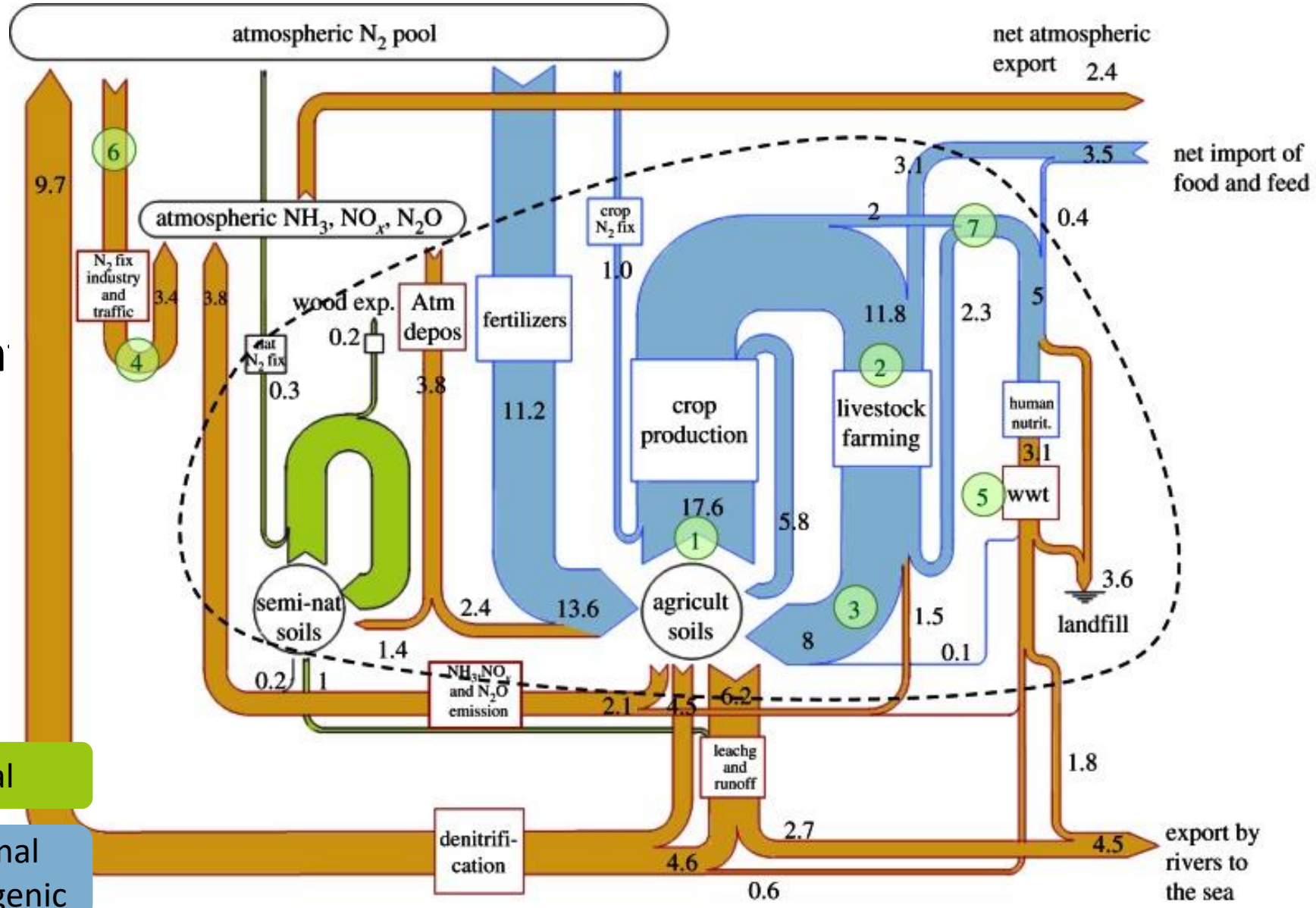
The N cycle

Haber–Bosch

energy requiremen

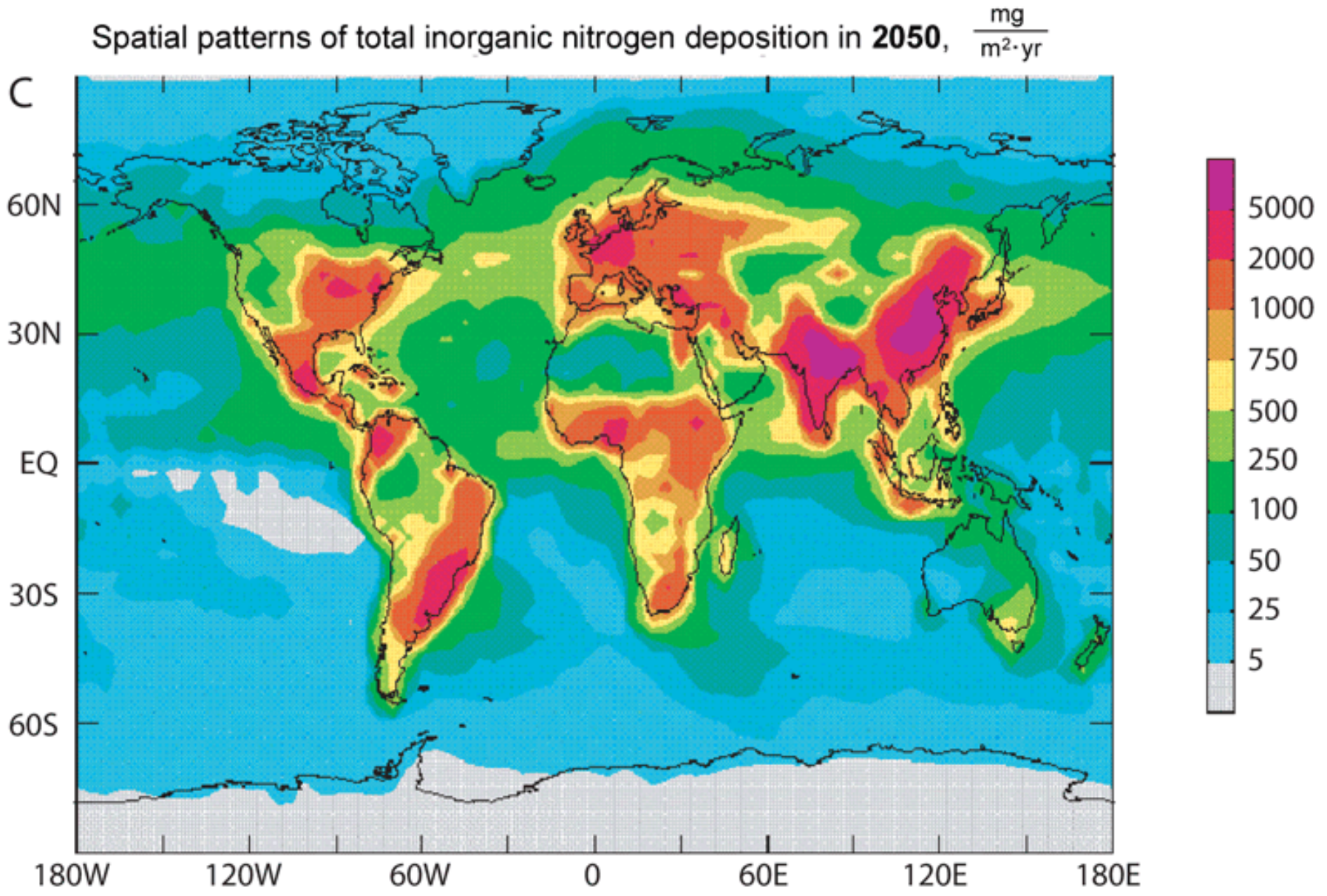
Greenhouse gases

Global cycle



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

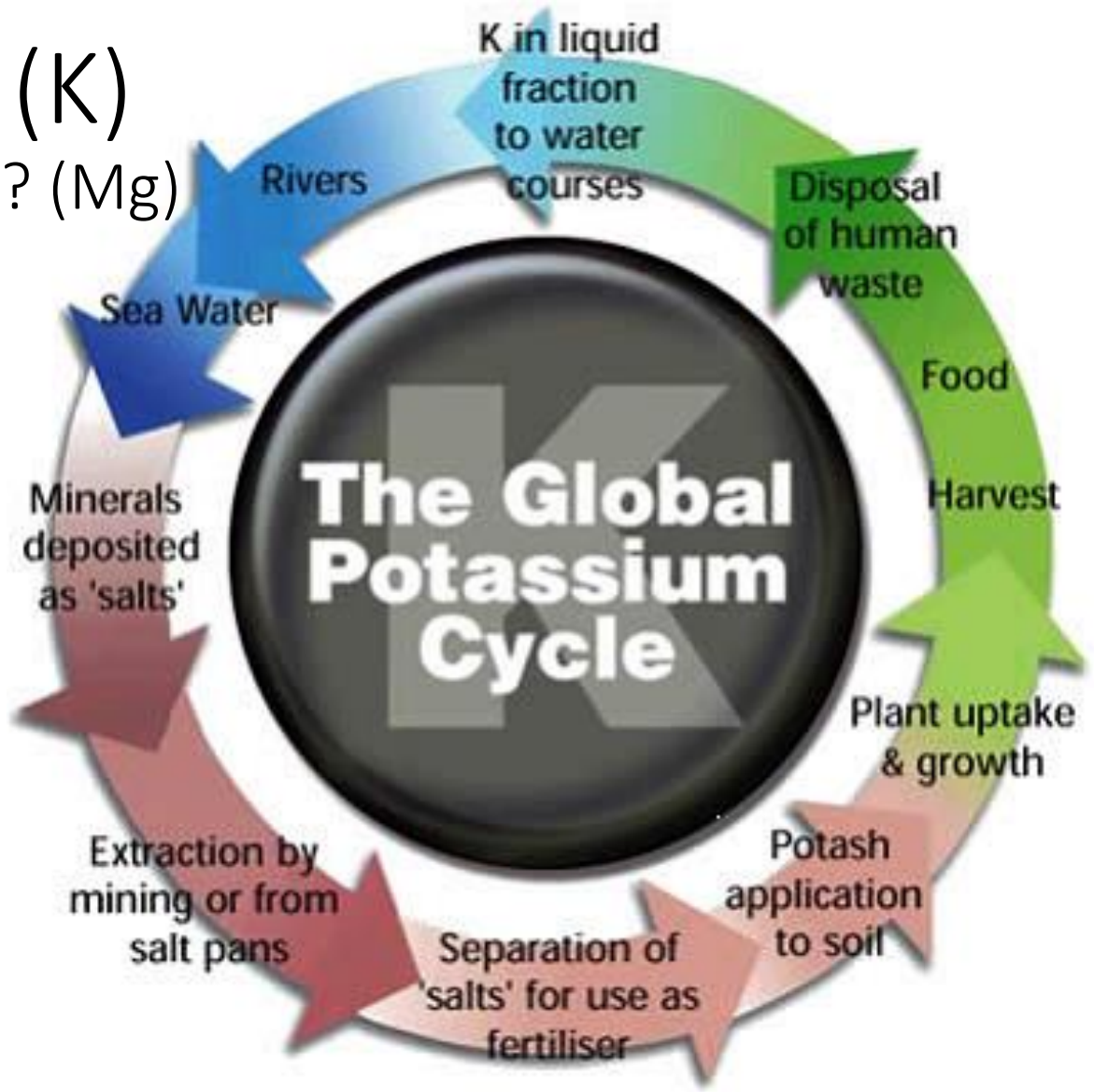
N crisis



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/

3. Why do I argue for dry?

Nutrient recovery from sanitation is important.

Nutrient recovery is easier from ‘dry’ material?

Effect of compliant discharge of sewered systems 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

* When things are working well!

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.

Effect of compliant discharge of sewered systems on receiving bodies*

Substance/Parameter	General Limit (mg/ℓ)	Special Limit (mg/ℓ)
Chemical Oxygen Demand (COD)	75	
Ammonia (ionised and un-ionised) as Nitrogen	6	
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

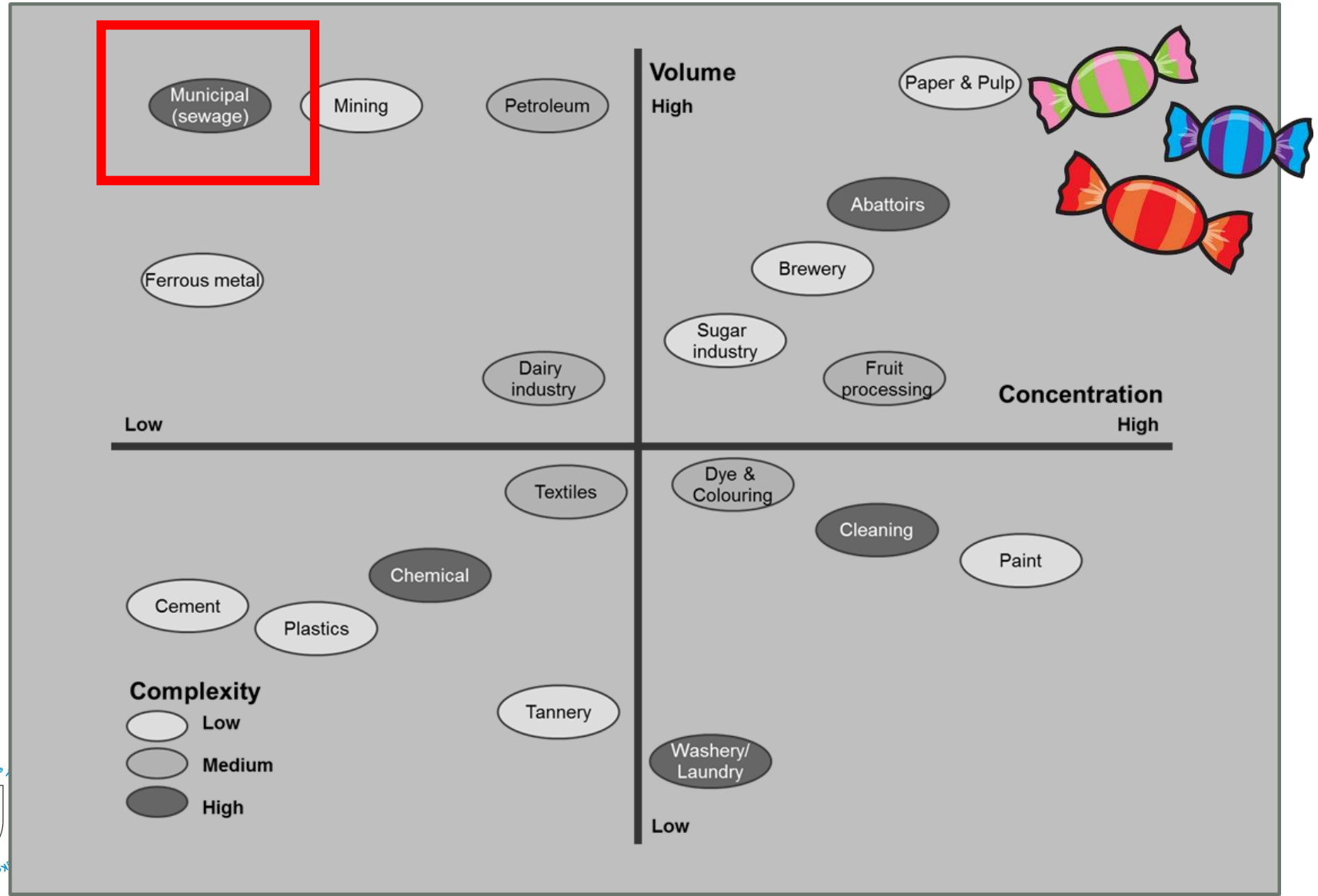
* When things are working well!

EUTROPHICATION

1mg/L = 1kg/ML

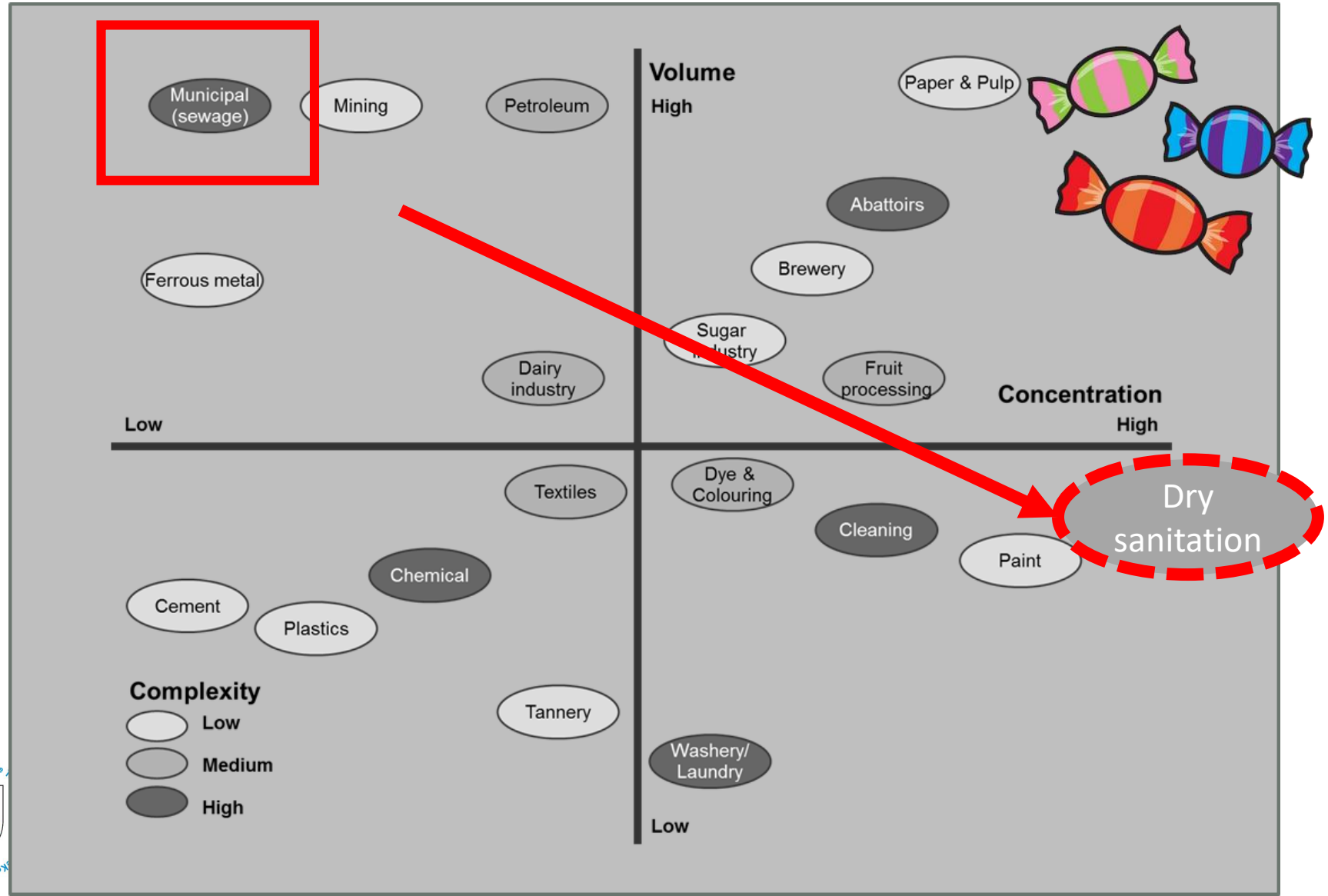
20ML/day pla = 20 00 000 / day
Each L has 1 of
20 000 000 L/day 1mg P =
20 000 000 mg P/day =
20 kg P per day.

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		

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		

Potential for the Waste(water) Biorefinery

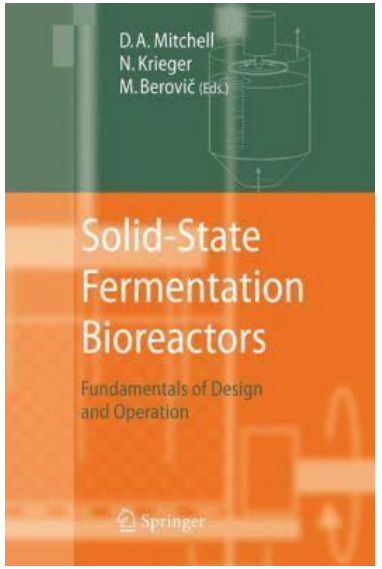
1. Bioproducts
   i. Biobased building blocks
      - New functionality
      - Drop in products
   ii. Complex, functional macro-molecules

Citric acid
Glutamic acid
Lysine

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

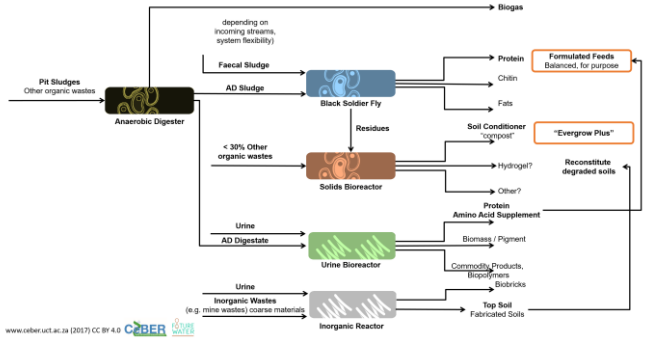
http://www.icsn.cnrs-gif.fr/spip.php?article927&lang=en

Fungi

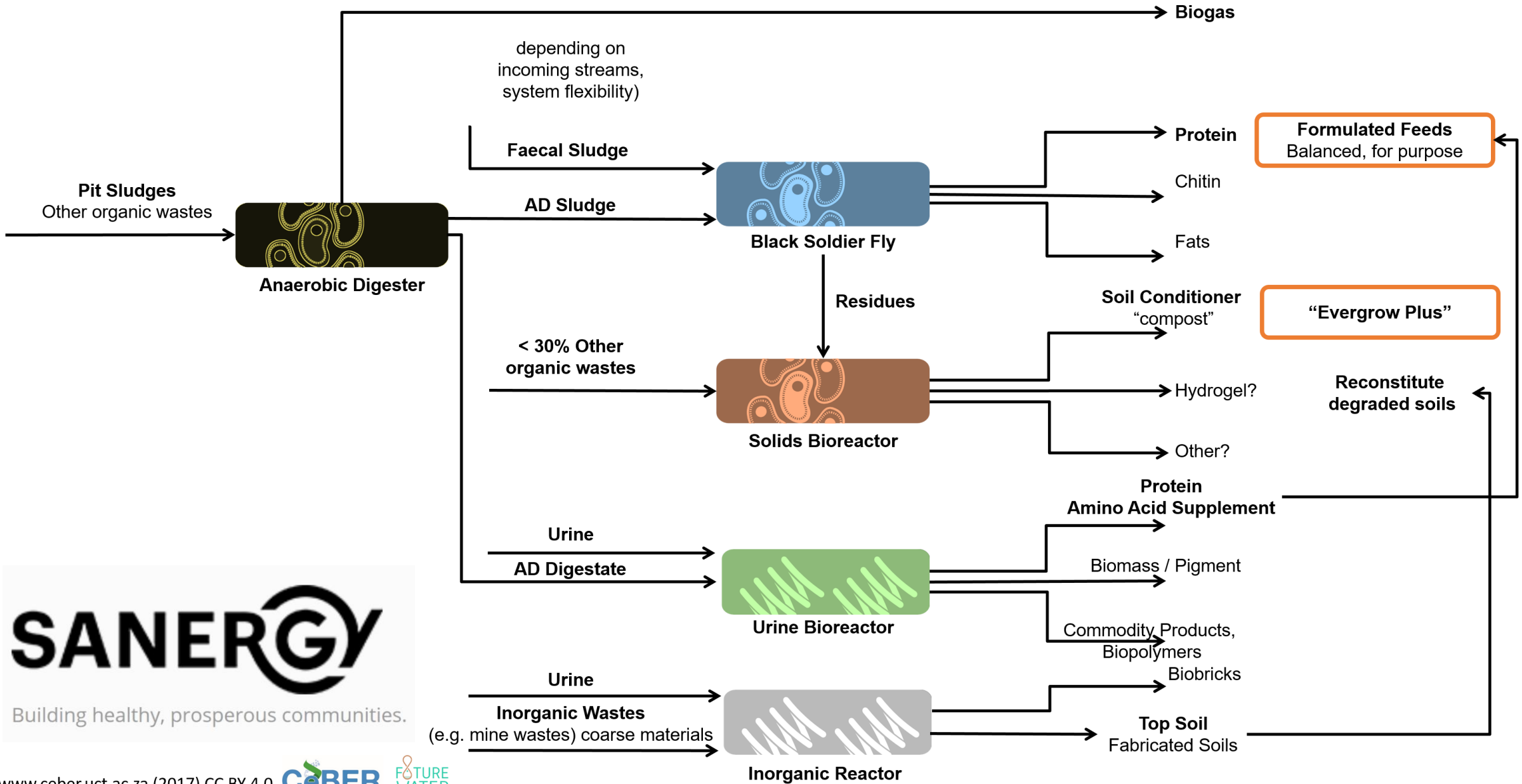


Sanitation as a (bio)engineered process

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		



SANERGY

Building healthy, prosperous communities.

www.ceber.uct.ac.za (2017) CC BY 4.0

3a. Dry: Specifically urine diversion, bucket.

User interface?

Verwoerd Rd
Google

House Jouissance

indiebio.co.za/house-jouissance

What do I consider non-negotiable in a toilet?

Convenience is assumed. As it should be.

Dignity, Convenience, safety, ease of cleaning, 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.

Dry / extremely low flush / foam flush virtually indistinguishable

The dry toilet is connected to a drum that can be emptied out once the waste has dried and reduced in volume. Sawdust helps to absorb moisture thus aiding the drying process.

THE LIVING LABORATORY

Verster has big plans for her mostly indigenous

will include a formal Zen garden with indigenous plants that mimic small Japanese flowers, a

What is the end game?

Is VIP the end game?

Fully sewered systems?

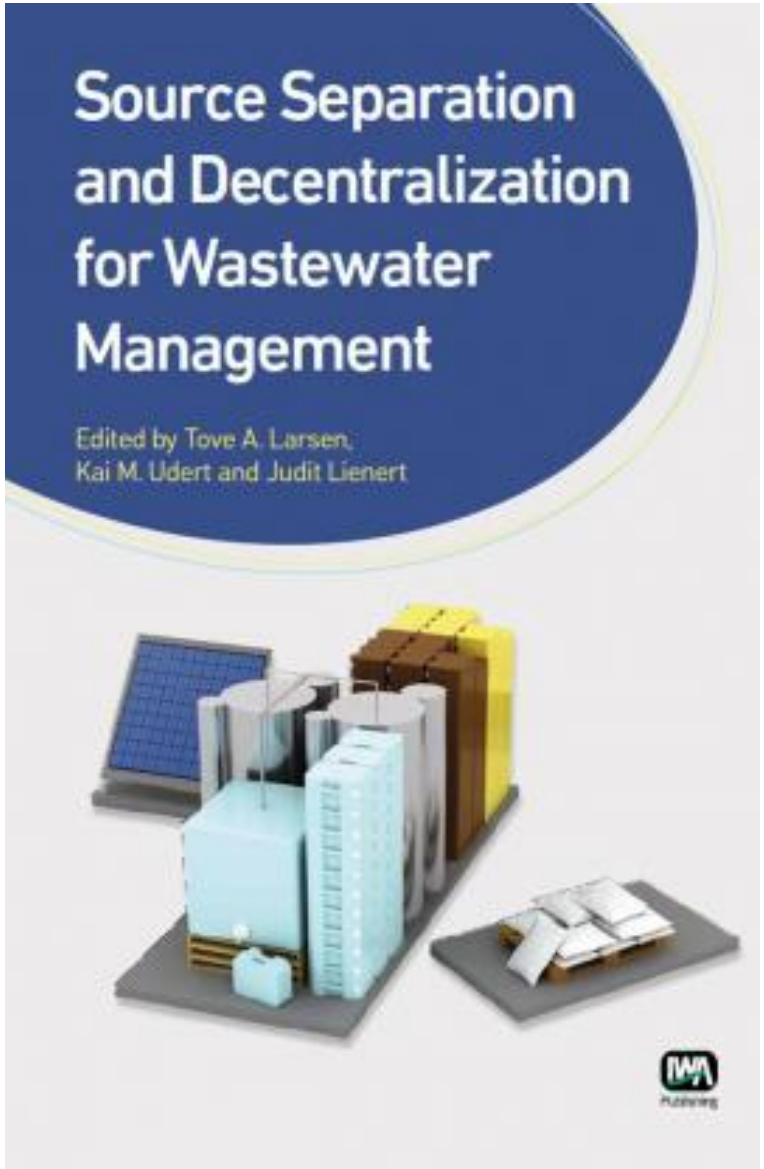
What is currently happening with greywater?

What do we expect to happen with greywater once the communities develop economically?

Source Separation and Decentralization for Wastewater Management

"Is sewer-based wastewater treatment really the optimal technical solution in urban water management? This paradigm is increasingly being questioned. Growing water scarcity and the insight that water will be an important limiting factor for the quality of urban life are main drivers for new approaches in wastewater management. Source

During the 1990s, several research groups started working on source-separating technologies for wastewater treatment. **Source separation was not new, but had only been propagated as a cheap and environmentally friendly technology for the poor. The novelty was the discussion whether source separation could be a sustainable alternative to existing end-of-pipe systems, even in urban areas and industrialized countries.**"



https://www.iwapublishing.com/books/9781843393481/source-separation-and-decentralization-wastewater-management

The big toilet fight

WET: sewered systems are the pinnacle of toilet evolution	vs.	DRY toilets for the win
1. Sewerage isn't about the toilets, it's about the greywater. 2. We can get the water back – wastewater reuse 3. Hydrotransportation is the most efficient 4. "proven public health success" "greatest 'medical' advance of the industrial era" 5. Dry sanitation, by contrast, exposes people (users, collectors etc.) to severe public health risks. 6. In dense urban settlements, more cost-effective, easier to manage.		1. Nutrient recovery: food security, soil health 2. Producing N, mining P bad for environment: imbalanced cycle, NOx greenhouse gas 3. Dry toilet waste more concentrated, easier to recover 4. Dry toilet infrastructure is cheaper than flush infrastructure 5. Effluent even from well managed wastewater treatment works = eutrophication

Current compromise: Urine diversion, potential for hybrid systems. New systems probably smaller scale.

Condominial approach

http://indiebio.co.za/resources

http://indiebio.co.za/wp-content/uploads/2017/11/Verster_et_al_29nov17_Peri_Urban_Sanitation_WWBR.pdf

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

NO TO PIT LATRINES!
(even VIPs)
NO TO LONG DROPS!

"you would rather prevent than address the aftermath"

YES to:

Composting toilets
Urine diversion composting toilets
Crème de la crème e.g. Separett
Bucket toilets reloaded

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

Contemporary Scandinavian bathroom design using vacuum toilets

Comfort and design is not inferior using extremely low flush toilets

Photos: P.D. Jenssen

www.umb.no

Department of Plant and Environmental Sciences, P.D. Jenssen

NORWEGIAN UNIVERSITY OF LIFE SCIENCES

24

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/

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

4. What is needed from a government budget / financial perspective to support the Sanitation Economy?

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

High quality standards

Professional operation

Wastewater treatment as a **production system**

"smaller" infrastructure more flexible, less vulnerable

1. Water reuse

2. Energy (heat) recovery

Decentralisation

Industrial eco-systems require combination of different sectors:

modularity

Water supply

Wastewater treatment

Waste treatment

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

What is needed from a government budget / financial perspective to support the Sanitation Economy?

Please help us learn: What are your thoughts?

Looking forward to further discussions during this workshop.

5. How to govern responsibly when decentralisation is a feasible option?

Many things function better if controlled from the grassroots, but need resources from government. Tension between government centres of resources, which wants to retain control (?) and grassroots which should be the source of democratic control

Please help us learn: What is your thoughts?

How to govern responsibly when decentralisation is a feasible option?

Many things function better if controlled from the grassroots, but need resources from government. Tension between government centres of resources, which want to retain control (?) and grassroots which should be the source of democratic control

Thank you! Let's learn together…

www.indiebio.co.za/resources

bernelle@indiebio.co.za

@indiebio

www.futurewater.uct.ac.za/
/FW-WWBR
/FW-sustainable-sanitation

www.ceber.uct.ac.za/

Joshua Palfreman

joshpalfreman@gmail.com

Skype: joshpalfreman

LinkedIn:
https://www.linkedin.com/in/joshua-palfreman-69871032/

WhatsApp:
SA: +27 61 272 7035
+44 7928 186 613