Eawag
Swiss Federal Institute of Aquatic
Science and Technology

Sanitation Systems and Technologies

Part 2 : Treatment, Disposal and Resource Recovery

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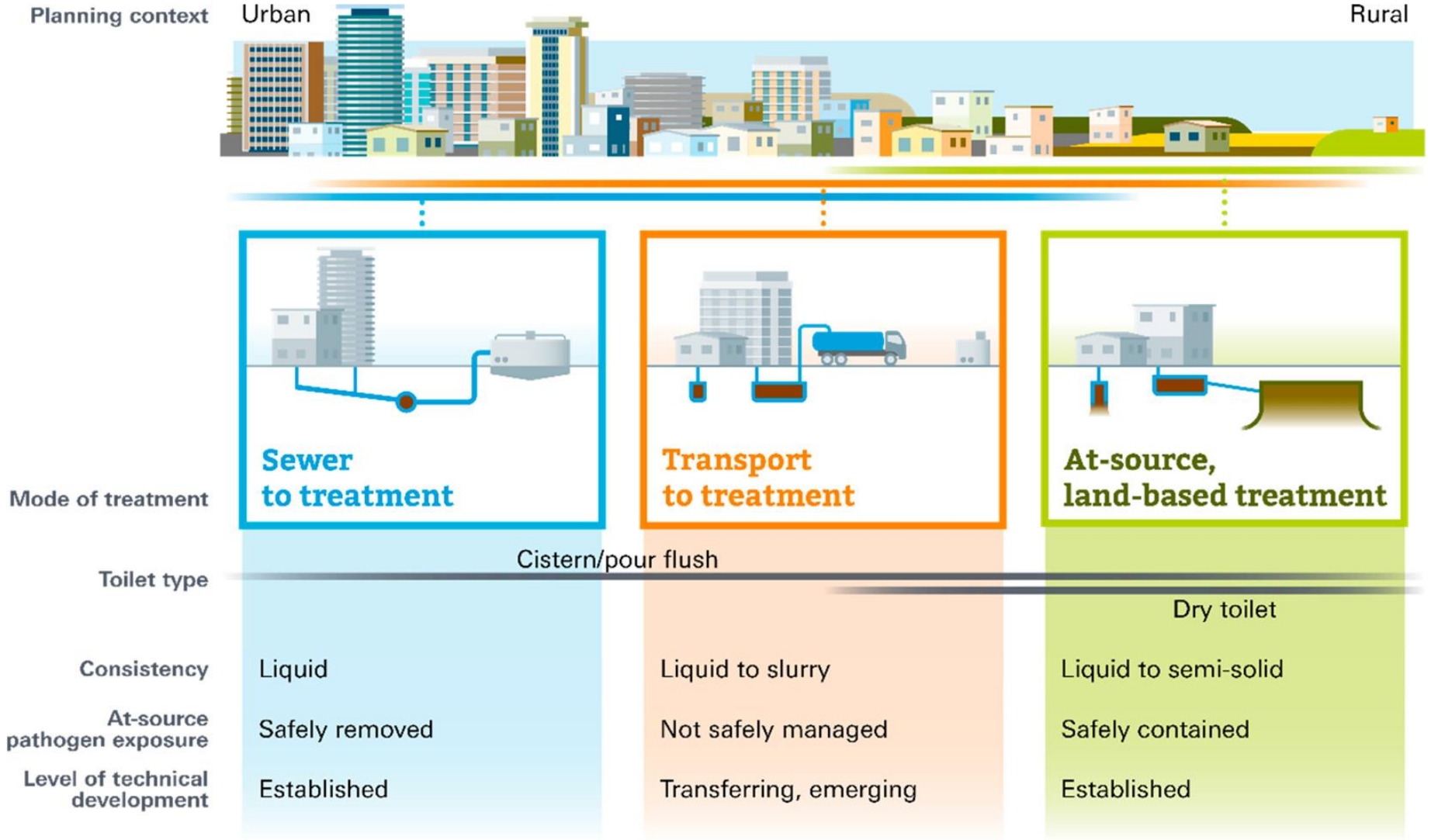
Learning objectives

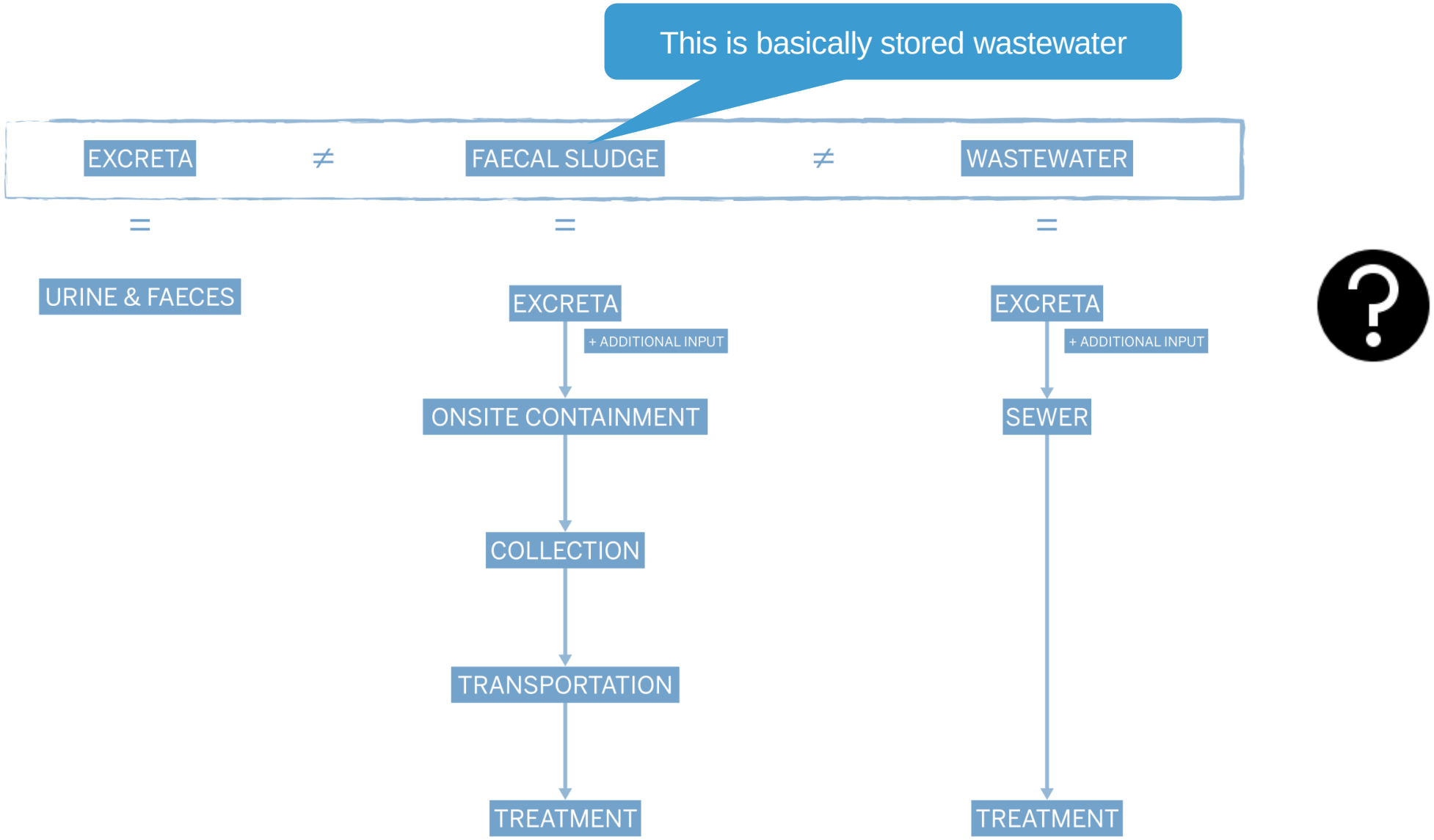
- Describe the difference between faecal sludge, sewered wastewater and excreta.
- Explain the Engineering Design Approach for faecal sludge management .
- Compare different resource recovery products and treatment technologies associated with them.
- Explain the treatment objectives of faecal sludge treatment and link them to treatment technologies.

Terminology:
What is faecal sludge (/stored wastewater)?



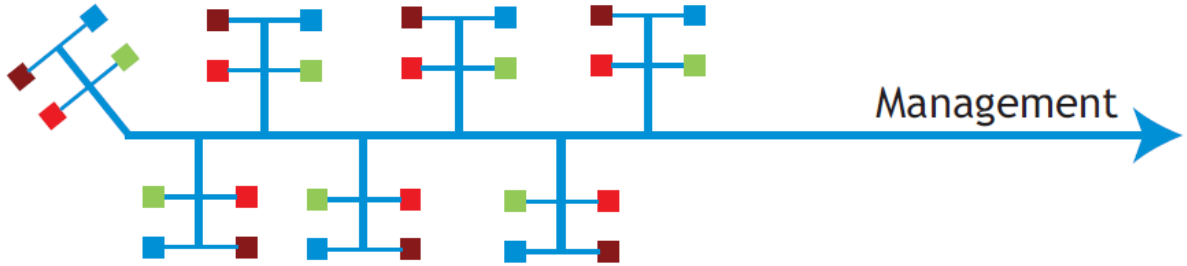
Strande, Linda, et al. "Urban sanitation: new terminology for globally relevant solutions?." *Environmental Science & Technology* 57.42 (2023): 15771-15779.

Terminology: What is faecal sludge?

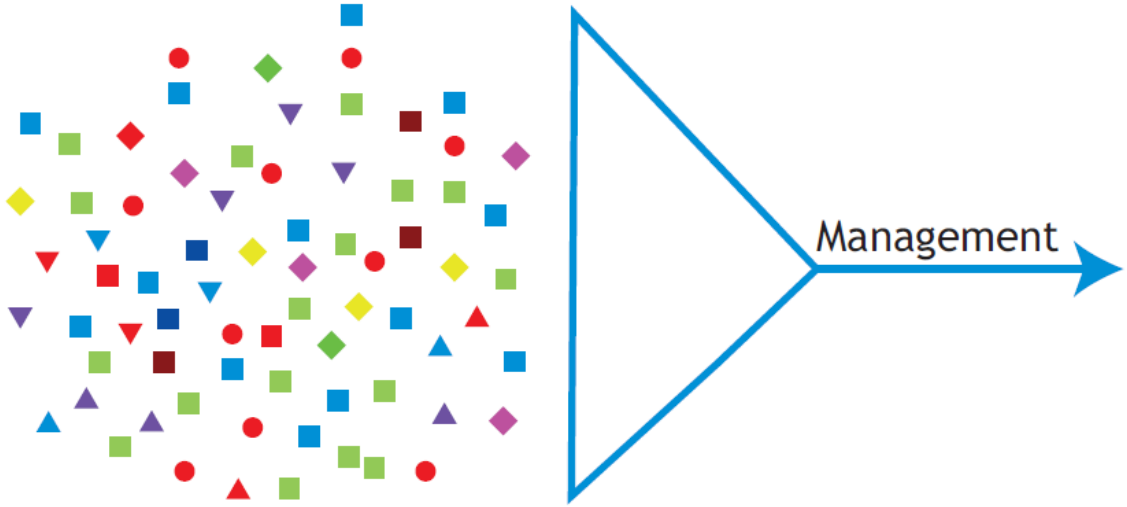


Wastewater versus faecal sludge

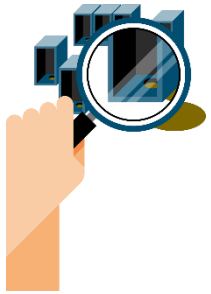
Sewered wastewater



Faecal sludge
(Stored wastewater)



Faecal sludge characteristics are very variable!



Faecal Sludge Management (FSM) Service Chain

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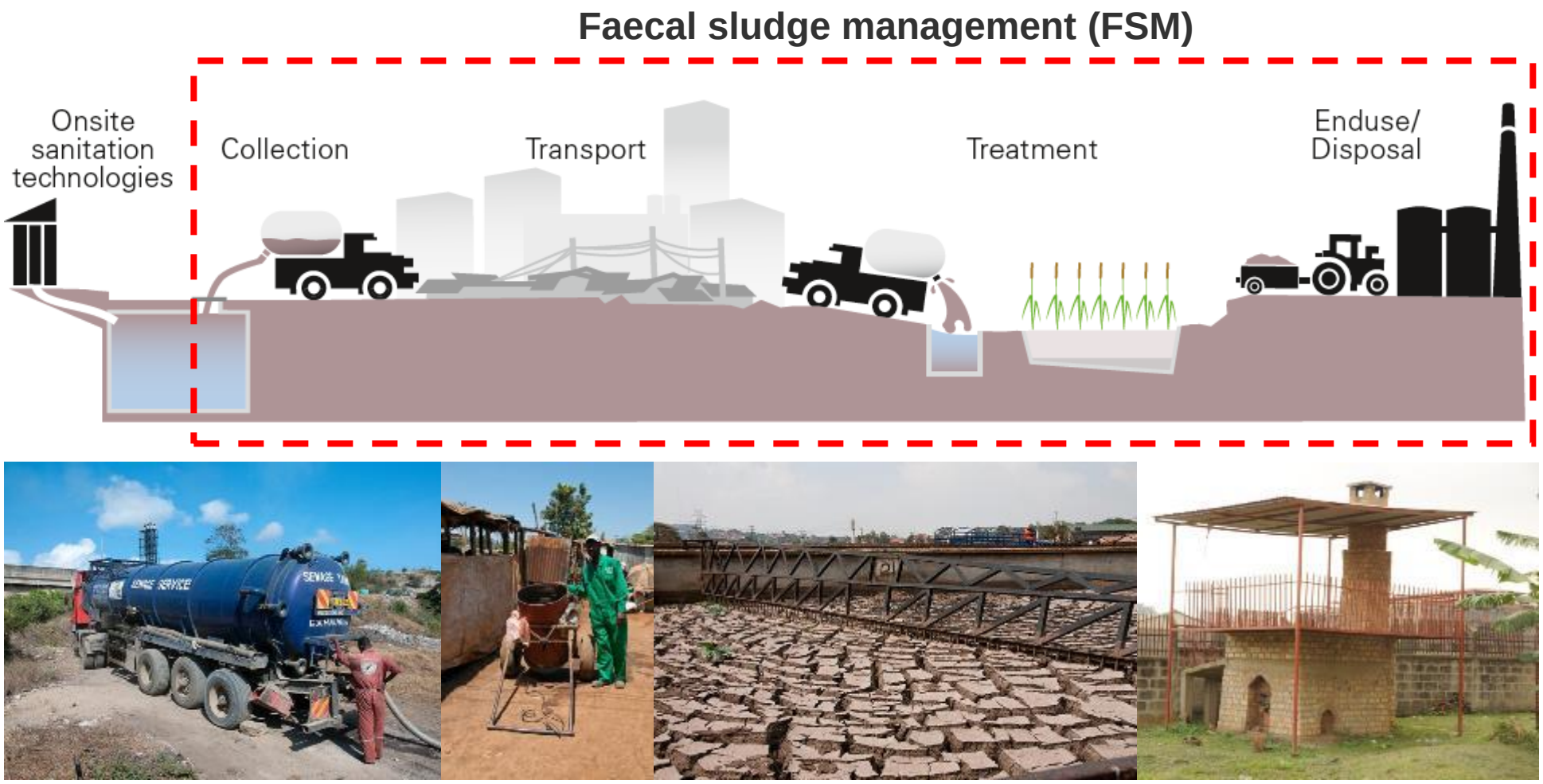
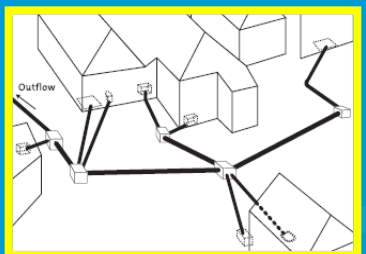
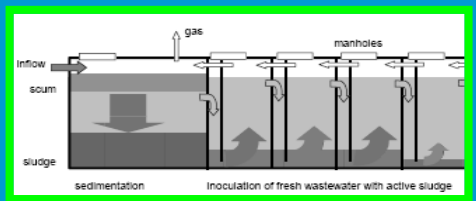


What happens when decentralized systems are not managed properly?

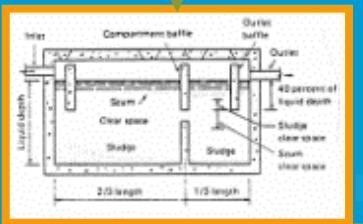
User Interface



Conveyance



(Semi-) Centralized Treatment



Collection and Storage

Use/Disposal

Untreated wastewater entering the environment is a global problem

The New York Times

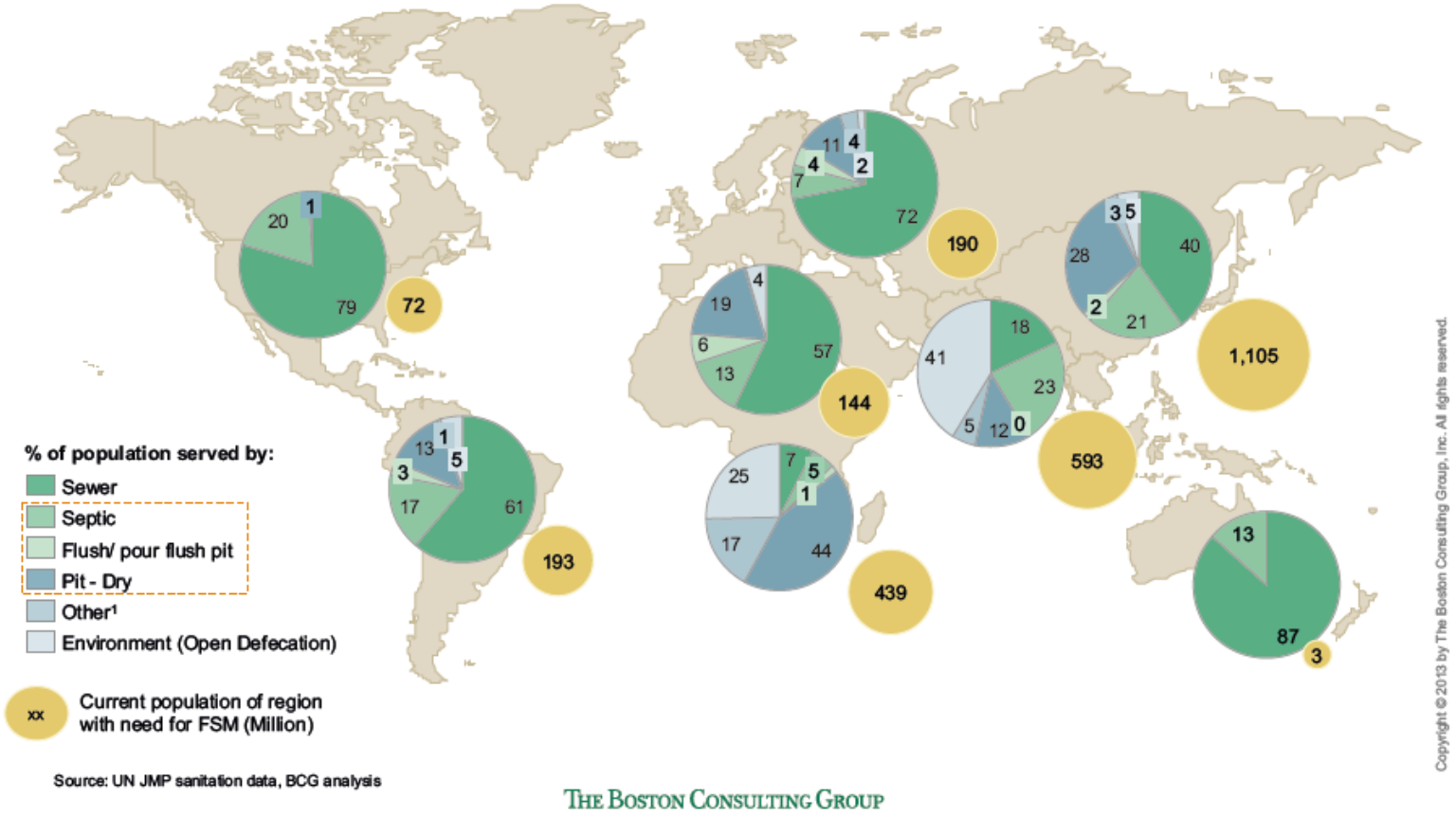
A Toxic Stew on Cape Cod: Human Waste and Warming Water

Climate change is contributing to electric-green algae blooms. Massachusetts wants a cleanup of the antiquated septic systems feeding the mess, but it could cost billions.

Photo: Linda Strande

Global relevance?

- Sanitation needs of 2.7 billion people worldwide are met by **non-sewered sanitation systems**.
- Majority of non-sewered sanitation systems are not safely managed (61−72% in Africa, 62−68% in LAC, 100% in SE Asia, and 5−100% in W. Pacific)



Challenges pushing towards decentralized solutions:

- Rapid urbanization & densification
- Expenses
- Resource Recovery

Cairns-Smith et al., 2014; Berendes et al., 2017

Treatment Technologies

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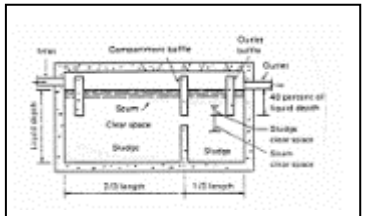
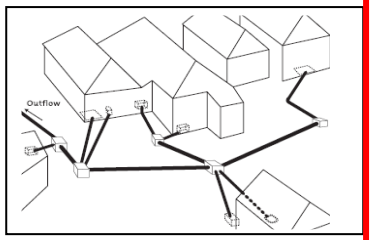
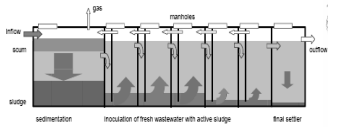
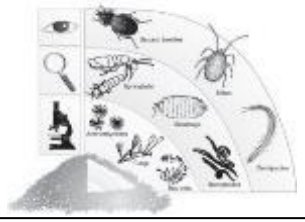
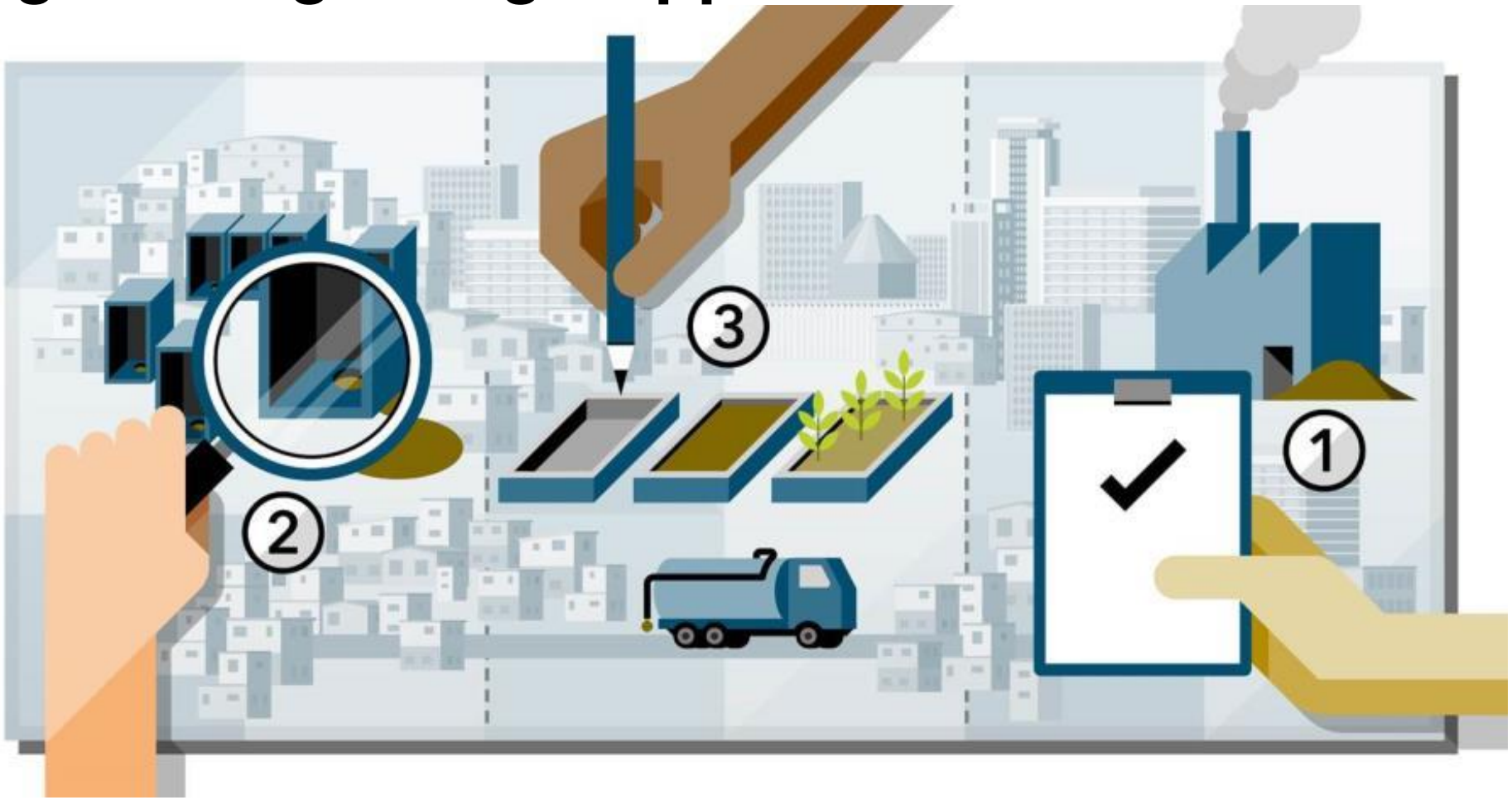
User Interface	Storage	Conveyance	(Semi-) Centralised Treatment	Use and / or Disposal
				
○ Dry Toilet ○ Urine Diverting Dry Toilet (UDDT) ○ Urinal ○ Pour Flush Toilet ○ Cistern Flush Toilet ○ Urine Diverting Flush Toilet	○ Urine Storage Tank / Container ○ Single Pit ○ Single Ventilated Improved Pit (VIP) ○ Double Ventilated Improved Pit (VIP) ○ Fossa Alterna ○ Twin Pits for Pour Flush ○ Dehydr. Vaults ○ Composting Chamber ○ Septic Tank ○ Etc.	○ Jerry can / Tank ○ Human-Powered Emptying and Transport ○ Motorized Emptying and Transport ○ Simplified Sewer ○ Solids-Free Sewer ○ Conventional Gravity Sewer ○ Transfer Station (Holding Tank)	○ Anaerobic Baffled Reactor (ABR) ○ Anaerobic Filter ○ Waste Stabilization Ponds ○ Aerated Pond ○ Constructed Wetland ○ Trickling Filter ○ Activated Sludge ○ Drying Beds ○ Co-composting ○ Biogas Reactor ○ Etc.	○ Fill and Cover / Arborloo ○ Applic. of Urine ○ Application of Dehydr. Faeces / Compost/Sludge ○ Irrigation ○ Soak Pit ○ Leach Field ○ Fish Pond ○ Floating Plant Pond ○ Water Disposal / Groundwater Recharge ○ Surface Disposal ○ Biogas Combust.

Engineering Design Approach

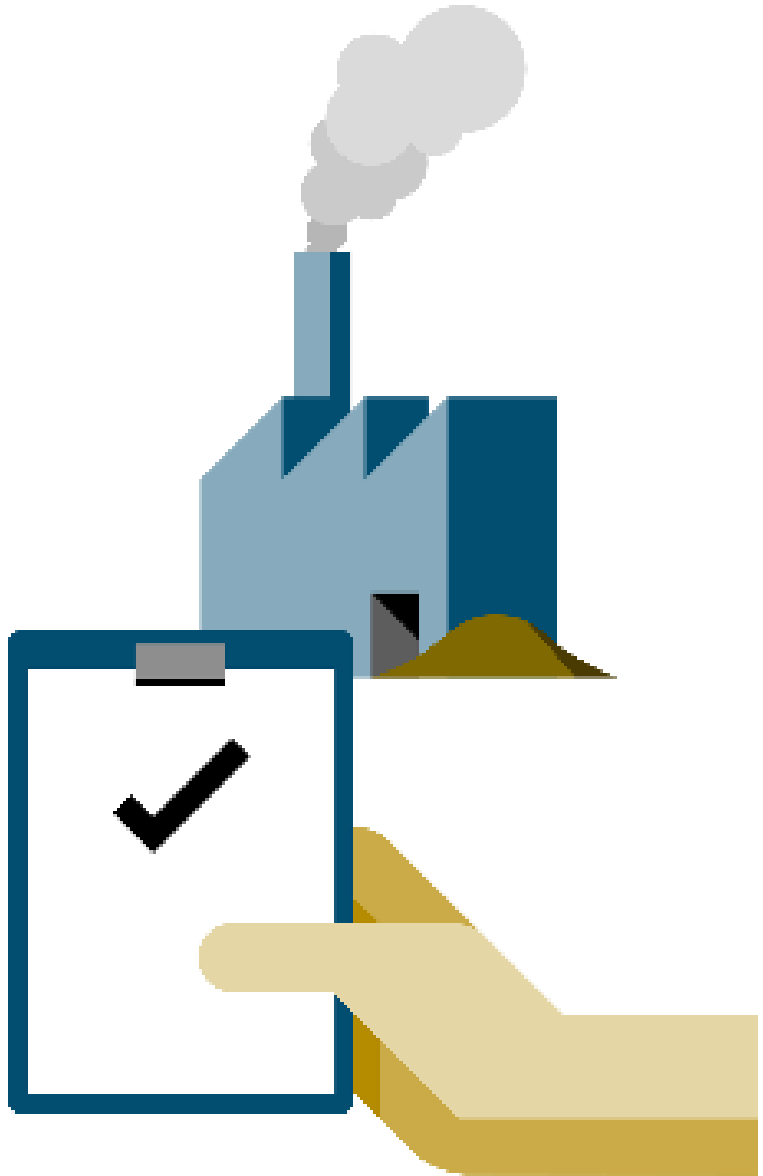


Step 1: Define treatment objectives and resource recovery or disposal
Step 2: Quantify and characterize influent faecal sludge
Step 3: Design of treatment technology for resource recovery

Engineering Design Approach

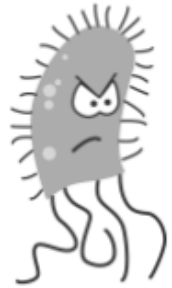
Step 1 - Define:

- **Treatment objectives**
- **Resource recovery or disposal**



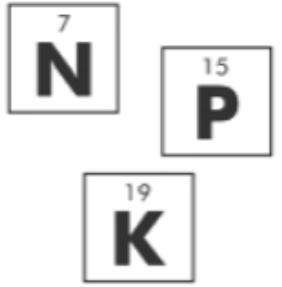
Treatment Objectives Activity

PATHOGENS



ORGANIC MATERIAL

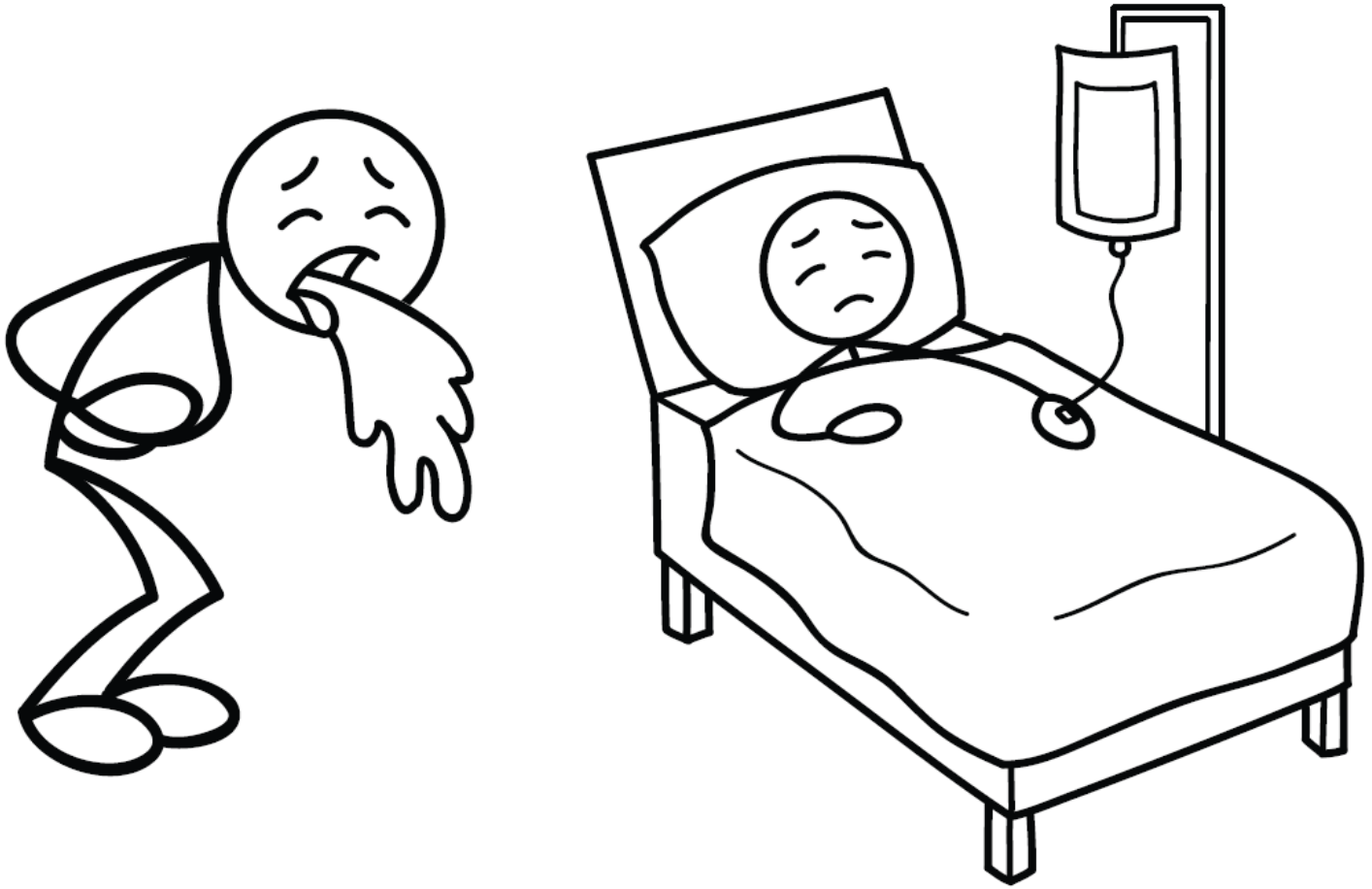
NUTRIENTS



WATER

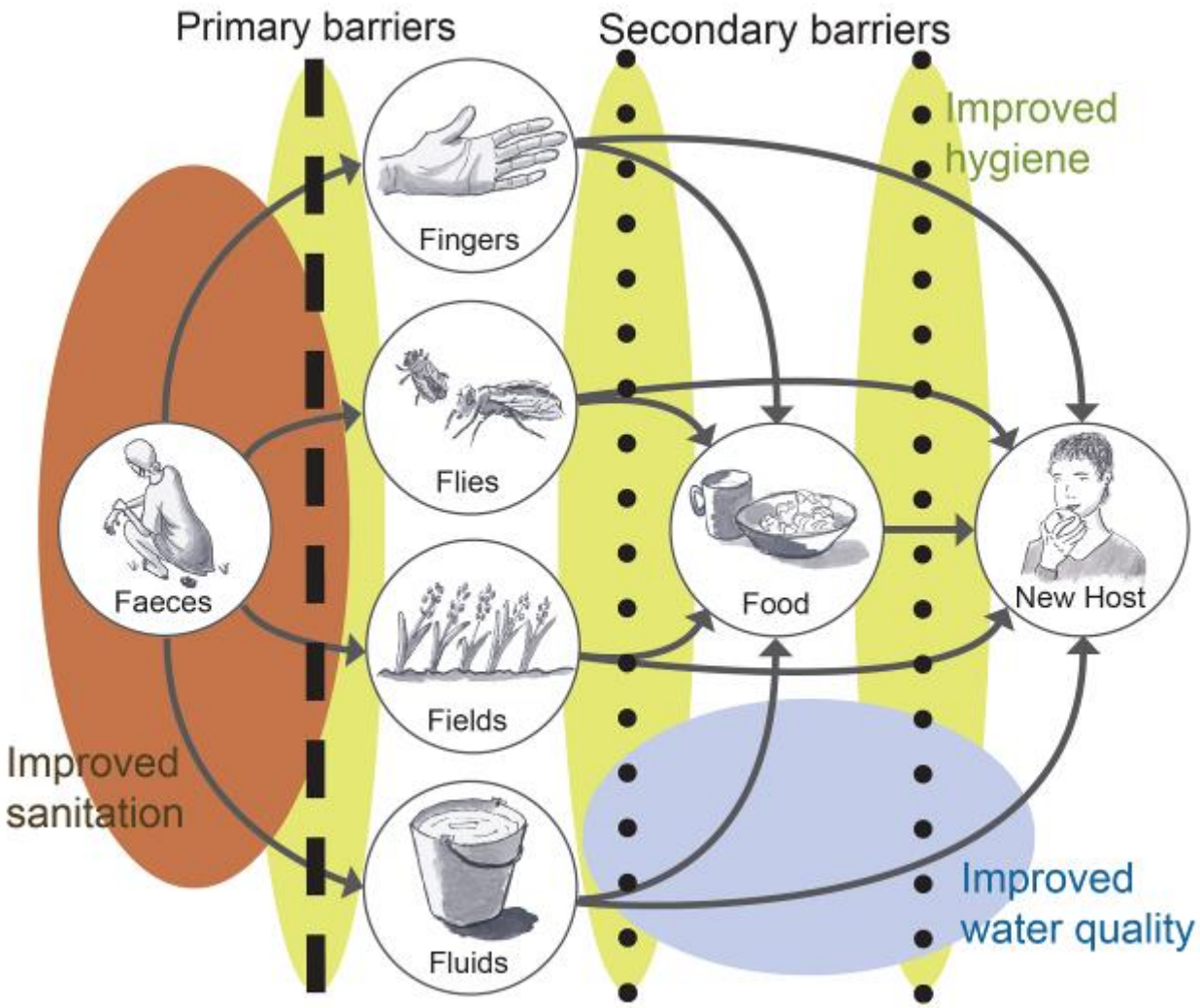
Treatment objectives

What component will make people sick?



Treatment objectives

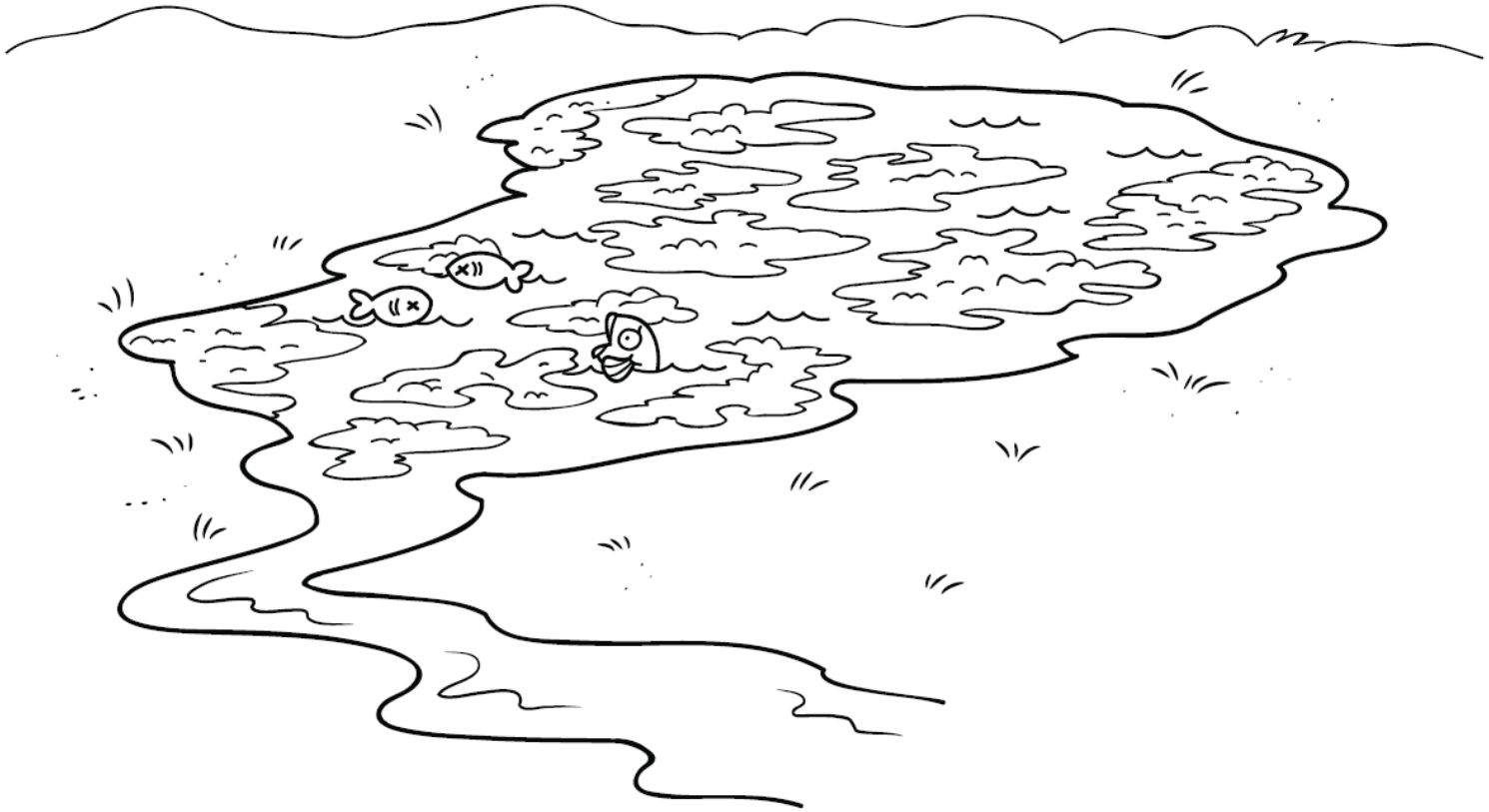
Transmission pathways of pathogens



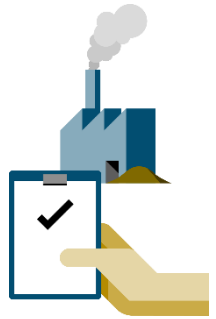
(adapted from WHO 2005)

Treatment objectives

What component can cause eutrophication?



Treatment objectives



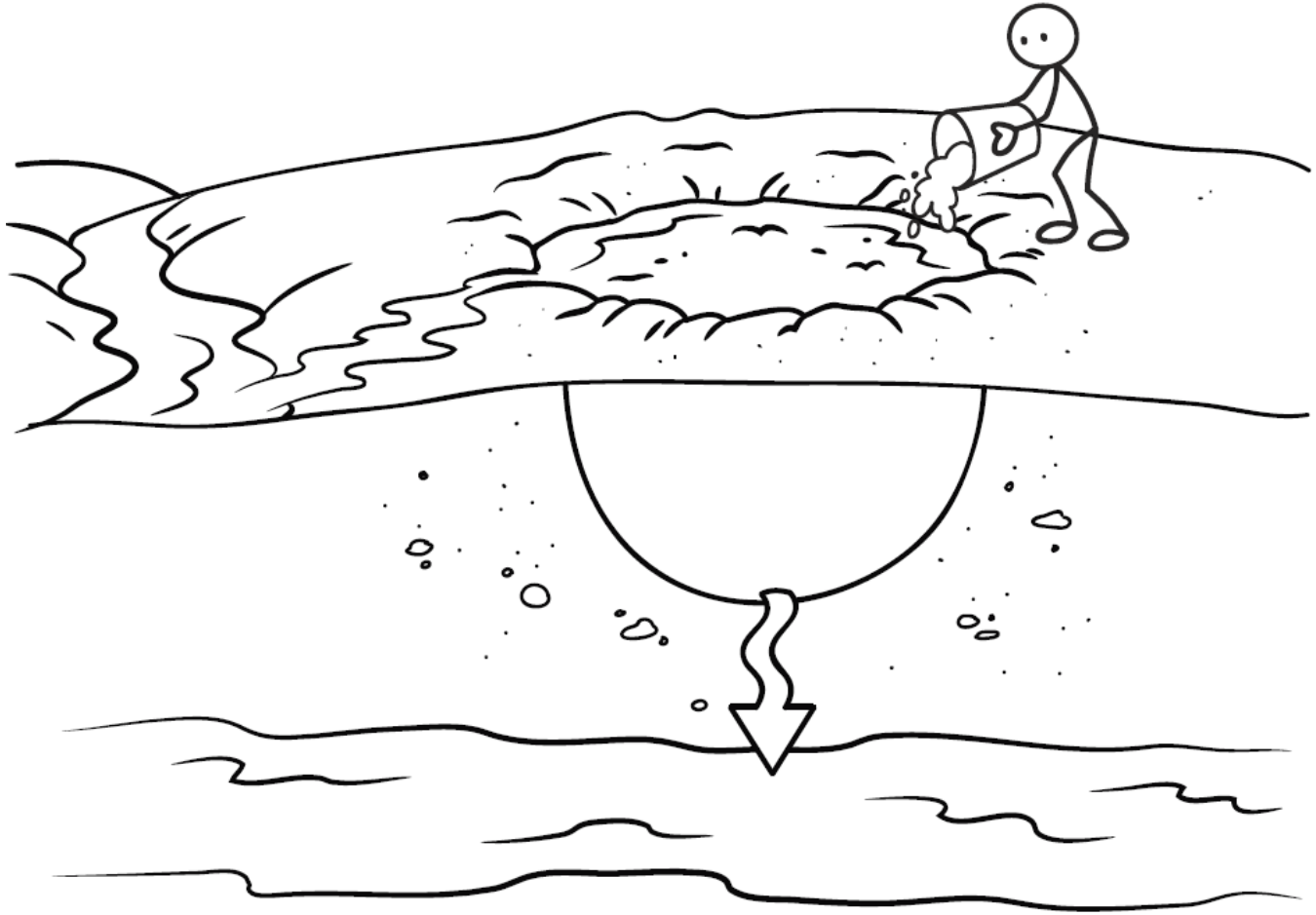
What component would make faecal sludge smell badly?

Treatment objectives

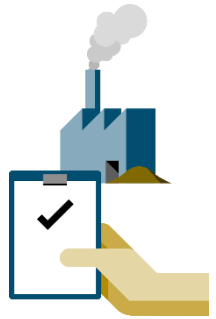
What component makes faecal sludge heavy and voluminous to manage?

Treatment objectives

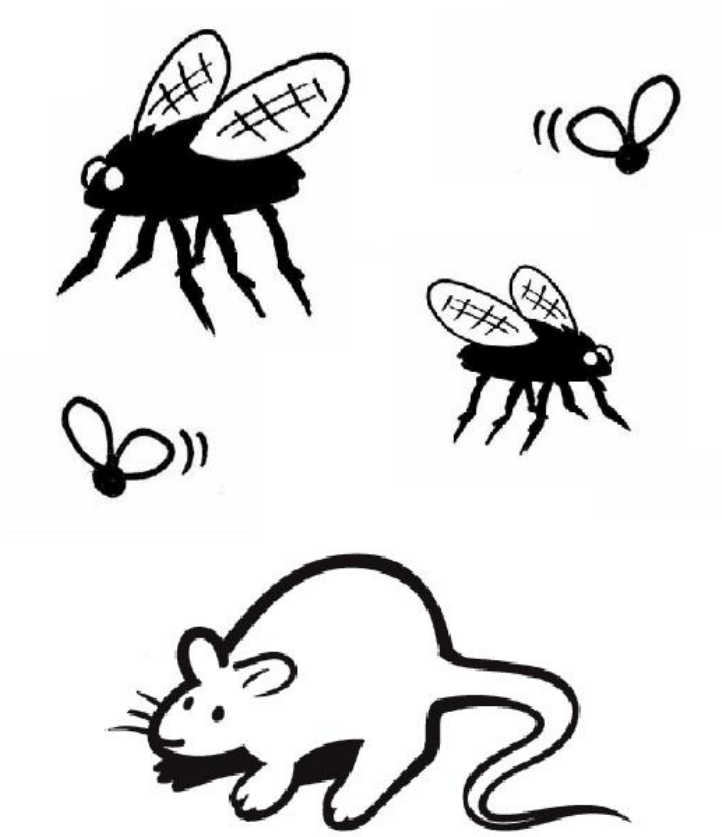
What component will increase the risk of water contamination?



Treatment objectives

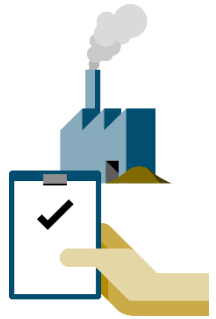


What component would attract vectors such as flies and rats?



Treatment objectives

1. Pathogen inactivation
2. Stabilization
3. Nutrient management
4. Dewatering

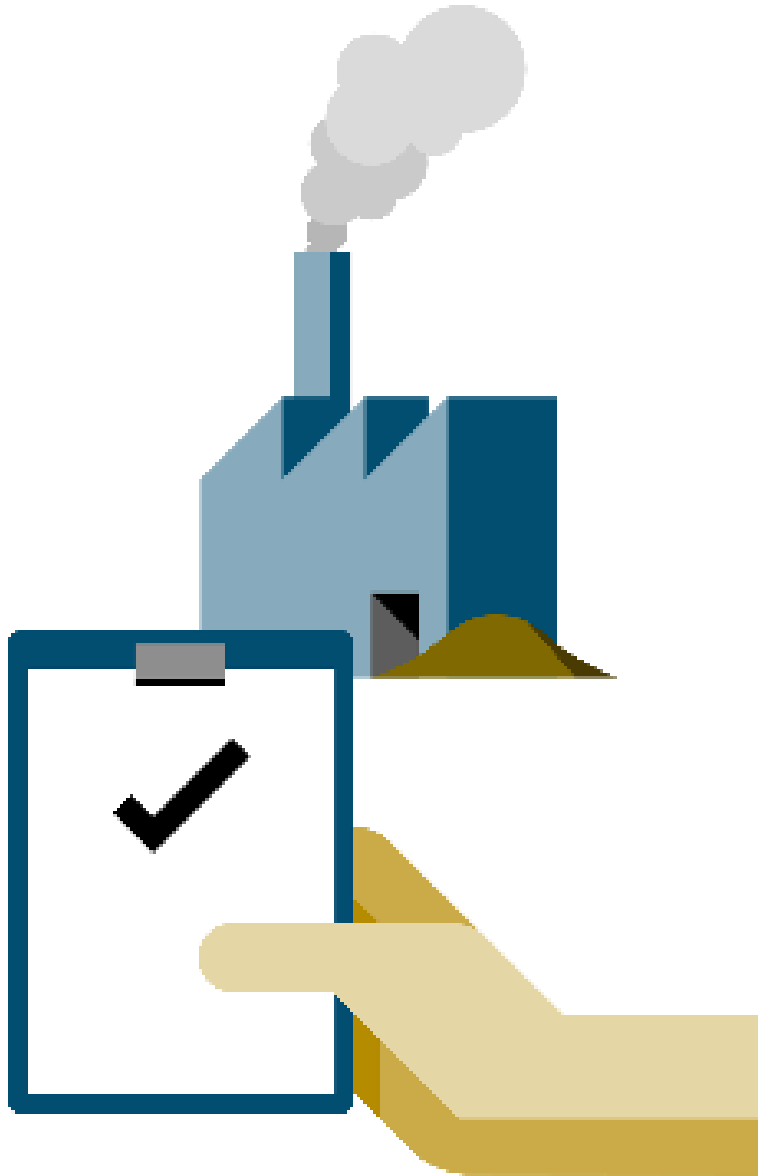


The ultimate goal of faecal sludge management: protection of public and environmental health

Engineering Design Approach

Step 1 - Define:

- Treatment objectives
- Resource recovery or disposal



Treatment technologies

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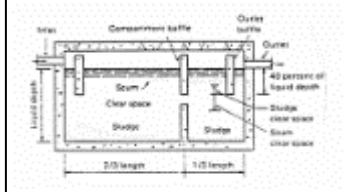
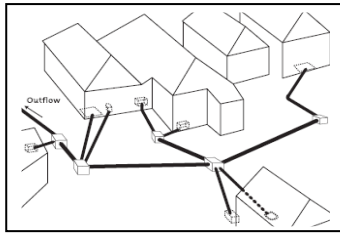
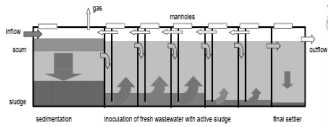
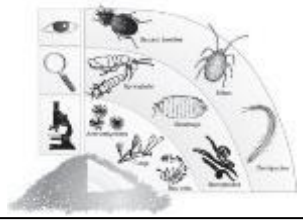
User Interface	Storage	Conveyance	(Semi-) Centralised Treatment	Use and / or Disposal
				
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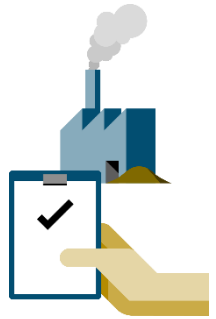
Do you know any products that can be made from faecal sludge?

Designing for end-use / resource recovery

Factors influencing product production:

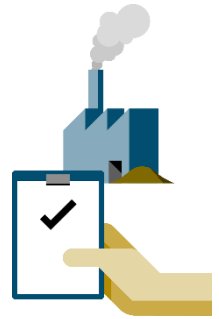
- Type, quality and costs of input material available
- Socio-cultural acceptance
- Local demands
- Legal aspects
- Availability of materials and equipment
- Availability of space
- Soil and groundwater characteristics
- Local knowledge and capacity



Designing for end-use / resource recovery

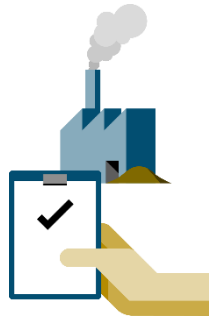
Challenges

- No effluent standards / standards not enforced
- Revenues from faecal sludge treatment products could offset faecal sludge treatment costs
- Market for end products could help ensure sustainable operation
- Markets for faecal sludge treatment end products are undeveloped



Resource recovery options for faecal sludge

Resource	Treatment product	Product type
Energy	Solid fuel	Pellets, briquettes, powder
Energy	Gas fuel	Biogas
Energy	Electricity	Conversion of biogas, or gasification of solid fuel
Food	Protein	Black soldier flies, fish meal
Food	Animal fodder	Plants from drying beds, dried aquaculture plants
Food	Fish	Grown on effluent from faecal sludge treatment
Material	Building materials	Additive to bricks, road construction
Nutrients	Soil conditioner[1]	Compost, pellets, digestate, black soldier fly residual
Nutrients	Fertilizer[2]	Pellets, powder
Nutrients	Soil conditioner[3]	Untreated sludge, dewatered sludge from drying beds
Water, nutrients	Reclaimed water	Effluent from faecal sludge treatment

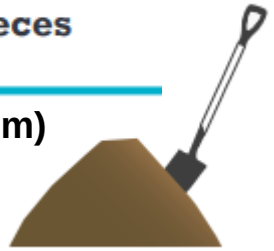


Trade-off of between energy potential and nutrient recovery

Resource recovery – Soil conditioner

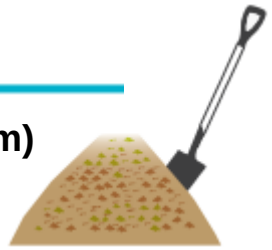
R.8 Dried Faeces

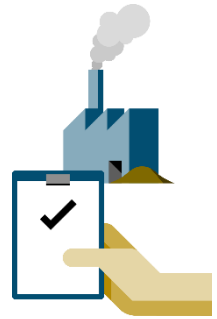
(D.3 in Compendium)



R.11 Compost

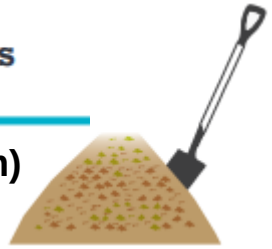
(D.4 in Compendium)





R.9 Pit Humus

(D.4 in Compendium)



R.12 Ash from Sludge

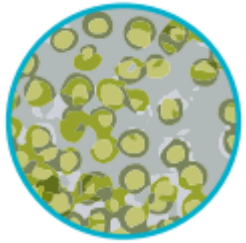
R.14 Nutrient-Enriched Filter Material

R.10 Dewatered Sludge

(D.5 in Compendium)

R.13 Biochar

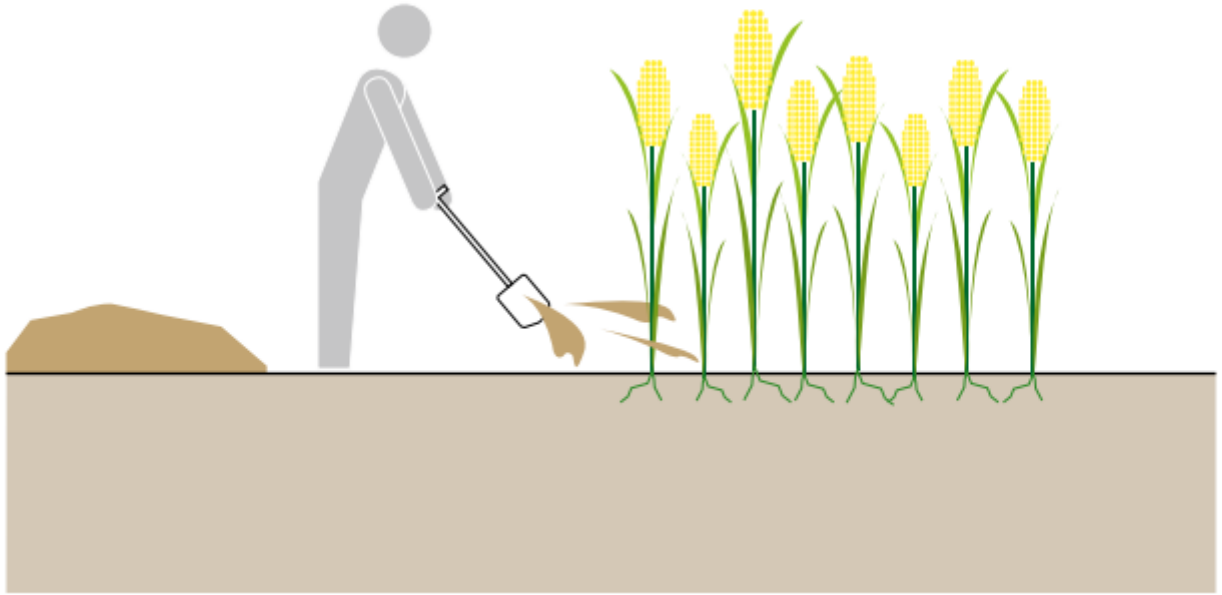
R.15 Algae



Resource recovery – Soil conditioner

D.4	Application of Pit Humus and Compost	Applicable to: Systems 2, 3

Application Level:	Management Level:	Inputs: Pit Humus, Compost
★★ Household ★★ Neighbourhood ★ City	★★ Household ★★ Shared ★ Public	Outputs: Biomass



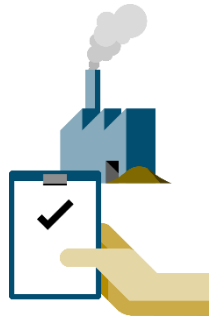
Advantages:

+ Improves structure of soil
+ Reduces chemical fertilizer needs
+ Low costs
+ Low risk of pathogen transmission

Disadvantages

– Long maturation times
– Low social acceptance in some areas

Resource recovery – Solid fuels



End products to be used as fuels:

Dried faecal sludge

Briquettes/pellets

Charcoal / Biochar

Dewatering and drying is key!

Resource recovery – Biochar

R.13 Biochar

Intended use:	Application level:	Treatment technologies:
Soil conditioner, Water purification, Energy production	* Household ** City ** Regional * Global	T.27 Carbonisation
Technical maturity: High		

Compiled by: *Swedish University of Agricultural Sciences (SLU)*

Advantages:

+ Can be used as a solid fuel (char) or soil conditioner (biochar)
+ Improves soil quality & structure
+ Carbon-neutral or carbon-negative

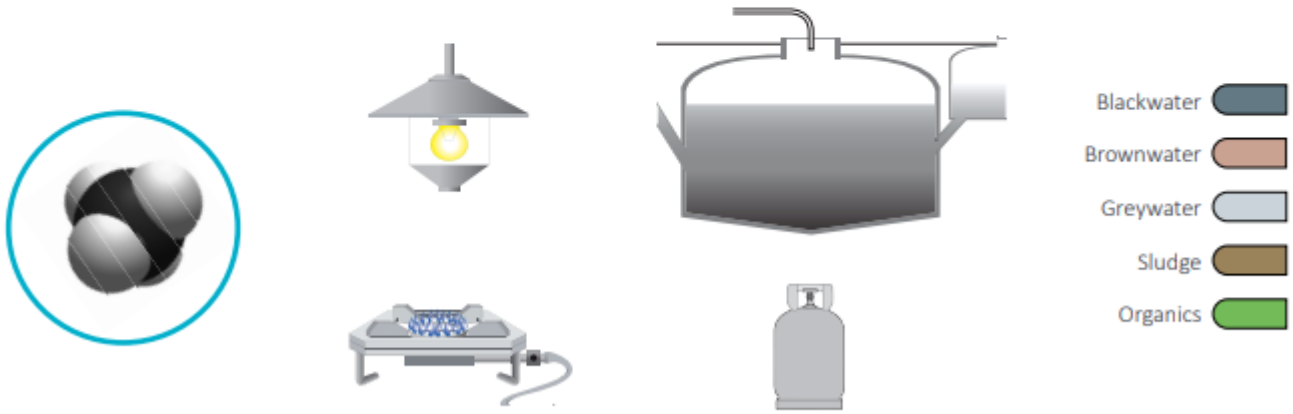
Disadvantages

– Dust during soil application
– Sorption of pesticides and herbicides
– Nitrogen loss

Resource recovery – Gas fuel

R.21 Biogas (D.13 in Compendium)

Intended use:	Application level:	Treatment technologies:
Heat, Electricity, Vehicle fuel	** Household ** City * Regional Global	(S.12 Biogas Reactor, T.11 Upflow Anaerobic Sludge Blanket Rector UASB, T.17 Biogas Reactor)
Technical maturity: High		



Compiled by: *Tilley et al. (2014) and Swedish University of Agricultural Sciences (SLU)*

Advantages:

+ Low-cost energy source from renewable ressources
+ Replaces fuel wood for cooking
+ Few operational skills and little maintenance required

Disadvantages

– Low storage time, low energy density
– Leaked / unburned methane is a GHG emission

Resource recovery – Reclaimed water

R.3 Sanitised Blackwater

Intended use:	Application level:	Treatment technologies:
Liquid fertiliser, Agricultural irrigation	** Household ** City ** Regional * Global	T.32 Ammonia Sanitisation/Urea Treatment, T.33 Lime Sanitisation
Technical maturity: High		

Compiled by: *Swedish University of Agricultural Sciences (SLU)*

Advantages:

+ Reduces depletion of groundwater and improves availability of drinking water
+ **Reduced the need for fertilizer (*Fertigation*)**
+ Low risk of pathogen transmission if water is properly treated
+ Low capital and operational costs depending on the design

Disadvantages

– Expert design and installation
– Drip irrigation normally required
– Risk of soil contamination
– Risk of groundwater contamination
– Social acceptance is low

Designing for end-use / resource recovery

Other potential resources:

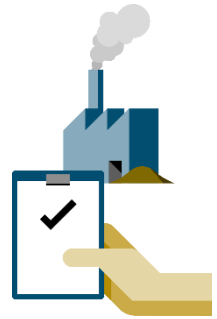
(from Guide to Sanitation Resource Recovery Products and Technologies)

- Urine
  - Stored (R.1)
  - Concentrated (R.2)
  - Dry (R.6)
  - Struvite (R.7)
- Digestate (R.4)
- Macrophytes (R.16)
- Black soldier flies (R. 17)
- Worms (R.18)
- Aquaculture (R.20)

End-uses without resource recovery:

(from Compendium of Sanitation Systems and technologies)

- Soak pit (D.7)
- Leach field (D.8)
- Water discharge (D.11)
- Surface disposal (D.12)



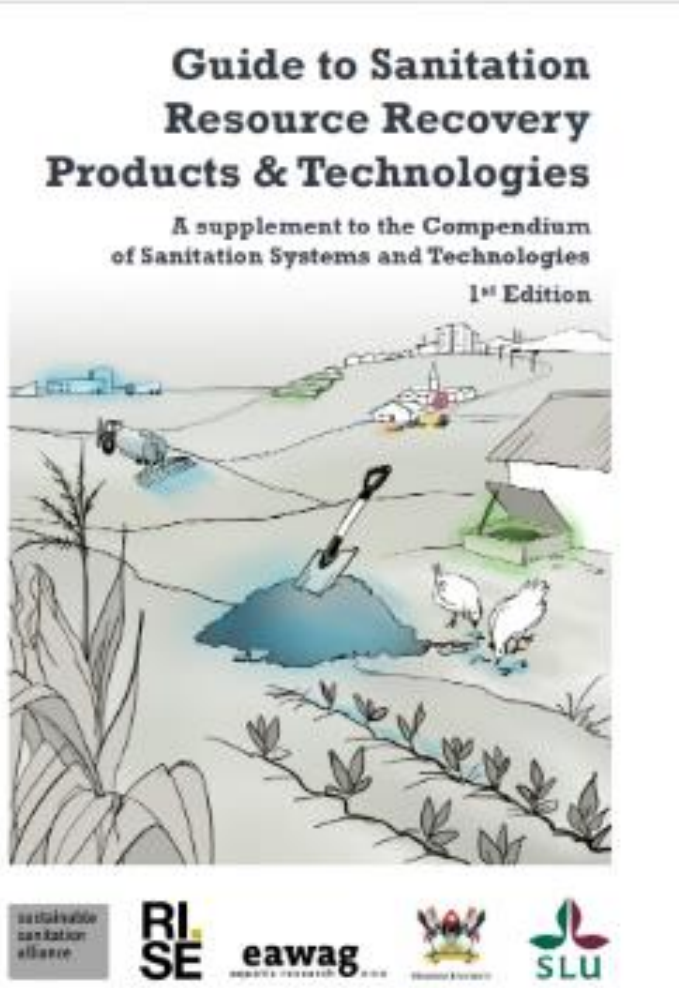
Resource Recovery

Guide to Sanitation Resource Recovery Products & Technologies

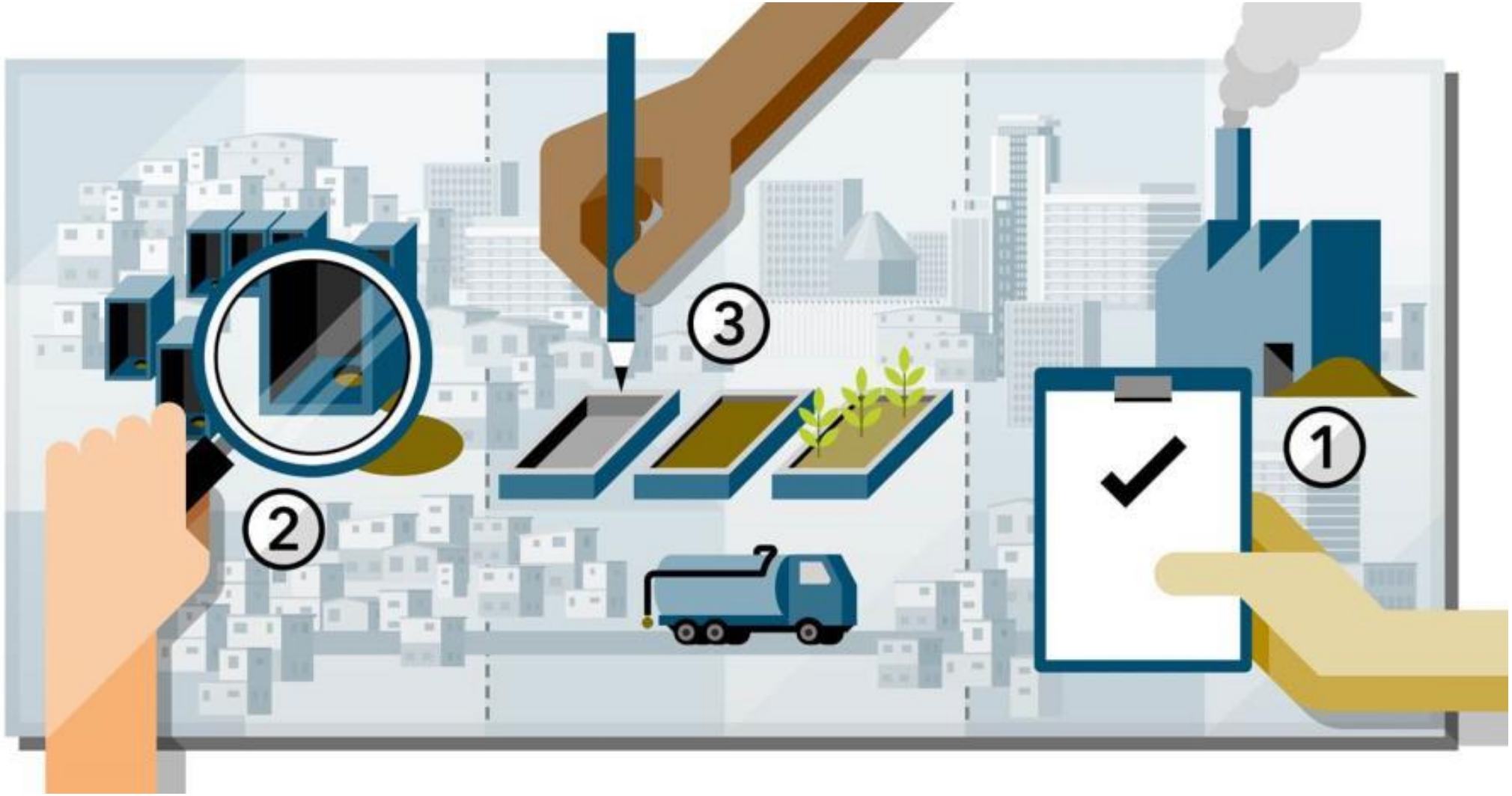
Part 1: Reuse Products

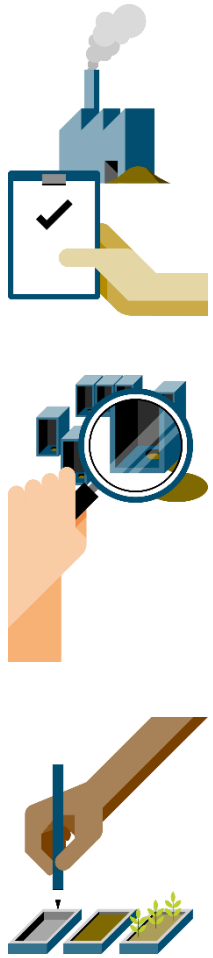
Part 2: Treatment Technologies for Resource Recovery

https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/4008#



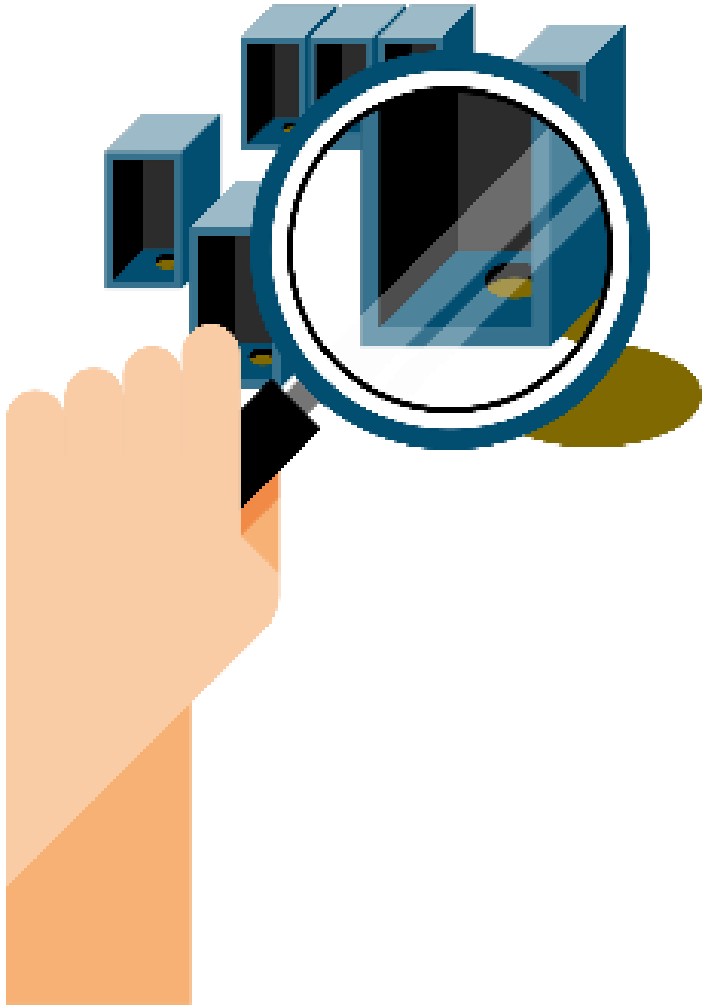
Engineering Design Approach



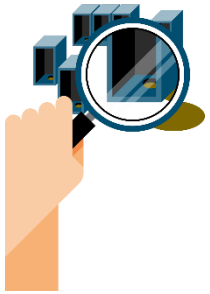


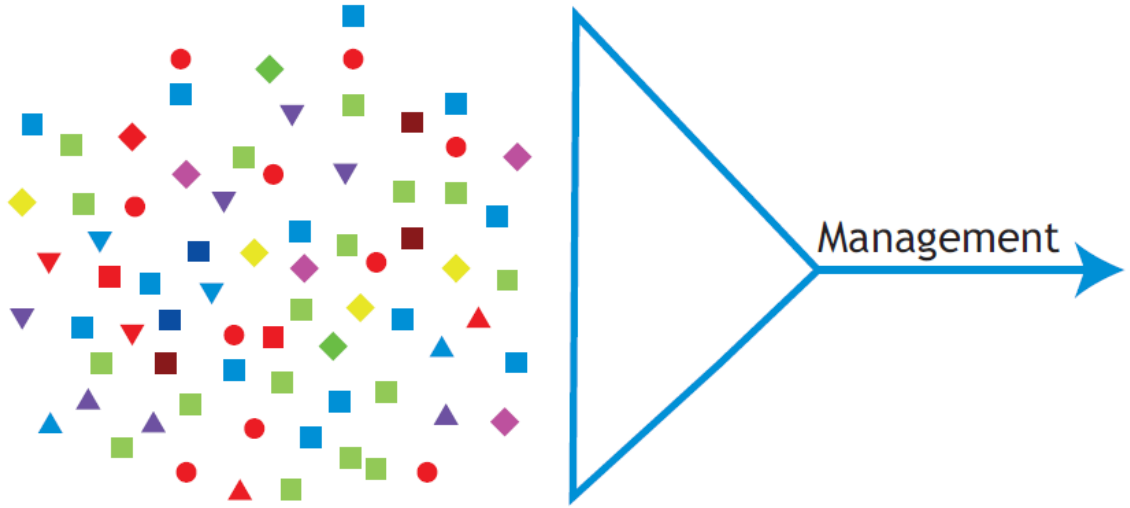
Engineering Design Approach

Step 2: Quantification and characterization of influent sludge



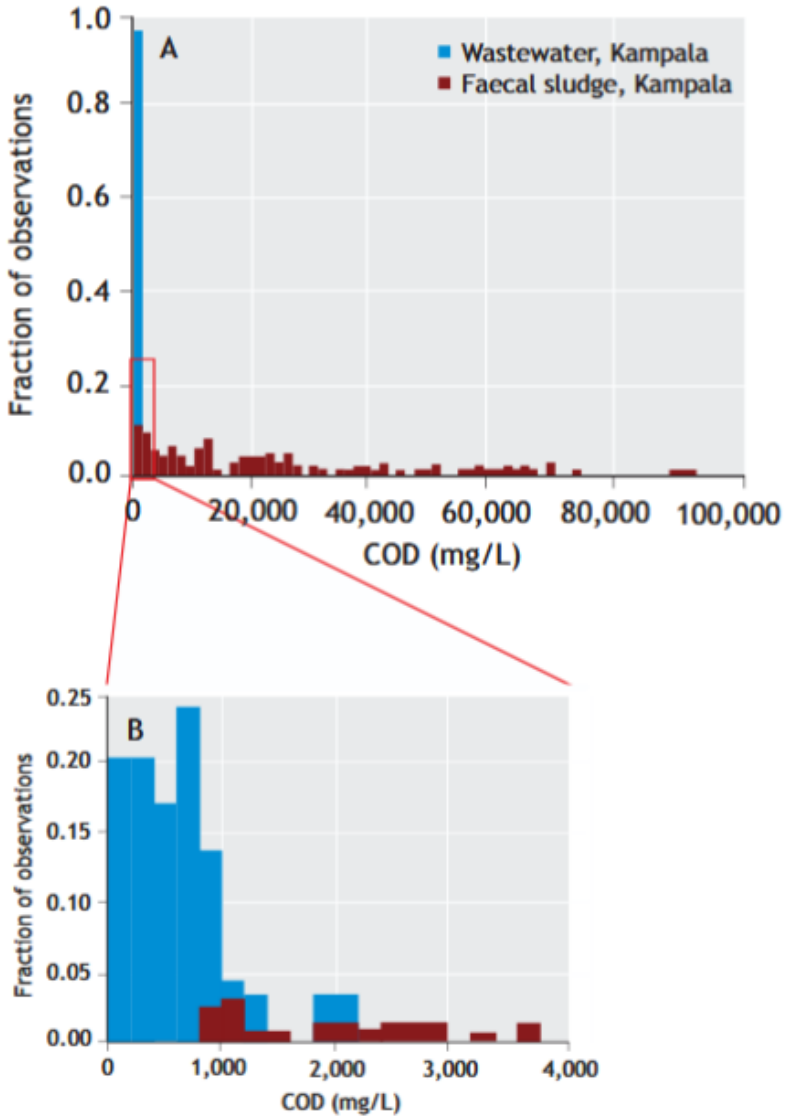
Reminder:
Faecal sludge characteristics are highly variable!

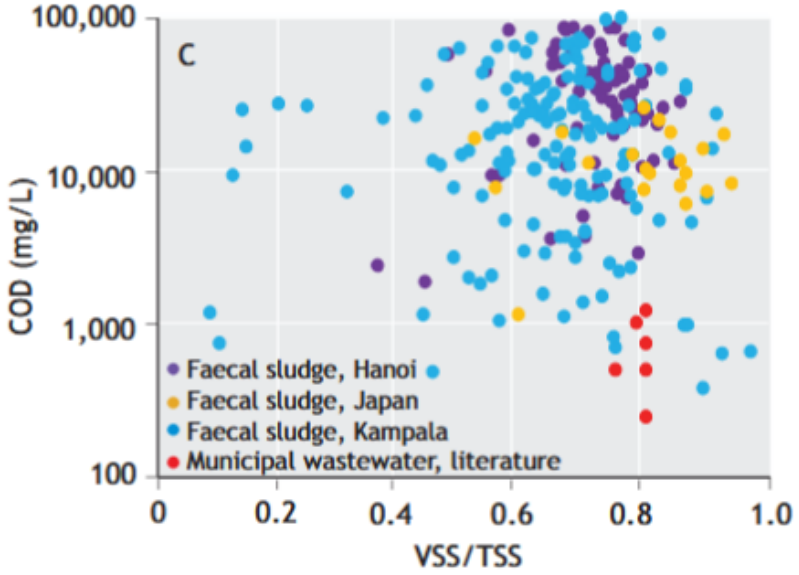




Variability of faecal sludge characteristics

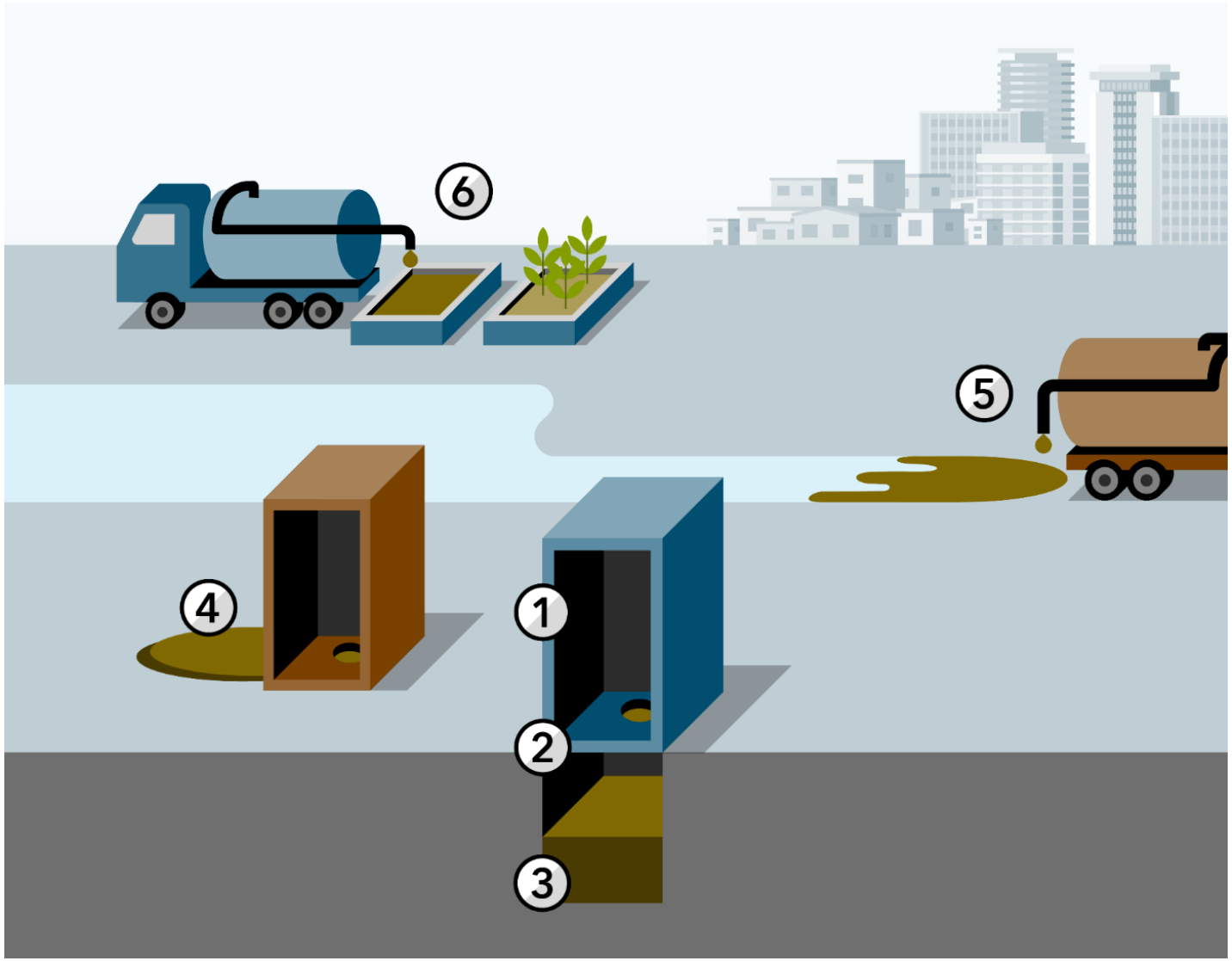
Faecal sludge characteristics (Quality)

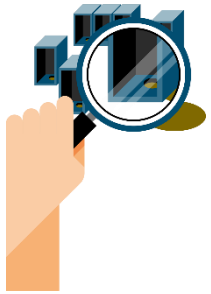




Velkushanova, K., Brdjanovic, D., Koottatep, T., Strande, L., Buckley, C., & Ronteltap, M. (2021). *Methods for faecal sludge analysis*. IWA publishing.

Quantities





1. Excreta produced
2. Faecal sludge produced
3. Faecal sludge accumulated
4. Faecal sludge emptied, but not collected
5. Faecal sludge collected, but not delivered to treatment plant
6. Faecal sludge treated

Resources on Quantities and Qualities (Q&Q)

eawag aquatic research

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

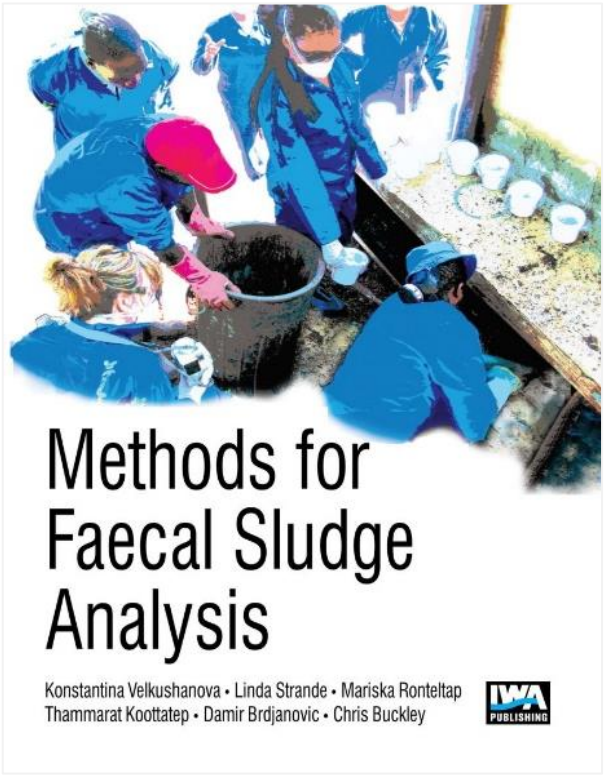
Research article

Methods to reliably estimate faecal sludge quantities and qualities for the design of treatment technologies and management solutions

Linda Strande[a,*], Lars Schoebitz[a], Fabian Bischoff[a], Daniel Ddiba[b], Francis Okello[b], Miriam Englund[a], Barbara J. Ward[a], Charles B. Niwagaba[b]

[a] Eawag: Swiss Federal Institute of Aquatic Science and Technology, Department of Sanitation, Water and Solid Waste for Development (Sandec), Überlandstrasse 133, 8600, Dübendorf, Switzerland

[b] Department of Civil and Environmental Engineering, College of Engineering, Design, Art and Technology (CEDAT), Makerere University, P.O. Box 7062, Kampala, Uganda



Research Paper

Methods for estimating quantities and qualities (Q&Q) of faecal sludge: field evaluation in Sircilla, India

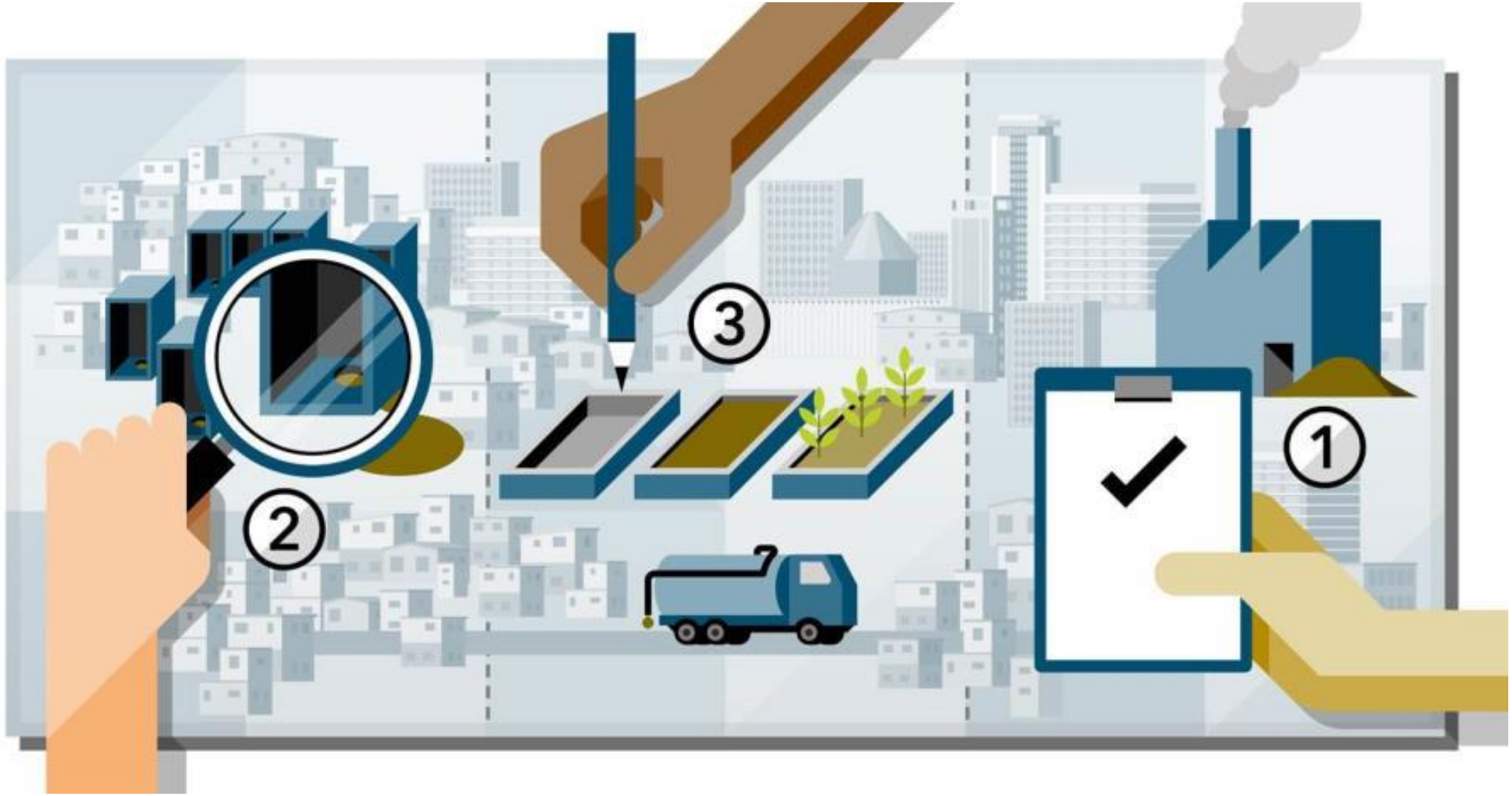
Prerna Prasad, Nienke Andriessen, Anantha Moorthy, Amrita Das, Kayla Coppens, Rohini Pradeep and Linda Strande

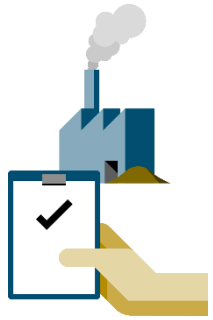
Massive Open Online Course (MOOC)

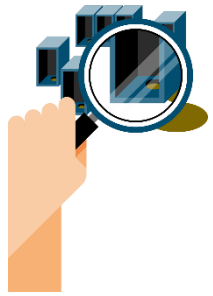
coursera.org/learn/faecalsludge

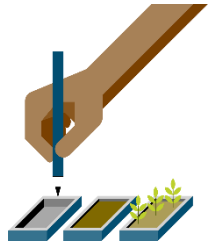
https://www.youtube.com/watch?v=J9GsW2mCKXM

Engineering Design Approach









Design of treatment technology (combination)

Appropriate FS treatment technology (combination)

… to arrive at solution

Step 3: Design treatment

… considering all design variables…

- FS characteristics and quantities
- Existing FS infrastructure and services
- Skills and capacities
- Legal requirements, regulations, norms
- Social acceptance
- Operation and maintencance
- Financial viability
- Etc.

work backwards…

Step 2: Quantify and characterize influent faecal sludge

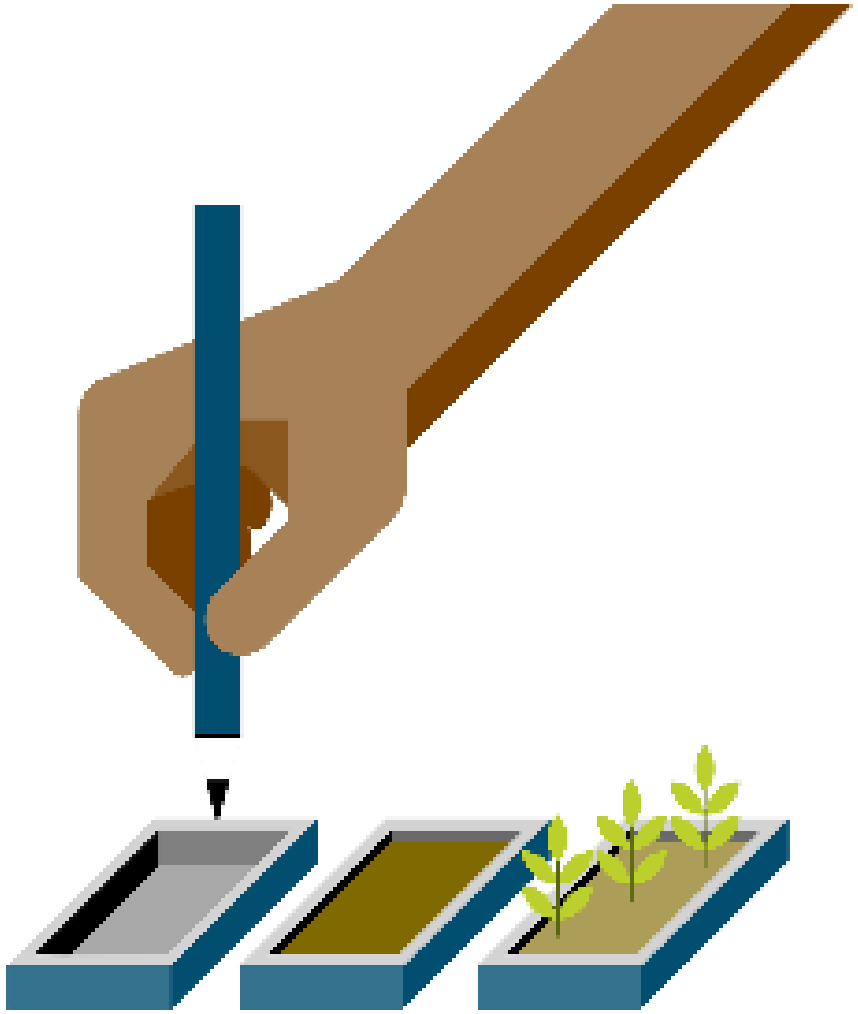
Over-design wastes money and resources

Under-design does not protect human and environmental health

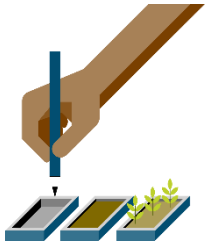
Step 1: Define treatment objectives and resource

Engineering Design Approach

3. Design of treatment technology for resource recovery



Treatment technologies



Pre-treatment

example: removal of oil, grease, sand or trash

Primary treatment: solid-liquid separation (dewatering)

example: a settling-thickening tank

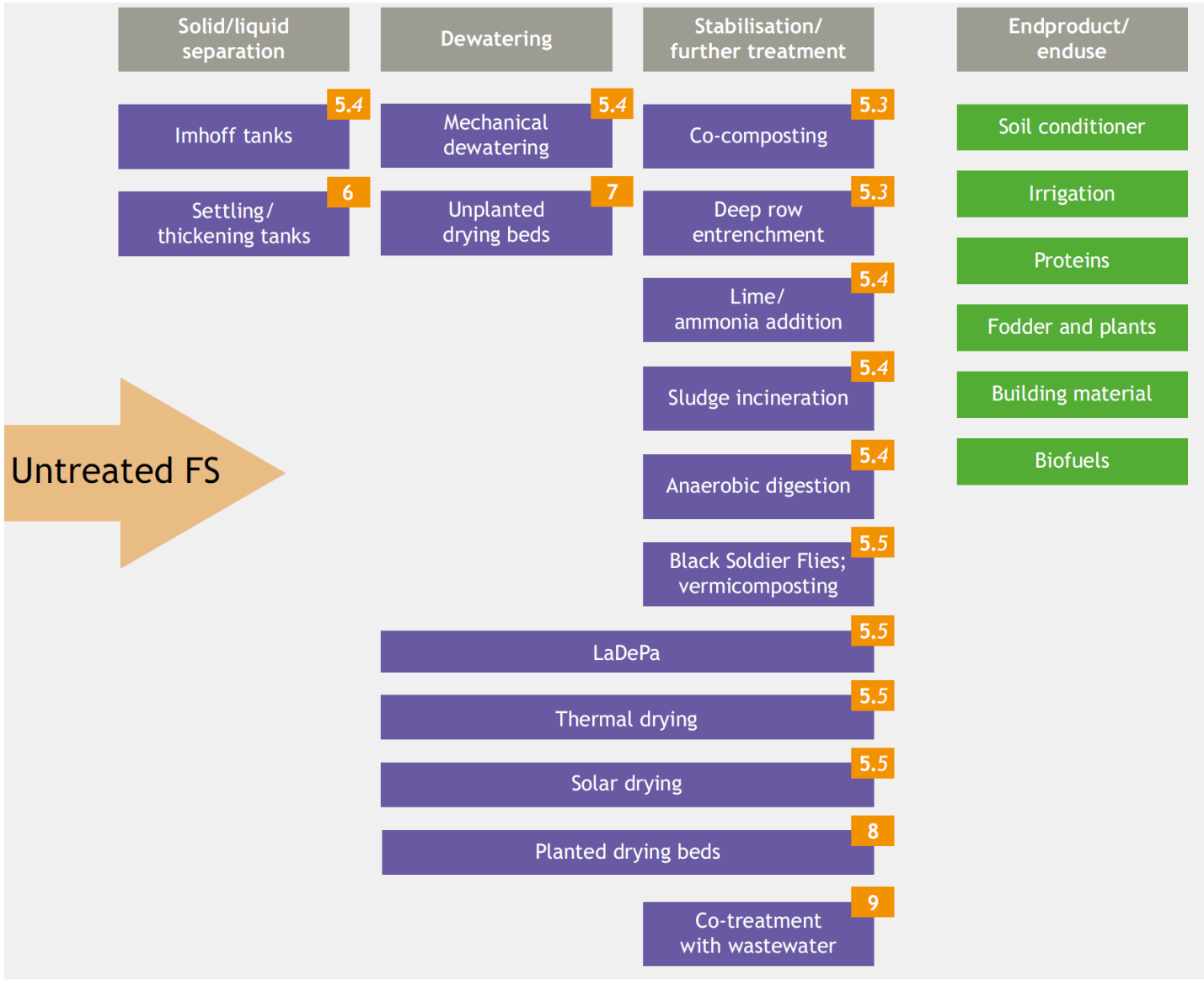
Secondary treatment: biological removal of organic matter, nutrients and remaining suspended solids

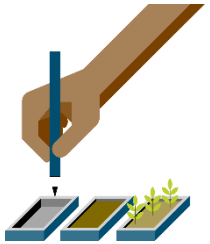
example: anaerobic baffled reactor (ABR), waste stabilization pond (WSP)

Post-treatment or tertiary treatment: final polishing

example: removal of remaining pathogens, nutrients or micropollutants

Treatment technologies



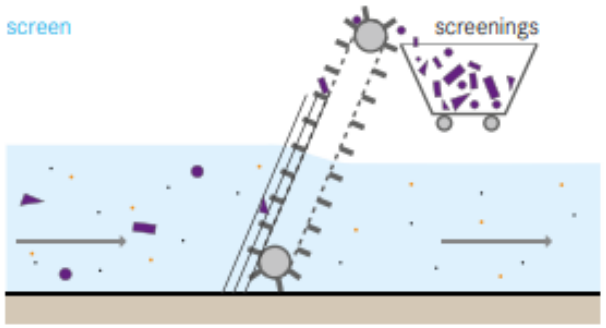


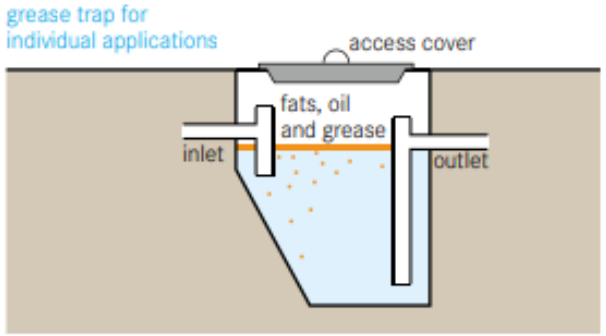
In general, often need several technologies in a particular order to effectively treat faecal sludge.

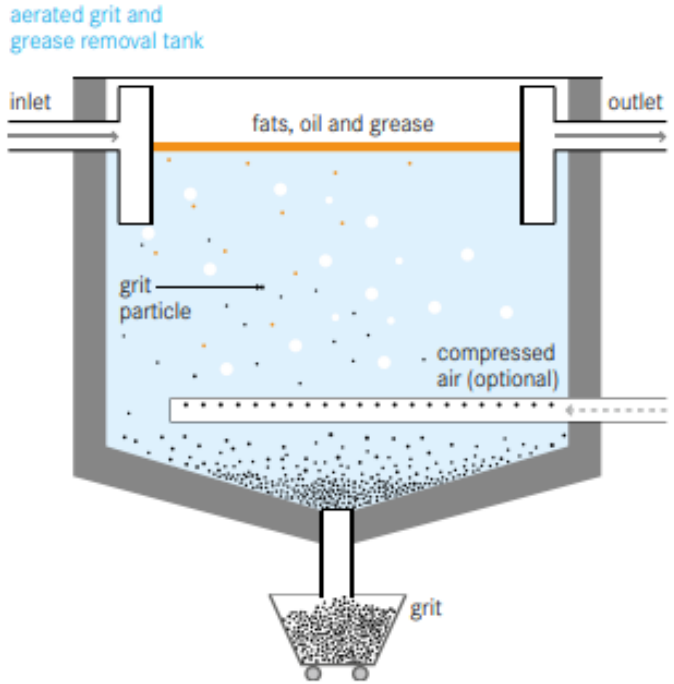
Pre-treatment

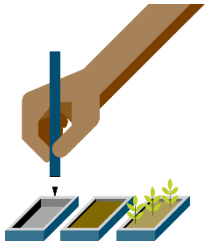
PRE **Pre-Treatment Technologies** | Applicable to: **Systems 1, 6-9**

Application Level:	Management Level:	Inputs: Blackwater, Brownwater, Greywater, Sludge
★ Household	★ Household	Outputs: Blackwater, Brownwater, Greywater, Sludge, Pre-Treatment Products
★★ Neighbourhood	★ Shared	
★★ City	★★ Public	









Advantages:

+ Relatively low capital and operating costs
+ Reduced risk of impairing subsequent Conveyance and/or Treatment technologies
+ Higher lifetime and durability of sanitation hardware

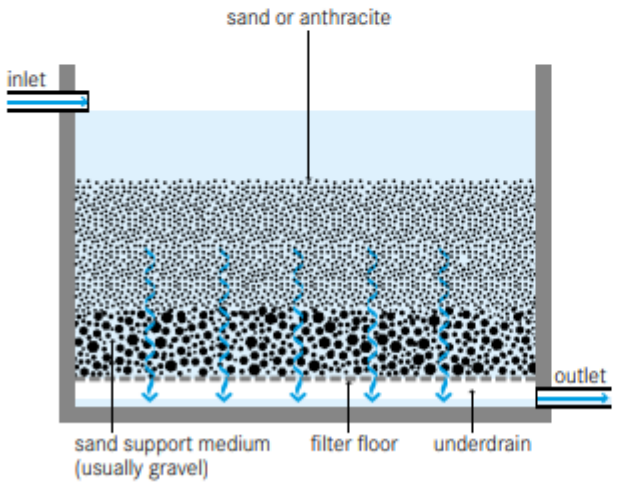
Disadvantages

- Frequent maintenance required
- The removal of solids and grease is not pleasant

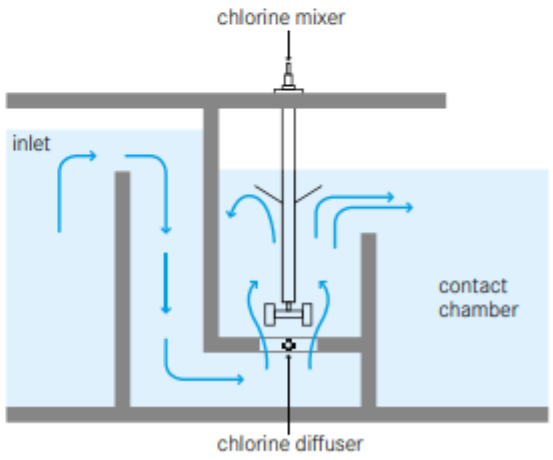
Post-treatment or tertiary treatment

POST **Tertiary Filtration and Disinfection** | Applicable to: **Systems 1, 6-9**

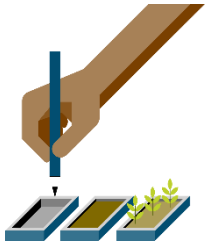
Application Level:	Management Level:	Inputs: Effluent
Household Neighbourhood City	Household Shared Public	Outputs: Effluent



tertiary filtration (e.g., depth filtration)



disinfection (e.g., chlorination)

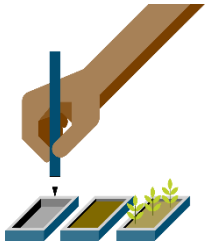


Advantages:

+ Additional removal of pathogens and/or chemical contaminants
+ Allows for direct reuse of treated wastewater

Disadvantages

- Skills, Technology, spare parts and materials may not be locally available
- High capital and operating costs
- May require constant source of electricity or chemicals
- Continuous monitoring
- Filter materials need regular maintenance
- Chlorination / Ozonation can form toxic by-products



Pre-treatment

example: removal of oil, grease, sand or trash

Primary treatment: solid-liquid separation (dewatering)

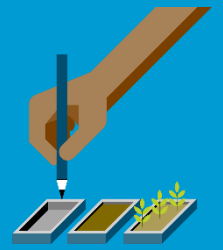
example: a settling-thickening tank

Secondary treatment: biological removal of organic matter, nutrients and remaining suspended solids

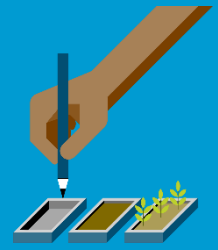
example: anaerobic digestion

Post-treatment or tertiary treatment: final polishing

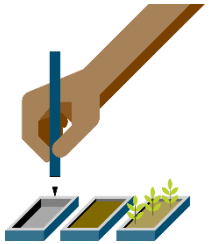
example: removal of remaining pathogens, nutrients or micropollutants



Treatment Technology Activity



Treatment Technology Activity
Plenary



Besides treatment objectives, treatment products and level of technology development, there are other factors which may influent the selection of treatment technologies

- **Cost**
- **Environmental factors (groundwater level, climate, etc.)**
- **Available technology, material and skills**
- **Power requirements**
- **Space availability**
- **Legal regulations**

Photos

Settling-thickening tank

Unplanted drying beds

Planted drying beds

Mechanical dewatering

eawag aquatic research

Pilot installation in Freetown, Sierra Leone

Photos: Gibril Kamara

Co-composting

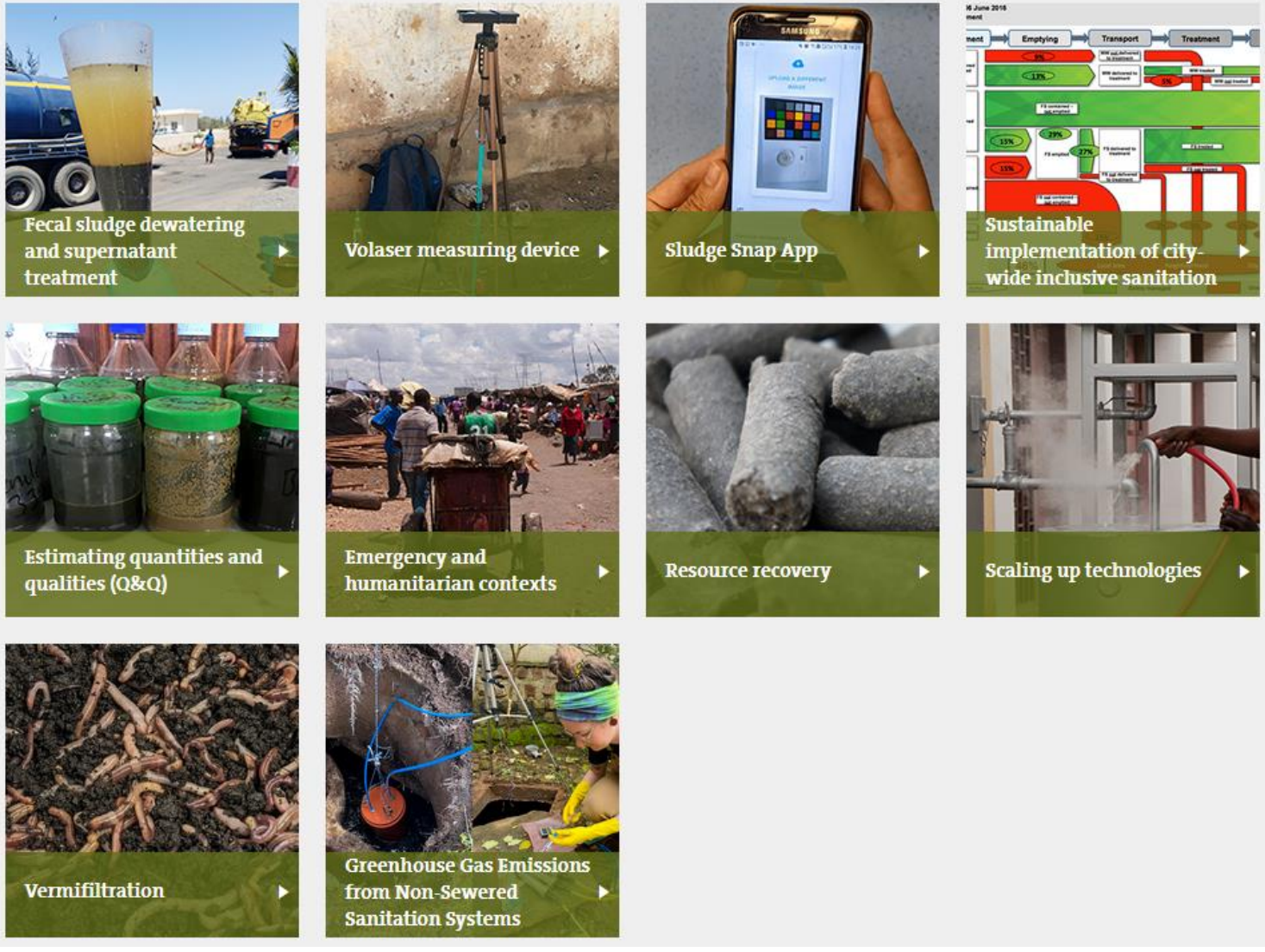
Waste stabilization ponds

For more information…

Management of Excreta, Wastewater and Sludge

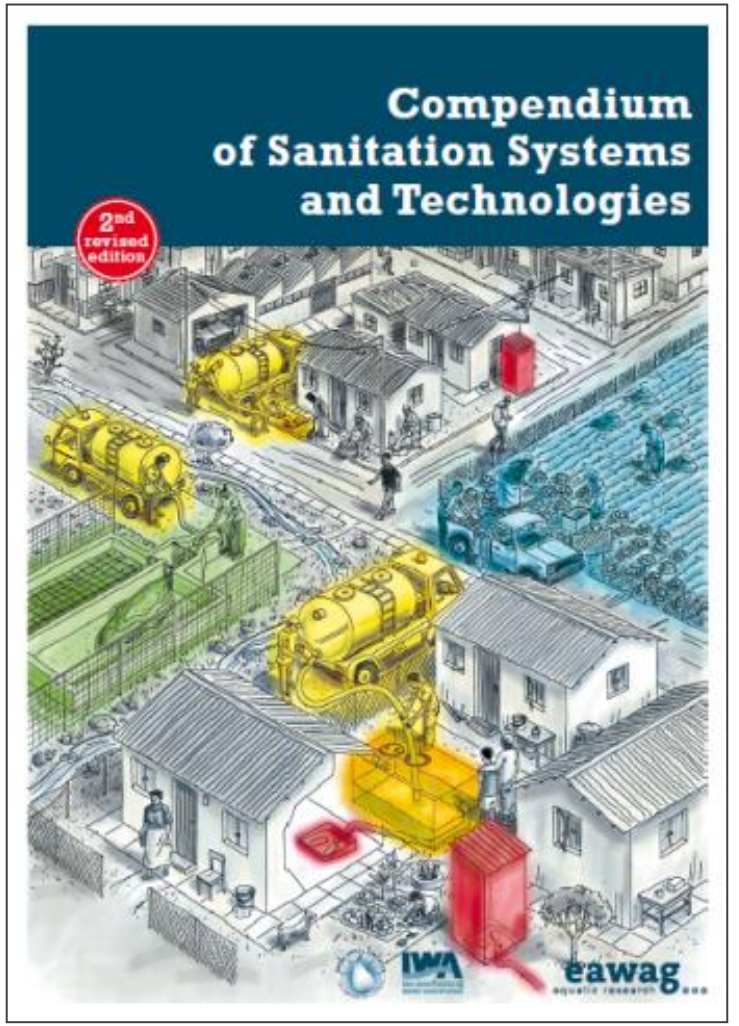
eawag aquatic research

Ongoing Research Projects



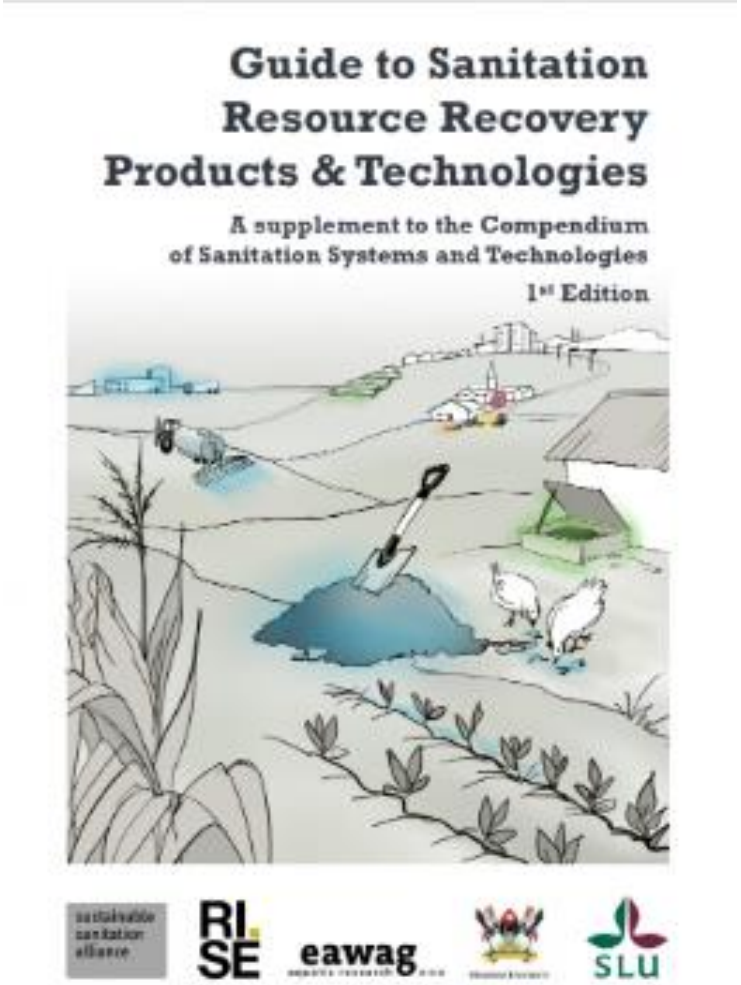
www.sandec.ch/mews

Compendium of Sanitation Systems and Technologies



sandec.ch/compendium

Guide to Sanitation Resource Recovery Products & Technologies



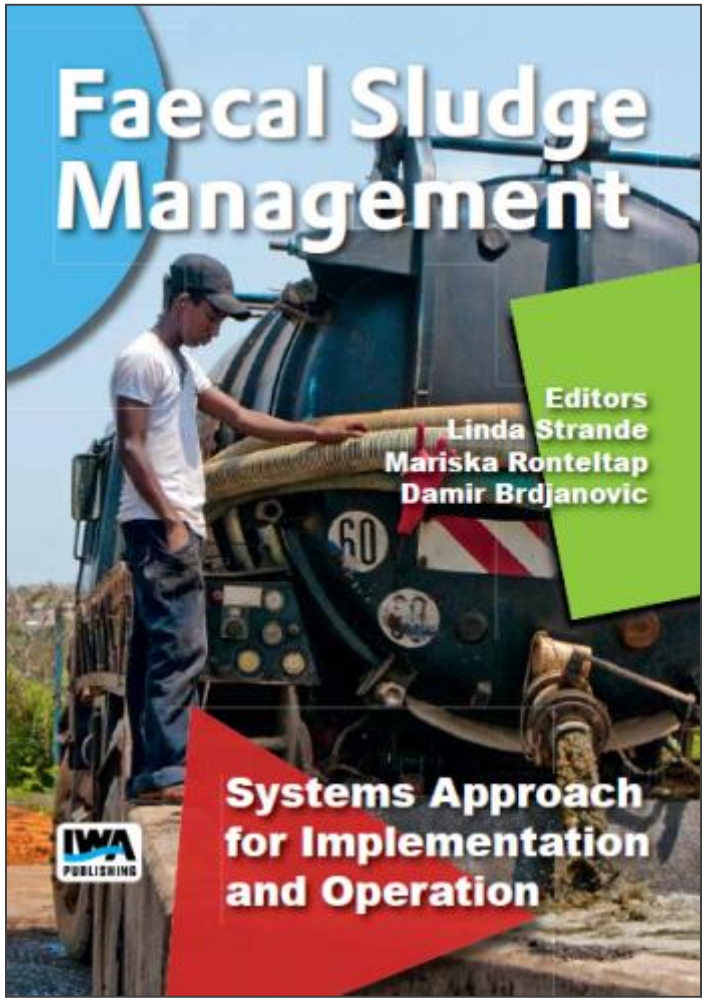
https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/4008#

Overview of anything FSM

Including:

- Characteristics
- Treatment technologies
- Planning
- Enabling enviroment
- Systems approach

www.sandec.ch/fsm_book

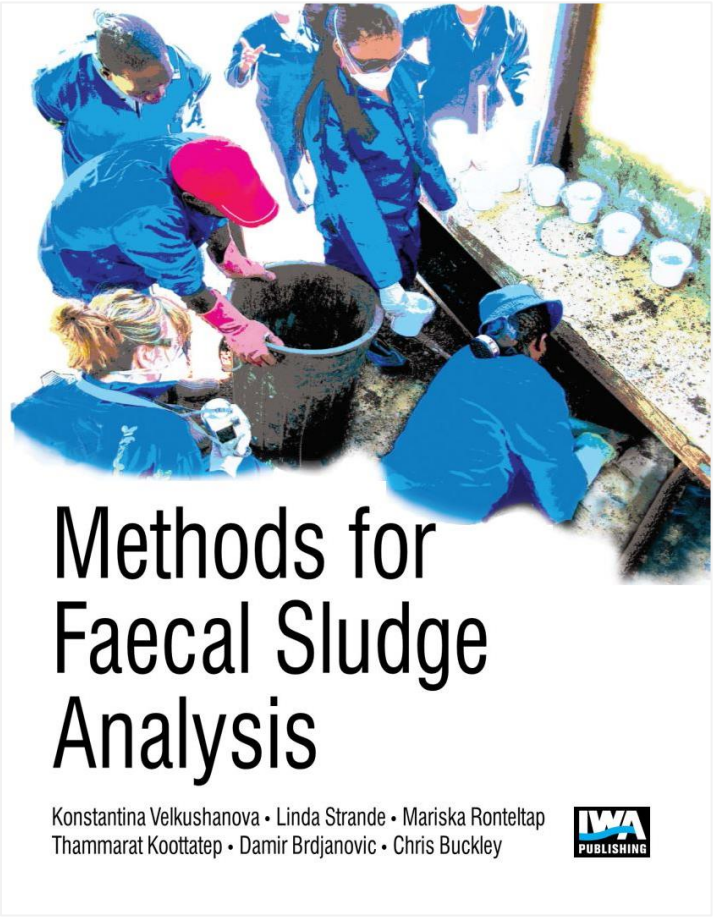


Guidelines for standard practices

Including:

- Background info on types of faecal sludge
- Methods for sample collection
- Health and safety procedures for handling
- Approach for estimating quantities & qualities on community to city-wide scale
- Laboratory methods for faecal sludge analysis

www.sandec.ch/fsm_methods



Learning objectives

- Describe the difference between faecal sludge, sewered wastewater and excreta.
- Explain the Engineering Design Approach for faecal sludge management .
- Compare different resource recovery products and treatment technologies associated with them.
- Explain the treatment objectives of faecal sludge treatment and link them to treatment technologies.