Waste(?)water innovative management solutions

Riga Technical University, Latvia

Tālis Juhna

RTU, 30 of May 2022

FACTS & FIGURES about RTU

1862
RIGA TECHNICAL UNIVERSITY

15 000 STUDENTS

12% FOREIGN STUDENTS

600 PHD STUDENTS

MORE THAN
140 000
ALUMNI

140 STUDY PROGRAMS

48 STUDY PROGRAMS COMPLETELY TAUGHT IN ENGLISH

4 AFFILIATIONS: CESIS, LIEPAJA, VENTSPILS, DAUGAVPILS

1031 ACADEMIC STAFF & RESEARCHERS

RTU ENGINEERING HIGH SCHOOL

Source: RTU data

Water Research and Environmental Biotechnology Laboratory
Established in 2002: RTU Faculty of Civil Engineering

STAFF


TALIS JUHNA


BRIGITA DALECKA


JANIS RUBULIS


VIKTORIJA DENISOVA


LINDA MEZULE


KRISTINA TIHOMIROVA


KAMILA GRUSKEVICA


KRISTINE RUGELE


KASPARS NEILANDS


SANDIS DEJUS


MARTINS STRODS


JANIS NEILANDS


ALINA NESCERECKA


ANDA BERZINA

VISITING STAFF


SERGEJS NAZAROVS


DAINA PULE

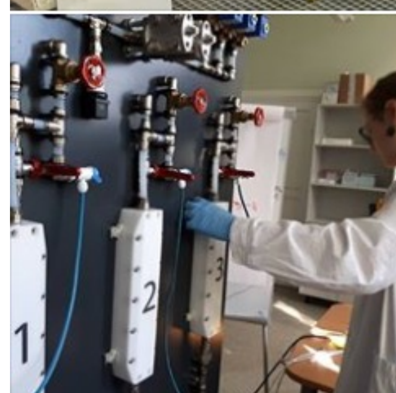
WATER RESEARCH BIOTECHNOLOGY

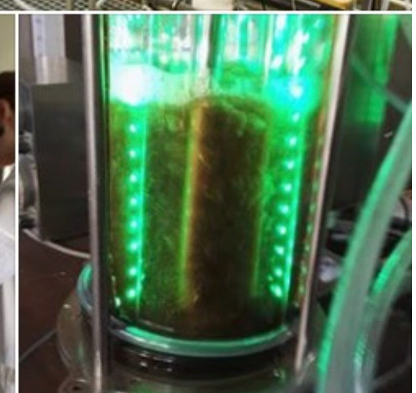
Expertise: microbiology, chemistry, engineering design, quality modeling, stormwater

Turnover in projects > 0.7 MEuro (H2020, FET-OPEN, Intereg etc)

From idea to protype

2-3 startups per 5 years





The study courses

- Wastewater treatment
- Stormwater management
- Microbiology
- Sludge management
- **Water treatment (me)**
- **Bioreactor theory (me)**

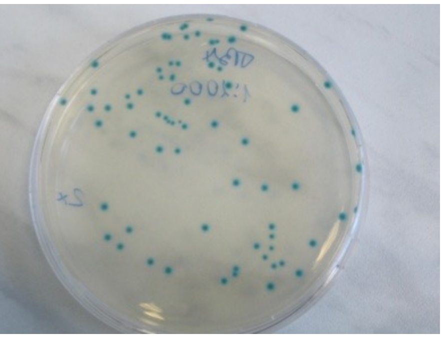
Recent topics

- Detection of nonculturable bacteria
- Use of wastes for energy production
- Application of sensors for contamination control
- Phosphorous enhances removal
- Green wastewater management
- Reducing biofouling of membranes

Source: RTU Water&Bioteh lab

Molecular methods for pathogen viability detection

Cultivability vs *in situ* identification

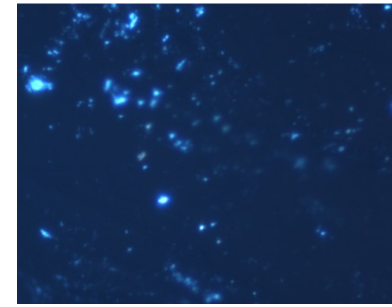


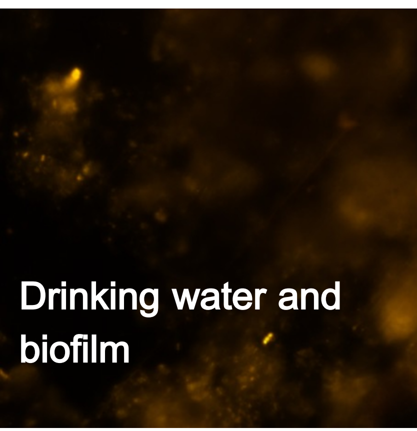
Why?

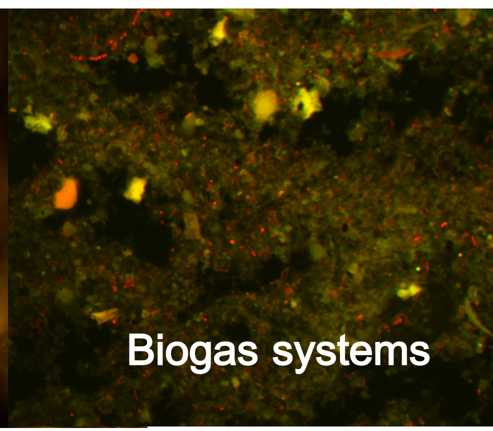
Not all bacteria are cultivable

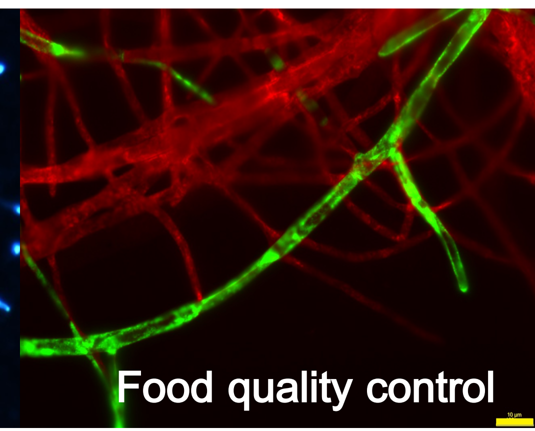
Too complicated media needed

Time-consuming









More accurate models > better technologies

Waste or resource?

Future of resource recovery plants

Energy Safety ⟷ Water

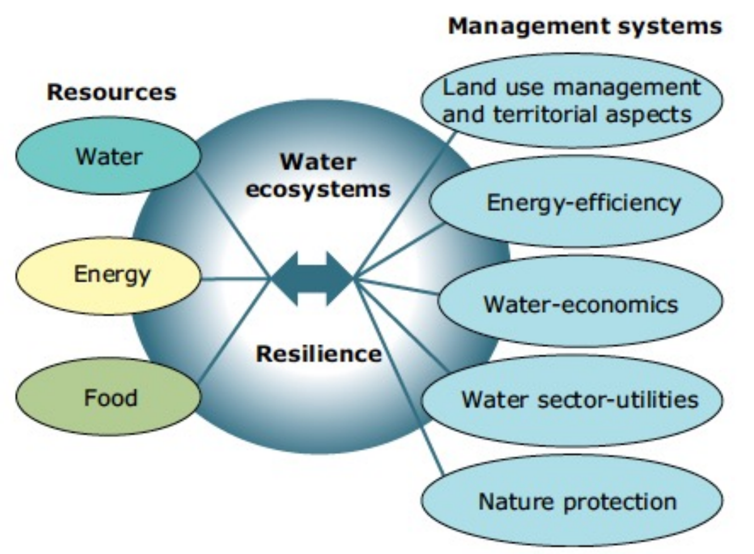
Addressing water sustainability (EEA)

1970-2000: reducing pollution

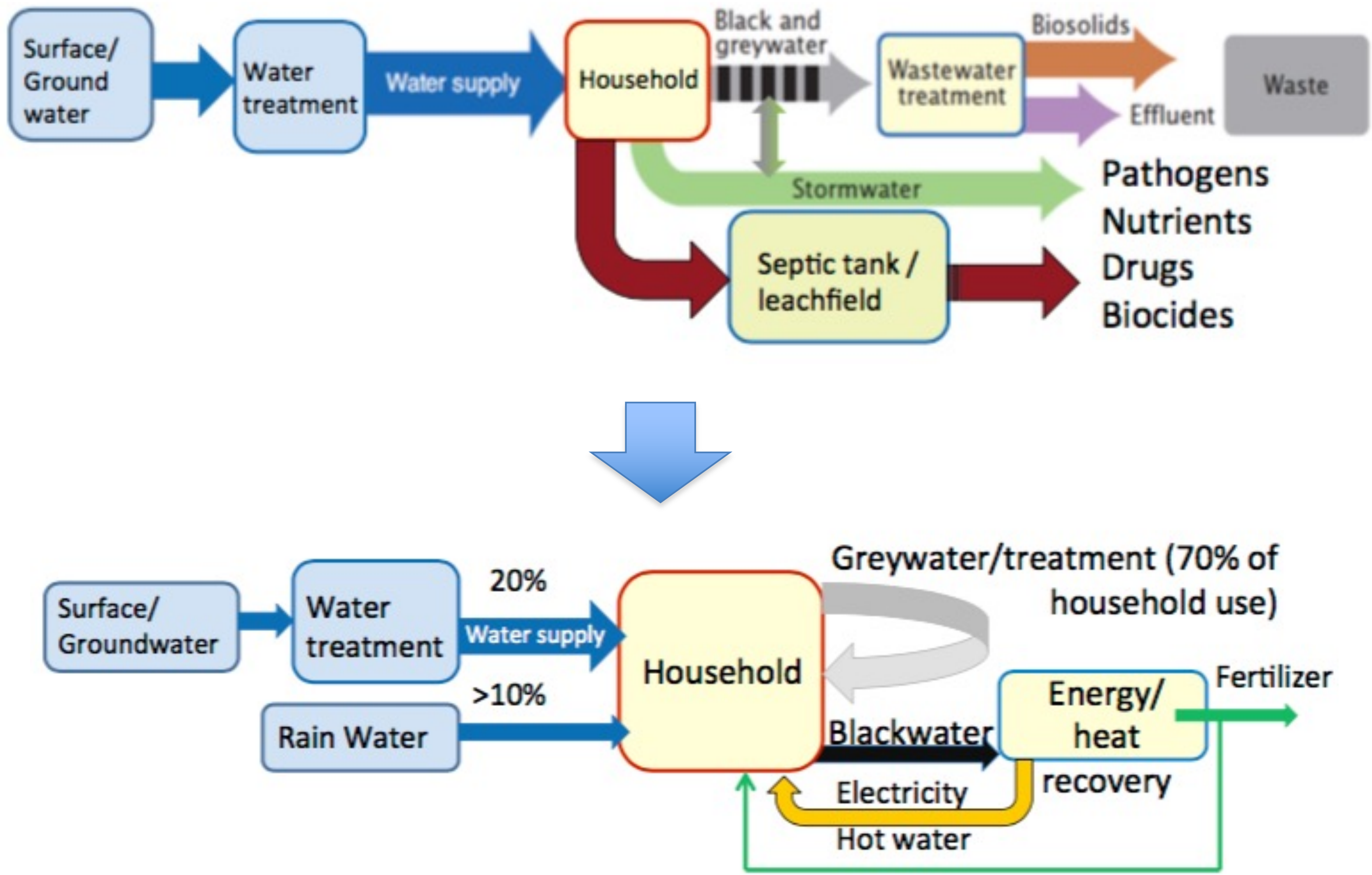
2000-2015: efficacy of water management

2015-2050: recovery on nutrients and energy

Figure 3.1 The water-energy-food nexus and the way it is managed influence water ecosystems and their resilience

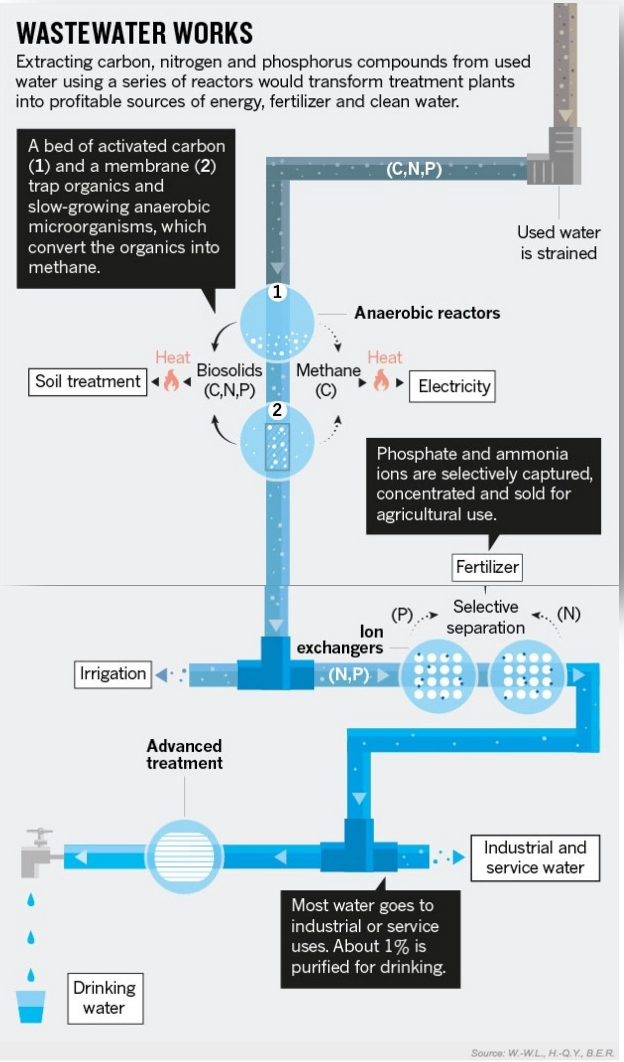


Source: EEA, 2012.

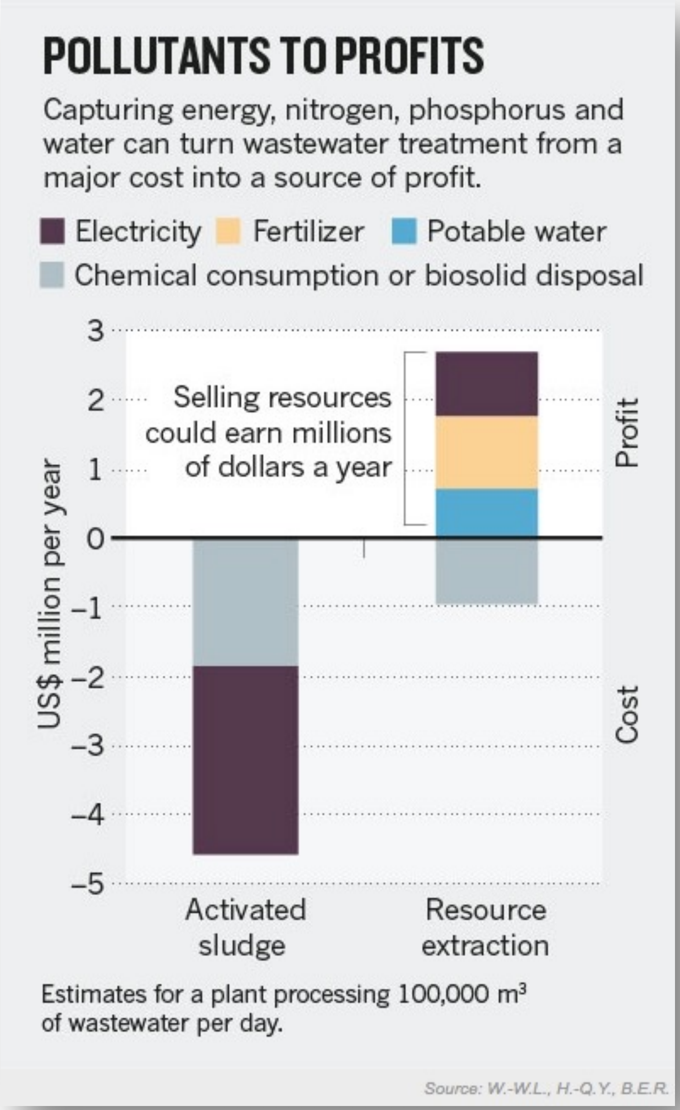


"one water" approach

Source: Nicholas Ashbolt



No Sustainability without profitability



Source: Journal Nature

Nutrients are not wastes but rather resources

Shift to Circular economy

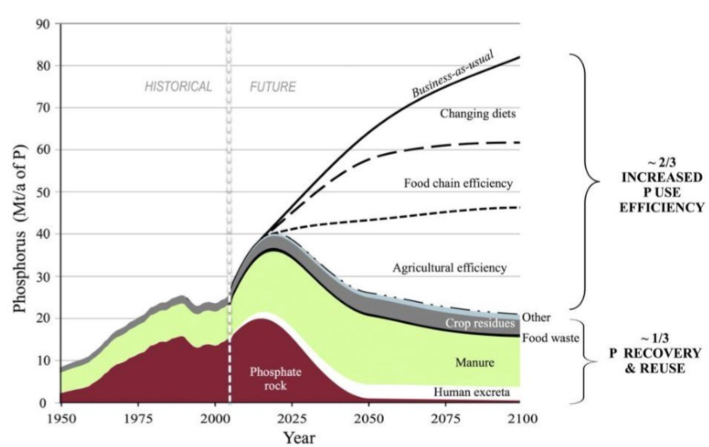
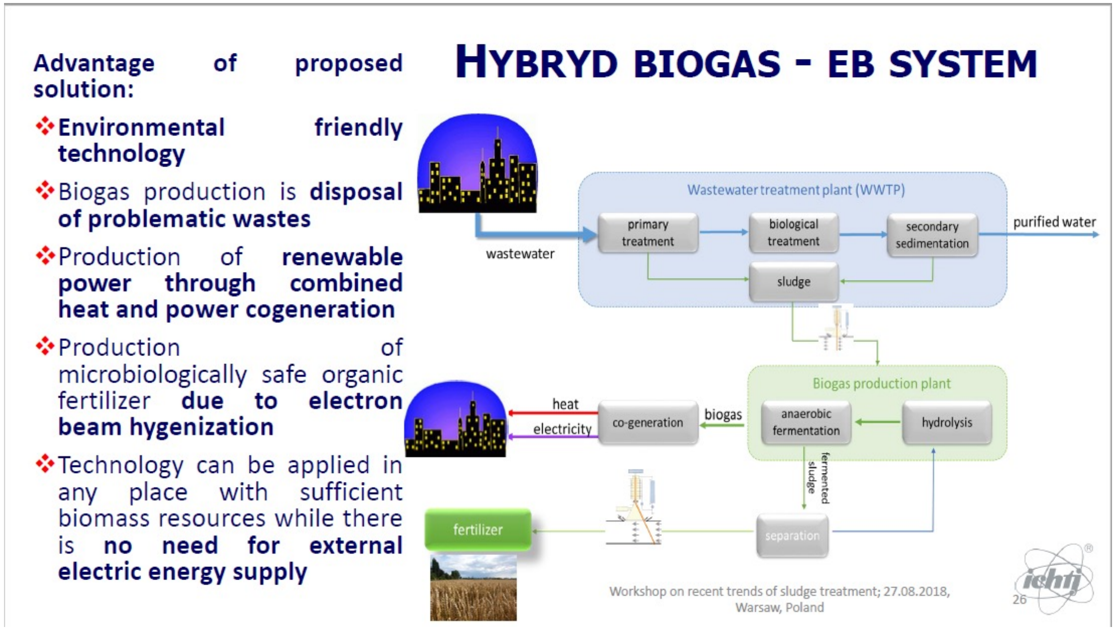


Figure 1 - A sustainable scenario for meeting long-term future phosphorus demand through phosphorus use efficiency and recovery (Cordell et al. 2011).

Emerging problems

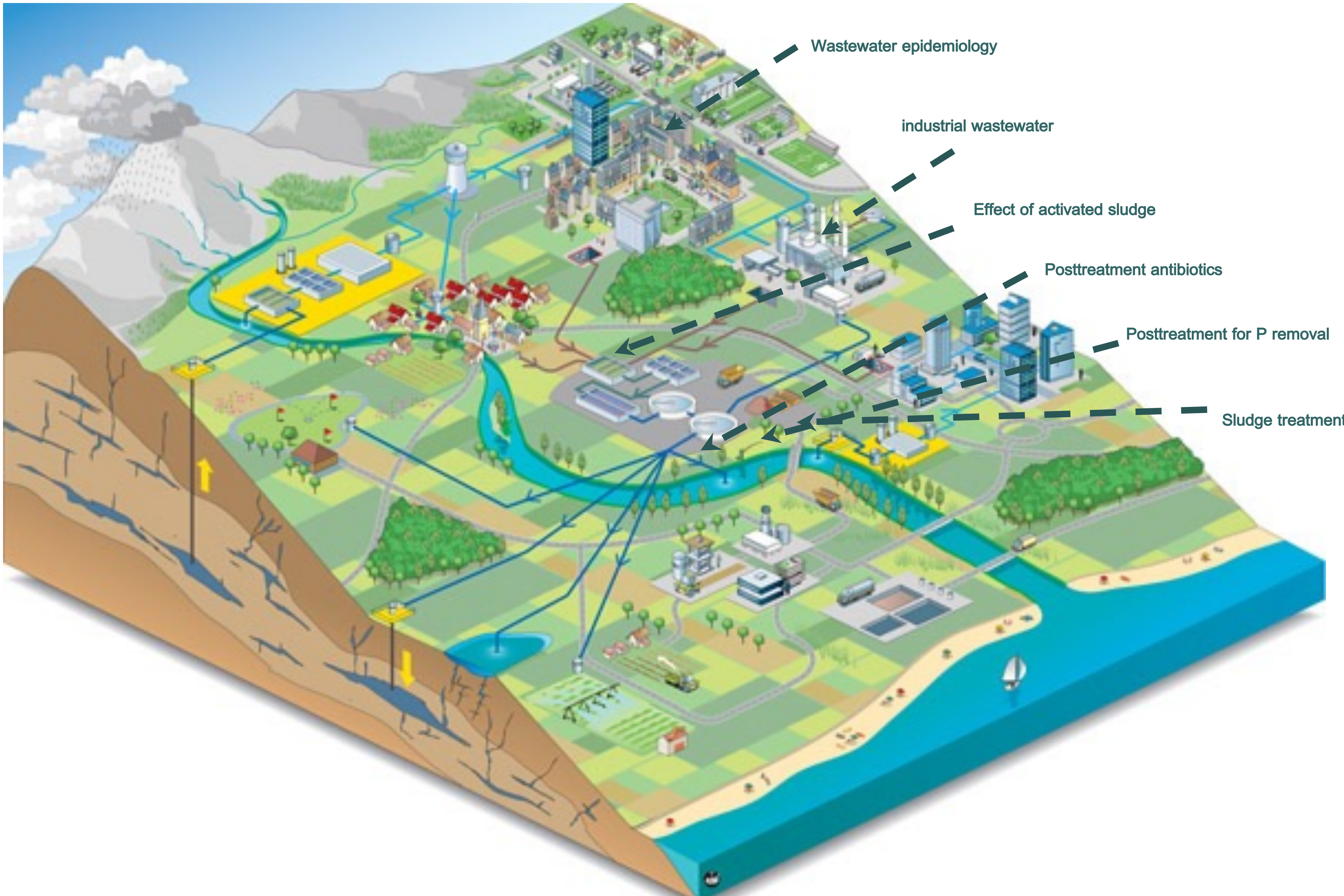
- Antibiotic-resistant bacteria
- Microplastics
- PFAS, antibiotics



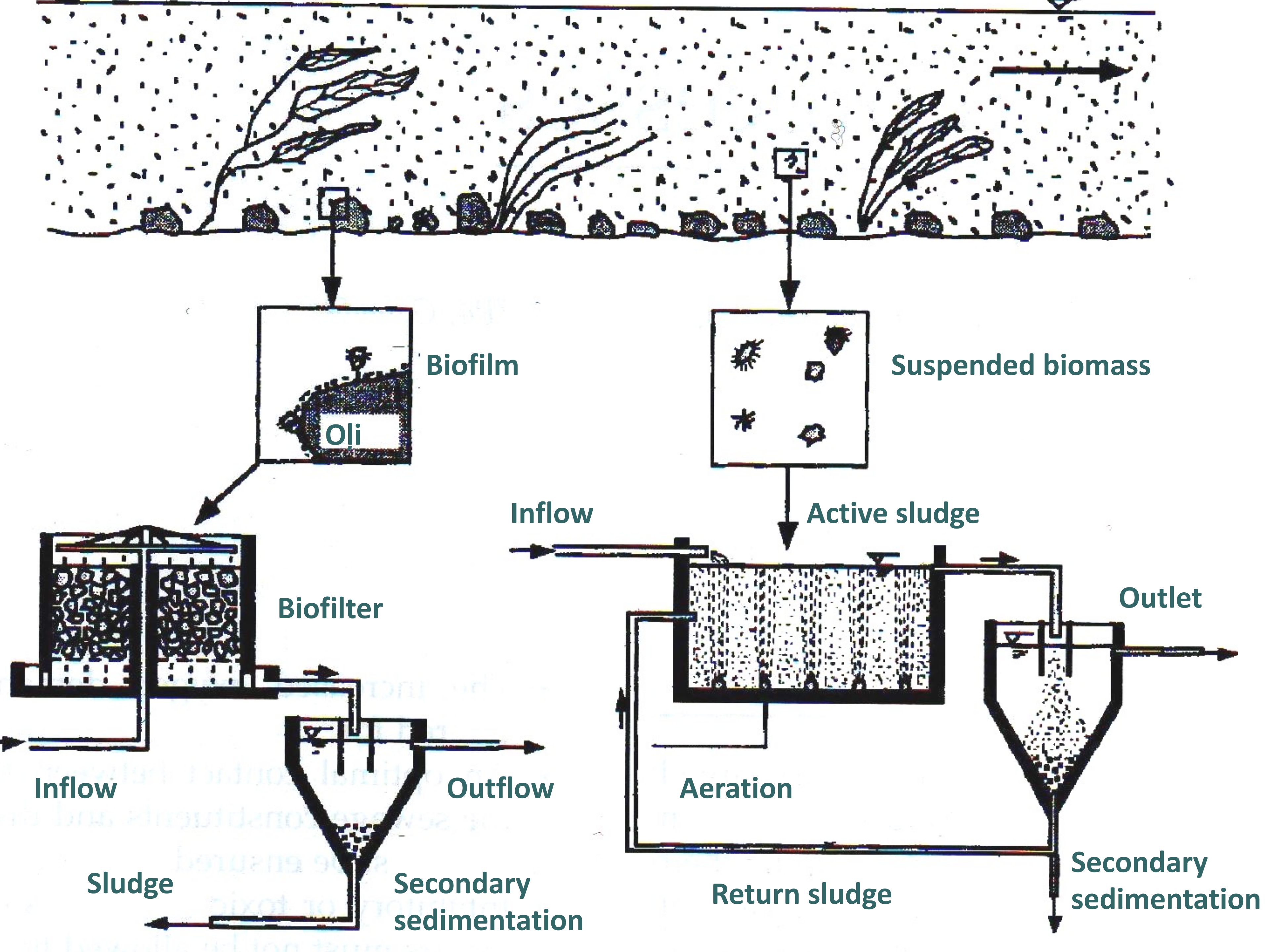
Content of the lecture

- Few basics concepts in biology
- Research on wastewater at our lab
- Q&A

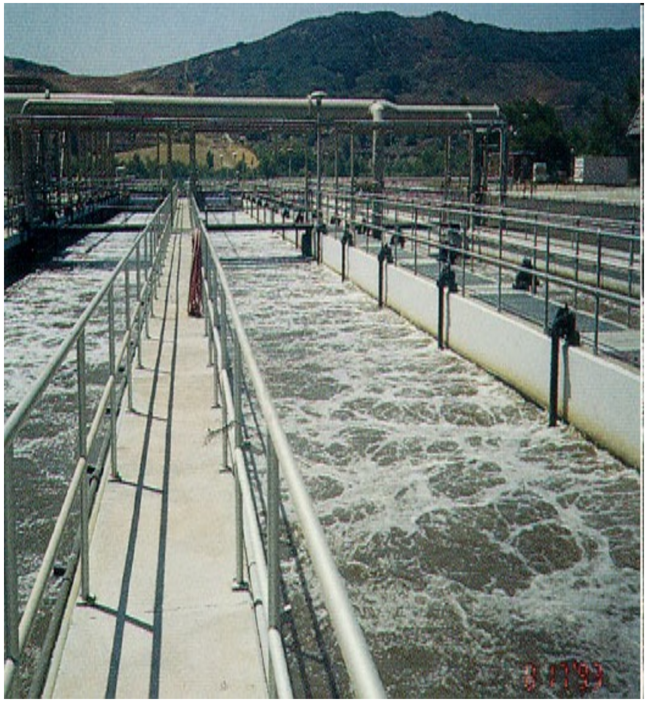
Today's topics



Effect on activated sludge

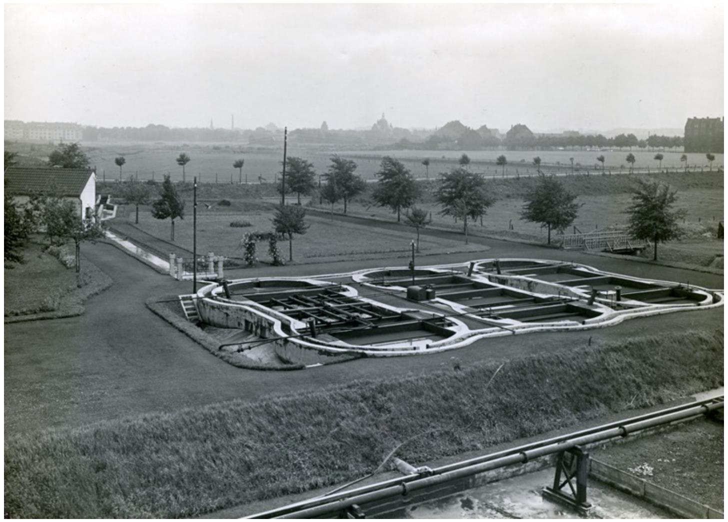


Biofilm
Oli
Suspended biomass
Inflow
Active sludge
Biofilter
Outlet
Inflow
Outflow
Aeration
Sludge
Secondary sedimentation
Return sludge
Secondary sedimentation



Activates sludge process – “gold standard”

- History of activated sludge: Ardern, Lockett, 1914



five weeks continuous aeration was required in order to completely nitrify an average sample of Manchester sewage. If, however, the resultant solid matter was allowed to deposit, and the purified sewage removed by decantation and replaced by a further sample of crude sewage, complete nitrification of this second dose of sewage ensued within a reduced period of time. It was shown that accumulated deposit resulting from the complete oxidation by prolonged aeration of successive quantities of sewage, which were termed 'activated' sludge, had the property of enormously increasing the purification effected by the simple aeration of sewage.

- From empiric to mathematical model – chemical or biological
- Residence time 4-8 d

Calculation according to a bioreactor theory

Monod equation

↓

Mass balance for completely mixed reactor (steady state)

↓

dX/dt = const.

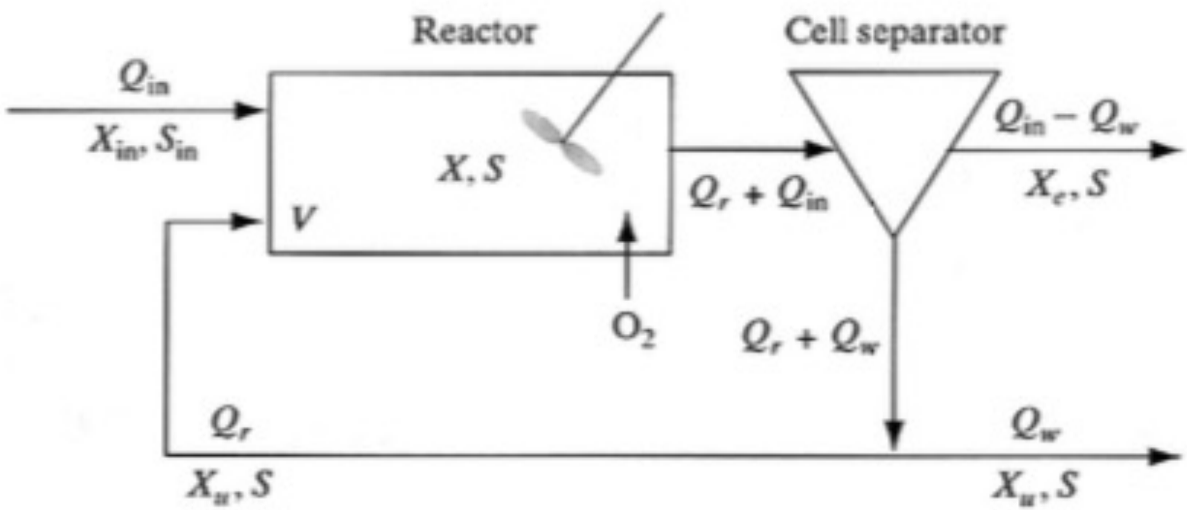
↓

$$S = \frac{K_s(1+\theta k_d)}{\theta(Yk - k_d) - 1}$$

←

$$X = \frac{\mu_{max}(S_0 - S)}{k(1+k_d\theta)} = \frac{Y(S_0 - S)}{(1+k_d\theta)}$$

Notation of fluxes and variables at several points in the system:



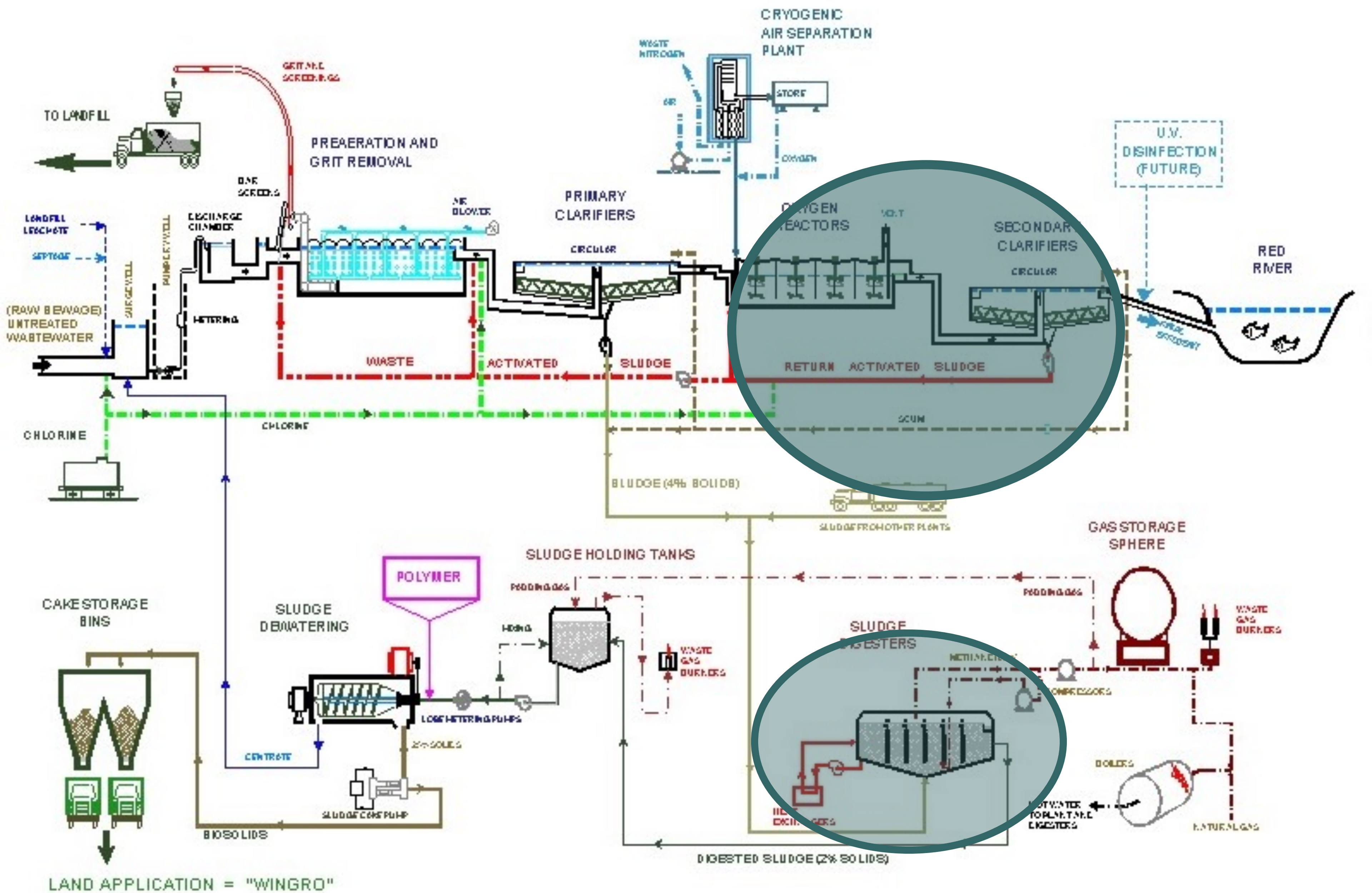
In continuous operation, where wastewater is constantly added and some of the mixture is constantly removed, the budgets of S and X are those of a continuously-stirred tank reactor (CSTR). If the reactor's volume is V (in m^3) and the volumetric flow rate is Q_0 (in m^3/day), the budgets are:

<u>Substrate:</u>

$$V\frac{dS}{dt} = Q_{in}S_{in} + Q_r S - (Q_{in} + Q_r)S - V\left(\frac{k_m SX}{K_S + S}\right)$$

<u>Cells:</u>

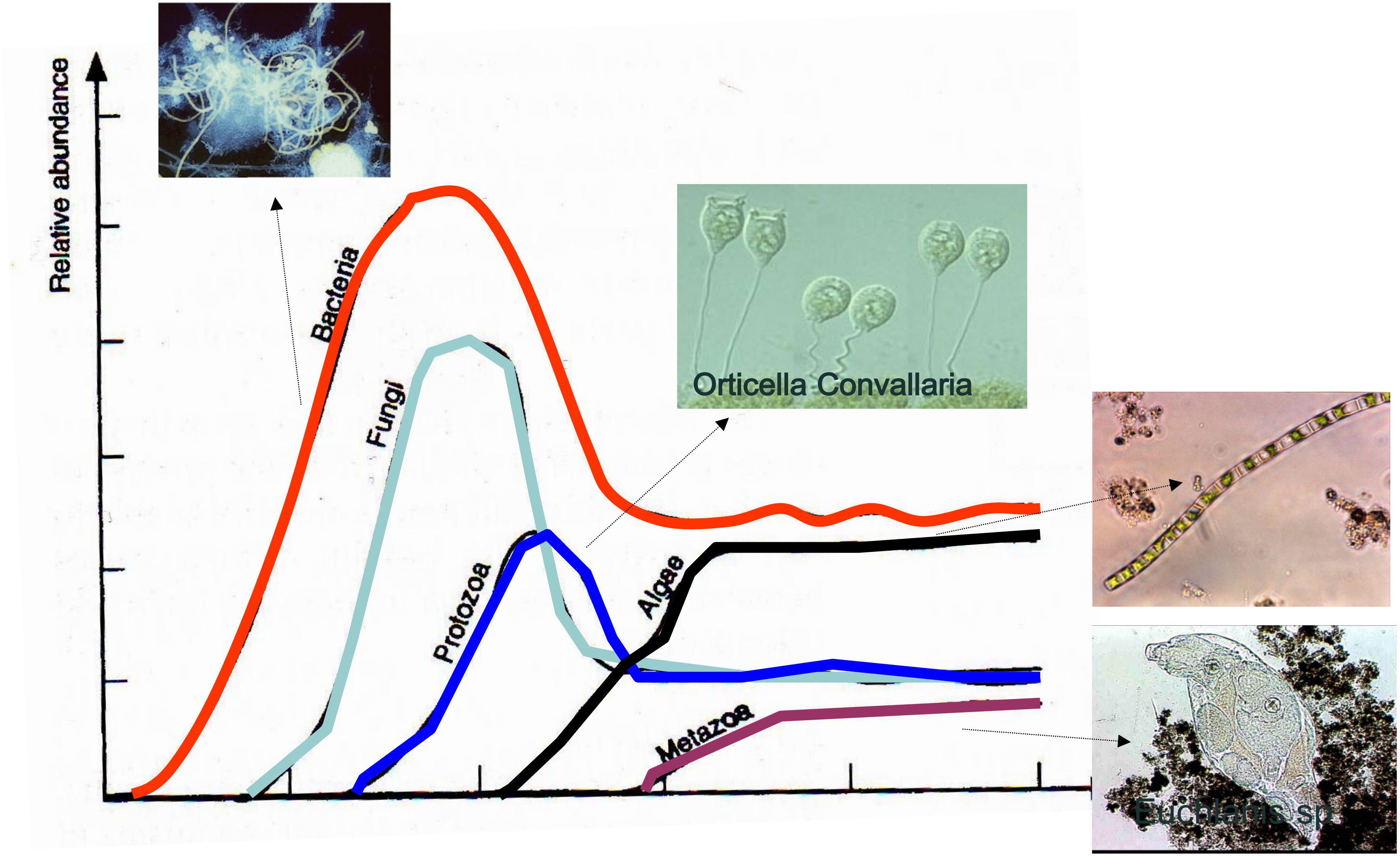
$$V\frac{dX}{dt} = Q_{in}X_{in} + Q_r X_u - (Q_{in} + Q_r)X + V\left(\frac{k_m YSX}{K_S + S} - k_d X\right)$$



NORTH END WATER POLLUTION CONTROL CENTRE

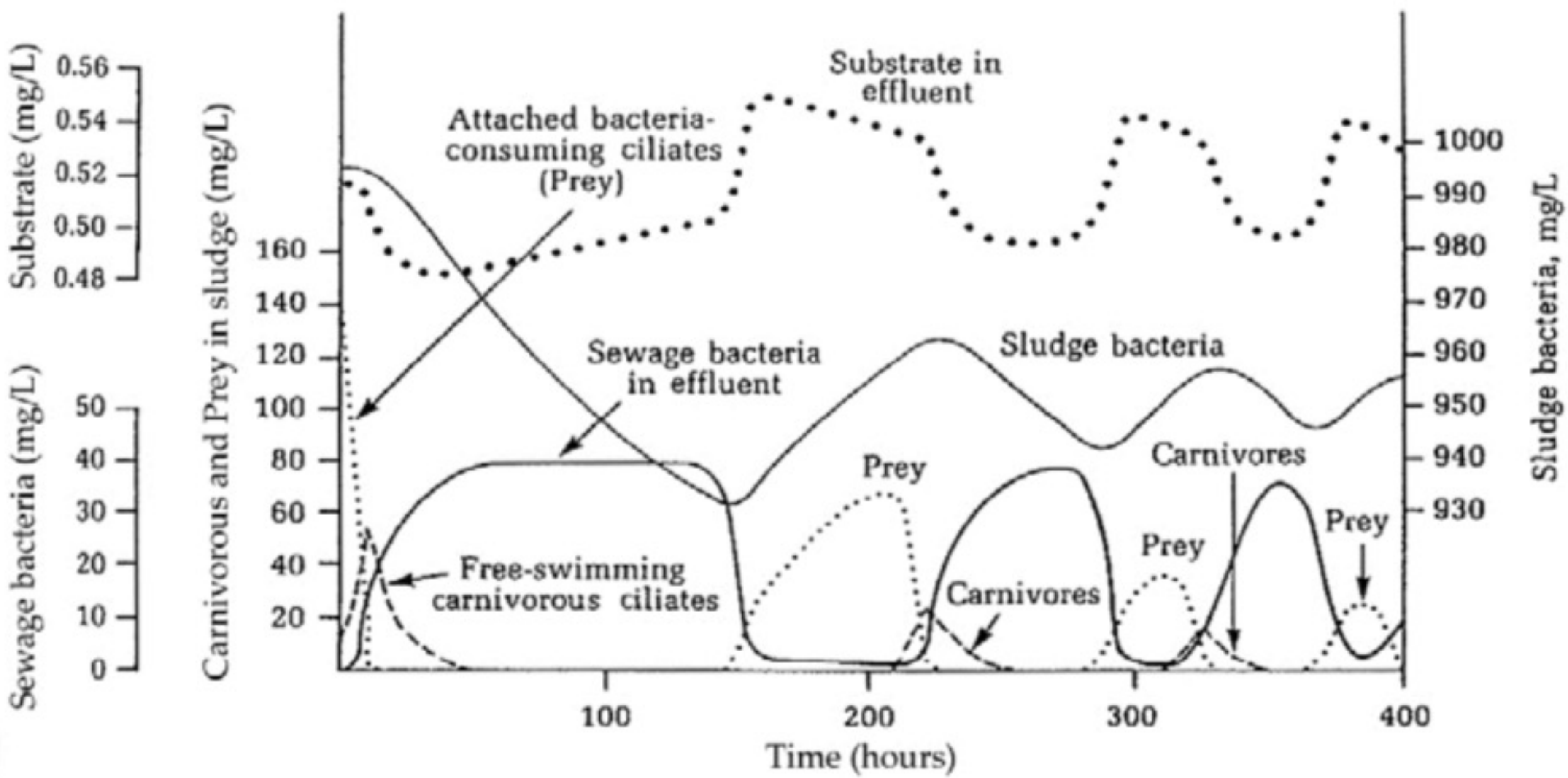
TREATMENT PROCESS SCHEMATIC

Activated sludge "evolution"



Avots: Iwai and Kitao, 1994

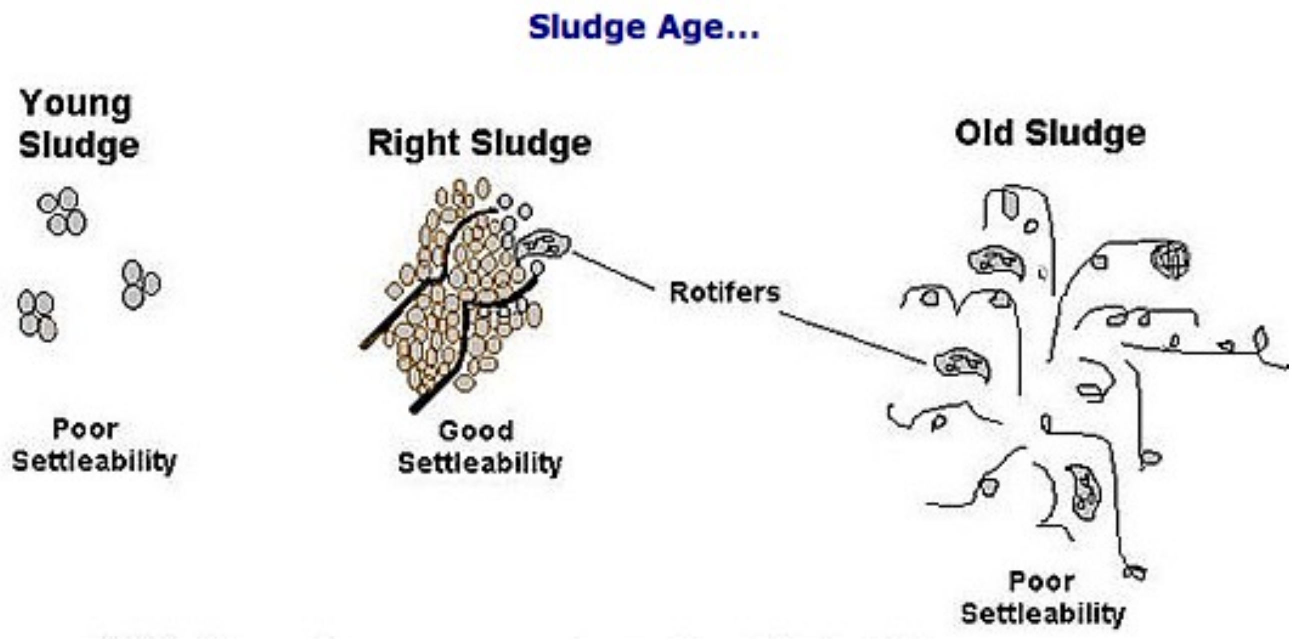
Avots:www.environmentalleverage.com



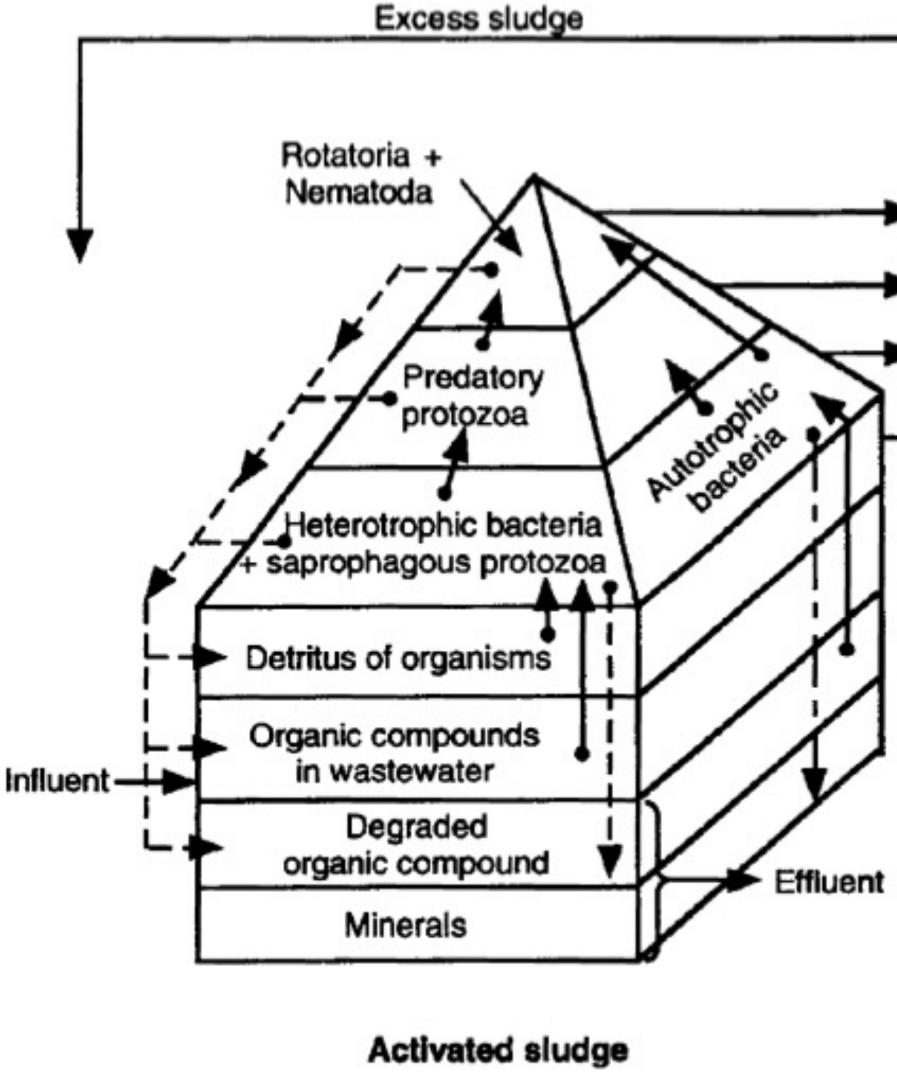
(From Davis & Cornwell, 2008; their source: Curds, 1973)

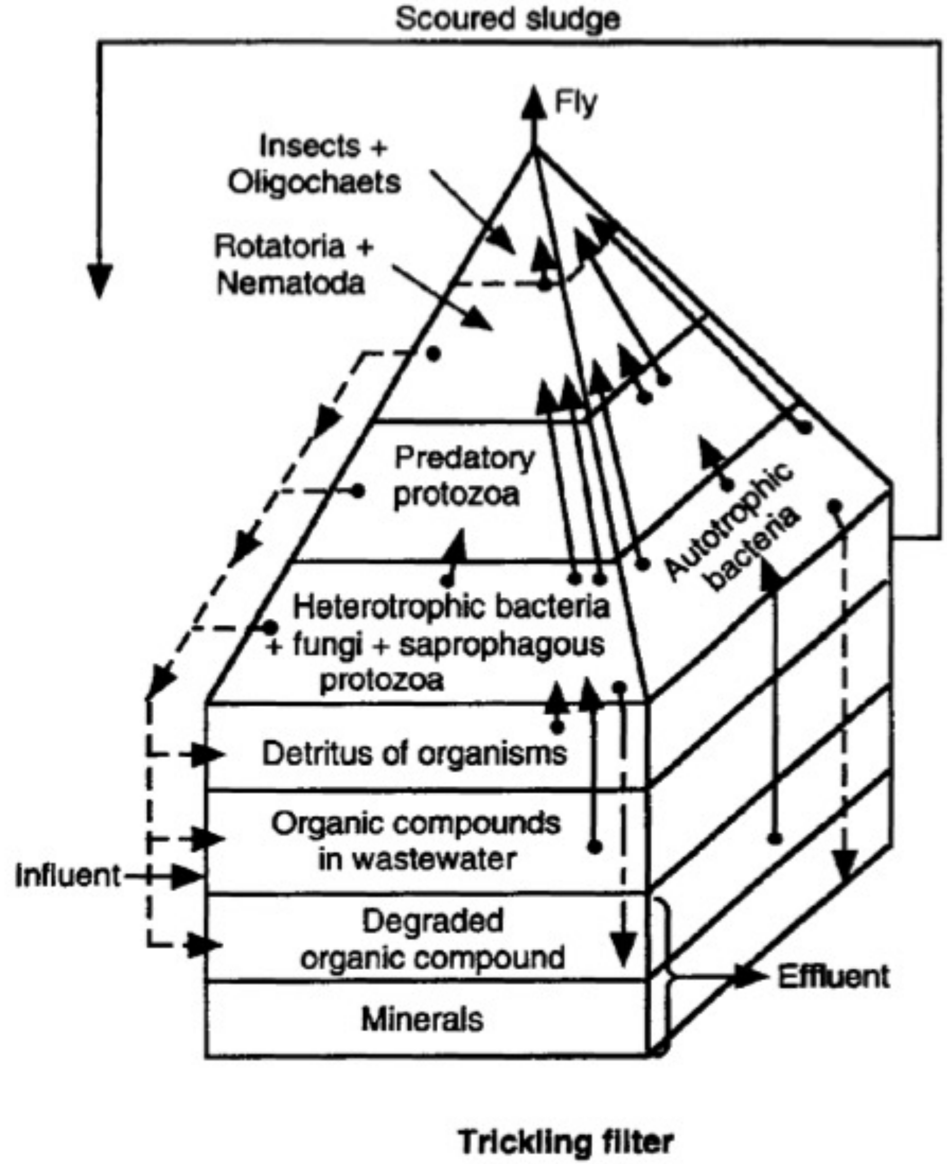
Sludge properties

- Sludge index: settleability
- Sludge bulking…
- Sludge age



http://web.deu.edu.tr/atiksu/ana52/acti4.html





Iwai and Kitao,1994

Sedimentation propreties are characterized by sludge volume (SV) and sludge volume index /SVI)

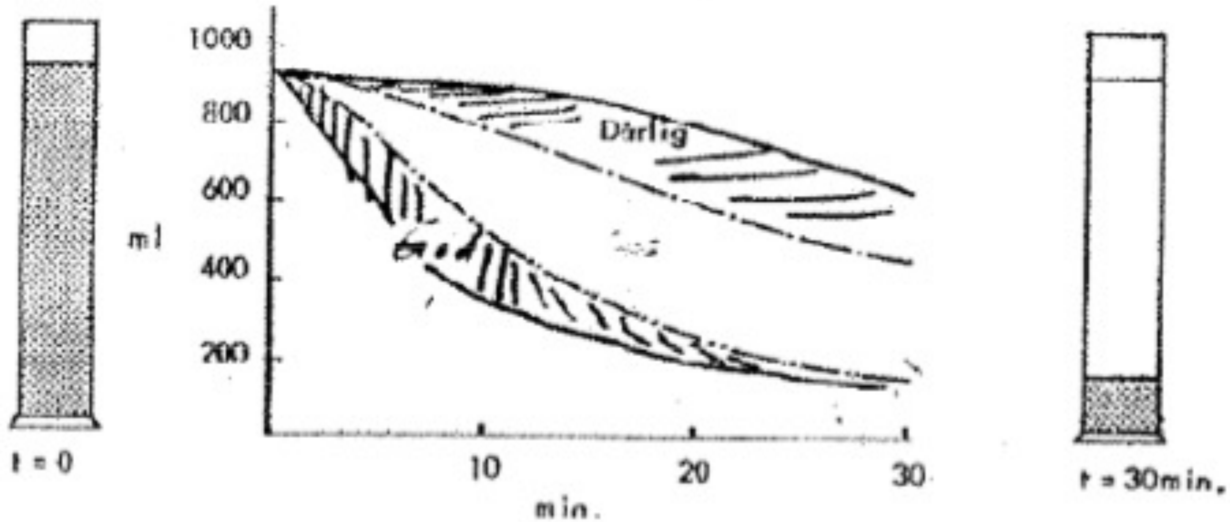


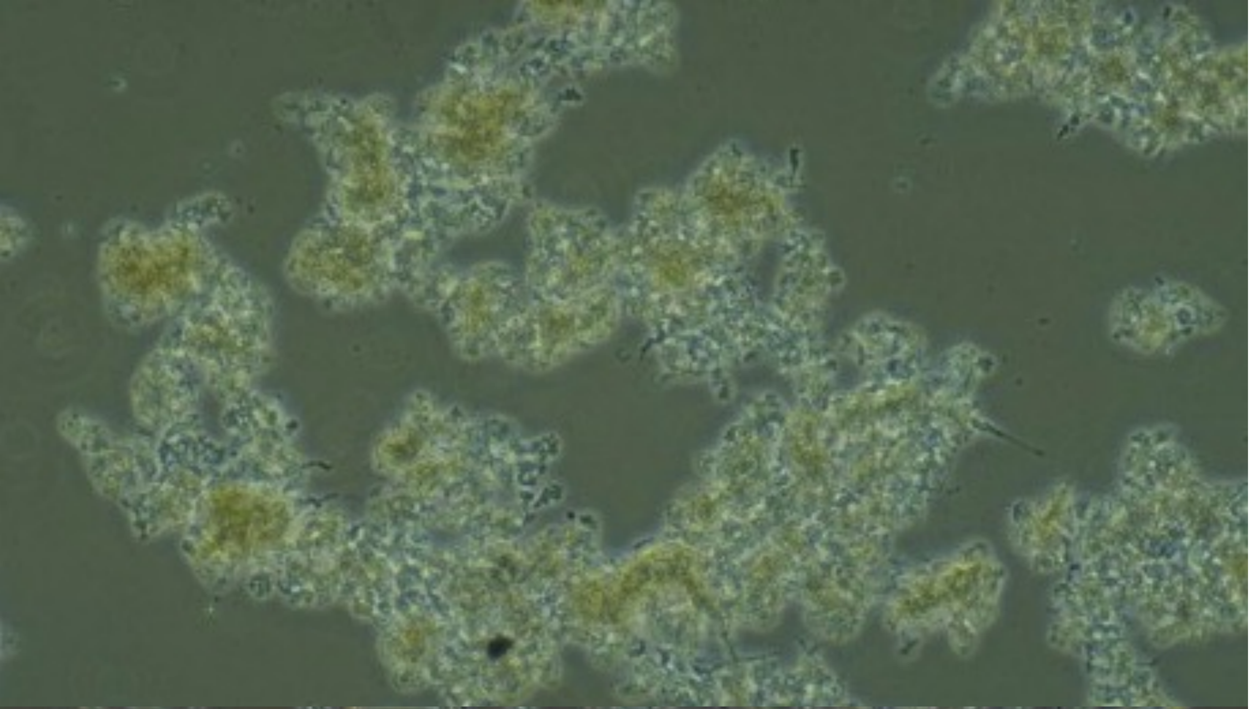
FIG. 13 - 5. Bestemmelse av slamvolum.

Sludge volume index:

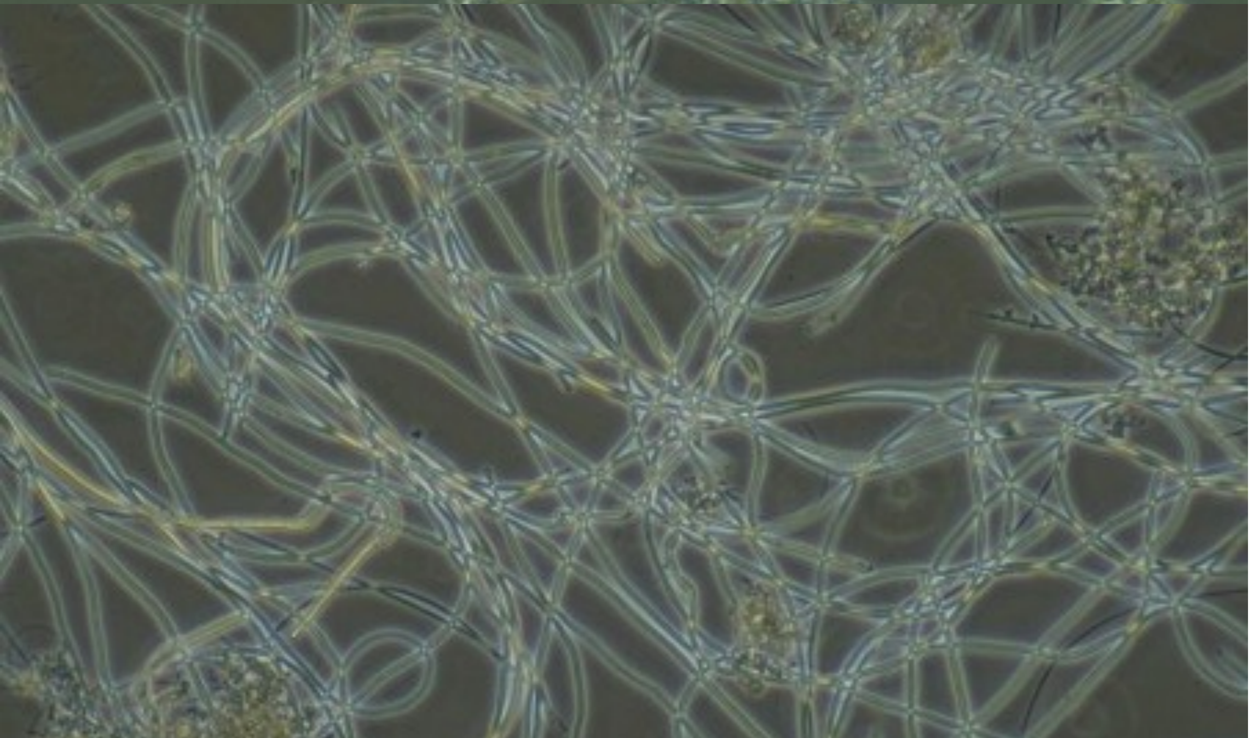
SVI = SV/X = (ml/l)/(g/l) = ml/g

Normal good operation : SVI < 100 ml/g

Difficult settling sludge: SVI > 150 ml/g



good sludge..



Bad sludge…

http://web.deu.edu.tr/atiksu/ana52/ani4091.html applied sciences MDPI

Type of the Paper (Article)

Impact of rapid pH changes on activated sludge process

Kristina Kokina[1,2*], Linda Mezule[1], Kamila Gruskevica[1], Romans Neilands[2,3], Ksenija Golovko[1], Talis Juhna[1]

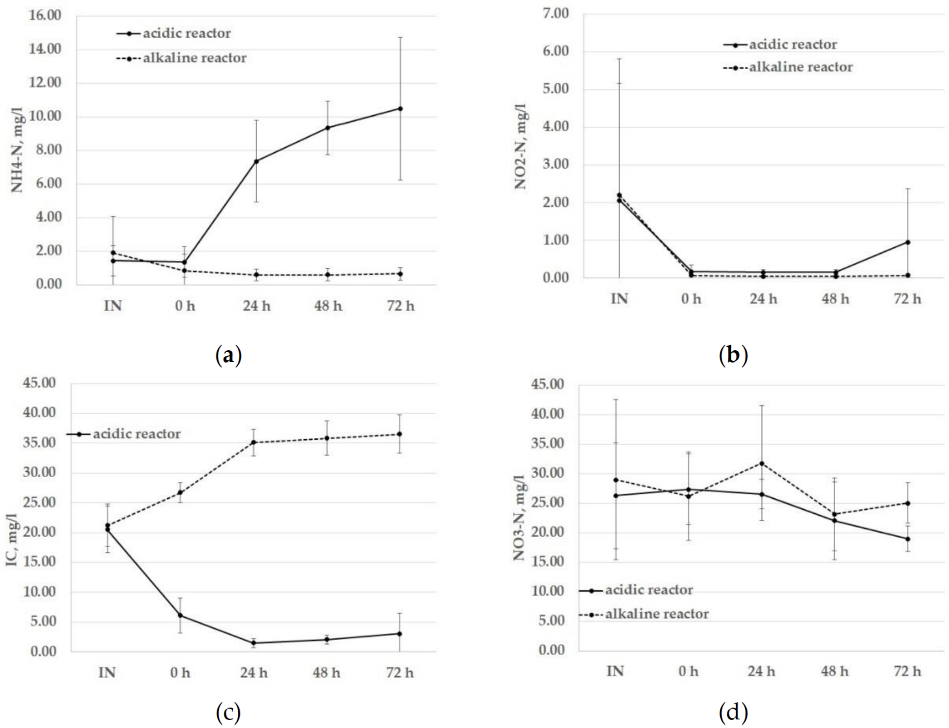
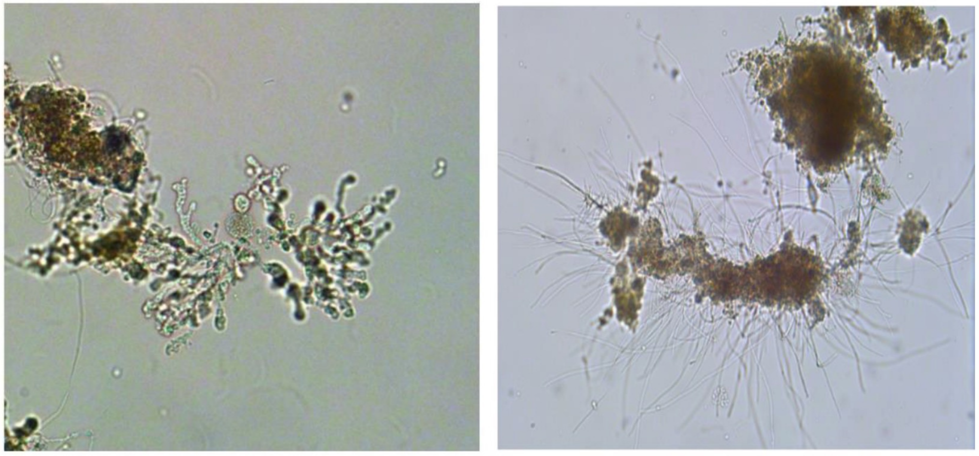


Figure 1. Changes of nitrogen and inorganic carbon compounds concentrations in acidic and alkaline pH reactors (n=3): (**a**) NH4-N; (**b**) NO2-N; (**c**) IC and (**d**) NO3-N.

Control of inhibitors such as salts and extreme pH on activated sludge process is important

..



(a) (b)

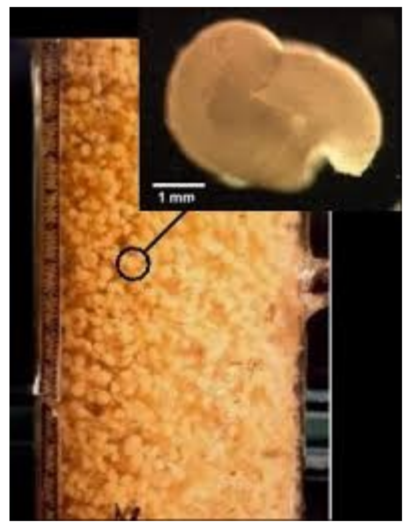
Figure 2. *Zoogloea ramigera* (a) in sludge of the acidic reactor and filamentous sludge in the alkaline reactor (b).

Compact biofiltration technology

Interreg Central Baltic

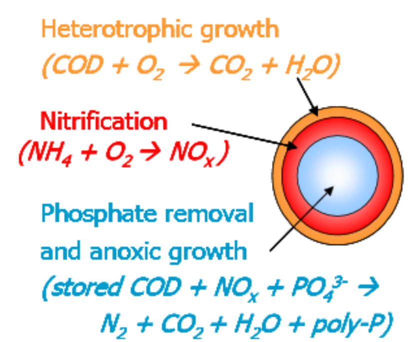
Source: RTU Water&Bioteh lab

- The enhanced biological phosphorus removal process
- Granular biofilm growth (microbial crystallization)
- Effective technology for wastewaters treatment containing high organics, nitrogen, phosphorus and toxic substances (Jiang et al., 2002; Moy et al., 2002; Tay et al., 2002b; Lin et al., 2003; Adav et al., 2007a,b,c,d; Adav and Lee, 2008a).

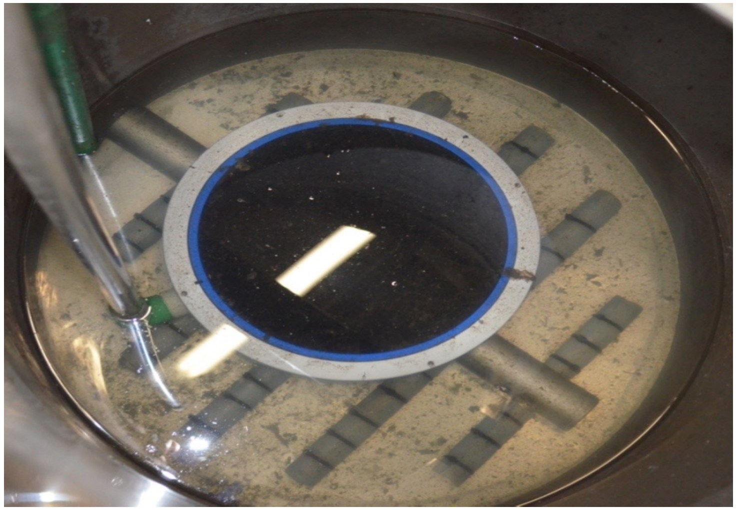


Aerobic Granular Sludge Technology developed by Dr. ir. Merle de Kreuk (2006)

Aerobic Granular Sludge - Scaling-up a new technology. PhD Thesis, Department of Biotechnology, Technical University Delft, The Netherlands



Kreuk, 2006



The reactors were operated of 6 hours cycle:

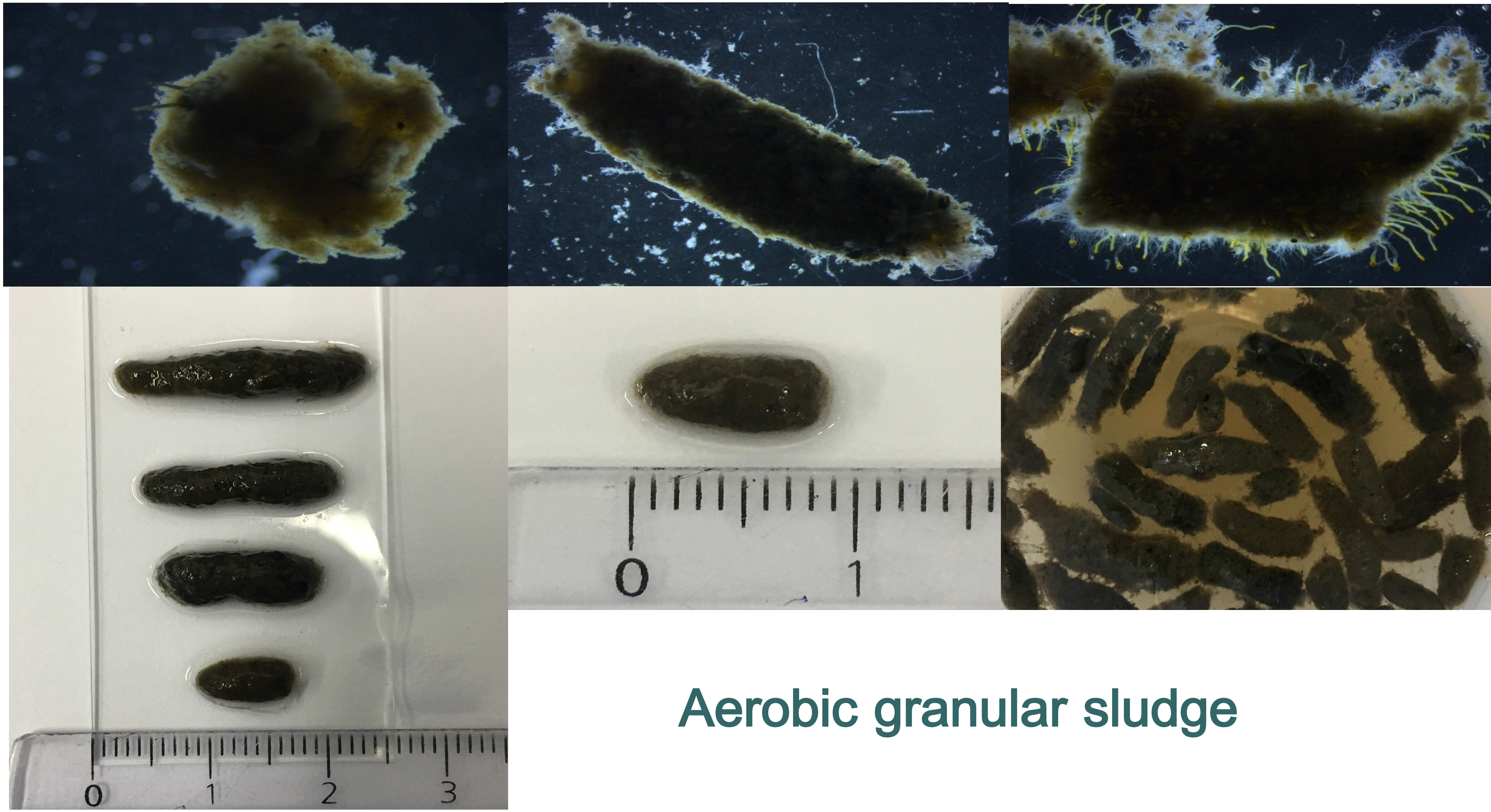
5 min feeding and effluent discharge

210 min aeration

25 min settling

- Add air and water flow meters
- Membranes for effective aeration (small bubbles)
- Automatic system control

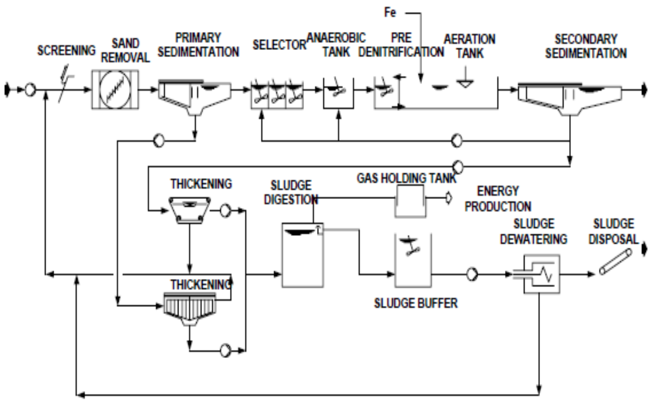
Source: RTU Water&Bioteh lab, K.Kokina



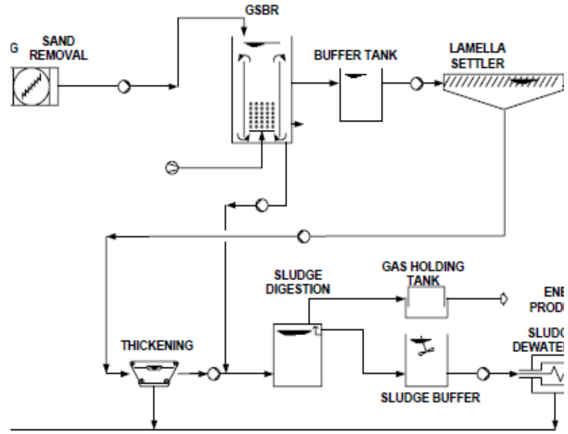
Aerobic granular sludge

Source: RTU Water&Bioteh lab, K.Kokina

Advantages of compact biofiltration technology



Process scheme for reference treatment plant (DE Kreuk, 2006, Dissertation)



Process scheme for Nereda® with post treatment (DE Kreuk, 2006, Dissertation)

Compact reactors

Up to 75% smaller footprint

Easy-to-operate

Cost-effective

- Enhanced biological phosphorus removal process
- Granular biofilm growth
- Effective technology for wastewaters treatment containing high organics, nitrogen, phosphorus and toxic sub-stances.

Aerobic granular sludge is recognized to be superior to conventional activated sludge in terms of settling ability, compactness, treatability, etc. It has a settling velocity greater than 10 m/h and sludge volume index (SVI) up to 30 mL/g [H. Linlin,205]]

(Activates sludge SVI 80 to 120 mL/g)

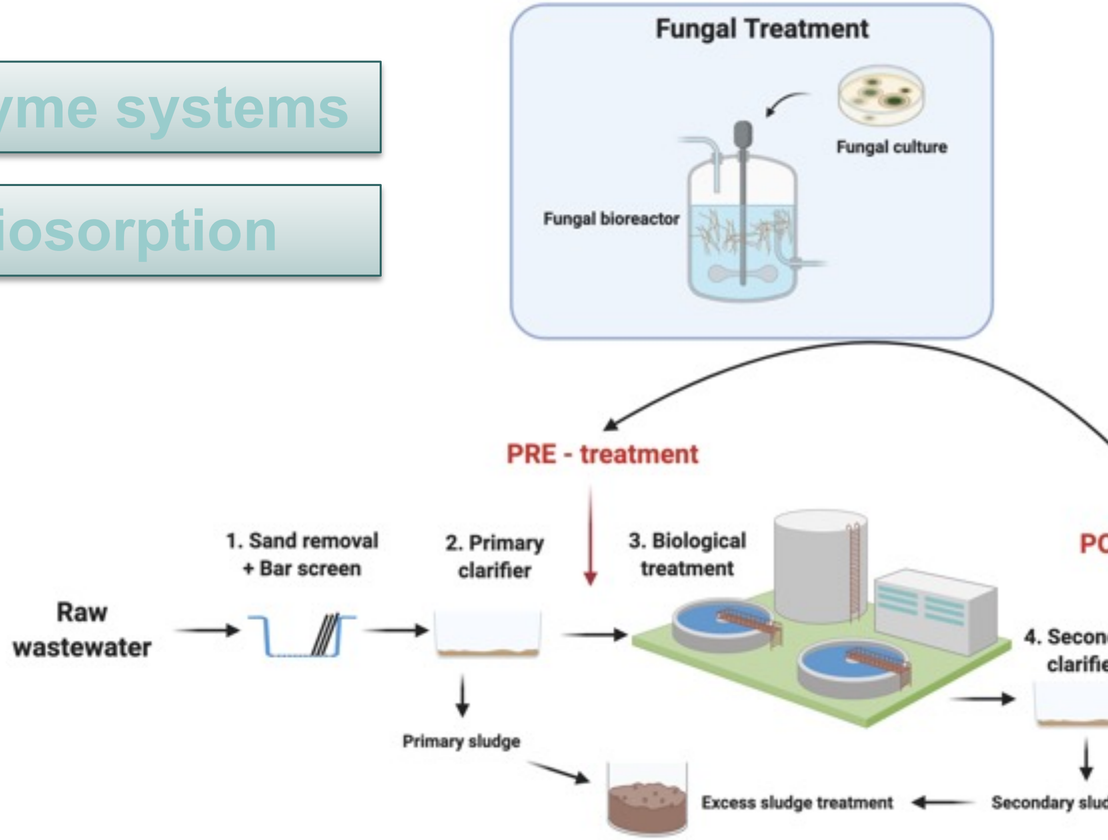
Source: RTU Water&Bioteh lab, K.Kokina

Posttreatment for antibiotics

BIOLOGICAL TREATMENT WITH FUNGI

Enzyme systems

Biosorption



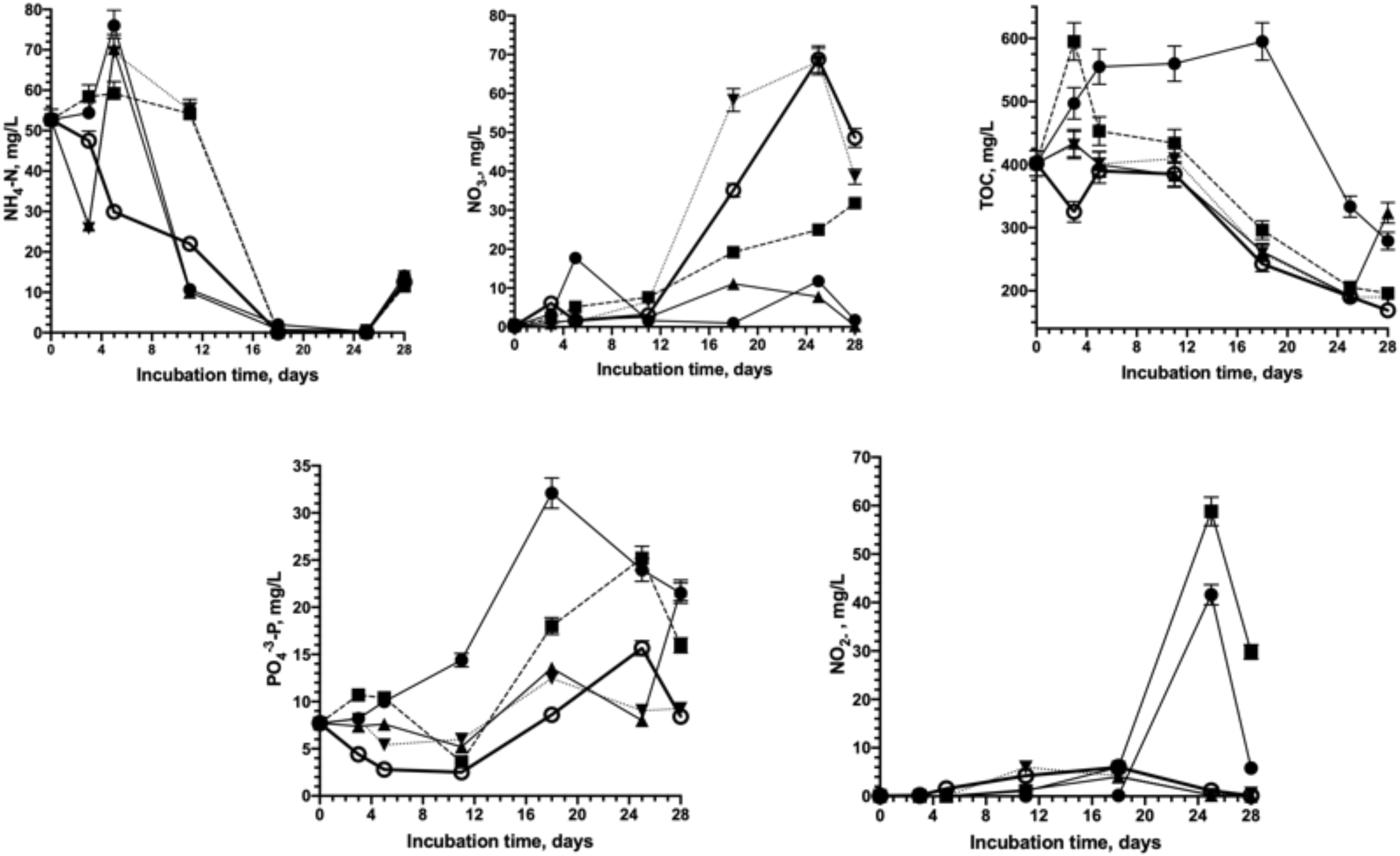
Sankaran, S., Khanal, S. K., Jasti, N., Jin, B., Pometto, A. L., and Van Leeuwen, J. H. (2010) Use of filamentous fungi for wastewater treatment and production of high value fungal byproducts: A review. Critical Reviews in Environmental Science and Technology, 40(5), 400–449.

Source: RTU Water&Bioteh lab, B. Daļecka

Fungi for wastewater treatment

- Bacteria are conventionally are used for wastewater treatment, but it is not effective in breaking down recalcitrant organics such as antibiotics and endocrine system disrupting organics
- We have learned to use fungi as the primary step for wastewater treatment, providing low residence time and no need for pH adjustment (experiments are running now)

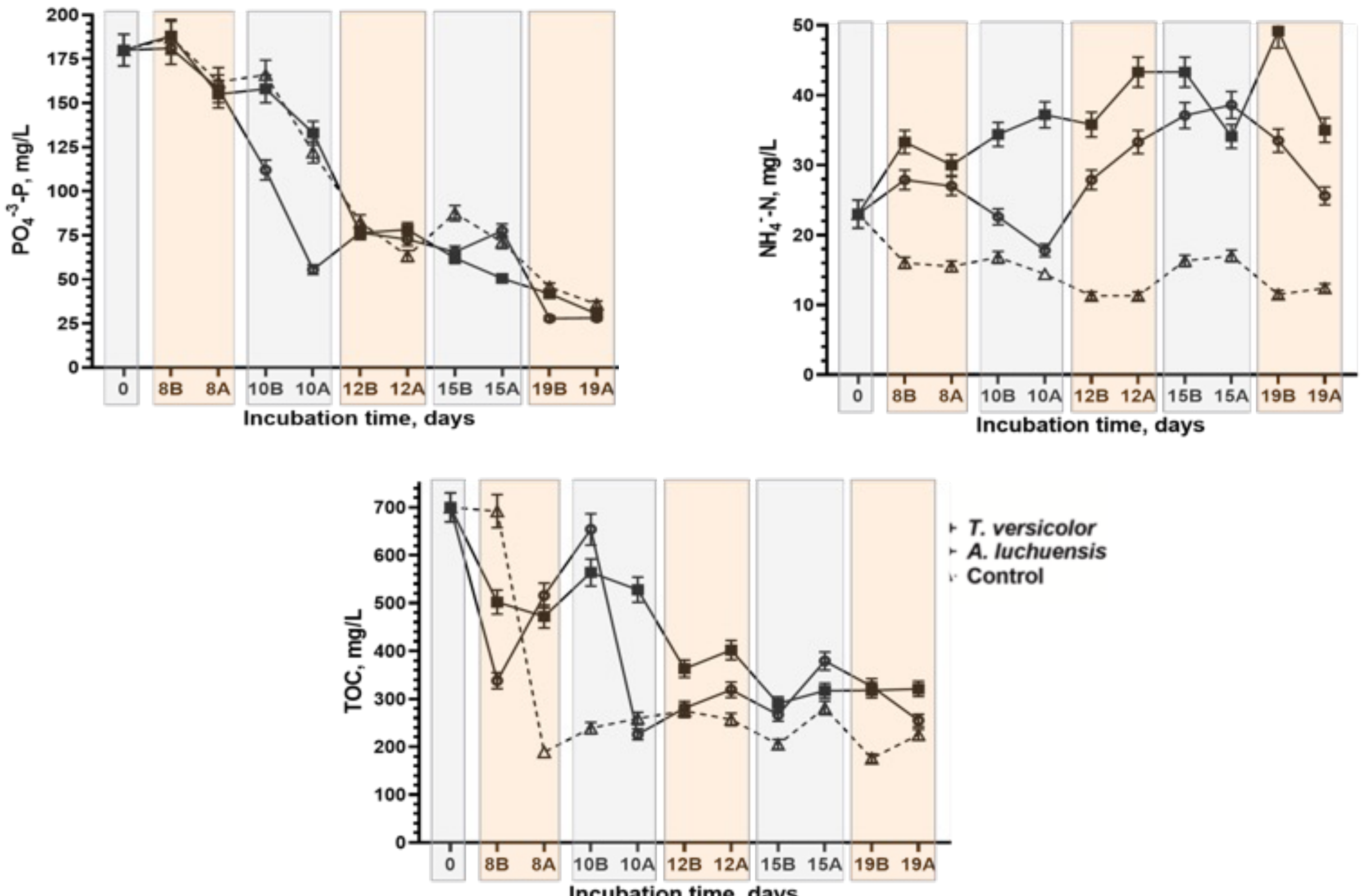
Nutrient removal in pilot-scale



Source: RTU Water&Bioteh lab, B. Daļecka

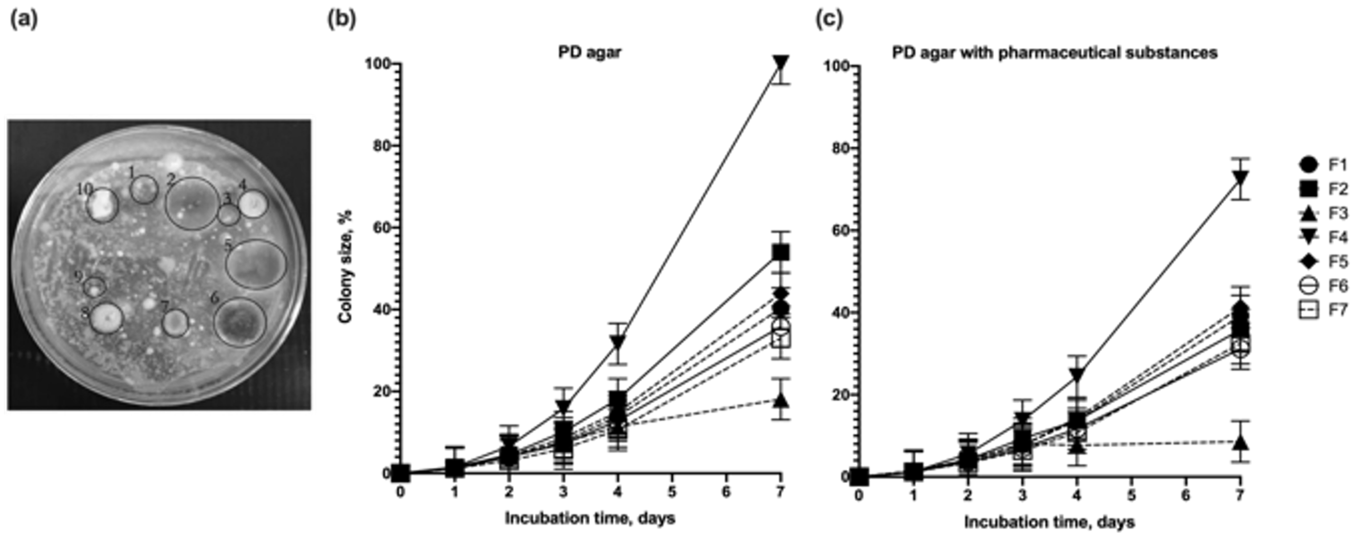
Nutrient removal in pilot-scale

P, N, and TOC reduction from non-sterile wastewater by *T. versicolor* and A. *luchuensis*

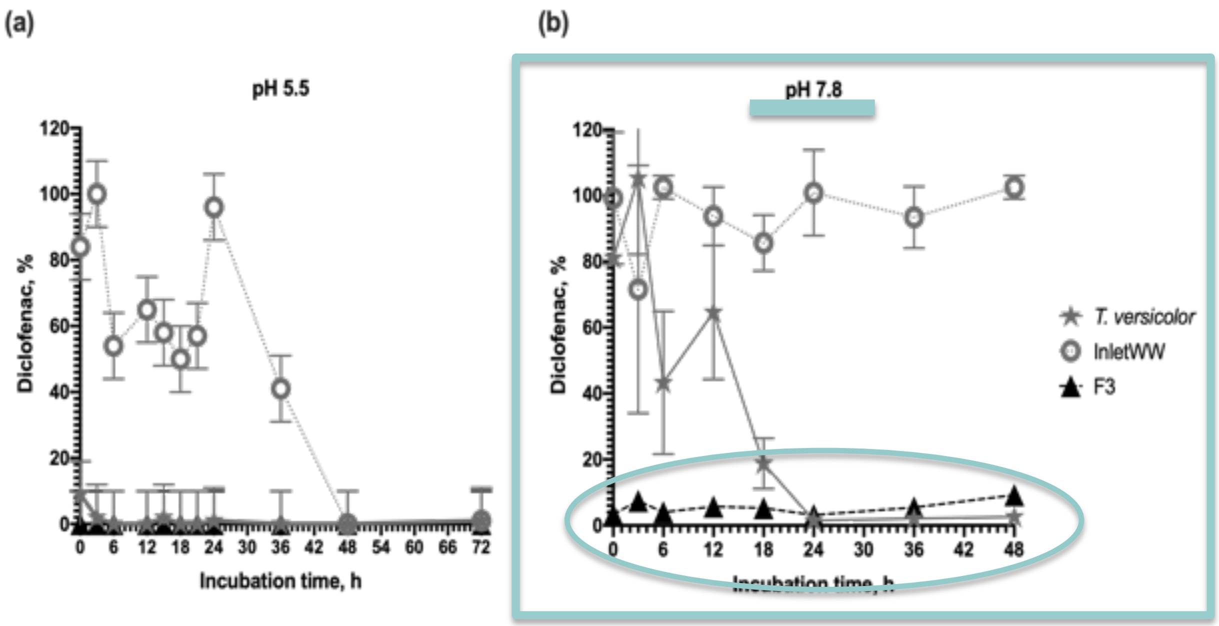


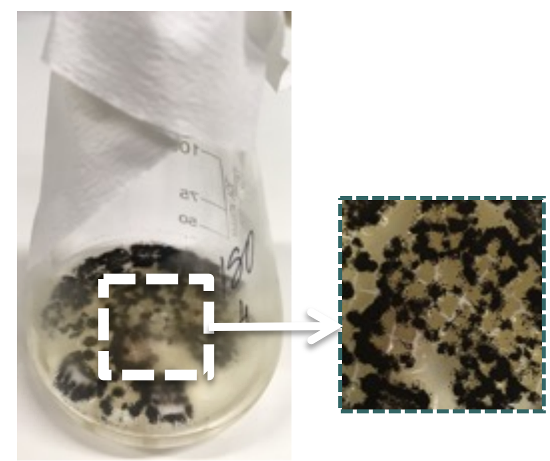
Source: RTU Water&Bioteh lab, B. Daļecka

Isolation and test the removal effieciency of isolates



A. luchuensis

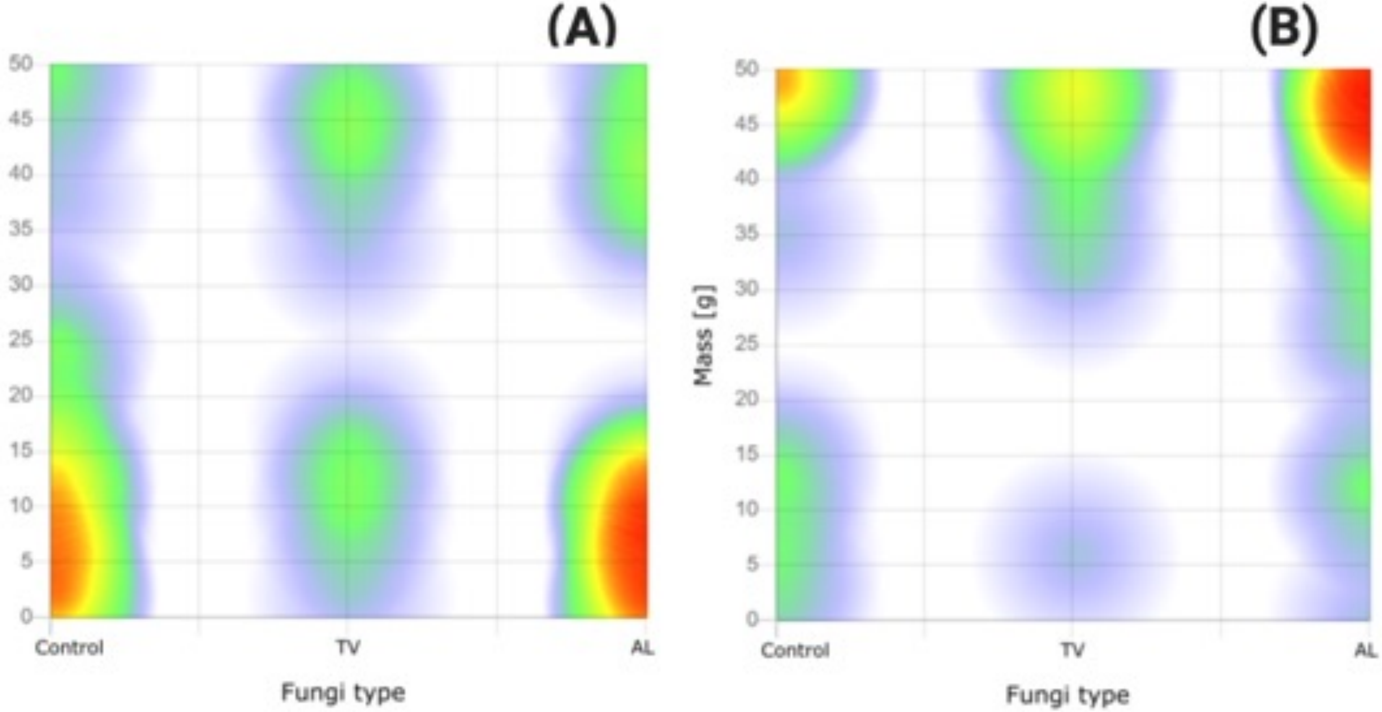


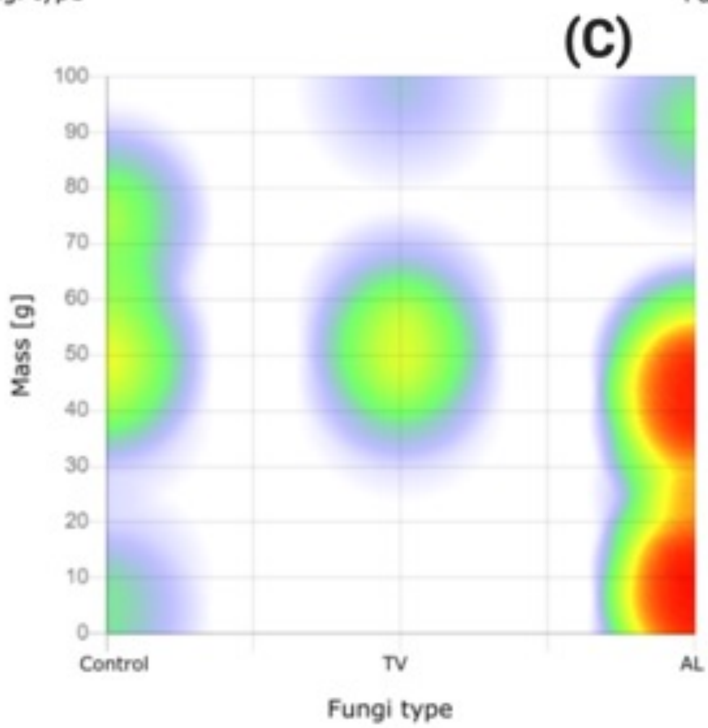


NON-STERILE

Source: RTU Water&Bioteh lab, B. Daļecka

AI based platform analysis and comparison of ROIs

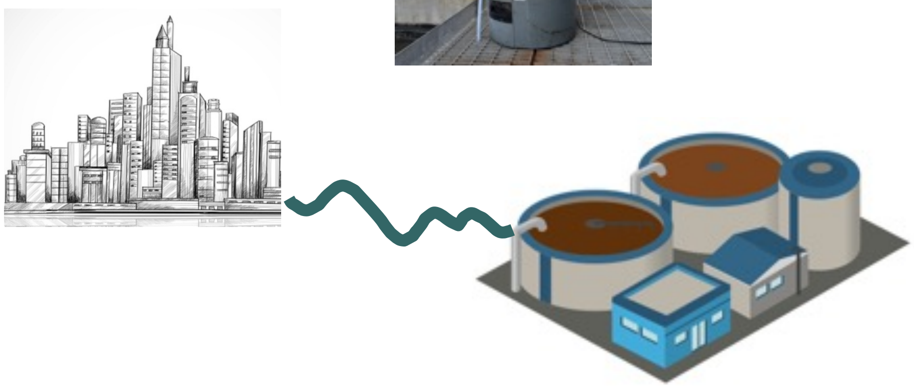


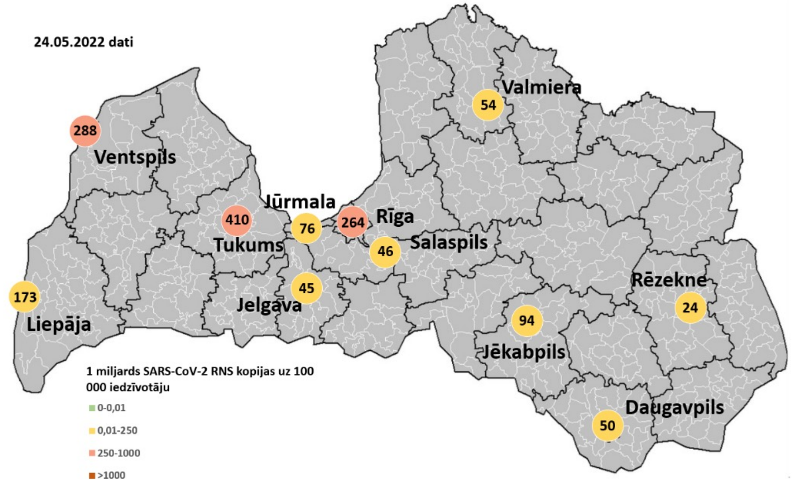


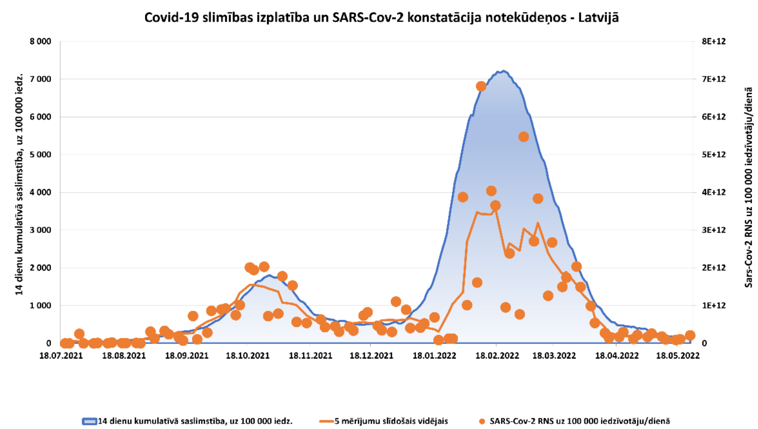
AI based platform analysis and comparison of ROIs for T. versicolor (TV), A. luchuensis (AL), and negative control without fungal biomass addition (A) after bioaugmentation; (B) after pharmaceutical removal; (C) after all incubation time of 35 days in order to model the optimal biomass addition and selection of fungi for fungal bed pelleted bioreactor optimal operation to remove pharmaceutical substances from wastewater (red - high, green – medium, blue – low, white - zero probability).

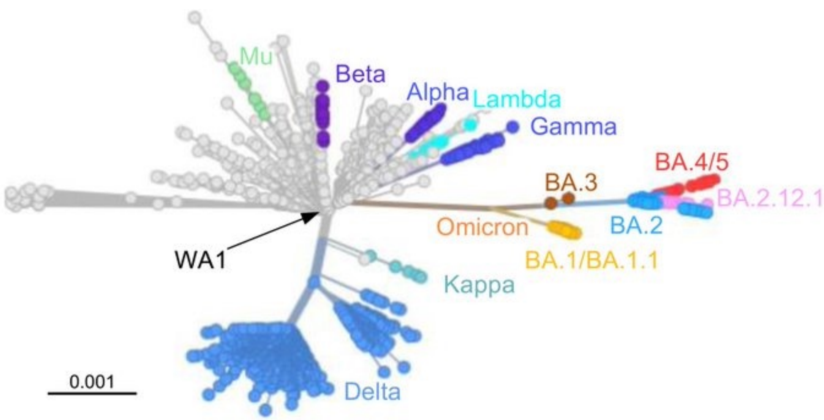
Source: RTU Water&Bioteh lab, B. Daļecka

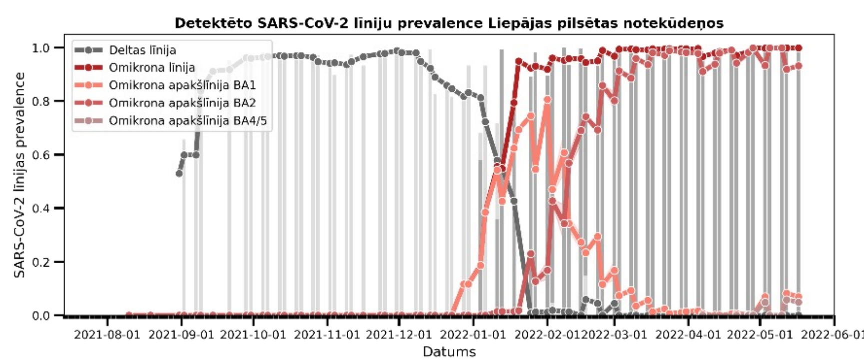
Wastewater epidemiology





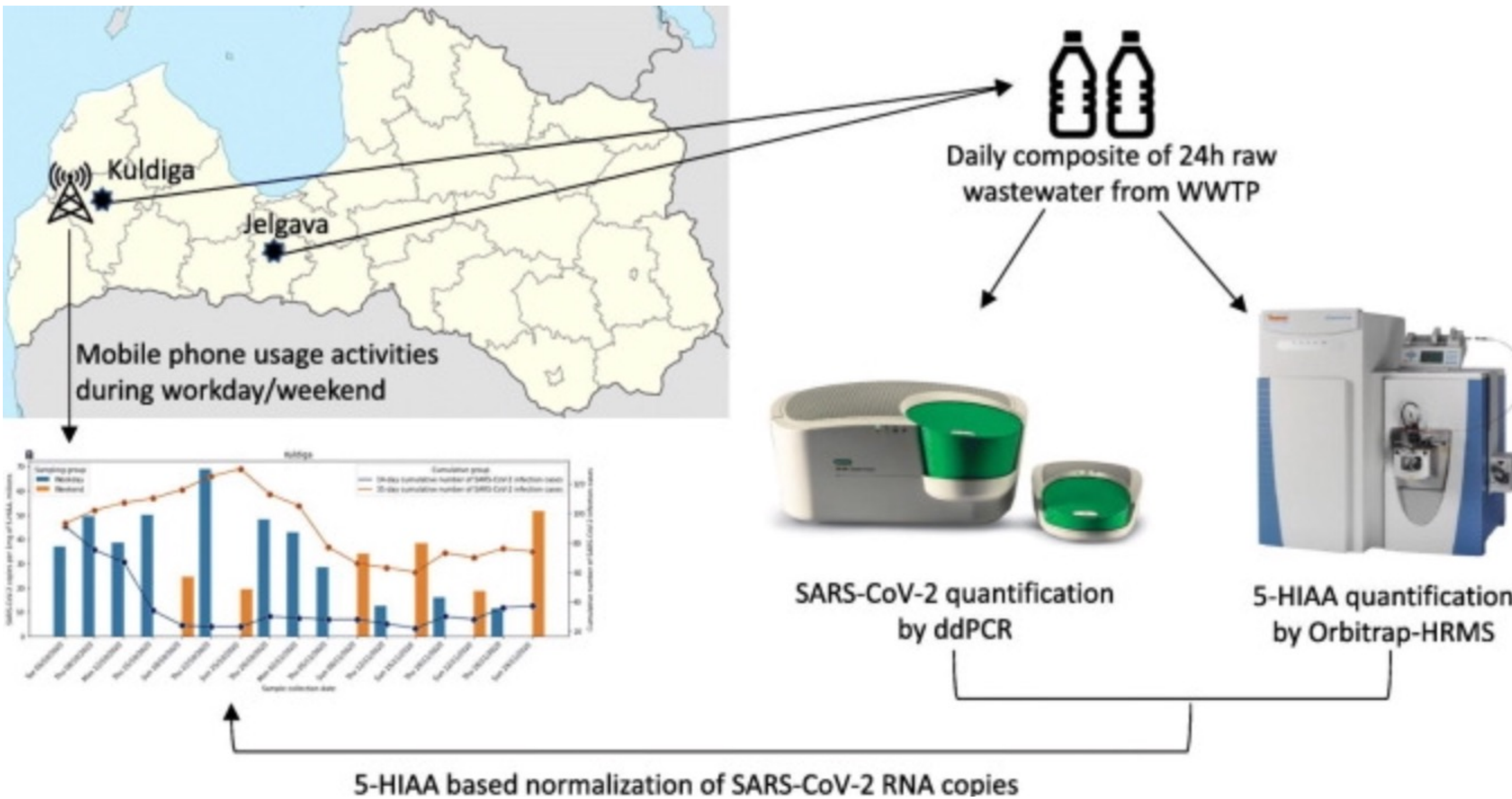


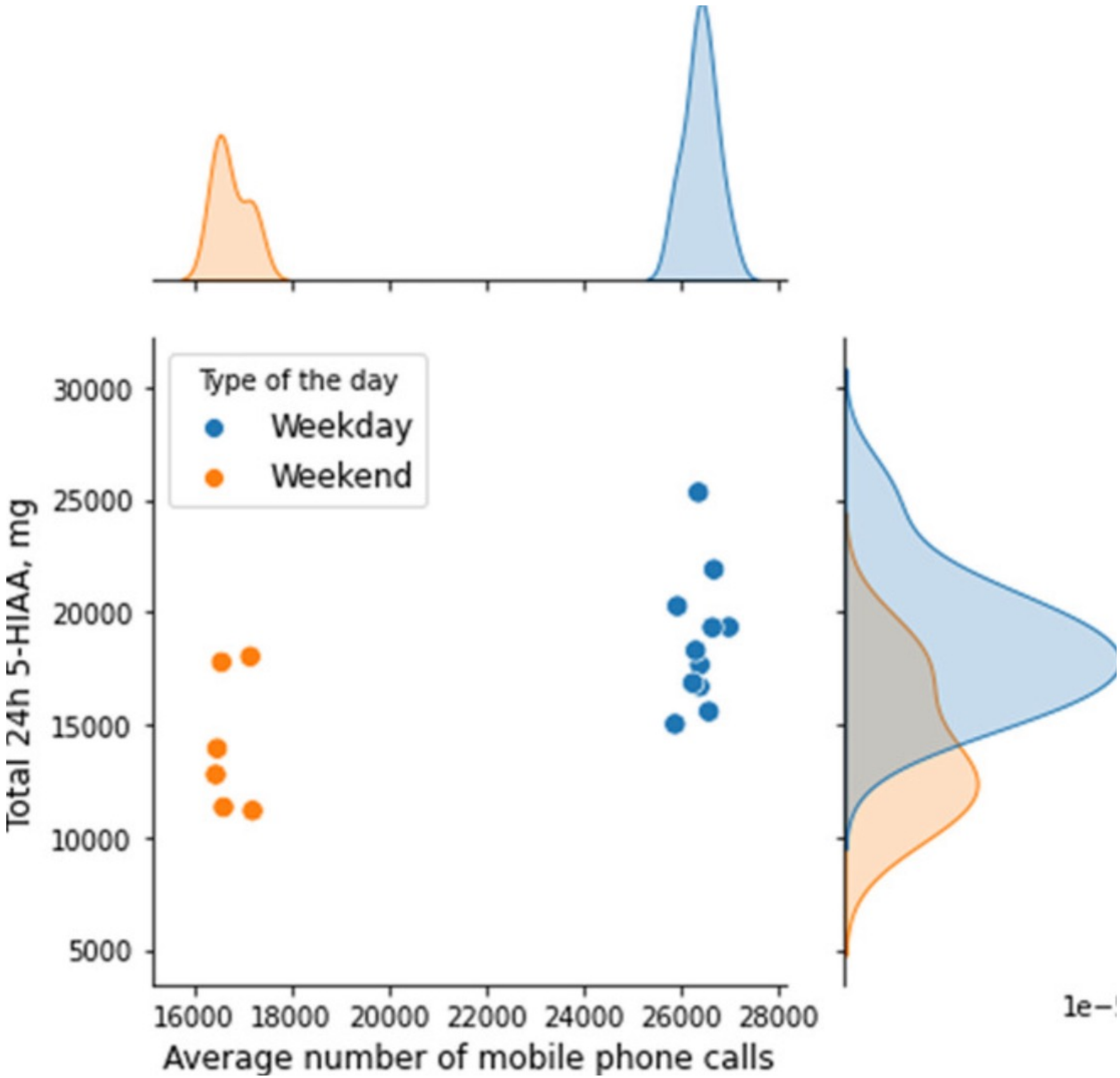




Source: RTU Water&Bioteh lab, S.Dejus, R.Ozols, U. Dumpis et al

Source: Dita et al 2022



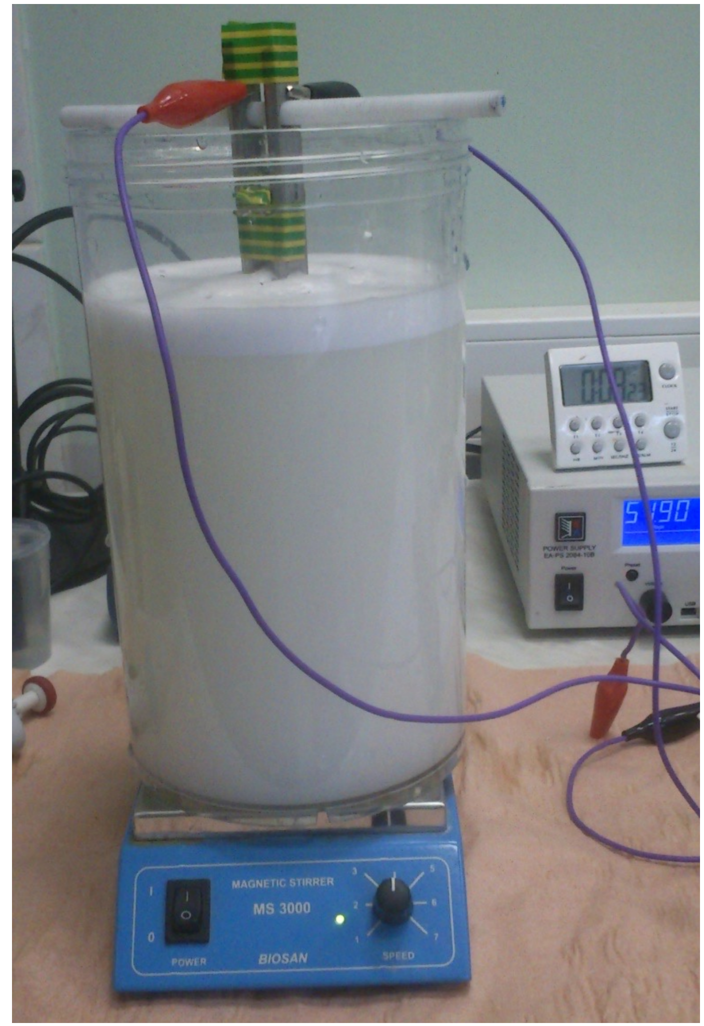


Type of the day
Weekday
Weekend
30000
25000
20000
15000
10000
5000
Total 24h 5-HIAA, mg
16000
18000
20000
22000
24000
26000
28000
Average number of mobile phone calls
1e−

Industrial wastewater

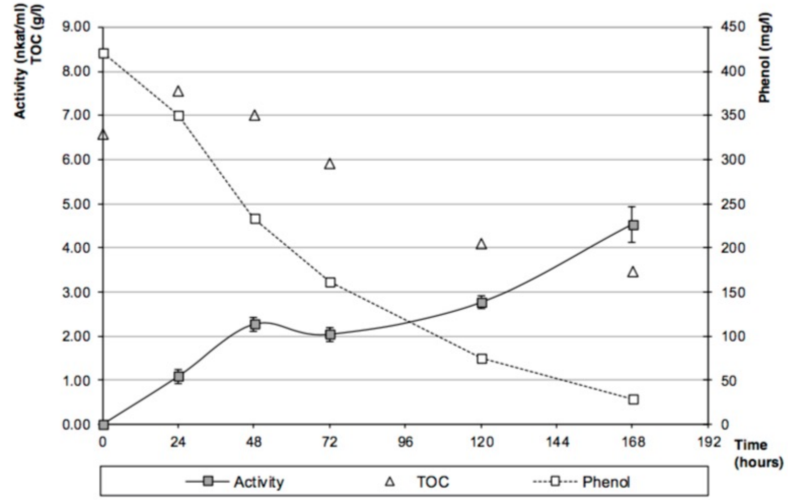
Removal of heavy metals from glass fiber industry: splitting wastewater flow

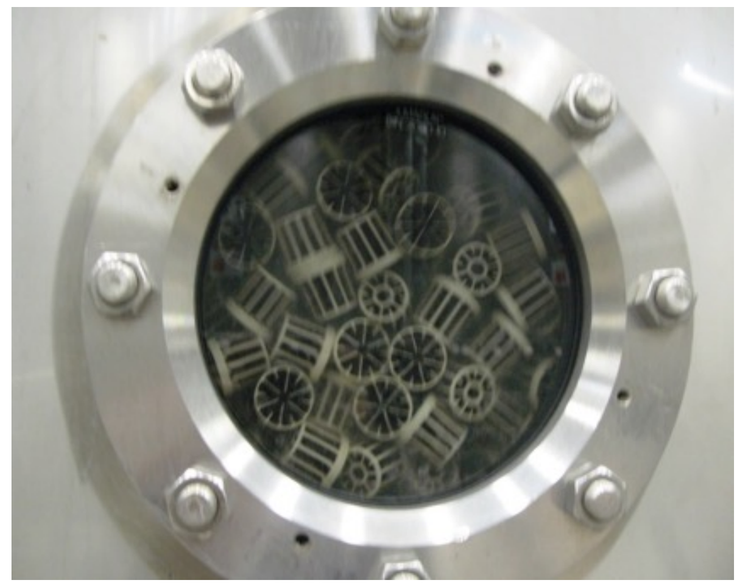
VALMIERA GLASS®



Source: RTU Water&Bioteh lab, J.Rubulis

http://www.blueboxresearch.com





AstraZeneca, Sodertalje, Sweden

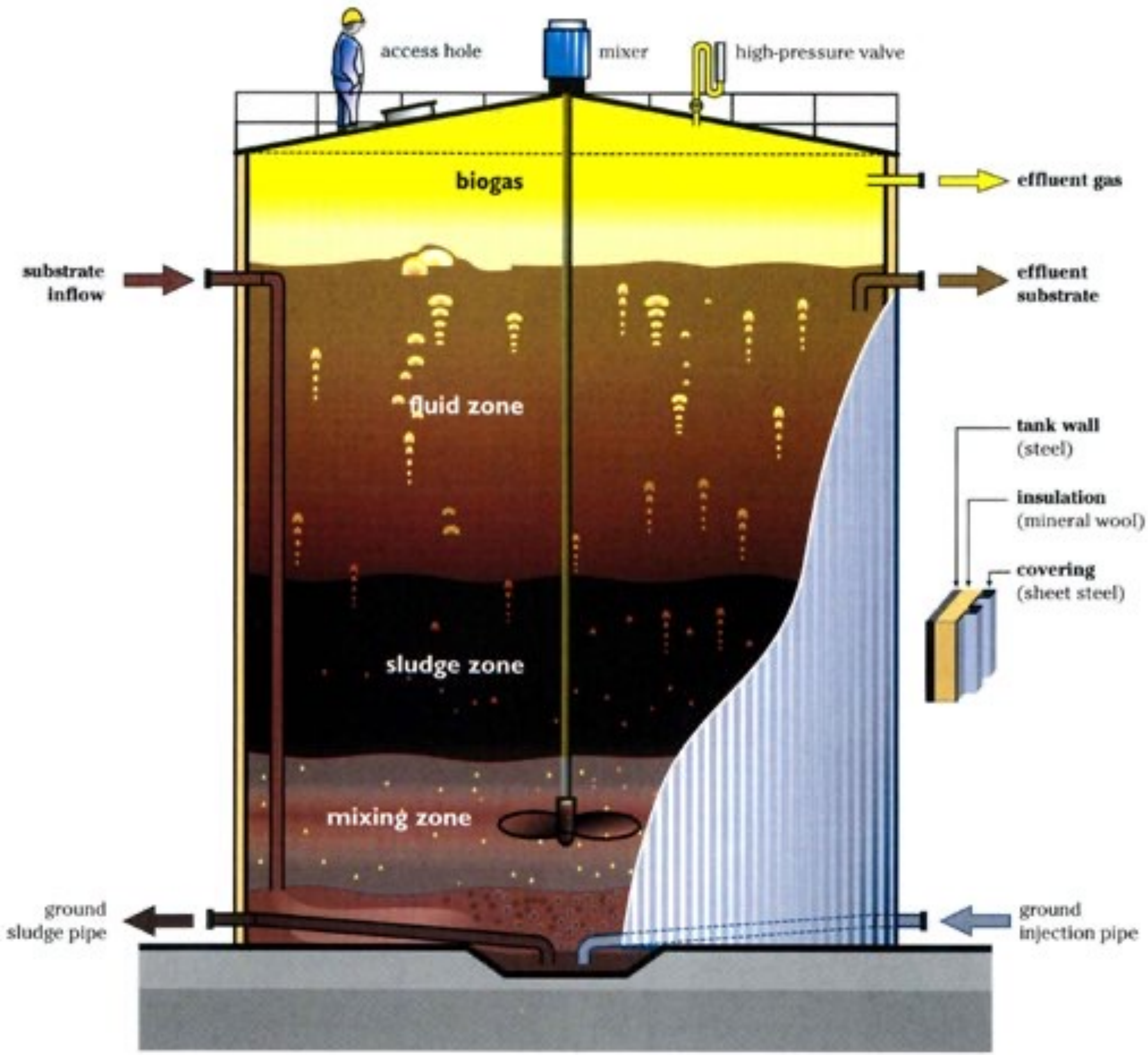
The Open Biotechnology Journal, 2015, *9*, (Suppl 1-M10) 93-99 93

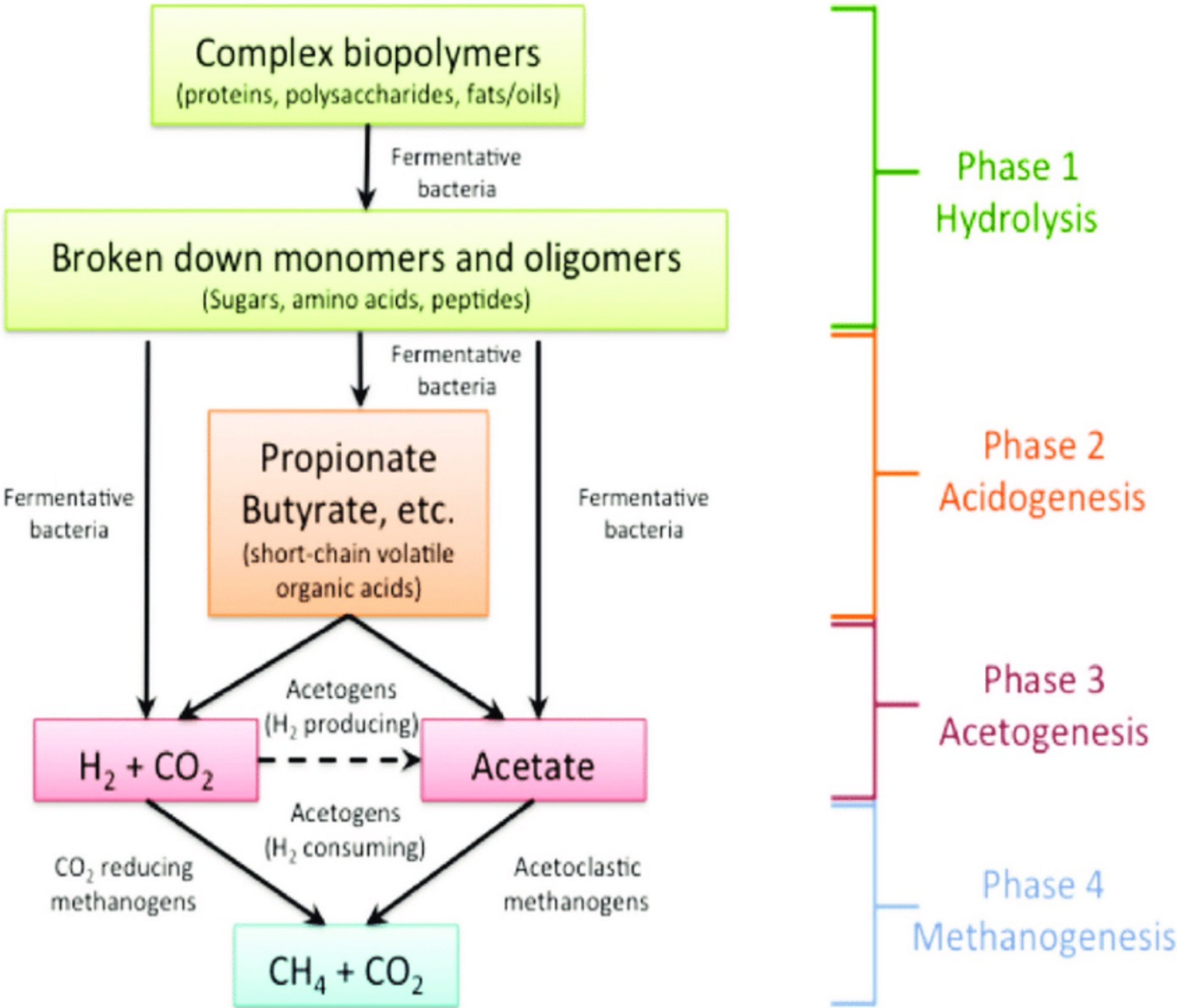
Open Access

Factors Governing Degradation of Phenol in Pharmaceutical Wastewater by White-rot Fungi: A Batch Study

Source: RTU Water&Bioteh lab, M. Bernāts

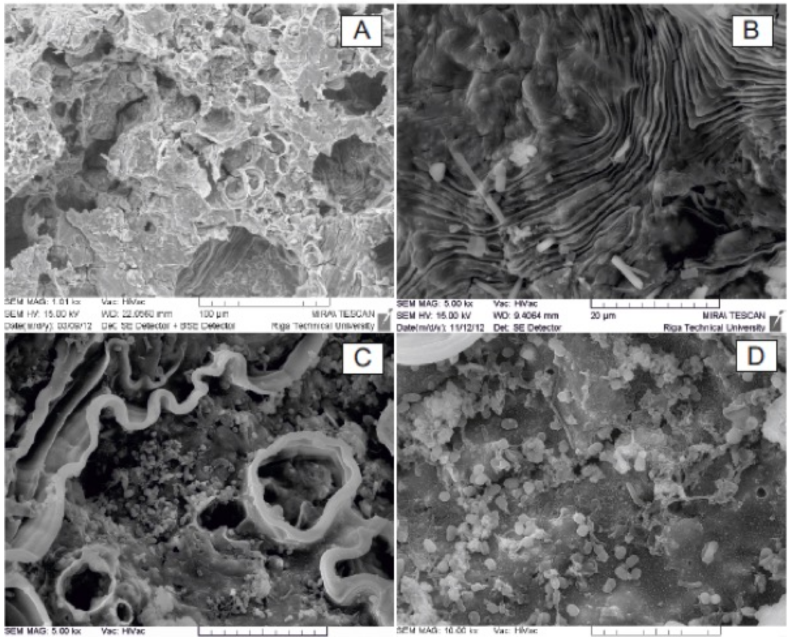
Sludge treatment

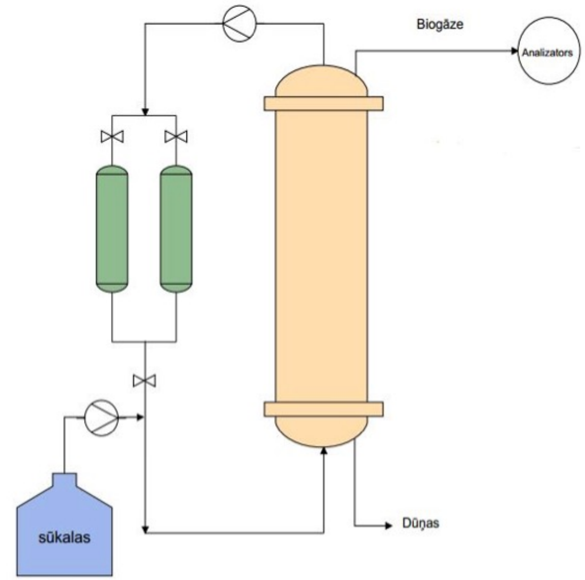

access hole
mixer
high-pressure valve
biogas
effluent gas
substrate inflow
effluent substrate
fluid zone
tank wall (steel)
insulation (mineral wool)
covering (sheet steel)
sludge zone
mixing zone
ground sludge pipe
ground injection pipe



Schematic representation of anaerobic digestion (source: https://www.e-education.psu.edu/egee439).

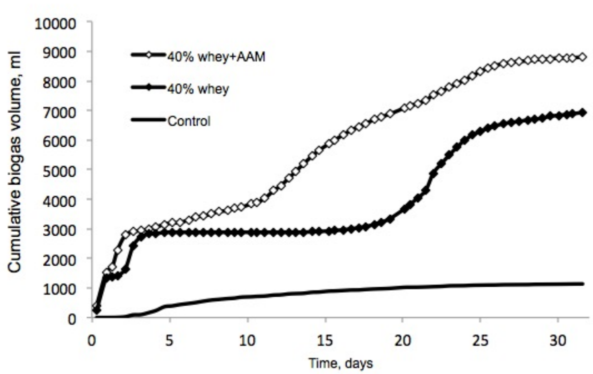
Biogas from sludge or milk wastewater

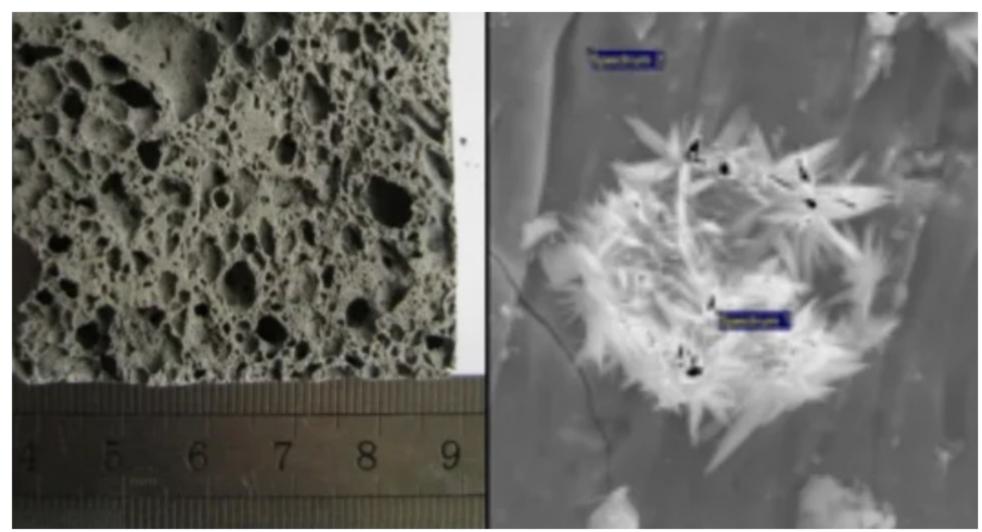




Natural pH buffer

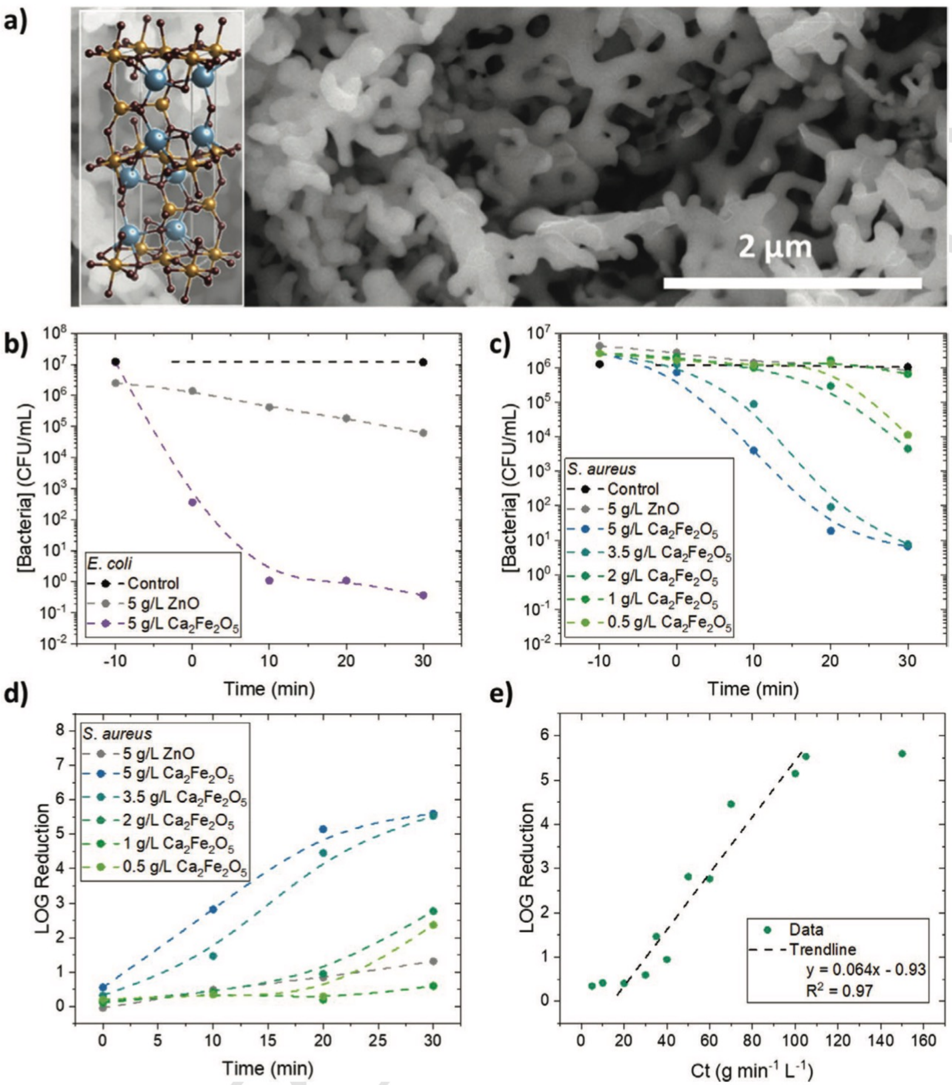
Stabilizes pH thus increases yield of gas





Ruǵele et al 2014

Sludge desinfection with affordable active materials



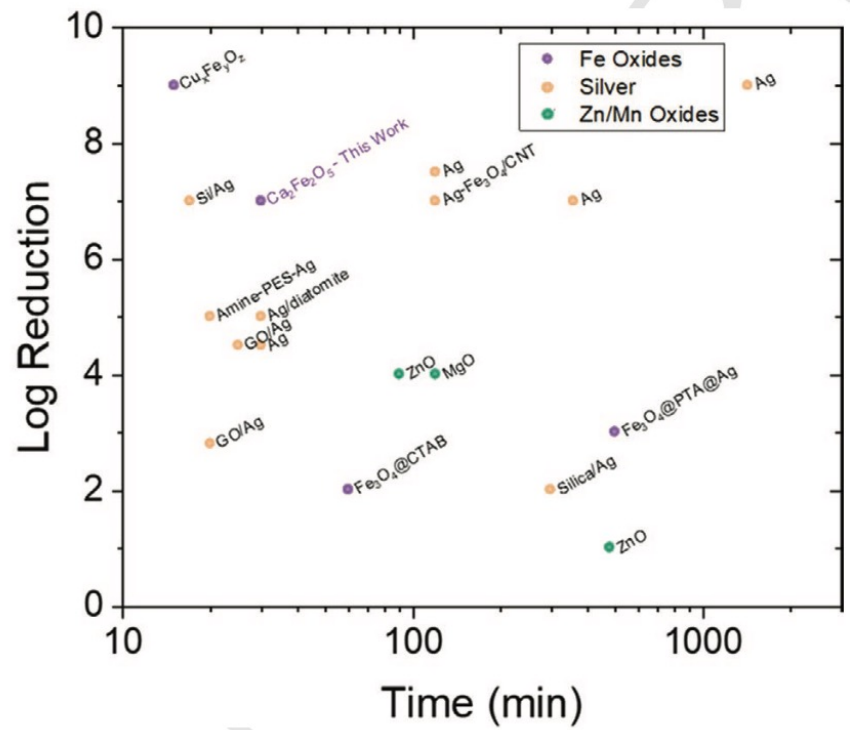
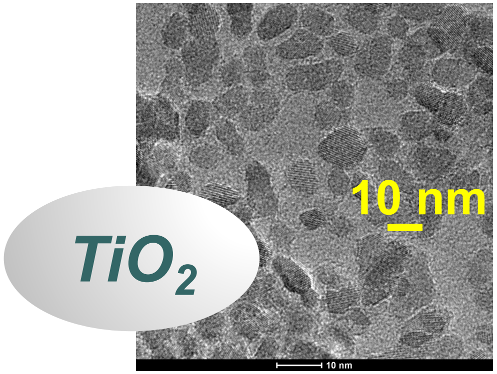


Figure 8. Comparison of disinfection performance of various materials with data in literature (see Table S7 of the Supporting Information for full details).[40–56]

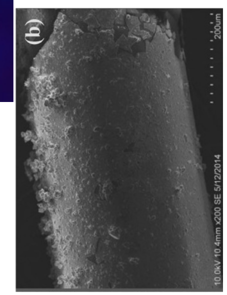
Vanags et al 2021

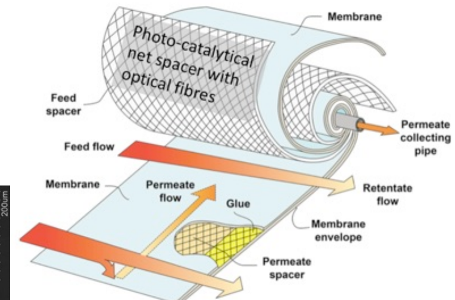
ADVANCED SUSTAINABLE SYSTEMS
DOI: 10.1002/adsu.202100130
www.advsustainsys.com

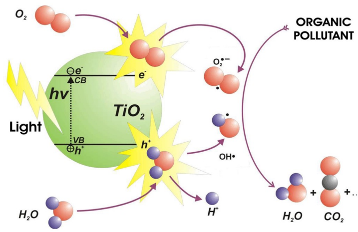


+

Side-glowing optical fibers coated with catalysts







A.O. Ibhadon, P. Fitzpatrick, *Catalysts* 2013, *3*(1), 189-218

$$O_2 + e^- \rightarrow O_2^{\bullet -}$$
$$O_2^{\bullet -} + 2H^+ + e^- \rightarrow H_2O_2$$
$$H_2O_2 + H^+ + e^- \rightarrow OH^\bullet + H_2O$$

$$h^+ + H_2O \rightarrow H^+ + OH^\bullet$$
$$2h^+ + 2H_2O \rightarrow 2H^+ + H_2O_2$$

Inexpensive catalysts to be tested: TiO_2 brownmillerite

$Ca_2Fe_2O_5/Fe_2O_3$

The gas technology it has been implemented…

NeoZeo Biogas Upgrading Modules

Fuel from lignocellulose wastes

Enzymes produced with low energy

Continuous process of enzyme production

Fuels and valuable chemicals from alternative resources

Raw materials (resources) → Pre-treatment → Hydrolysis → Fermentation → Product recovery

Locally available, abundant and renewable biomass

+ sludge

Hydrolytic enzyme production from white rot fungi

Simple pre-treatment technologies validated at laboratory and pilot scale

Fermentable carbohydrate production

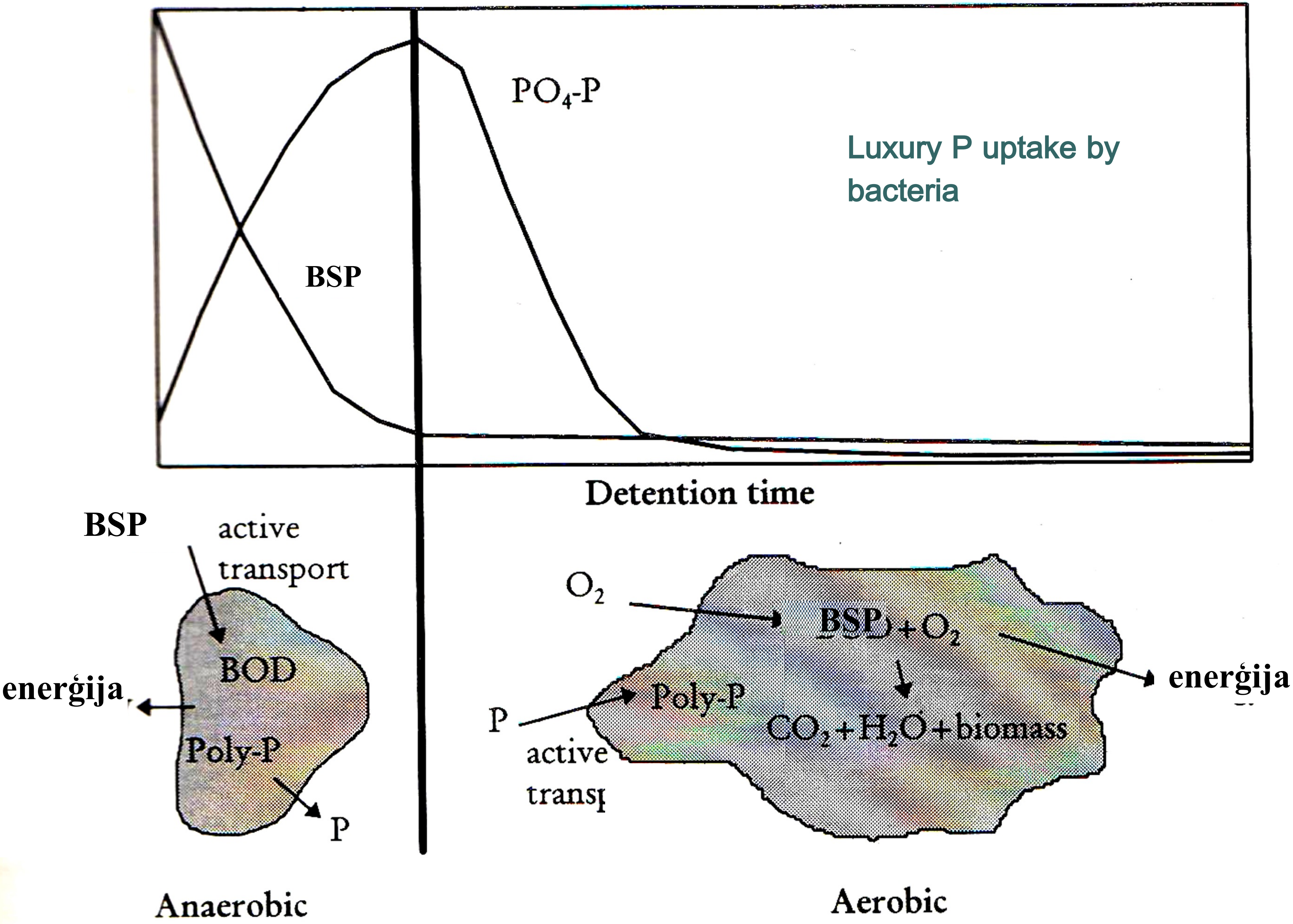
Batch and reactor scale alcohol (ethanol and butanol) fermentation

Alcohol recovery with gas stripping and other non-destructive methods

WATER RESEARCH BIOTECHNOLOGY

Source: RTU Water&Bioteh lab, L. Mežule

Posttreatment from nutrients

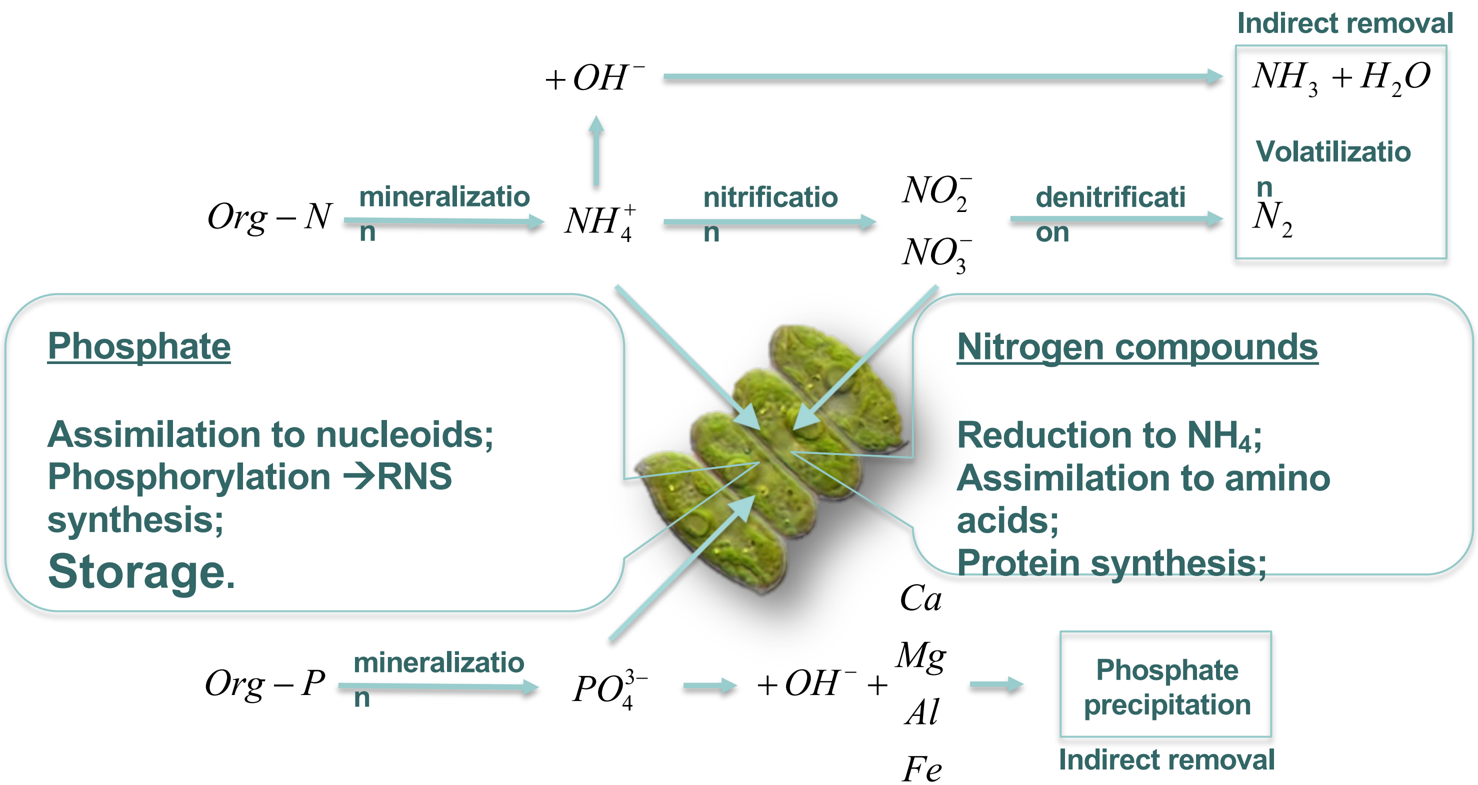


PO4-P
Luxury P uptake by bacteria
BSP
Detention time
BSP
active transport
BOD
energija
Poly-P
P
O2
BSP + O2
energija
P
Poly-P
CO2 + H2O + biomass
active transp
Anaerobic
Aerobic

Algea for postreatment of wastewater

- Using our experience of controlling nutrients metabolisms in microbes we are developing methods for removal of phosphorus and nitrogen with algae
- We have demonstrated that by imposing the stress to algae it is possible to enhance phosphorus uptake several times, thus reducing size of bioreactors and increasing their efficacy
- To reduce energy consumption for algae harvesting we develop artificial food chain approach using zooplankton and higher animals and plants

Nutrient removal mechanisms by algae

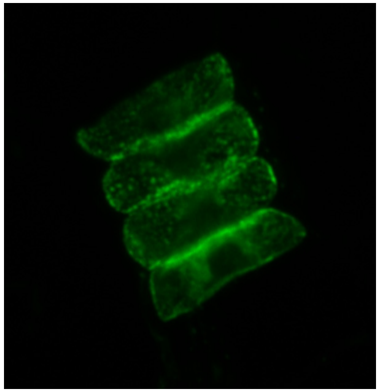


Source: RTU Water&Bioteh lab, A. Lavrinovičs

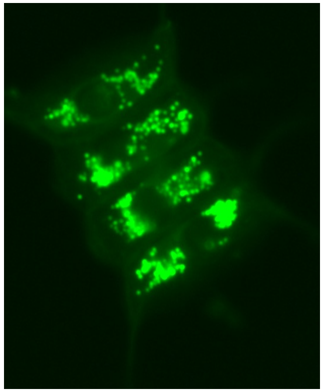
Phosphorus storage

- Stored as Polyphosphate granules within the algal cells → used at low external phosphorus conditions; **3 – 5 times**
- Luxury uptake – consumes more phosphorus than necessary for cell metabolism;
- *Usual* Poly-P content – 1.5% of total cell weight;
- Enhanced luxury uptake[1] :
  - Temperature;
  - Light;
  - External P availability;
- **Our approach - starvation and recirculation.**

DAPI staining and fluorescent microscopy



No Poly-P storage

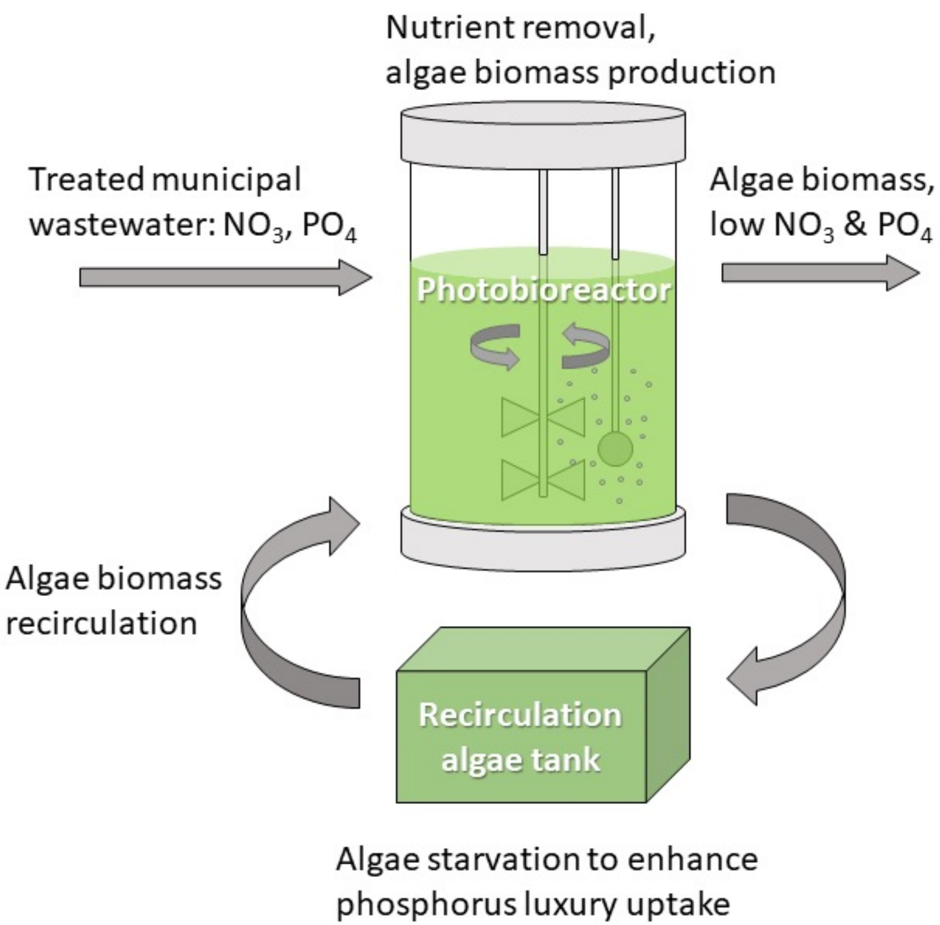


Poly-P granules

[1] Powell, N.; Shilton, A. N.; Pratt, S. and Chisti, Y. 2008. Factors influencing luxury uptake of phosphorus by microalgae in waste stabilization ponds, *Environmental Science and Technology*, 42(16), pp. 5958–5962.

Source: RTU Water&Bioteh lab, A. Lavrinovičs

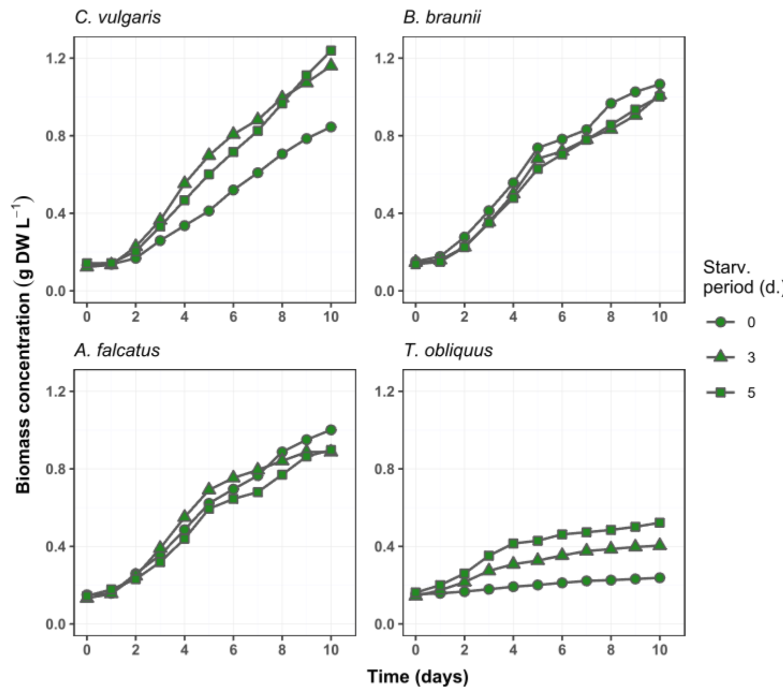
Enhanced phosphorus luxury uptake



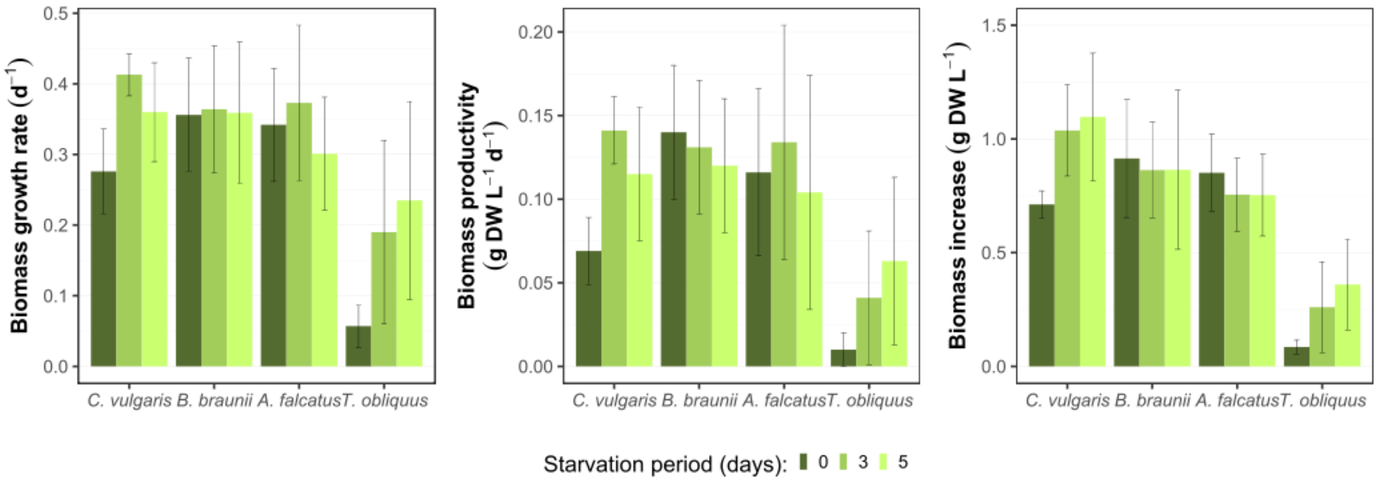
Source: RTU Water&Bioteh lab, A. Lavrinovičs

Table 3. Nutrient removal rates and biomass uptake kinetics (mean values, n = 3)

	Starvation period (days)	Nutrient removal (%)		Biomass nutrient consumption (Y), (mg N(P) g⁻¹ DW)		Nutrient uptake rate (k), (d^{-1})	
		NO_3-N	PO_4-P	NO_3-N	PO_4-P	NO_3-N	PO_4-P
C. vulgaris	0	97.7	96.6	57.70	31.70	209.07	114.87
	3	98.9	99.2	29.75	21.12	72.04	51.14
	5	98.1	99.4	34.76	22.12	96.68	61.53
B. braunii	0	99.3	97.3	29.19	15.63	72.77	38.96
	3	99.0	99.1	28.17	16.79	66.26	39.50
	5	98.6	99.2	29.23	15.06	68.72	35.40
A. falcatus	0	98.7	97.7	44.32	25.95	129.40	75.77
	3	98.4	99.2	35.31	23.88	94.74	64.08
	5	98.7	91.2	49.87	17.89	165.47	59.37
T.obliquus	0	10.2	44.5	32.20	111.56	563.02	1.10
	3	10.8	62.4	12.50	49.29	65.66	2.02
	5	3.6	37.8	2.97	5.67	12.65	0.36



Citation: Lastname, F.; Lastname, F.; Lastname, F. Title. *Microorganisms* **2021**, *9*, x. https://doi.org/10.3390/xxxxx



Source: RTU Water&Bioteh lab, A. Lavrinovičs

Alternative 5: Eco-machine (John Todd Ecological Design)

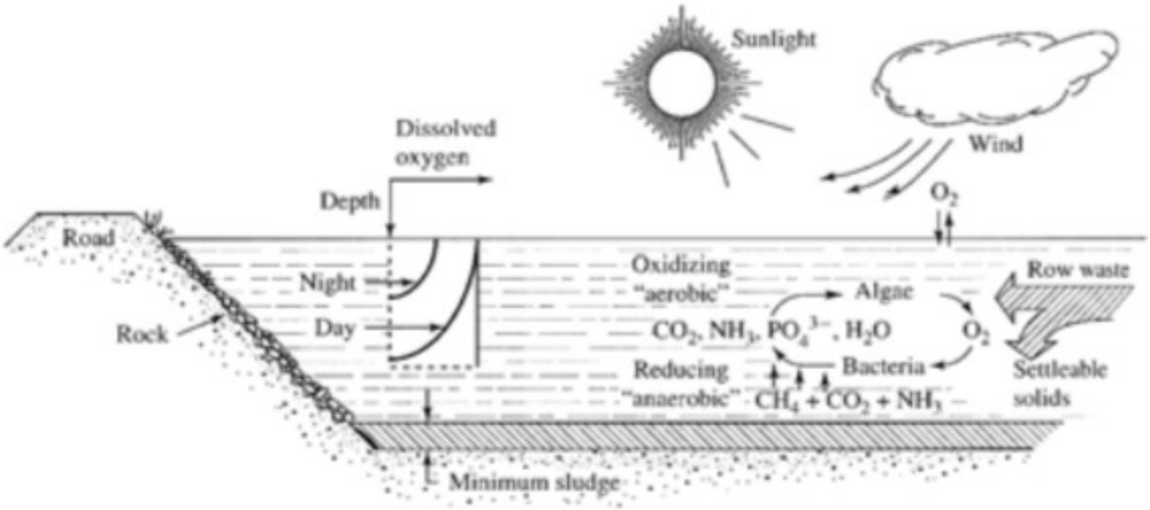
www.toddecological.com/

inside

Rest area and welcome center along Interstate 89 in Sharon, Vermont.

The wastewater from the toilets is treated on site by an eco-machine designed by John Todd.

Alternative 4: Aerated Lagoons and Stabilization Ponds



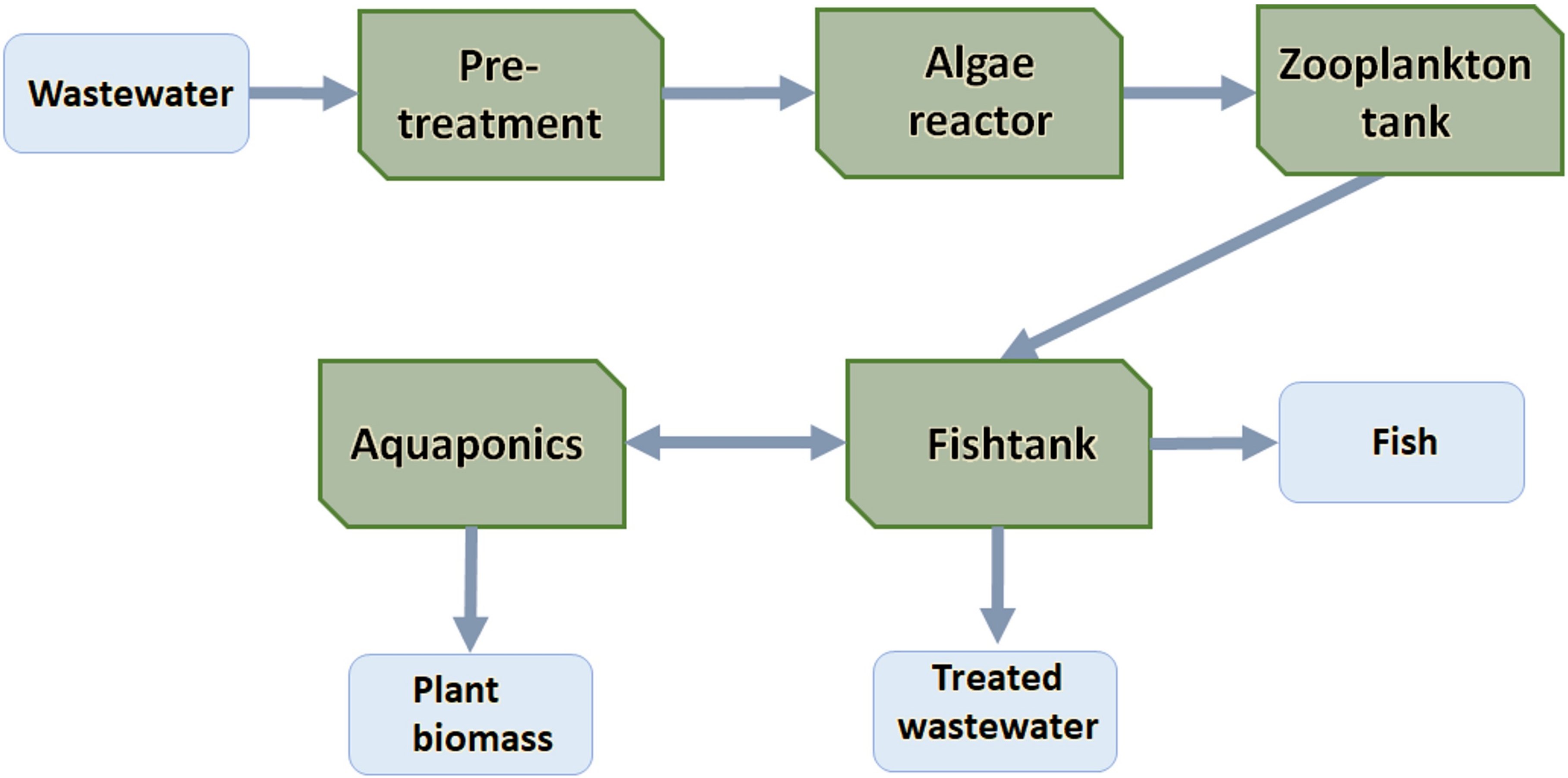
In this process, nature is essentially left to run its course, with or without a little help from aeration.

The system looks less technological and is thus better integrated in the landscape, but it occupies much more real estate. Odor may also be a nuisance.

ttp://www.lagoonsonline.com/technote5.htm

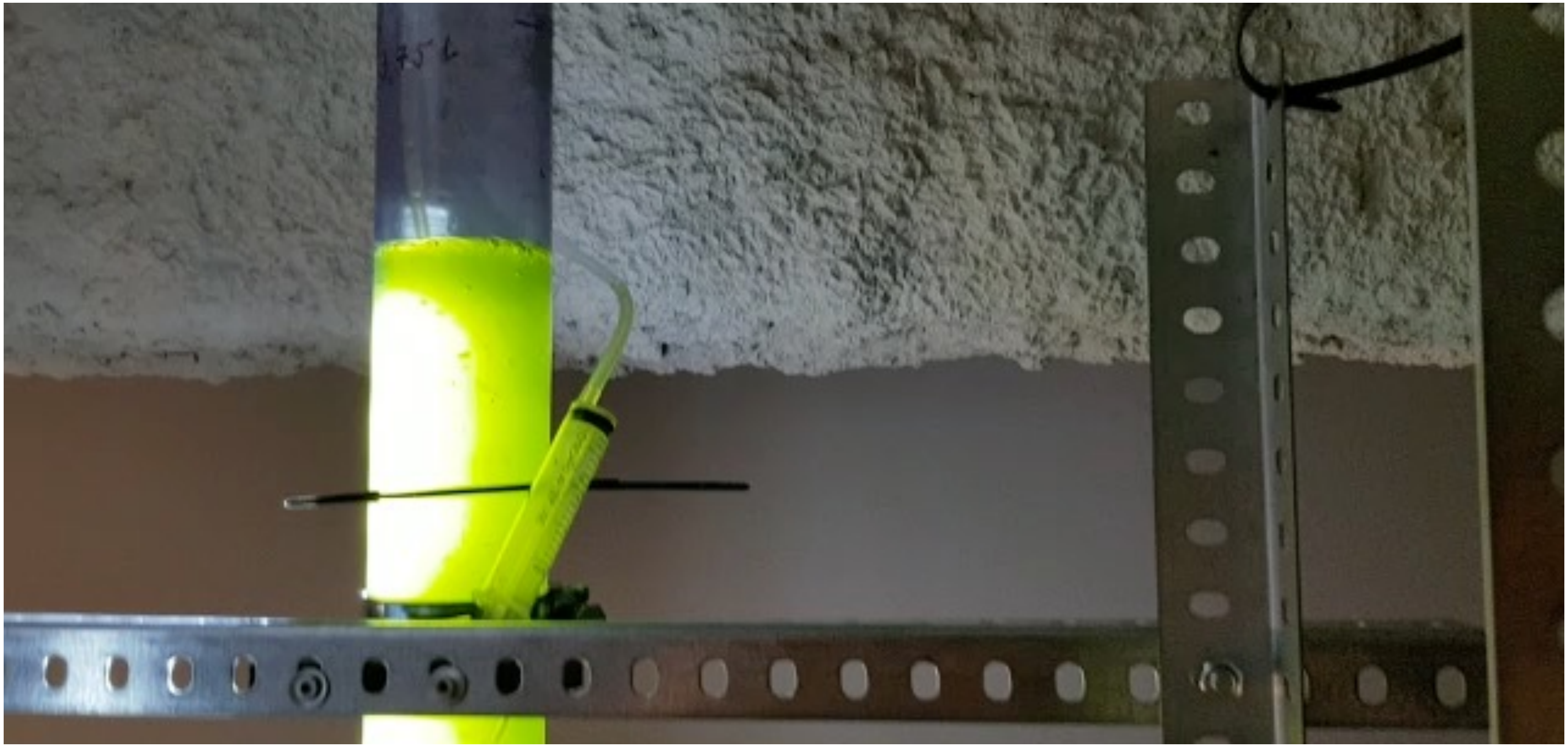
http://www.lagoonsonline.com

The concept



https://mobile.facebook.com/rtuzic/videos/280947025241391 4/?_rdr

A prototype developed by VIP students



Source: RTU Water&Bioteh lab, A. Lavrinovičs

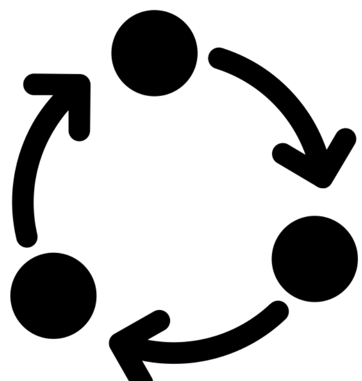
Proposal for the «life support systems»

Use of luxury P uptake of algae to enhance removal of nutrients from urine and wastewater

Source: RTU Water&Bioteh lab, T.Juhna

to encourage to do bioscience at home

zooplankton



SBR **algea**

fish and aquponic

Thank you!