Nordic Bioplastic Conference
April, 2025

Biopolymers from biological treatment plants: A golden group for the production of sustanaible polymers?

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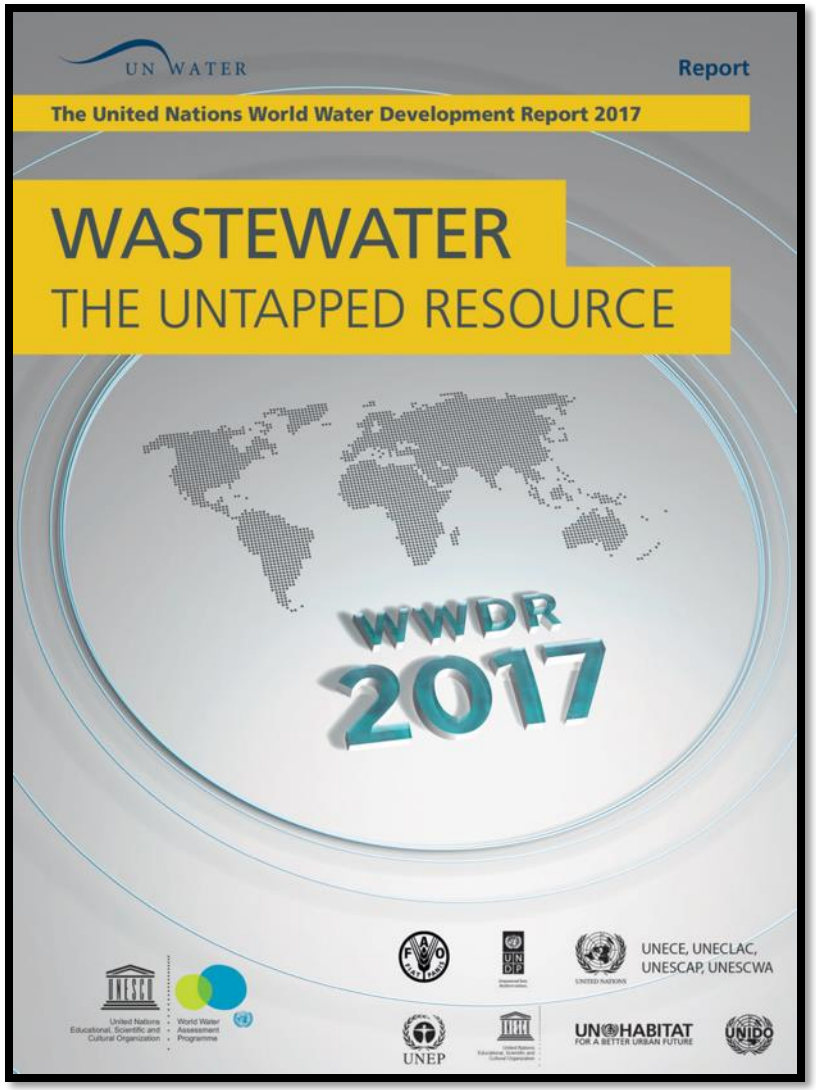
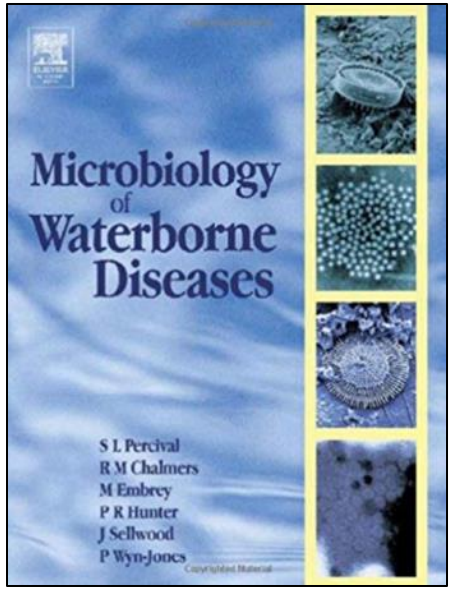
DENMARK



Yearly global production of wastewater:
> 350 km^3 (≈ 10-20% of freshwater withdrawals)

Only 20% is treated

- The rest is released to the environment!

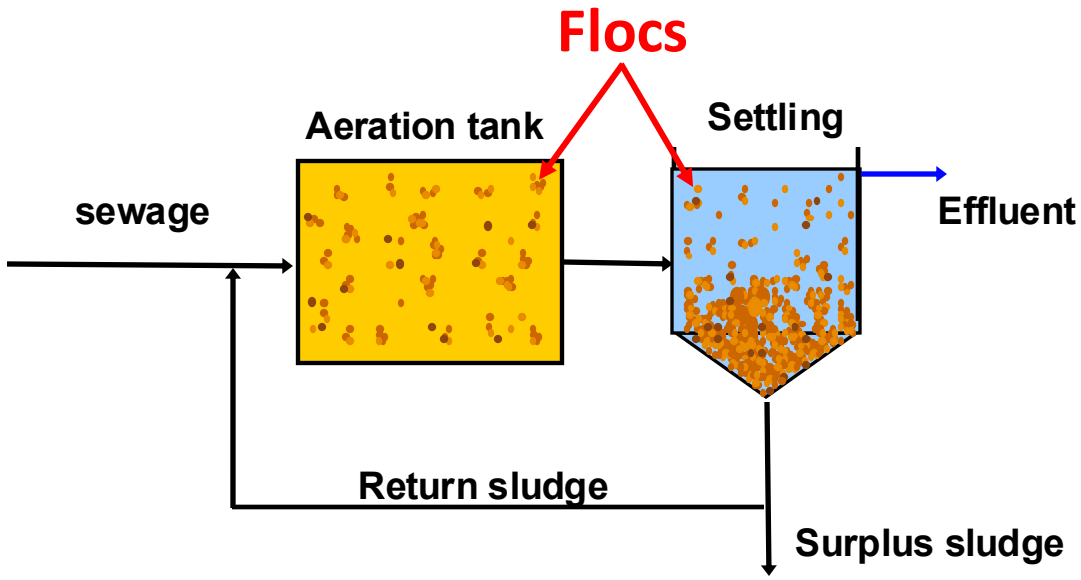


- **Sustainable source** of water, energy, nutrients and other recoverable materials

Sludge is not just sludge – sludge is **activated** sludge

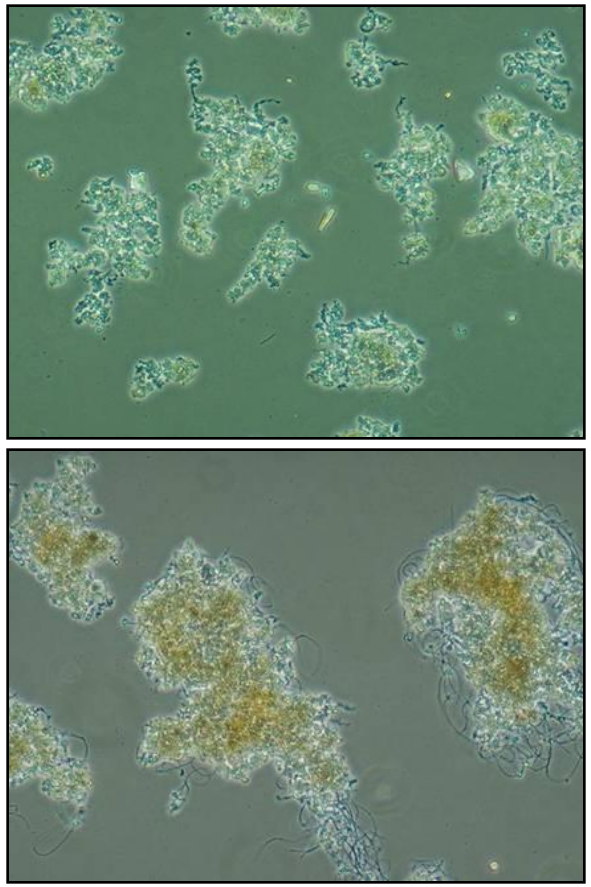
Sewage treatment

- Before 1900: Septic tanks (anaerobic processes)
- Around 1900: Aeration of tank and filters
- 1913-1914: **Activation of sludge** by aeration and return sludge (alive!)

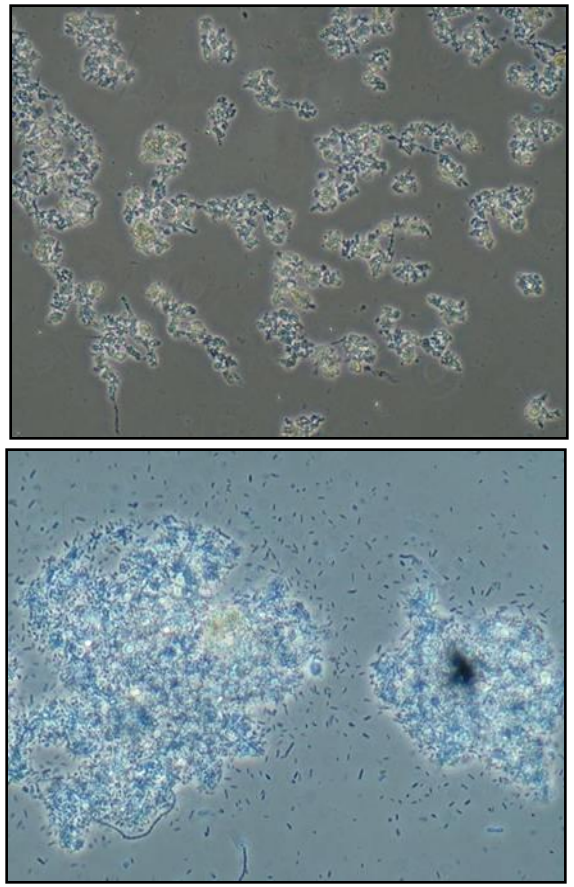


Ardern and Lockett
Manchester, UK, 1914

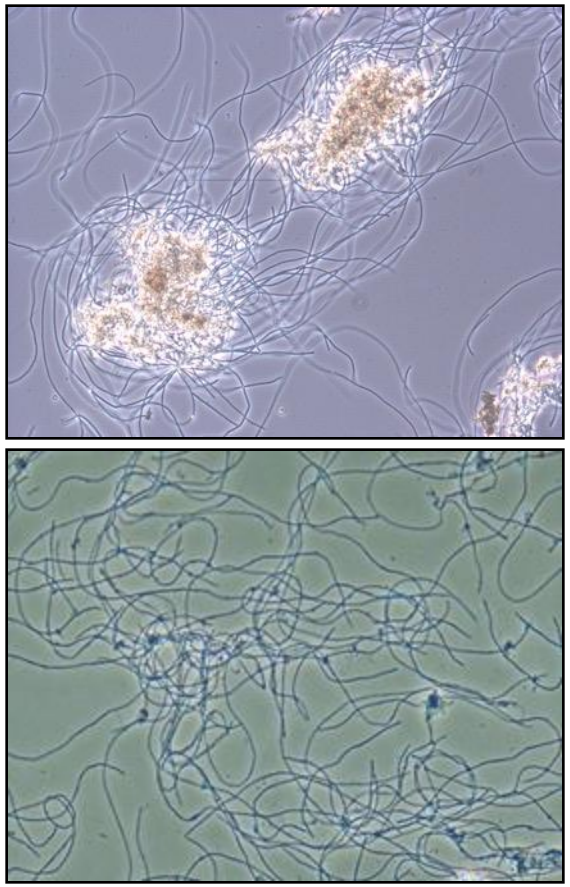
Activated sludge flocs – the key units – exist in many forms



Normal activated sludge flocs

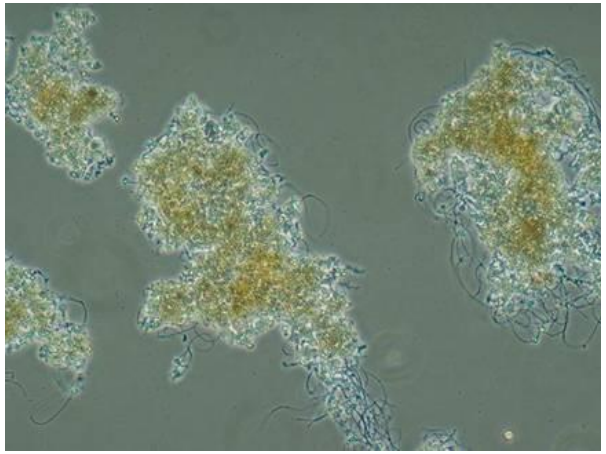


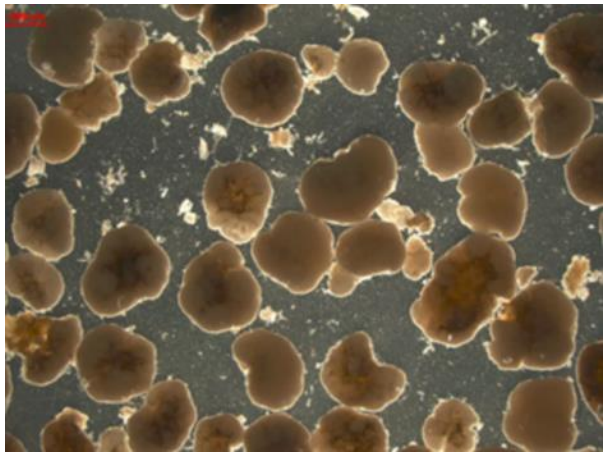
Small or weak flocs



Many filamentous bacteria

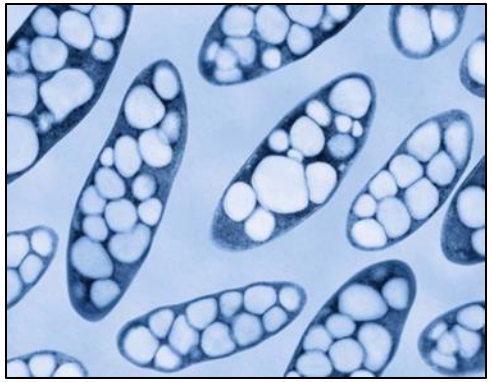
Recovery of biomass materials from wastewater treatment plant (WWTPs)

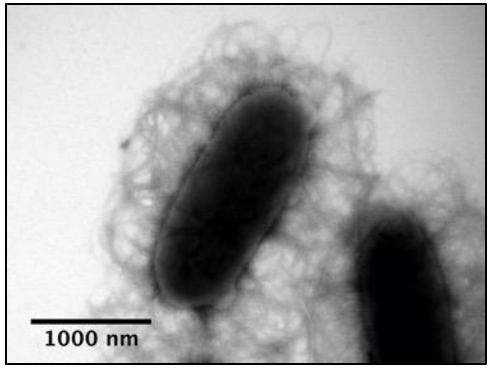




Biological flocs and granules

Storage producs





Extracellular biopolymers

Bioplastics

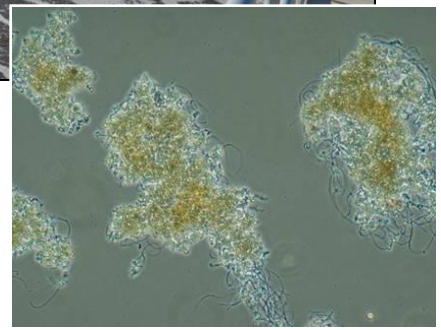
Phosphate/ammonium

Composite materials

Recovery of extracellular polymers from wastewater treatment residuals as a new circular biopolymer

NNF-Challenge 2022-2027

Goal: Convert one of the world's largest biowaste products – activated sludge from WWTPs – into high-value biomaterials



Activated sludge flocs

Biopolymer (EPS) extraction

Hydrogel

Composite materials

Bioplastics

Flame retardants

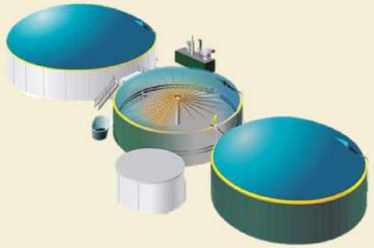
Largest plants in the world: treat wastewater from 3-8 mio persons

Deer Island Treatment plant, Boston

Best-practice today

Wastewater treatment

Excess microbial biomass



Biogas plant

Biogas

Excess biowaste

Fertilizers

REThiNk approach

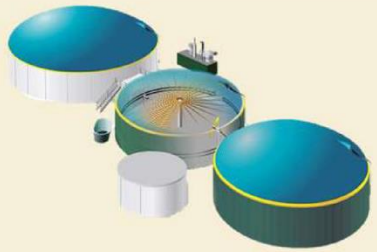
Wastewater treatment

Excess microbial biomass

Production facility

Pretreated residual biomass

Extracted EPS



Biogas plant

Biogas
(same amount)

Excess biowaste
(50% less)

Fertilizers

EPS formulation

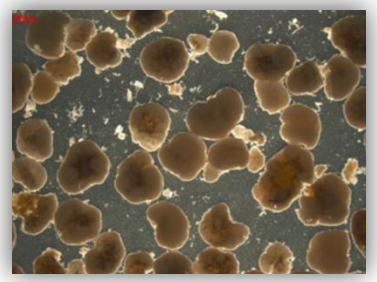
Biopolymers
Added value

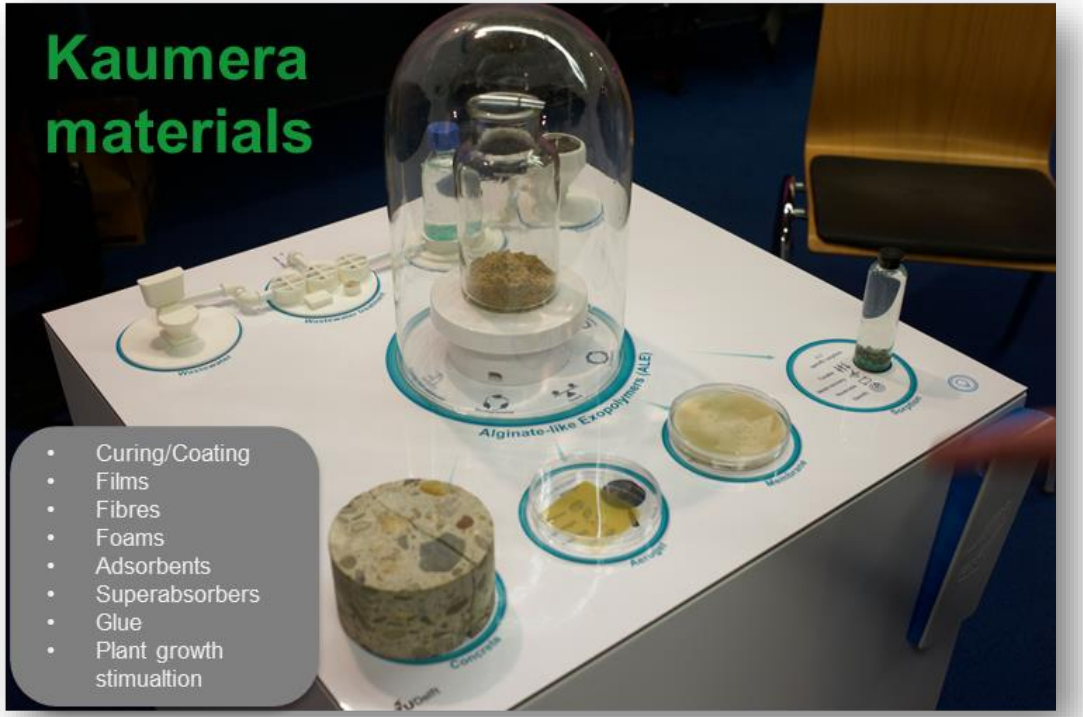
Extracellular polymers from **granular sludge** as raw material

kaumera
nereda® gum

Biopolymers from
granular sludge

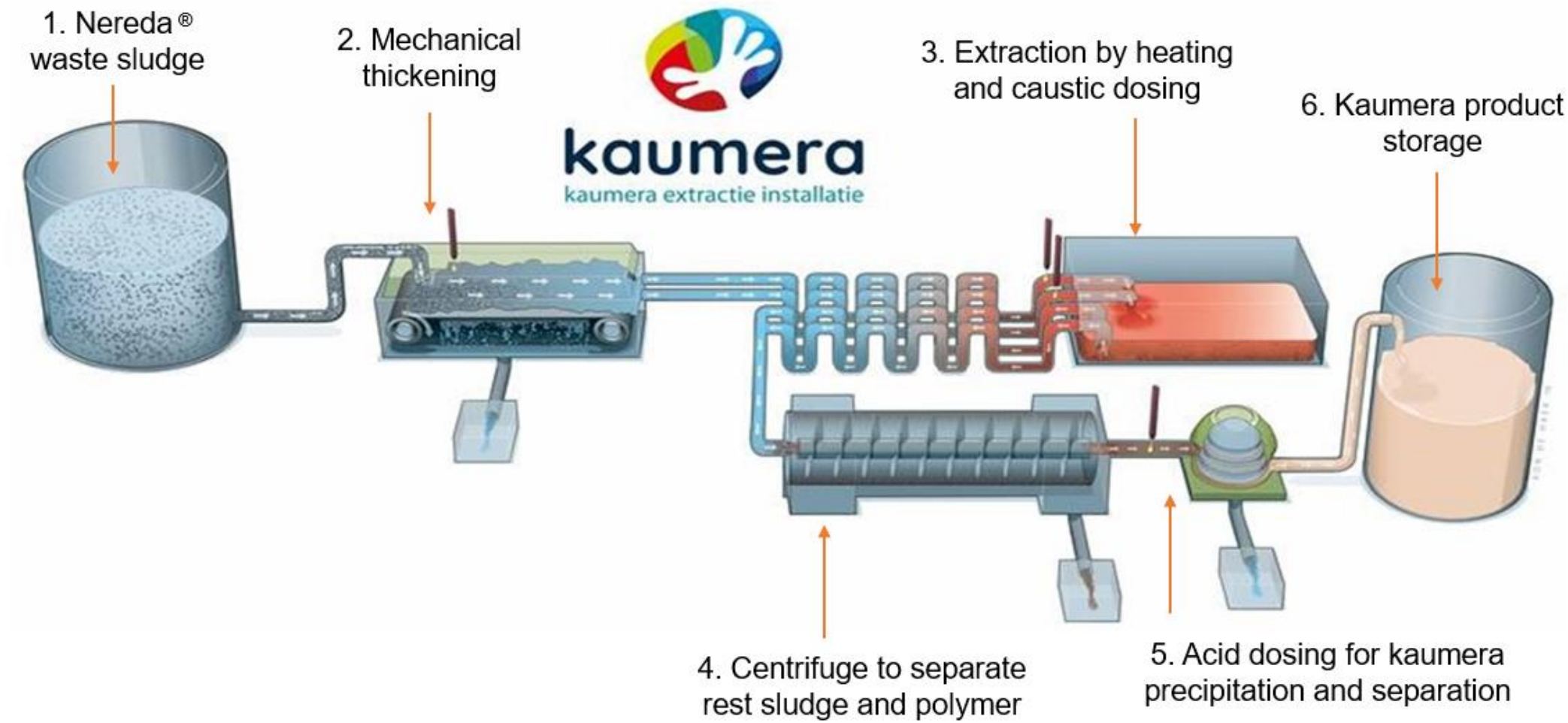
Nereda®
a product of Royal HaskoningDHV





- Biopolymers (replace oil-based polymers)
- Gel-polymers: No oil competition
- Gel-polymers: Market supply is limited
- Many new materials possible

Kaumera production from Nereda® sludge



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2020: Zutphen demonstration plant (Dairy, The Netherlands)
Kaumera extraction about 1.400 ton DS/year (1.600 m^3 gel)

WWTP Utrecht
430,000 persons served
2,500-5,000 ton/year Kaumera

Production price: 0.5-1 Euro/kg

Total for NL: 150,000 ton/year

TU Delft

Problem: Logistics and business model

Resource

Defined polymer production

Consumer product

Private company

Sludge

Raw ALE

Defined polymer production

Consumer product

Public authority

Private company

TU Delft

Flocculent **activated sludge** has a huge global potential

- Ca. 30 kg activated sludge pr. person/year
- Ca. 175,000 tons for Denmark
- 20-30% can be extracted as biopolymer
- World potential biopolymer production from AS: 50-100 million tons/year
- 2050: Estimated world plastic market demand: 1,200 million tons/year

Composite materials

Flocculants
(harbours, mining industry)

Flame retardants

Bioplastics

Flocculent **activated sludge** has a huge global potential

Scientific questions

How to predict the biomaterial potential of activated sludge?

How to steer and control the process?

Composite materials

Flocculants
(harbours, mining industry)

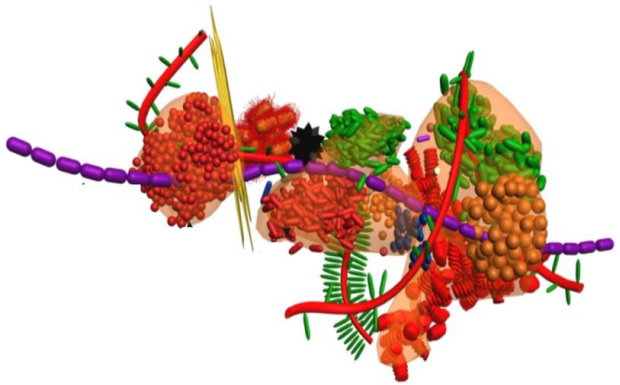
Flame retardants

Bioplastics

Which extracellular polymeric substances (EPS) do the bacteria produce?

Overall EPS components

- Polysaccharides
- Proteins
- Glycoproteins
- Lipids
- Nucleic acids (DNA, RNA)
- (Humic substances)
- …..



Activated sludge floc

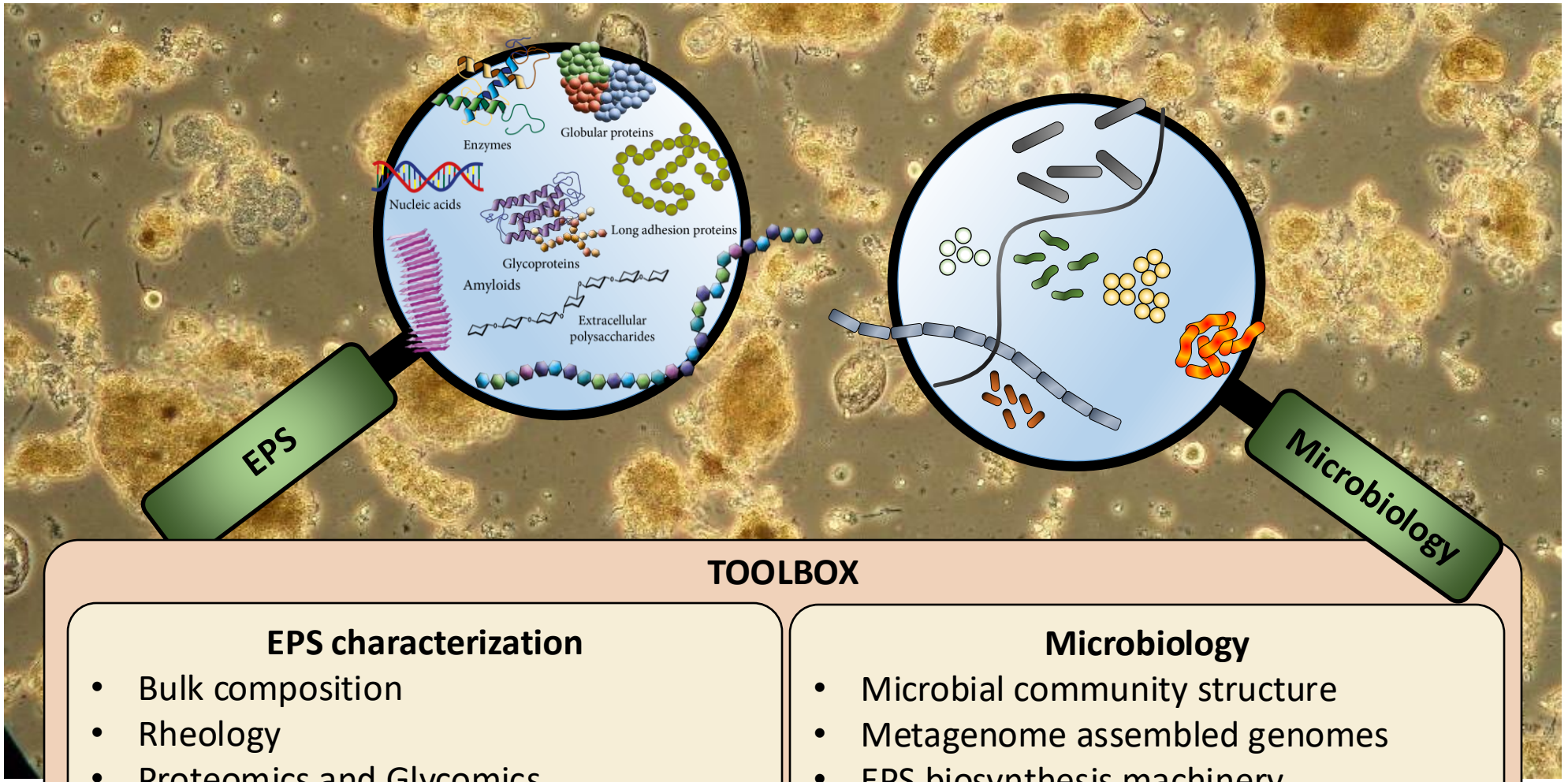
Examples of polysaccharides

- Cellulose
- Alginate
- Xanthan
- Pel
- …..

Problem:

The bacteria in WWTPs are very poorly known and their EPS production largely unknown.

Activated sludge composed of poorly described bacteria and biopolymers!



TOOLBOX

EPS characterization

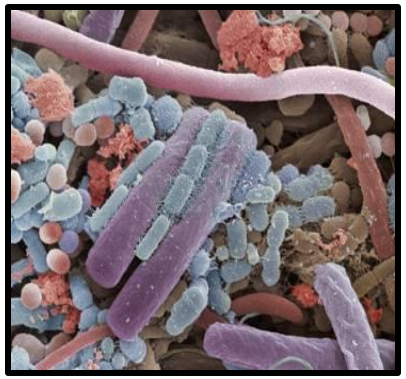
- Bulk composition
- Rheology
- Proteomics and Glycomics
- Bulk and single molecular biophysics
- Supramolecular chemistry
- Natural product chemistry

Microbiology

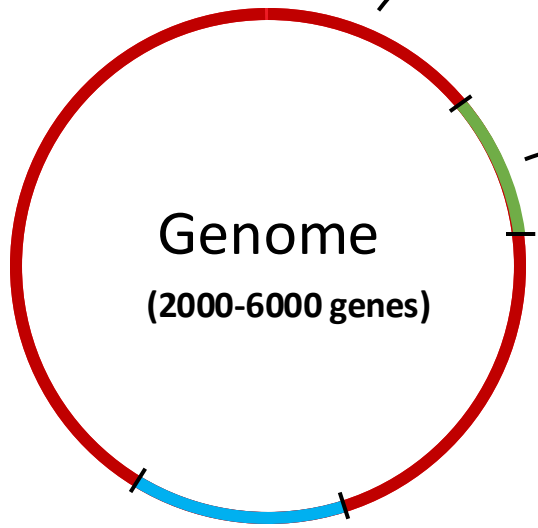
- Microbial community structure
- Metagenome assembled genomes
- EPS biosynthesis machinery
- Genome-centric transcriptomics
- Isolation of pure cultures
- Isolate and characterize important EPS

How to identify microorganisms?

Challenge!



DNA-based methods



Genome
Phylogenomic + metabolic models

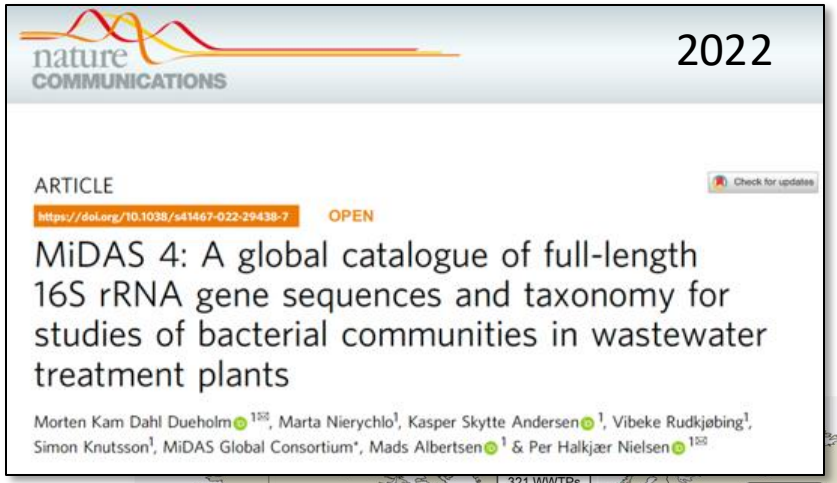
Functional genes (e.g., *amoA*)

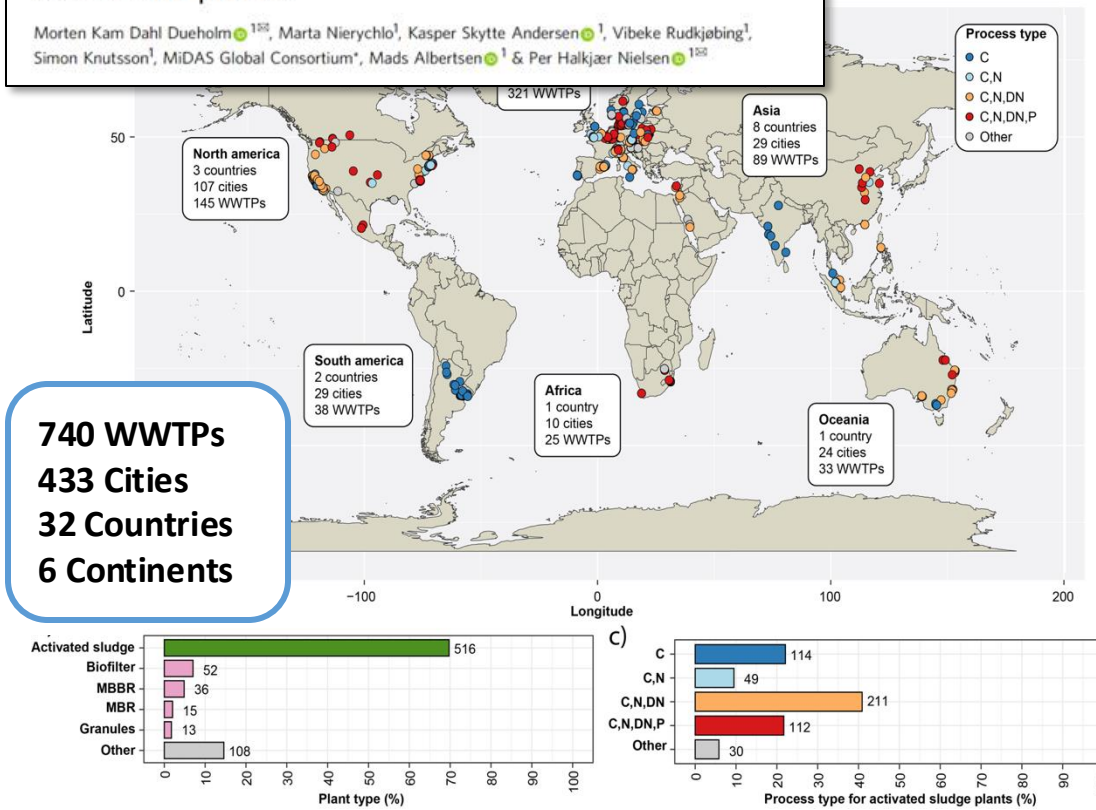
16S rRNA gene
(1500 -1600 bp)

Fingerprint

Unique for different bacteria

Few species are abundant worldwide





Only ≈ **800 genera and 1,500 species** constitute most of the biomass in global activated sludge WWTPs

Morten Dueholm

MiDAS Field Guide: Info about microbes in wastewater treatment and bioenergy systems

Wastewater

Digesters

Activated sludge

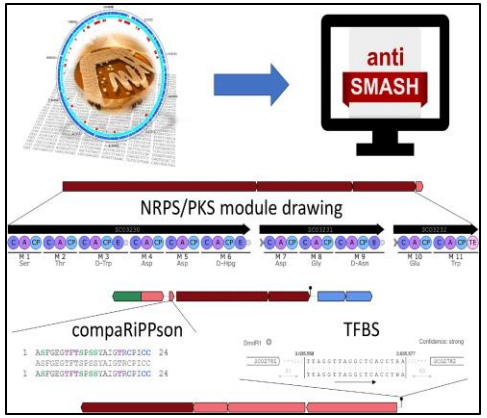
http://midasfieldguide.org/

Granules

Biofilters

MBBR

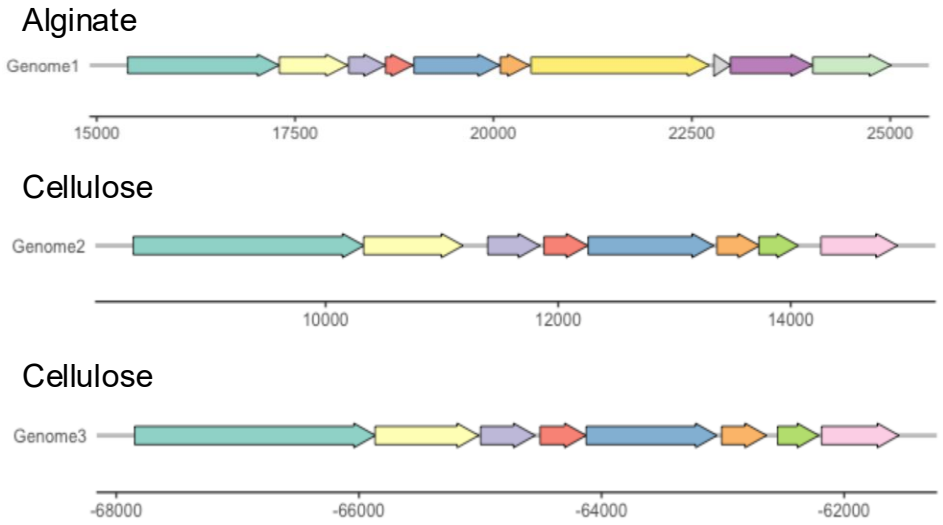
Biopolymer production can be predicted based on identity, genome and use of the online tool **epsSMASH** (release summer 2025)



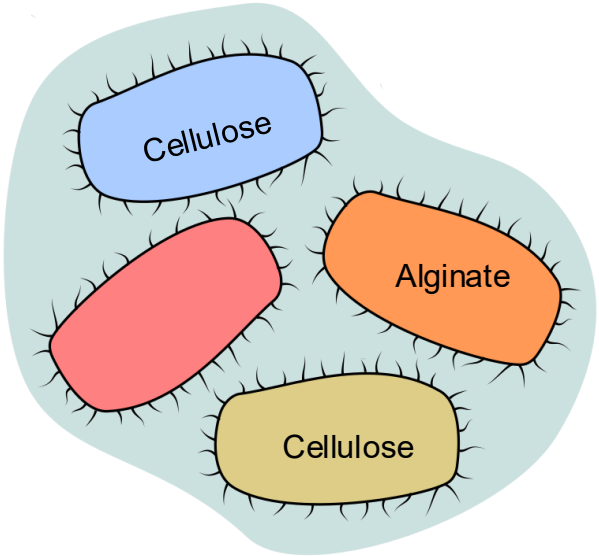
MiDAS global genome database

Bacterial genomes

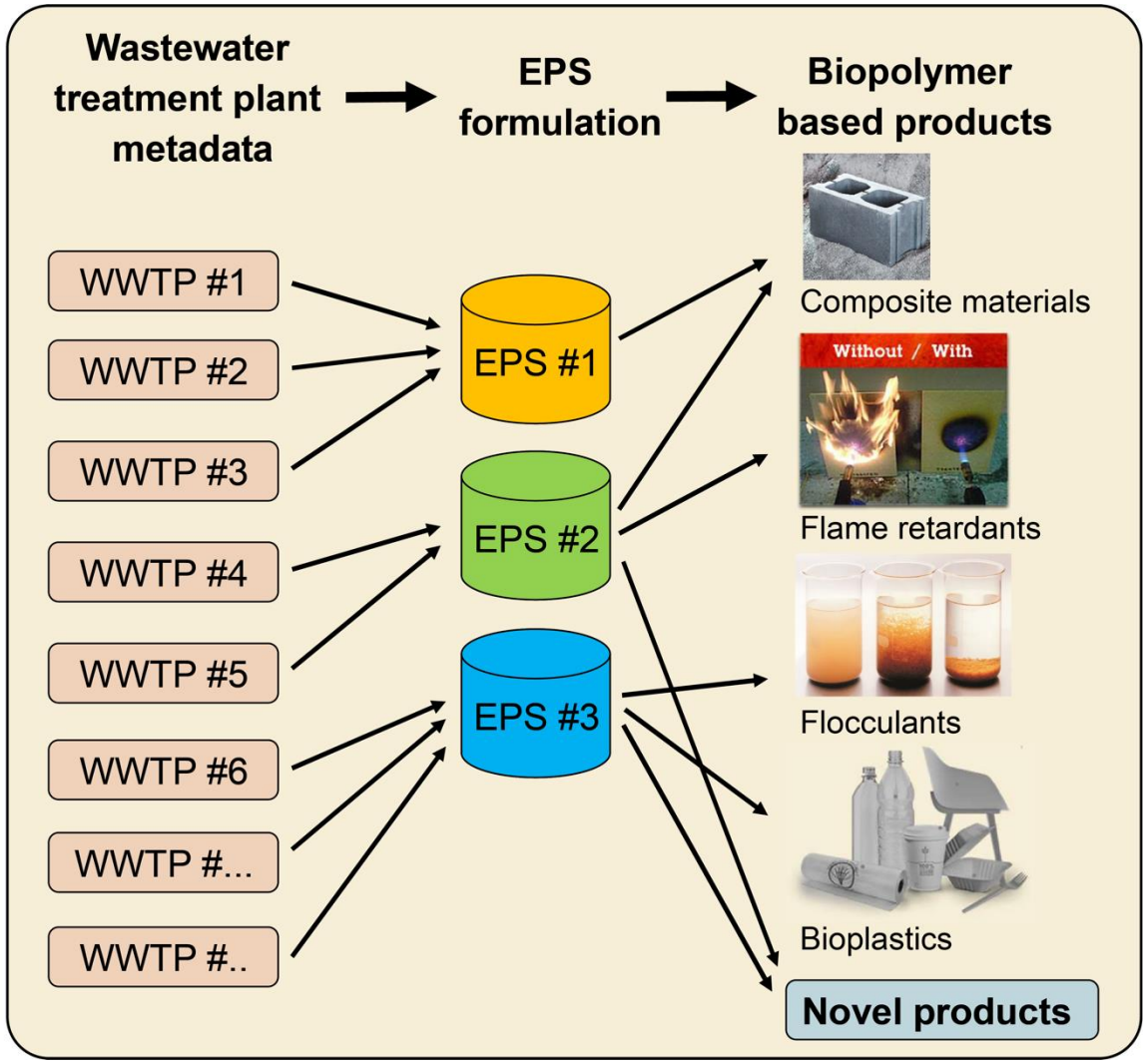
eps SMASH



Predicting EPS potential in microbial community



The REThiNk project will use basic science to enable a circular economy



WP1: Extraction and characterization of extracted EPS from different activated sludge types. **TUD**

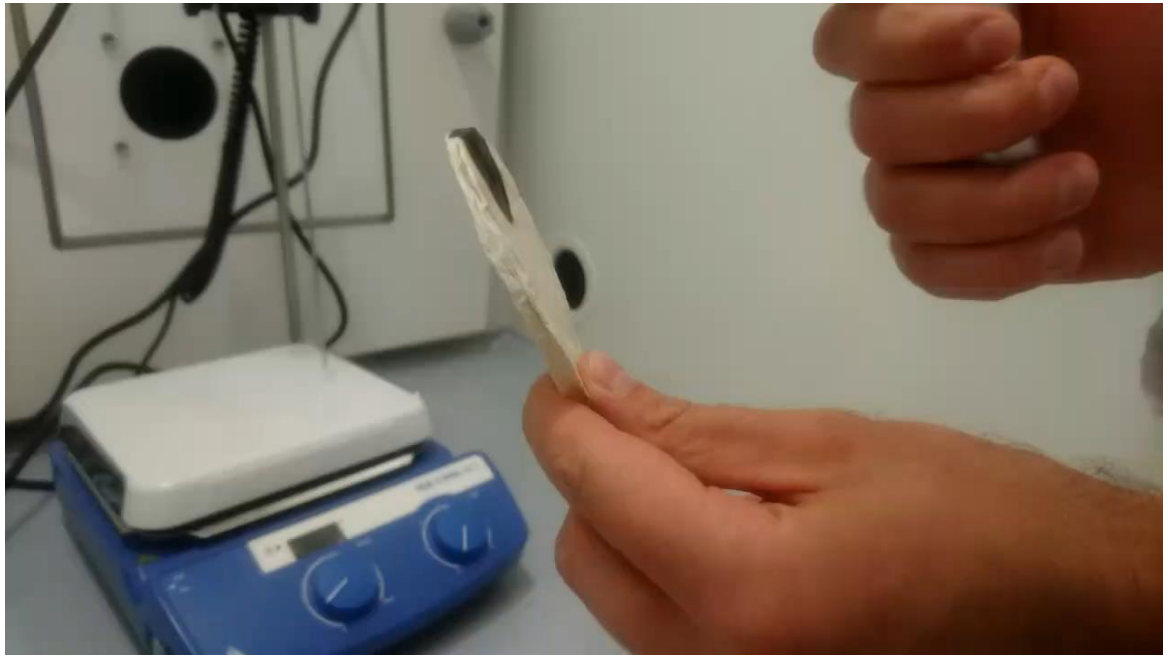
WP2: Uncovering the genetic potential and regulation of EPS synthesis in activated sludge bacteria. **AAU**

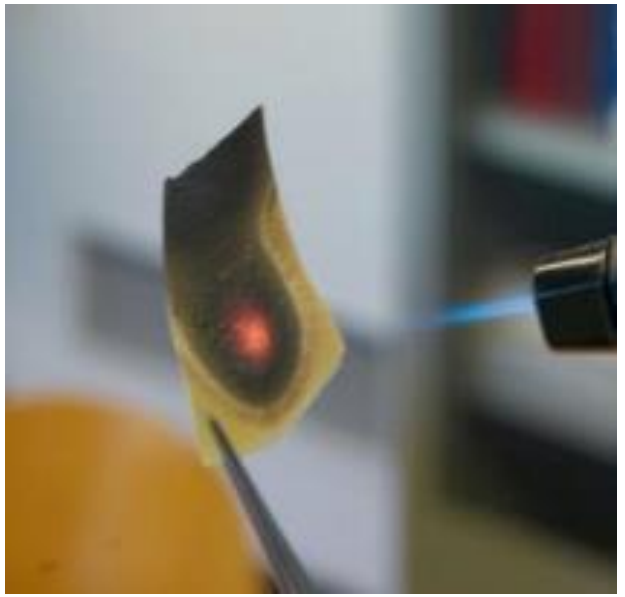
WP3: Isolation and functional and chemical characterization of individual EPS components. **AU**

WP4: A predictive model of microbial communities for optimal EPS production and quality. **AAU**

WP5: Product design based on activated sludge polymers. **TUD**

Kaumera Foams - Flamability:





80 micron, 1970°C

Contents lists available at ScienceDirect

Water Research

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

Flame retardant property of flax fabrics coated by extracellular polymeric substances recovered from both activated sludge and aerobic granular sludge

Nam Kyeun Kim [a], Ningtao Mao [b], Richard Lin [a], Debes Bhattacharyya [a], Mark C.M. van Loosdrecht [c], Yuemei Lin [c,*]

[a] Centre for Advanced Composite Materials, Mechanical Engineering Department, University of Auckland, New Zealand
[b] Performance Textiles and Clothing Research Group, School of Design, University of Leeds, Leeds, LS 2 9JT, UK
[c] Department of Biotechnology, Delft University of Technology, Delft, the Netherlands

Biobased/Biodegradable
Fire resistant (no fire retardants)
At least 5 minutes @ 1970 °C
No smoke formation

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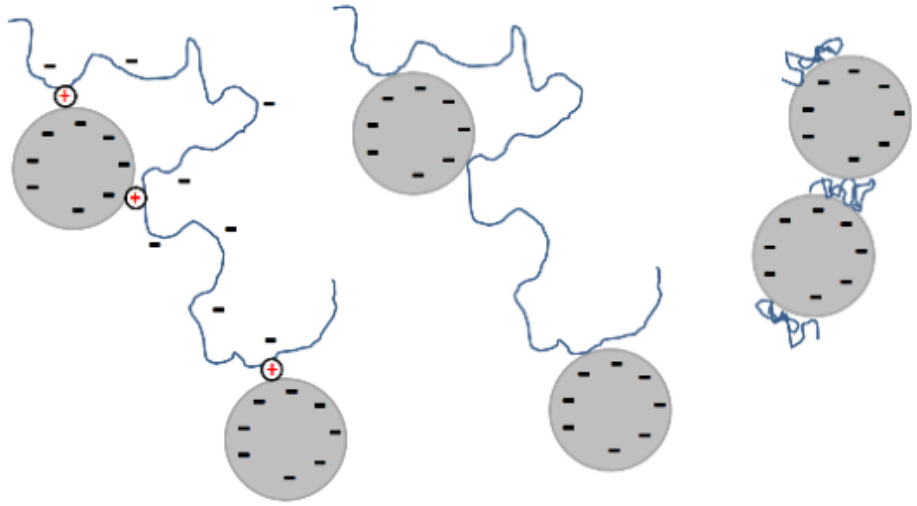
Flocculation of clay by biopolymers

- Adarsh Shajimon
- Chassagne Claire



Left and middle: bridging flocculation. The anionic polyelectrolyte on the left needs a cation (in red) to bridge to the clay; right: patching flocculation

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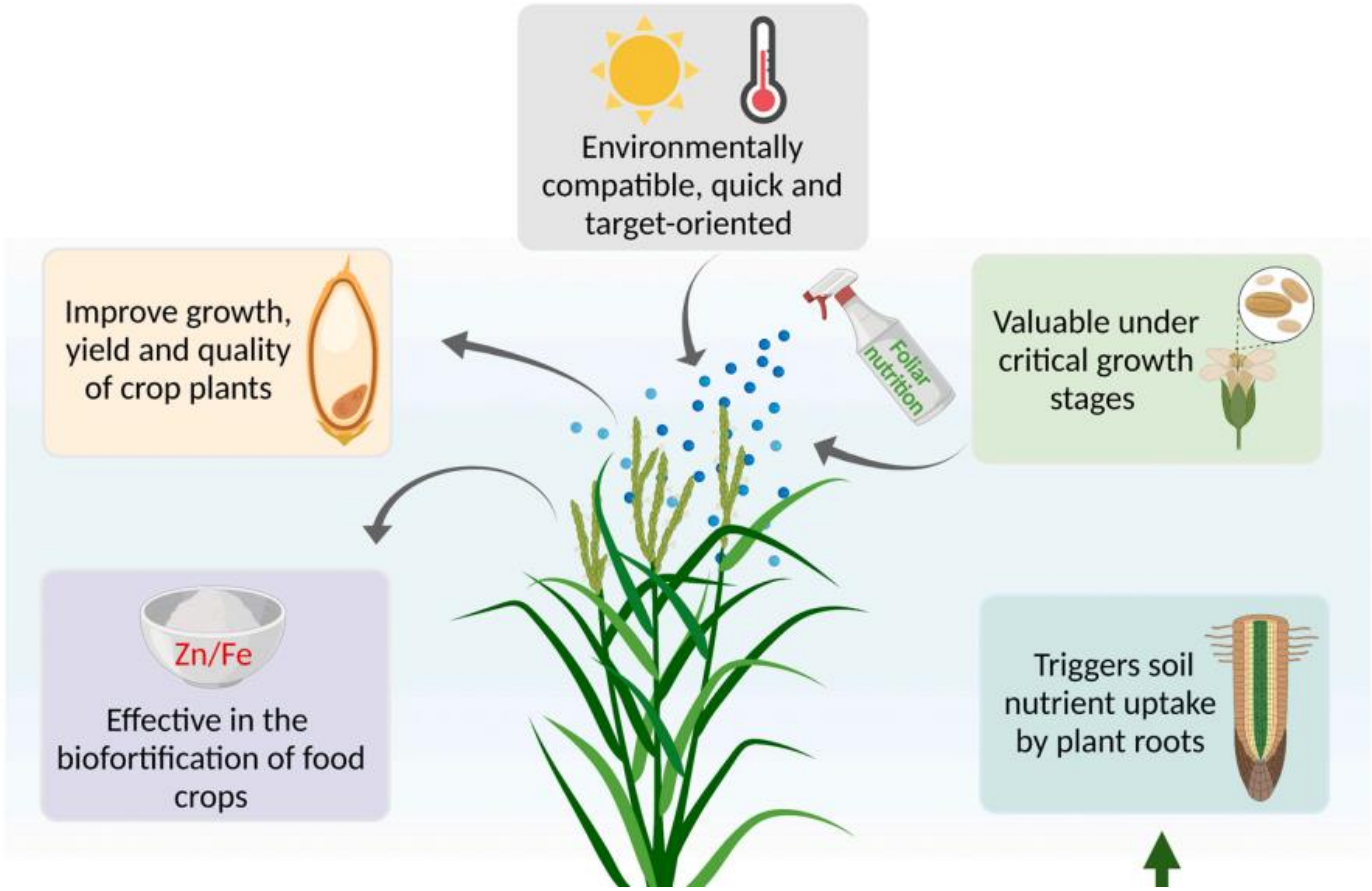
Foliar fertilization – using EPS in agriculture

Ji Li

- Supplying nutrient deficiency, e.g. Ca deficiency for fruits
- Improving nutritional status of plants, e.g. increase grain mineral densities
- Increasing crop yield and its quality
- Carrying herbicide, insecticides …



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EPS and cellulose integration in film development

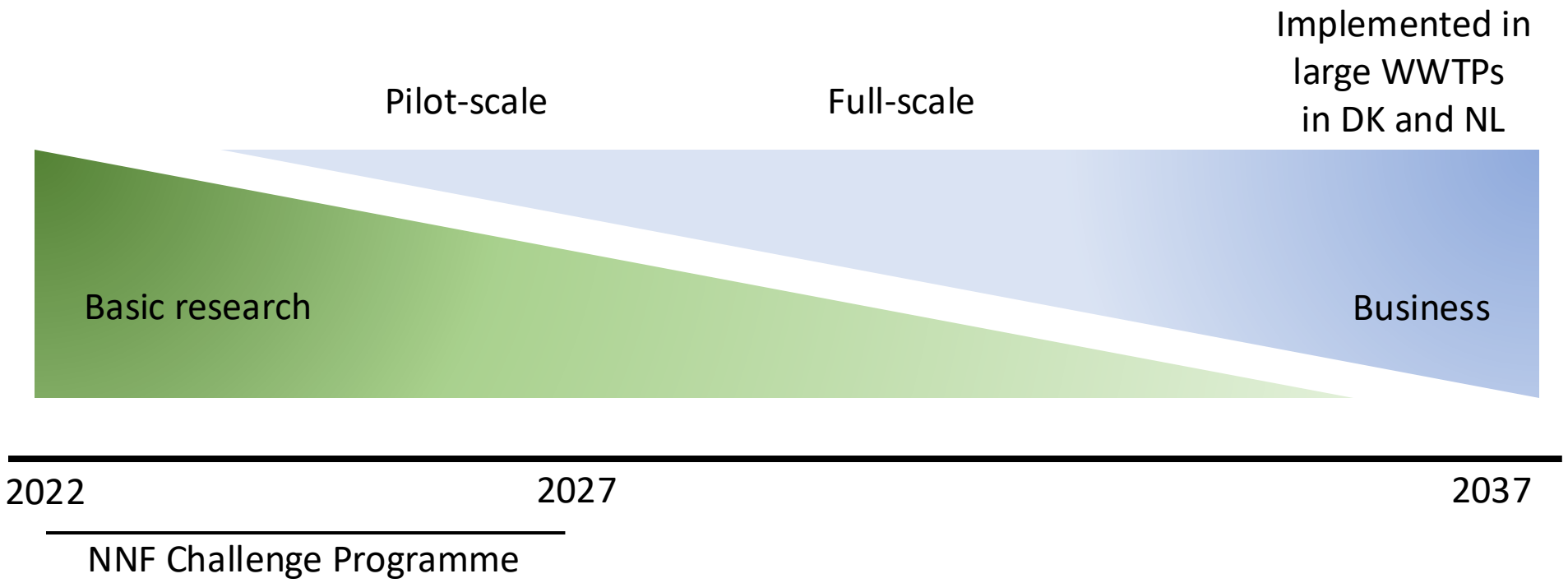
- Blended films are homogeneous
- EPS and cellulose are integrated and form a new network /composite material

Tom Seviour

Javier Gil

AARHUS UNIVERSITET

We invite for collaboration with utilities and consultants in Denmark and the Netherland



Take Home

- Biopolymers from wastewater treatment plants have potential to be applied in construction materials, textiles, papers and many other products, and for circular use in the water and wastewater treatment sector.
- The total amount of surplus sludge is reduced 15-20% before final deposit: reducing costs and CO_2 emission.
- Huge global resource recovery potential. But still long way to go, e.g., quality and quantity.
- Marked potential of biopolymers from treatment plants needs validation by inclusion of the plastic industry – is not a key activity of the water utilities.
- Application of biopolymers as bio-based alternative will reduce dependency on fossils and first-generation biomass.
- Legislation, EU-rules, etc can be a challenge but also a helper.

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Yuemei Lin

TU Delft

Mark van Loosdrecht

AARHUS UNIVERSITET

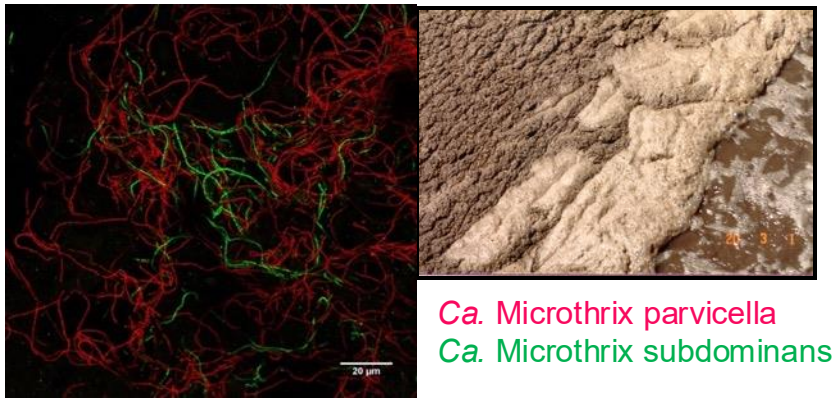
Thomas Seviour

RETHiNk

novo nordisk fonden
Benefiting people and society

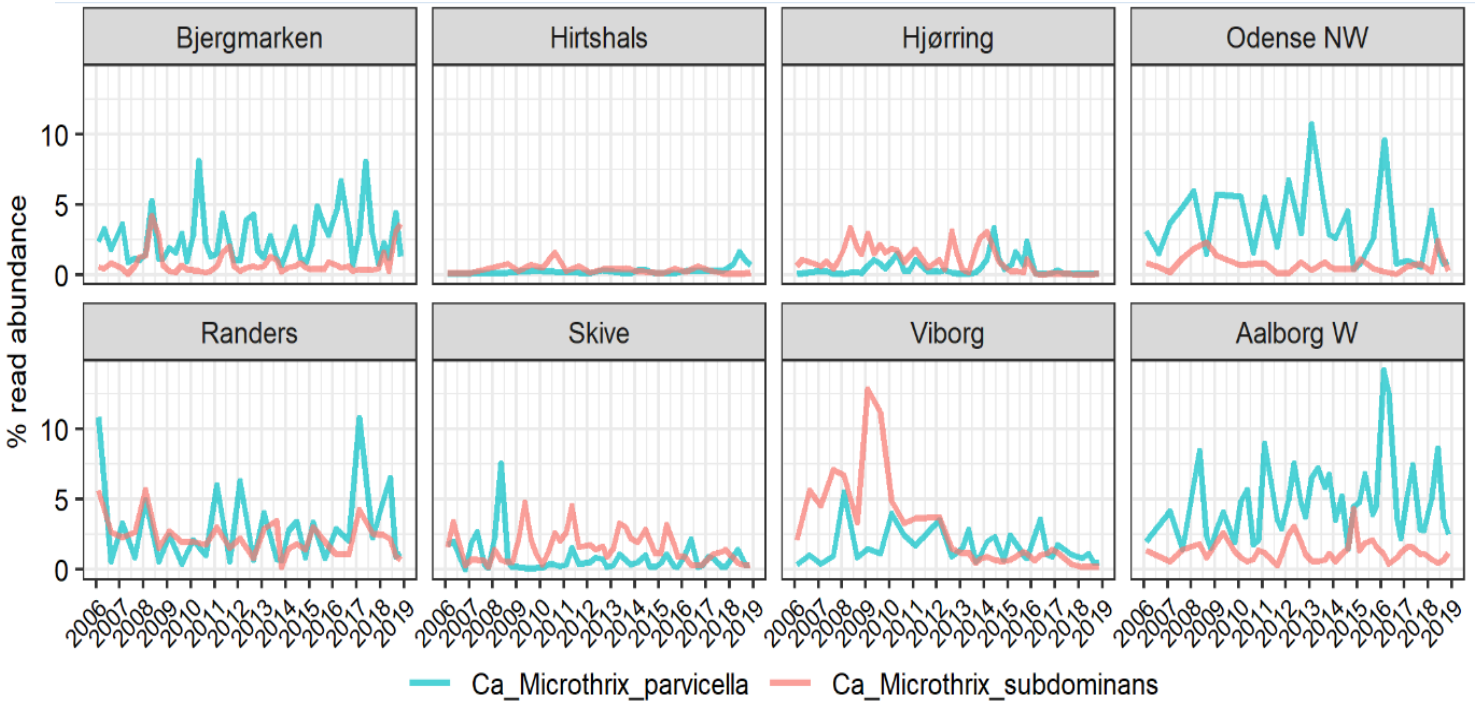
Questions?

Ca. Microthrix: Plant-specific occurrence and species-specific seasonal variations



Ca. Microthrix parvicella
Ca. Microthrix subdominans

Relative abundance in Danish WWTPs: 2006-2019



- Causes **severe foaming problems** in many plants – but not all.
- Two species show differences in seasonal dynamics:
  - *Ca.* M. parvicella: **strong seasonal dynamic** (peak spring and fall).
  - *Ca.* M. subdominans: **no clear seasonal dynamic**

Nierychlo et al., 2020, *Front. Microbiol.*

Marta Nierychlo

Research groups from AAU, AU and TU Delft

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DENMARK

Per Halkjær Nielsen

Global microbial community structure, function, and dynamics, MiDAS fieldguide

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DENMARK

Morten Dueholm

Uncultured bacteria, EPS production, microbial physiology, proteins

TU Delft

Mark van Loosdrecht

Kaumera polymers, EPS extraction and characterization, formulation and new materials

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Thomas Seviour

Physico-chemistry of specific EPS, novel methods for EPS characterization