BIOREMEDIATION OF POLLUTED FRESHWATER SYSTEMS

The Biological Basis of Wastewater Treatment

Why the microbiology decides everything — and where bioremediation takes it next

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PURPOSE OF THIS SESSION

What this presentation sets out to do

1 Establish the common ground

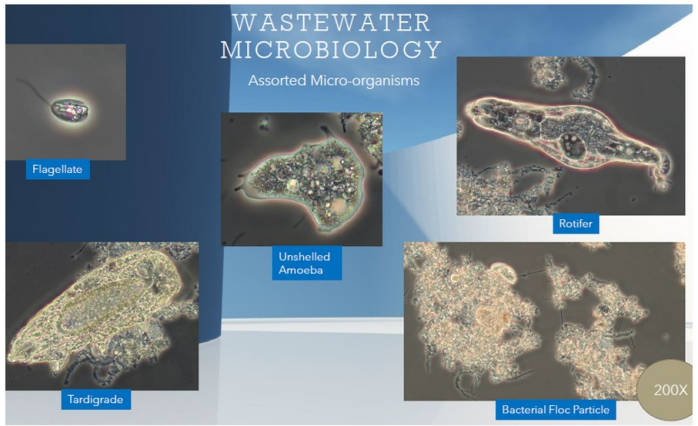
Everyone in this room — municipal, industrial, regulatory, technical — needs the same working picture of what a treatment plant actually is: a managed microbial ecosystem, not a set of tanks.

2 Show where the current process is failing

A century-old design is being asked to carry loads, chemicals and energy costs it was never built for. The failure modes are microbiological, and they are predictable.

3 Open the case for bioremediation

If the biology is the mechanism, then the biology is also the lever. This is the ground the rest of this presentation builds on.



The organisms doing the work

> *"The concept of treatment is very simple. The bacteria remove small organic carbon molecules by eating them."*

WHERE WE START FROM

A 1914 process, carrying a 2026 load

1914

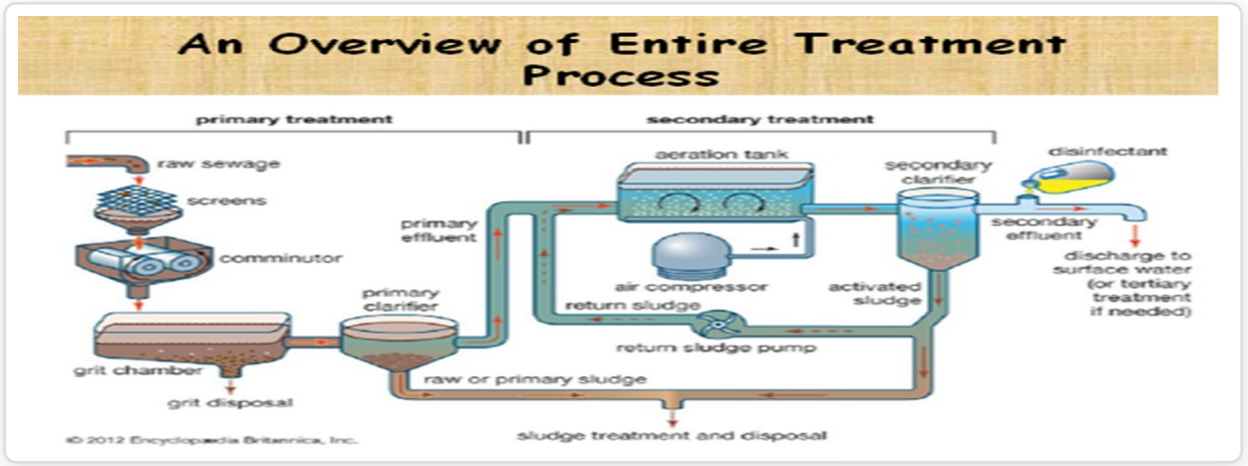
The year the activated sludge process entered service. It celebrated its centenary in 2014 and remains the global default.

75%

Of a treatment works' electrical energy goes to aeration alone — more than clarifiers, sludge pumps, heating and dewatering combined.

40%

Of incoming COD is removed as settled solids before biology even starts. Everything after that is microbial work.



Primary, secondary and tertiary treatment in one view

What has changed since 1914

- Industrial effluent volume now dwarfs domestic sewage — in the UK by roughly seven times.
- Recalcitrant and toxic chemicals arrive that the bacteria degrade slowly, or that kill them outright.
- Storm surge flows overwhelm hydraulic design on plants already at capacity.
- Discharge consents have tightened while energy and chemical costs have risen sharply.

From the interceptor to the receiving water

1 Primary

Screens, grit removal and settlement. Removes most solids — up to 40% of the COD. What settles out is primary sludge.

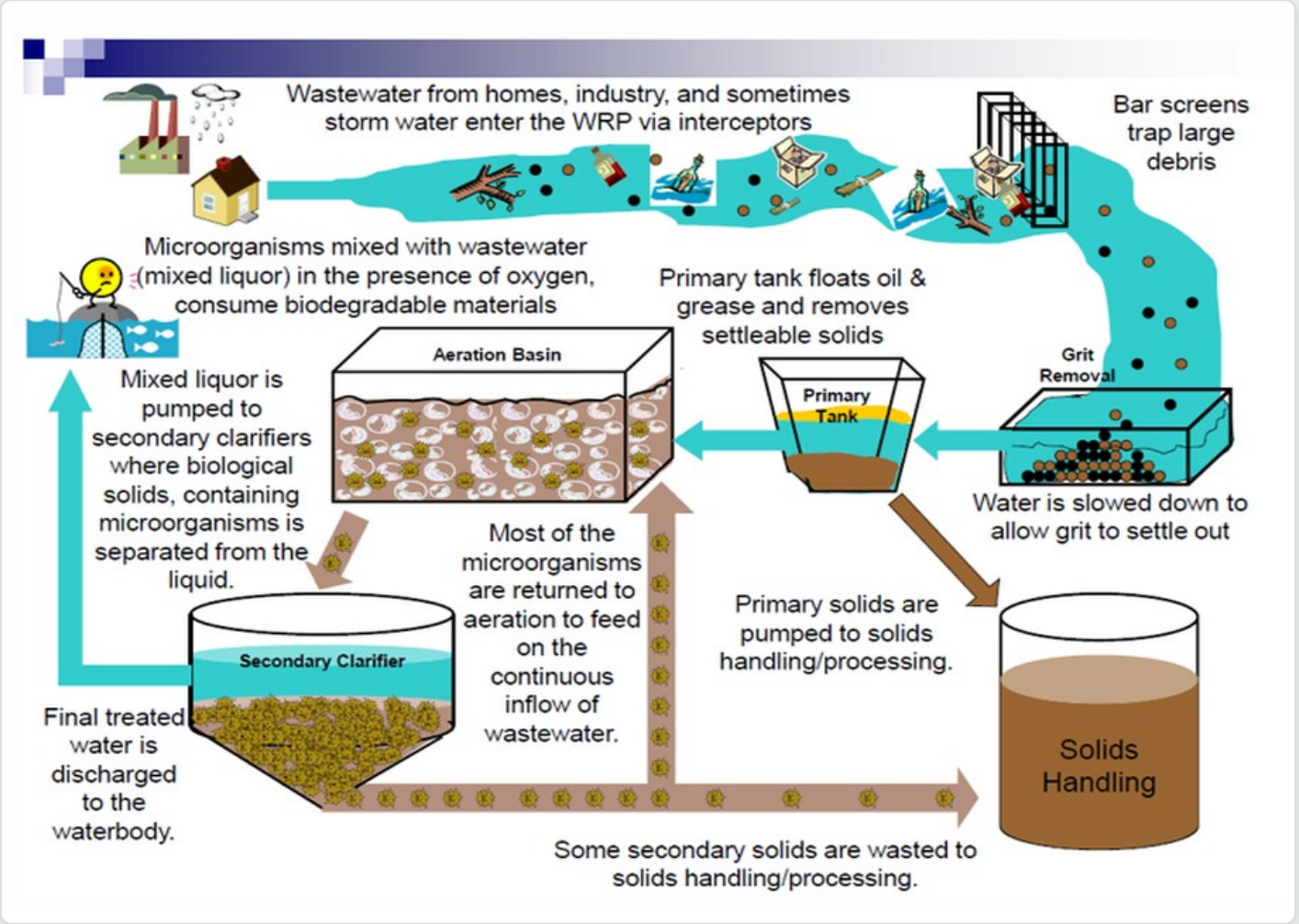
2 Secondary

The biological step. Activated sludge bacteria consume carbon and oxidise ammonia. This is where treatment actually happens.

3 Tertiary

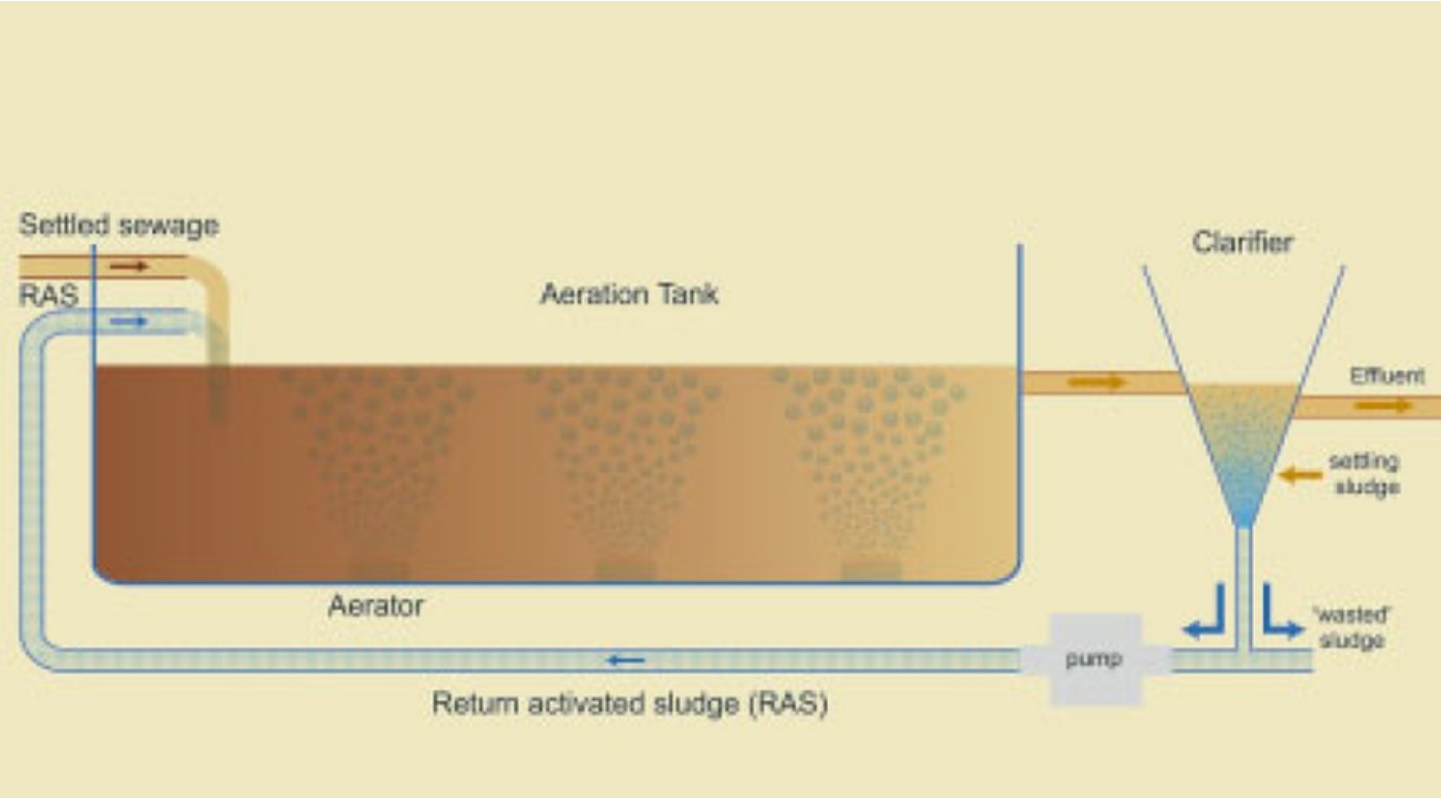
Polishing — further removal of nitrogen, phosphate, suspended solids or pathogens, as the discharge consent requires.

Everything upstream is preparation. Everything downstream is verification. The biology is the plant.



Municipal, industrial and storm flows through a water reclamation plant

Inside the aeration tank



Plug-flow layout: aeration tank, clarifier, return activated sludge (RAS) and wasted sludge

3–5 m

Typical aeration tank depth. Aerators supply oxygen and keep the sludge in suspension.

25–50%

Of tank flow is returned as RAS to hold the working bacterial concentration.

90–95%

Of influent BOD should be removed by the outlet — earlier means wasted capacity, later means a polluting discharge.

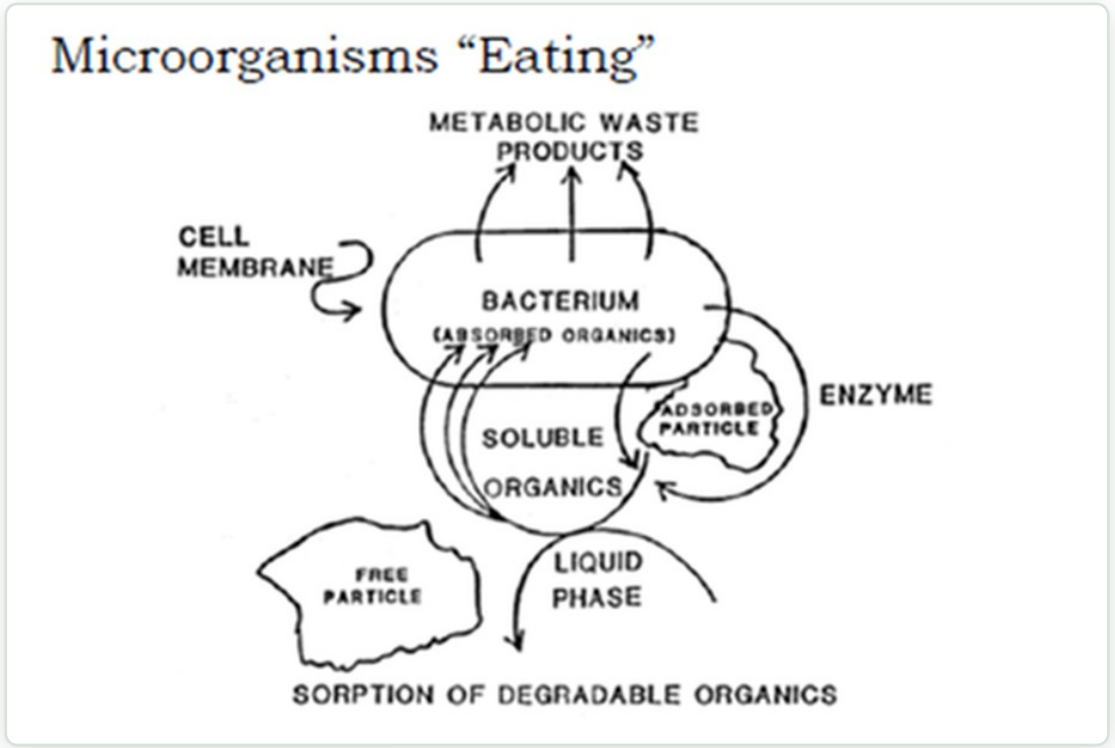
Respiration rate falls along the tank as food is consumed — so aeration demand falls with it. Measuring SOUR along the length shows where treatment completes.

What the bacteria are actually being fed

100 : 17 : 5

Carbon : nitrogen : phosphorus in domestic sewage (variously stated as 100:19:6) — close to the ideal for growth of the activated sludge bacteria. Industrial effluent is rarely so obliging.

~60%	of the organic carbon is particulate; slightly under half of that settles out.
1 nm – 100 µm	particles stay in colloidal suspension and adsorb onto the sludge flocs during treatment.
Brewing, pulp & paper	effluents are deficient in N and P — those nutrients must be dosed in for treatment to proceed.



Sorption of degradable organics: how a bacterium takes up its food

Easily biodegradable material — proteins, amino acids, peptides, carbohydrate, fats and fatty acids — makes up the bulk of domestic load.

Three ways to measure organic strength

TOC — Total Organic Carbon

- Combustion, then measure the CO_2 released.
- Analytically straightforward.
- Includes stable carbon that biology can never break down.

COD — Chemical Oxygen Demand

- Hot sulphuric acid with potassium dichromate.
- Fast — results in 2–4 hours, so usable for process control.
- Overestimates removable carbon; misses part of benzene, toluene and some pyridines.

BOD_5 — Biological Oxygen Demand

- Oxygen uptake by a bacterial seed over five days in the dark.
- The closest measure of what the plant can actually degrade.
- Five days is useless for controlling today's influent.

Why BOD_5 always reads lower than COD Bacteria cannot degrade everything the dichromate oxidises — and some of the carbon they do remove is not oxidised at all, it becomes new bacterial biomass. Short-term tests (BOD_{ST}) running in 30 minutes to a few hours are now replacing BOD_5 for influent control.

Nitrification and denitrification

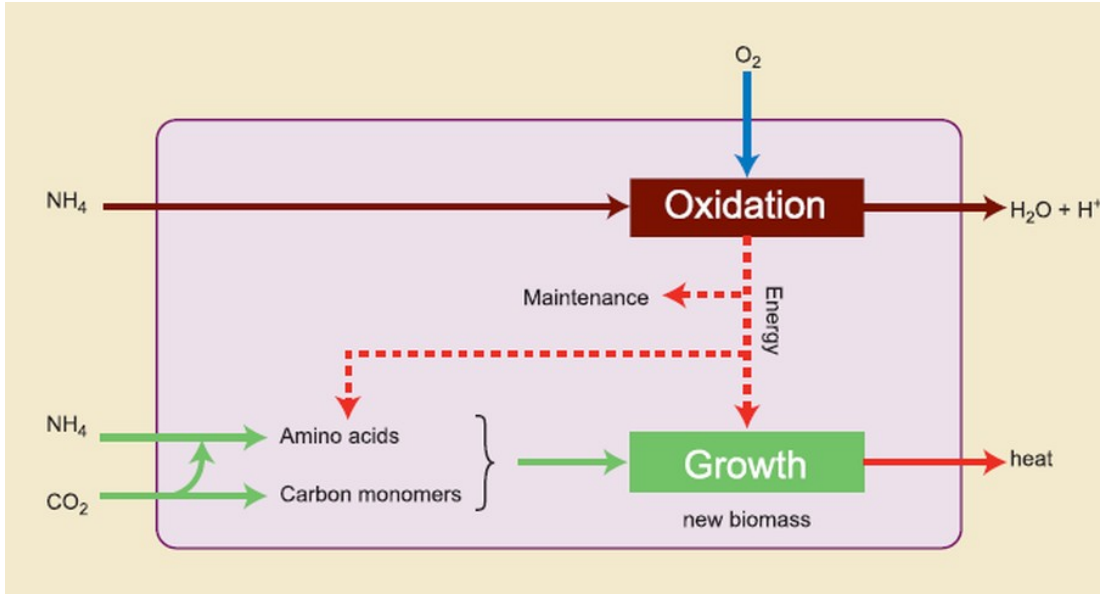
Nitrification

- A bacterial process that converts ammonia nitrogen to nitrate and consumes alkalinity.

- $NH_4 + 1.5\ O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2\ H^+ + H_2O + \text{Energy}$
  Ammonia · Oxygen · Nitrite · Acid · Water

- $NO_2^- + 0.5\ O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- + \text{Energy}$
  Nitrite · Oxygen · Nitrate

Two organisms, two steps: Nitrosomonas then Nitrobacter



The nitrifier's economy: oxidation funds growth

Strictly aerobic

Ammonium is oxidised to nitrate only in the presence of oxygen. No oxygen, no nitrification.

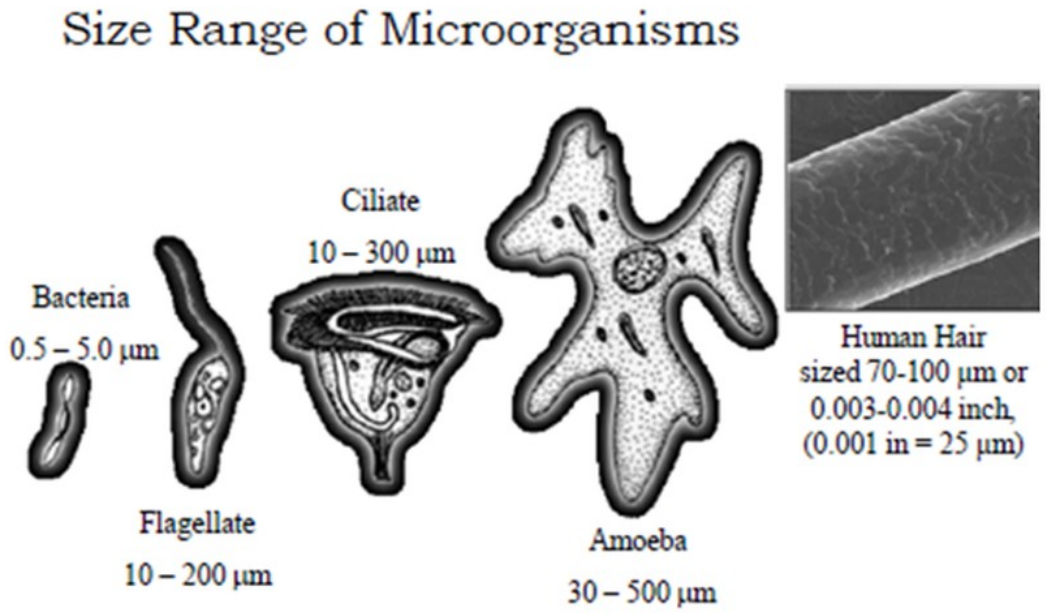
Strictly anoxic

Denitrification reduces nitrate to N_2 gas using an added carbon source — methanol or glycol — with nitrate as the electron acceptor.

Fragile by nature

Nitrifiers tolerate only 8–30 °C, all but stall below 15–20 °C, need 2.0–2.5 mg O_2/l at 20 °C, and are far more easily poisoned than carbonaceous bacteria.

A competing ecosystem of roughly 300 bacterial species



Scale: bacteria 0.5–5 µm, flagellates 10–200 µm, ciliates 10–300 µm, amoebae 30–500 µm — against a human hair at 70–100 µm

95% Bacteria — heterotrophs feeding on organic carbon, plus a small autotrophic minority. They do the removal.

~4% Protozoa — free-swimming and stalked ciliates that graze dispersed bacteria and polish the effluent.

<1% Metazoa — rotifers and tardigrades. Their presence signals an old, stable, well-aerated sludge.

Autotrophic nitrifiers grow slowly and are routinely out-competed by the faster heterotrophs. Nitrogen removal is therefore always the first capability a stressed plant loses.

THE UNIT OF TREATMENT

The floc is the plant

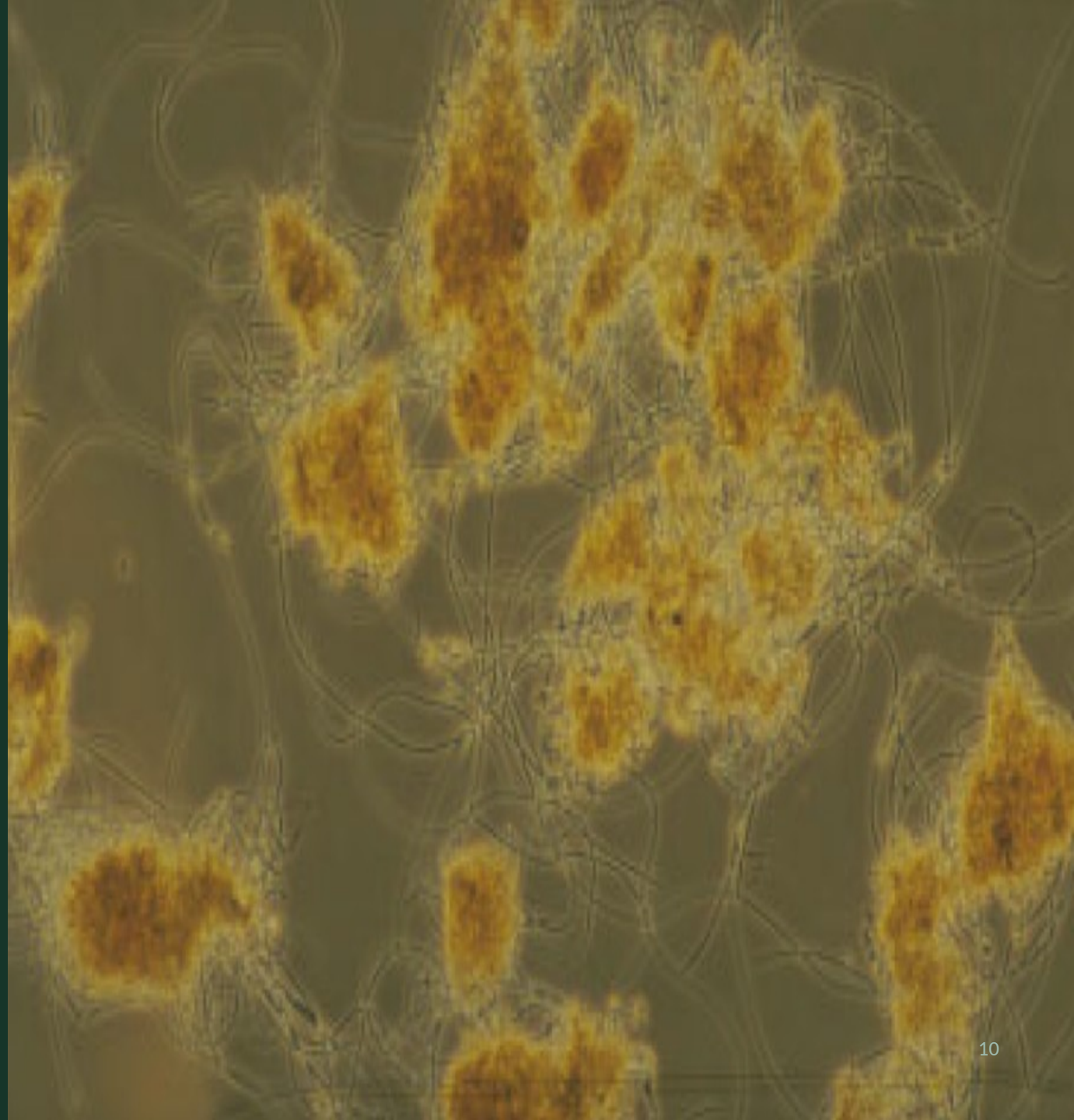
Bacteria concentrate inside a porous aggregate of secreted organic polymer. A medium floc can harbour several million cells.

Flocs range from under 10 µm to 1 mm. They must be robust enough to survive aeration shear, yet open enough for oxygen and substrate to diffuse in.

Fine particulates and large molecules adsorb onto the floc on entry — which keeps secreted enzymes right next to their substrate.

Oxygen is the constraint

Dispersed bacteria keep growing at 0.6 mg O_2/l. To reach the centre of a large floc you need 1.2–2.0 mg O_2/l in the mixed liquor. Run below 2.0 and floc cores go anoxic and are colonised by facultative anaerobes.



Four settlement failures — and what each one tells you

1 Deflocculation

Flocs fail to form or are torn apart by aeration turbulence. Little settlement, turbid effluent, consent failure — and bacteria are washed out faster than RAS can replace them.

Low DO · high sludge loading · low pH · toxic influent

2 Pin-point floc

Small dense flocs with too little extracellular polymer to hold together. Settles poorly, biomass lost to effluent.

Sludge age > 5–6 days · very low F:M · toxics inhibiting the filaments that would form the skeleton

3 Foaming & mousse

Nocardia hyphae bind a thick greasy tan blanket that traps flocs and removes them from the RAS. Scum traps cannot cope with the volume.

Reduce sludge age to wash Nocardia out · anti-foam · surface chlorination

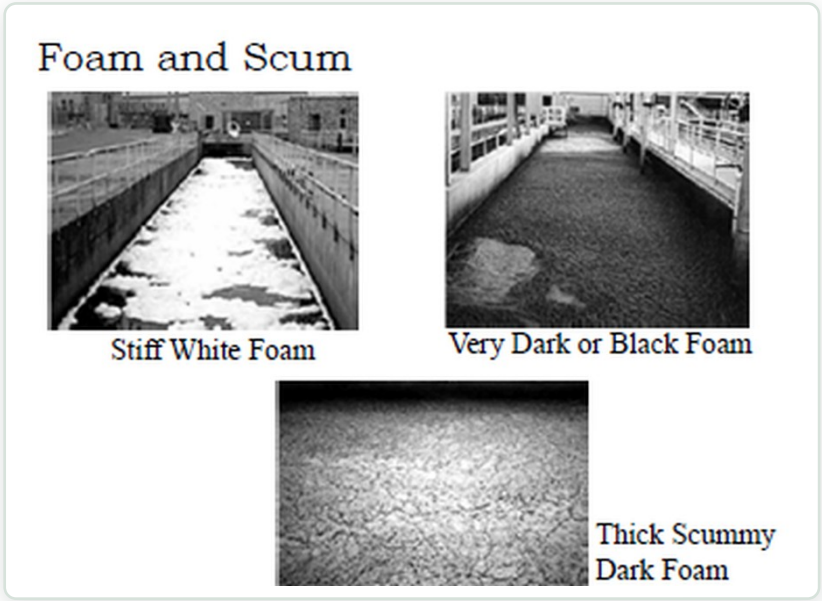
4 Filamentous bulking

Filaments bridge between flocs. The effluent looks beautifully clear — but the blanket rises up the clarifier and MLSS return collapses.

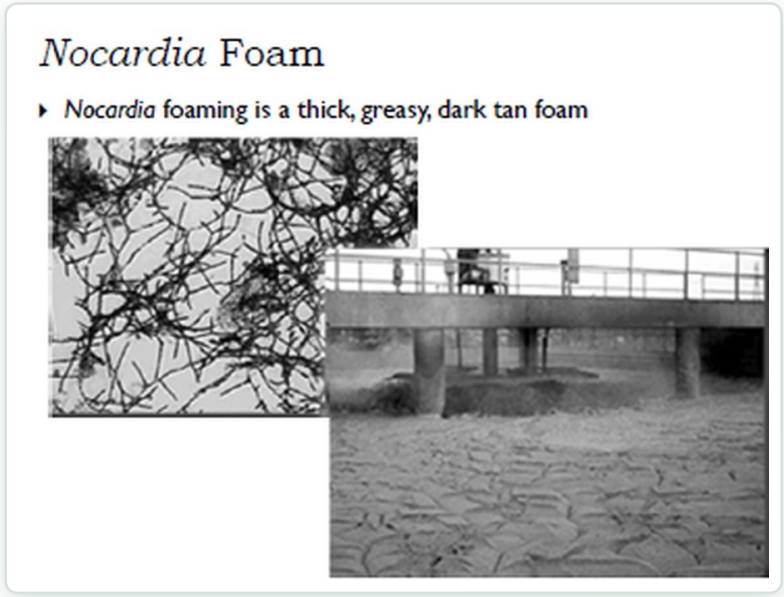
F:M outside 0.2–0.45 kg BOD/kg MLSS/d · N or P deficiency · low DO

Settlement is the single most common reason a compliant plant starts failing its consent — and it is always a microbiological signal first.

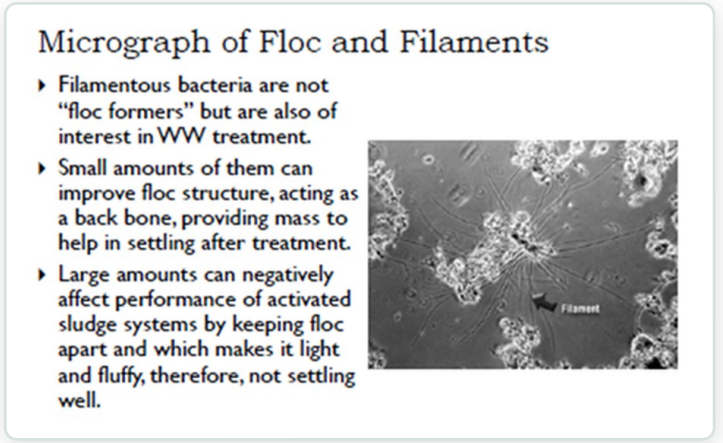
Reading the plant with your eyes



Stiff white foam, dark foam and thick scum — each a different diagnosis



Nocardia: thick, greasy, dark tan — the intractable one



Filaments extending out of the floc

Stiff white foam

High F:M — high influent BOD against low MLSS, or unmetabolised surfactants.

Clarifier covered in "ash"

Denitrification starting in the clarifier, or an over-aerated mixed liquor with F:M far below extended-aeration range.

Filaments are not the enemy

A small amount forms the backbone of a good floc and improves settling. Too much holds flocs apart and keeps the sludge light and fluffy. The distinction is quantity, not presence.

Six numbers that run a treatment works

MLSS

800–1,500 mg/l low-rate · 2,000–4,000 mg/l conventional · 8,000+ high-rate

The universal proxy for biomass. Higher is not better — it costs aeration and wrecks settlement.

MLVSS

70–80% of MLSS

The organic fraction, driven off by combustion at 550 °C. A closer estimate of live biomass.

F:M ratio

0.2–0.45 kg BOD / kg MLSS / d

Food against organisms. Below range, filaments out-compete floc-formers. In practice the engineer moves it by changing sludge wastage.

MCRT / SRT

3–15 days typical

How long the bugs stay in contact with the food. Under 3 days gives a young, slow-settling sludge and a turbid effluent.

SVI

50–150 mL/g preferable

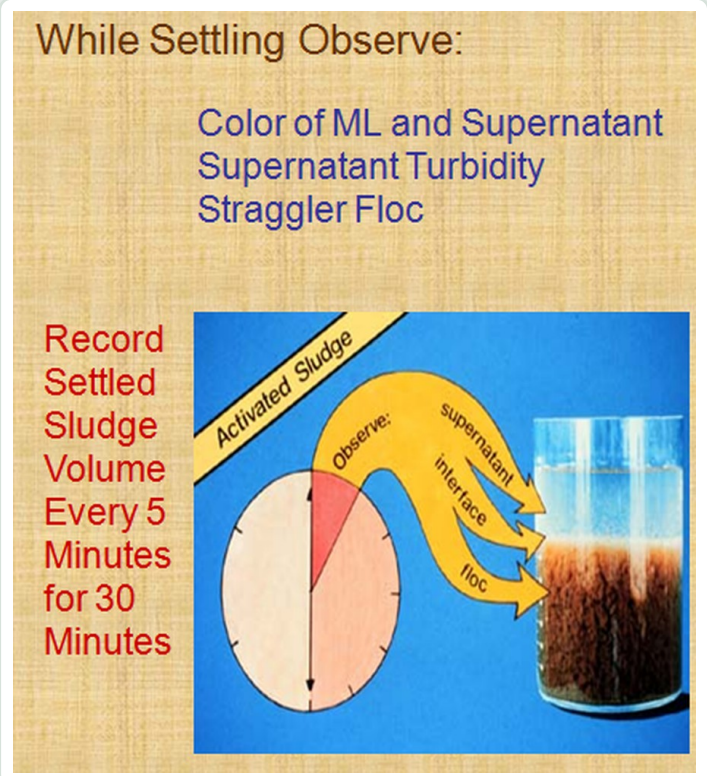
Volume occupied by 1 g of MLSS after 30 minutes settling. Lower means better settleability.

Dissolved oxygen

2–4 mg/l in the aeration tank

Wastewater at 20 °C holds only ~9.2 mg O_2/l saturated. Oxygen stops limiting above 1.5–2.0 mg/l for flocs.

What the operator does every shift



Settleometer: record settled sludge volume every 5 minutes for 30 minutes

Primary effluent, return sludge, mixed liquor, secondary clarifier

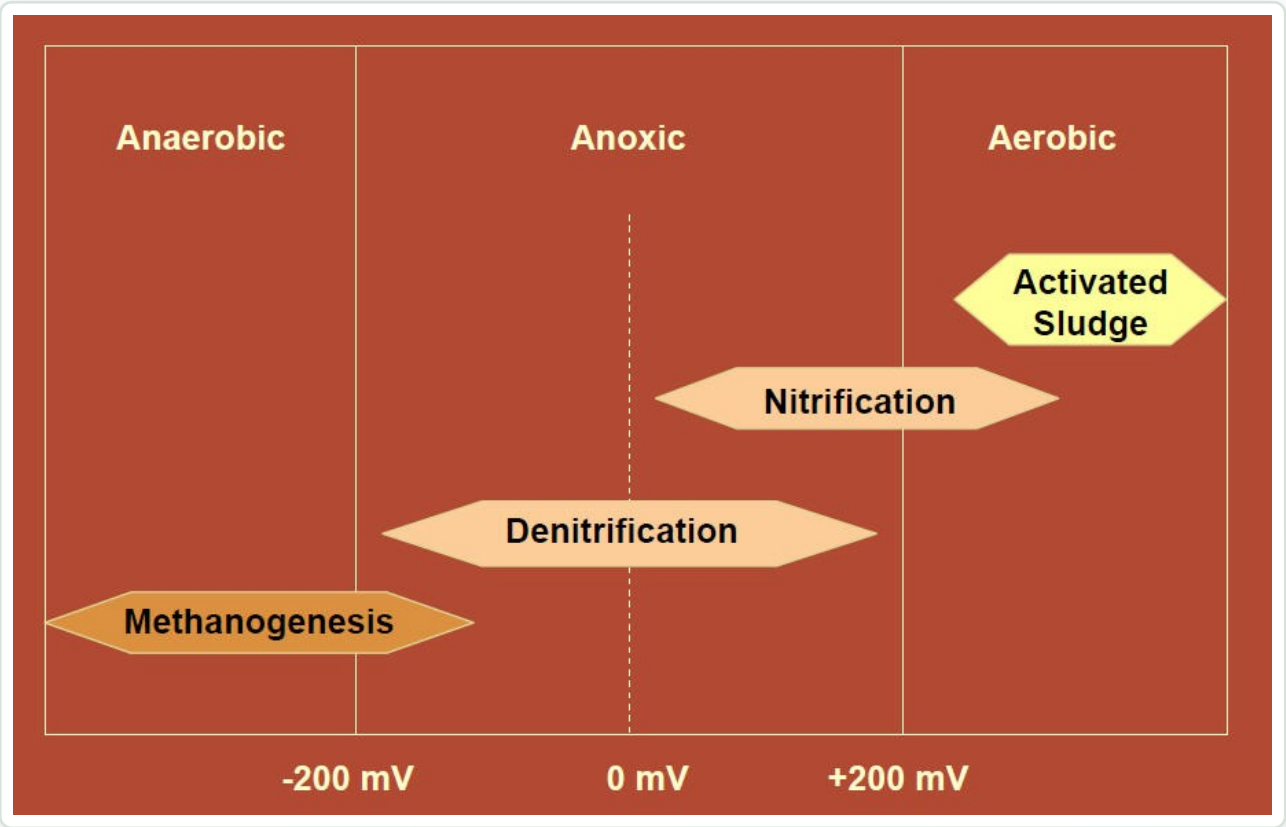
While it settles, observe

- Colour of the mixed liquor and supernatant
- Supernatant turbidity
- Straggler floc at the interface
- Floc carry-over from the clarifier

Clarifier monitoring

- Sludge blanket level
- Suspended solids and turbidity in the effluent
- RAS flow control and metering
- DO and pH in the clarifier effluent

The redox ladder decides which chemistry you get



Where each process sits on the ORP scale

Aerobic · above +200 mV

Activated sludge proper. Carbon oxidation and nitrification both run here.

Anoxic · around 0 mV

Nitrate replaces oxygen as the electron acceptor. Denitrification — nitrogen leaves as N_2 gas.

Anaerobic · below –200 mV

Sulphate reduction and methanogenesis. Odour, corrosion, and a plant in trouble.

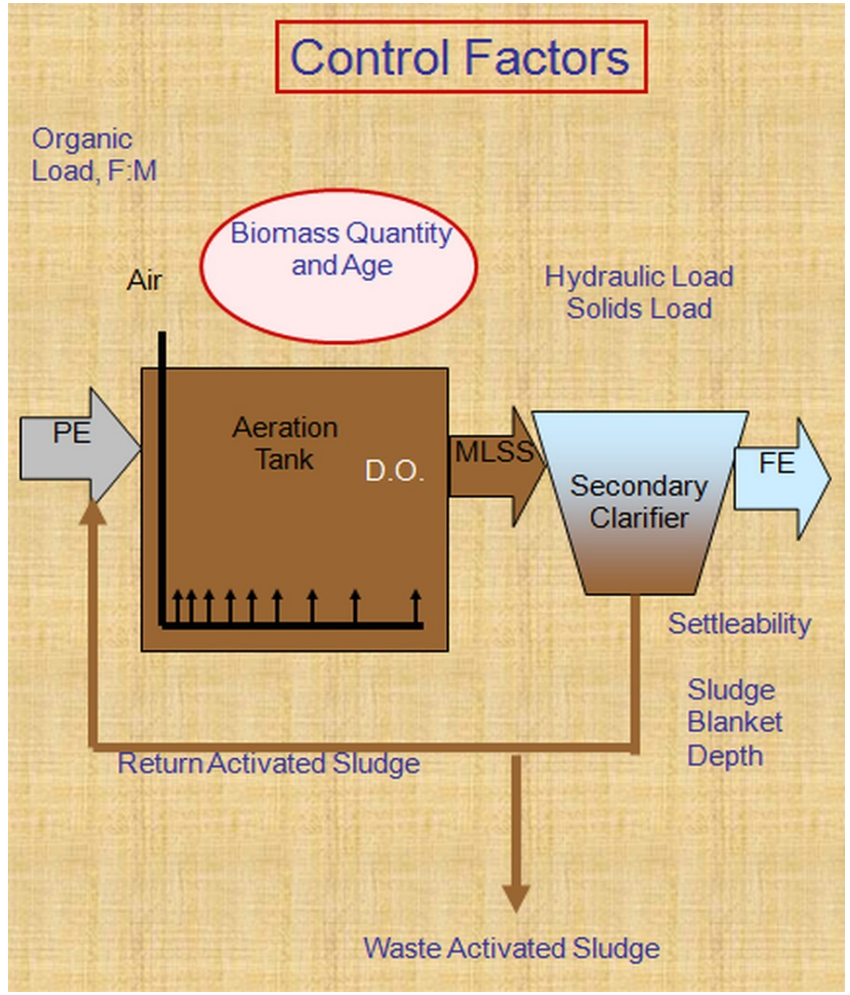
Rising sludge in the secondary clarifier is this diagram in action: DO drops, the blanket goes anoxic, nitrogen bubbles form on the flocs and float them to the surface.

Every lever, and what it pulls

Only three inputs are genuinely under the operator's control

- Air — dissolved oxygen in the aeration tank, and with it up to three-quarters of the site's energy bill.
- Sludge wastage — which sets MLSS, sludge age and therefore F:M. This is the master lever.
- RAS rate — which holds biomass in the reactor and the blanket at the right depth in the clarifier.

Influent flow and influent BOD arrive as they arrive. Nutrient dosing and chemical addition are corrections, not controls — and every one of them is a recurring cost.



Respirometry closes the loop: measure the sludge's oxygen uptake rate and you can determine the critical oxygen concentration, size nutrient dosing to maximise respiration, and detect a toxic influent before it kills the plant.

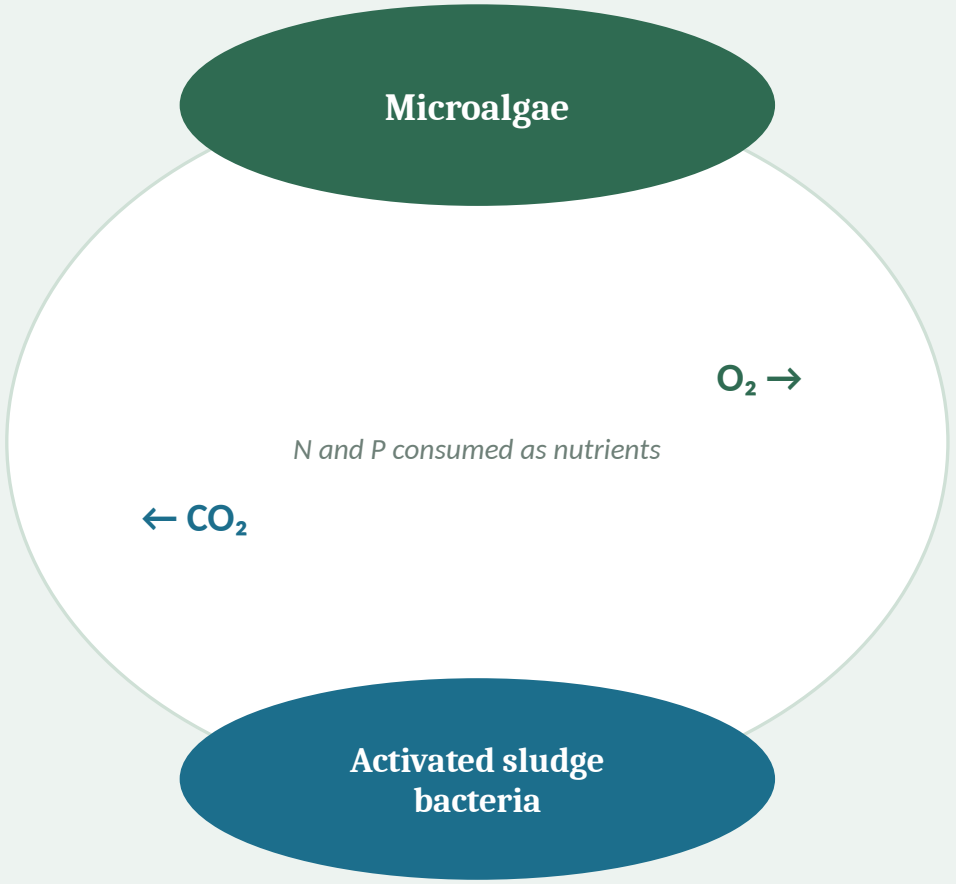
What the conventional process costs us

Energy	Aeration alone consumes up to 75% of plant electricity — and it is consumed continuously, whether or not the biology needs it.
Chemicals	Ferric chloride and ferrous sulphate for phosphorus precipitation; cationic polymers for thickening; methanol or glycol as an external carbon source for denitrification.
Contamination	Commercial iron sulphate carries arsenic, zinc, nickel and lead as impurities. These are added to the works and accumulate in the sludge.
Infrastructure	Precipitated solids and sulphates corrode concrete and sewer pipes downstream of the dosing point.
Carbon	The process emits CO_2 as a by-product — while consuming energy generated elsewhere to do it.

Every one of these is a consequence of solving a biological problem with chemistry and electricity.

THE ALTERNATIVE

Microalgae activated sludge (MAAS)



The MAAS loop: photosynthetic oxygen replaces blown air

Combined nutrient removal

Microalgae take up nitrogen and phosphorus directly from the aqueous phase — no precipitation chemistry required for P, no methanol required for N.

Oxygen without blowers

Photosynthesis releases O_2 into the same reactor where the activated sludge bacteria need it. The single largest energy line disappears.

Carbon in, not out

Bacterial CO_2 becomes algal feedstock rather than a stack emission.

The honest caveat

Settleability remains the open question — there is a real knowledge gap between cultivation and pilot-scale harvesting. Cyanobacterial and fungal filaments in the sludge appear to help the algae aggregate as floc rather than staying in suspension.

WHERE THIS LEAVES US

Four things worth agreeing before we go further

1

The plant is an ecosystem, not a machine

Almost every compliance failure presents first as a change in the microbial community — bulking, foaming, deflocculation, loss of nitrification. Treat the biology and the numbers follow.

2

Diagnosis is cheap; failure is not

Settleometer, microscope, SVI, F:M, respirometry. None of it is expensive. Almost none of it is done consistently.

3

Chemistry is a correction, not a cure

Every dose of iron, polymer or methanol is a recurring cost that also adds heavy metals, sulphates and complexity to the works.

4

Biology can carry more of the load

Microalgae-assisted treatment, targeted bioaugmentation and better process control all attack the same three cost centres: energy, chemicals and sludge.

The rest of this session takes each of these from principle to practice.

ACKNOWLEDGEMENTS

Sources and credits

Source material

- The Biological Basis of Wastewater Treatment — layout by John Main, illustrations by Marian Littlejohn; published by Strathkelvin Instruments Ltd, 2005.
- Anbarasan Anbalagan (2016), Cultivation System for Wastewater Treatment — Mälardalen University Press Licentiate Theses No. 240.
- Wastewater Microbiology & Process Control — Toni Glymph, Metropolitan Water Reclamation District of Greater Chicago.
- Activated sludge micrographs courtesy of Ray Kenny.

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Thank you.