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ENERGY FORUM, AALTO UNIVERSITY

Sustainable Sewage Treatment From Waste to Value

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Overview

Principles of wastewater treatment

Your own impact on the environment and the water cycle

Wastewater treatment plant (WWTP) as a large biotech facility

Zoom-in to mass and energy flows

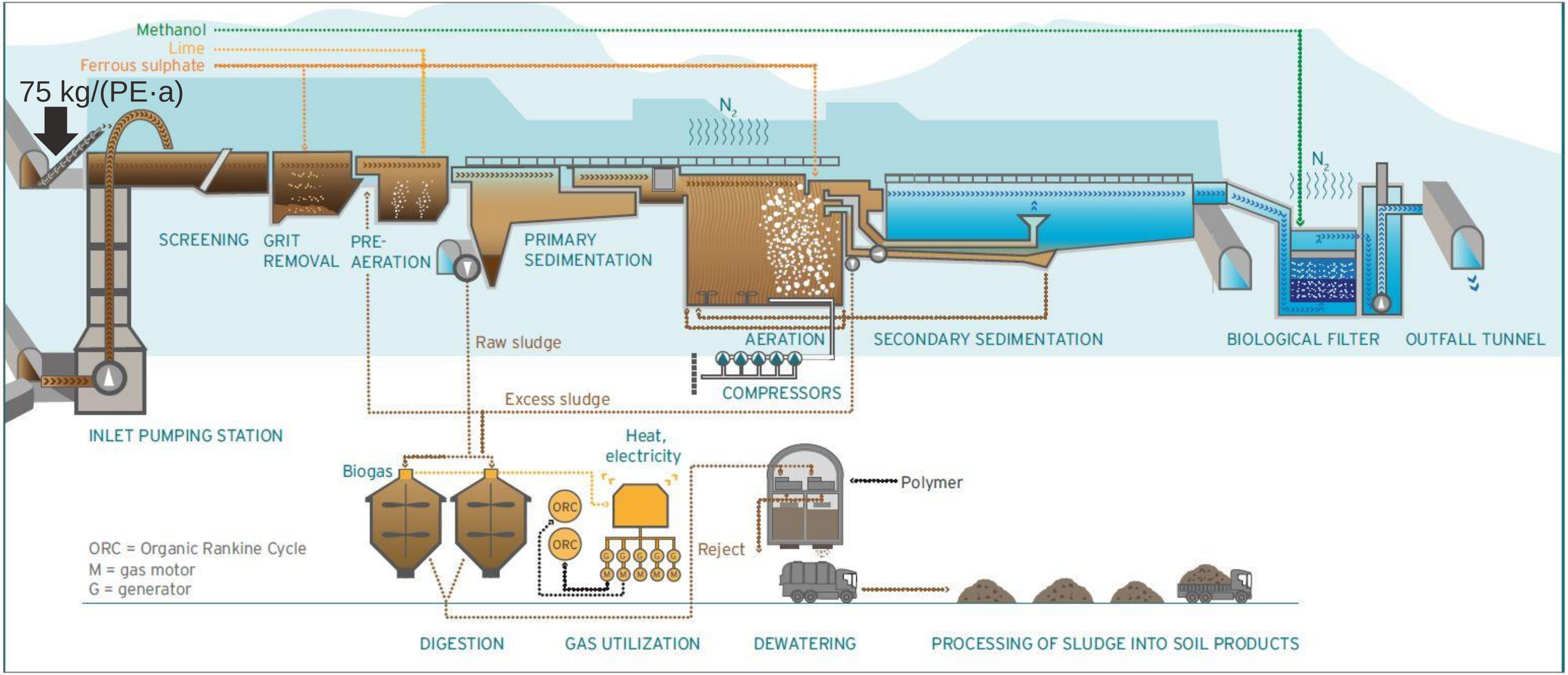
Energy self-sufficiency of WWTPs

Renewable methane as energy source

Nutrient recycling

Ideas are needed

Helsinki, Viikinmäki, 800 000 PE (Person Equivalents)



Nutrient release per capita – PE Person Equivalent

Average waste load – Dimensioning of the wastewater treatment plants

- Feed flow per day 400 l/(PE·d)

Your personal impact per year

- Solids 75 kg/(PE·a)
- Carbon 55 kg/(PE·a)
- Nitrogen 6 kg/(PE·a)
- Phosphorus 0.75 kg/(PE·a)

Environmental impact

Biochemical impact of the nutrients on the environment

- Phosphorus has by far the largest impact if released to the environment
- 1 g phosphorus can build up approx. 100 g biomass

- 1 g N ➔ 14 g biomass
- 1 g P ➔ 100 g biomass

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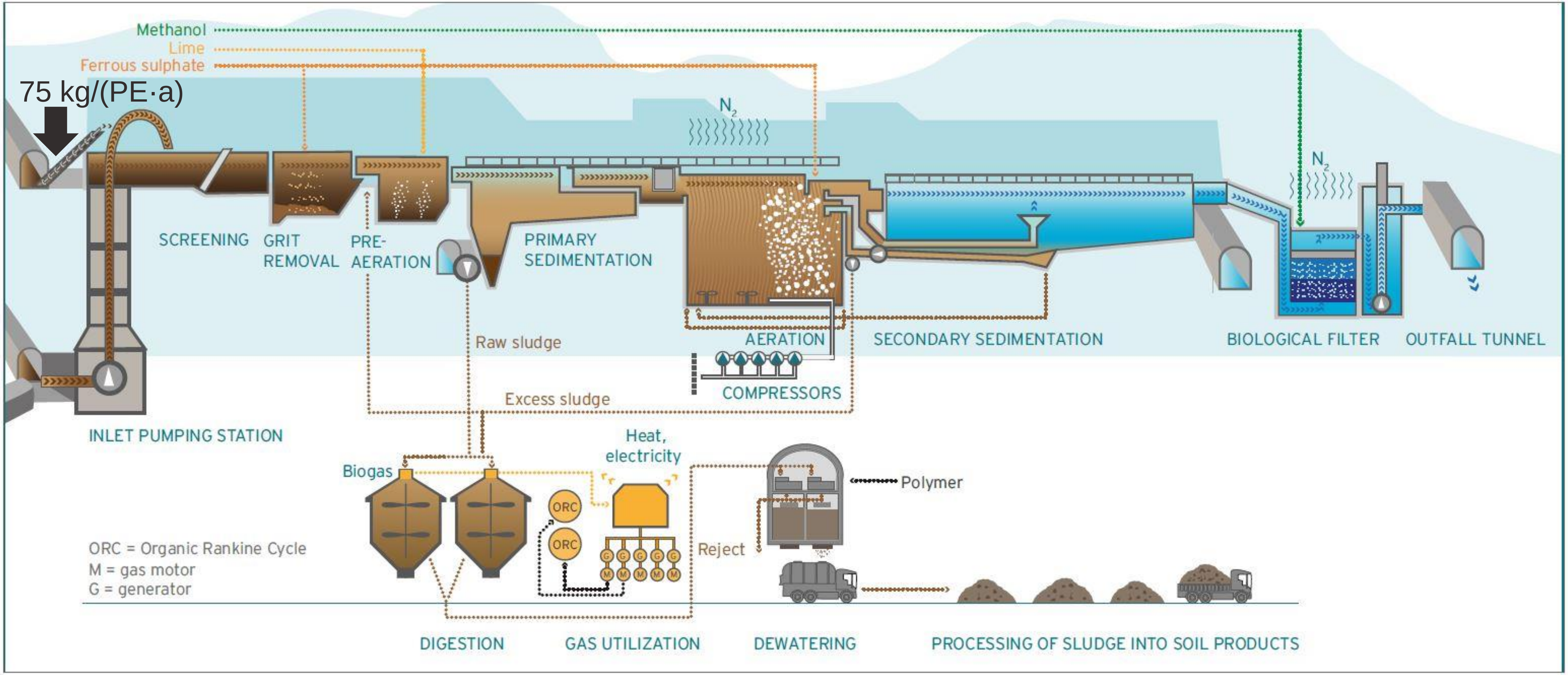


Biological treatment step – Zoom-in on “Biology”

Two steps are necessary for nitrogen degradation

Nitrification (aerobic = oxygen consuming step)

$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$

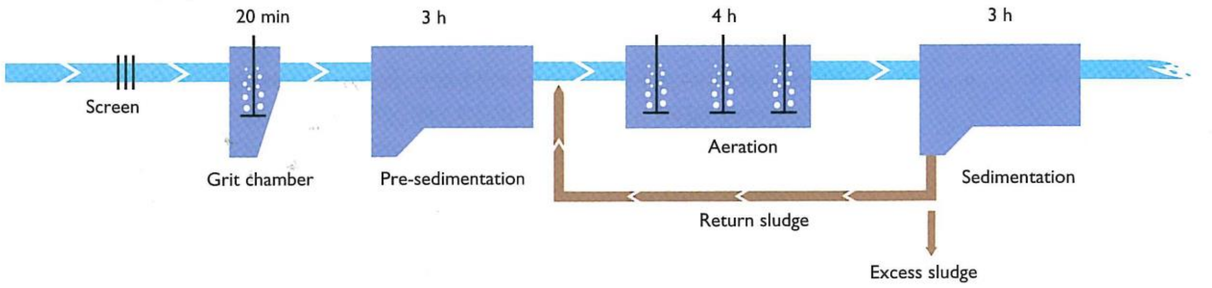
Denitrification (anaerobic = lack of oxygen)

$2NO_3^- + H^+ + [CH_2O] \rightarrow N_2 + HCO_3^- + H_2O$

Nitrogen is released to the air as N_2. Carbon is consumed as carbon source and released as CO_2.

The result is microbial sludge with bound C and P.

Nutrient Recycling: The Nitrogen Cycle



Biological degradation of nitrogen

- Energy need for the aeration **30 kWh/(PE·a)**
- Nitrogen feed load **6.5 kg/(PE·a)**
- Specific energy need for the degradation of nitrogen 2.5 kWh/kg N ➔ **16 kWh/(PE·a)**

Haber-Bosch process (ammonia synthesis)

- Specific energy need ≈10 kWh/kg N (Source: Ullmann encyclopedia)
- World production: 150 million metric tons ammonia per year, and increasing
- 1.5 % of the global energy production
- 3-5 % of the global carbon dioxide release

➔ Nitrogen is run in a cycle with a massive energy input ➔ Energy saving potential

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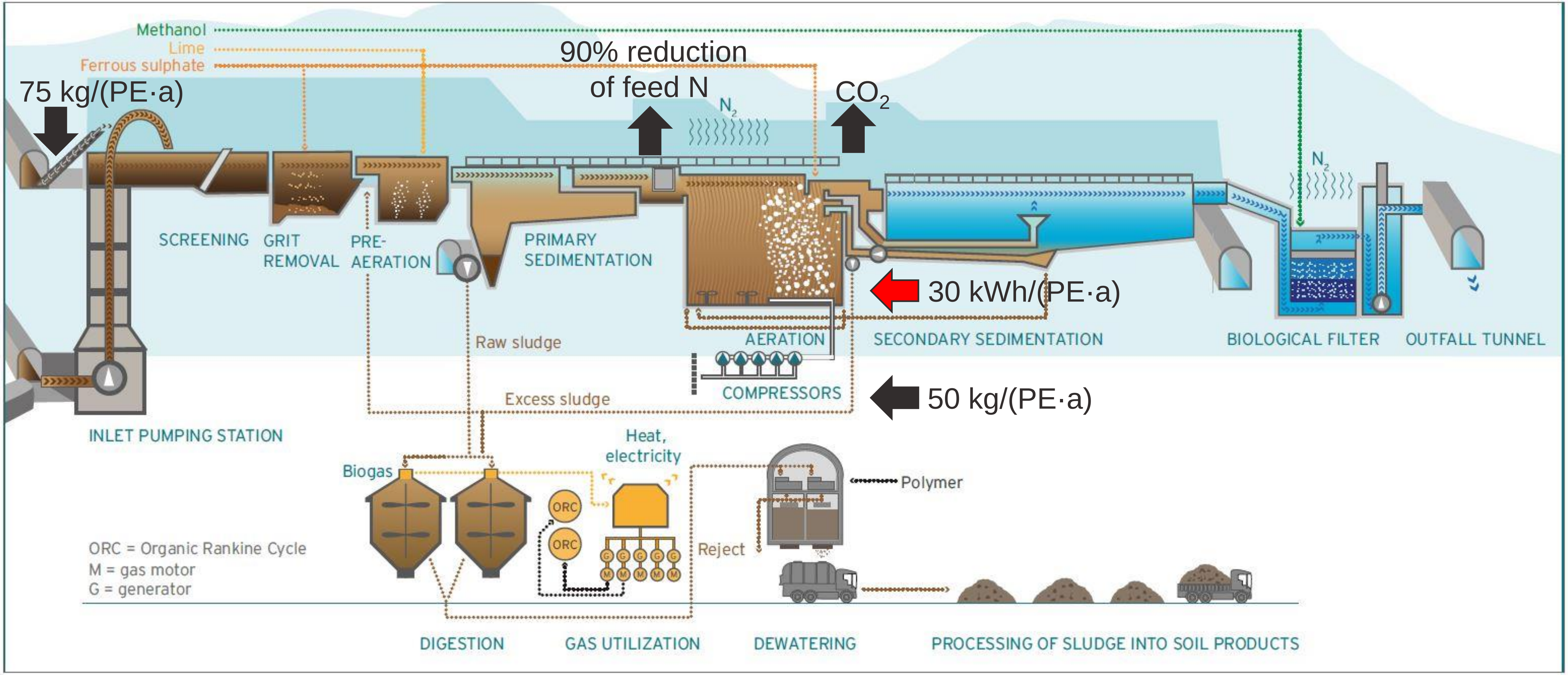


Anaerobic digesters are biotech reactors

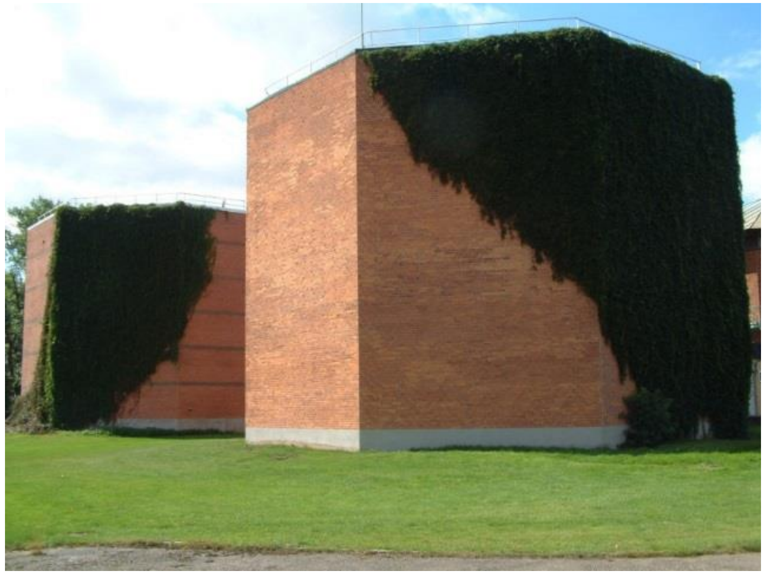
Large reactors 1000 to 4000 m^3

Residence time 15 to 25 days

Temperature 35 to 38 °C (mesophilic) – Energy need

Gentle mixing

Robust against
changes in the substrate



Anaerobic Digestion – Biotech in wastewater treatment

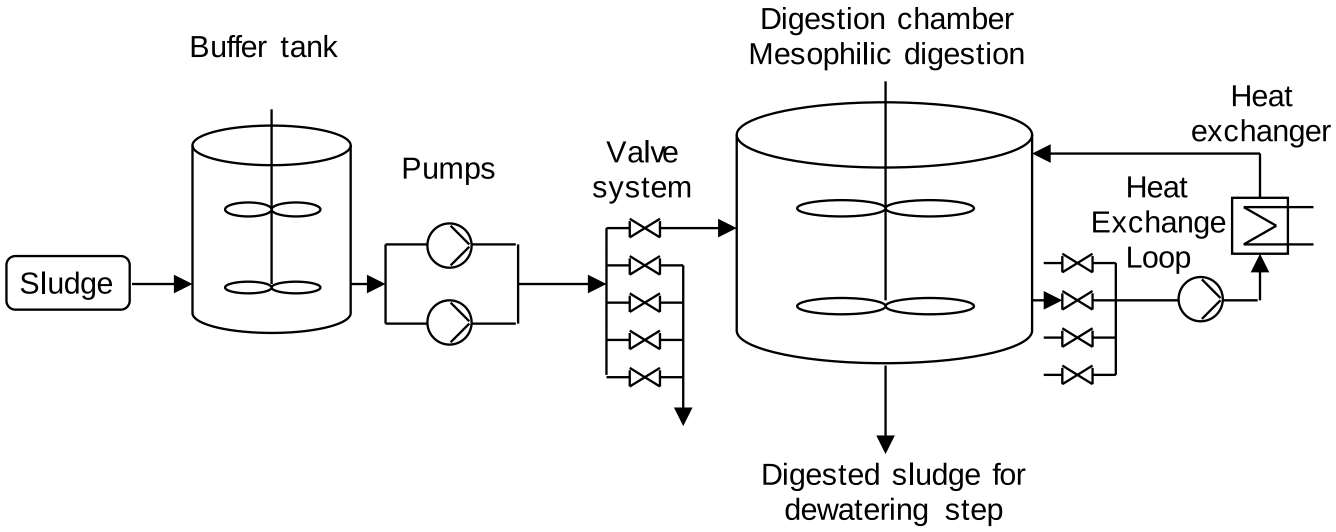
Main task: **Reduction** of the organic part ➔ Disposal costs up to 300 EUR/t Dry Solids (DS)

Energy self-sufficiency of the wastewater treatment plant

Sludge feed to digestion: **52 kg/(PE·a) as solids**

- 70-80 % organic matter in solids

Volume and cost reduction



Sludge effluent: **25 kg/(PE·a) as solids**

- 50-60 % organic matter in solids

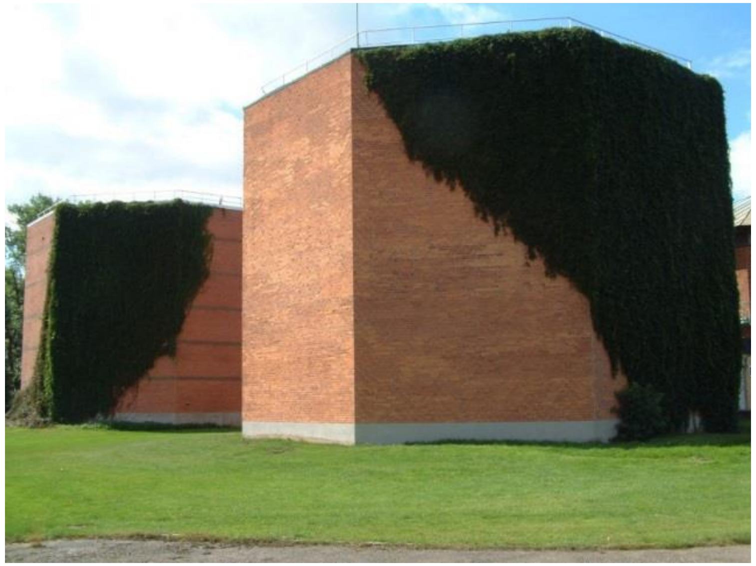
Still, most of the organic matter is left

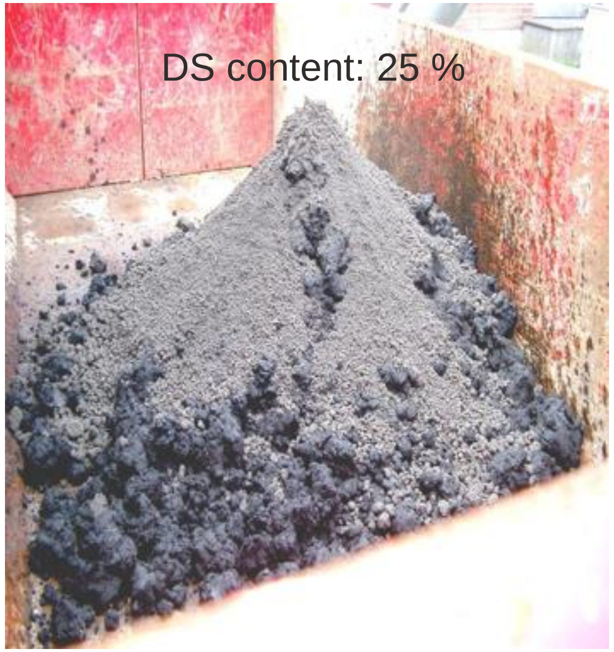
- It can be a raw material. Create new ideas for further use.

Sludge is the end product of the wastewater treatment

Disposal costs per metric ton DS

- Sludge dry matter for disposal 25 kg/(PE·a)
- 200-300 EUR Incineration
- 150-200 EUR Composting, Disposal
- 100-150 EUR Agriculture





Methane formation process

A microbial consortium

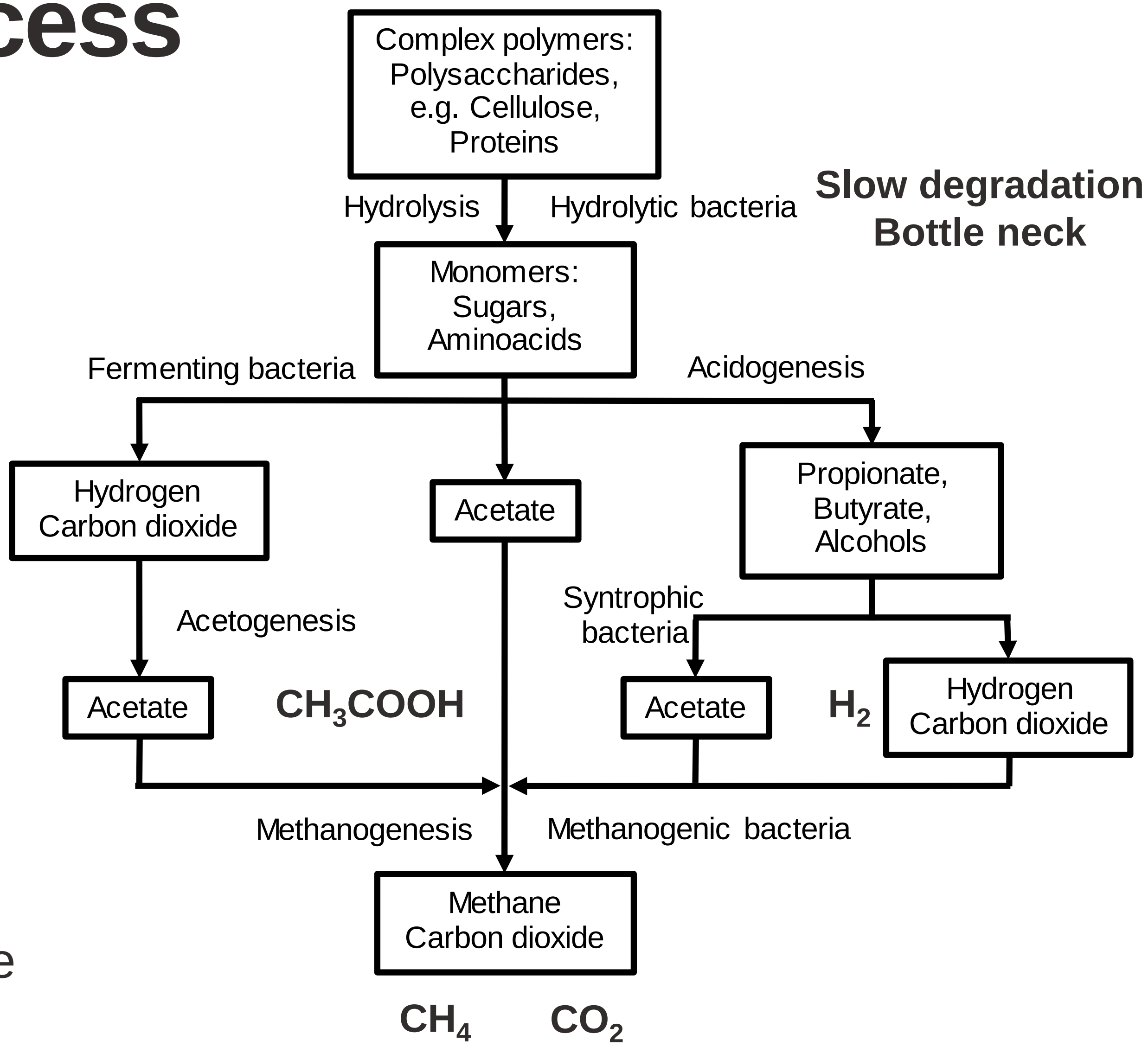
- A large number of different microbes
- Microbes are specialized on substrates

Biochemical mechanism

- Complex organic compounds are degraded
- Shorter units
- Monomers

Target

- Make the carbon-based nutrients bioavailable
- Produce energy for microbial metabolism



Biogas and Biomethane

CH_4 H_2S

CO_2

Biogas

- Mix of 60 % methane, 40 % carbon dioxide and traces of hydrogen sulphide
- Can be used in Combined Heat and Power generation (CHP)

Biomethane

- Contains >95 % methane
- Upgrade: Stripping (= washing out) carbon dioxide and hydrogen sulphide by water
- Can be used in cars, buses, trains, gas grid

CH_4

Mass flows

Helsinki, Viikinmäki

Size: 800 000 PE (Person Equivalent)

Feed flow: 102 million m³/a wastewater

Biogas: 13.4 million m³/a ➔ 17 m³/(PE·a) biogas

➔ 10 m³/(PE·a) biomethane

➔ **94 kWh/(PE·a)**

Electric power production: 25 500 MWh/a (**31 kWh/(PE·a)**)

Dry sludge: 19 000 t/a ➔ 24 kg/(PE·a) ➔ Costs for disposal

Wet sludge (28 % DS) for disposal: 65 000 t/a (180 t/d)

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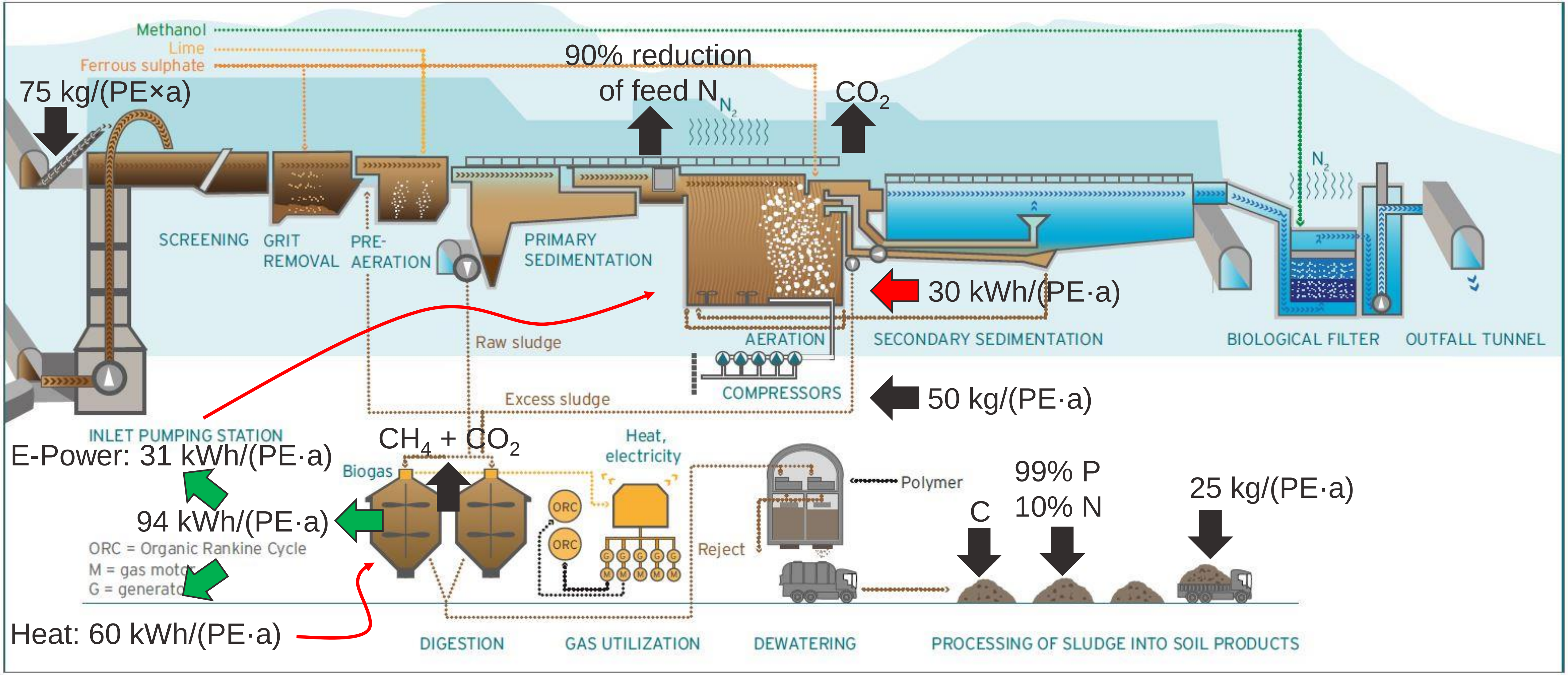


The Value in Waste

Waste reduction

- Minimizing the treatment costs
- Minimizing the disposal costs
- Degradation of harmful substances

Energy content

- Adding an extra loop to the carbon cycle

Recycling

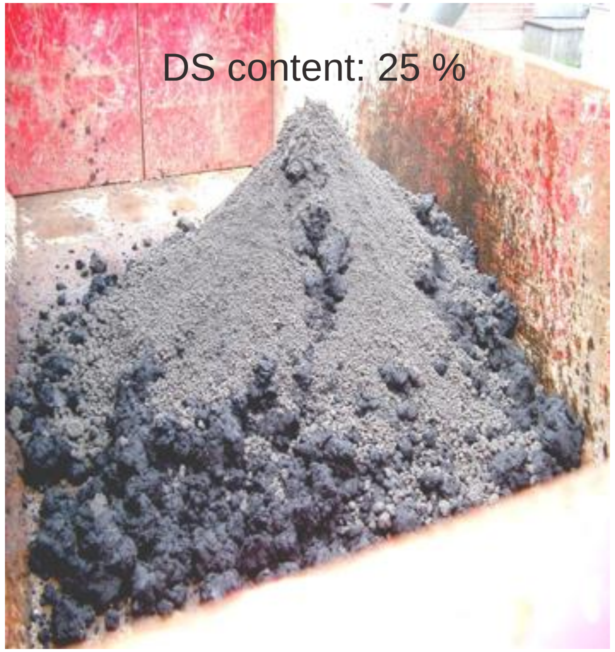
- Nutrients: N and P are valuable compounds – Cleaning step
- Prohibiting nutrients from release to the natural water cycle
- Recycling organic matter to agriculture

NH_3

N C

P

PO_4



New ideas are needed

Use the remaining 25 kg/(PE×a) ➔ Lower disposal costs

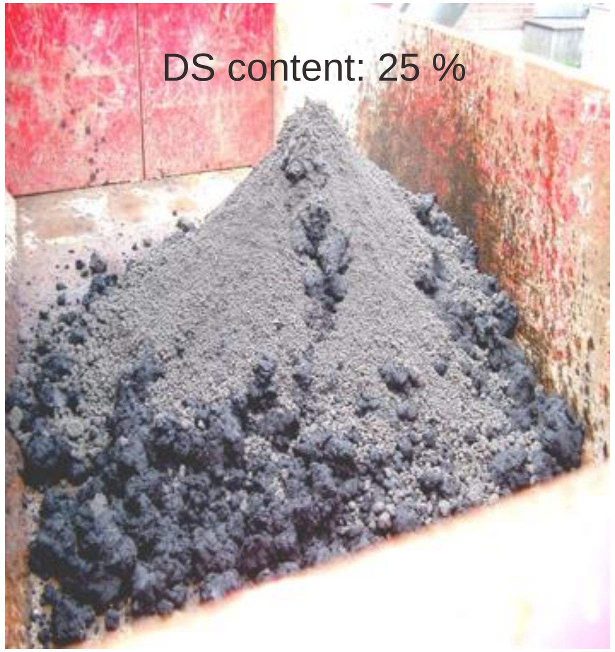
- Make the **biogas yield** more effective ➔ Increased income

Biorefinery – Produce other material than methane

- Hydrogen H_2 has much higher energy content
- Hydrogen is much more versatile
- Produce **bio-based building blocks**
- Monomers for bio-based and biodegradable plastics

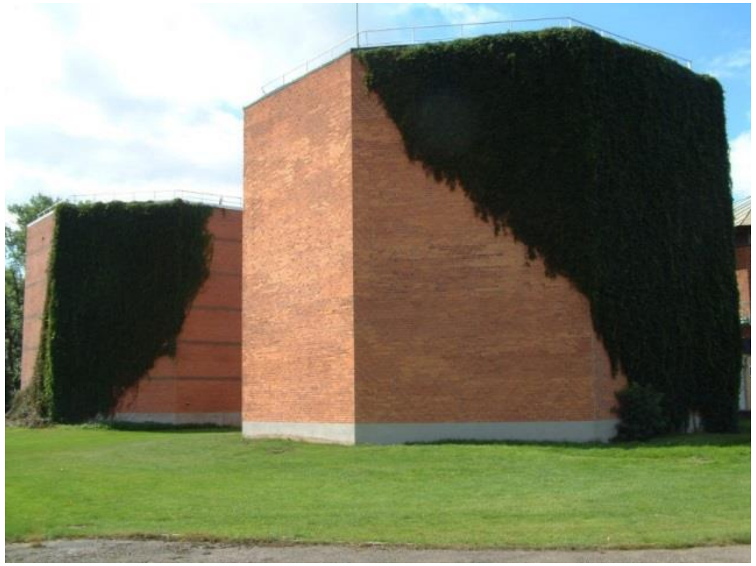
More effective nutrient recycling for N and P

CH_4



CO_2

H_2



Sources and further reading

Kemira Handbook: About Water Treatment

- Free Download https://www.kemira.com/insights/water-handbook-2020/

YouTube: Polymers in Wastewater Treatment:

- https://www.youtube.com/watch?v=TKAHZECfXok

Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall (DWA)

- Many publications: http://de.dwa.de/

DESTATIS: https://www.destatis.de/DE/Startseite.html

European statistical office, EUROSTAT: https://ec.europa.eu/eurostat/web/main/home

International Water Association, IWA: http://www.iwa-network.org/

Viikinmäen jätevedenpuhdistamo: https://www.hsy.fi/

European Sustainable Phosphorus Platform: https://phosphorusplatform.eu/42-r-d-projects/514-p-rex

The End – Maybe not …

Thank you for your attention

Kiitos mielenkiinnostanne

Tack för ert intresse

Questions? – Kysymyksiä? – Frågor?