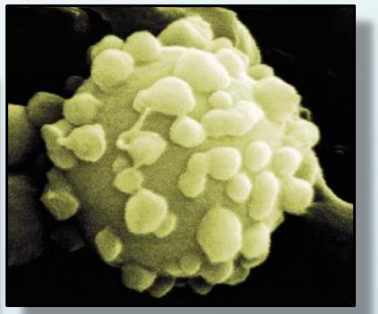
Harnessing the wonders of the microbial world to solve environmental problems

René Rozendal



Understanding Microbial Communities - Developing the Potential
Isaac Newton Institute Open for Business Event
4th of December 2014 - Isaac Newton Institute, Cambridge

About Paques

- Family owned business, founded in 1960
- Number of employees: ~400
- Number of Business Units: 4 (Europe, China, South America & India)
- Develop and commercialize novel biological solutions for wastewater and gas treatment
- More than 1,800 installations worldwide

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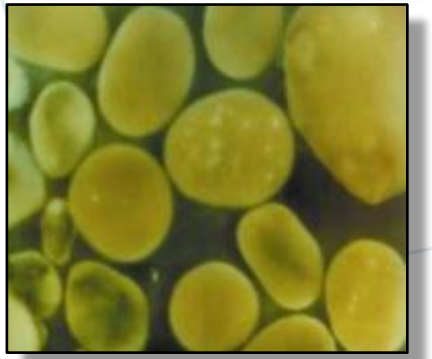
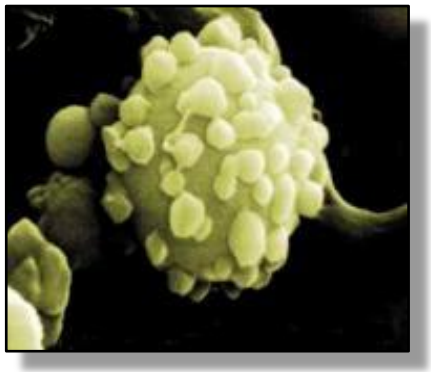
Microbial Diversity

Our approach

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"Application of useful microorganisms from nature in our high rate bioreactors"

In strong collaboration with universities!

TU Delft Delft University of Technology

WAGENINGEN UR For quality of life

Radboud Universiteit Nijmegen

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Environmental Biotechnology

- **Pure culture processes not feasible on waste**
  - "Dirty" environments, already full of microbes
  - Large flows, so sterilisation not economically feasible

- **Only option**:
  Understand the role that certain target microbes have in nature and recreate their preferred environment inside a bioreactor.
  - *Community engineering vs Genetic engineering*

Paques' product portfolio

Know how area	Application	Products
Organics	ANAEROBIC AND AEROBIC WATER TREATMENT	BIOPAQ®IC BIOPAQ®UASB / UASB+ BIOPAQ® AFR CIRCOX® BIOPAQ® UBOX
H_2S / SO_2	(BIOGAS) DESULFURISATION	THIOPAQ® BIODESOX®
Nitrogen & Phosphate	(DE)NITRIFICATION	ANAMMOX® PHOSPAQ® ASTRASAND®
Metals and sulphate	METAL RECOVERY SULPHATE REDUCTION	THIOTEQ® SULFATEQ® BIOMETEQ®
Separation	FILTRATION AND SOLID REMOVAL	ASTRASAND® ASTRASEPARATOR®

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Anaerobic Treatment

- World leader in anaerobic wastewater treatment
- Removal of organic contaminants
- Biogas production
- >1000 Biopaq references in more than 60 countries

BIOPAQ®

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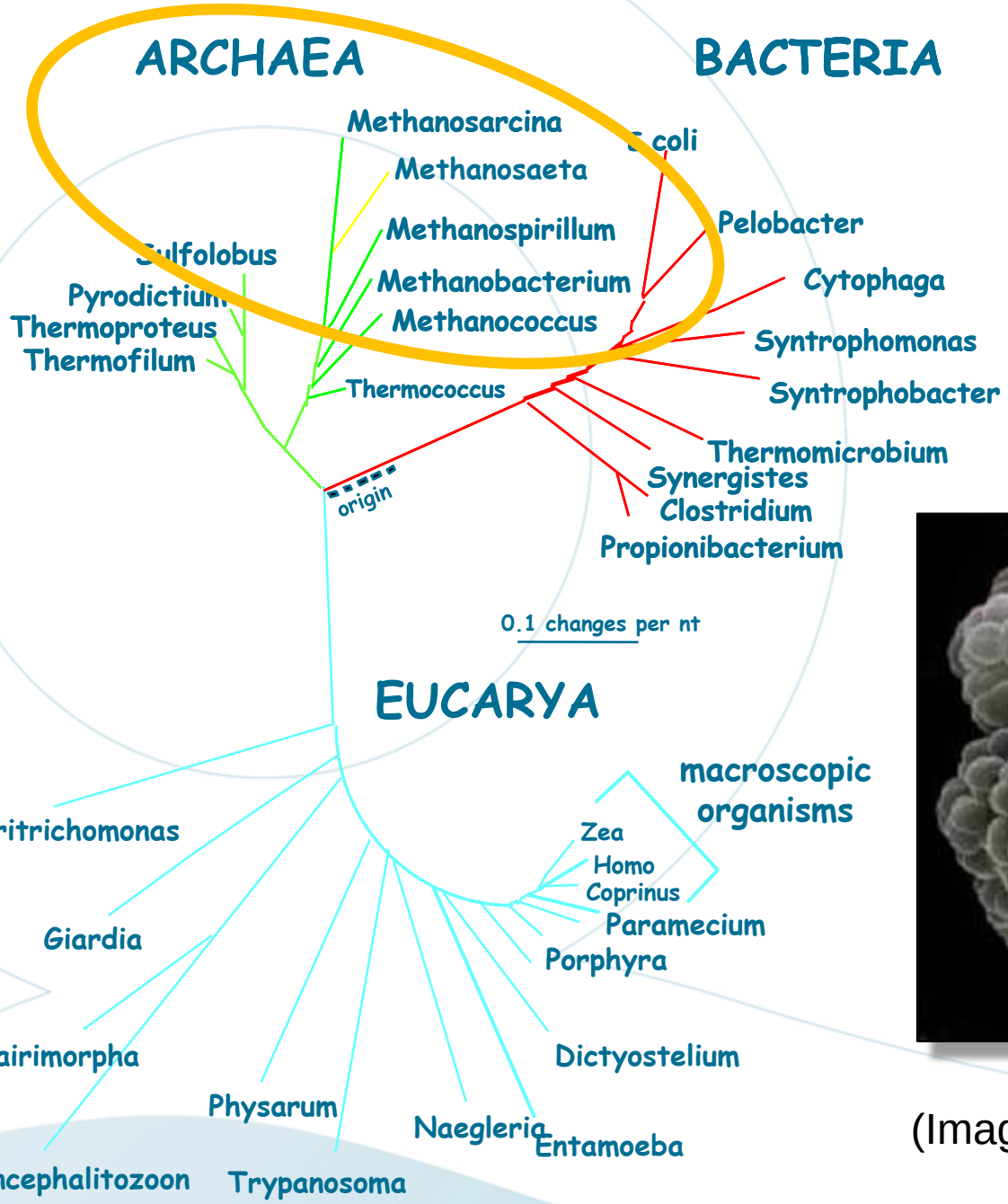
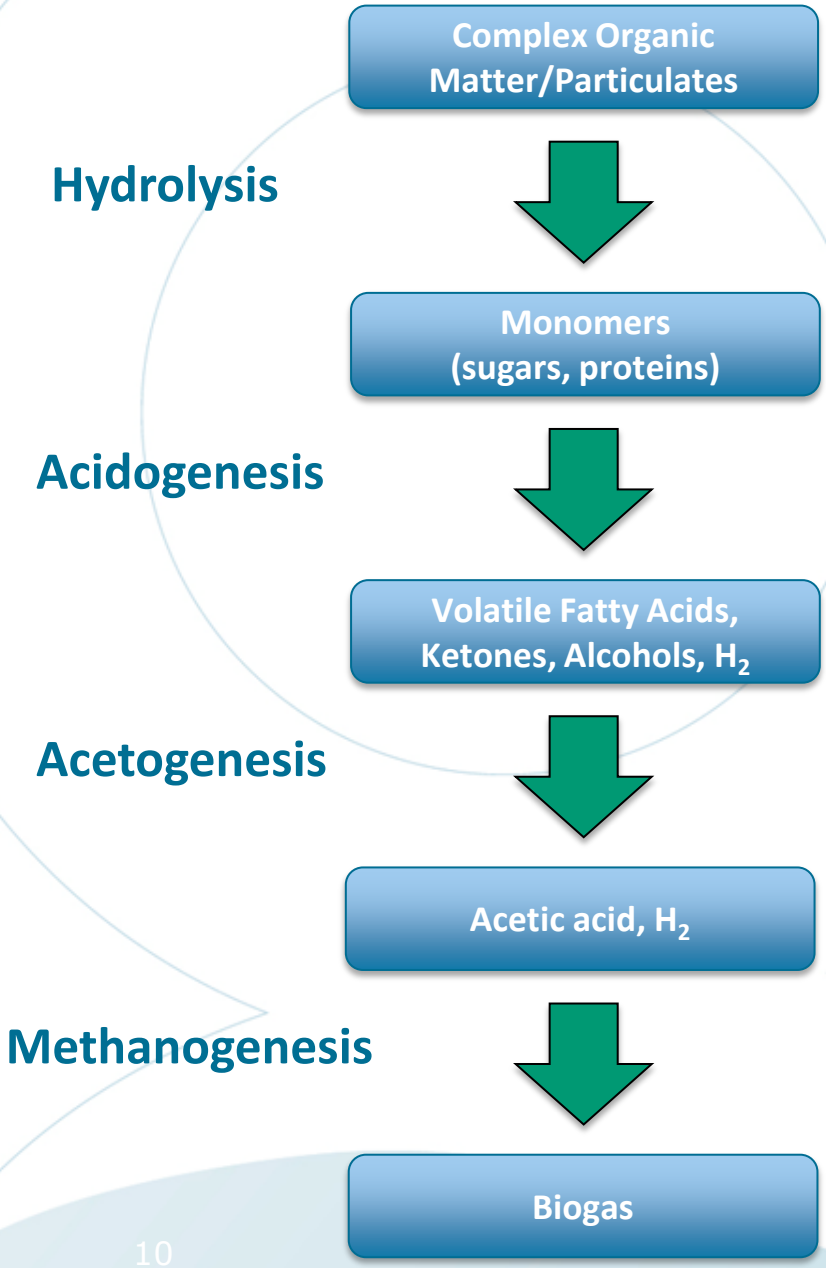
DALTON COLLECTING MARSH FIRE GAS



Methanosarcina
(Image by: Broad institute)

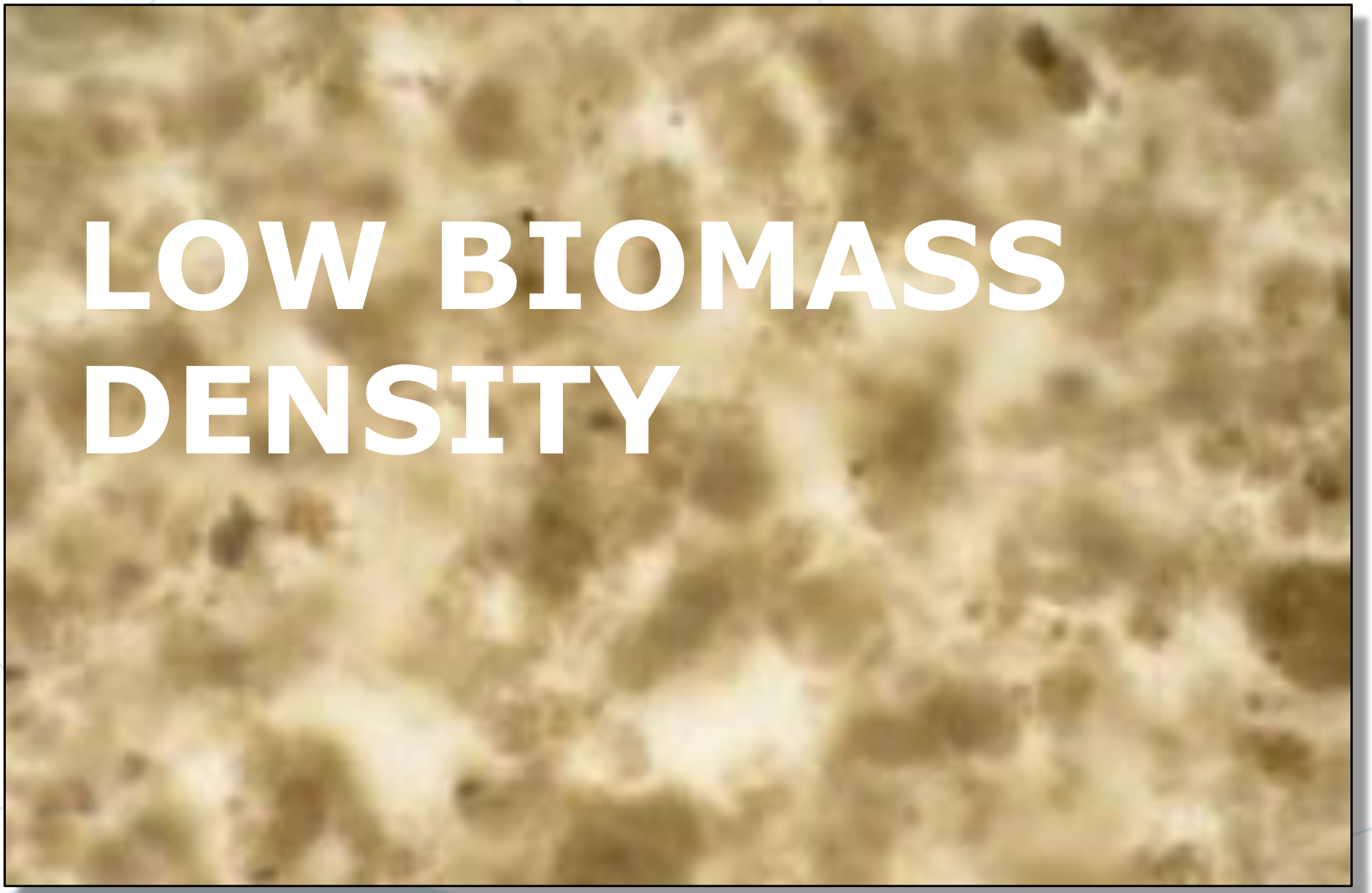
(Image by: Damien Batstone, The University of Queensland)



4 stages

- Products of one stage are the substrates of the next stage.
- Hydrolysis, acidogenesis, and acetogenesis done by bacteria
- Methanogenesis done by specialised archaea

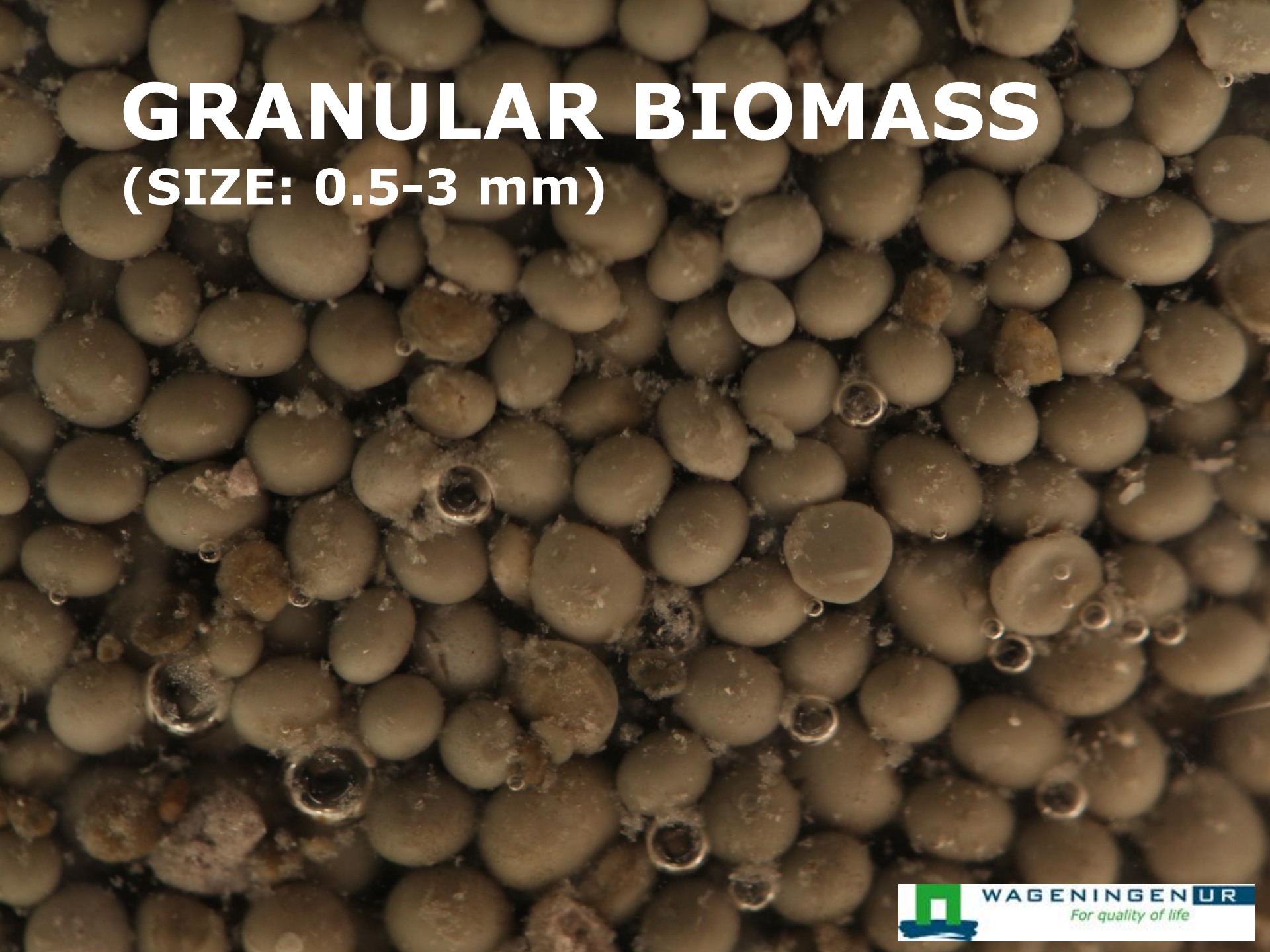
Before the 80's, flocs were used



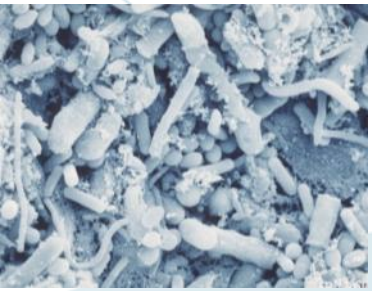
Then anaerobic granules were discovered

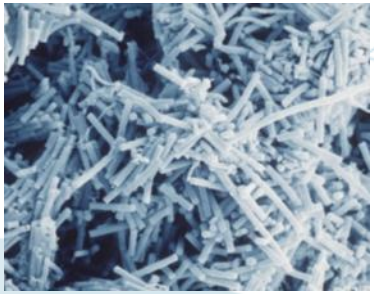
- During the 70's development of anaerobic granular sludge technology (Lettinga) 

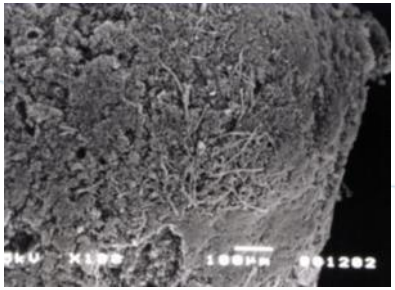
- Much more microbial biomass per m^3 reactor, so much higher conversion rates

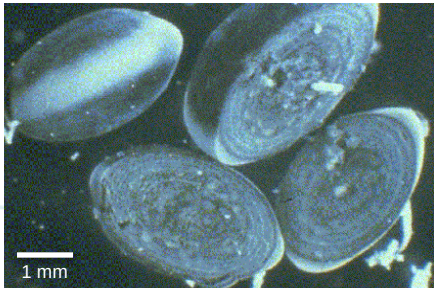

GRANULAR BIOMASS
(SIZE: 0.5-3 mm)
WAGENINGEN UR
For quality of life

Survival strategy
Biofilm & Granule formation





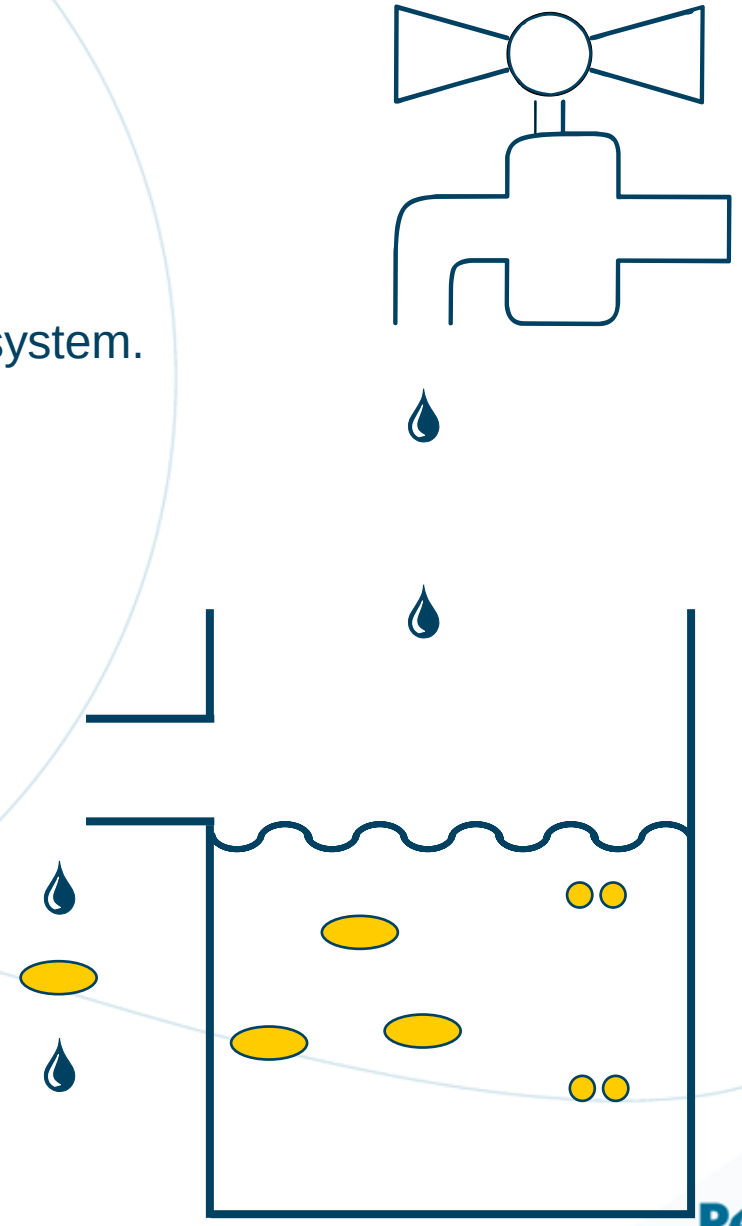




Photo's: *G. Gonzales-Gil, A.Alphenaar*

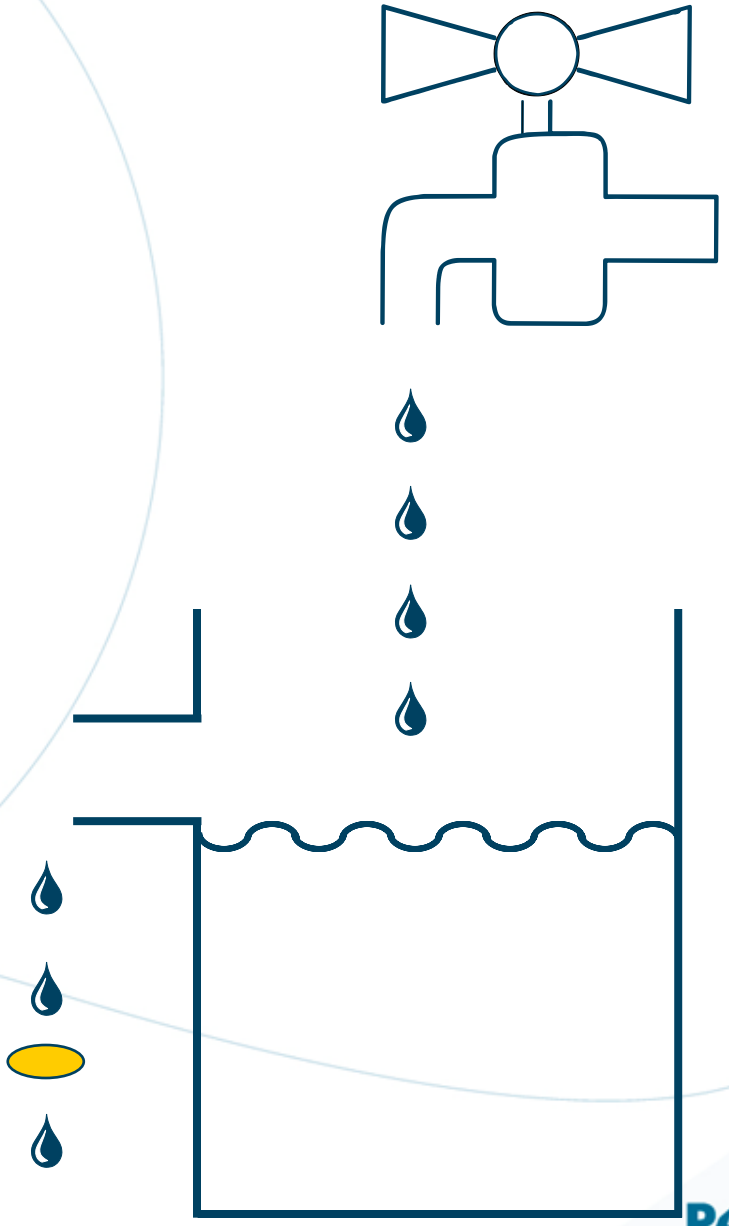
Dilution rate < growth rate

Microorganisms stay inside the system.



Dilution rate > growth rate

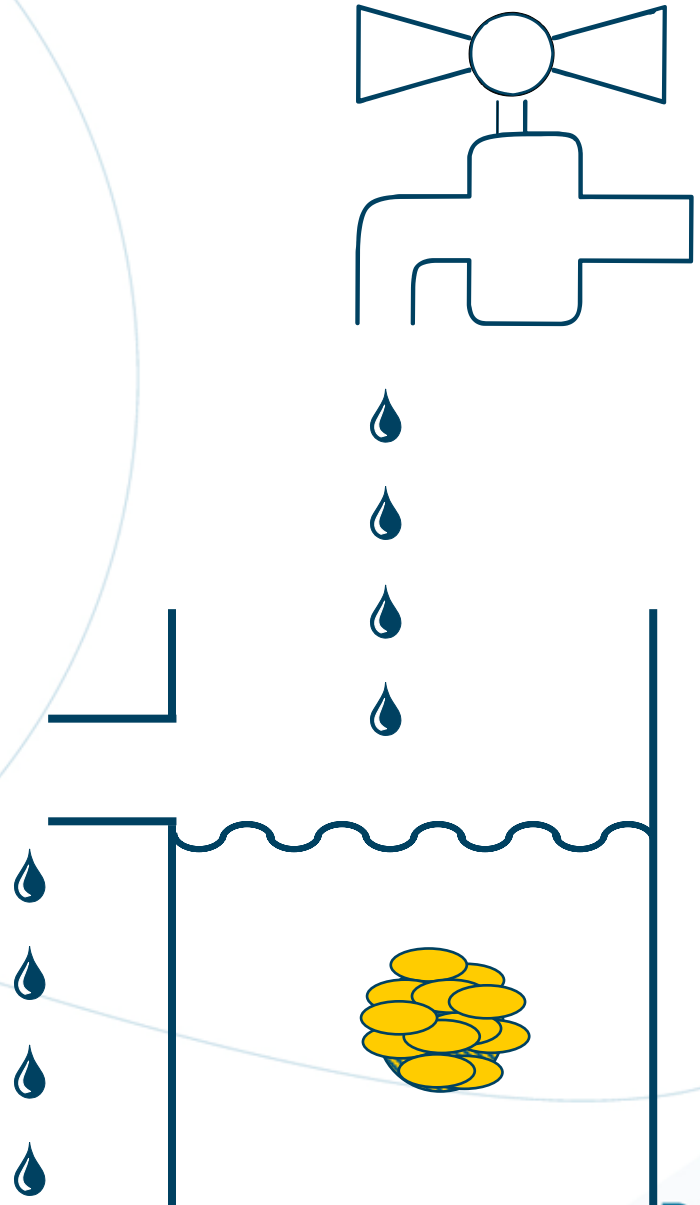
Wash out of microorganisms!



Dilution rate > growth rate

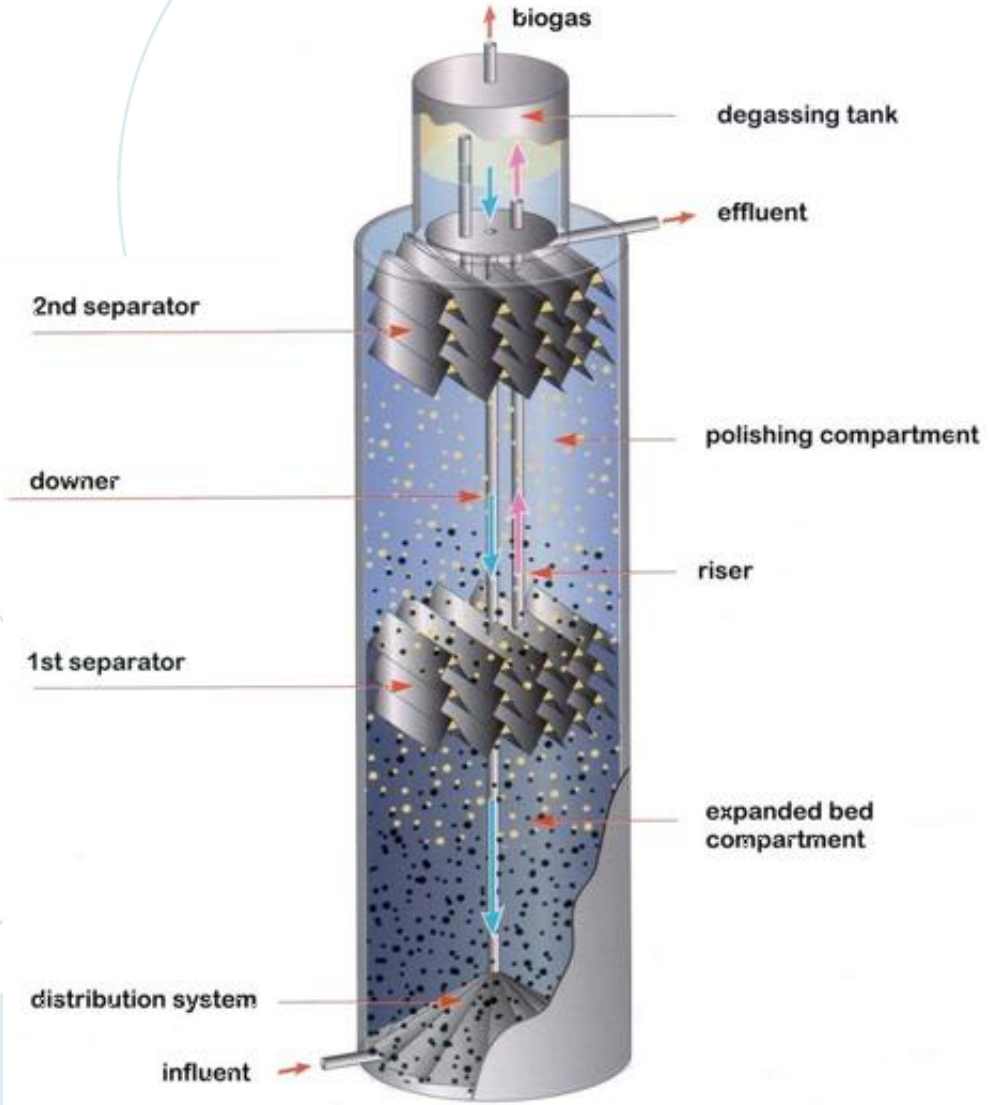
However, microbes are smarter than that!

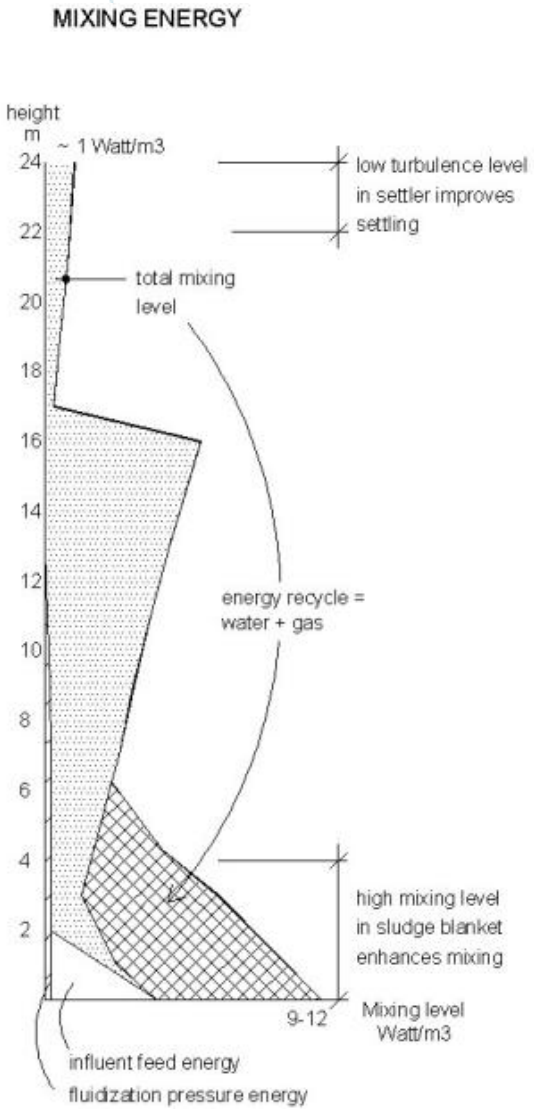
Under the right circumstances microorganisms can form granules to stay in reactor!



BIOPAQ®IC settler 8 m diameter

BIOPAQ® IC
Internal Circulation





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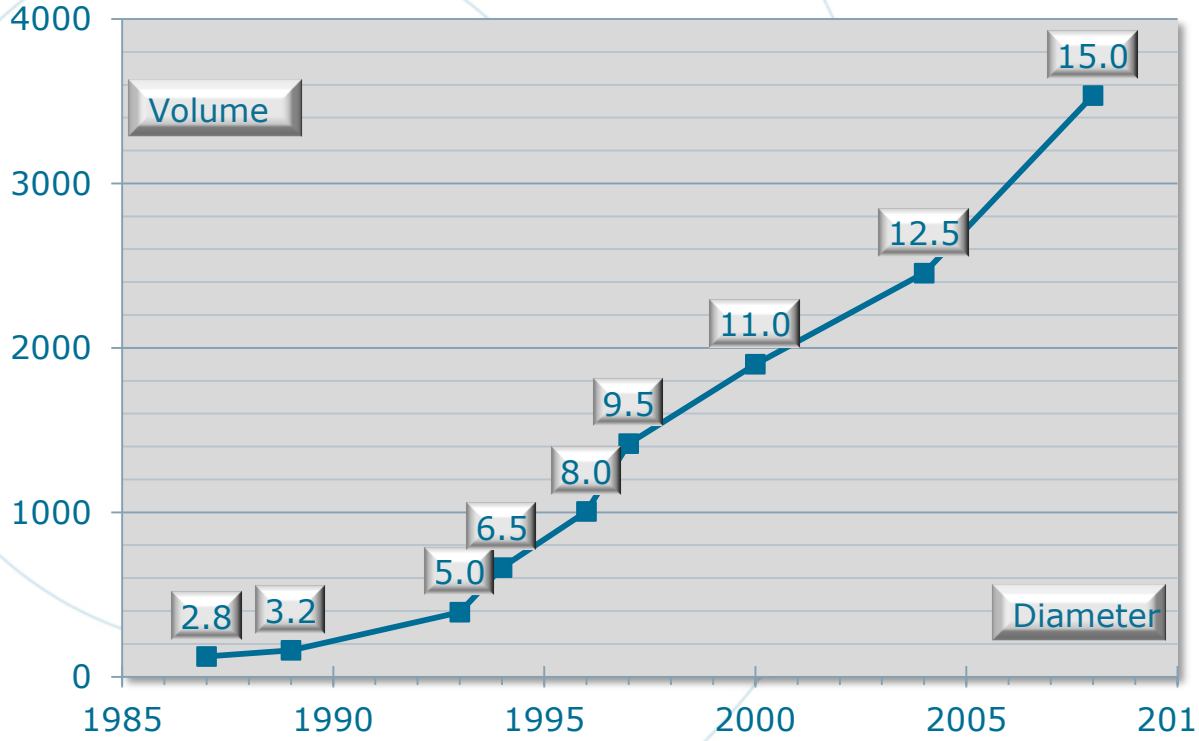
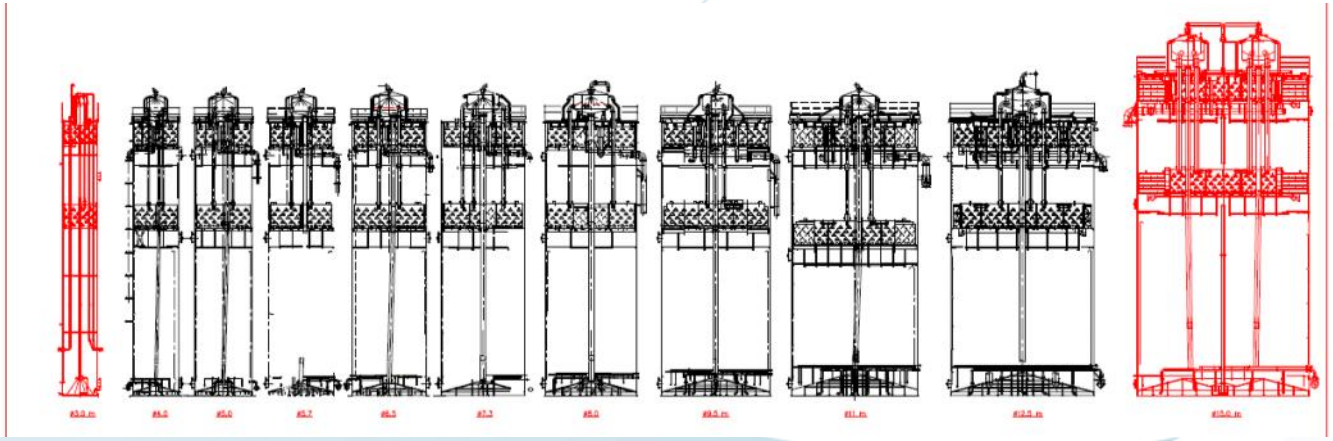
Product development - Size





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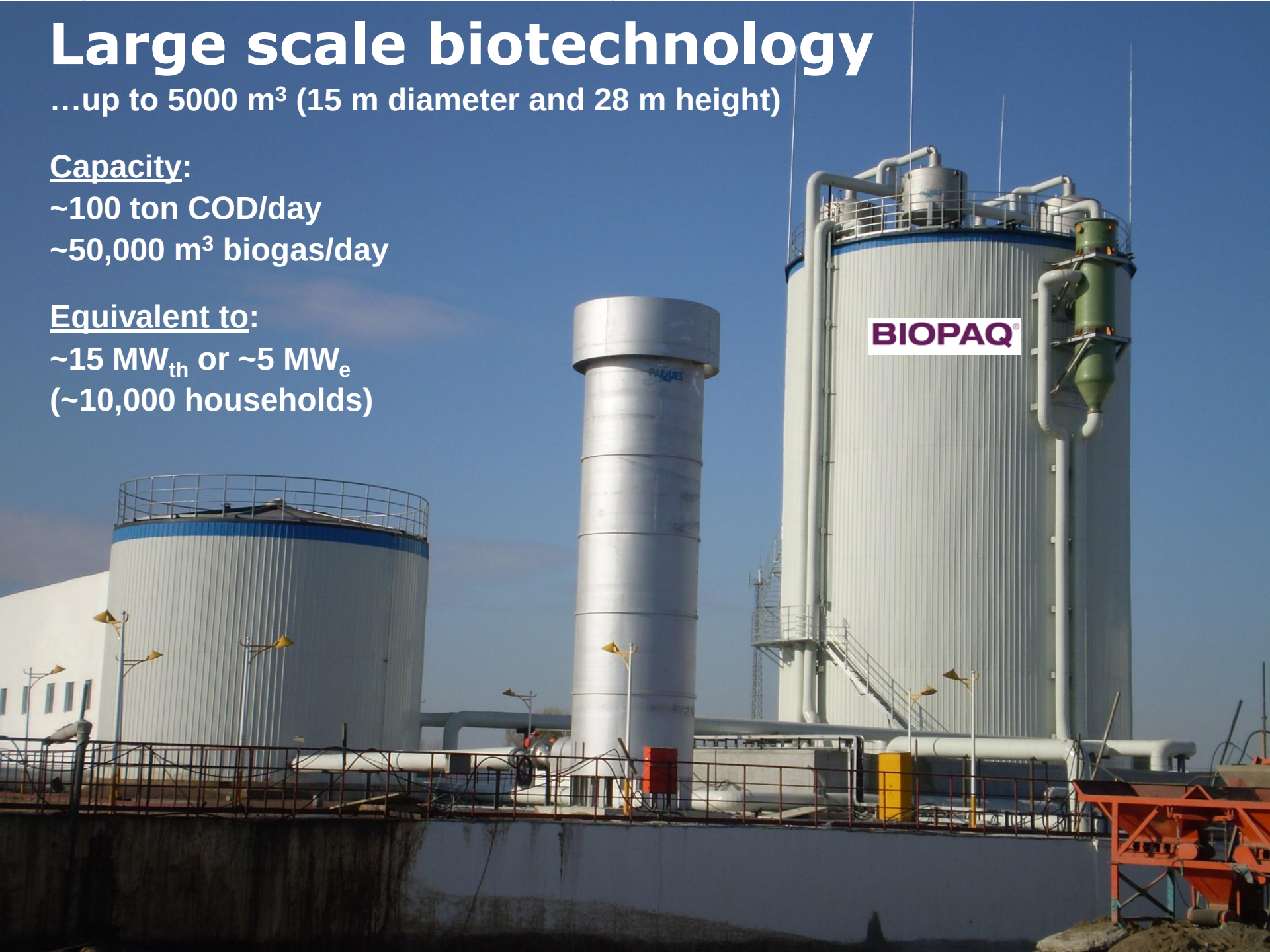
Large scale biotechnology

…up to 5000 m^3 (15 m diameter and 28 m height)

Capacity:
~100 ton COD/day
~50,000 m^3 biogas/day

Equivalent to:
~15 MW_{th} or ~5 MW_e
(~10,000 households)




Coca-Cola


Grolsch


Smurfit Kappa


ROYAL
COSUN


博天糖业
PAQUES


BEN&JERRY'S
PAQUES
Unilever

Biogas composition

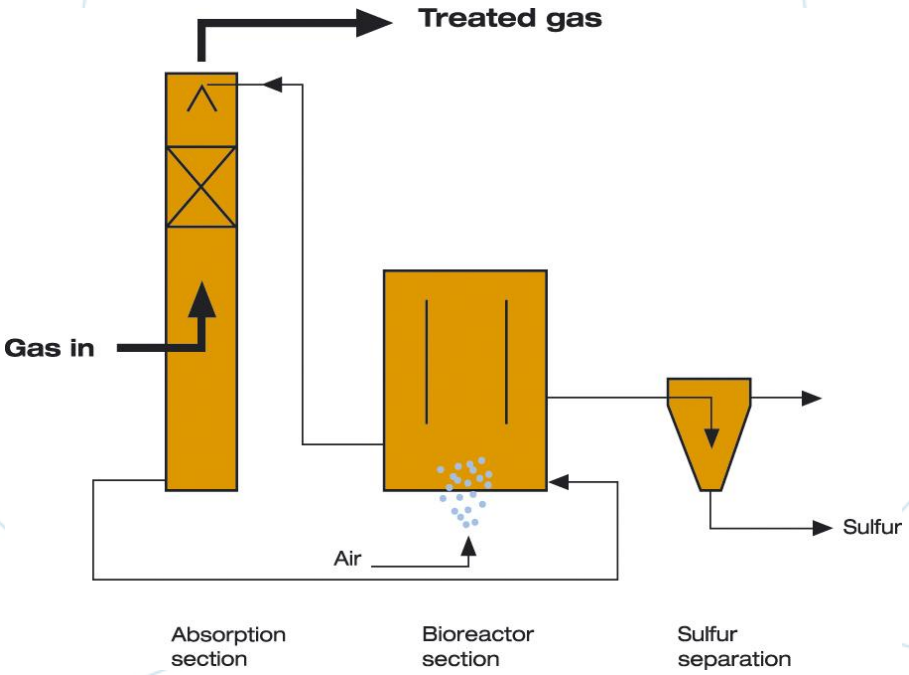
Compound	Vol%
Methane (CH_4)	50-90
Carbon dioxide (CO_2)	10-45
Water (H_2O)	0-5
Hydrogen sulphide (H_2S)	0-3.5

Consequenses of H_2S exposure

H_2S conc. (ppm)	(Possible) consequences
0.02	"Rotten egg" smell
1.6	Exposure limit (average over 8 hours)
10	Evacuation limit
100	Numbing of the olfactory nerves in 3 to 15 minutes Stinging of eyes and throat Risk of pulmonary oedema
200	Acute numbing of olfactory nerves Stinging of eyes and throat Risk of pulmonary oedema
500	Impairment of mental abilities Loss of sense of balance Numbing of respiratory organs in 30 to 45 min. Lethal after 30 to 60 min.
700	Rapid loss of consciousness (max. 15 min.) Breathing stops Lethal after 12 to 15 min.
1000	Immediate loss of consciousness Acute numbing of breathing "Knock down effect" Lethal within 3 min.

H_2S in Biogas: >>1000 ppm!!!

THIOPAQ® technology:
Conversion of H_2S to elemental sulphur

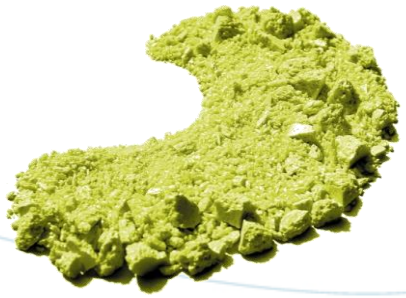


Absorber

$$H_2S + \mathbf{OH^-} \rightarrow HS^- + H_2O$$

Bioreactor

$$HS^- + ½\ O_2 \rightarrow S^0 + \mathbf{OH^-}$$



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H_2S removal by biological oxidation

Two possibilities:

- Complete oxidation:

  $H_2S + 2\ O_2 \rightarrow H_2SO_4$ (sulfuric acid - dissolved)

- Partial oxidation:

  $H_2S + 0.5\ O_2 \rightarrow H_2O + S^0$ (elemental sulfur – a solid)

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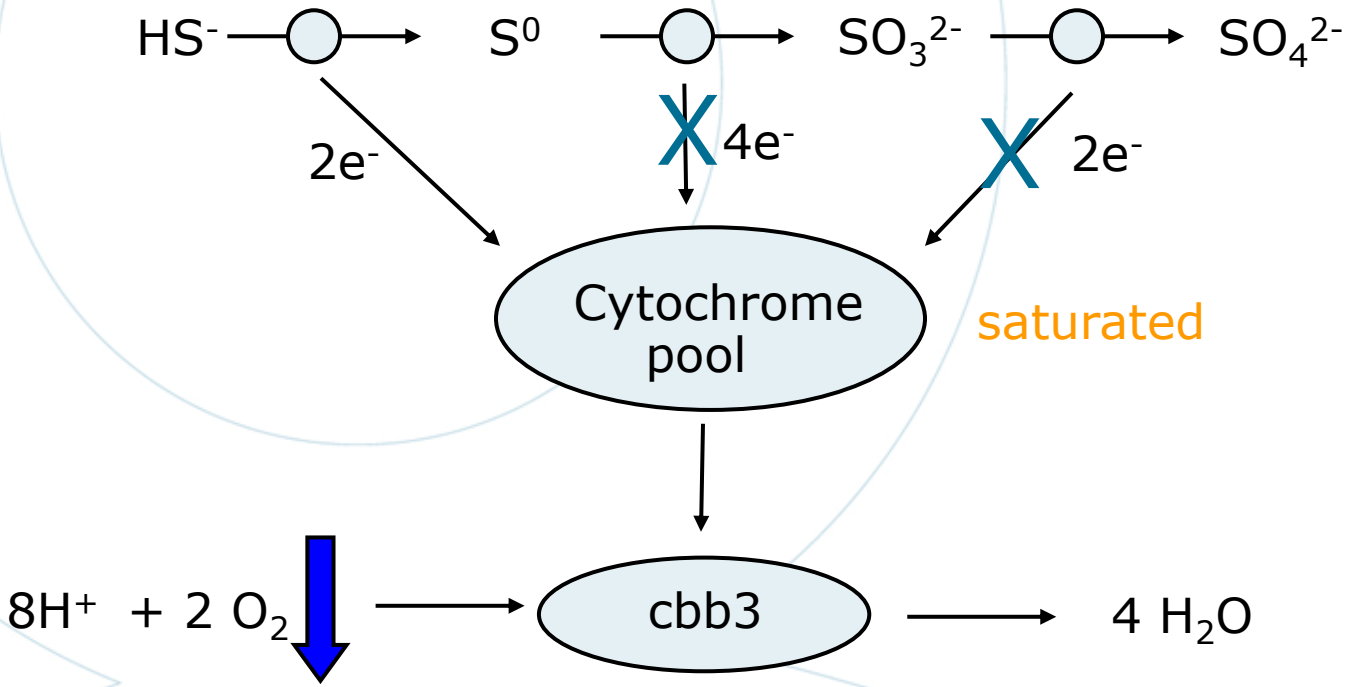
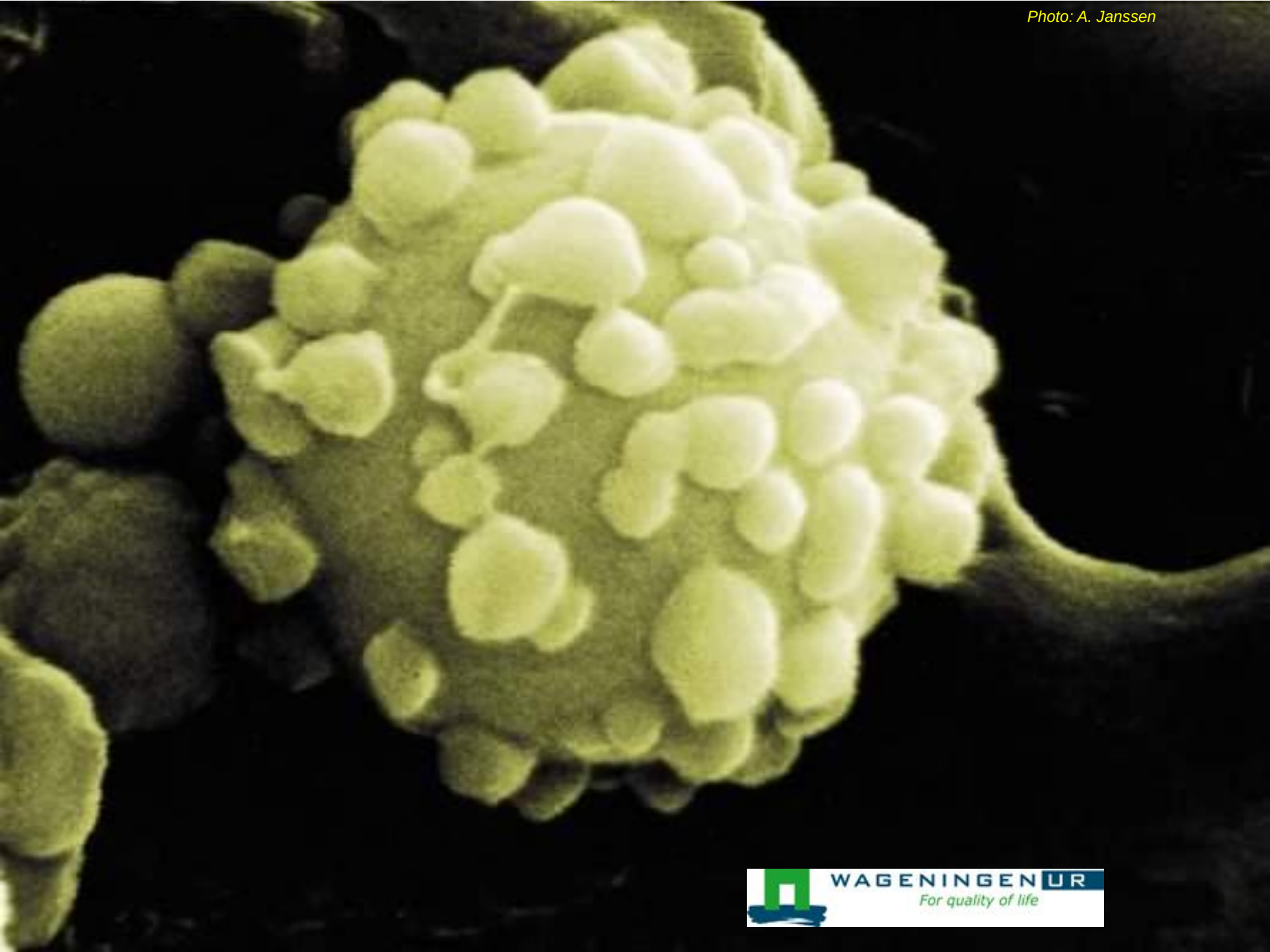
How to stimulate sulfur accumulation?



Oxygen supply via Redox Control (Janssen 1995)



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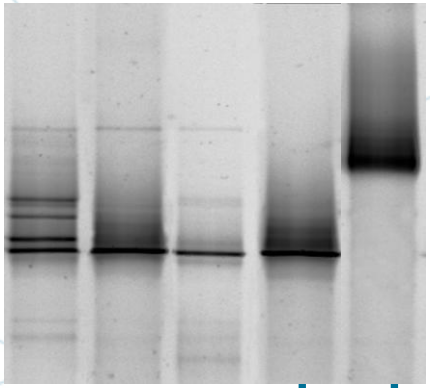
Natural Environment Thiopaq inoculum

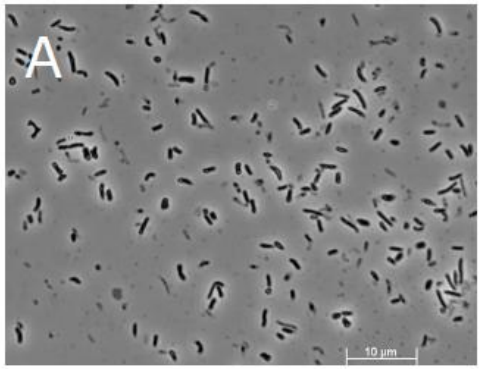
Sodium Bicarbonate

Fig. 14.1
Typical small shallow soda lake (Kulunda steppe, Altai, Russia)

DGGE analysis 16S rRNA



2009 2005 2006
Full Scale



Halothiobacillus W5, original dominant organism

Pure culture Thioalkalivibrio sp.

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0.02 ton S per day


0.5 ton S per day


0.9 ton S per day


2.8 ton S per day


4 ton S per day


13 ton S per day
AEROBIC REACTOR
R-9001

THIOPAQ®

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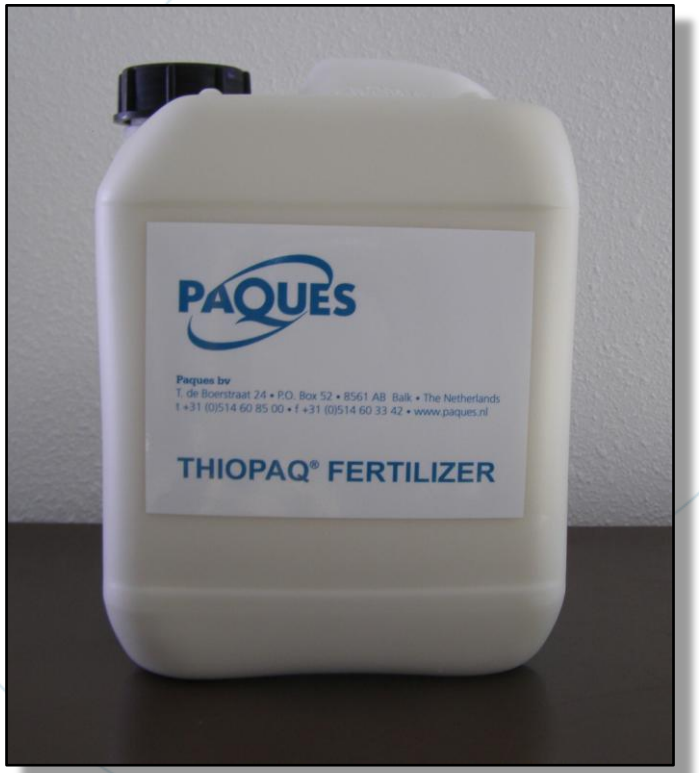
Gas desulphurisation with recovery

Paqell.

THIOPAQ® Fertilizer



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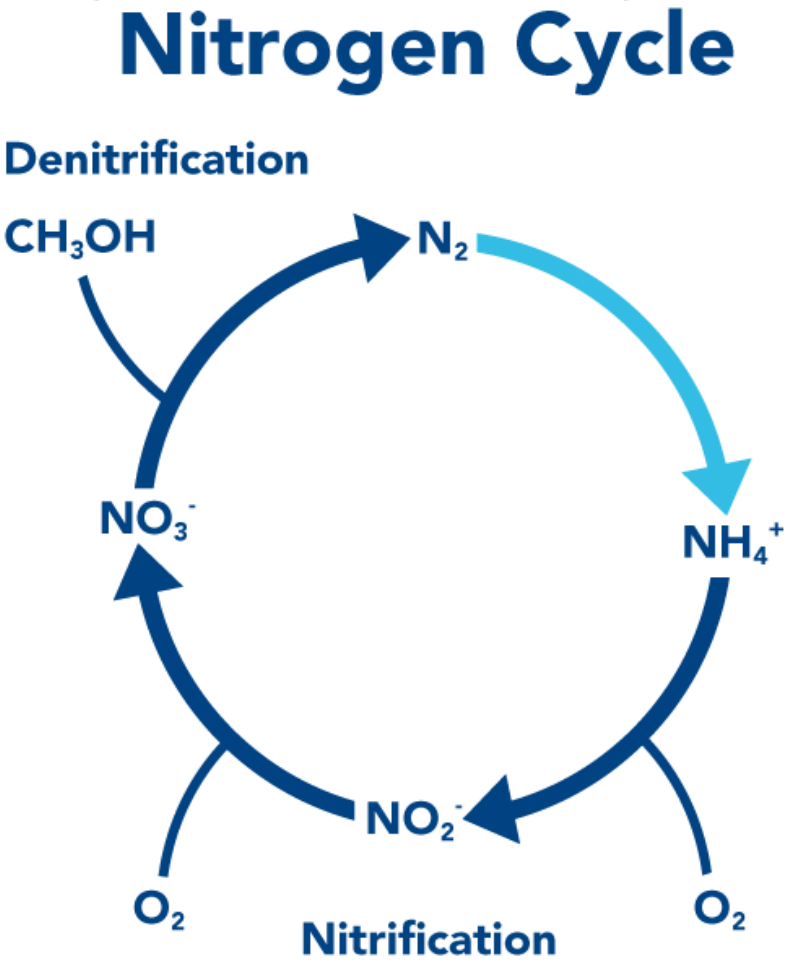
FERTIPAQ
Natural Solutions

PAQUES

ANAMMOX®
TOTAL NITROGEN REMOVAL



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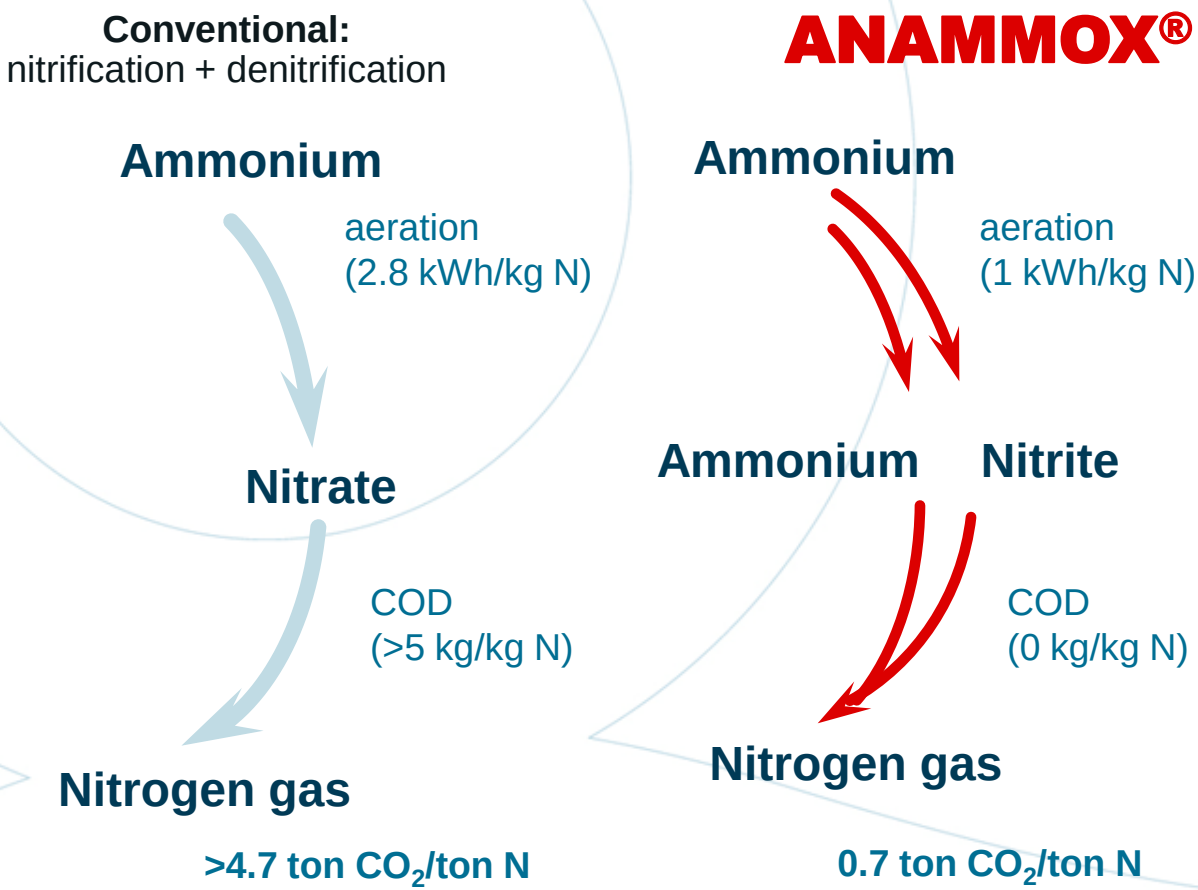
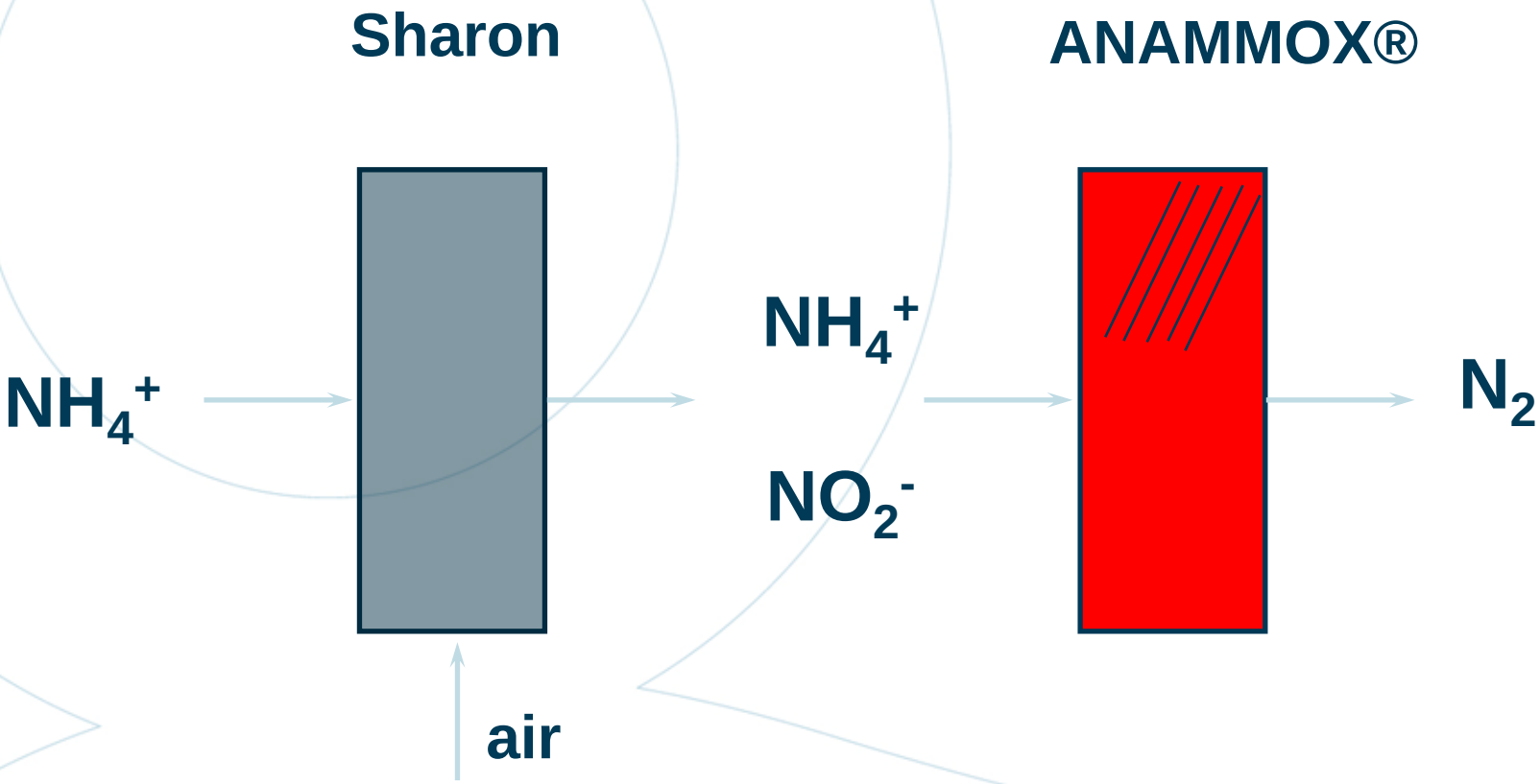
Comparison Conventional vs. ANAMMOX®

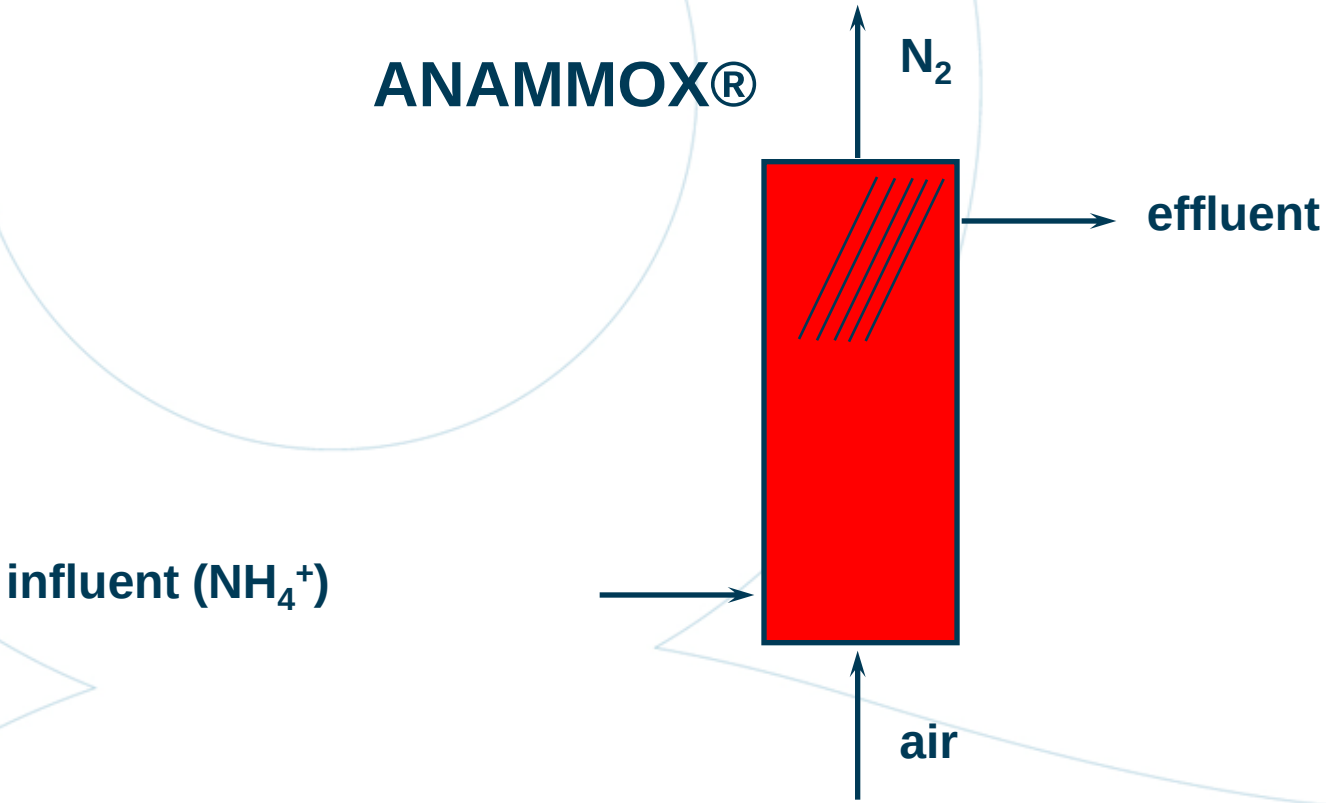


Our starting point: two-step ANAMMOX



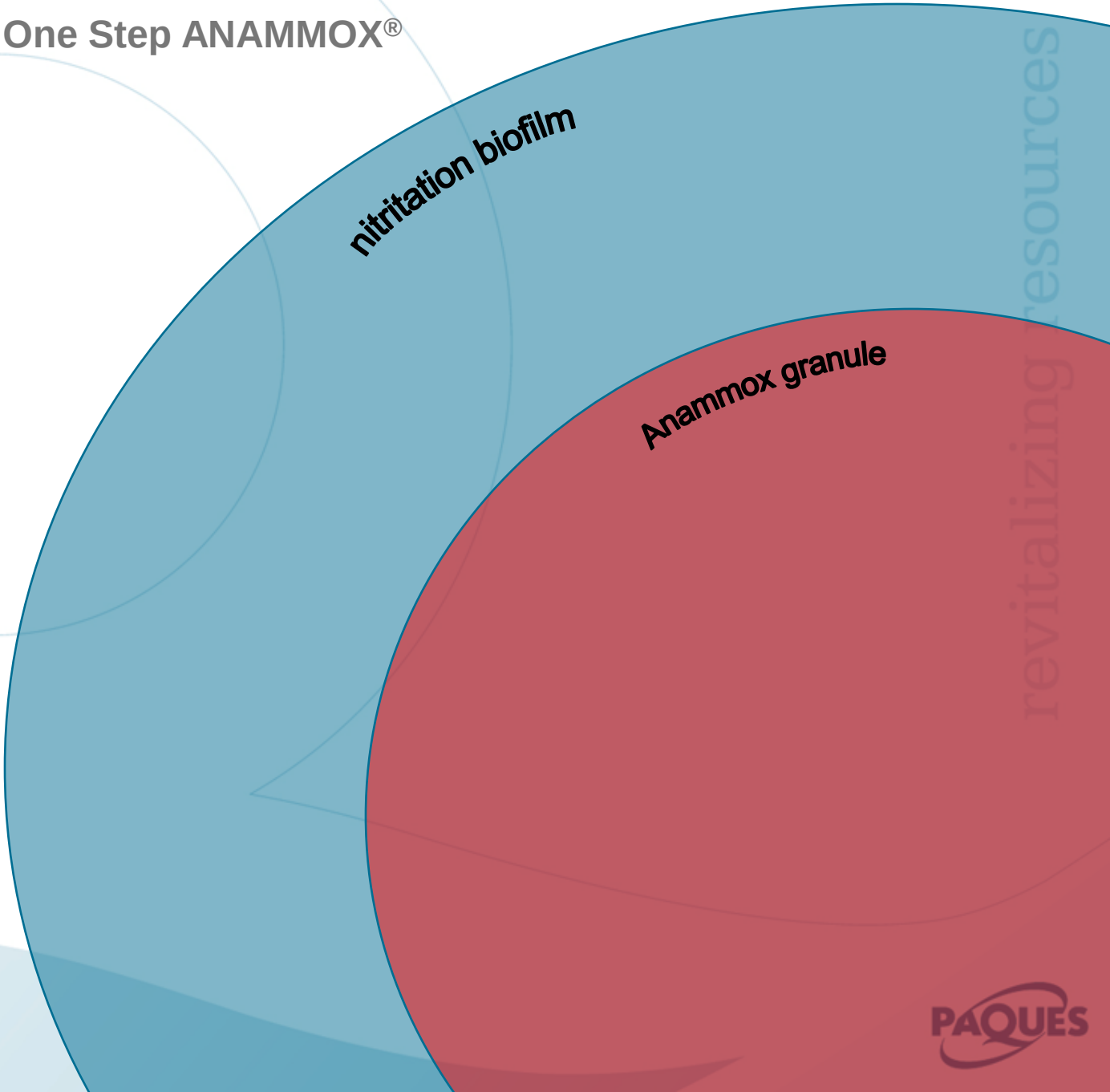
Rejection water WWTP Rotterdam 2002

Next step: one-step reactor

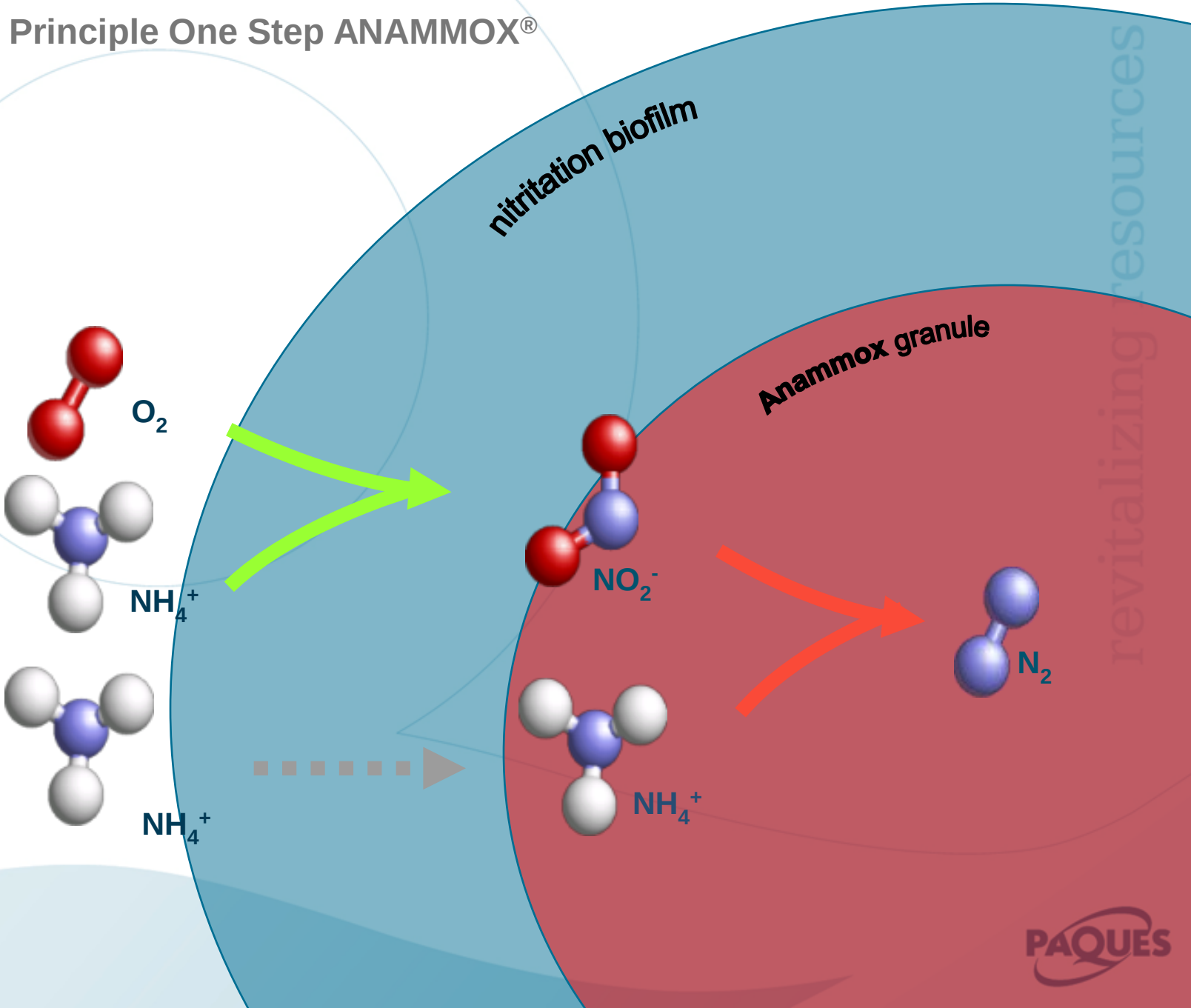


GRANULES AGAIN!

Principle One Step ANAMMOX®



Principle One Step ANAMMOX®



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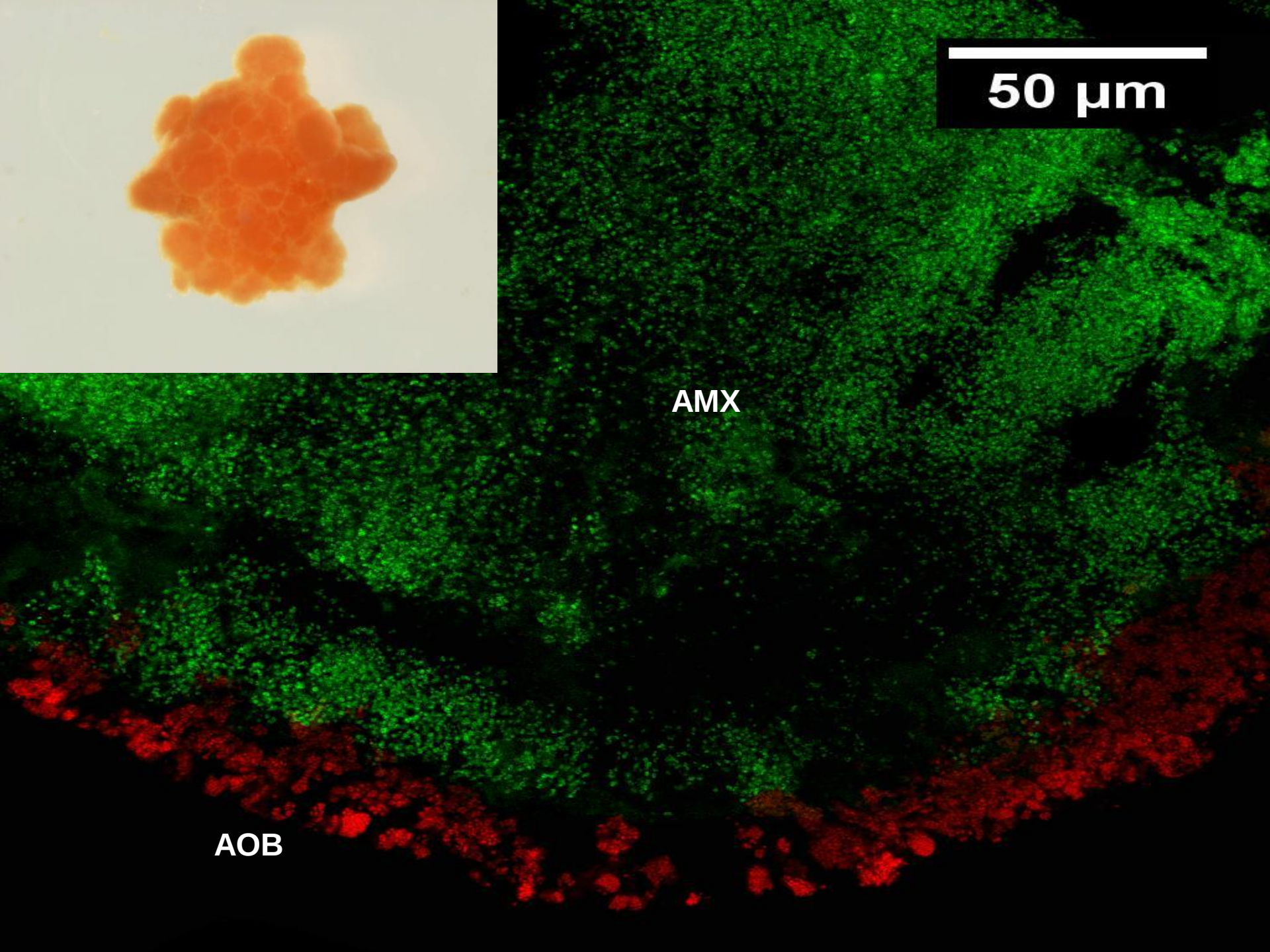
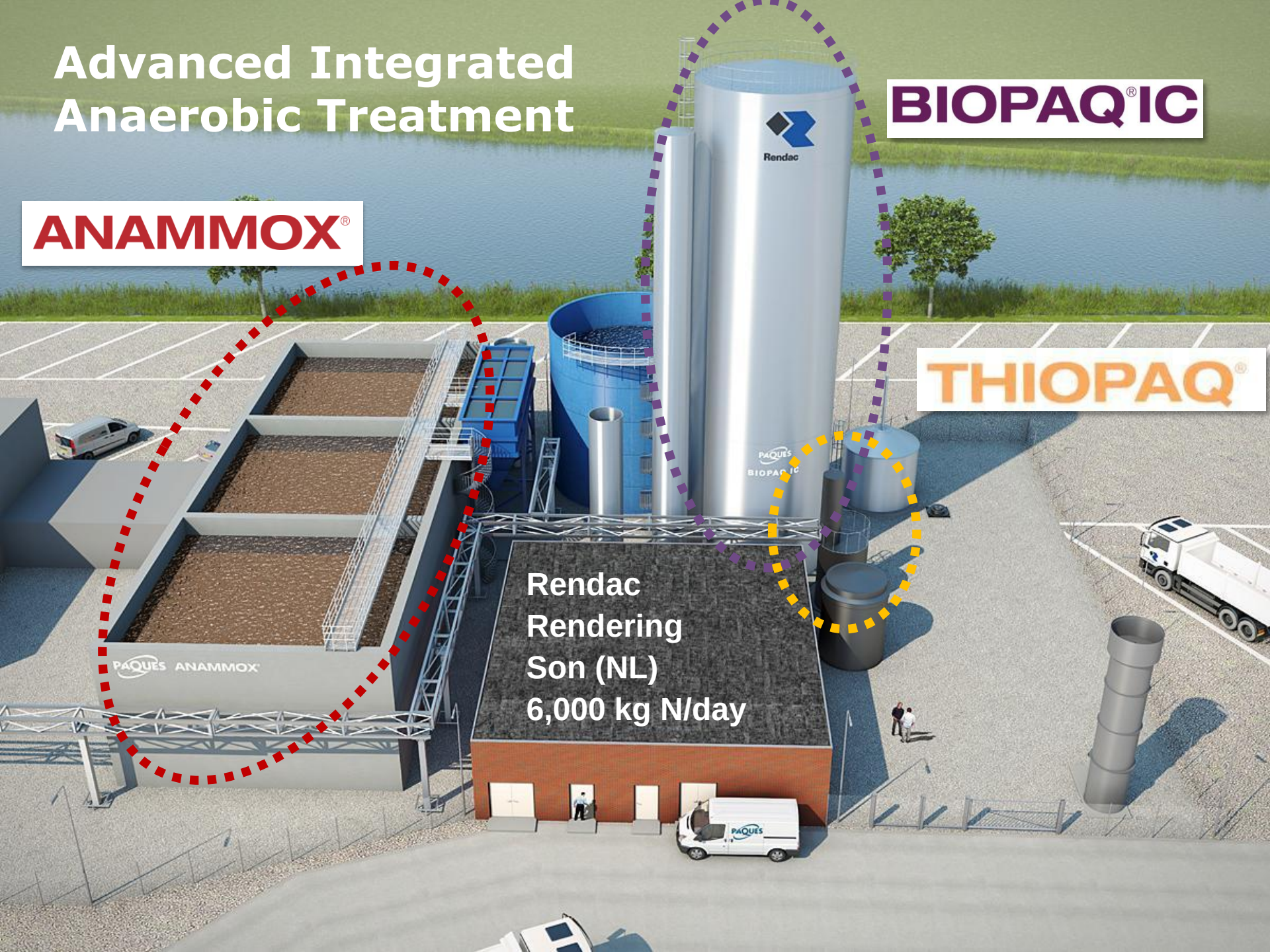

50 µm
AMX
AOB

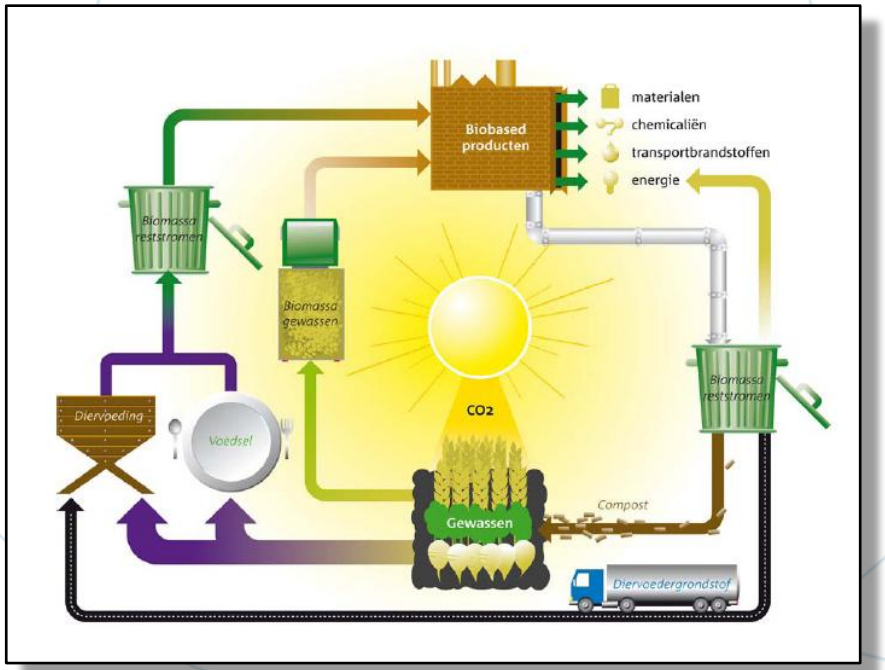

MEI HUA Group
Glutamate production
China
11,000 kg N/day

Advanced Integrated Anaerobic Treatment



What's next?

The Biobased Economy



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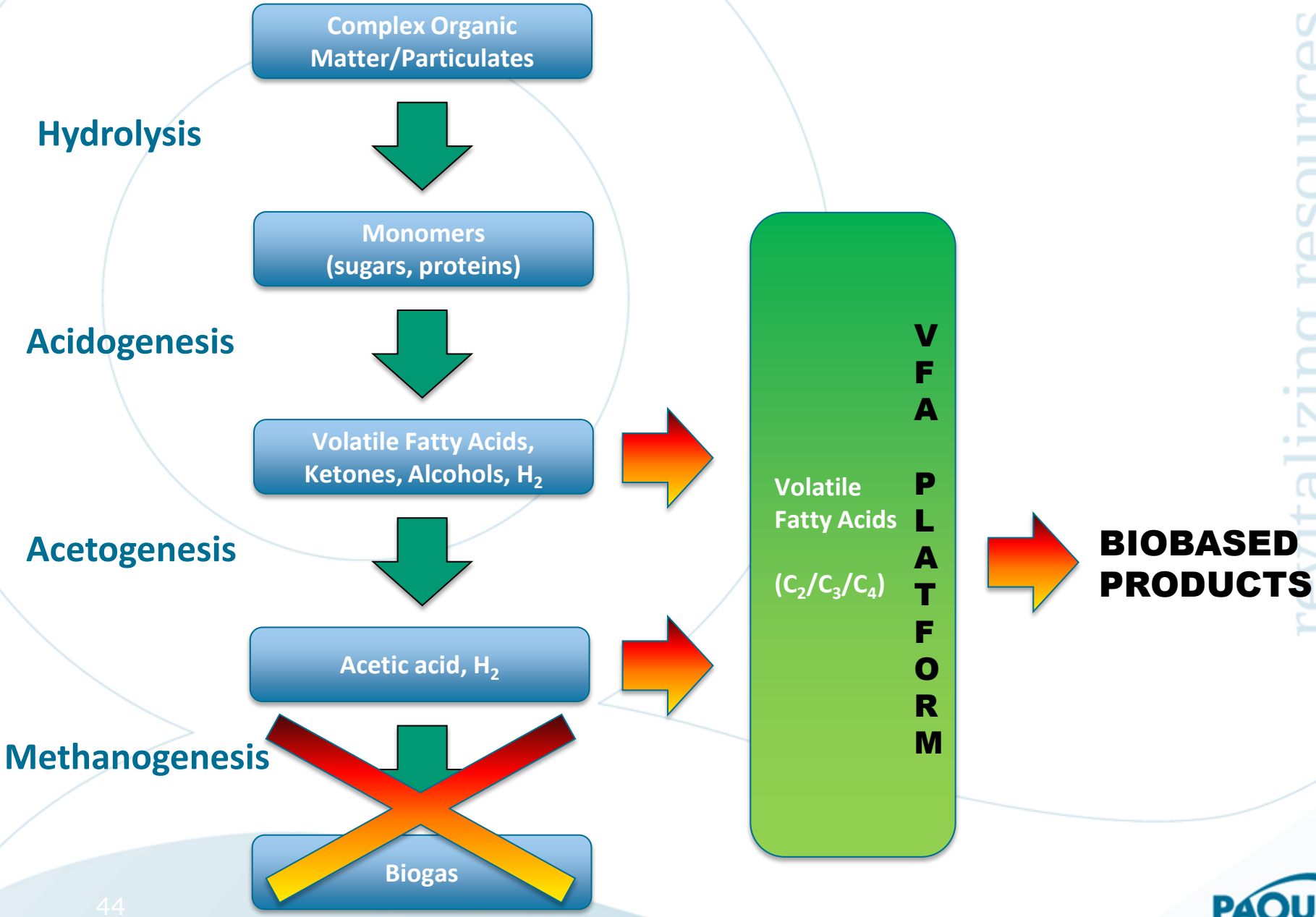
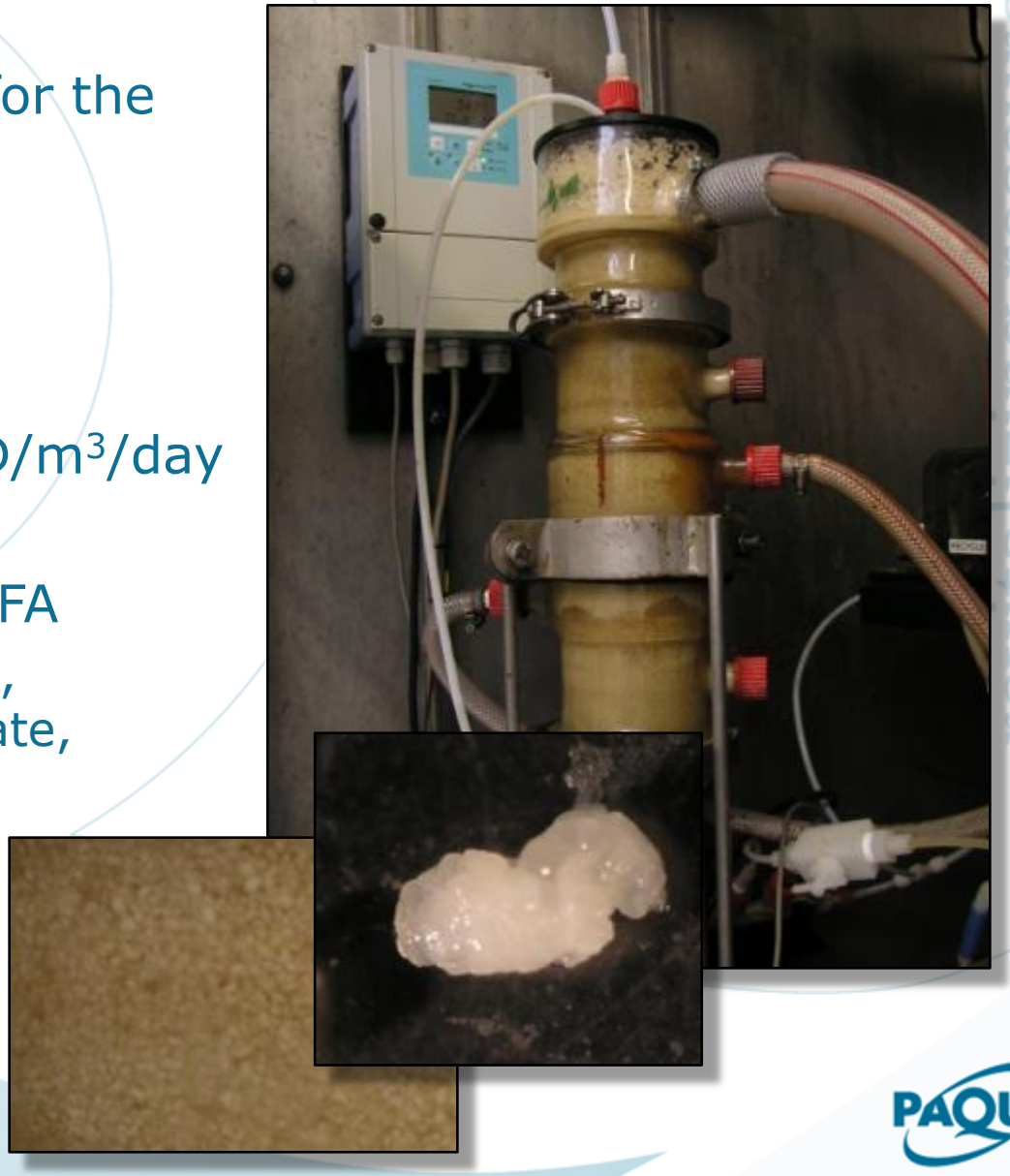
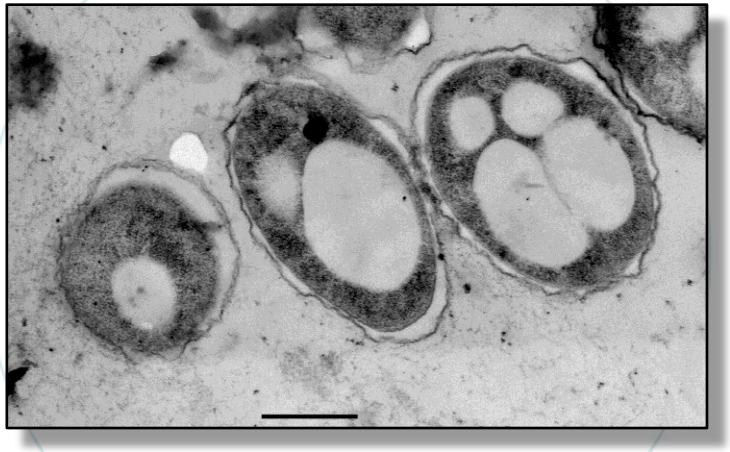


High Rate VFA Production

- High rate systems for the production of VFA
- Granular biomass
- VLR>> 100 kg COD/m^3/day
- Product: >10 g/L VFA
  - Mixture of acetate, propionate, butyrate, lactate, etc.



Bioplastic



Van Loosdrecht & Kleerebezem

- Poly-β-hydroxyalkanoate (PHA)
  - Common and widespread storage material in microorganisms
- Storage up to 90 wt% in granules
- Properties similar to petrochemical plastics
- Biodegradable
- Made from renewable resources
- Currently made using conventional fermentation.
- Too expensive to become a commercial success.

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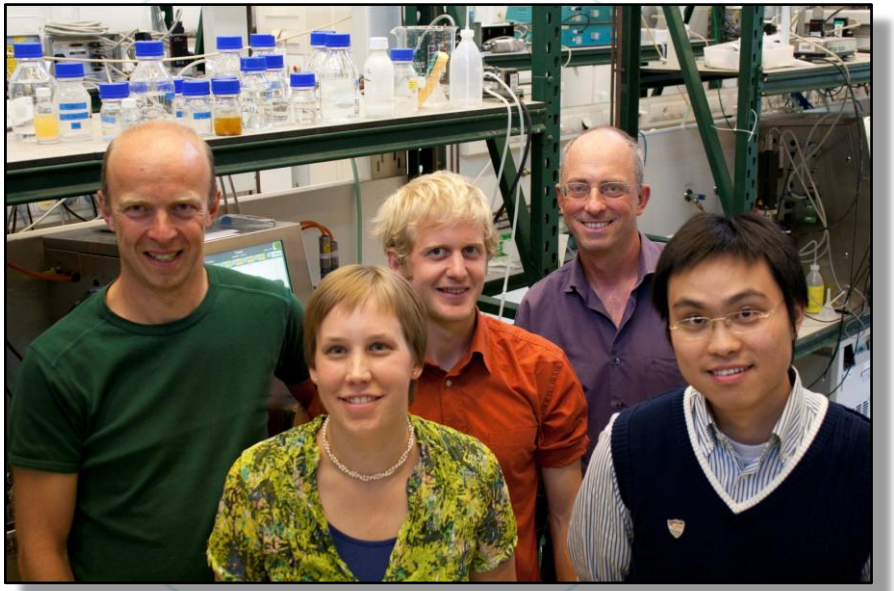
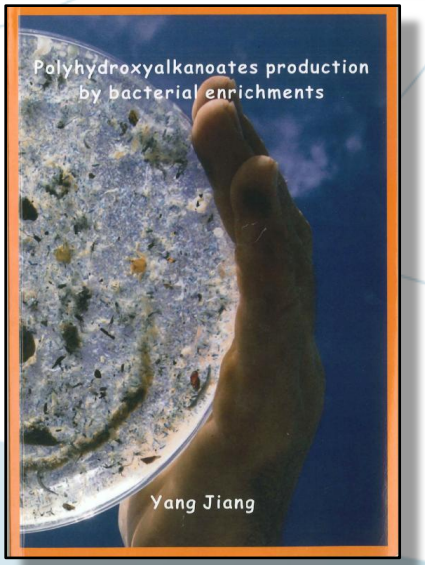
New process developed





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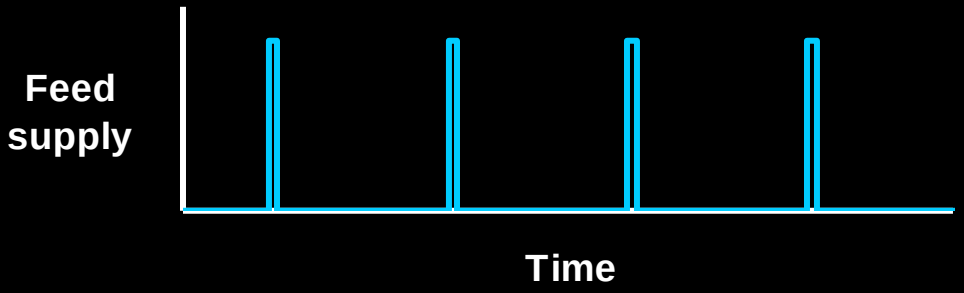
How does it compare?

Characteristics

- Mixed microbial cultures, so "normal" wastewater treatment
  - **No** genetically engineered micro-organisms!
- RBCOD (i.e., VFA) from wastewater as feed
  - **No** expensive raw materials required!
- High PHA accumulation percentages (**80-90% of dry weight)**
  - Lower Downstream Processing costs
  - Direct use possible (i.e., without Downstream Processing)
- Result: major cost improvement compared to conventional fermentation process!

Ecological role of bioplastics

PHA = ***Microbial Fat***



Pulse feeding of substrate favors growth of bioplastic producing microorganisms: feast famine regime

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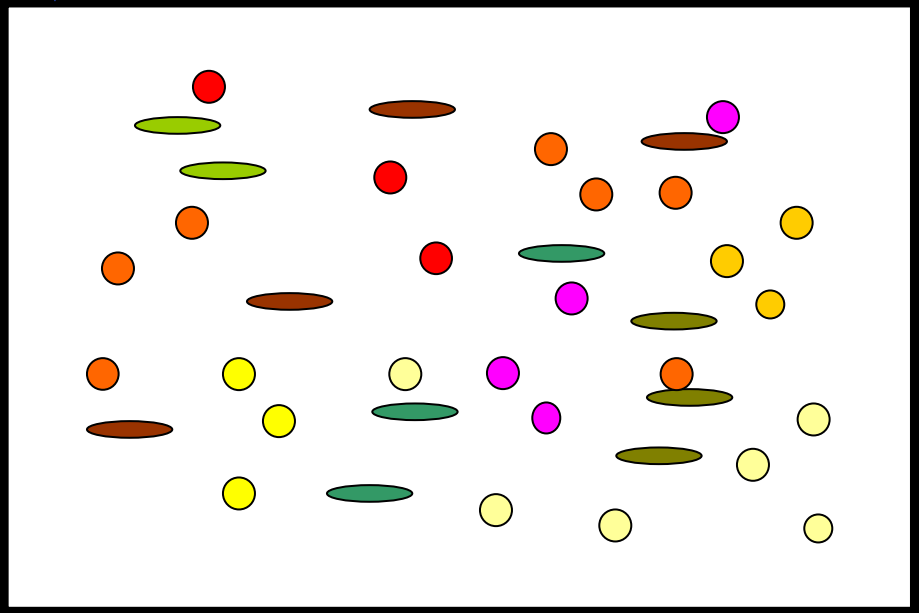
Microbial selection

Substrate



PHA storing bacteria

Non PHA storing bacteria

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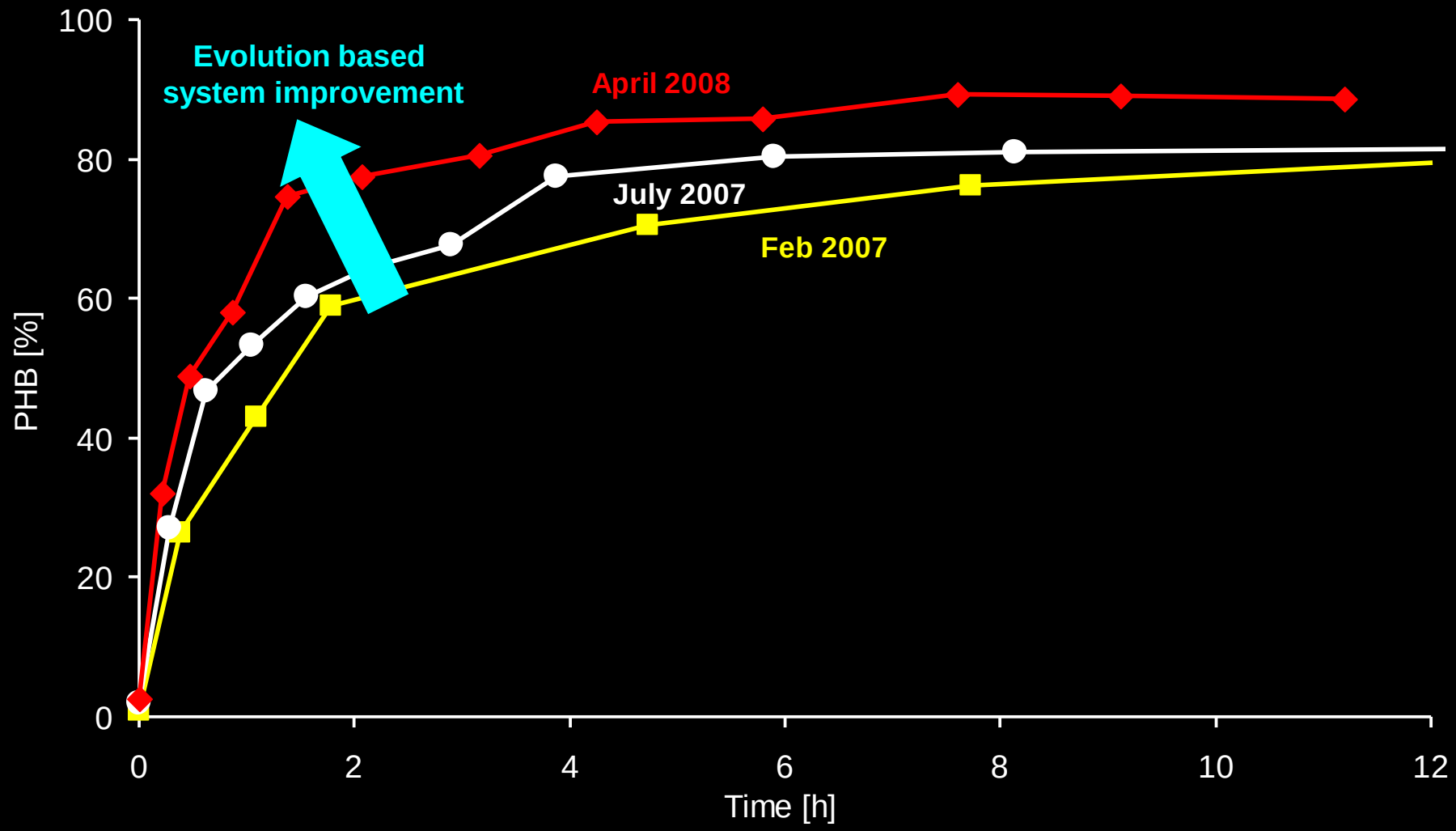

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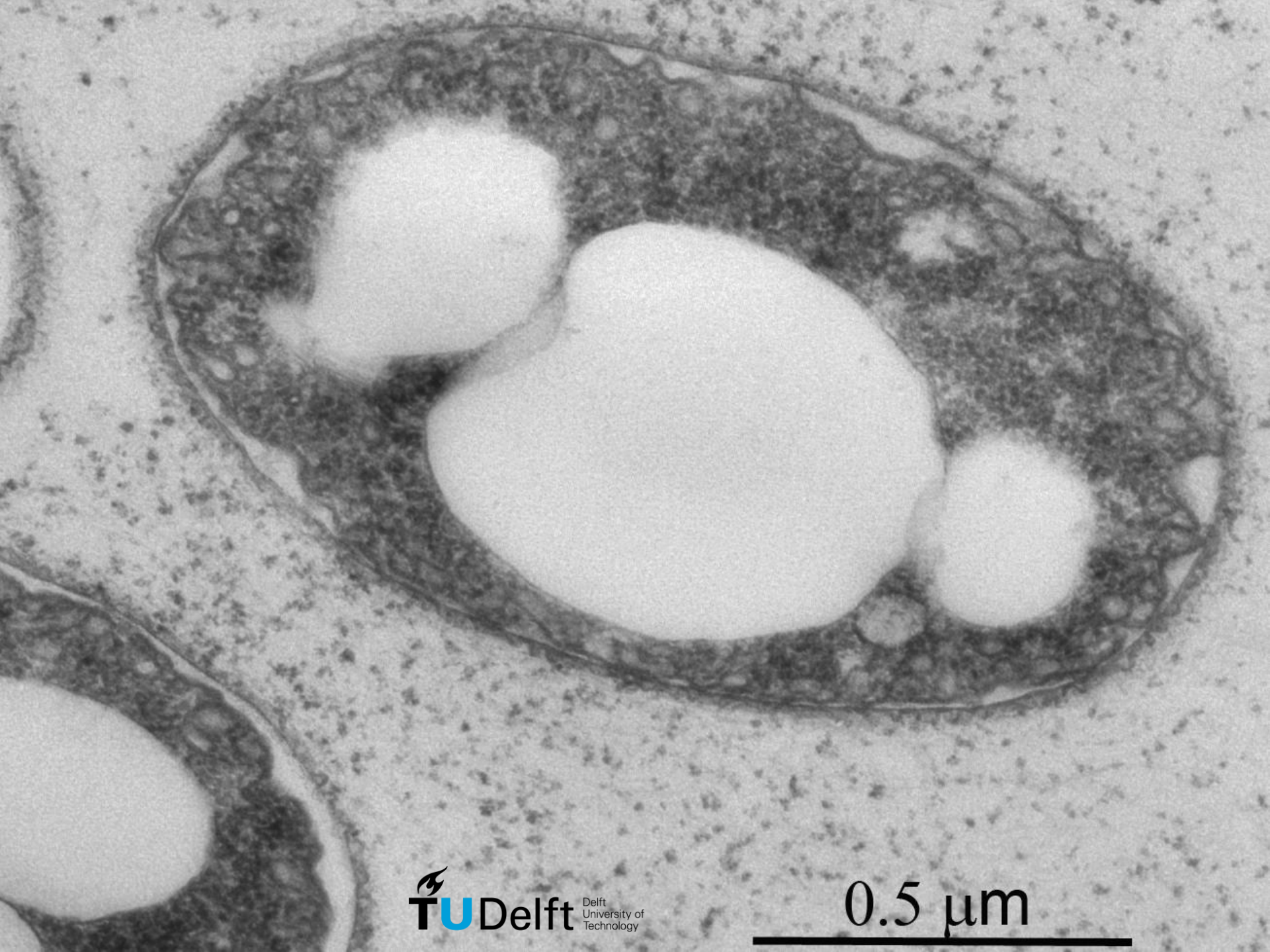
(Mark van Loosdrecht & Robbert Kleerebezem)


TU Delft
Delft University of Technology
0.5 µm

PHA Pilot Plant

Mars production plant Veghel, Netherlands

Capacitity : 1 kg/day

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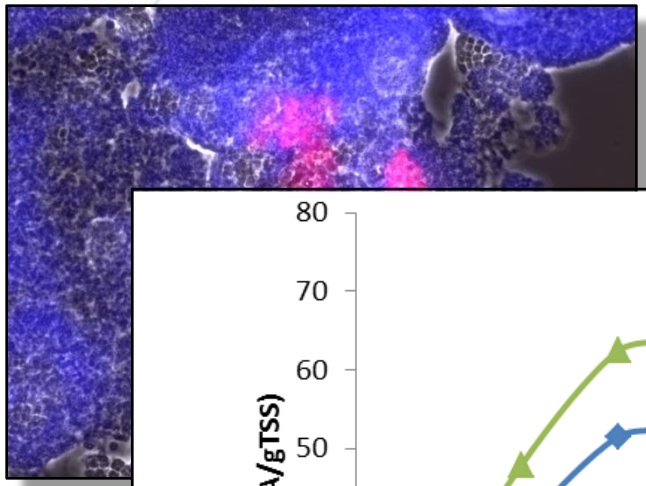
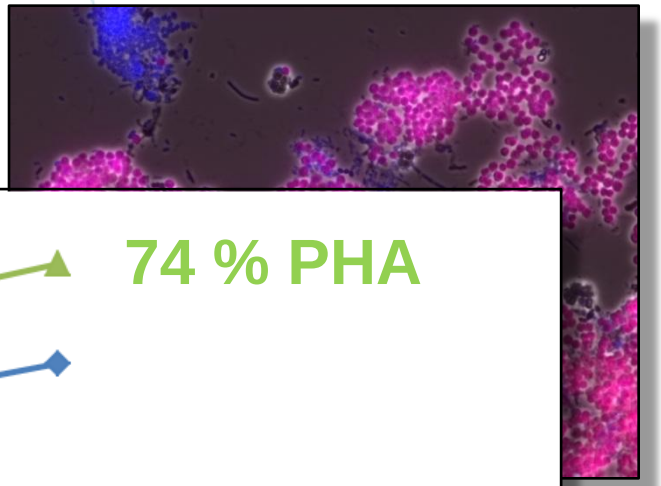
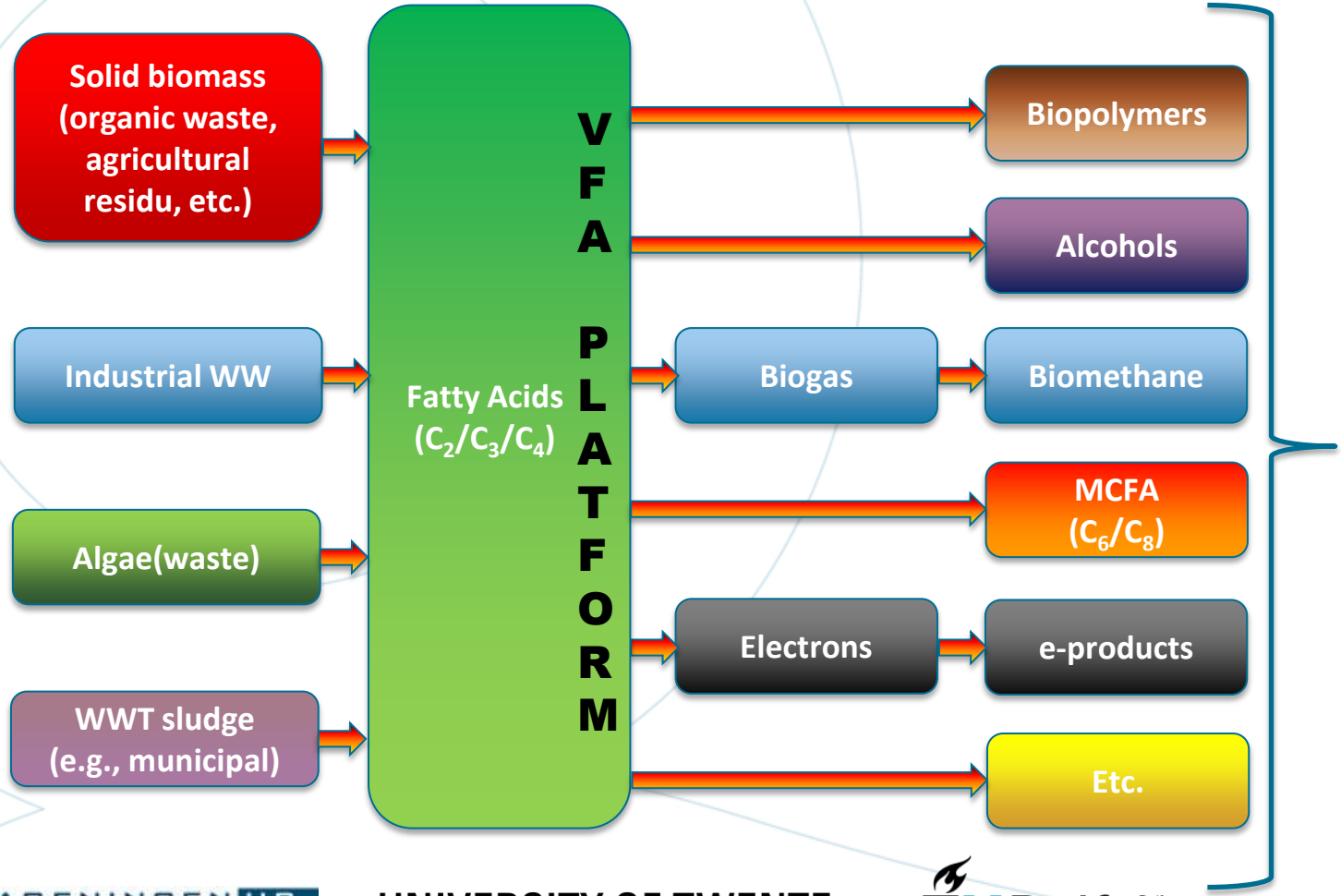
PHA pilot : Resultaten





VFA or carboxylate Platform



revitalizing resources

WAGENINGEN UR For quality of life

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STW

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Take away messages

- Environmental biotechnology is about understanding the role certain target microbes have in nature and recreating their preferred environment inside a bioreactor.

- In the past environmental biotechnology was mainly about treatment (C, N, S, etc.); the future will be about resource recovery (bioplastic etc.).

- All our technologies originated at universities, so for us a strong collaboration between universities and companies is of vital importance.

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