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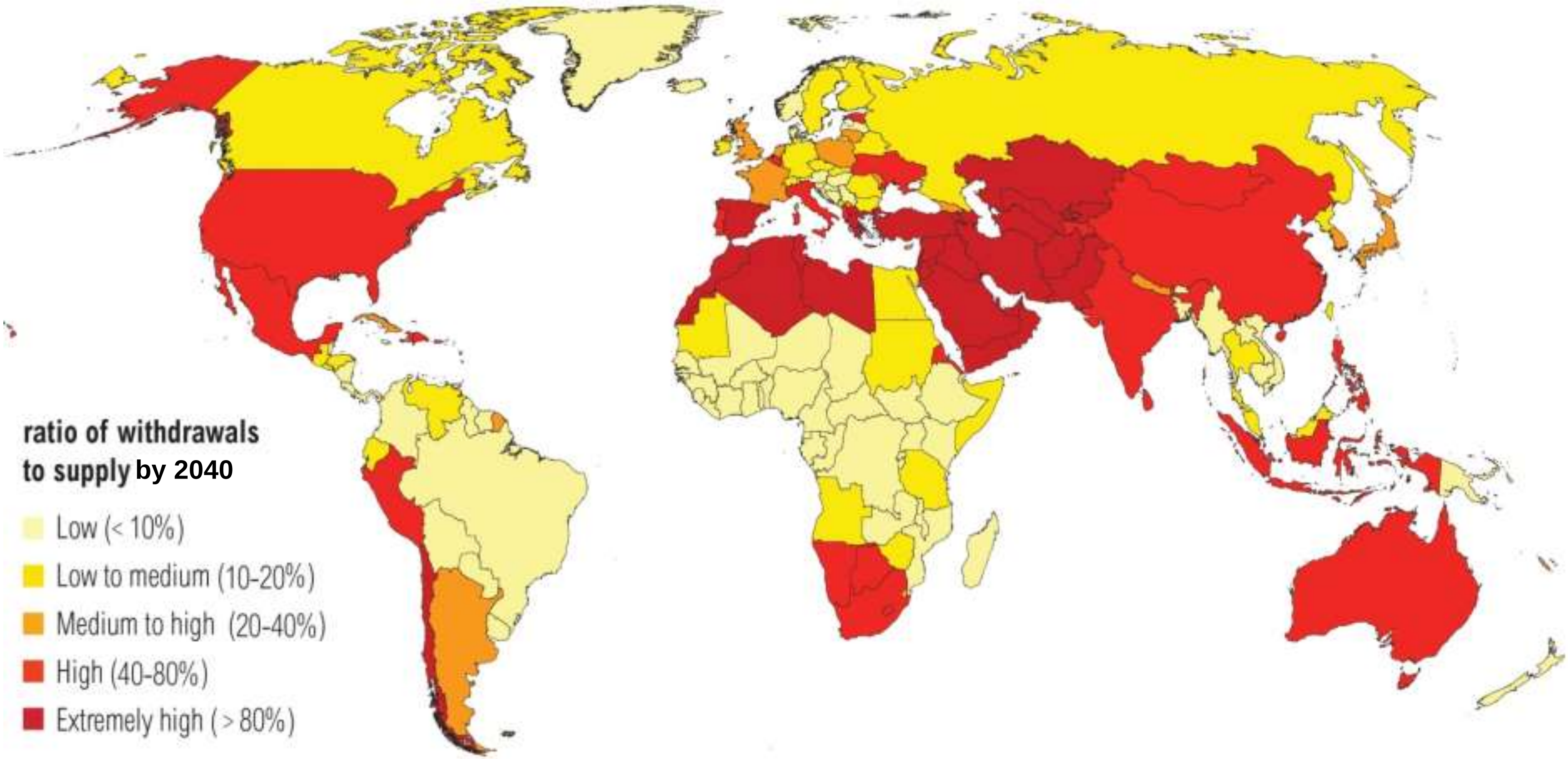
european centre of **excellence**
for sustainable **water technology**

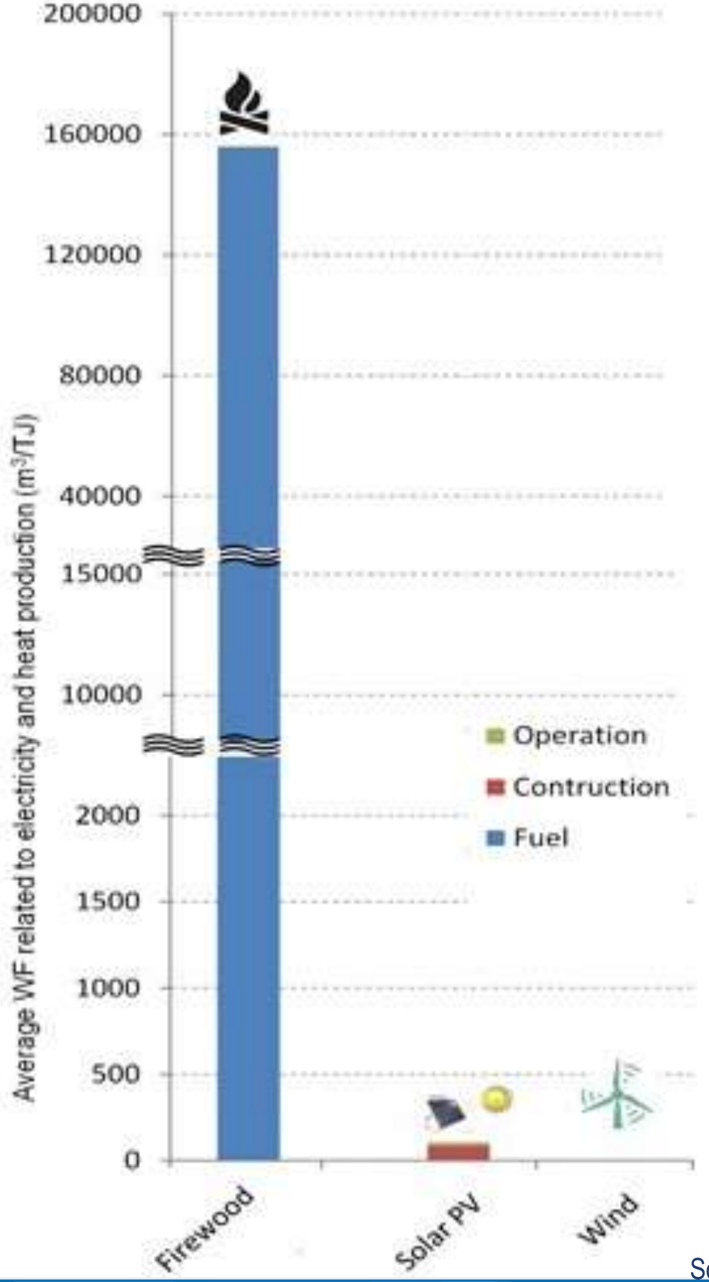
Recovery of CSNP

prof.dr.ir. Cees J.N. Buisman
Wageningen 9 november 2017

Water Scarcity limits biobased economy



Biomass production is very water intensive



Source: Mekonnen, Gerbens-Leenes & Hoekstra (2015)

Carbon source for Renewable chemicals

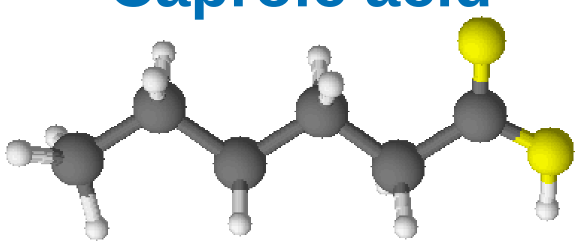
- Biowaste

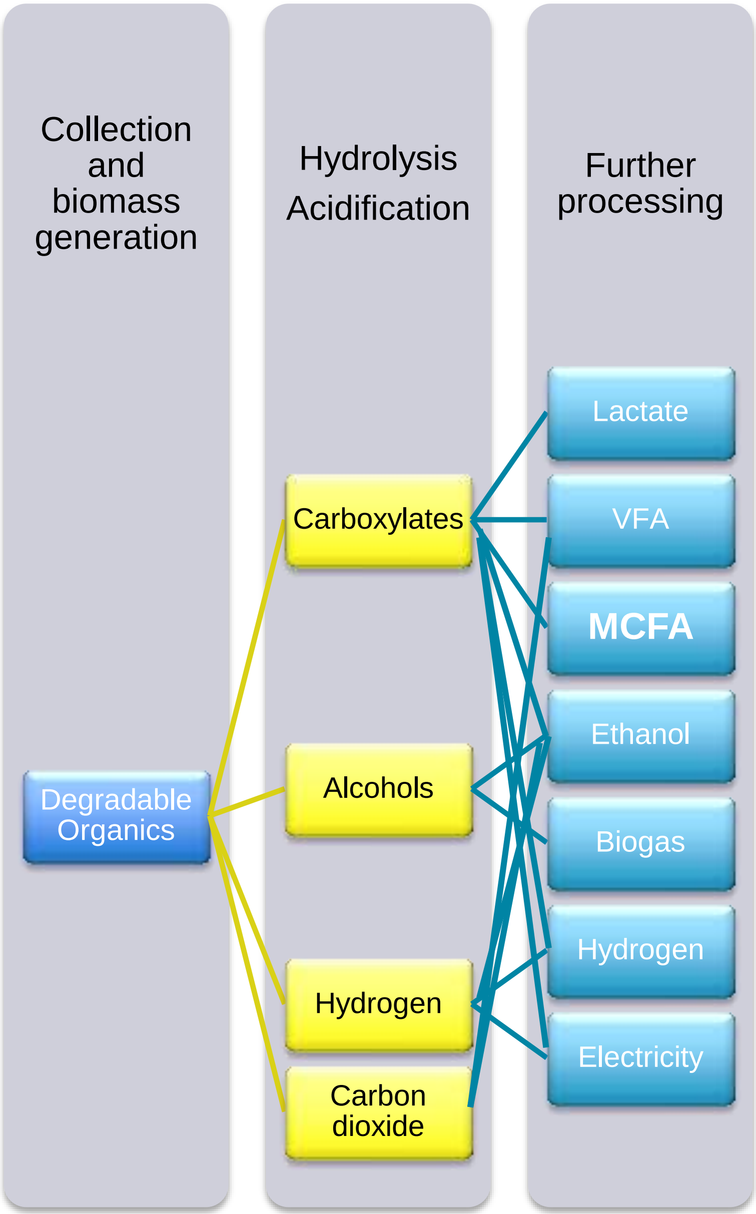
Carboxylate platform

- Alcohols
- Carboxylates
- Hydrogen, Biogas
- Electricity

Focus:

Caproic acid





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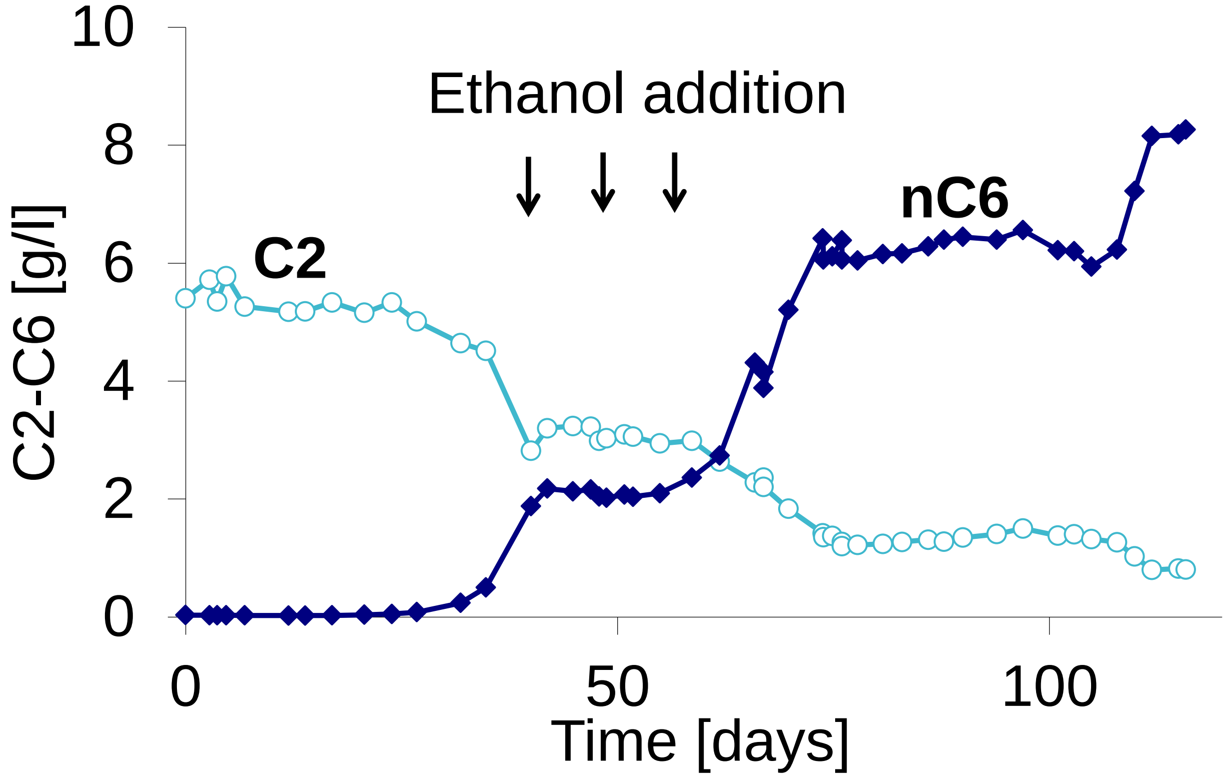
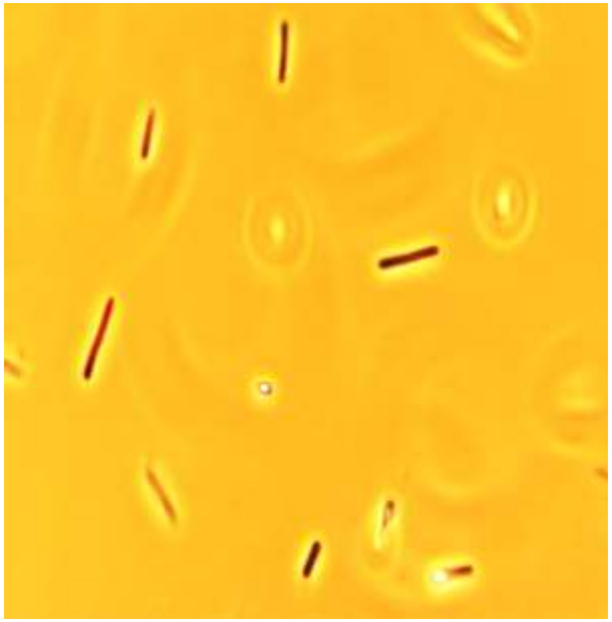
Proof-of-principle of open culture chain elongation of acetate to caproic acid (C6)





Clostridium kluyveri

VPR C6 0.45 $g.l^{-1}.d^{-1}$

Steinbusch K.J.J., 2010, PhD thesis, Liquid biofuel production
Steinbusch K.J.J et al. 2011. EES 4, 216-224.

World record on caproate (C6) production at 57 g/l/d with short HRT and high loads

MCFA selectivity 81%

4400 mol e^{-} m^{-3} day^{-1}

Grootscholten *et al.* BRT 136 (2013) 735–738

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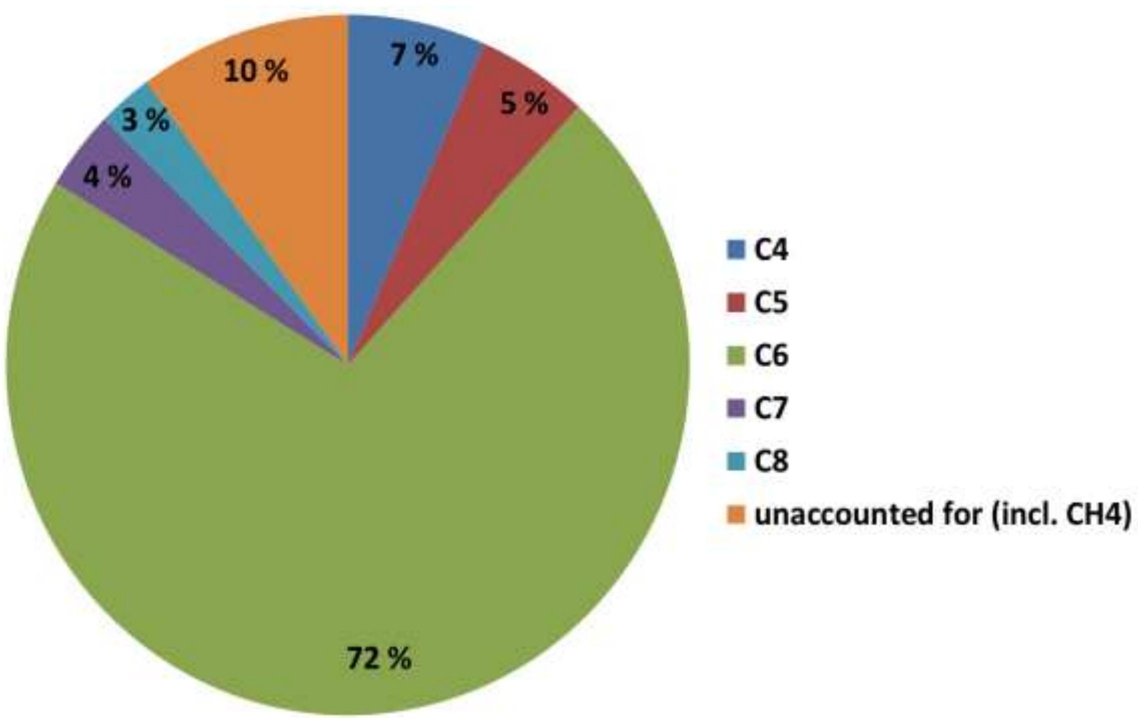
Two-stage MCFA production from real municipal solid waste and ethanol

MCFA selectivity 83%

VPR 28.1 g.l^{-1}.d^{-1}

Caproate 12.6 g l^{-1} > solubility caproic acid in water

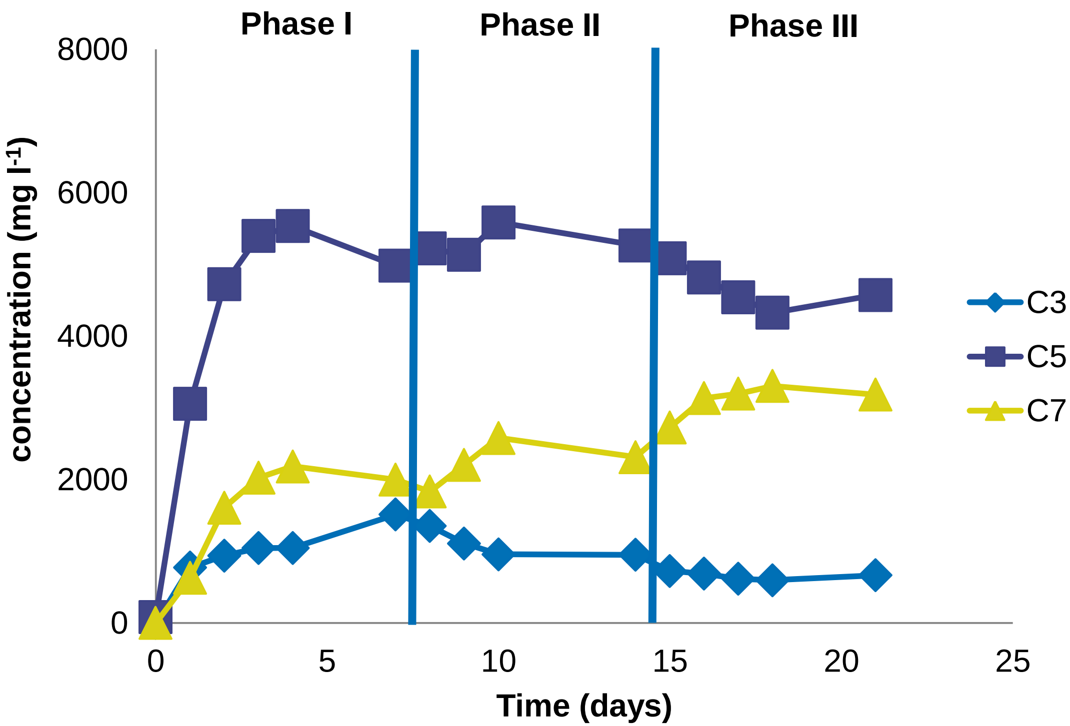


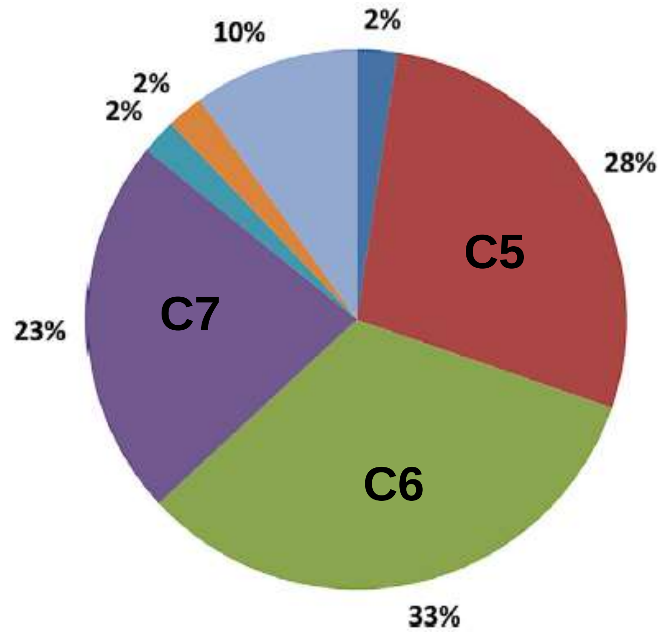
Grootscholten *et al.* Applied Energy 116 (2014) 223–229

Heptanoate (C7) production by chain elongation of propionate

C7 selectivity 23%

Heptanoate 4.5 $g.l^{-1}.d^{-1}$





Grootscholten *et al.* BRT 136 (2013) 715–718

Upscaling

Lab

~0.3 kg/d

Pilot

~3 kg/d

Full-scale

~3 ton/d

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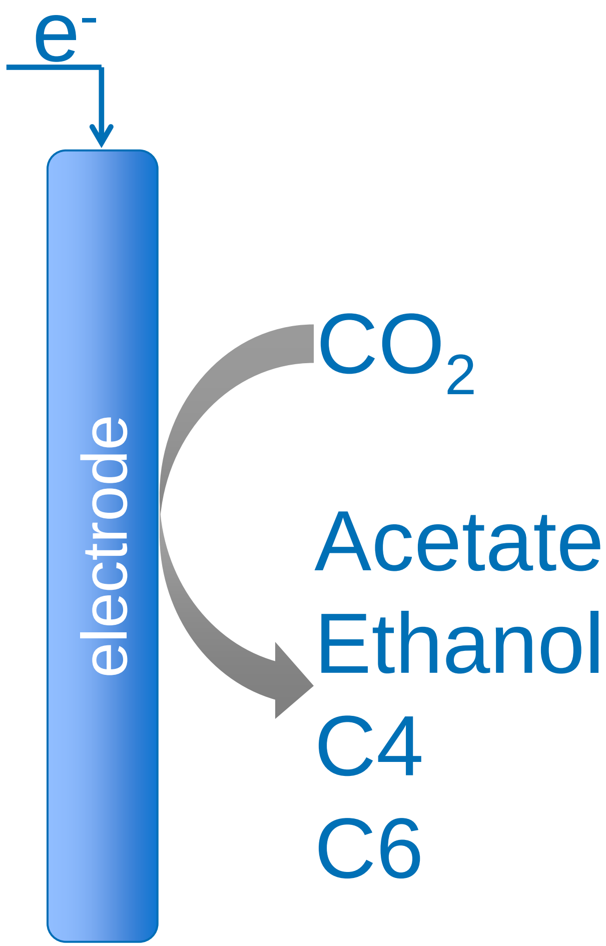
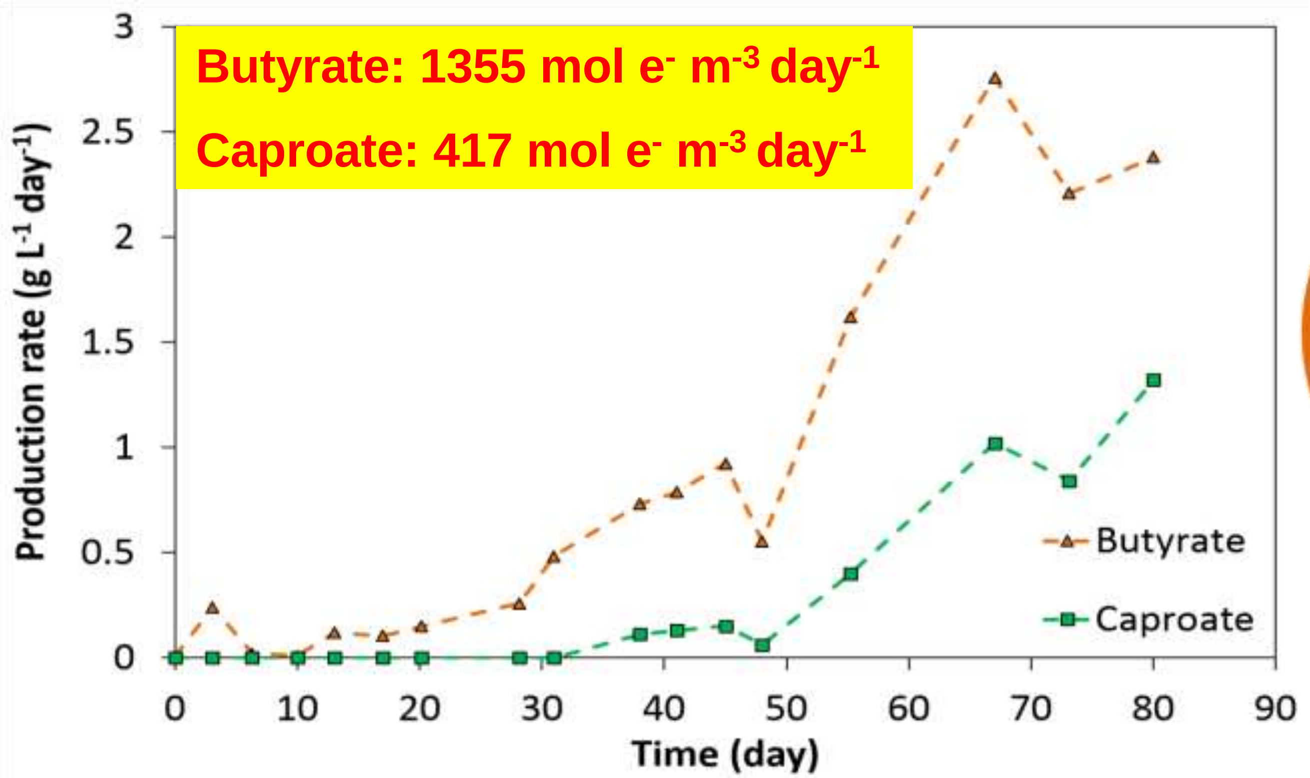
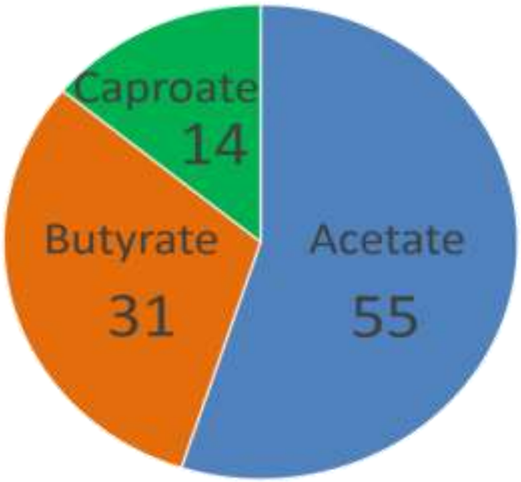
CHAINCRAFT

CO_2 + ⚡ → Chemicals



Bioelectrochemical caproate production without added mediator





Jourdin, L., Raes, S. M. T., Buisman, C.J.N., Strik, D.P.B.T.B. Critical biofilm growth throughout unmodified carbon felts allows continuous bioelectrochemical chain elongation from CO_2 up to caproate at high current density. Under revision. 2017

Sulfur resources dependent on fosil fuels

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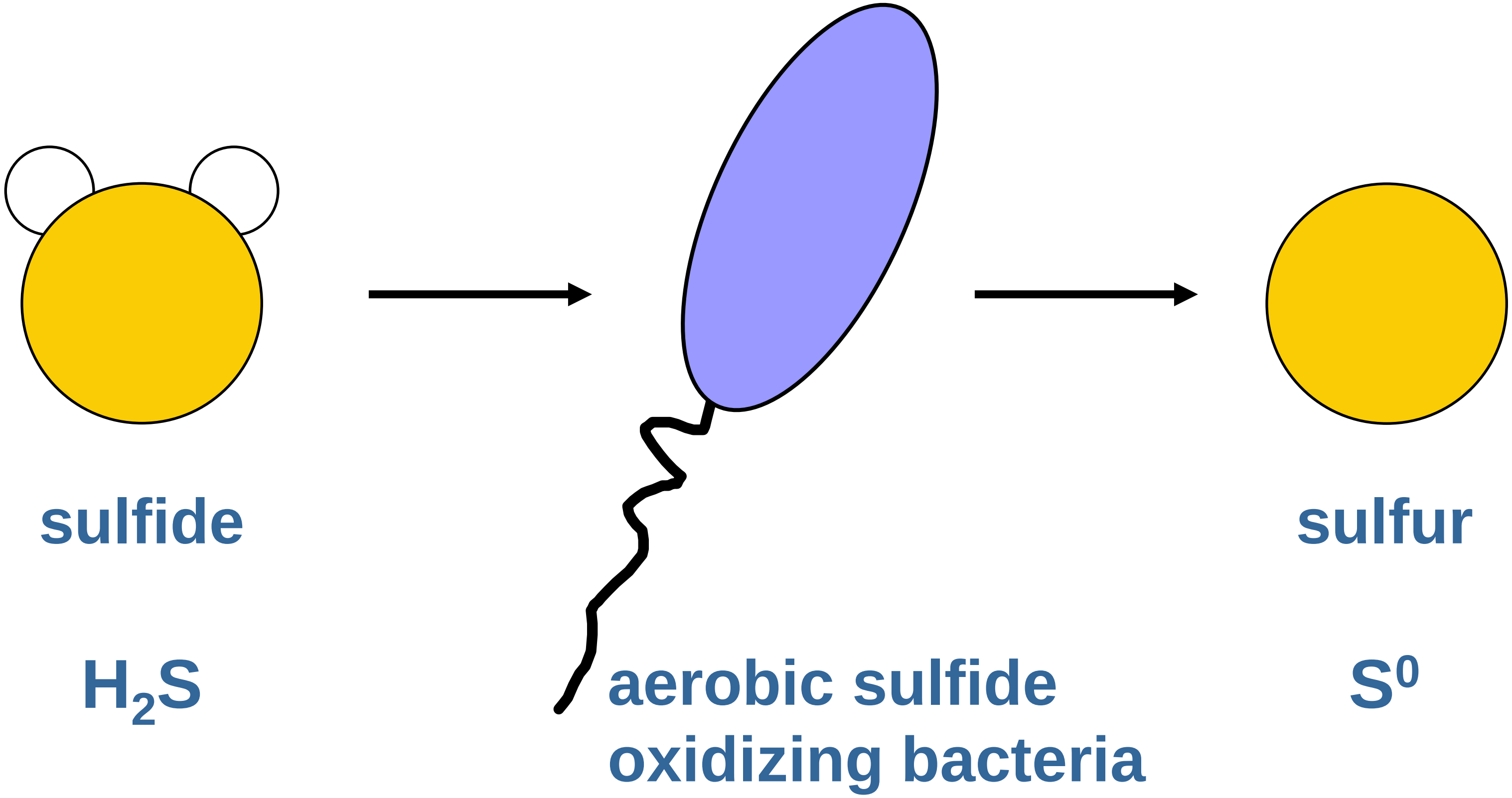
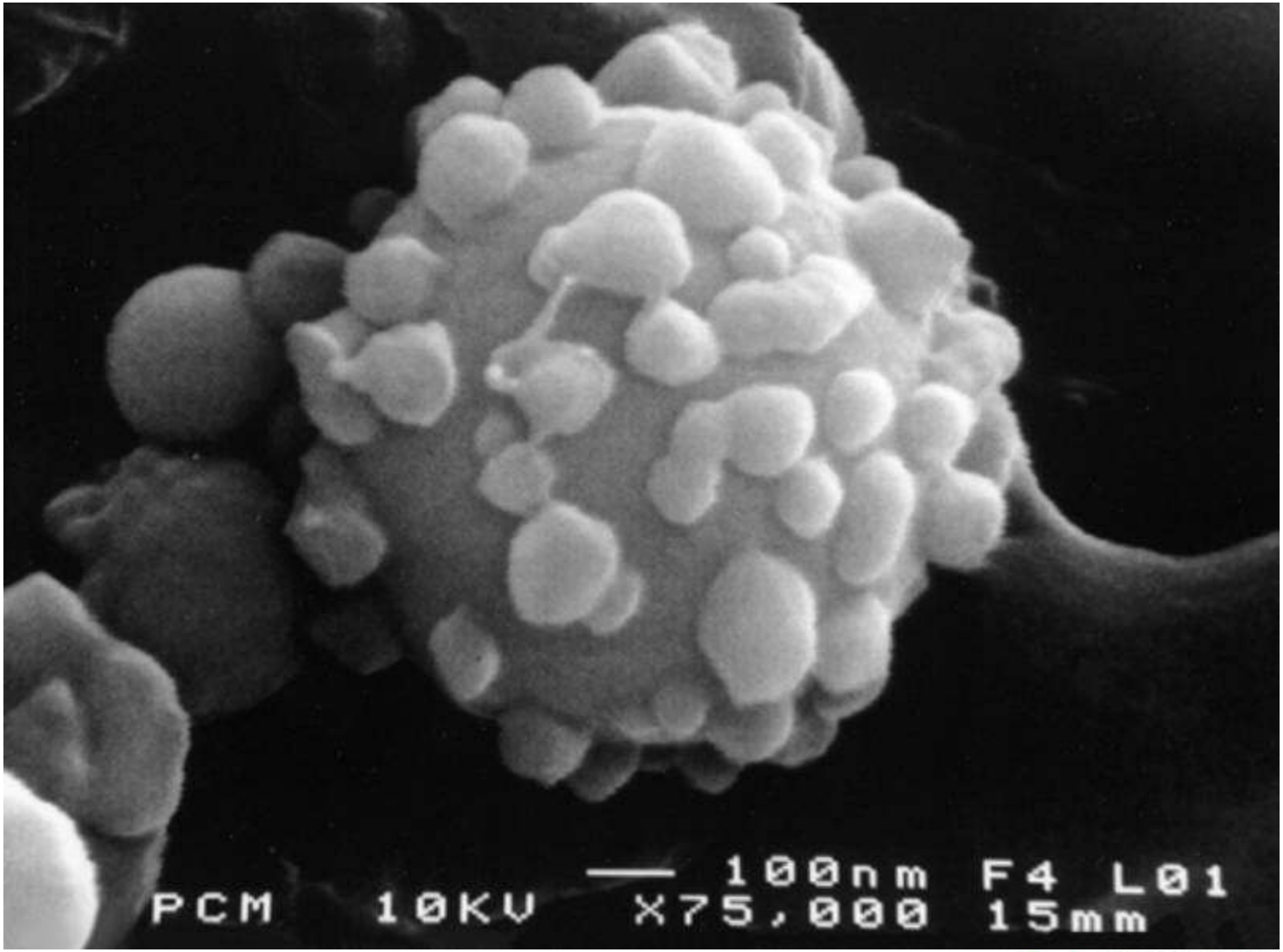
Biotechnological Sulfide Oxidation



Sulfur Excreting Bacterium



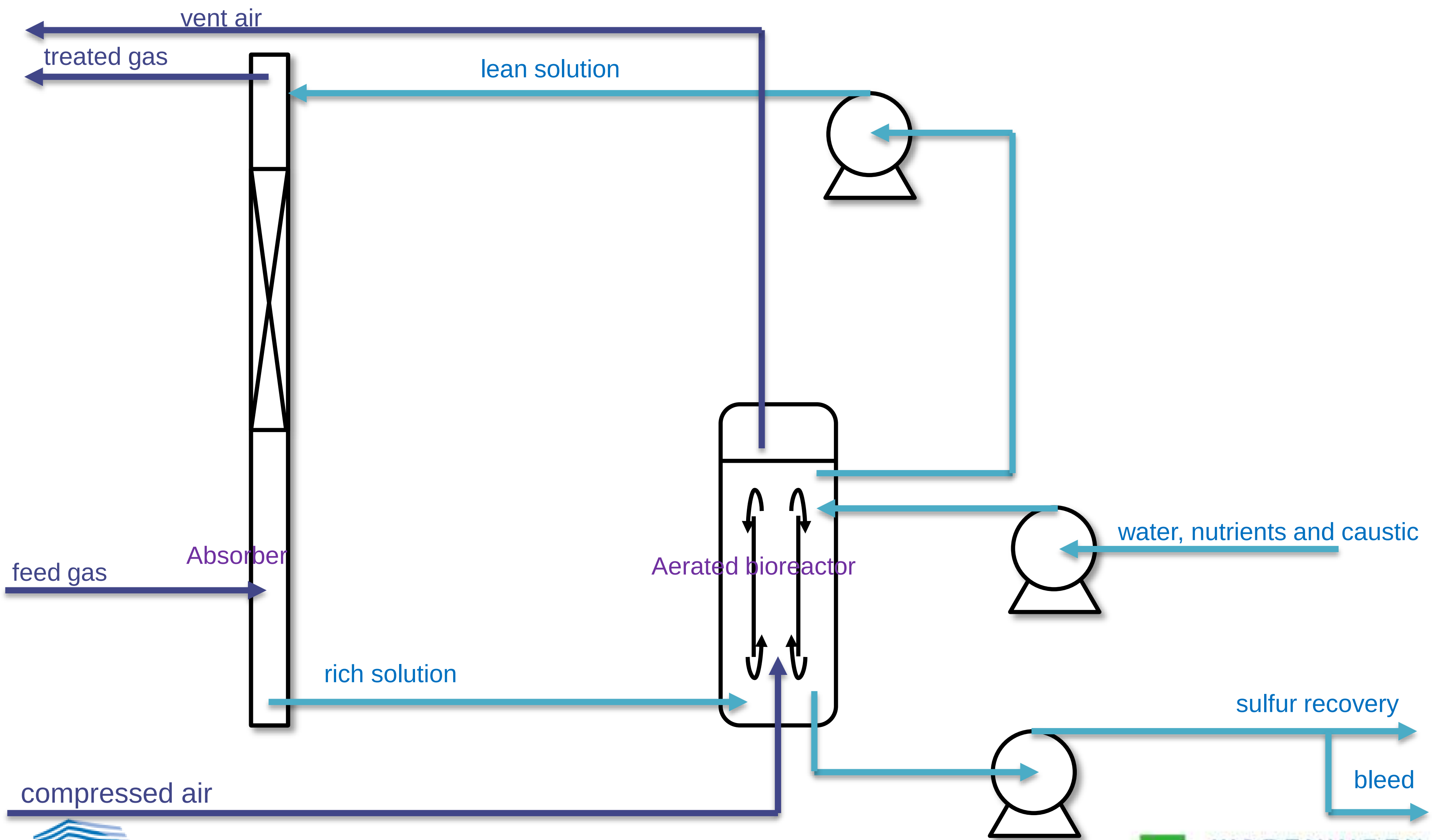
>200 H_2S recovery systems

Biosulfur as fertiliser
University of Alberta (Canada)

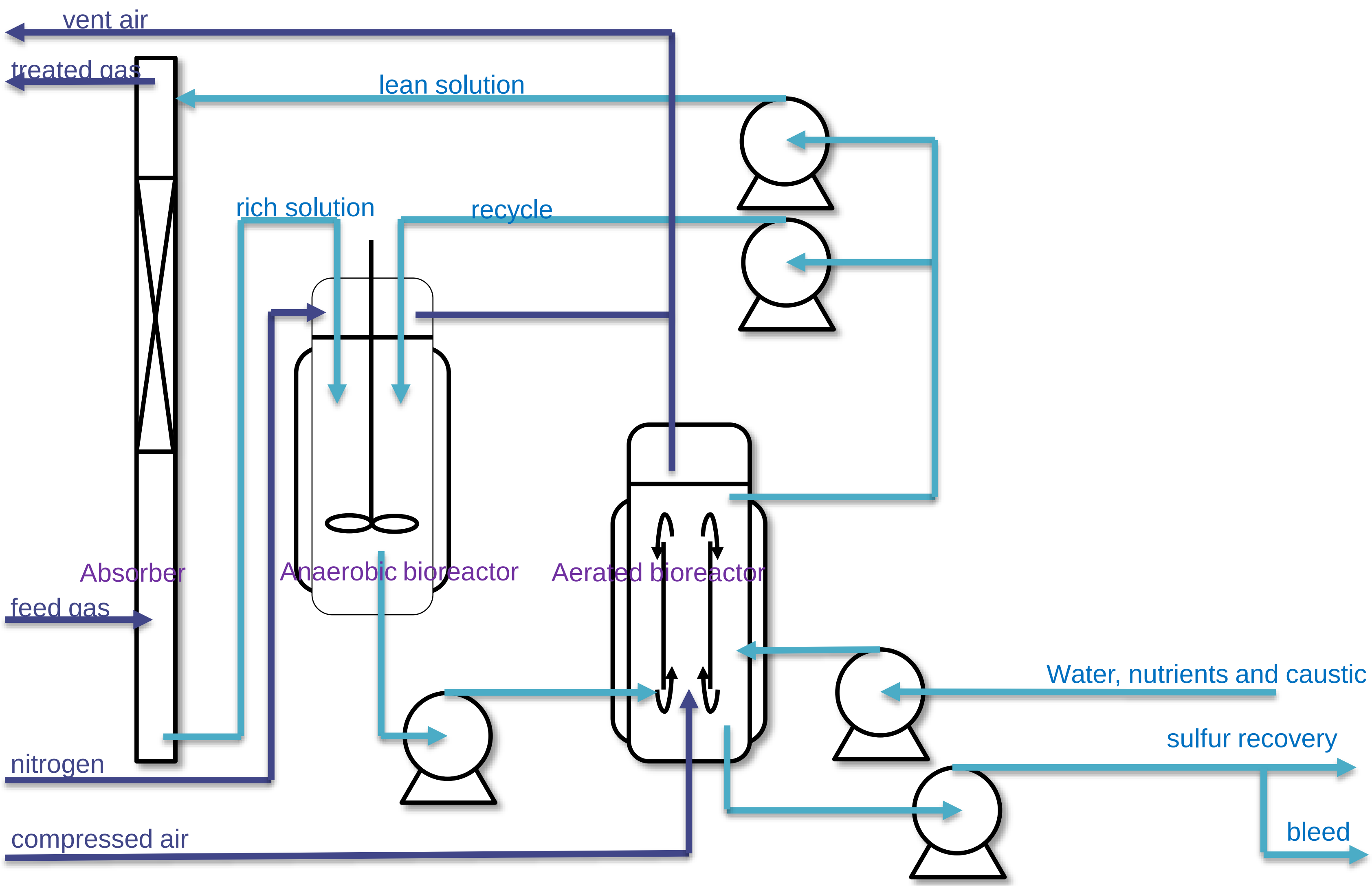
Sulfur source	Canola yield (g/pot) after 84 days
Reference test	15.6
S95	19.6
T90CR	16.1
Agrium S	20.2
$(NH_4)_2SO_4$	20.7
BIOSULFUR	**22.6**

Bron University of Alberta

Conventional Thiopaq®



New anaerobic step

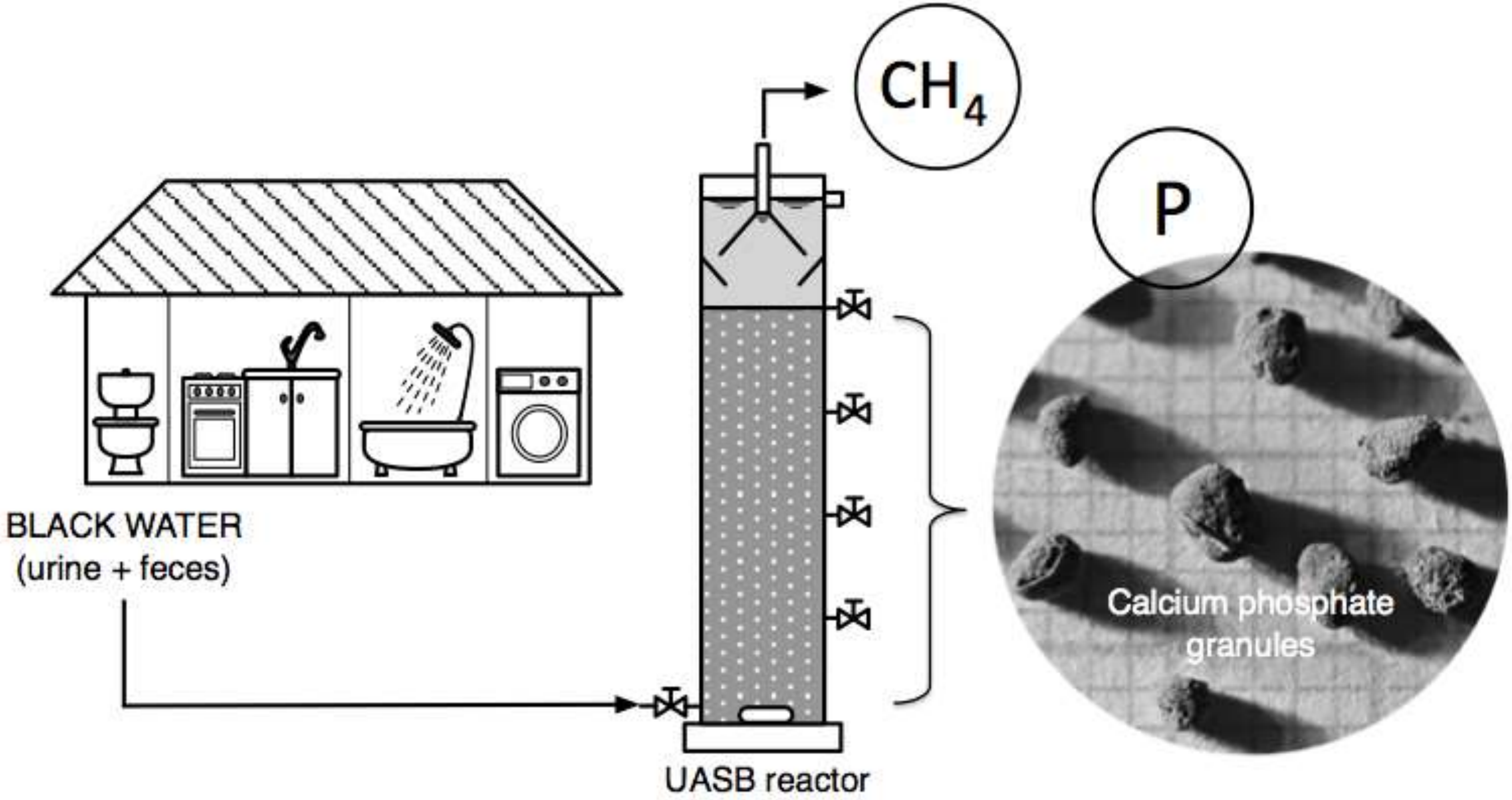


Strong efficiency improvement

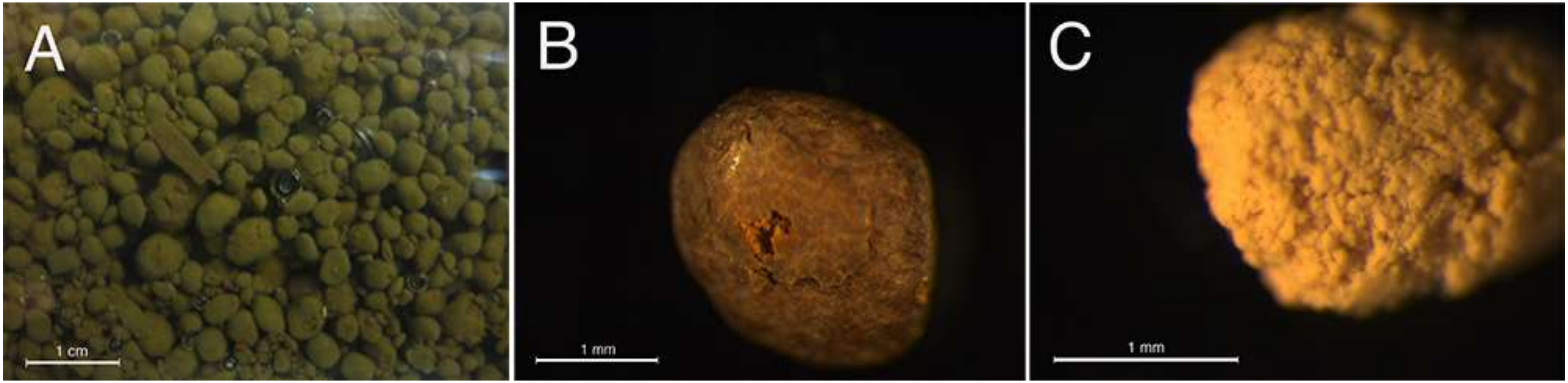
	Traditional line-up (no anaerobic bioreactor	**New line-up (including anaerobic bioreactor)**
S_8 (mol%)	**90**	**97**
SO_4^{2-} (mol%)	**5**	**2**
$S_2O_3^{2-}$ (mol%)	**5**	**1**
Caustic use (kg NaOH/kgS)	**0.35**	**0.1**

Phosphate depletion

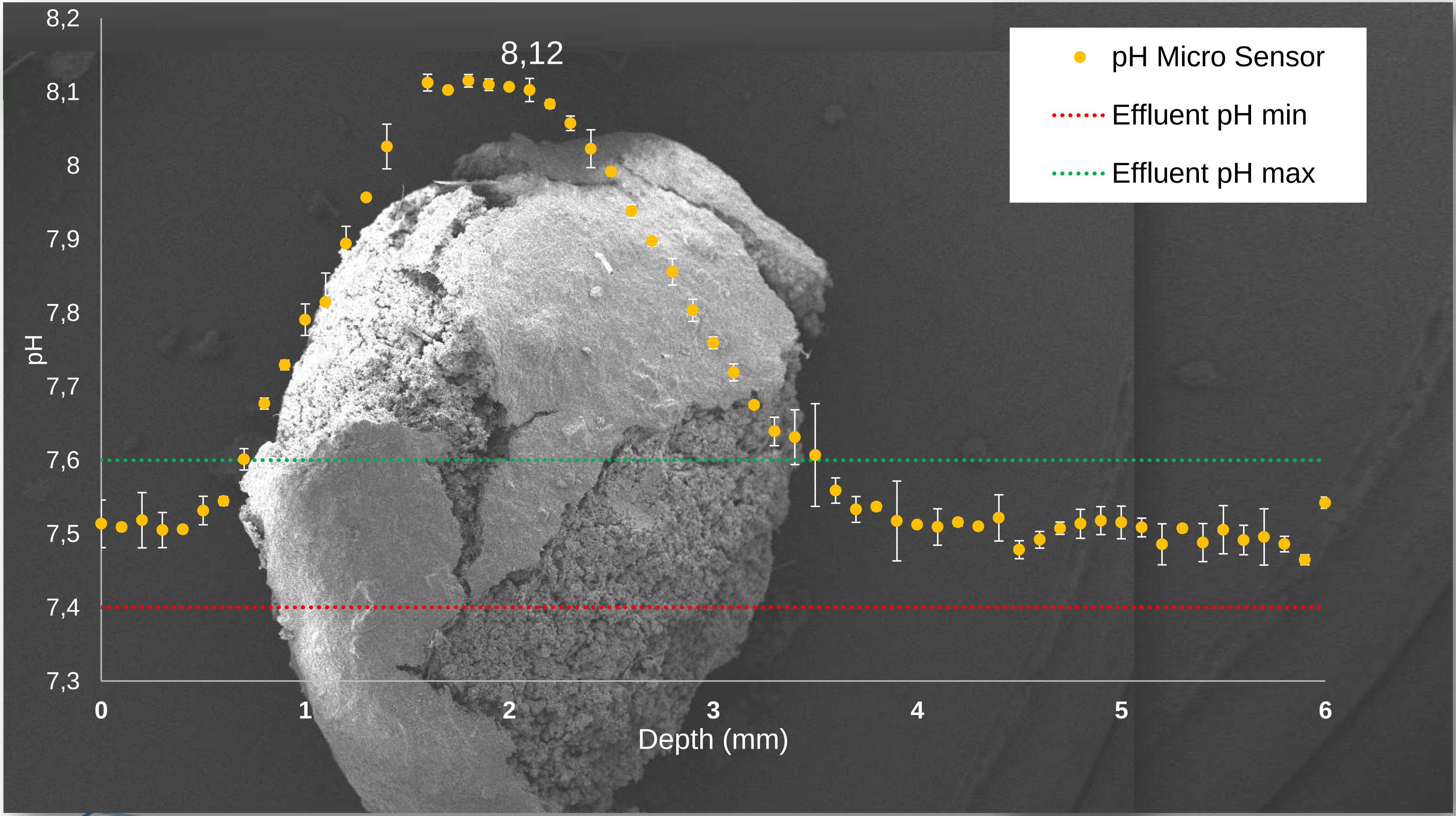
Simultanous recovery of CH_4 and P



Ca-P Crystals inside biofilm



pH profile across the granule



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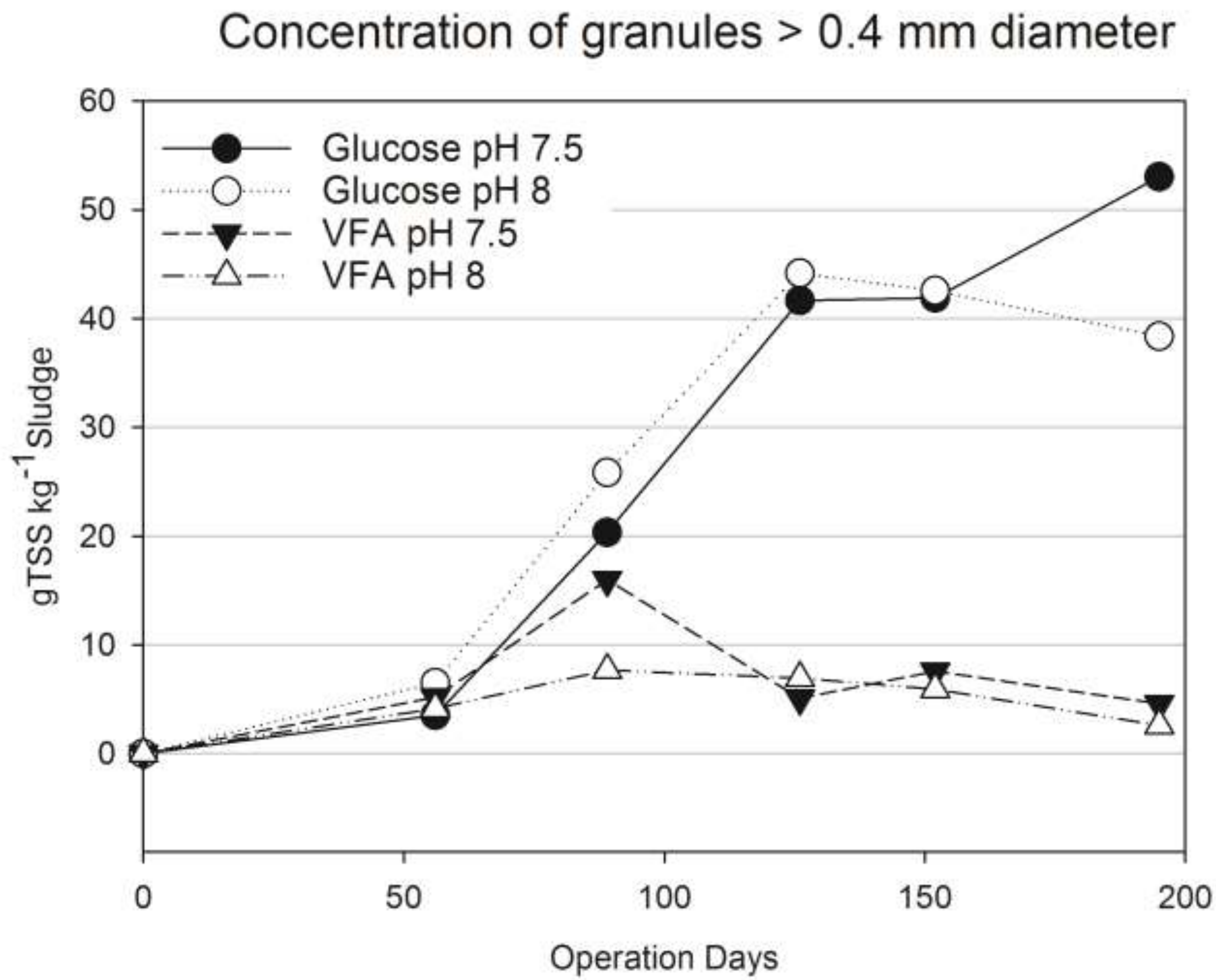
Glucose enhances the formation and growth of $Ca_x(PO_4)_y$ granules



Heavy metal content of P products ($g/kg - P_2O_5$)

Parameter	Unit	Bio-granules (demo-scale)	Phosphate rock
P_2O_5	%	41	40
Zn		743	1120
Cu		182	80
As		4	25
Cd	mg/kg	3	64
Cr	mg/kg	93	380

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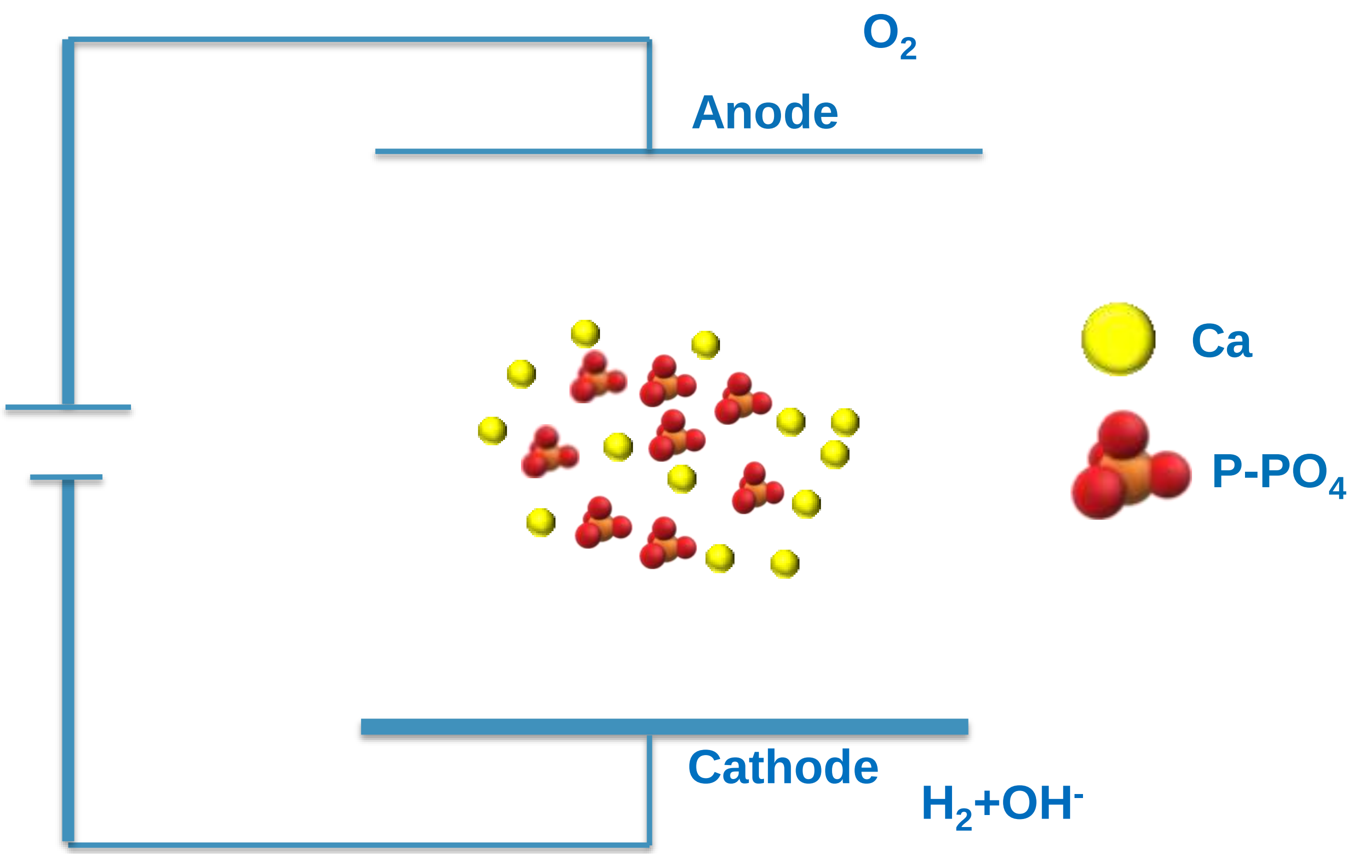
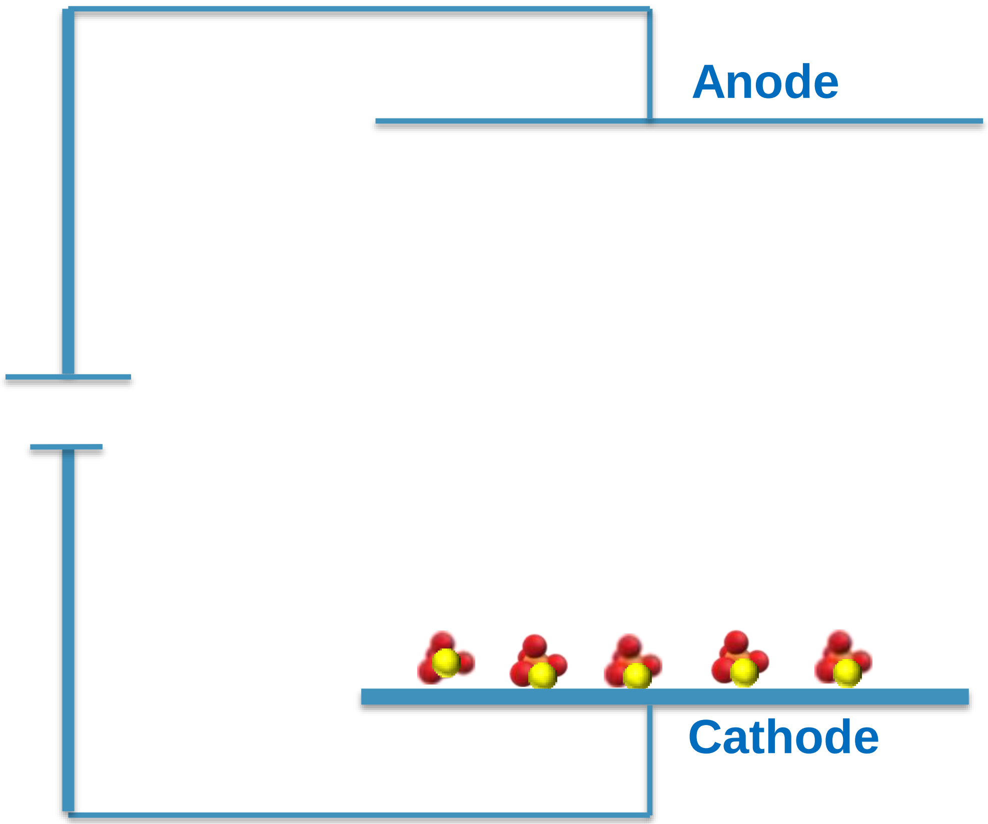
Electrochemical phosphorus recovery



Electrochemical phosphorus recovery



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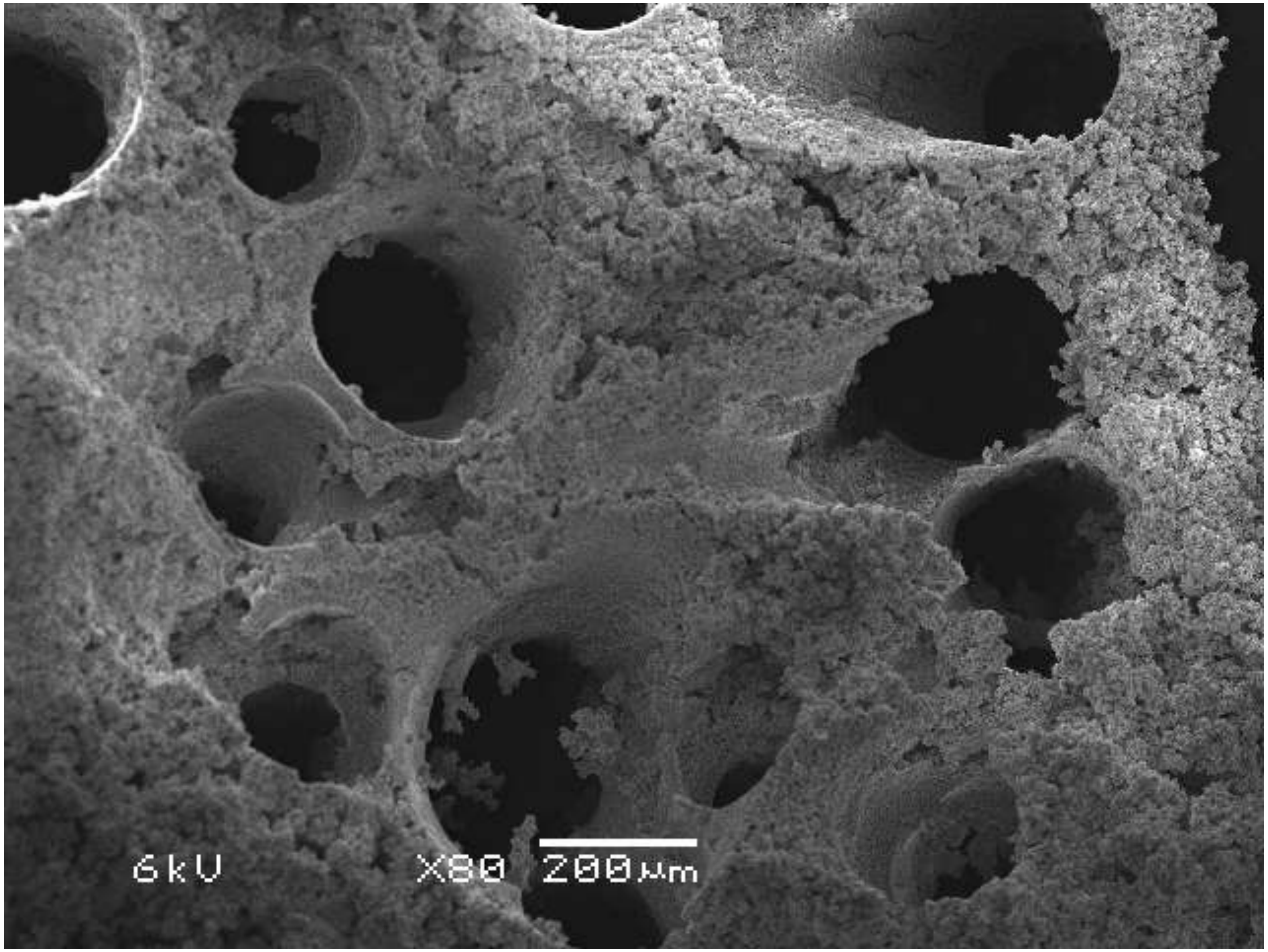
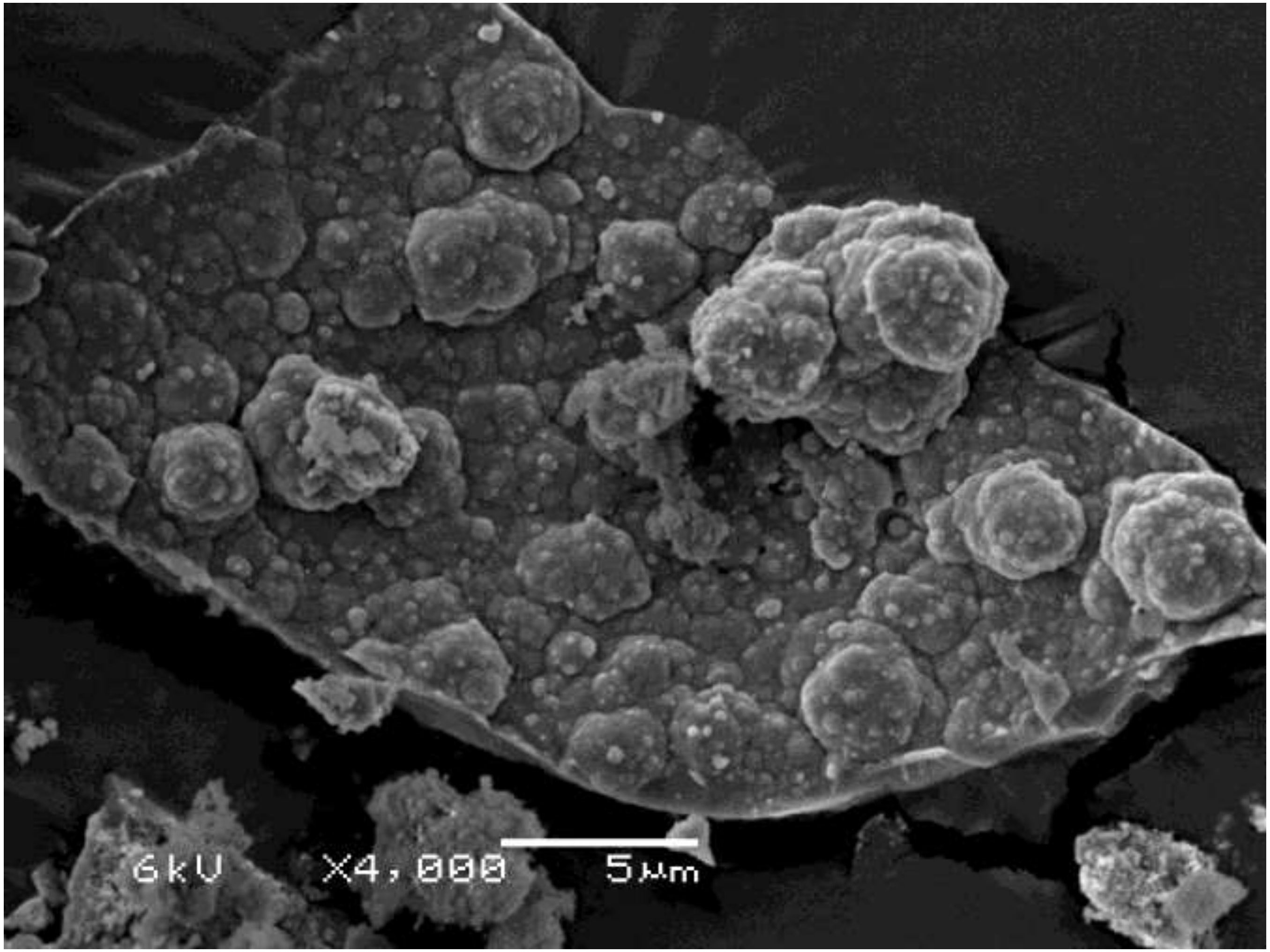
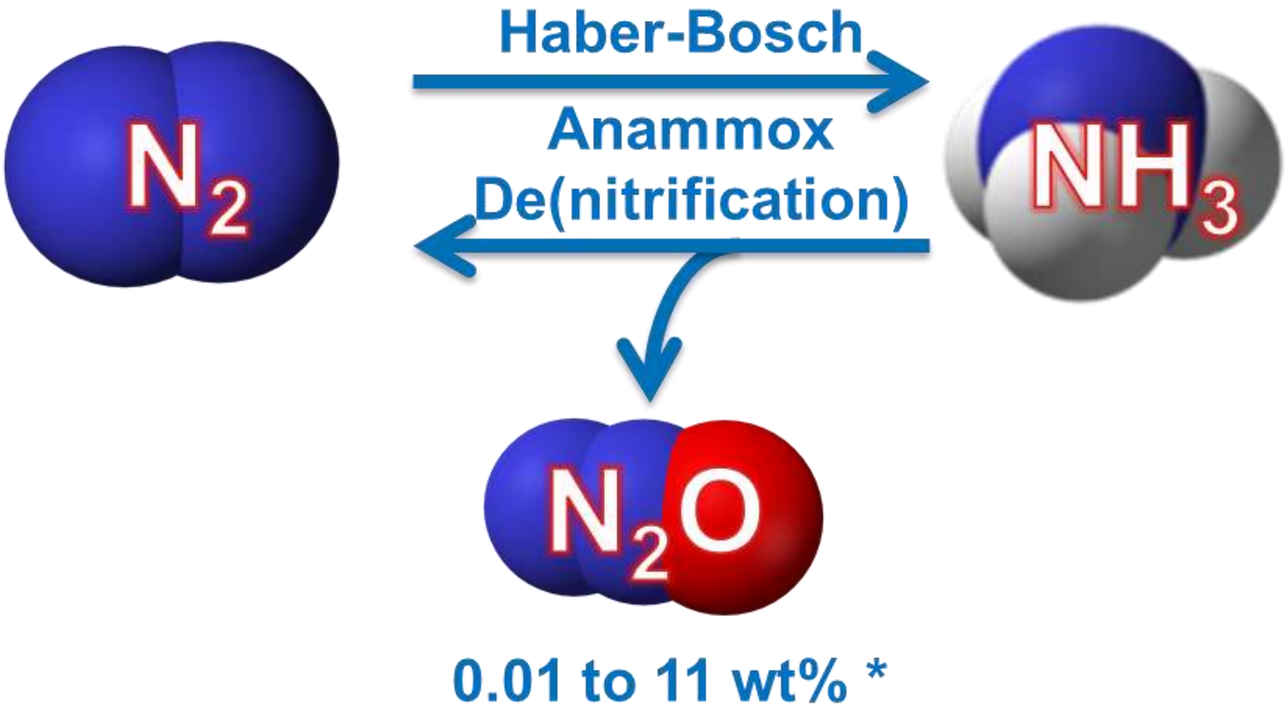
SEM images of precipitates at the surface of cathode



Amorphous calcium phosphate and calcium carbonate



Nitrogen is an climate issue

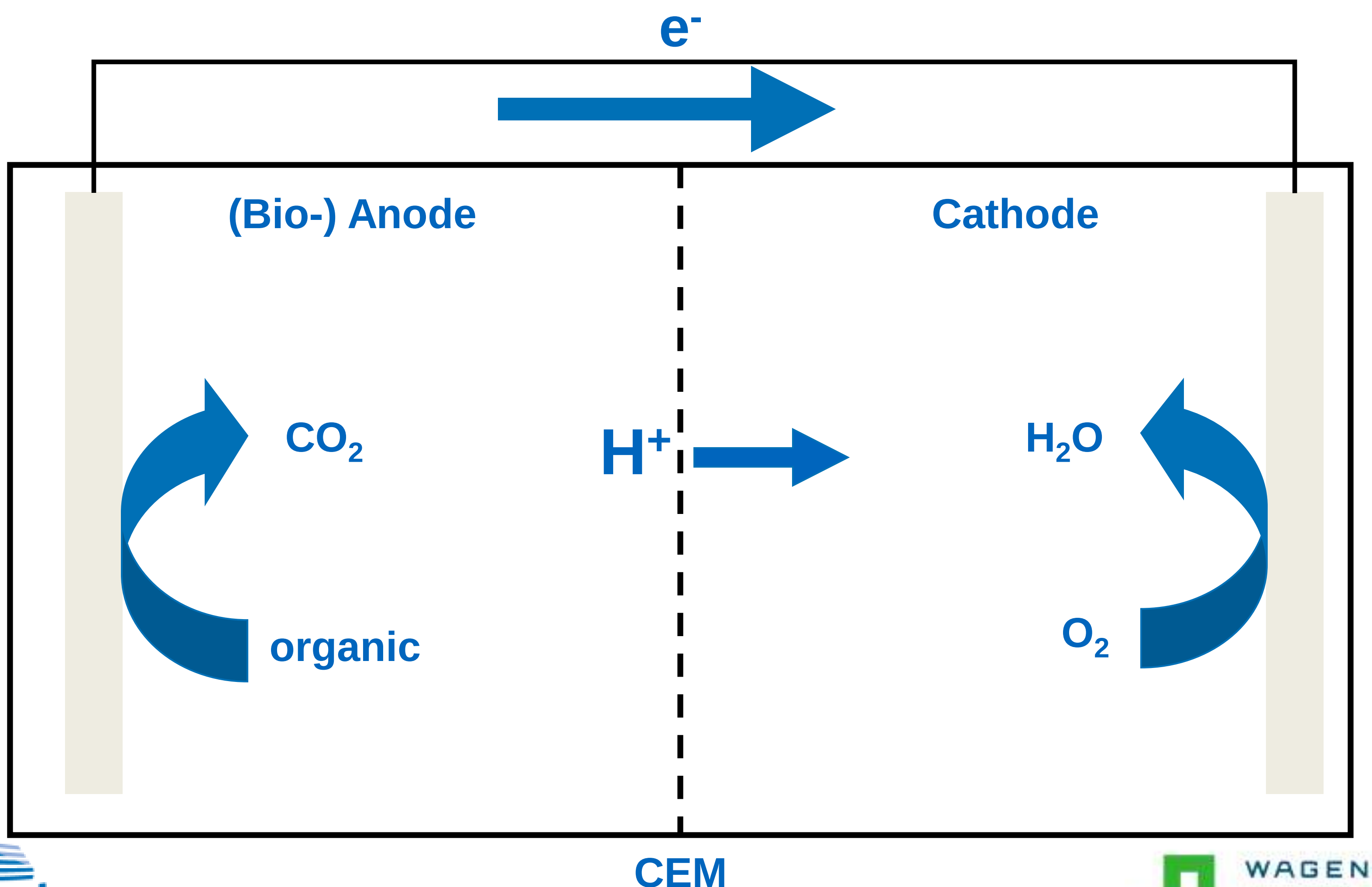


* STOWA Report 2011-30

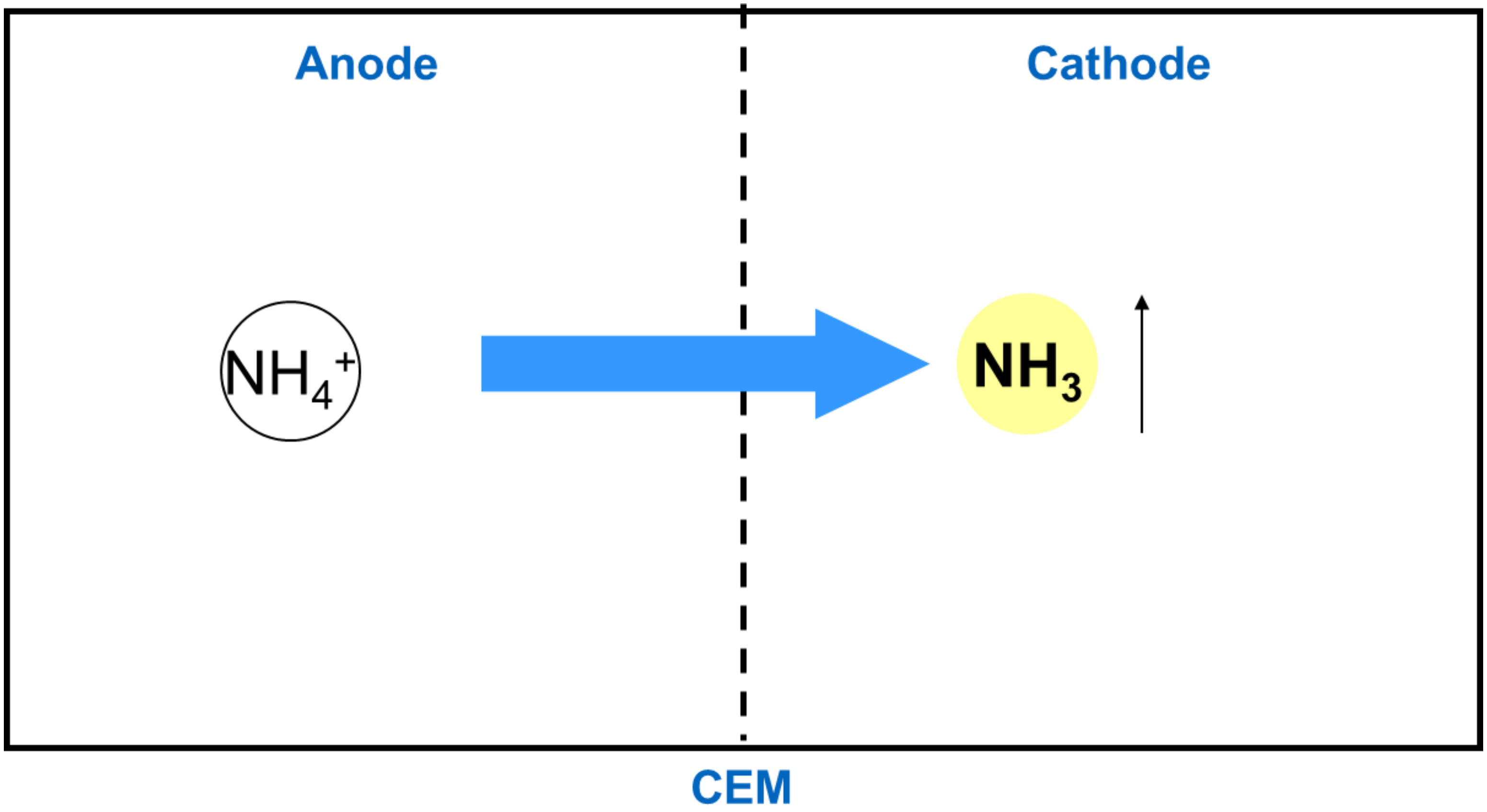
Urine contains nitrogen in high concentration

Nitrogen	9 g/L
COD	10 g/L

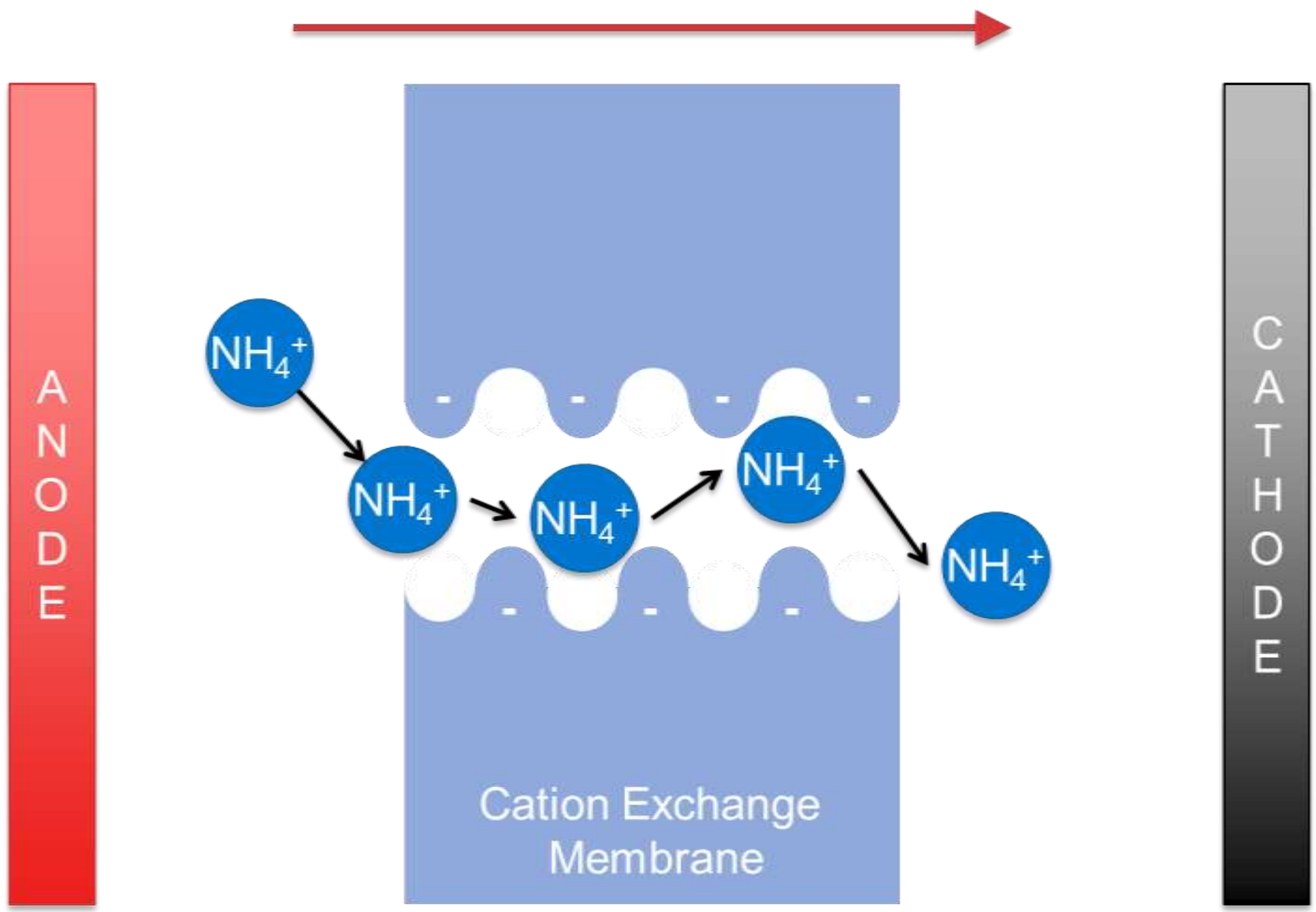
Microbial Fuel Cell



Case Ammonia Recovery



Current driven ammonia recovery



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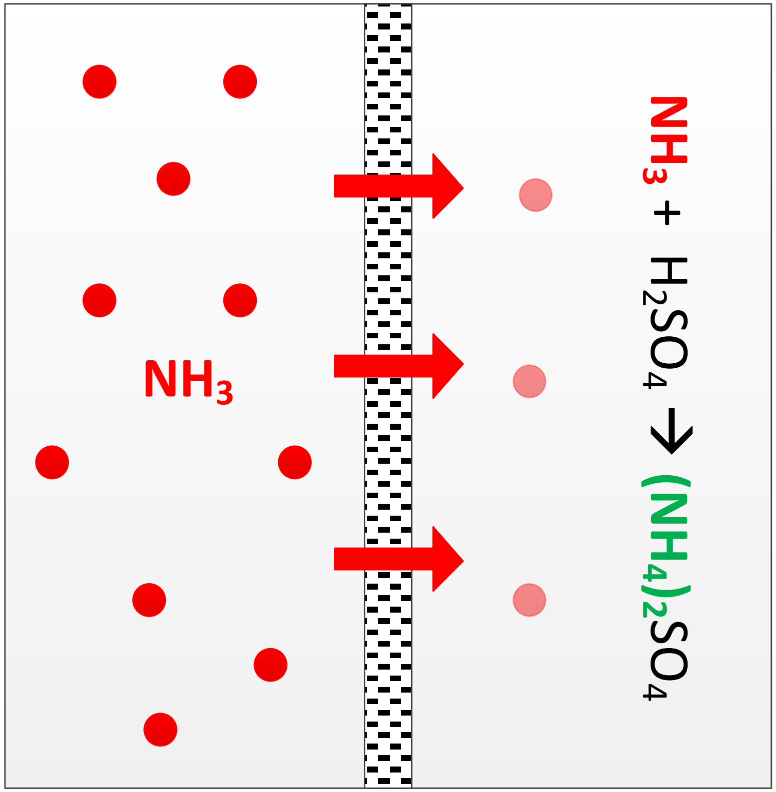
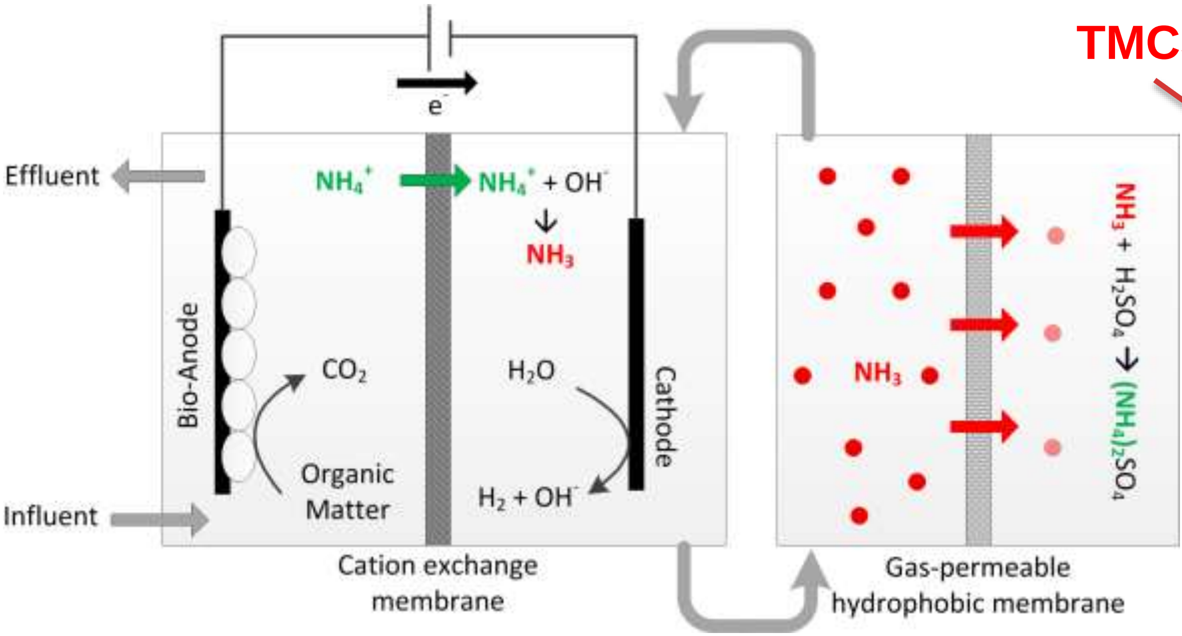
TransMembraneChemiSorption



Gas-permeable
hydrophobic membrane

Commercial TMCS module
size ~100cm^2 (3cm x 3cm x 1cm)

Trans membrane chemisorption (TMCS) integrated in the cathode of an BES



TMCS

P. Kuntke, P. Zamora, M. Saakes, C. J. N. Buisman, H. V. M. Hamelers, Environmental Science: Water Research & Technology, (2016).

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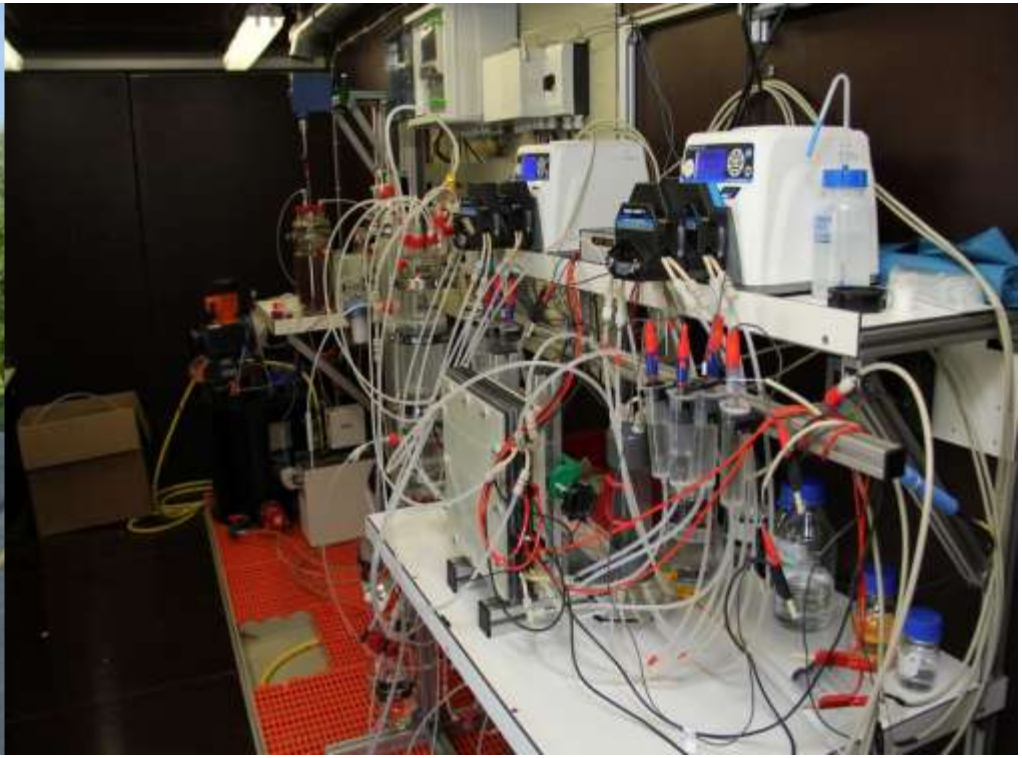
Piloting urine MFC
(30 persons)



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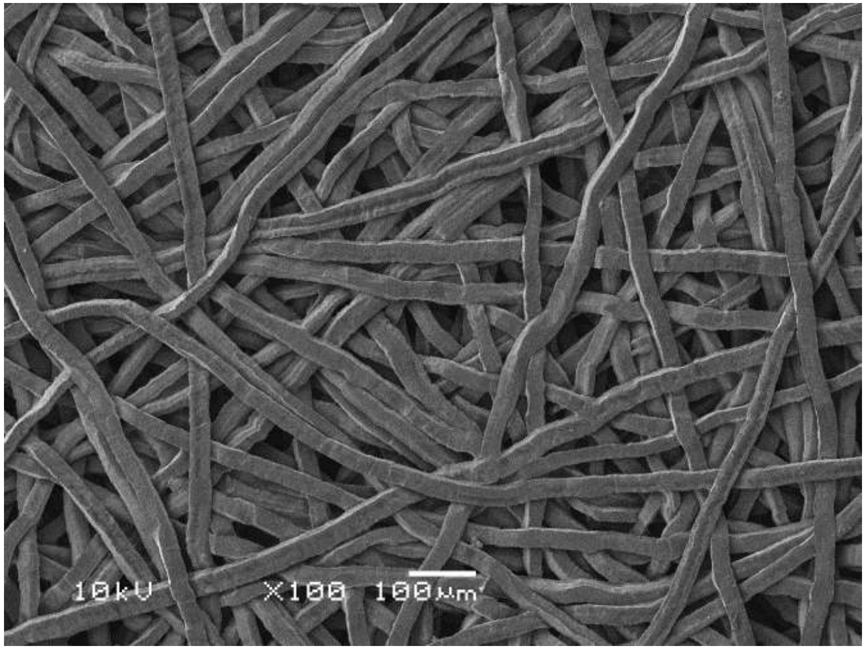
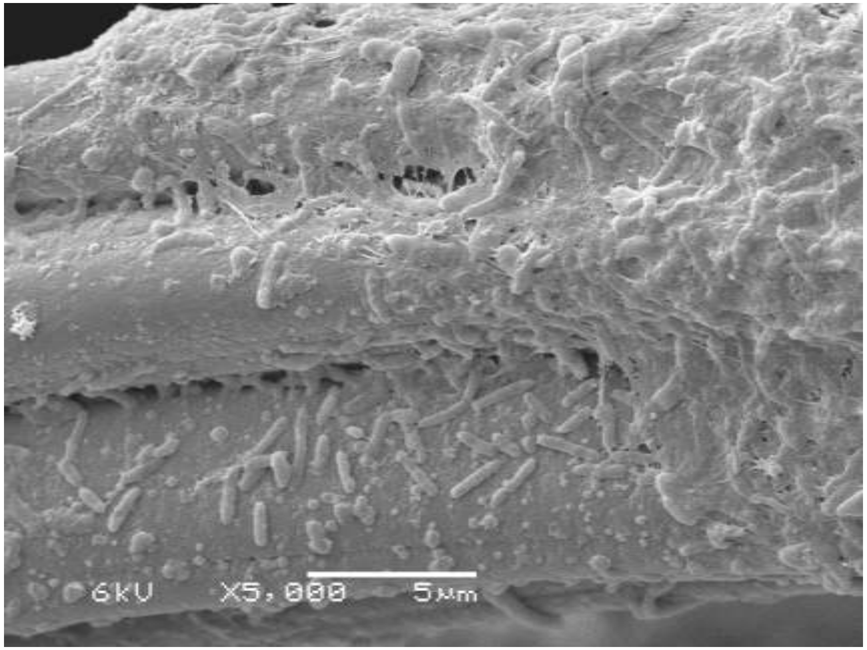
Current can be derived from (Bio-) Electrochemical System

- ES
- High rates, but high energy input

- BES

high rates, with low energy input





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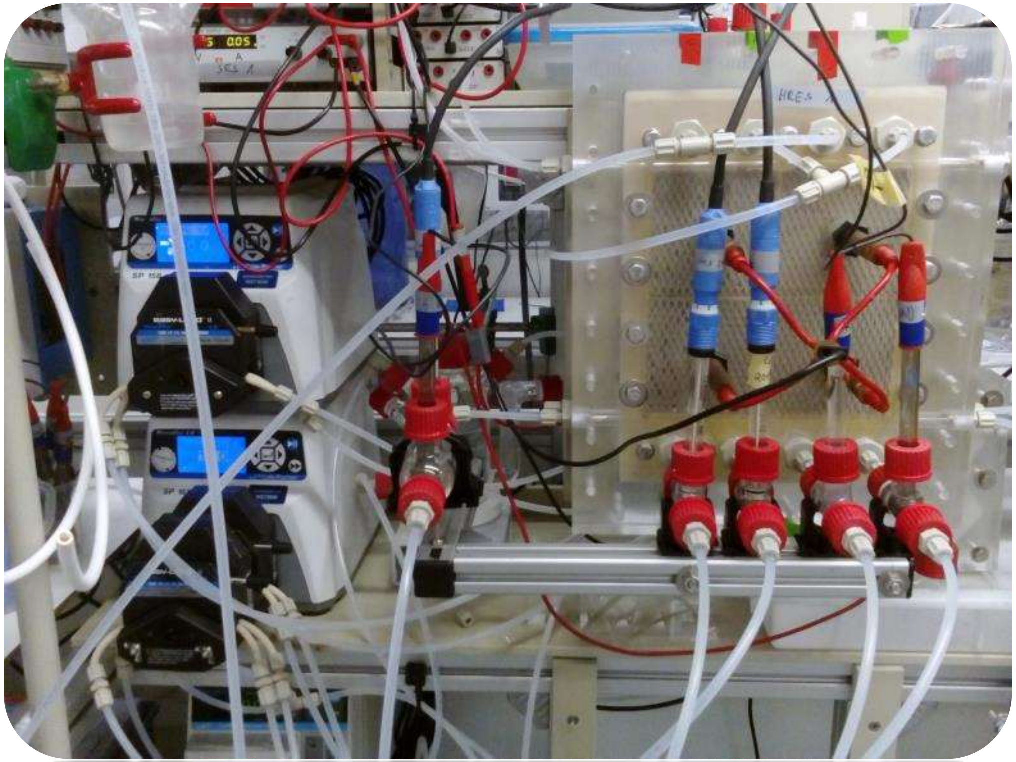
Steps forward – up-scaling (4x)



Hydrogen recycling allows for energy efficient ammonia recovery

Type of system		Energy demand MJ kg_N^{-1}
HRES		**6**
ES		12
Stripping		32
Anammox	+ HB	42 (5+37)
De(nitrification)	+ HB	51 (14+37)

Maurer et al., (2003) W.S.& T., 48, 1, 37-46
Kuntke et al., to be submitted

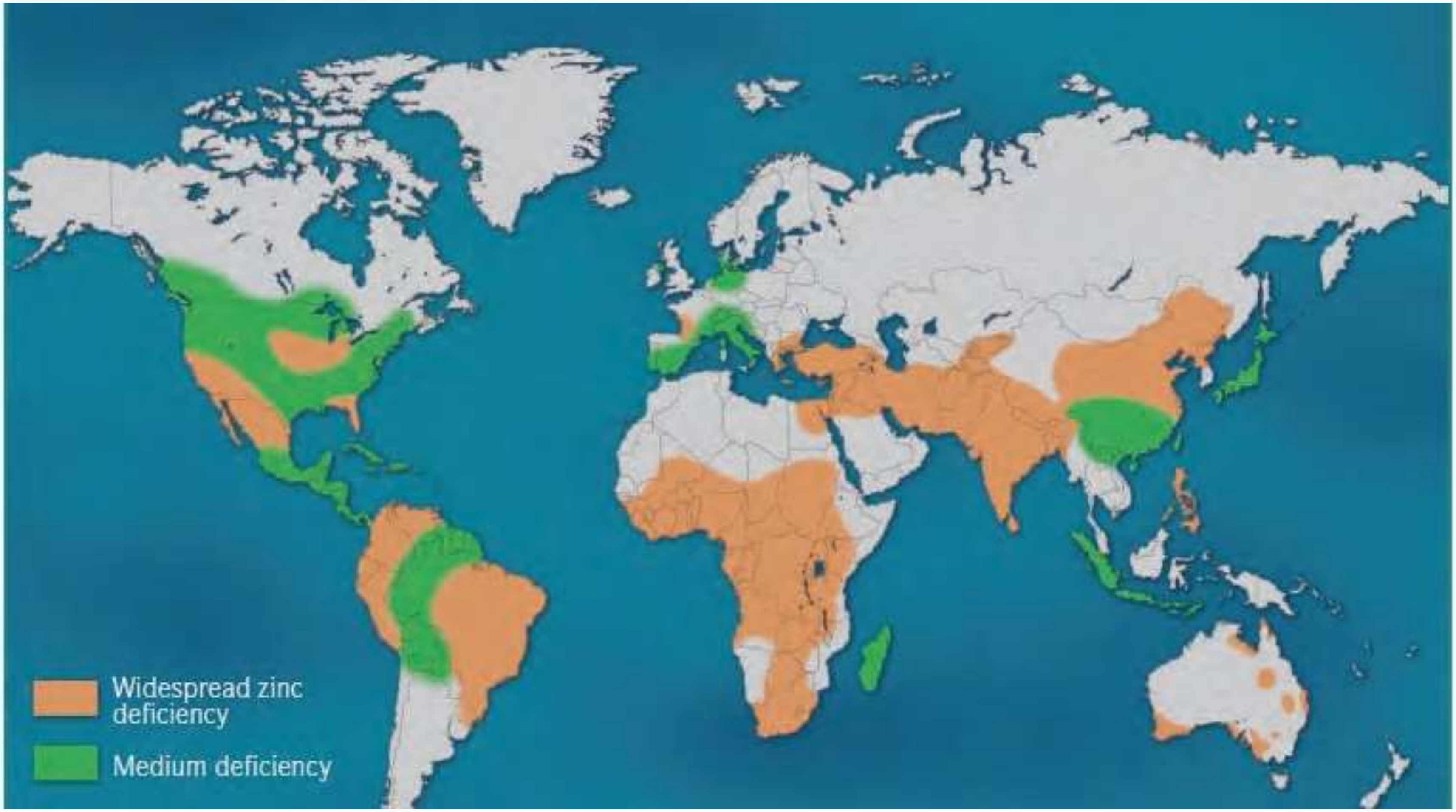
High transport rates in Electrochemical System allow for compact design

Type of system	Removal rate (kgN m^{-3} d^{-1})
HRES/ES	**15**
Anammox	2
De(nitrification)	1

Zinc deficiency effect

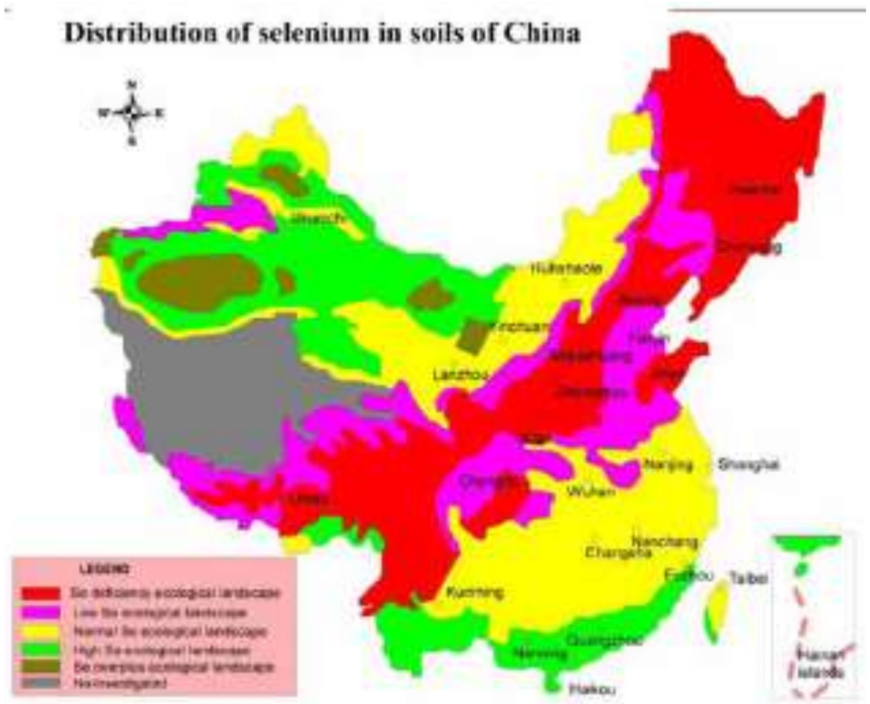
Bron: Alloway 2008

World Zinc Deficiency



Bron: Alloway 2008

Link between Se deficiency in soil and Se related disease in China

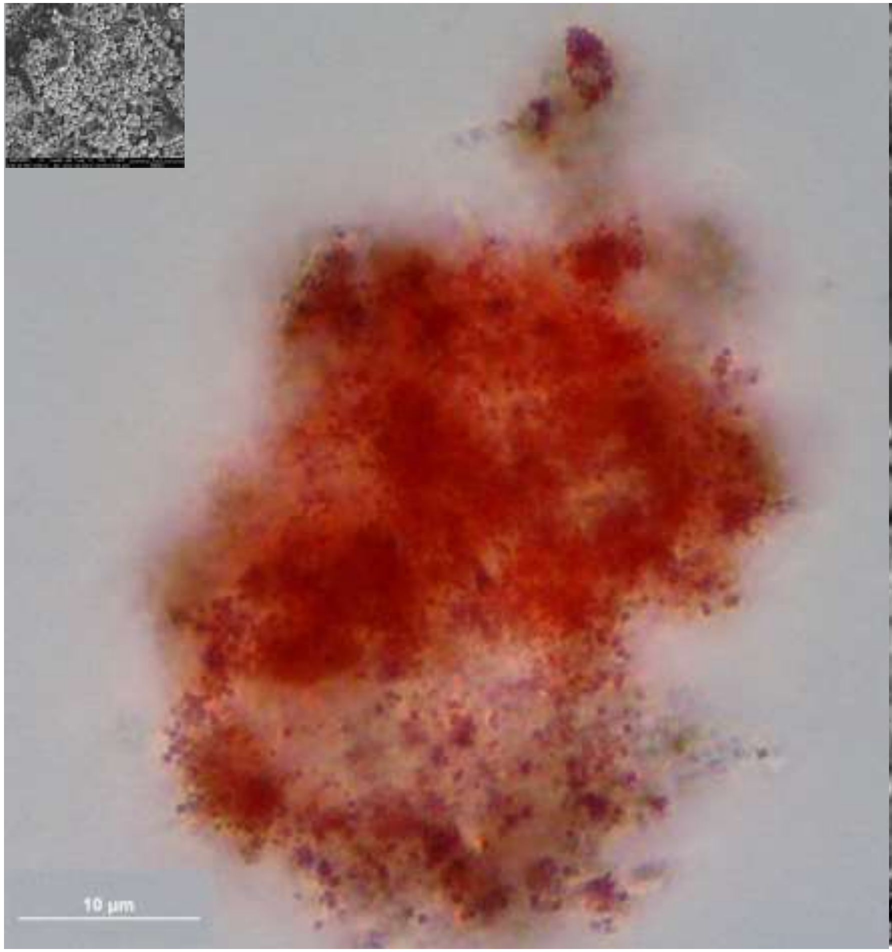


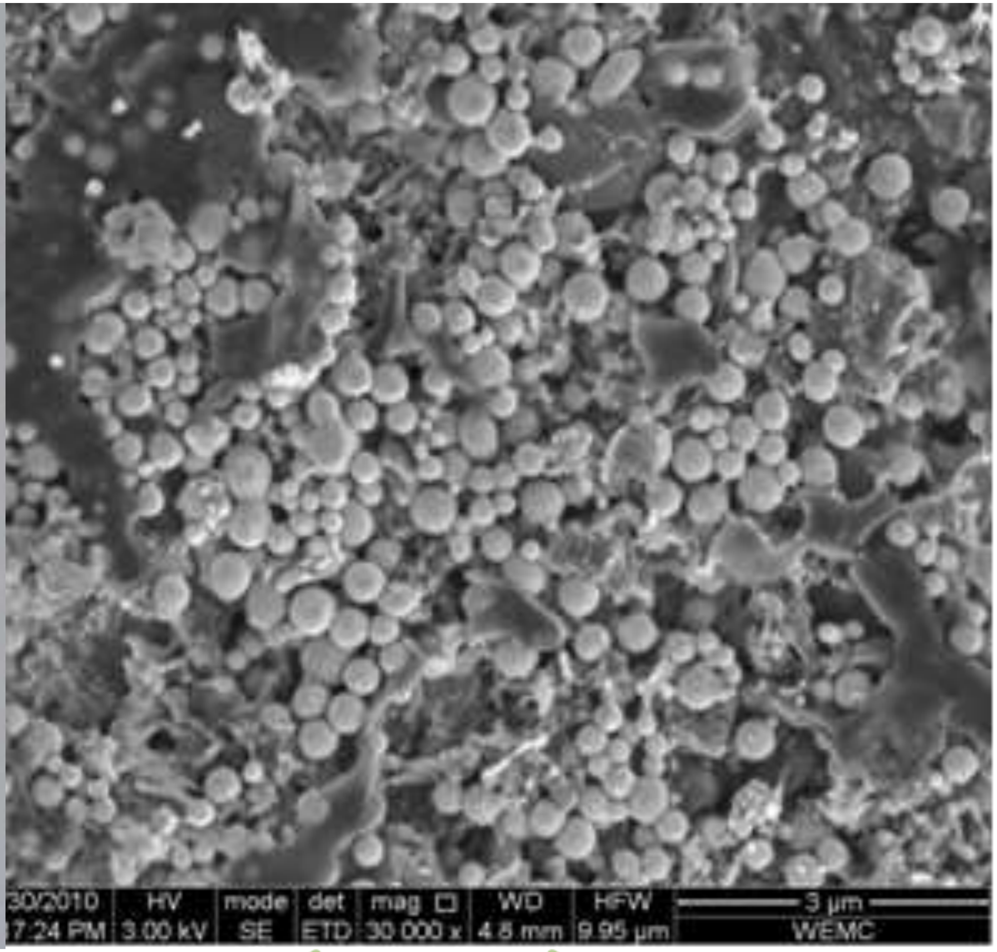
Bron: Alloway 2008

Crystals by selenate reduction?

$$2\ SeO_4^{2-} + \text{ethanol} \rightarrow 2\ Se(s) + 2\ HCO_3^{-} + 2\ OH^{-} + H_2O$$

Results T=30





10µm

3µm

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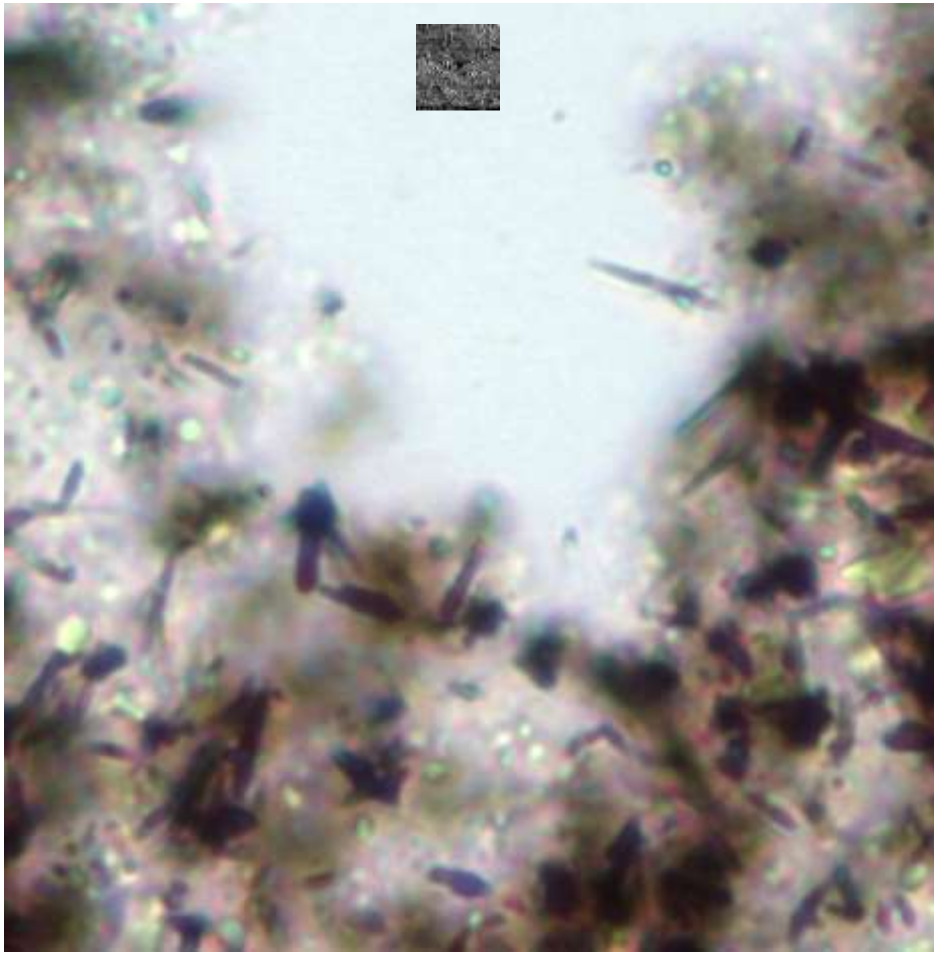
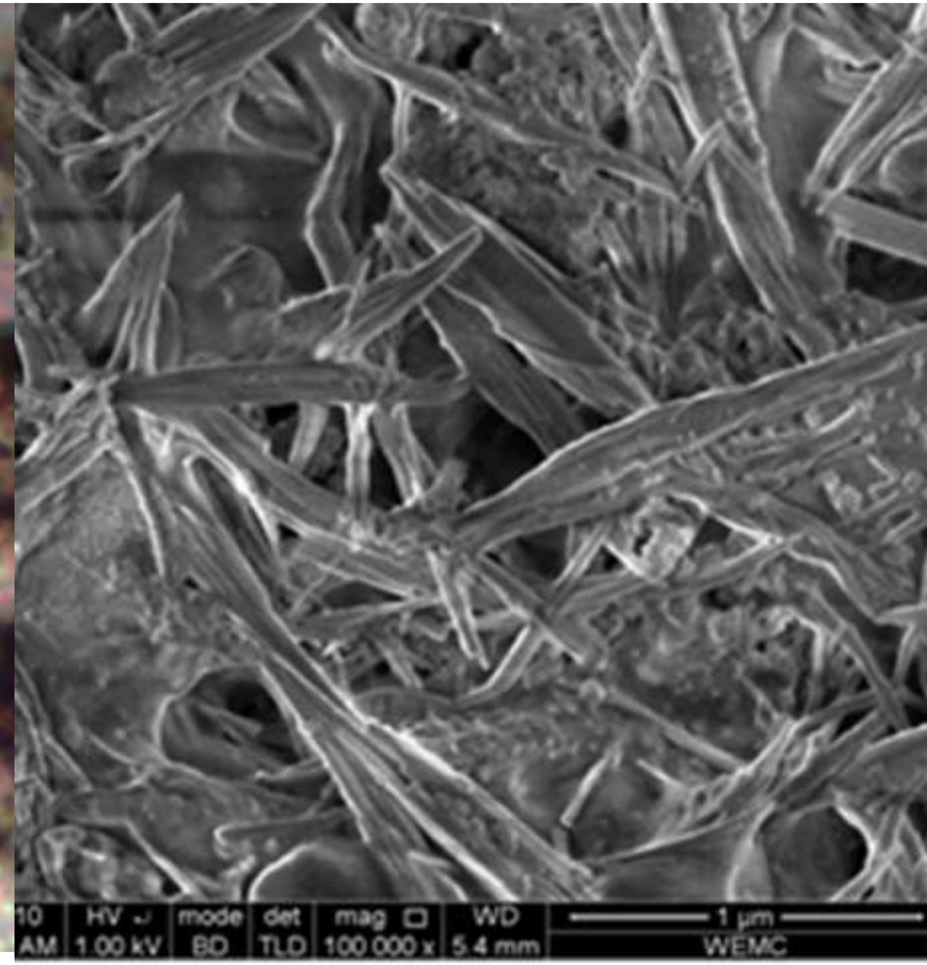
Gray selenium 'needles' aciculair (50°)





10 µm

1µm

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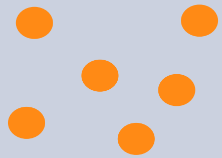
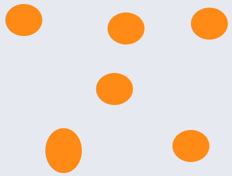
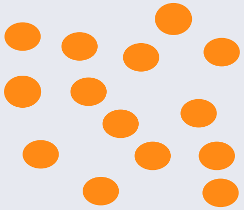
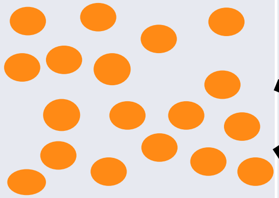
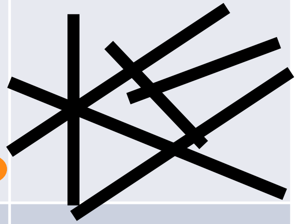
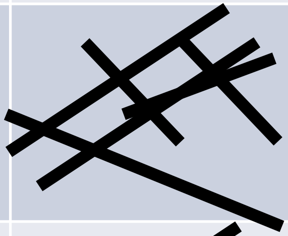
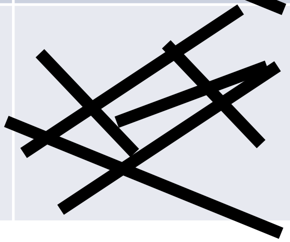
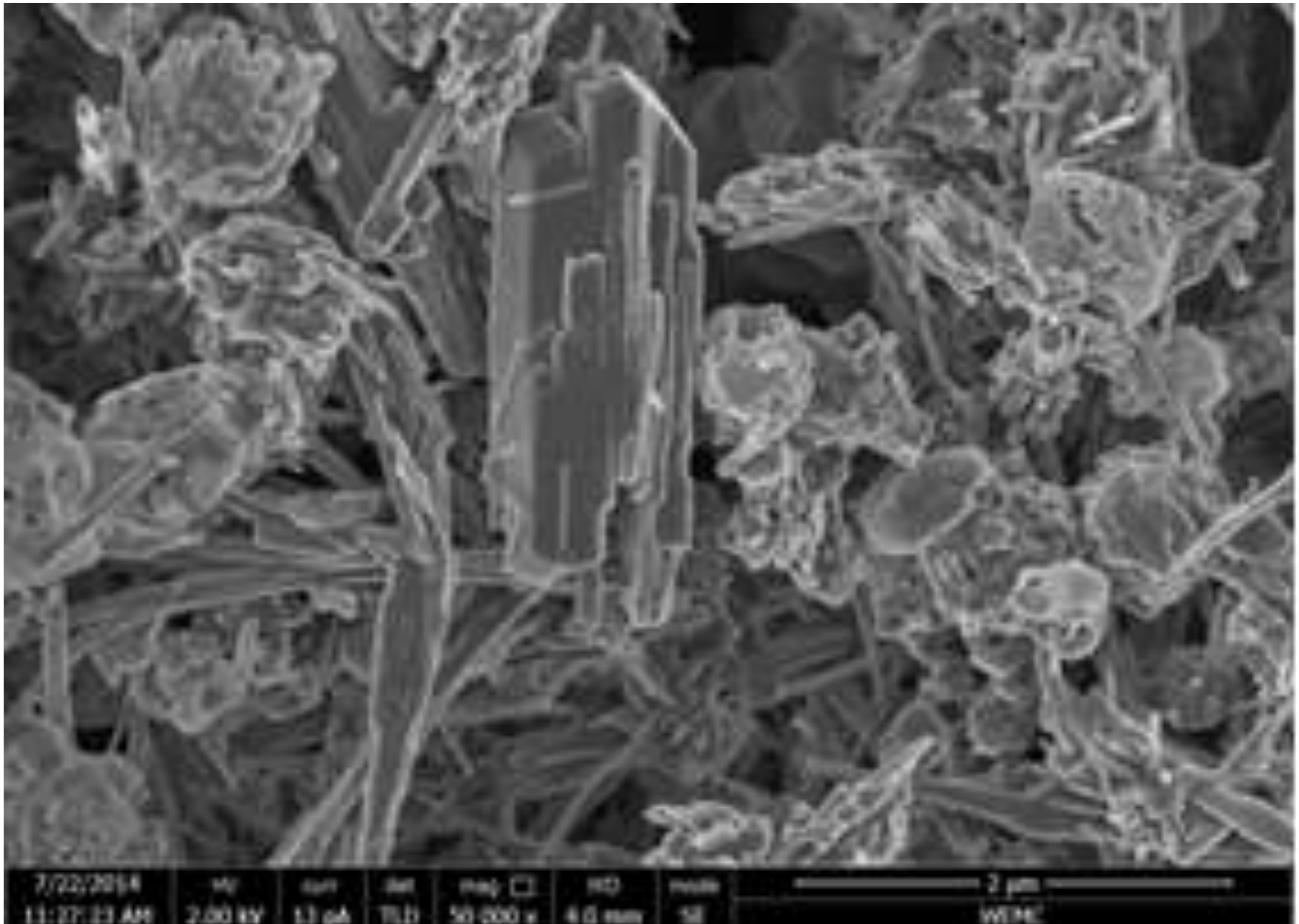
Effect pH and Temperature

T(°C) pH(-)	20	30	40	50
6				
7				
8				
9				

Crystaline selenium from reduced SeS_2



2 µm 1

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Increase in selenium particles (μm^3)

amorf sferical	**0.07**
crystaline aciculair	**2**
crystaline particles (via SeS_2)	**700**

Environmental Technology

Bio*recovery*

Our research focuses on *bio-based technologies for recovery of valuable components from* residual streams *in the form of fuels,electricity,sulphur, copper, and phosphate.*

Re*usable* **Water**

Water shortage threatens billions of people. Reuse and protection of our water sources are essential.
Our research focuses on *removal of nutrients, pathogens nutrients, pathogens from water.*

Urban *System Engineering*

Scale and speed of urbanization leads to new challenges for our urban services.
Closed resource cycles are necessary. We focus on *new sustainable biorecovery and cleaning concepts for management of urban and industrial water, sanitation, waste,nutrient and energy. Feedbacks from cities to agriculture are also studied.*

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TIMES SQUARE
NY
AÉROPOSTALE
Bio recovery group 2016

For more information:

www.wetsus.eu & www.ete.wur.nl
www.watercampus.nl
www.topsectorwater.nl

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- the Dutch Ministry of Infrastructure and the Environment
- the European Union (Horizon 2020 and Seventh Framework Programme)
- Northern Netherlands Provinces (REP-SNN)
- the City of Leeuwarden, the Province of Fryslân
- The Netherlands Organisation for Scientific Research (from 2017 onwards)

Ministry of Economic Affairs
Ministry of Infrastructure and the Environment
SNN
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