MELiSSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

CREATING A CIRCULAR FUTURE

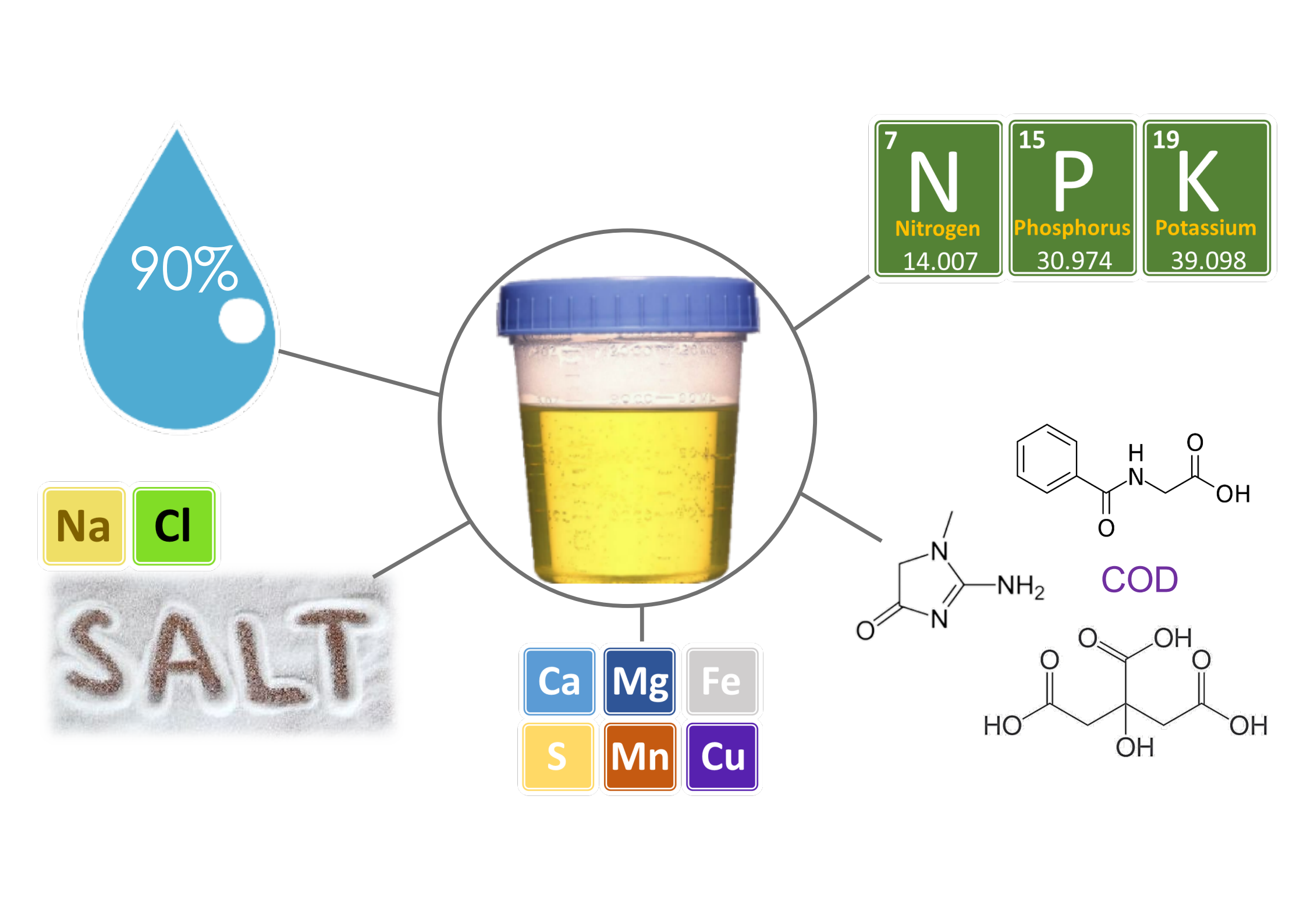
Combining (bio)electrochemical processes and nitrification for urine recycling in Space

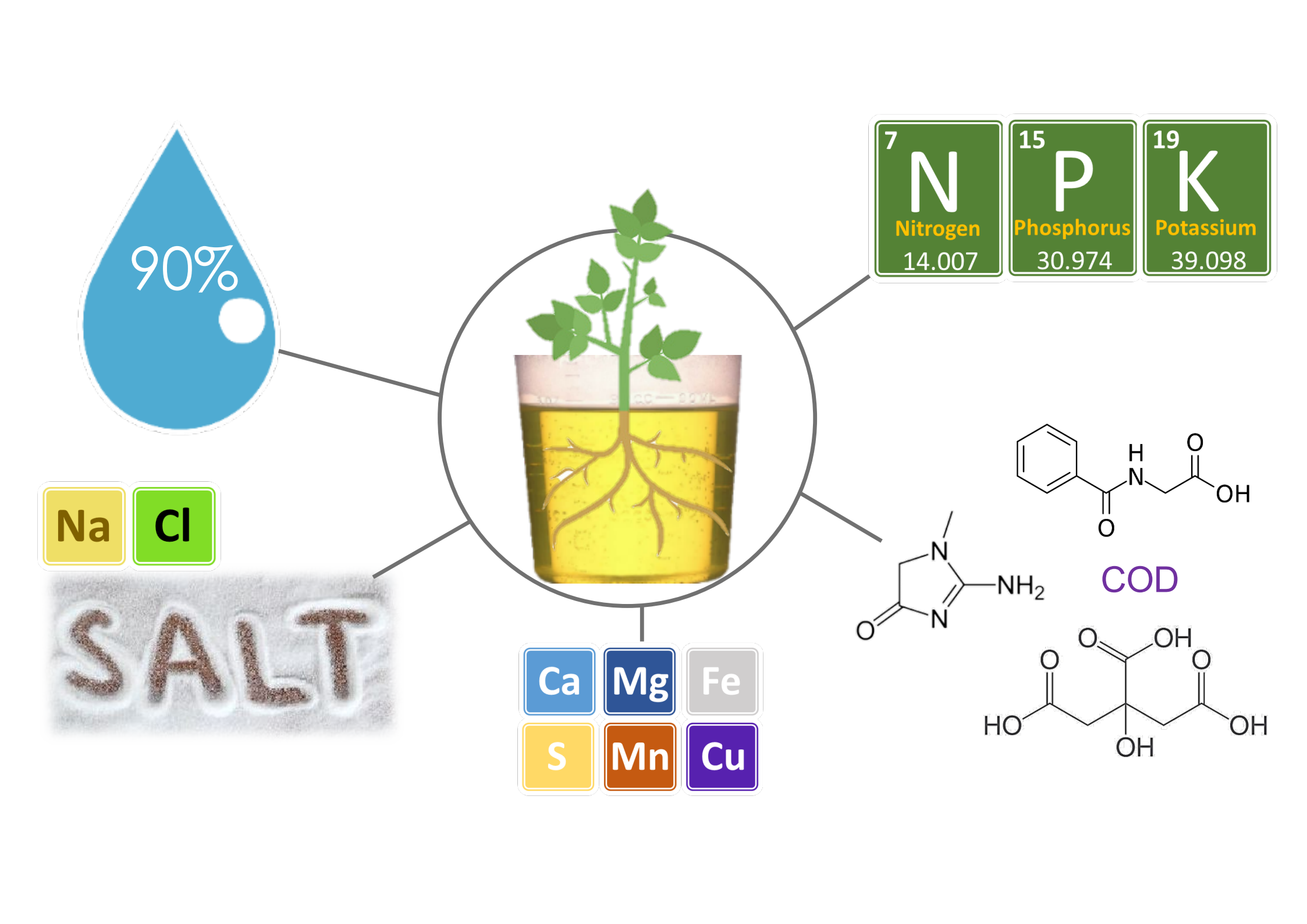
Jolien De Paepe, Maria Celeste Gritti, Kim De Paepe, Francesc Gòdia, Korneel Rabaey, Siegfried E. Vlaeminck, and Peter Clauwaert

GHENT UNIVERSITY

UAB Universitat Autònoma de Barcelona

MELiSSA FOUNDATION


90%
Na
Cl
SALT
Ca
Mg
Fe
S
Mn
Cu
7
N
Nitrogen
14.007
15
P
Phosphorus
30.974
19
K
Potassium
39.098
COD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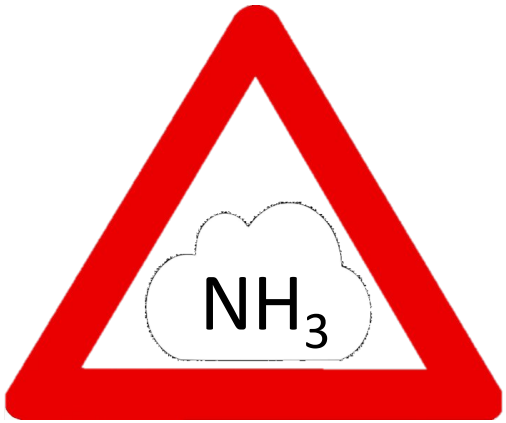
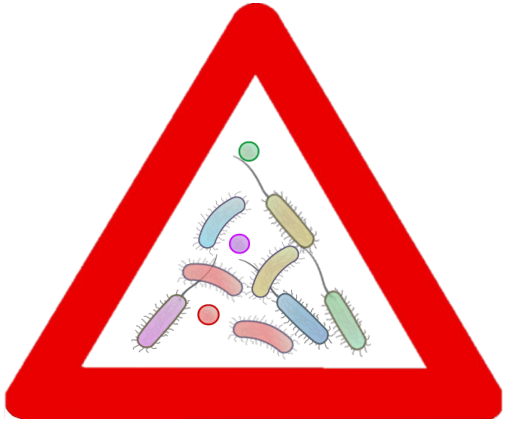
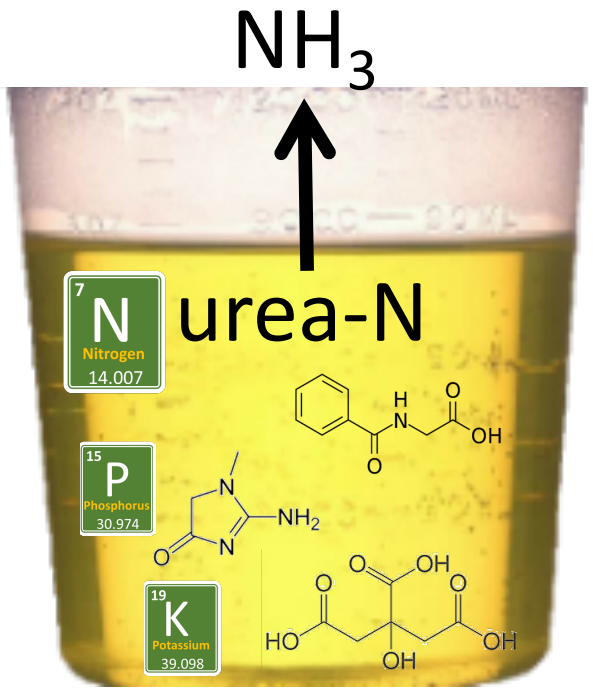

NH_3




NH_3
urea-N
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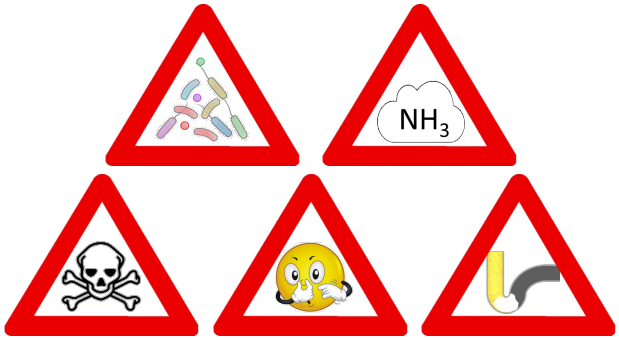
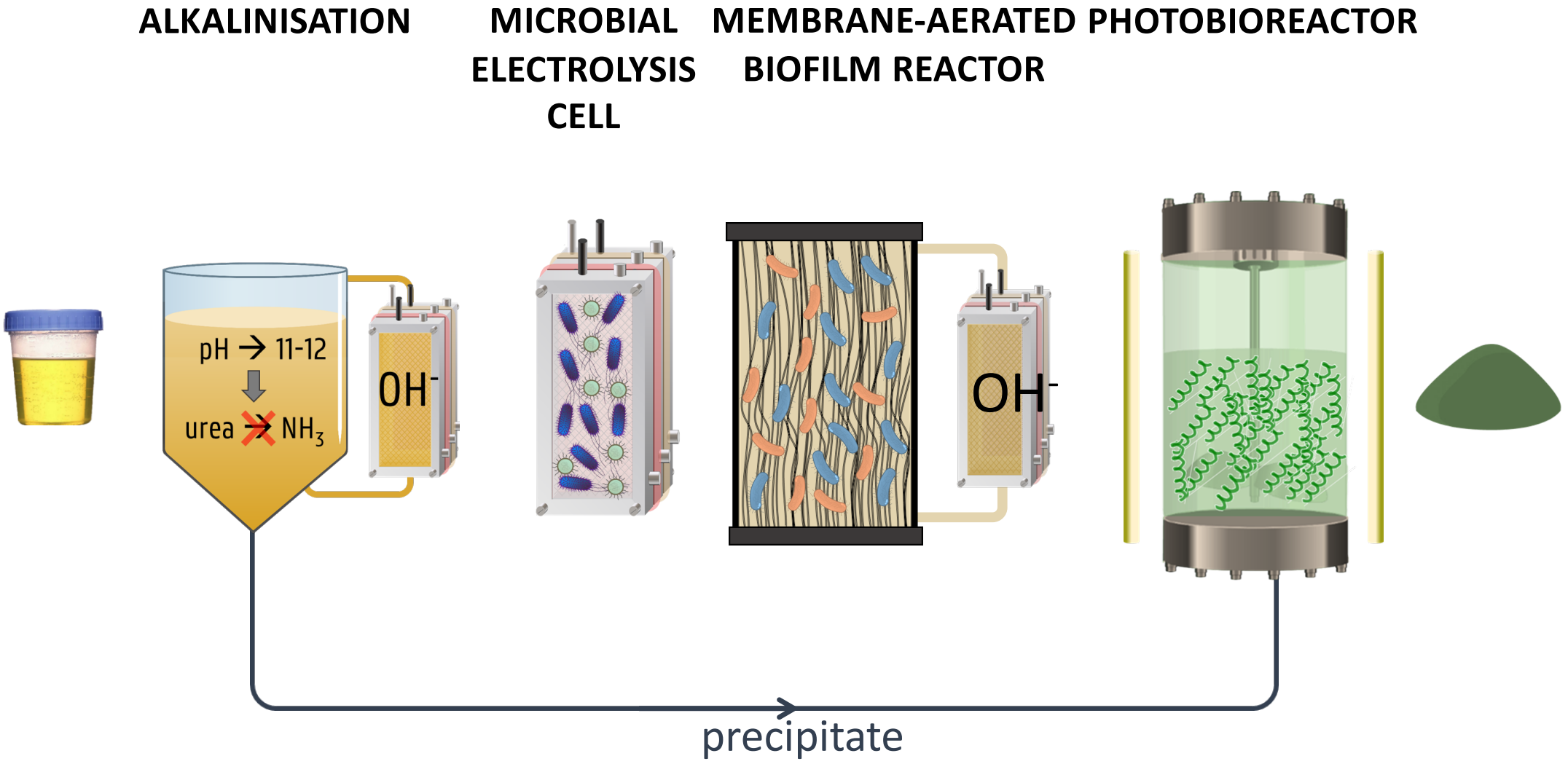

NH_3


SAFE PRODUCT
SAFE PRODUCT


STABL

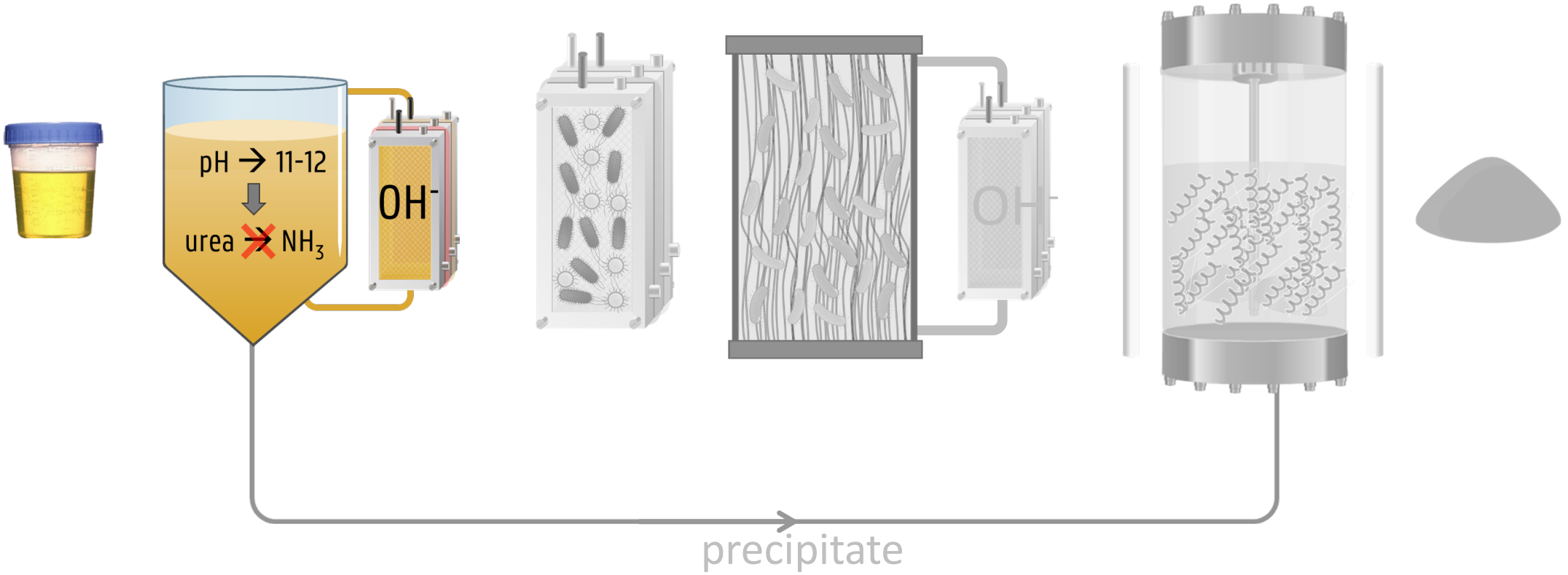

ALKALINISATION
MICROBIAL ELECTROLYSIS CELL
MEMBRANE-AERATED BIOFILM REACTOR
PHOTOBIOREACTOR
pH → 11-12
urea ⇏ NH3
OH-
OH-
precipitate

ALKALINISATION

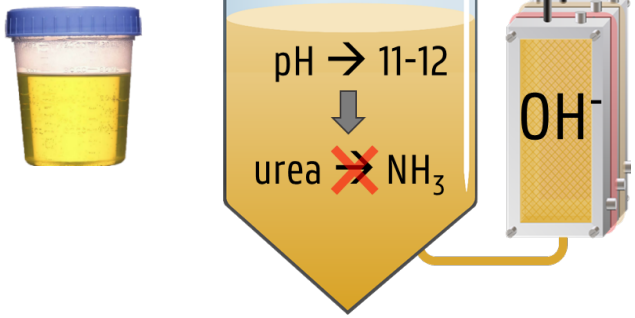
MICROBIAL ELECTROLYSIS CELL

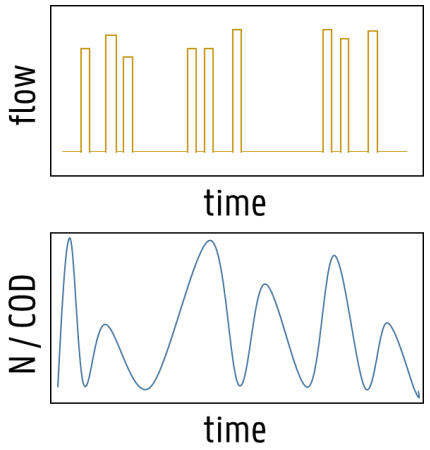
MEMBRANE-AERATED BIOFILM REACTOR

PHOTOBIOREACTOR

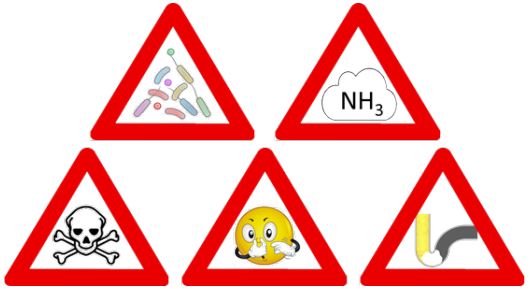


ALKALINISATION

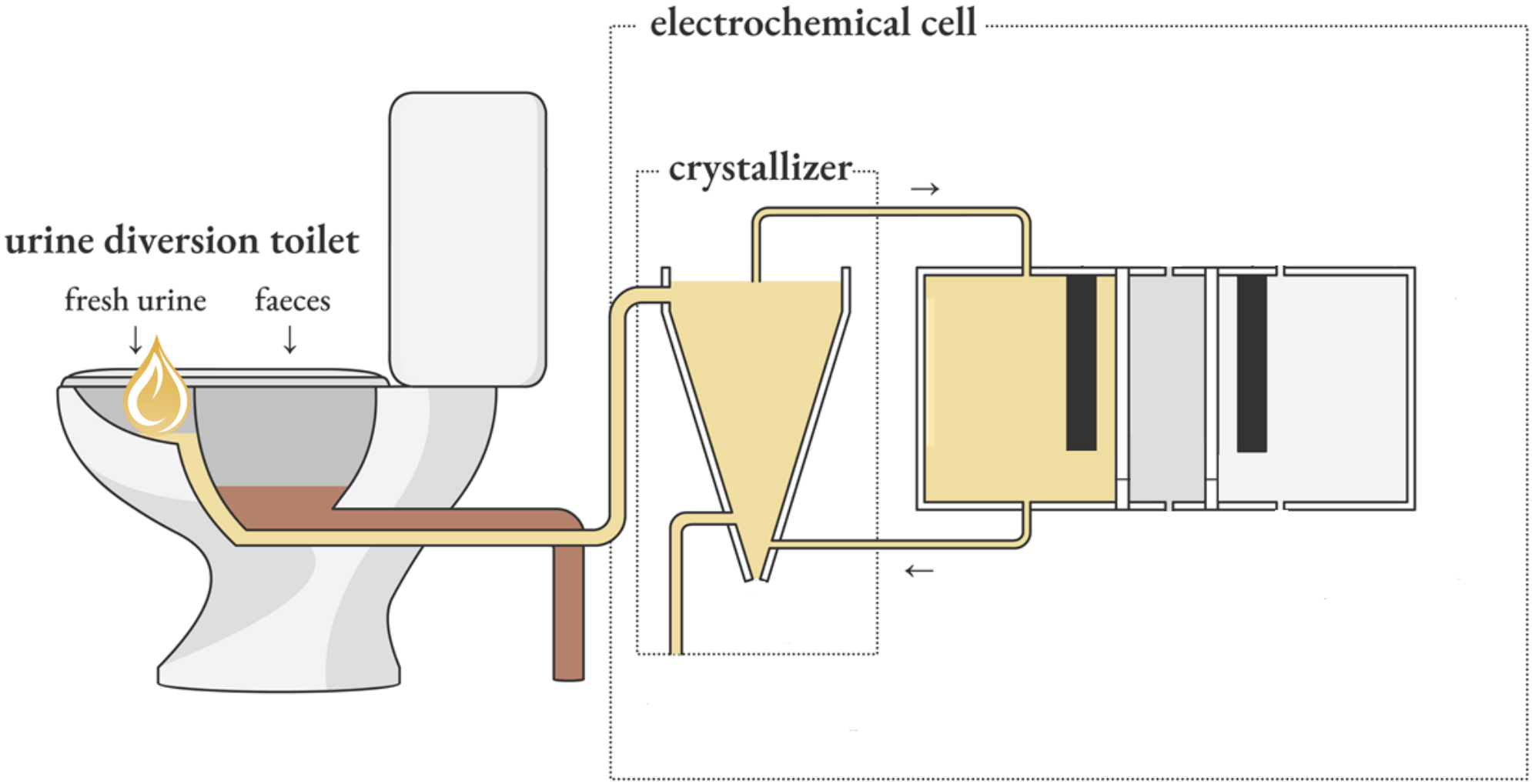


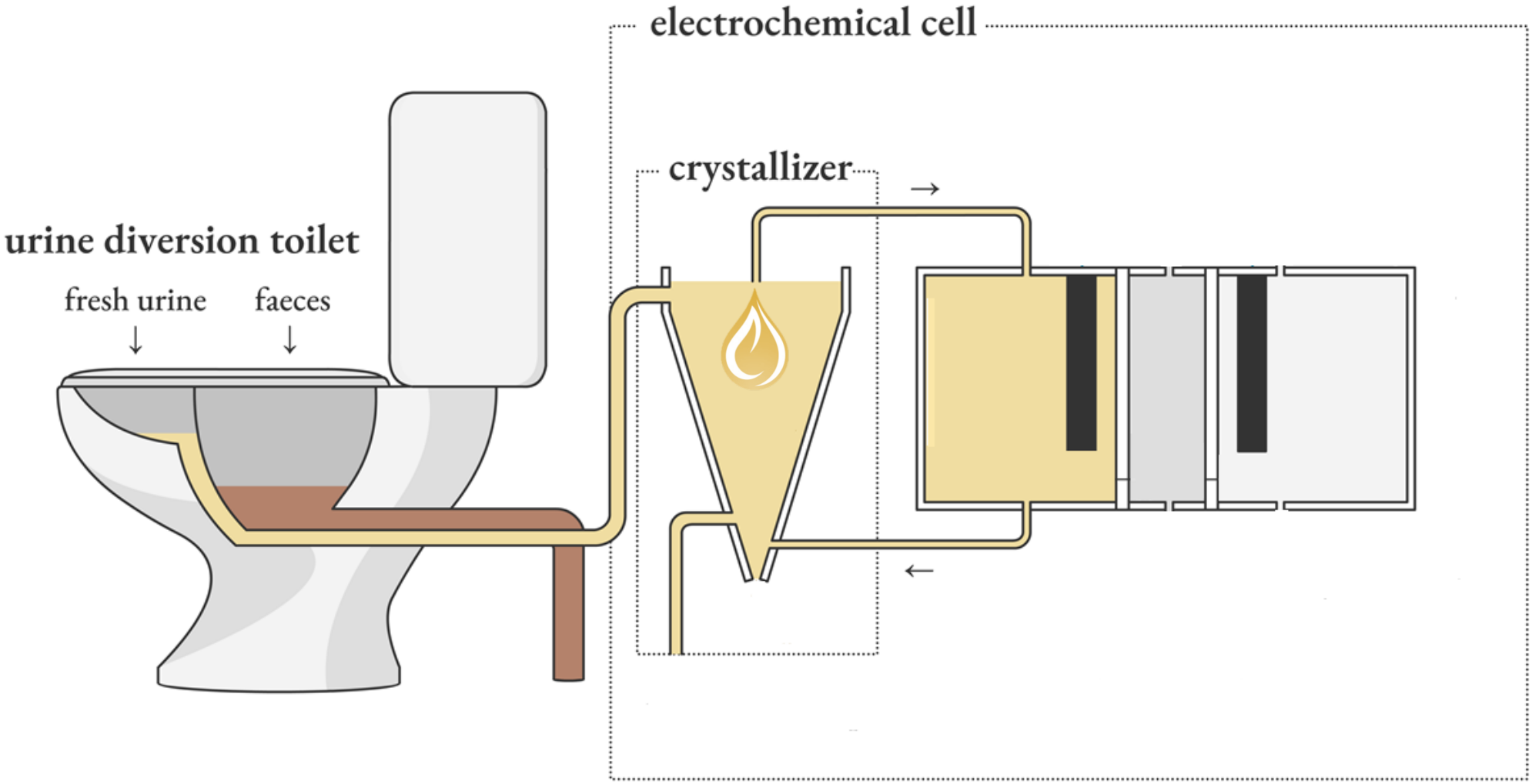


→ storage for equalisation



→ alkalinisation: high pH inhibits urea hydrolysis


electrochemical cell
crystallizer
urine diversion toilet
fresh urine
faeces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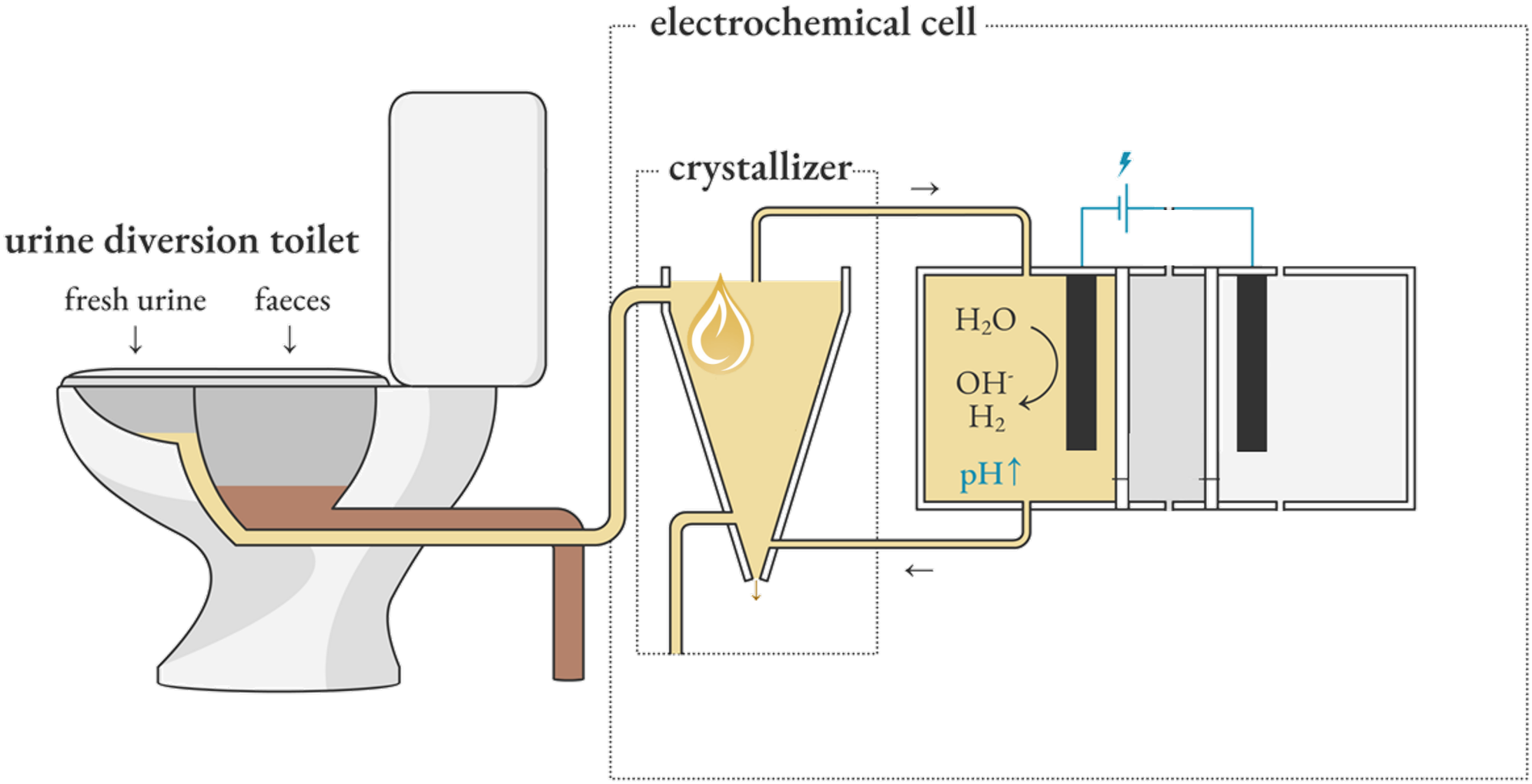
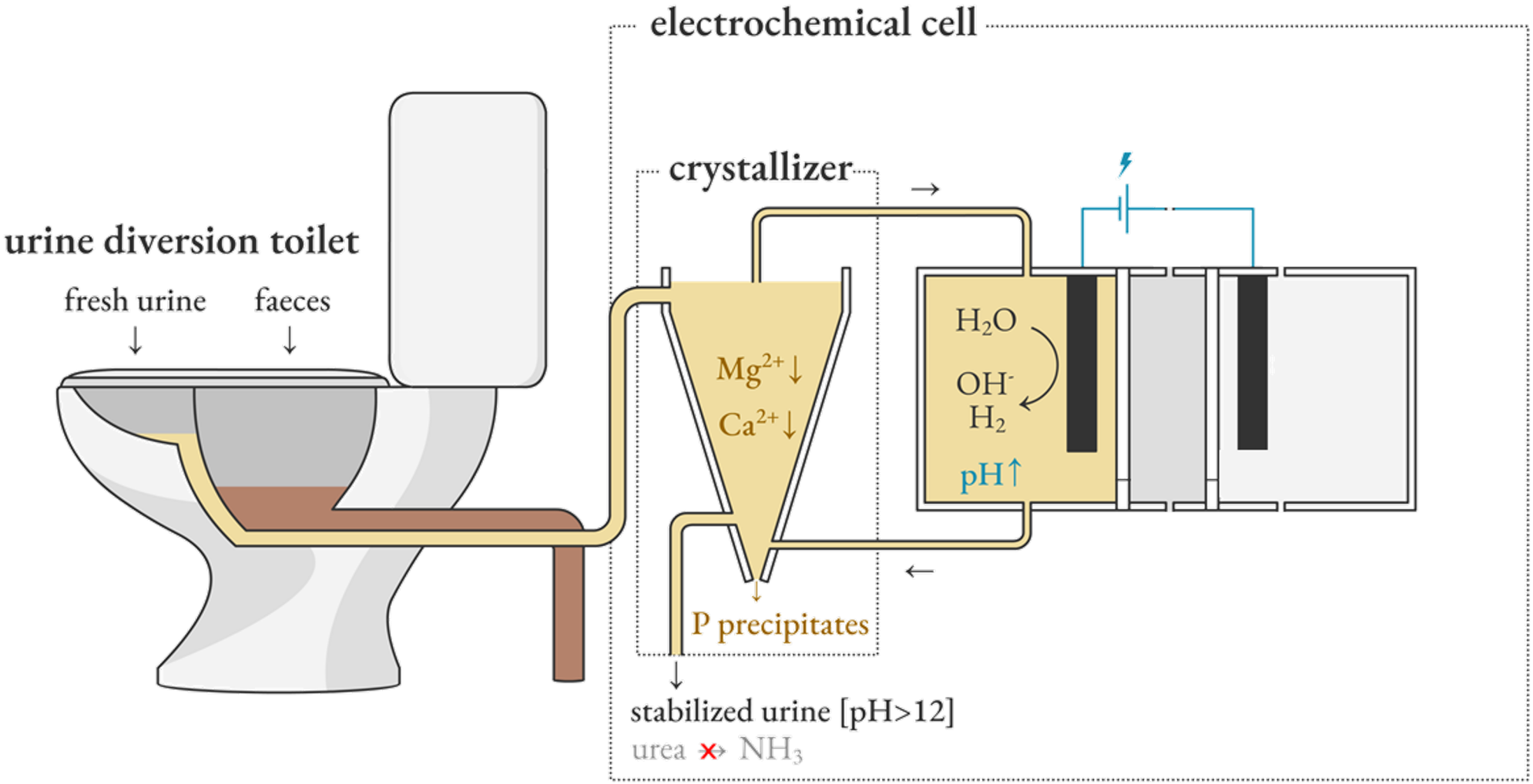
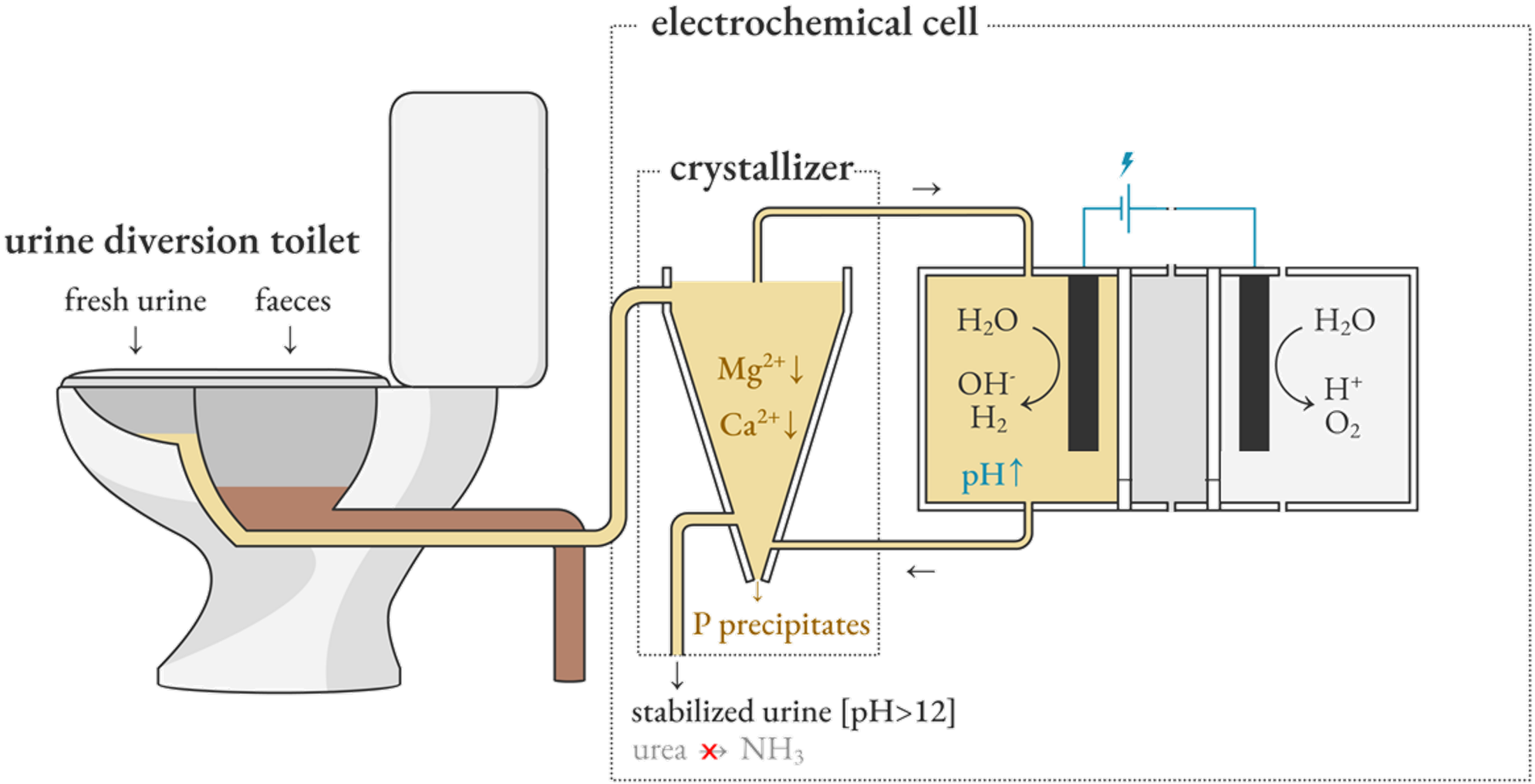

electrochemical cell
crystallizer
urine diversion toilet
fresh urine
faeces
H_2O
OH^-
H_2
pH↑


electrochemical cell
crystallizer
urine diversion toilet
fresh urine
faeces
$Mg^{2+}\downarrow$
$Ca^{2+}\downarrow$
H_2O
OH^-
H_2
pH↑
P precipitates
stabilized urine [pH>12]
urea ↛ NH_3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$Mg^{2+}\downarrow$
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H_2O
OH^-
H_2
pH↑
H_2O
H^+
O_2
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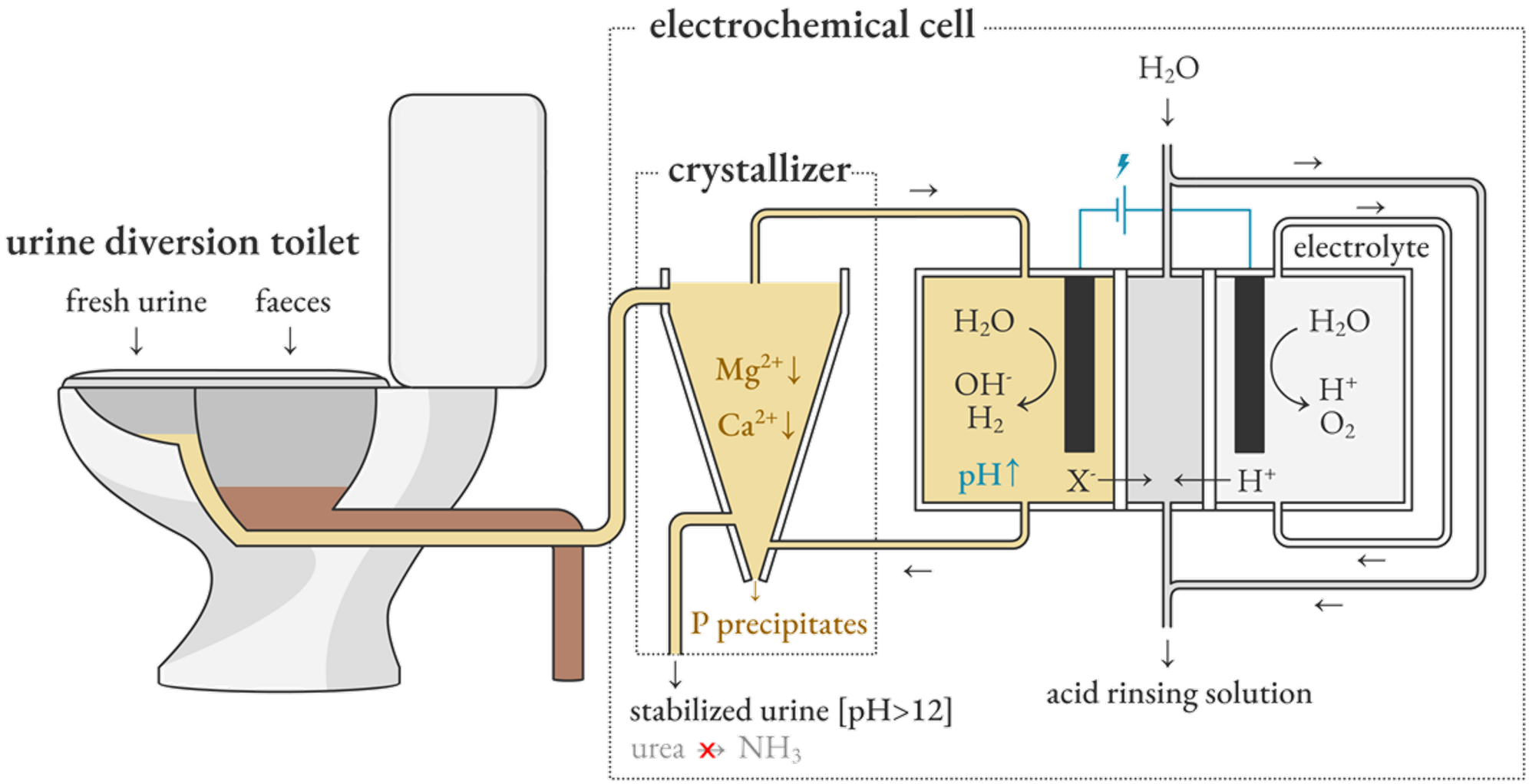
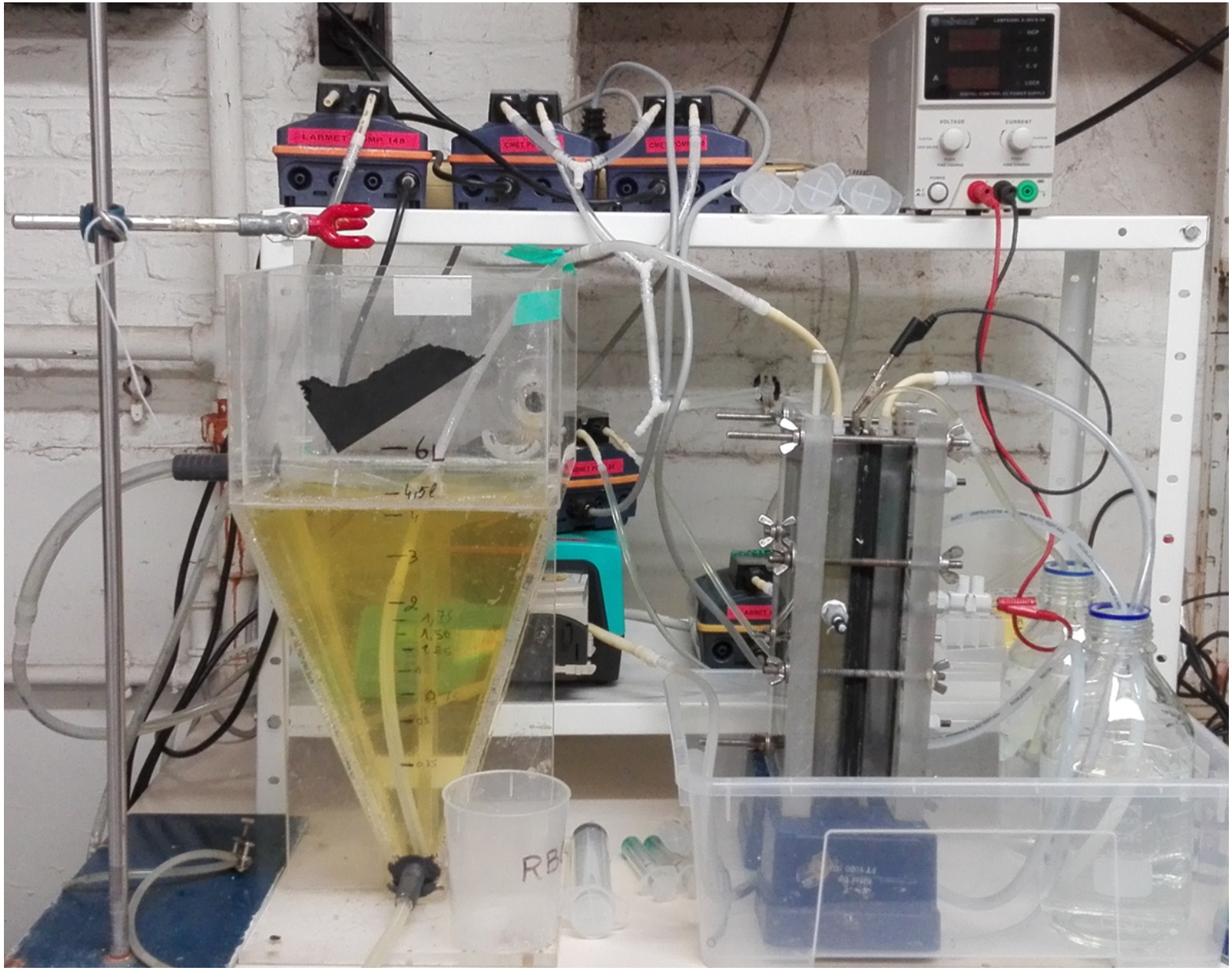
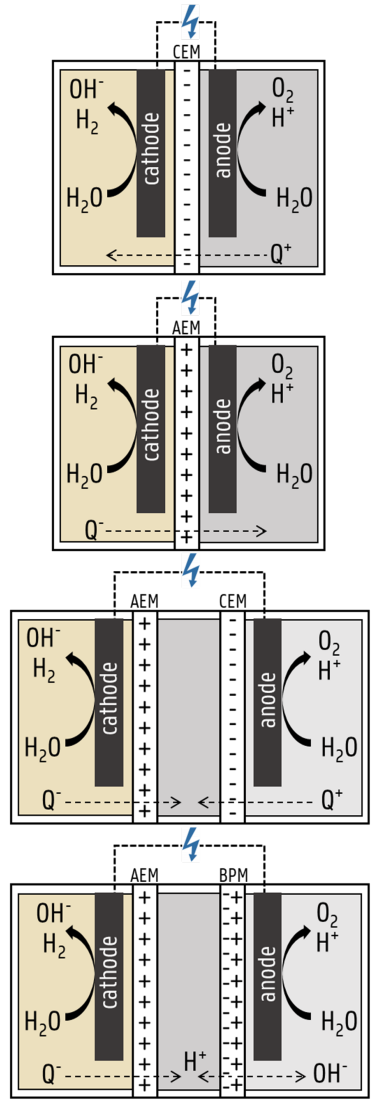
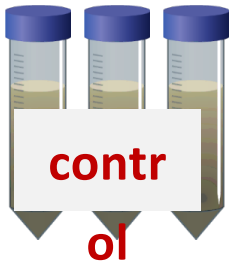
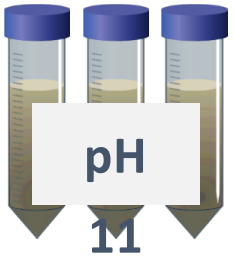

electrochemical cell
urine diversion toilet
fresh urine
faeces
crystallizer
H_2O
$Mg^{2+}\downarrow$
$Ca^{2+}\downarrow$
H_2O
OH^-
H_2
pH↑
X^-
H^+
electrolyte
H_2O
H^+
O_2
P precipitates
stabilized urine [pH>12]
urea ✗ NH_3
acid rinsing solution

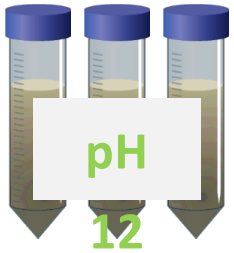




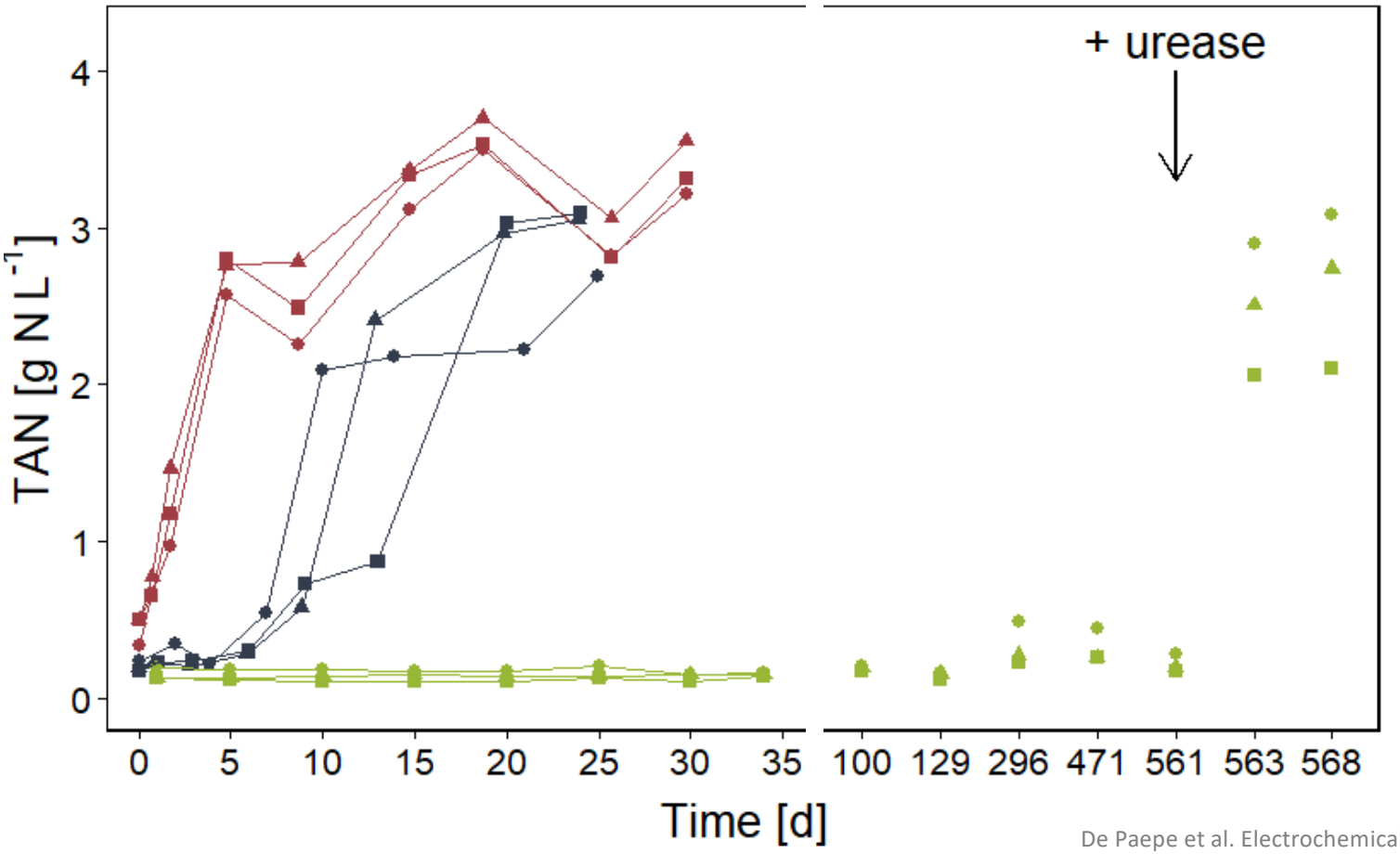
De Paepe et al. Electrochemically induced precipitation enables fresh urine stabilization and facilitates source separation.





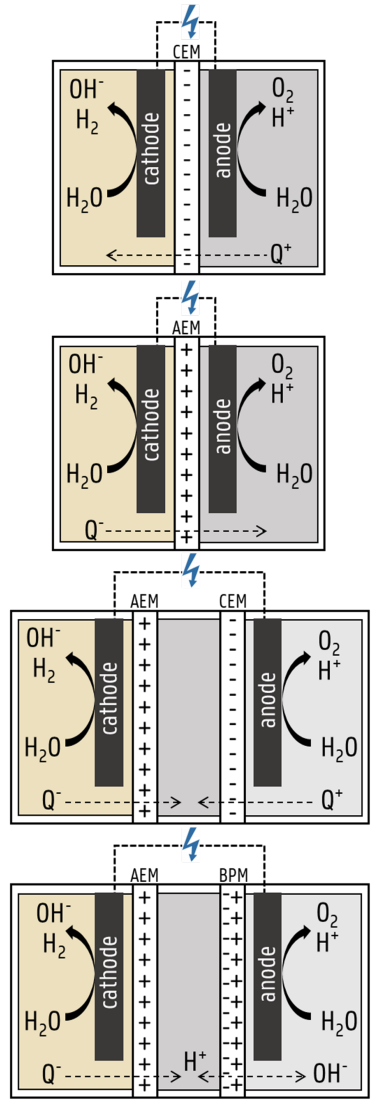


$$CO(NH_2)_2 + 2H_2O \rightarrow \underbrace{NH_3 + NH_4^+}_{=TAN} + HCO_3^-$$



De Paepe et al. Electrochemically induced precipitation enables fresh urine stabilization and facilitates source separation.

- ☑ Short-term stabilisation at pH 11
- ☑ Long-term stabilisation at pH 12
- ☑ No chemical/salt input with three compartment configuration
- ☑ >80% of calcium and magnesium and about 50-80% of phosphate was precipitated
- ☑ Precipitate: P recovery
- ☑ By-product: acid rinsing solution



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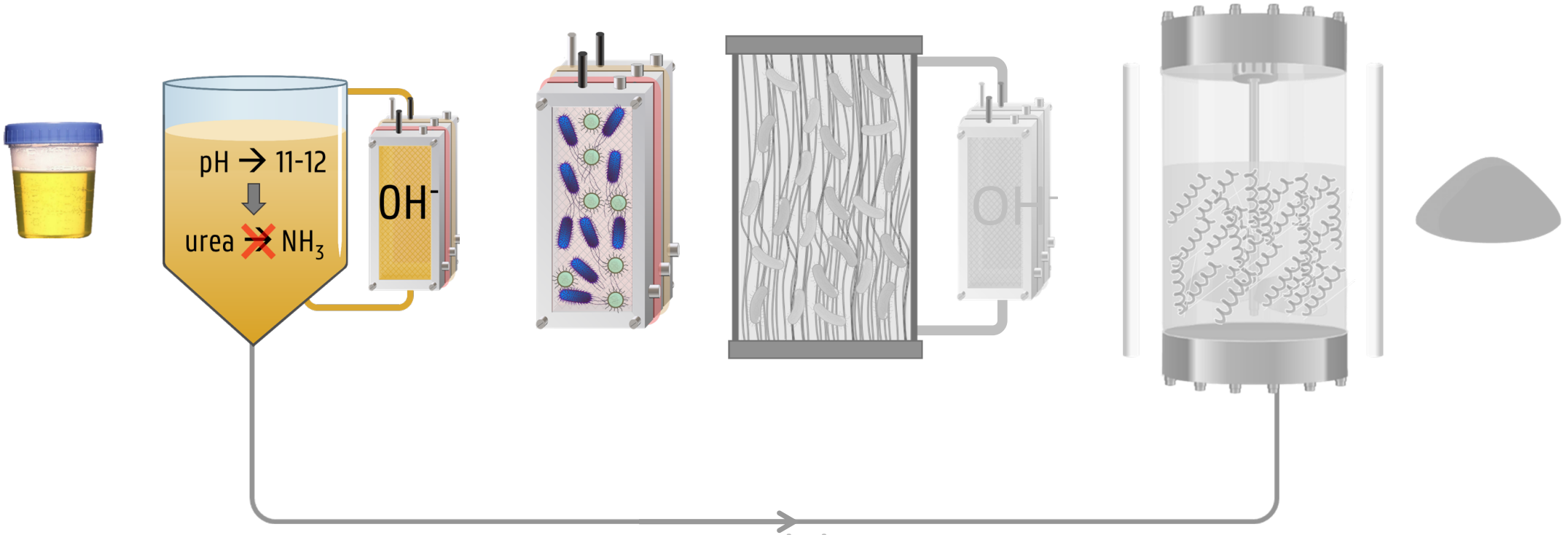
PHOTOBIOREACTOR



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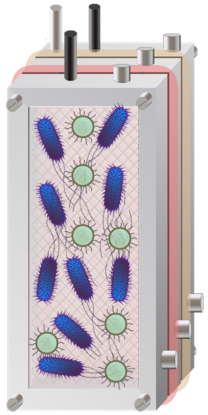
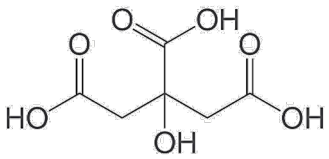
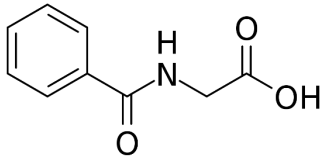
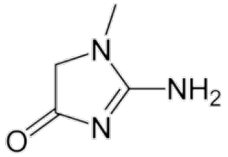




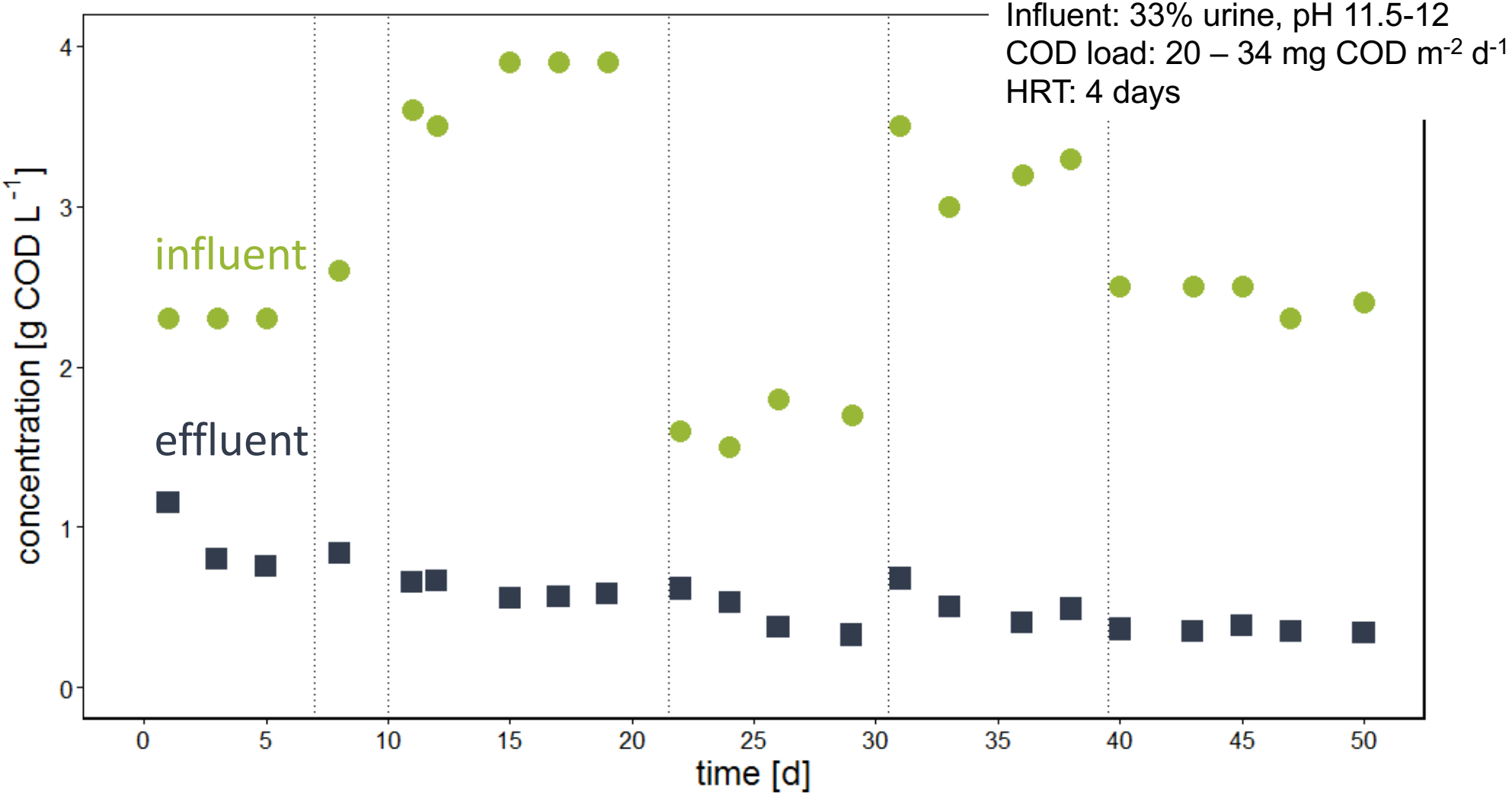




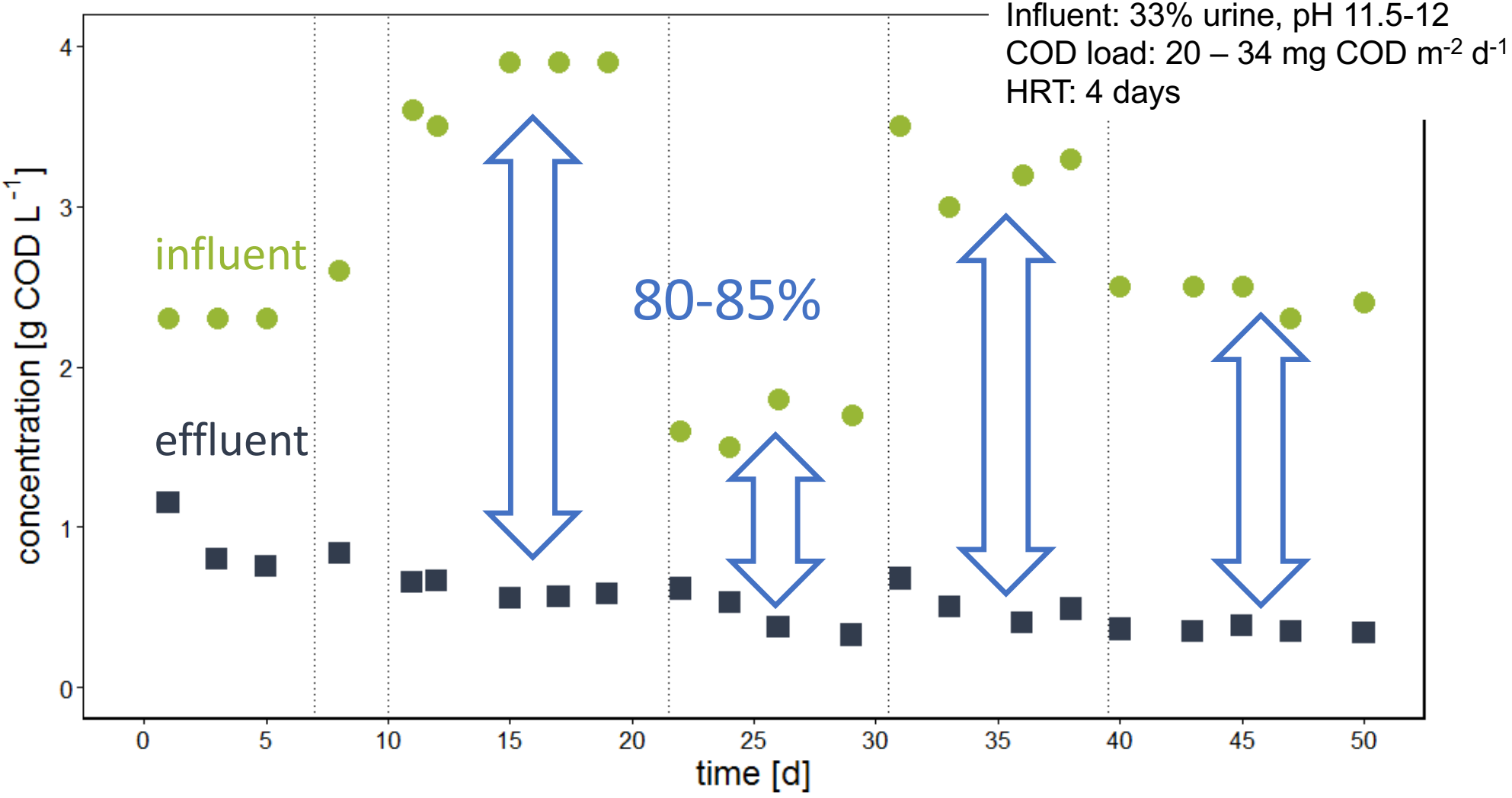
organics
COD

electroactive bacteria

COD → CO_2



De Paepe et al. Bio-electrochemical COD removal for energy efficient, maximum and robust nitrogen recovery from urine through membrane aerated nitrification. Water Research, 185 (2020) 116223



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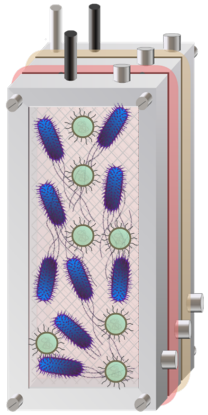
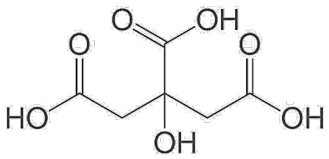
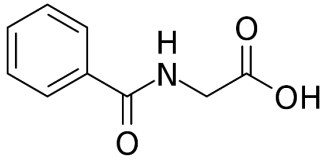
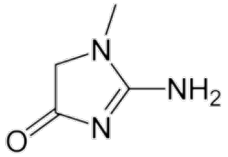






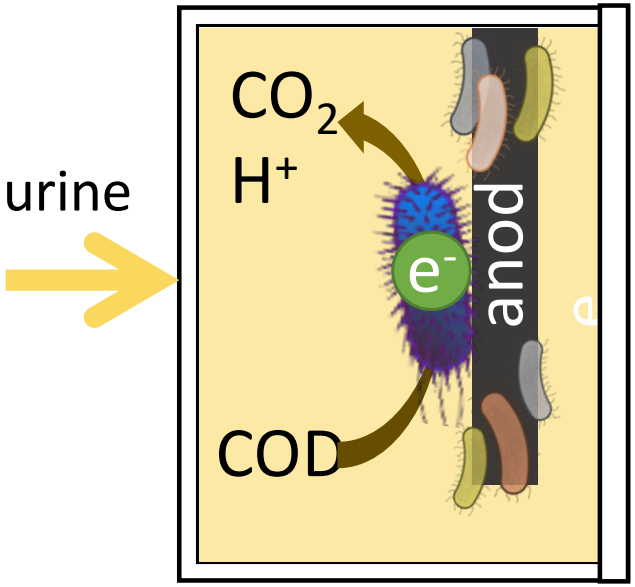


organics
COD

electroactive bacteria

COD

CO_2



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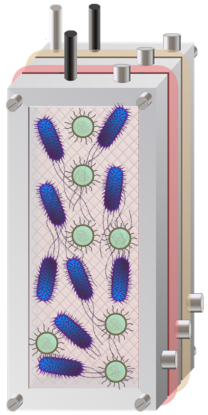

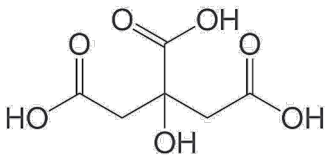

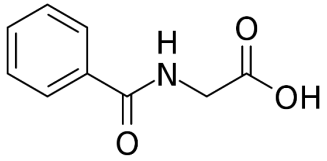

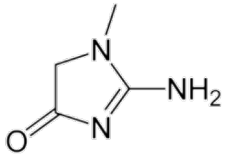

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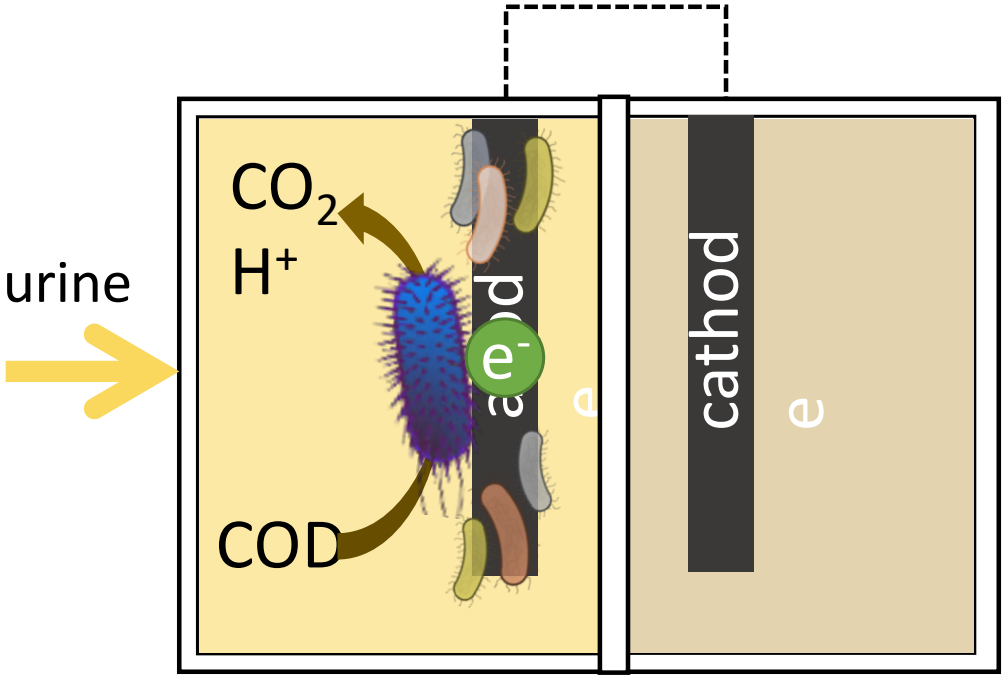
CO_2



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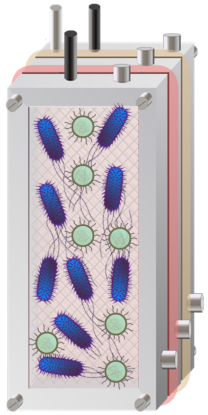

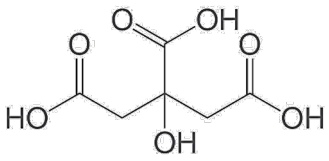

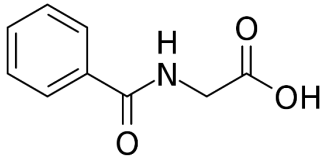

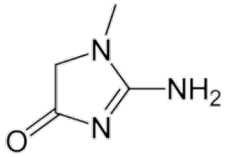

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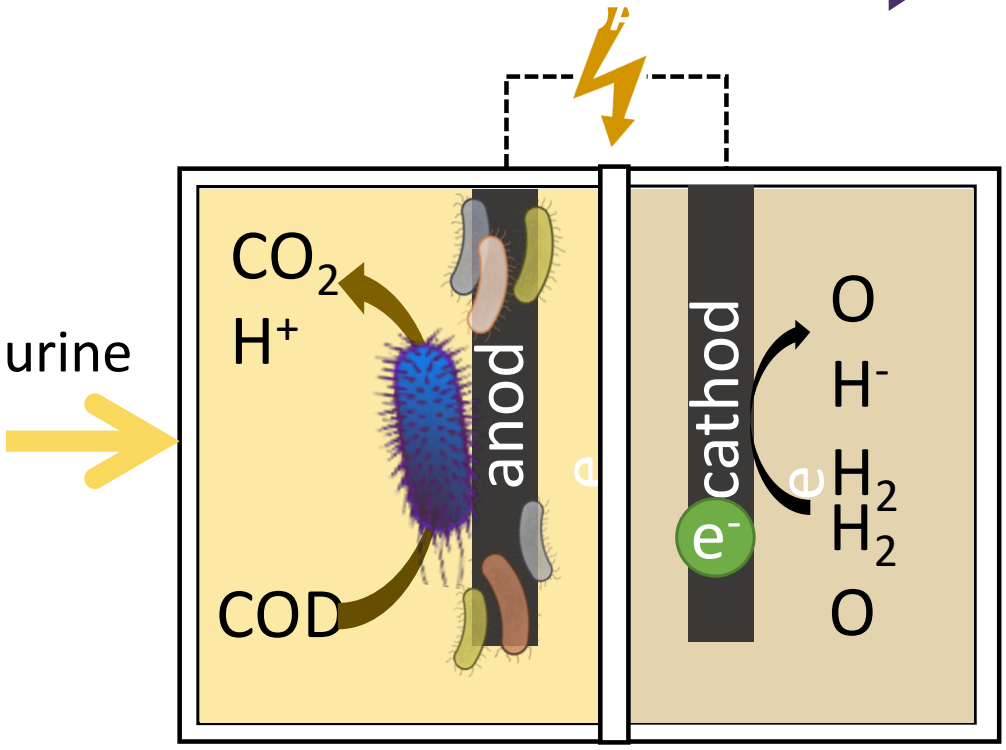

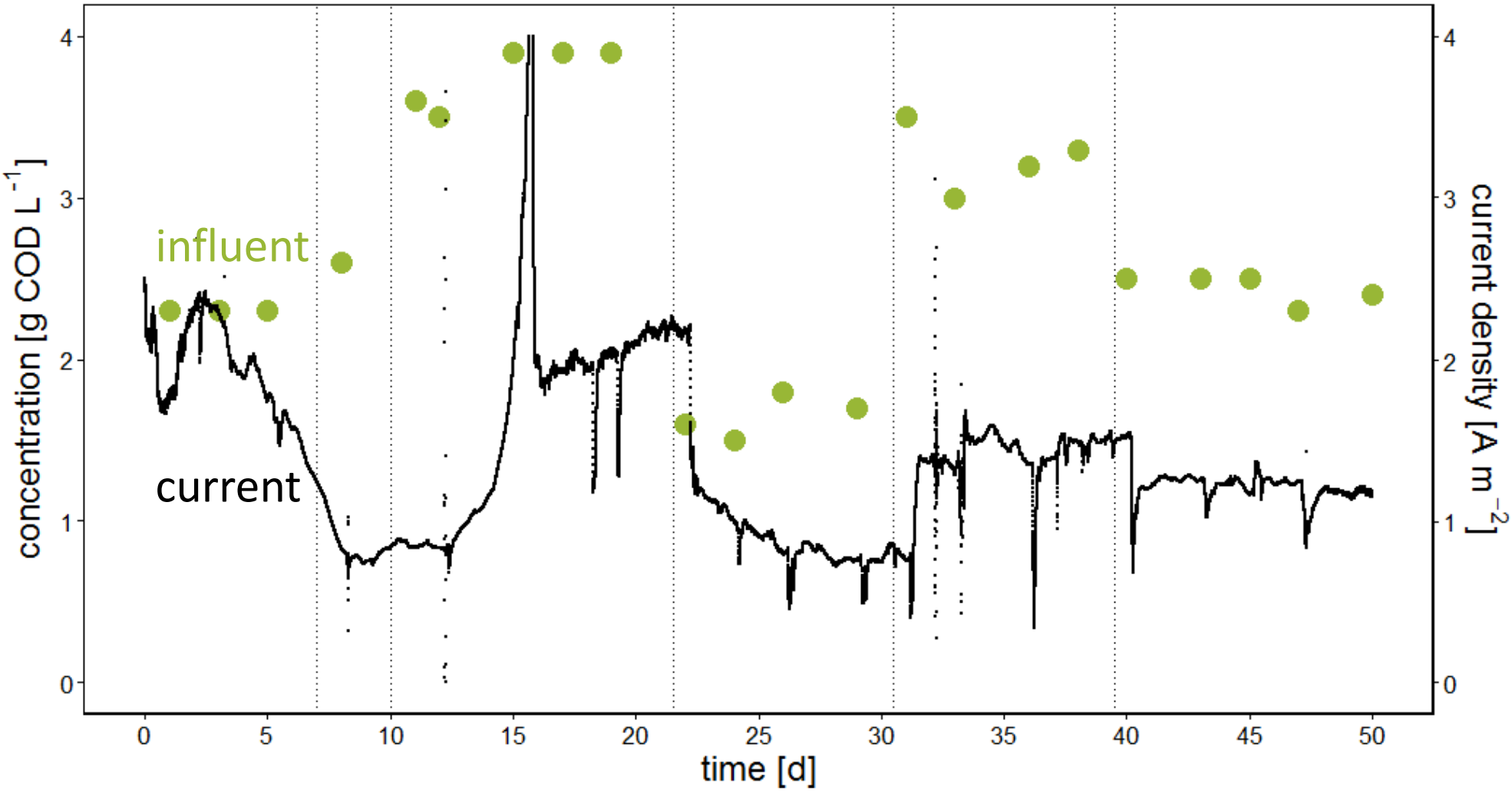

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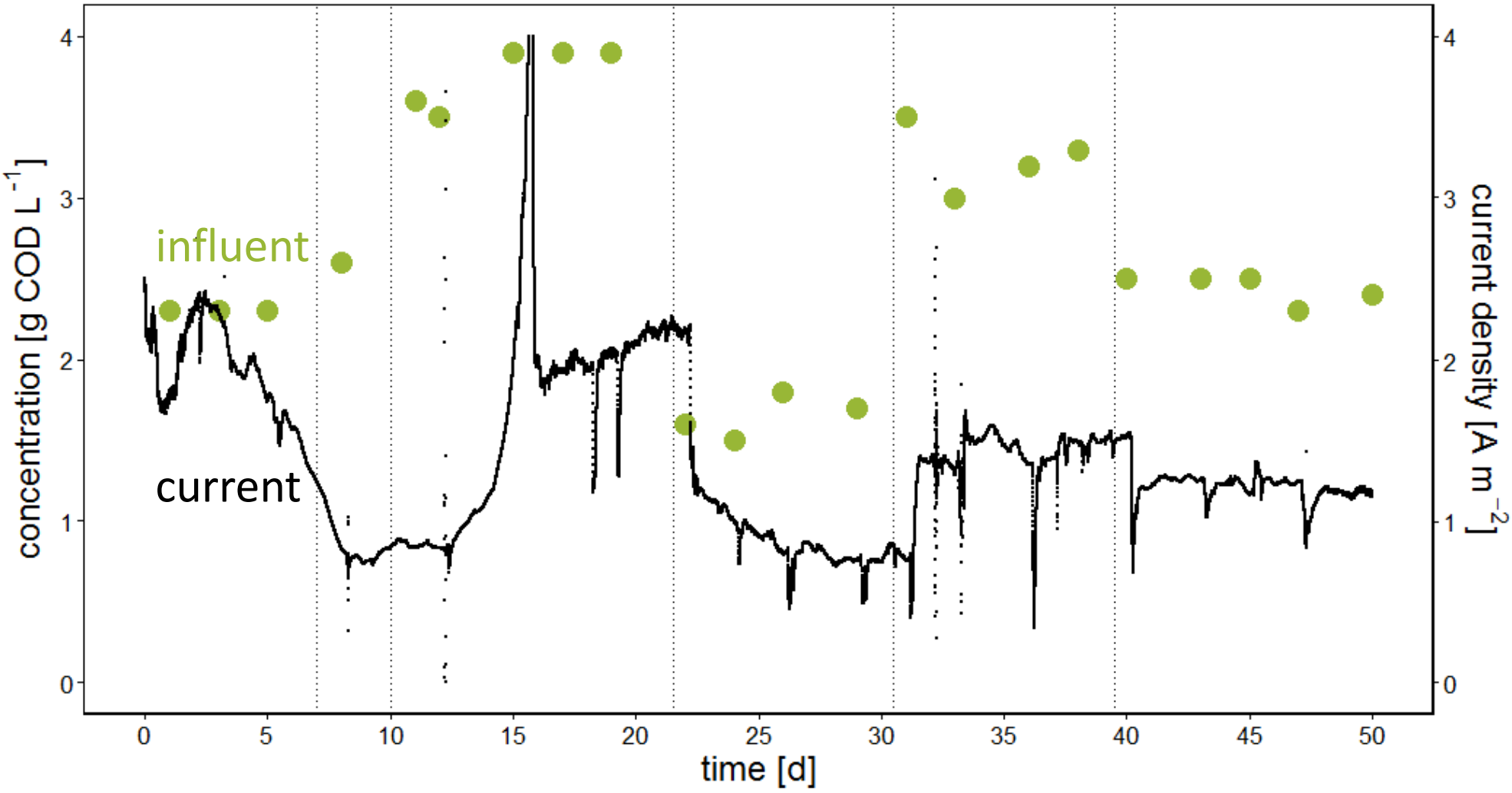

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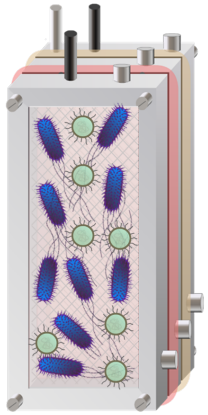
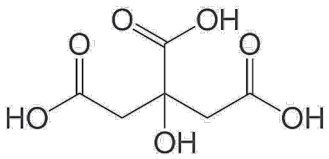
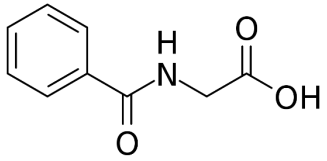
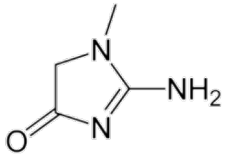
Coulombic efficiency: 27-46% → other electron sinks?

MICROBIAL ELECTROLYSIS CELL









organics
COD

electroactive bacteria

COD

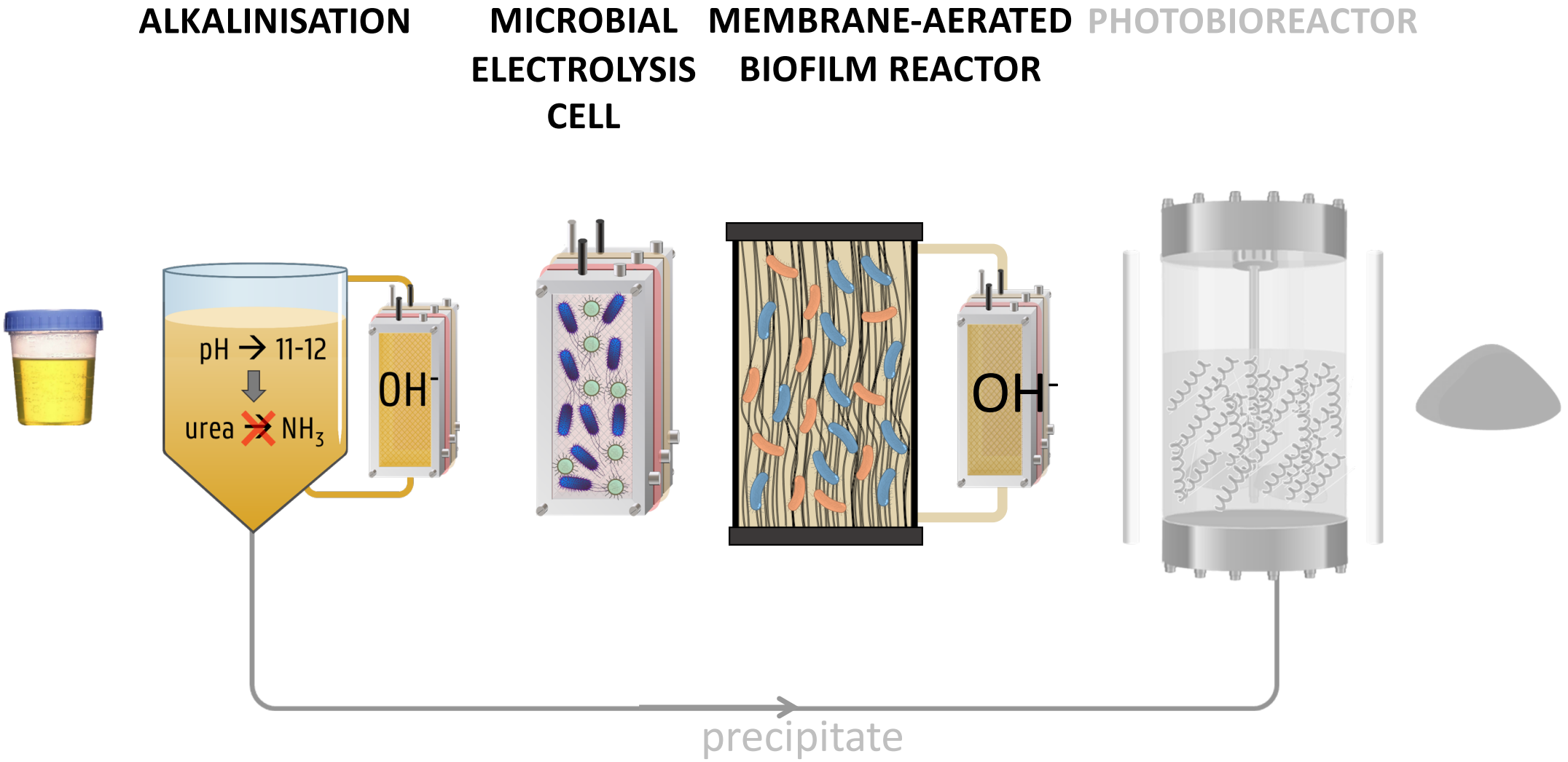
CO_2

ureolytic bacteria

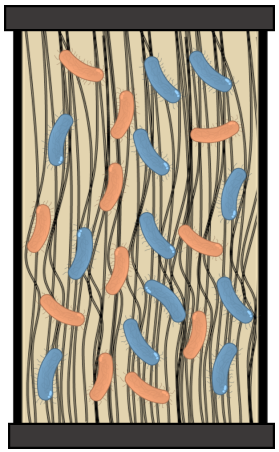
urea
$CO(NH_2)_2$

HYDROLYS

ammonium/
ammonia
NH_4^+/ NH_3


ALKALINISATION
MICROBIAL ELECTROLYSIS CELL
MEMBRANE-AERATED BIOFILM REACTOR
PHOTOBIOREACTOR
pH → 11-12
urea → NH3
OH-
OH-
precipitate

MEMBRANE-AERATED BIOFILM REACTOR



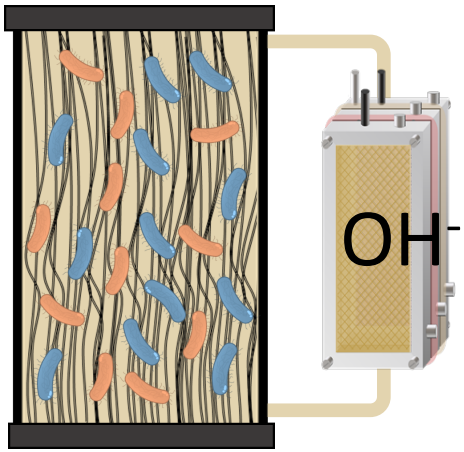
NITRIFICATIO N

AOB

NOB

ammonium NH_4^+ → **NITRITATION** → nitrite NO_2^- → **NITRATATION** → nitrate NO_3^-

MEMBRANE-AERATED BIOFILM REACTOR



NITRIFICATION

AOB

NOB

STABLE

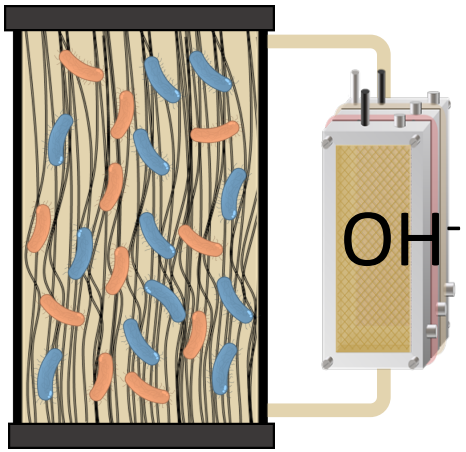
ammonium NH_4^+ → **NITRITATION** → nitrite NO_2^- → **NITRATATION** → nitrate NO_3^-

H^+

☑ Full nitrification without base addition

☑ No increase in salinity

MEMBRANE-AERATED BIOFILM REACTOR



NITRIFICATIO N

AOB

NOB

STABLE

ammonium NH_4^+ **NITRITATION** nitrite NO_2^- **NITRATATION** nitrate NO_3^-

O_2

MEMBRANE-AERATED BIOFILM REACTOR

NITRIFICATION

AOB

NOB

STABLE

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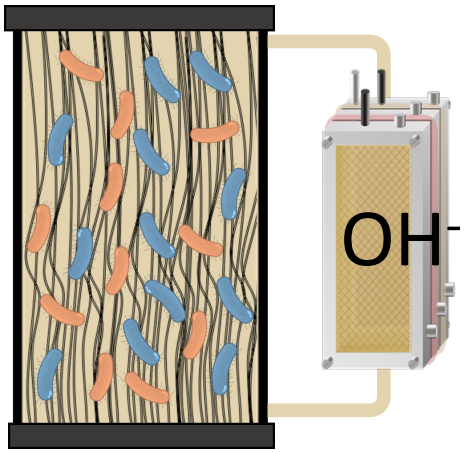
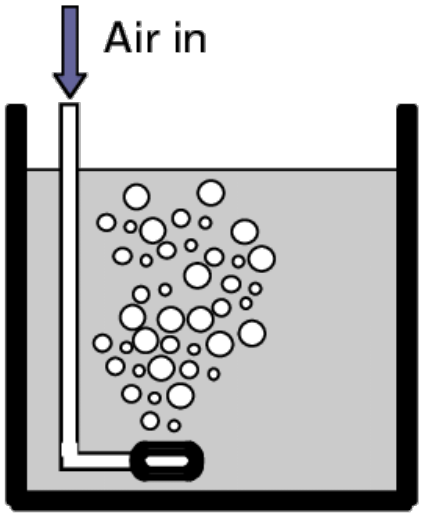
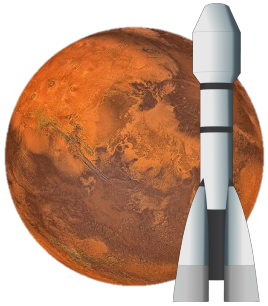
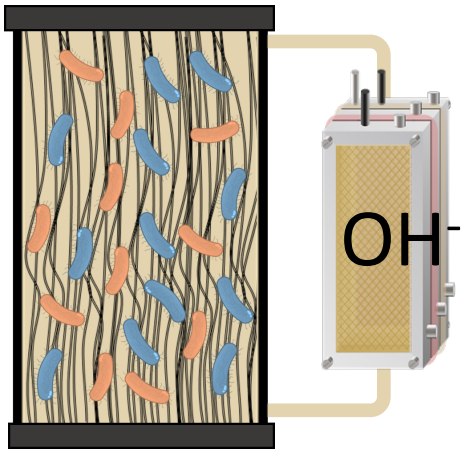




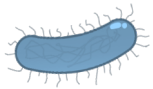


MEMBRANE-AERATED BIOFILM REACTOR

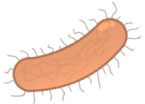


NITRIFICATIO N

AOB

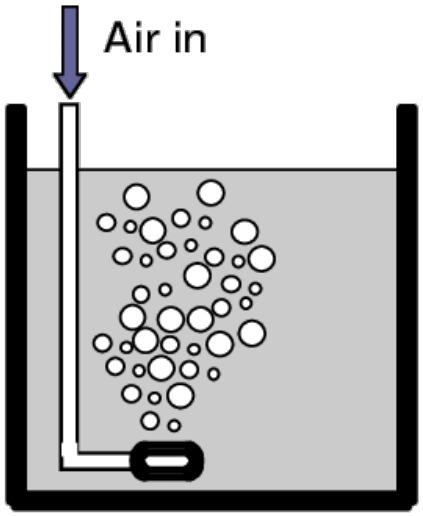


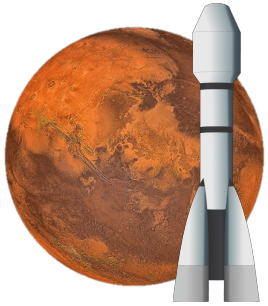
NOB

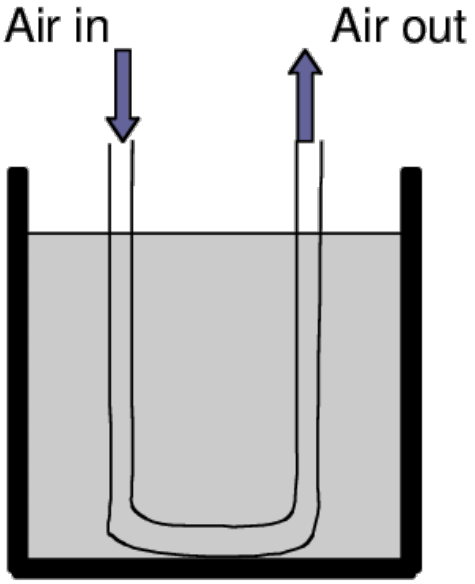


STABLE

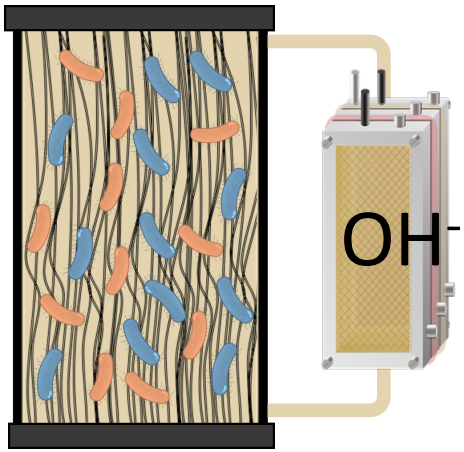
ammonium NH_4^+ **NITRITATION** nitrite NO_2^- **NITRATATION** nitrate NO_3^-







MEMBRANE-AERATED BIOFILM REACTOR



NITRIFICATION

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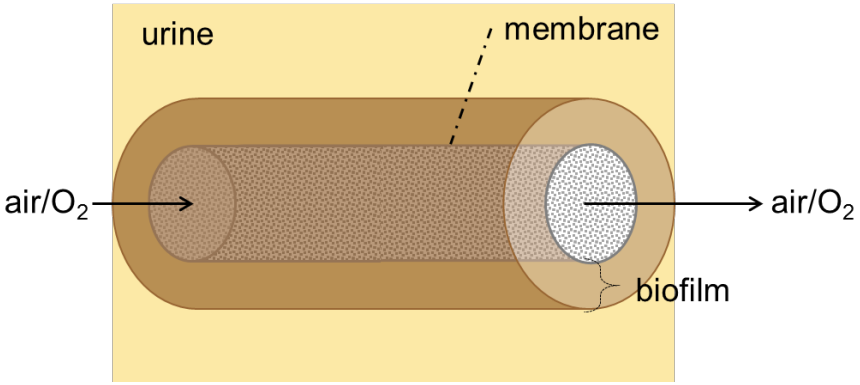
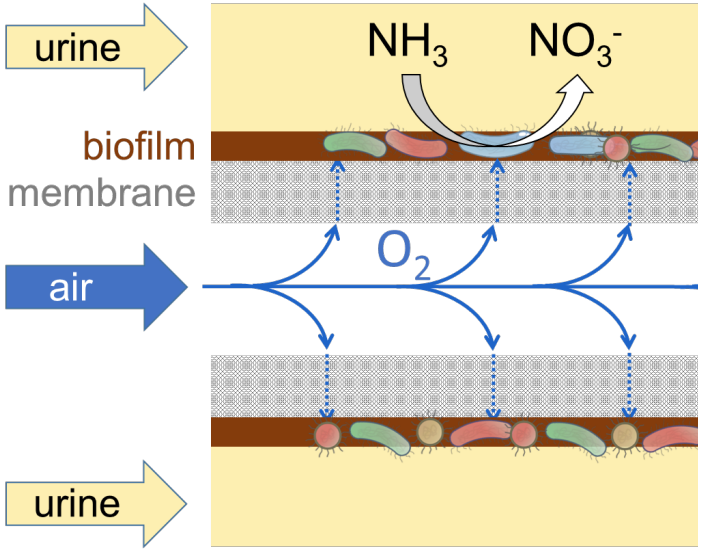
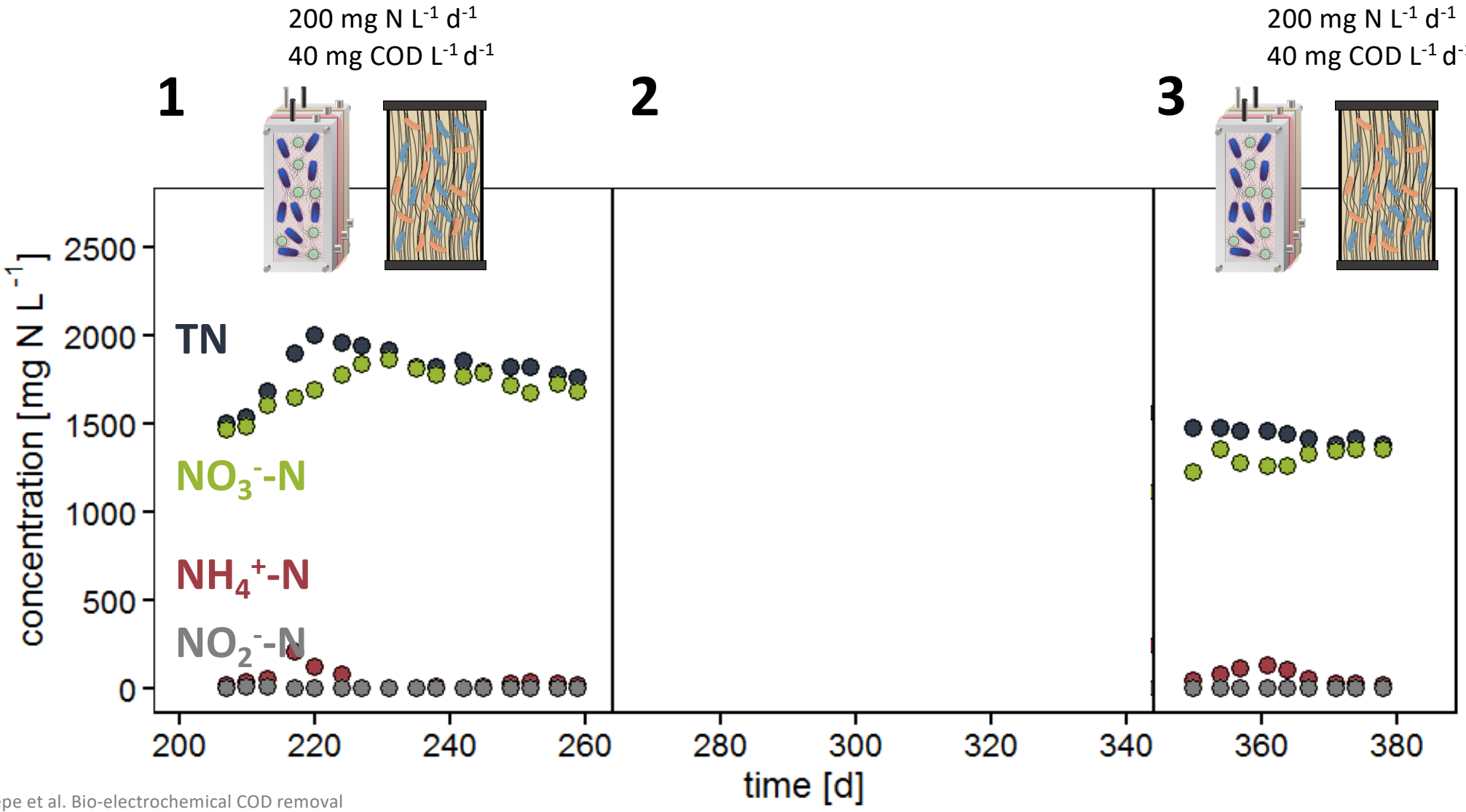
NOB

nitrite NO_2^- → **NITRATATION** → nitrate NO_3^-

STABLE

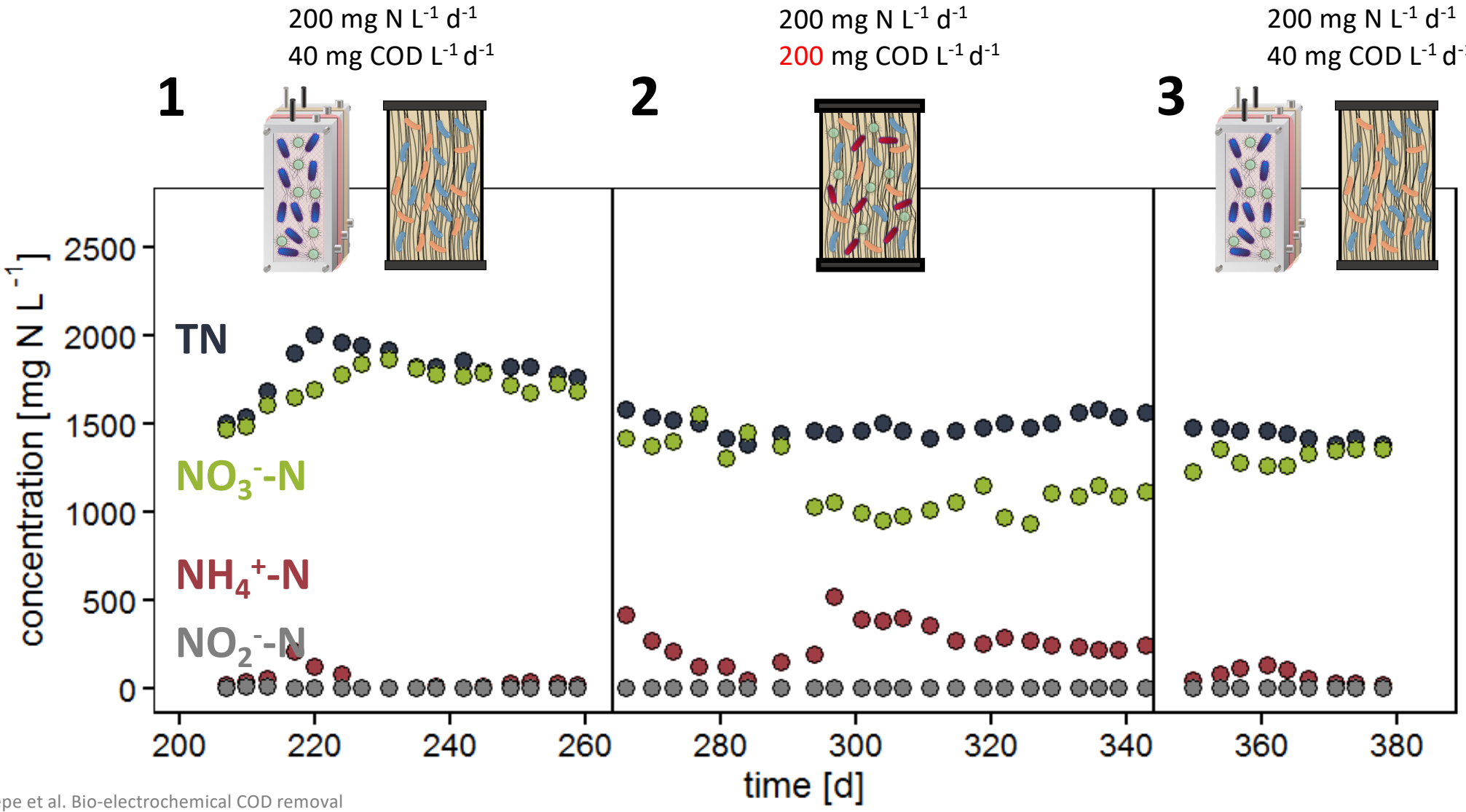






De Paepe et al. Bio-electrochemical COD removal for energy efficient, maximum and robust nitrogen recovery from urine through membrane aerated nitrification. Water Research, 185 (2020) 116223

TN = NH_4^+-N + NO_2^--N + NO_3^--N + org



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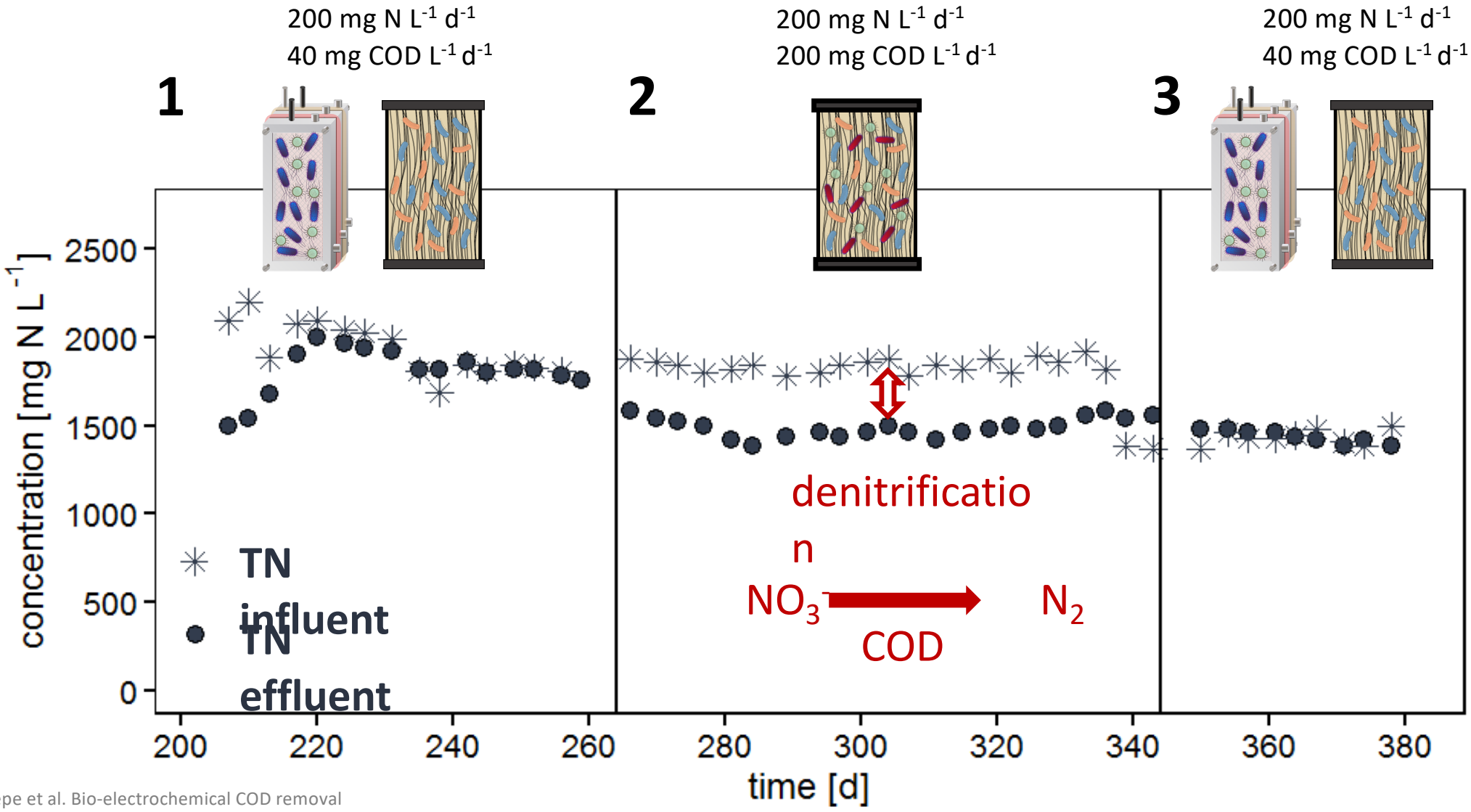

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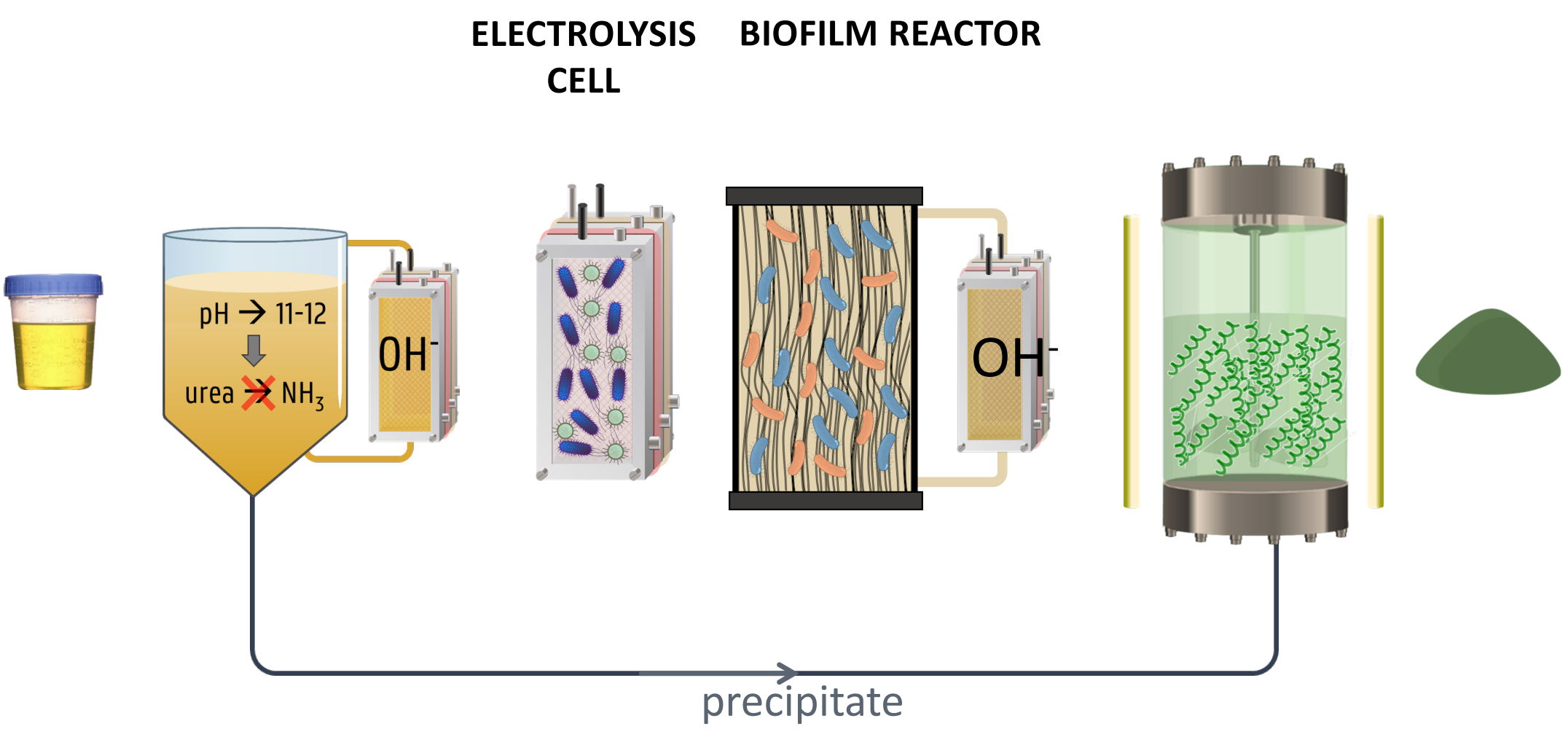
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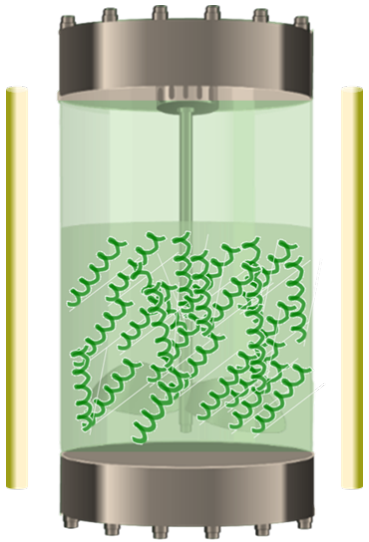
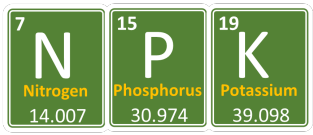
MICROBIAL ELECTROLYSIS CELL
MEMBRANE-AERATED BIOFILM REACTOR
PHOTOBIOREACTOR
pH → 11-12
urea → NH3
OH-
OH-
precipitate

PHOTOBIOREACTOR

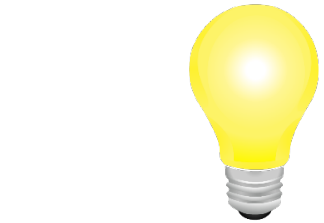




nitrified urine

CO_2

Limnospira

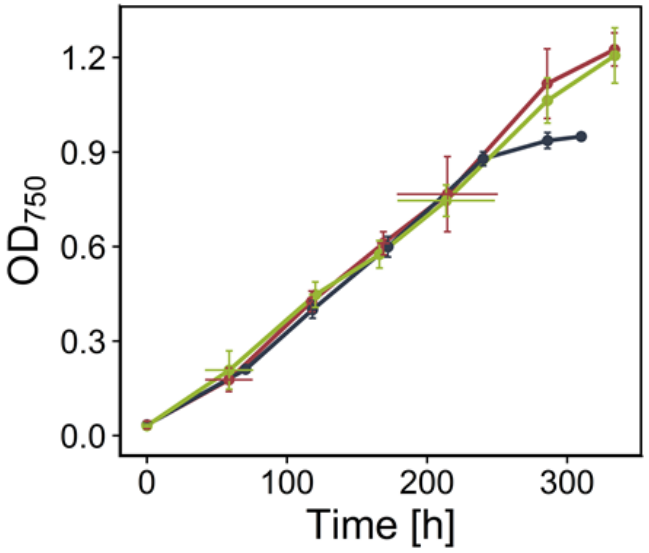


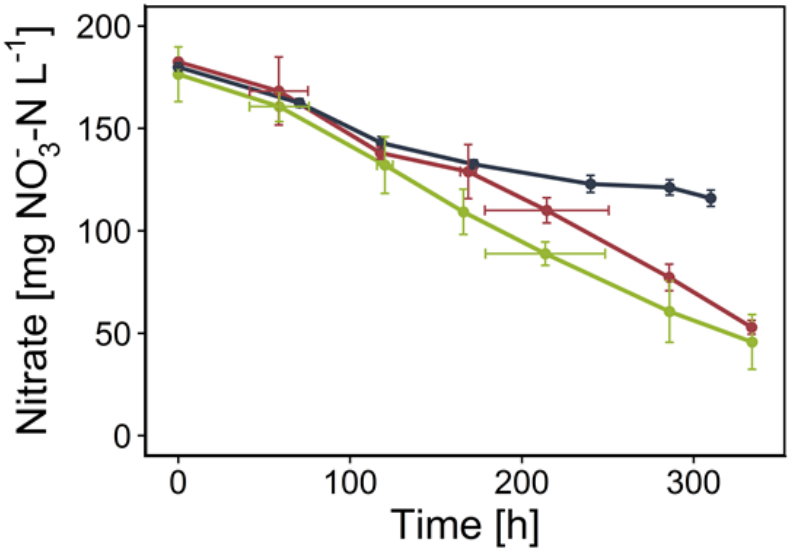
O_2

☑ Nitrified urine can be used as culture medium for *Limnospira*

☑ Dilution is essential to maximize the N uptake

☑ Supplementation with P, Ca, Mg, Fe and EDTA yielded same biomass production, protein content and nutrient uptake as synthetic medium



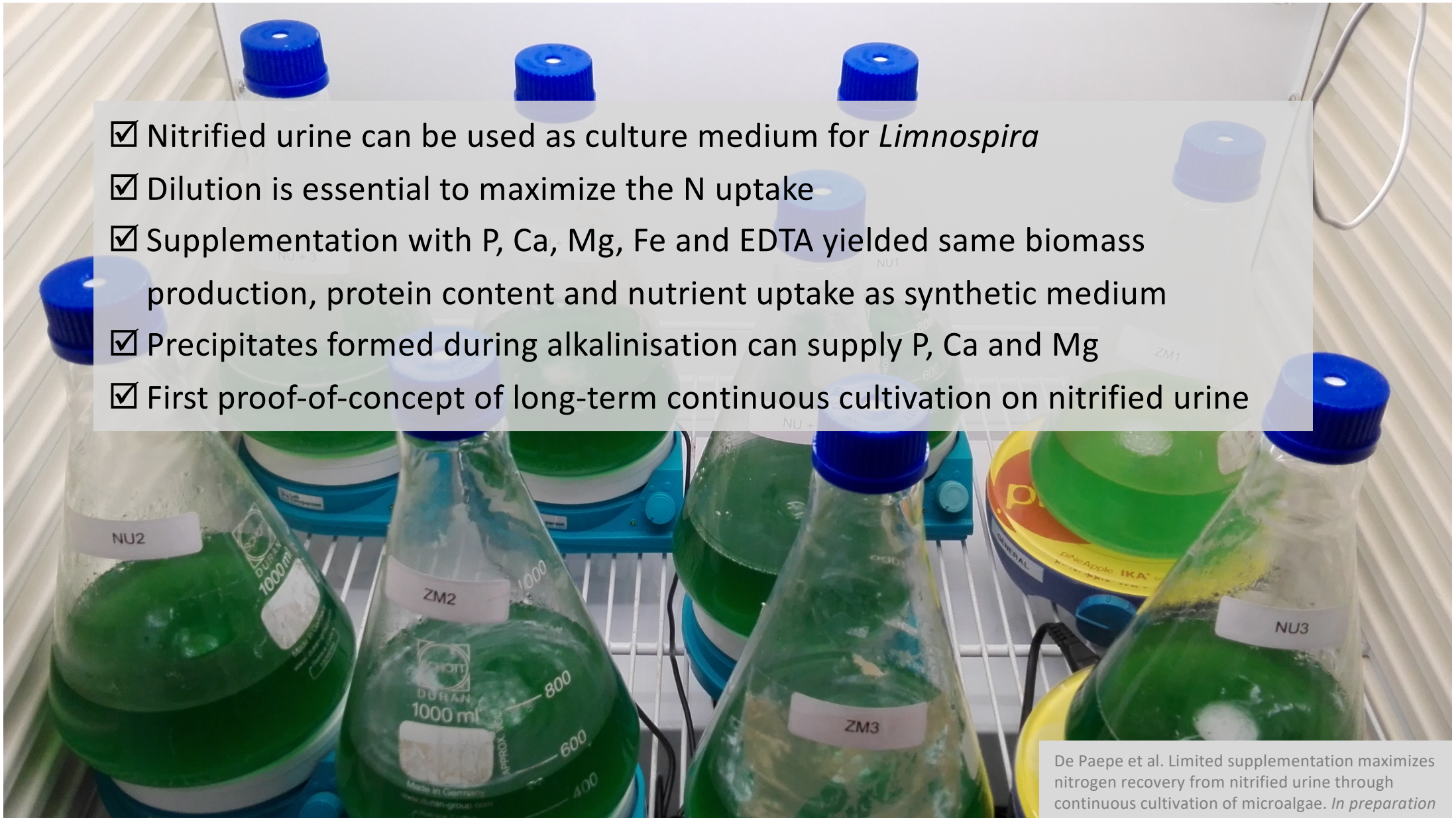


Zarrouk medium

Diluted nitrified urine

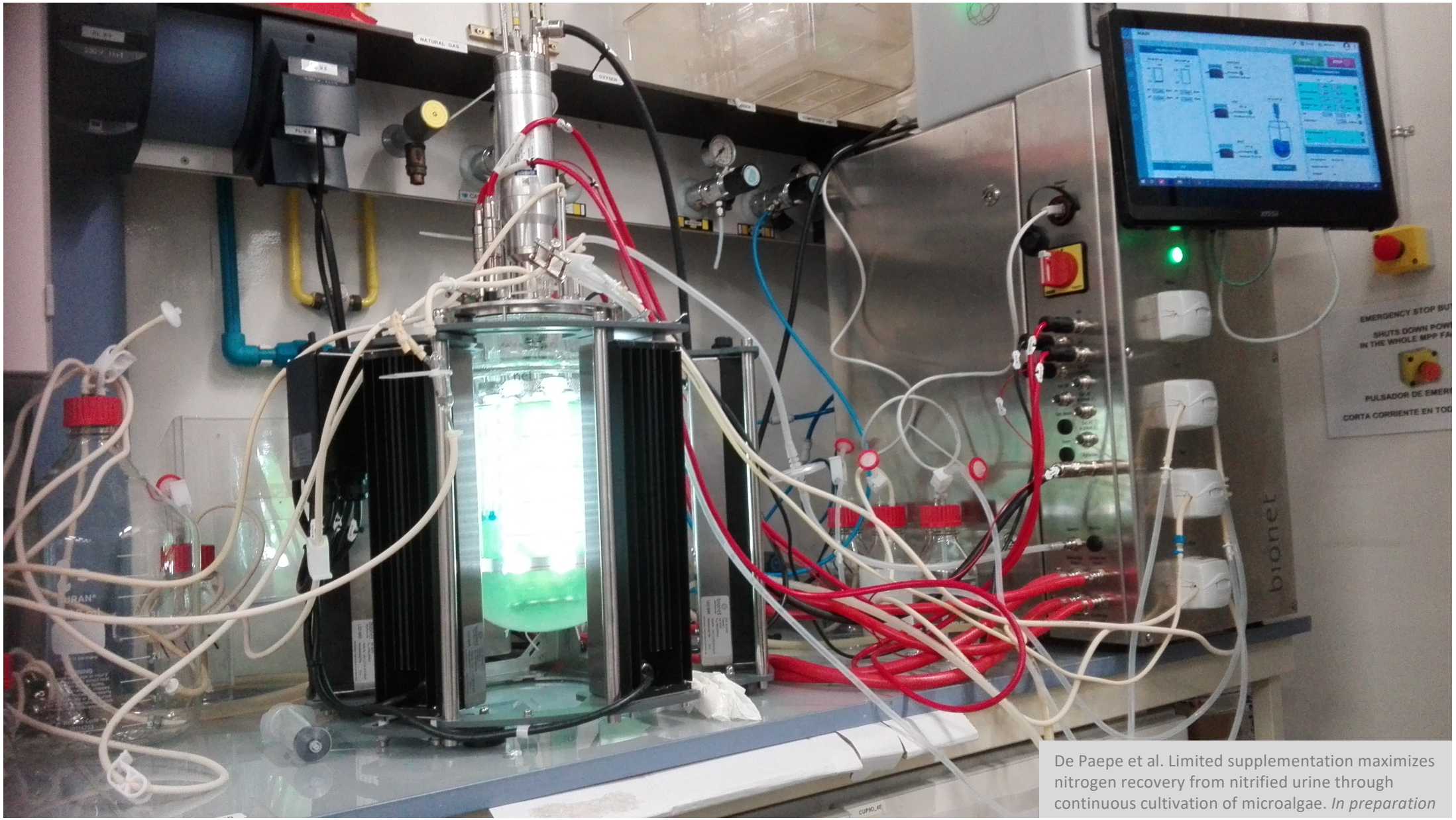
Diluted supplemented nitrified urine

De Paepe et al. Limited supplementation maximizes nitrogen recovery from nitrified urine through continuous cultivation of microalgae. *In preparation*



- ☑ Nitrified urine can be used as culture medium for *Limnospira*
- ☑ Dilution is essential to maximize the N uptake
- ☑ Supplementation with P, Ca, Mg, Fe and EDTA yielded same biomass production, protein content and nutrient uptake as synthetic medium
- ☑ Precipitates formed during alkalinisation can supply P, Ca and Mg
- ☑ First proof-of-concept of long-term continuous cultivation on nitrified urine

De Paepe et al. Limited supplementation maximizes nitrogen recovery from nitrified urine through continuous cultivation of microalgae. *In preparation*



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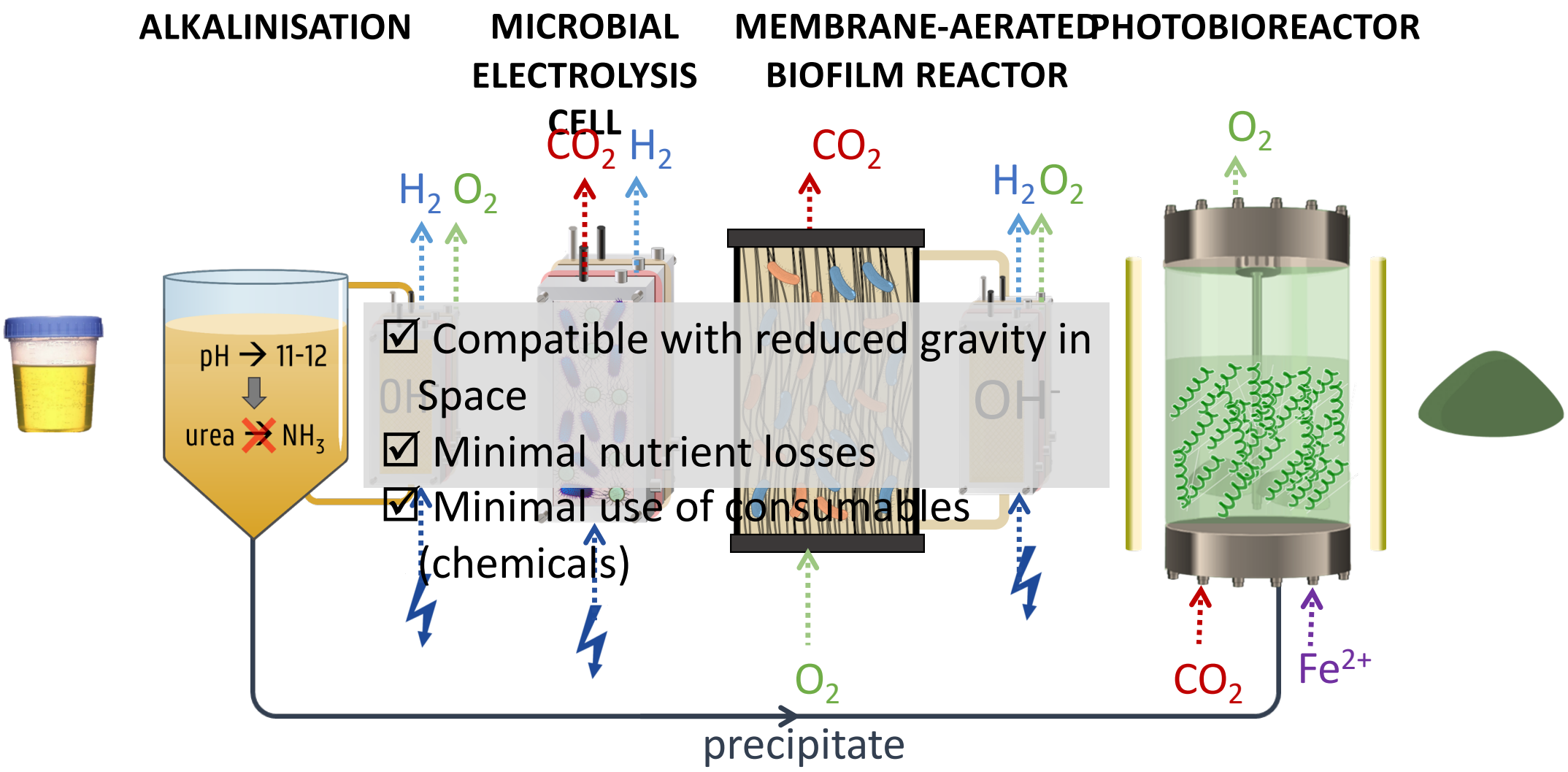
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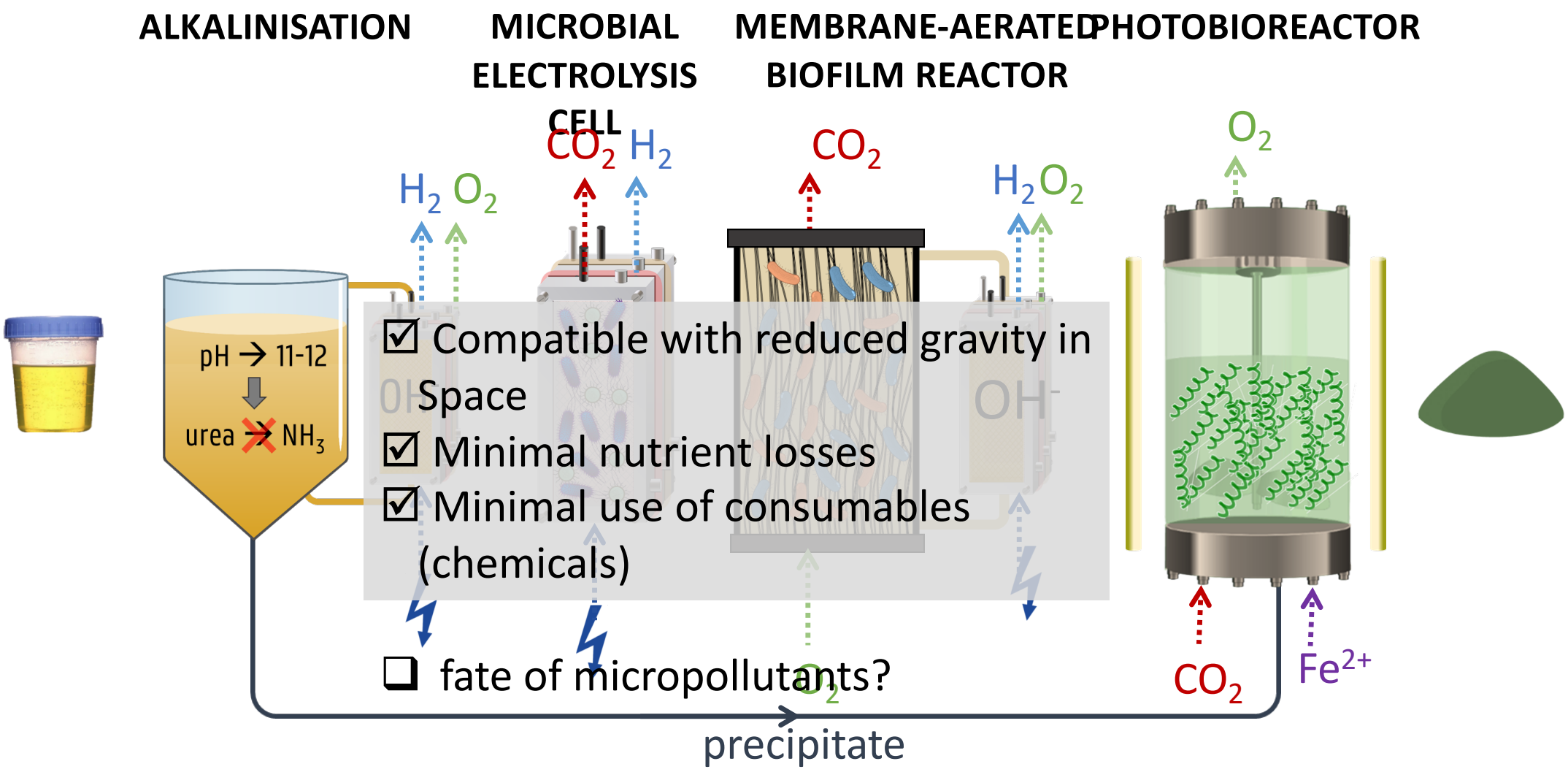
MEMBRANE-AERATED BIOFILM REACTOR
PHOTOBIOREACTOR
pH → 11-12
urea ⇏ NH3
H2 O2
CO2 H2
CO2
H2O2
O2
OH-
OH-
CO2
Fe2+
O2
precipitate
☑ Compatible with reduced gravity in Space
☑ Minimal nutrient losses
☑ Minimal use of consumables (chemicals)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precipitate
☑ Compatible with reduced gravity in Space
☑ Minimal nutrient losses
☑ Minimal use of consumables (chemicals)
❑ fate of micropollutants?

Jolien De Paepe, Ralph E.F. Lindeboom, Marjolein Vanoppen, Kim De Paepe, Dries Demey, Wout Coessens, Brigitte Lamaze, Arne Verliefde, Peter Clauwaert and Siegfried E. Vlaeminck.
Refinery and concentration of nutrients from urine with electrodialysis enabled by upstream precipitation and nitrification.
Water Research, 144 (2018), 76-86.
https://www.sciencedirect.com/science/article/abs/pii/S0043135418305554

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Jolien De Paepe, Laurens De Pryck, Arne R.D. Verliefde, Korneel Rabaey, and Peter Clauwaert.
Electrochemically induced precipitation enables fresh urine stabilization and facilitates source separation.
Environmental Science & Technology, 54 (2020), 3618-3627
https://pubs.acs.org/doi/abs/10.1021/acs.est.9b06804

Jolien De Paepe, Peter Clauwaert, Maria Celeste Gritti, Ramon Ganigué, Benedikt Sas, Siegfried E. Vlaeminck, and Korneel Rabaey. Electrochemical in-situ pH control enables chemical-free full urine nitrification with concomitant nitrate extraction.

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THANK YOU.

Jolien De Paepe
Center for Microbial Ecology and Technology, Ghent University
Jolien.DePaepe@UGent.be

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