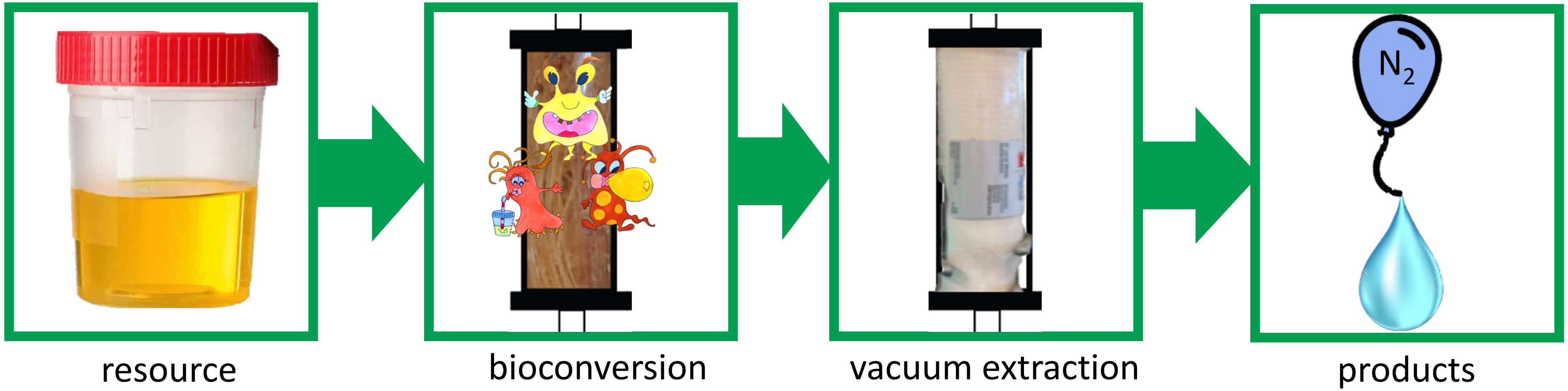
Nitrogen gas production and extraction from urine to compensate for gas losses in Space



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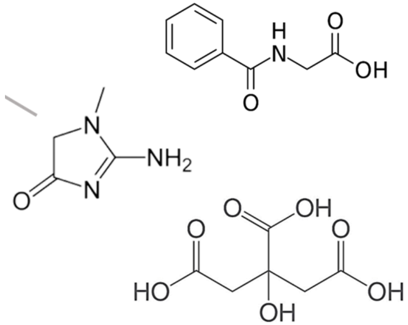
Urine: valuable resource in space

1.4 L astronaut^{-1} day^{-1}

water



organics

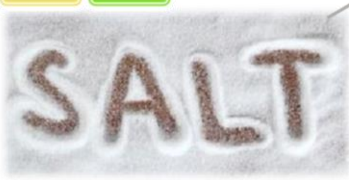
7 N Nitrogen 14.007

15 P Phosphorus 30.974

19 K Potassium 39.098

nutrients

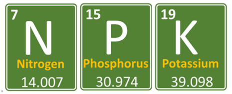
Na Cl



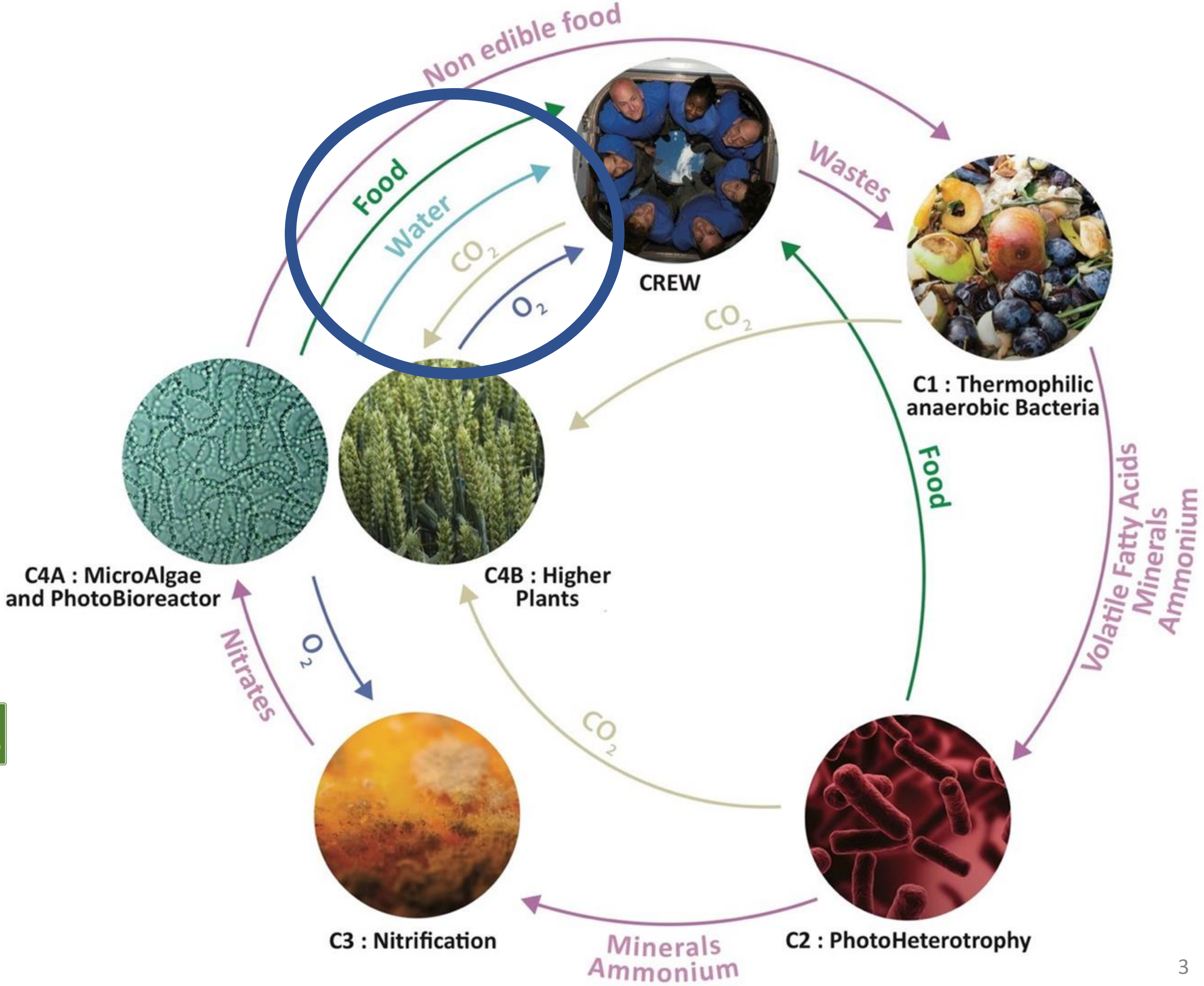
salts

Urine: key for regeneration

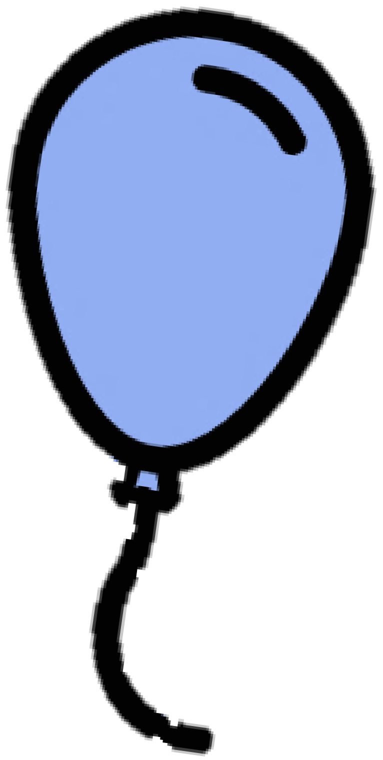
-clean water 

-food 

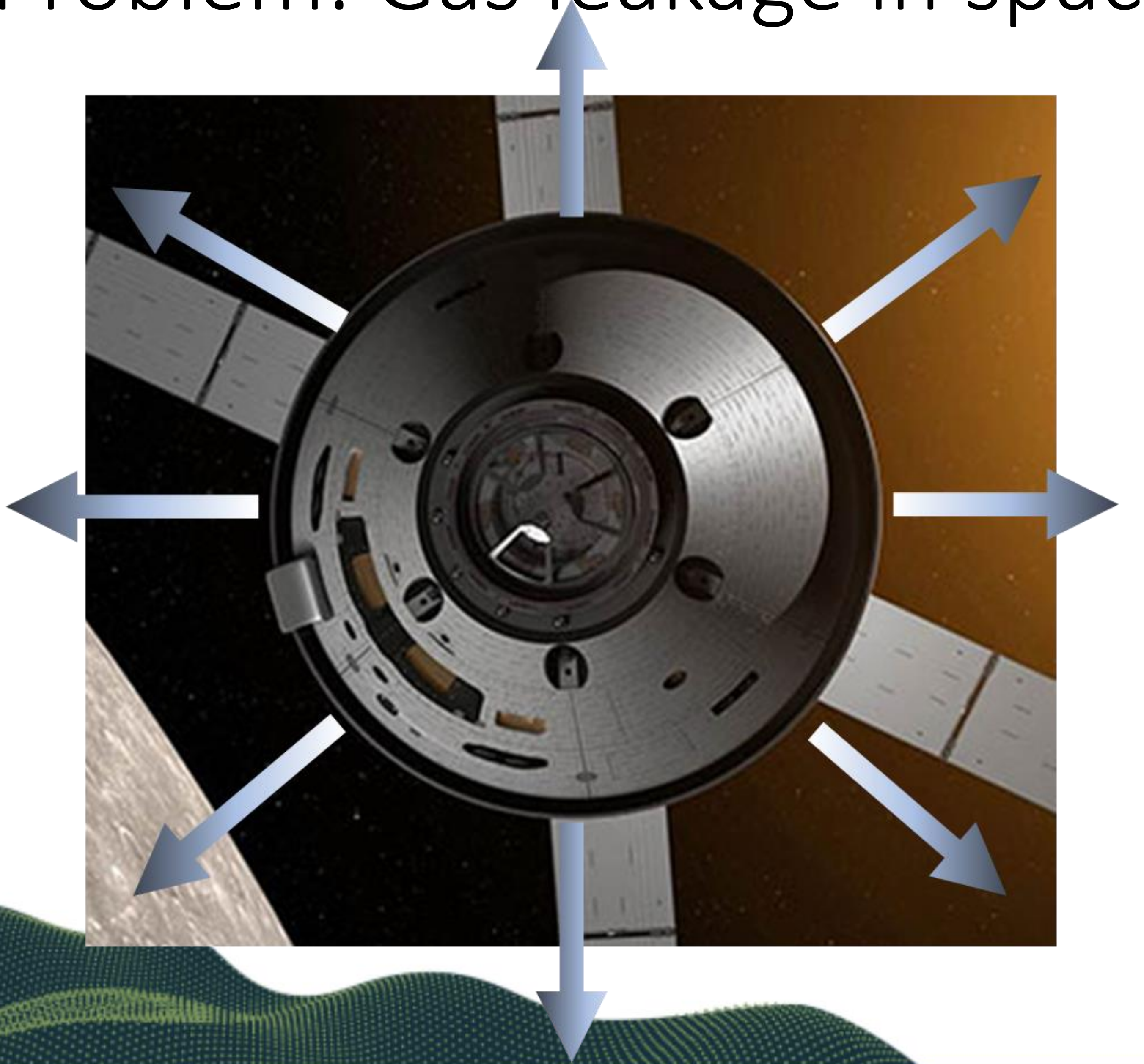
- air! 



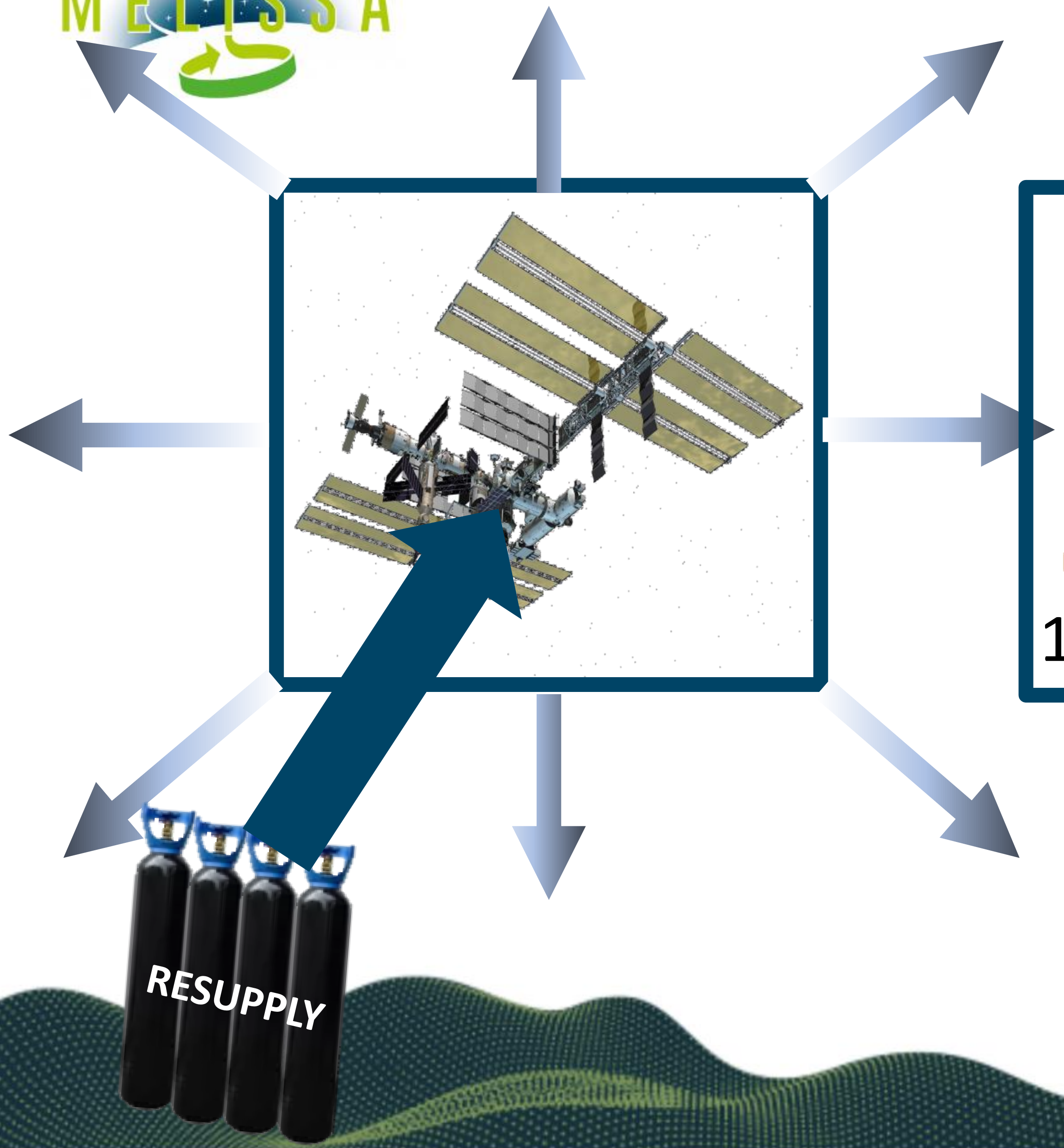
Air from urine?



Problem: Gas leakage in space



Leakage rates and mitigation strategy: ISS

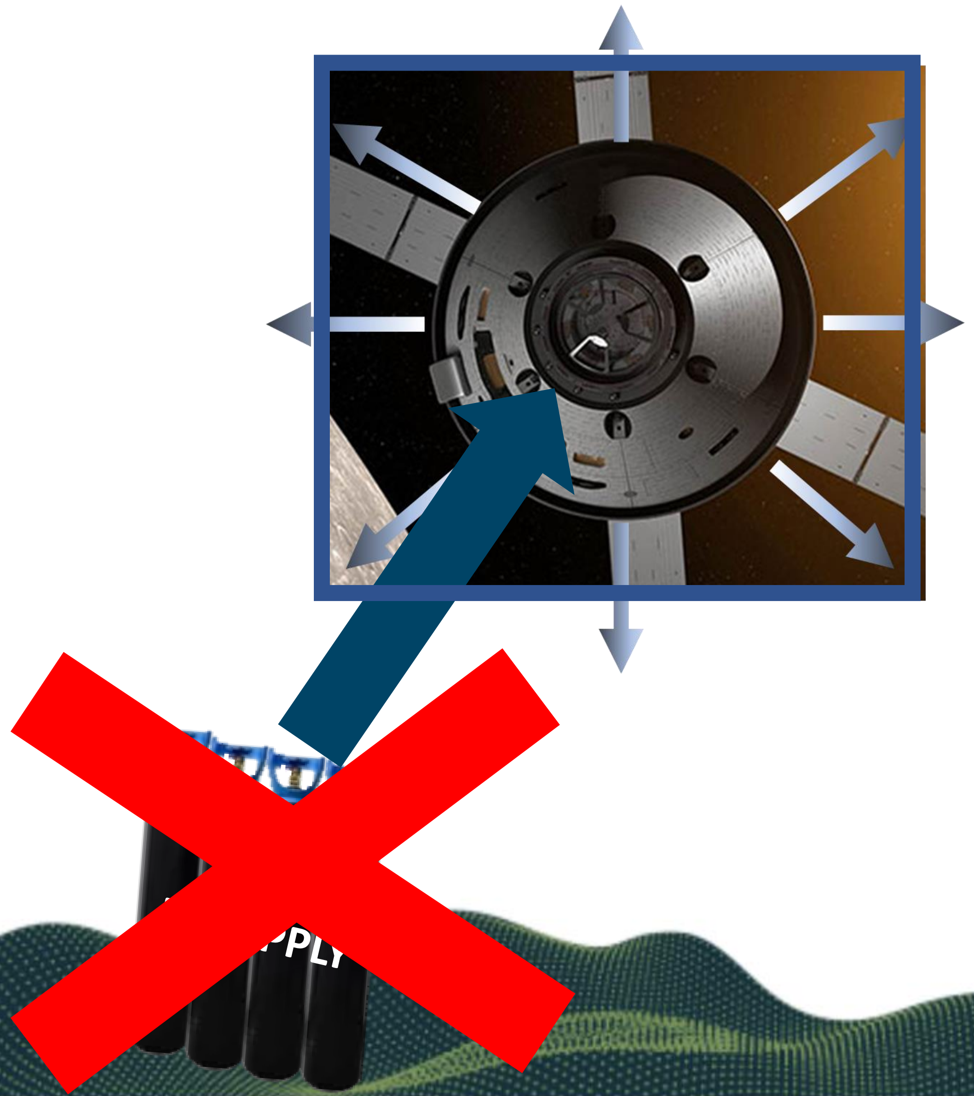


133 kg $year^{-1}$![1]

Resupply mission: Each 3 months[2]

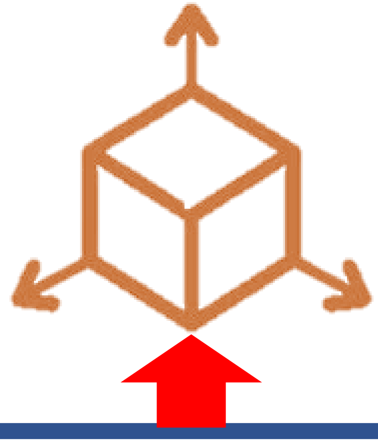
1(Schaezler & Cook 2015)
2(CNES 2013)

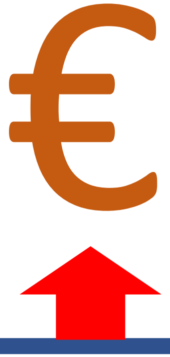
Leakage rates and mitigation strategy: Deep space mission



No resupply,
Mars: 650+ days

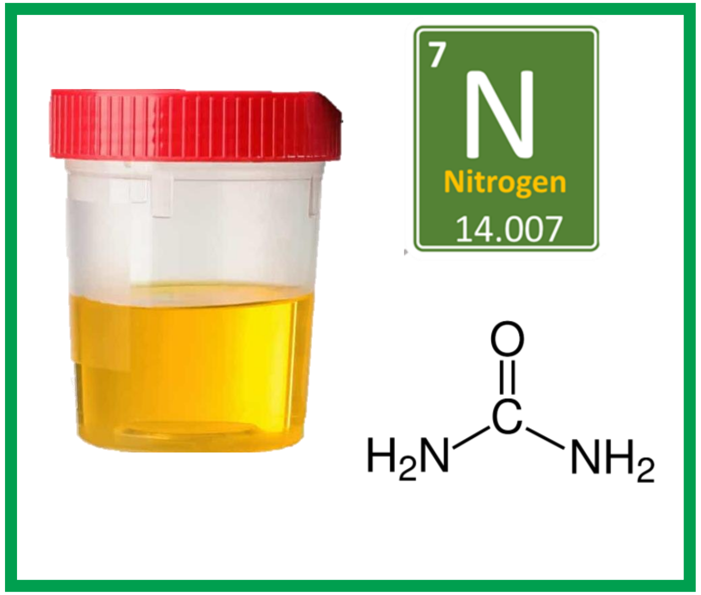
13 g N_2 per day in Orion DST





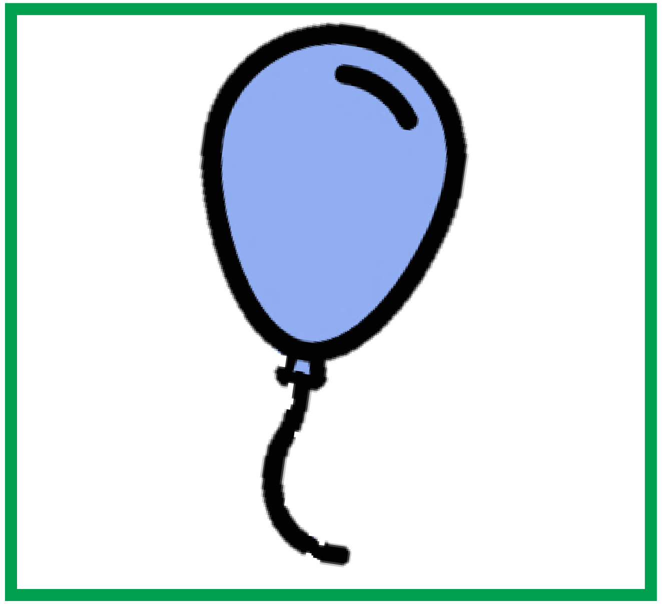
(Goodliff 2017)

Urine: source of air?



Urine:
4-9 g N L^{-1}
70% human waste-N

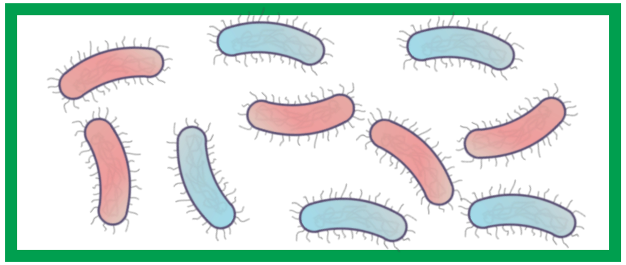
Need:
Resource-efficient conversion



21% O_2+ 79% N_2

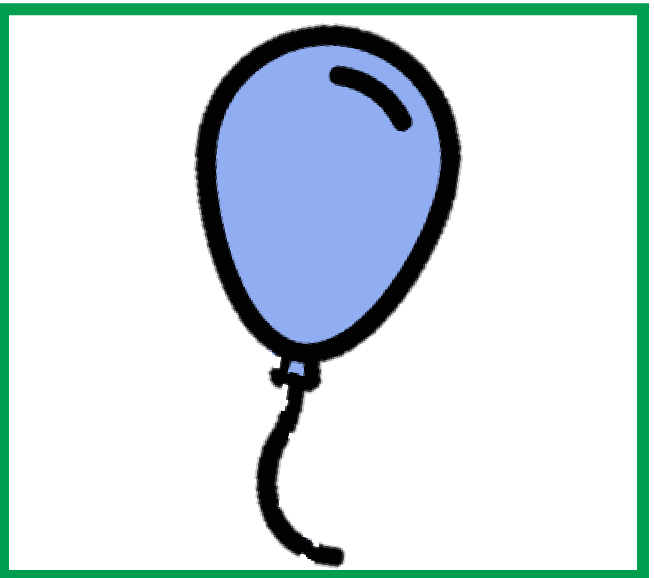
(Clauwaert et al. 2017)

Bioconversion



Resource-efficient conversion

Partial Nitritation/
Anammox



N-urea → NH_4^+ → N_2 +

NH_4^+ → NO_2^- (+O_2; *Aerobic Ammonia oxidizing bacteria (AerAOB)*)

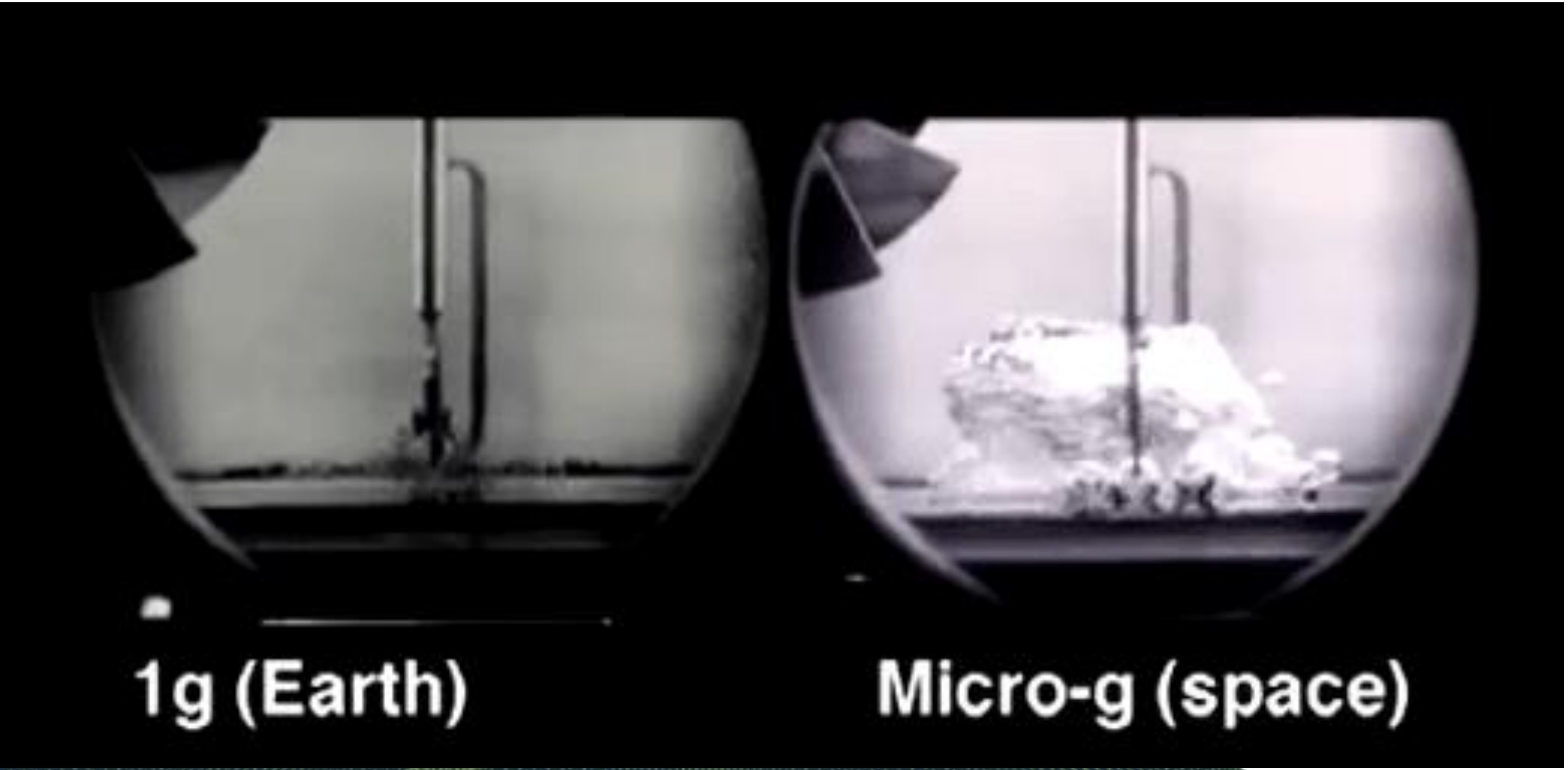
NO_2^- → N_2 (*Anoxic Ammonia oxidizing bacteria (AnAOB)*)

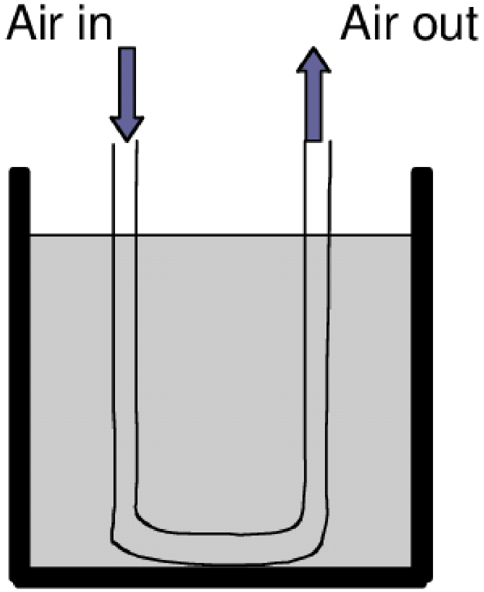
Compared to other nitrification/denitrification pathways

- Highest nitrogen gas yield
- Lowest oxygen demand
- No chemical oxygen demand(COD) input

Multiphase reactor operation

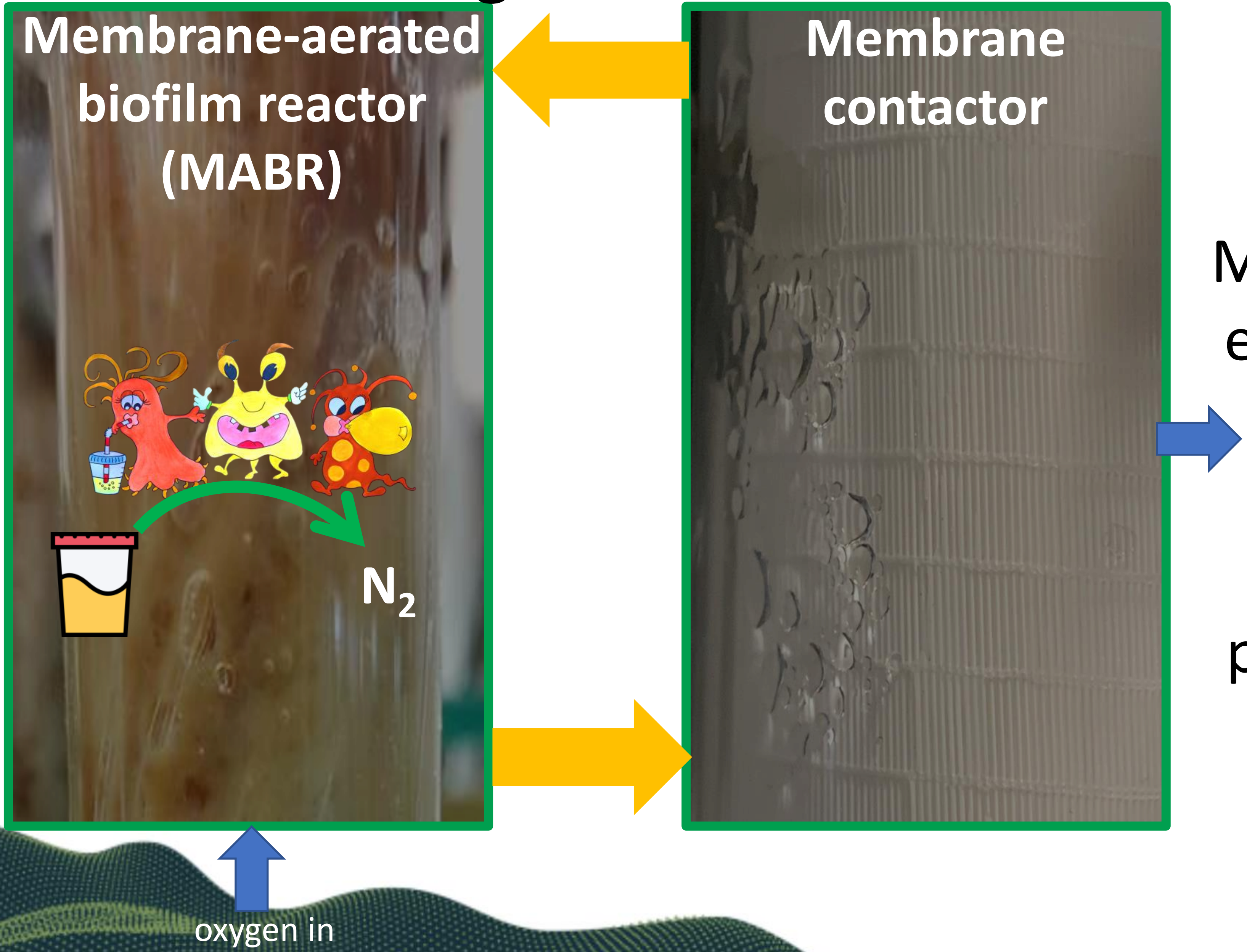
Bubbles don’t rise! No conventional aeration and separation





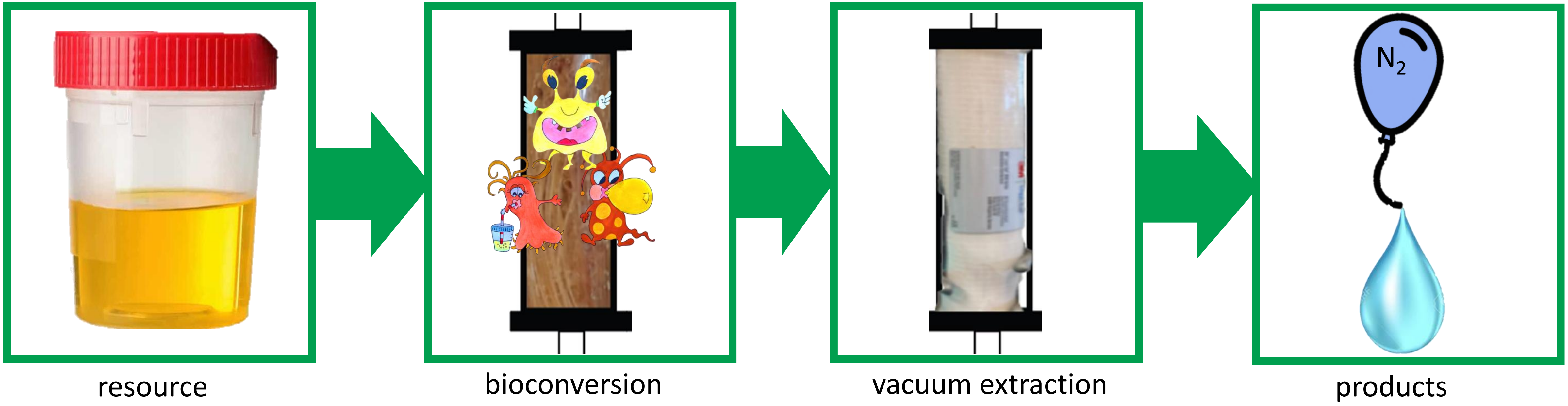
Membranes for aeration and gas extraction

Bioreactor design

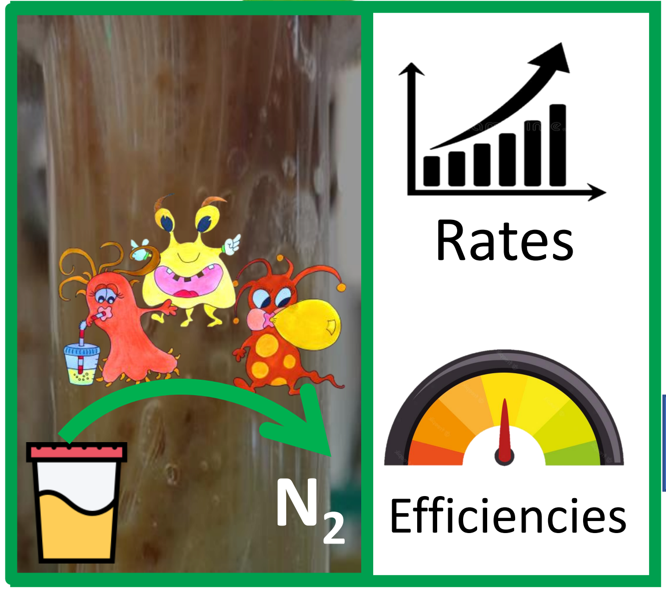


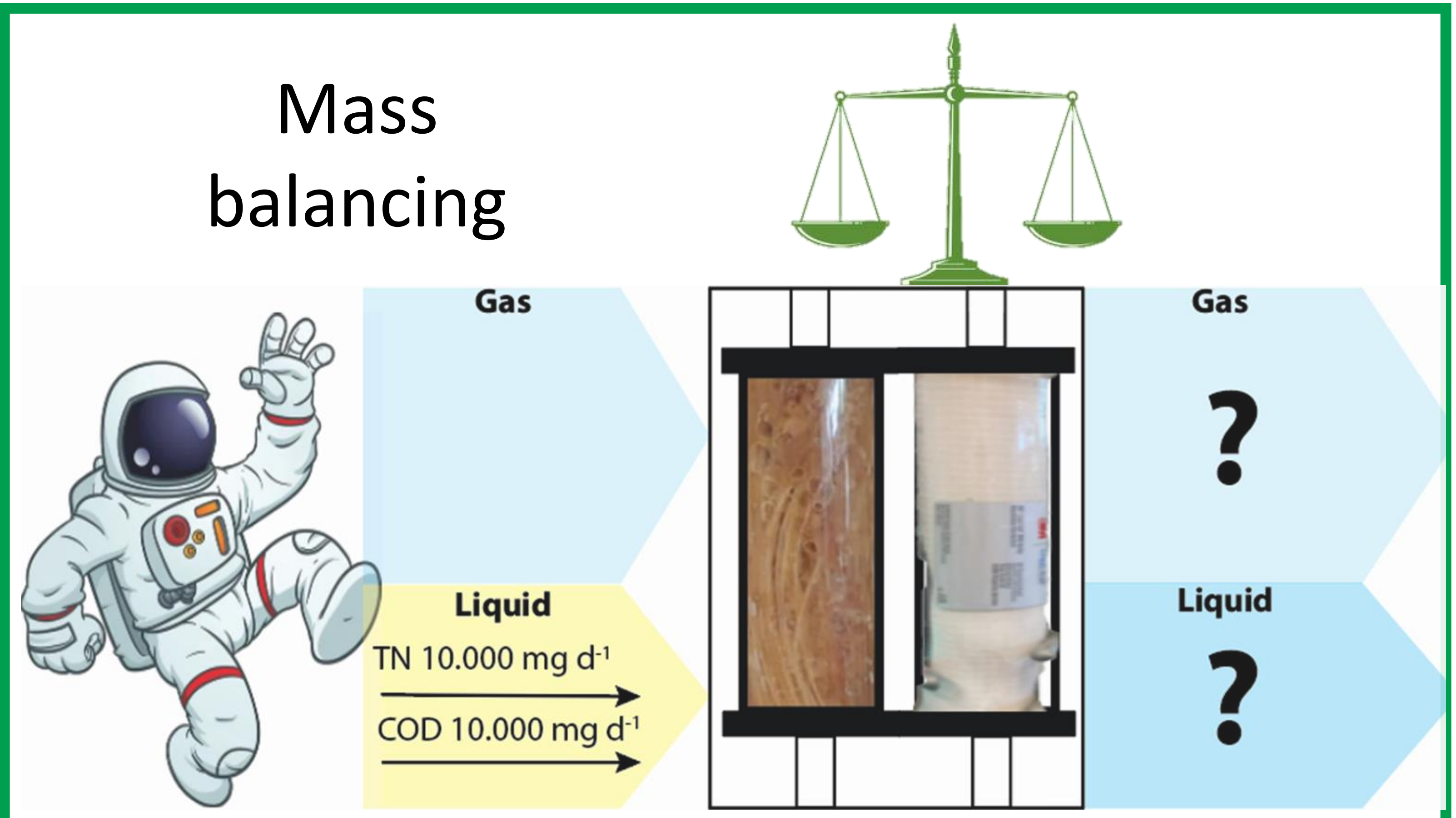
Membrane extraction
N_2
CO_2
Other products?

Goal: **N_2 production and extraction from urine** to compensate gas-losses and produce clean water



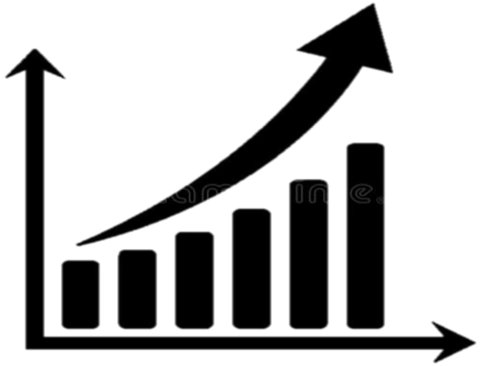
Can we produce and extract N_2-gas from urine in space?





How much urine needed to compensate gas losses?

1. Rates and efficiencies



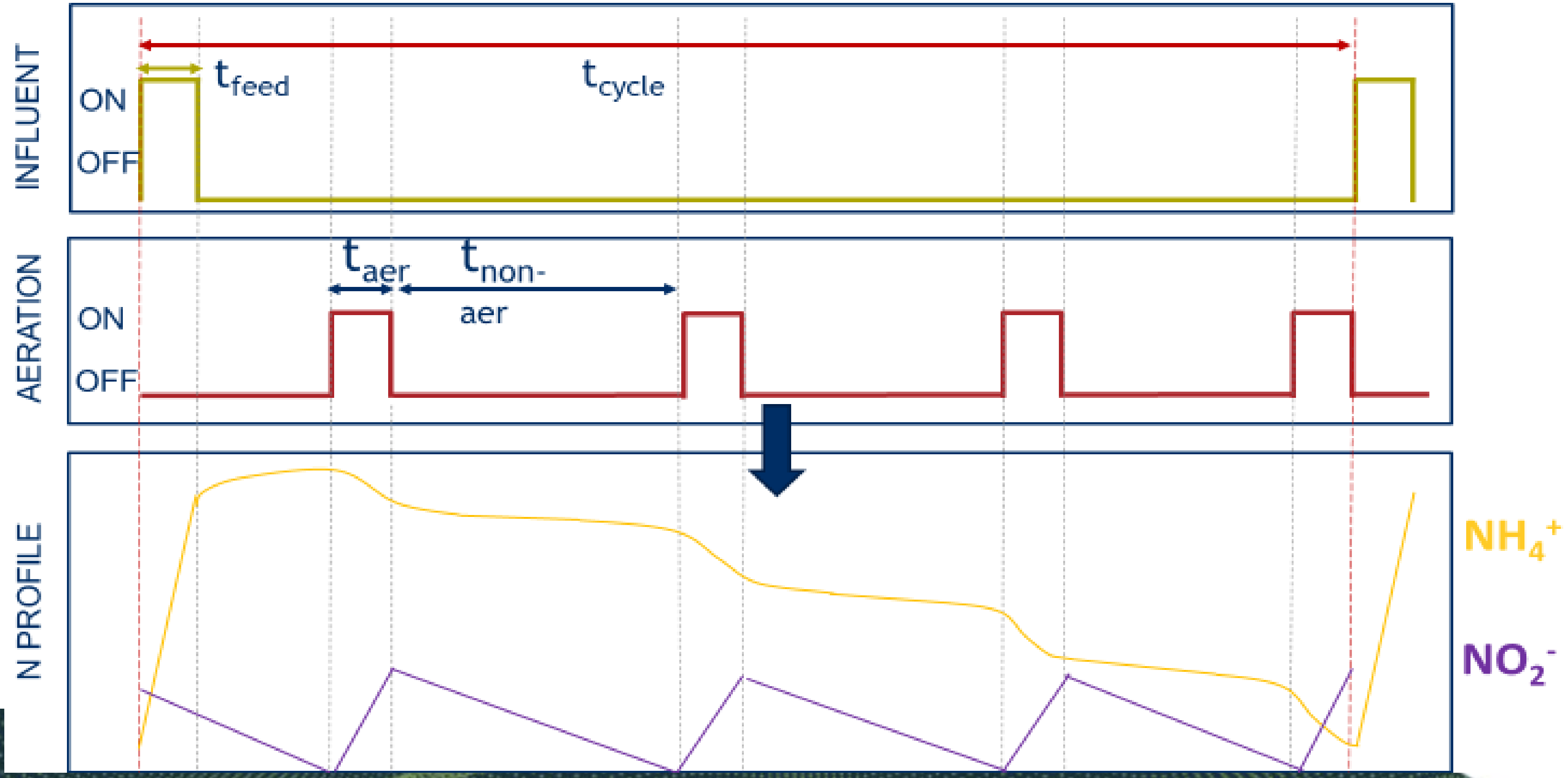
Method: PN/A sludge with startup on synthetic urine

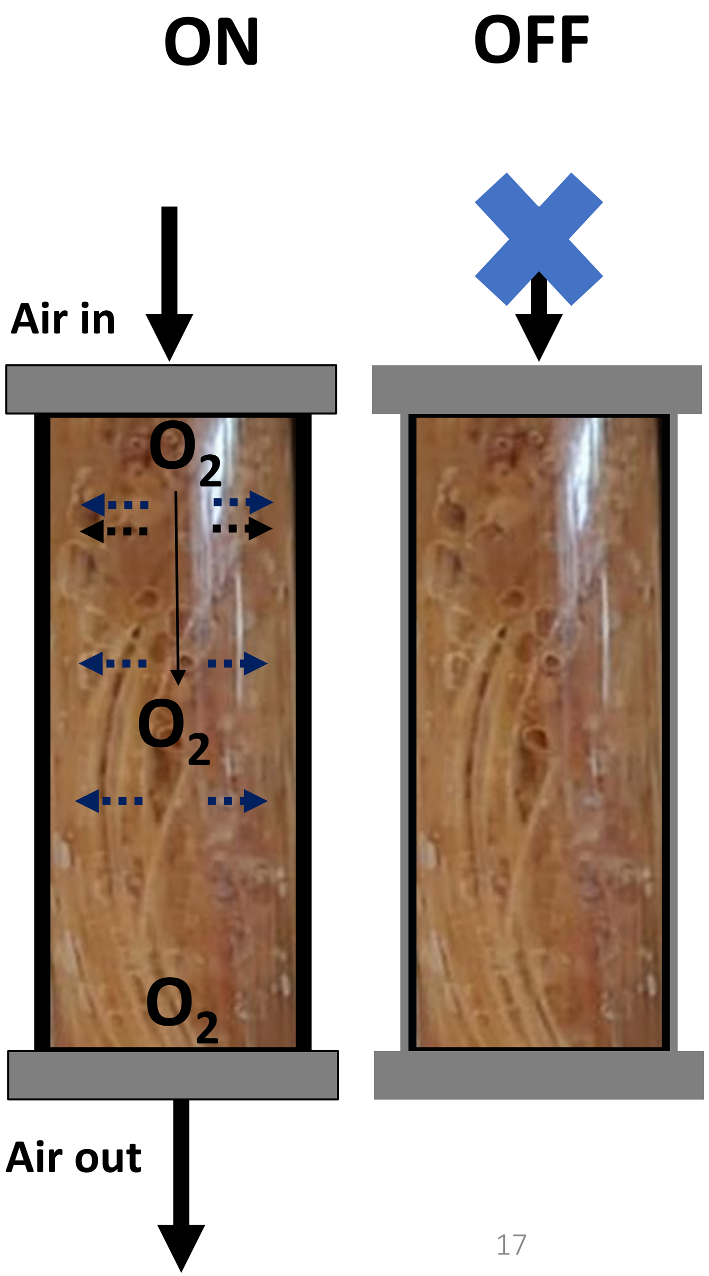
- Influent: 0.67 g N L^{-1} 10x diluted urine
- Inoculum: PN/A biomass , co-diffusion biofilm without ureolytic activity
- T = 27-28°C
- pH = 7-7.5

Day	1	4	21	60	189
Operation	Batch (spikes)	Continuous			
Influent	Synthetic (10%)				Real (10%)
Source of N	NH_4^+		Urea	Urea (75%), NH_4^+ (25%)	Complex (mainly urea)
Source of organics	Acetate			Creatinine, hippuric acid, citric acid	Complex

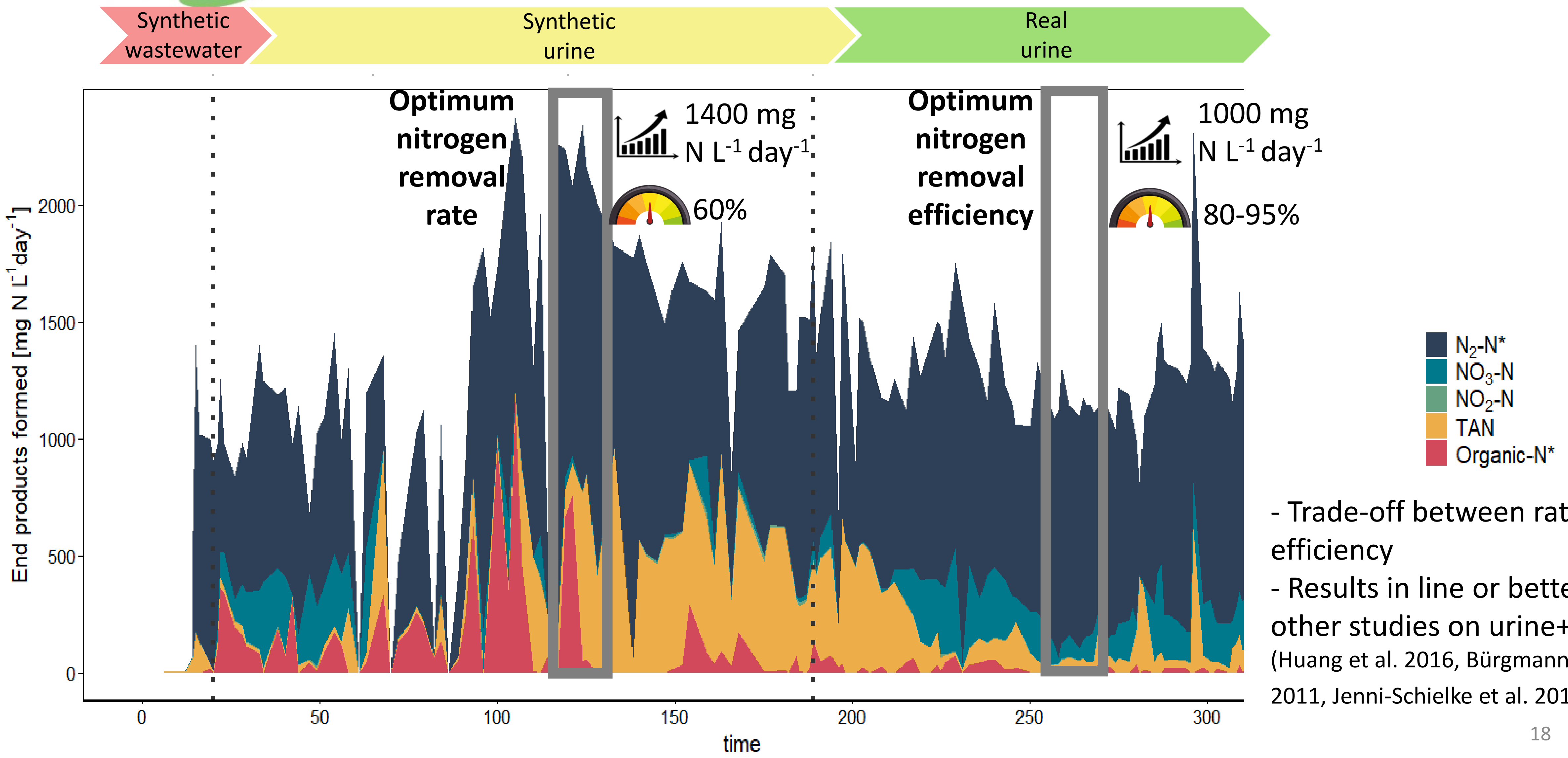
Method: Optimal aeration of MABR

- Interval based aeration ON/OFF
  - Provide O_2 for AOB-conversion: Partial Nitritation
  - Prevent NO_3^- formation by periodic anoxicity
  - DO cannot be used to steer aeration as bulk liquid DO = 0
  - Optimization of aeration and feeding regime (time and interval)



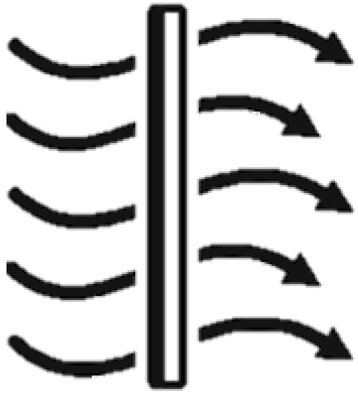


Nitrogen removal rates & efficiencies



- Trade-off between rate and efficiency
- Results in line or better than other studies on urine+PN/A (Huang et al. 2016, Bürgmann et al. 2011, Jenni-Schielke et al. 2015)

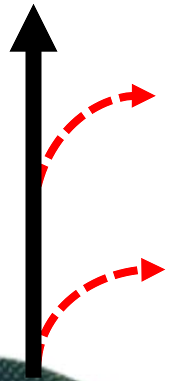
2. Membrane extraction



Membrane extraction & analysis: why?

- Need for gas/liquid separation, bubbles do not rise in Space
- Confirmation of N_2 and CO_2 production & mass balancing
- Quantification of (gas) side products:

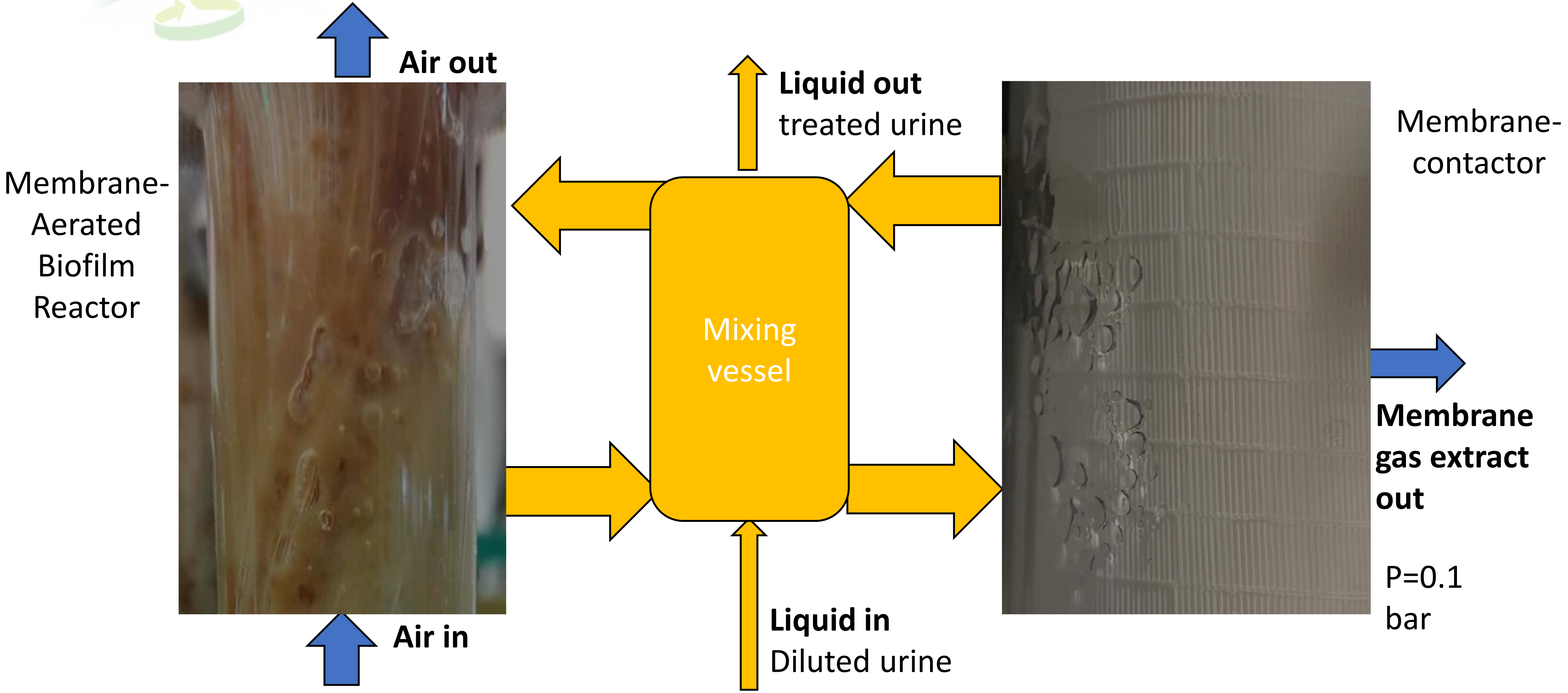
N_2



N_2O

NH_3

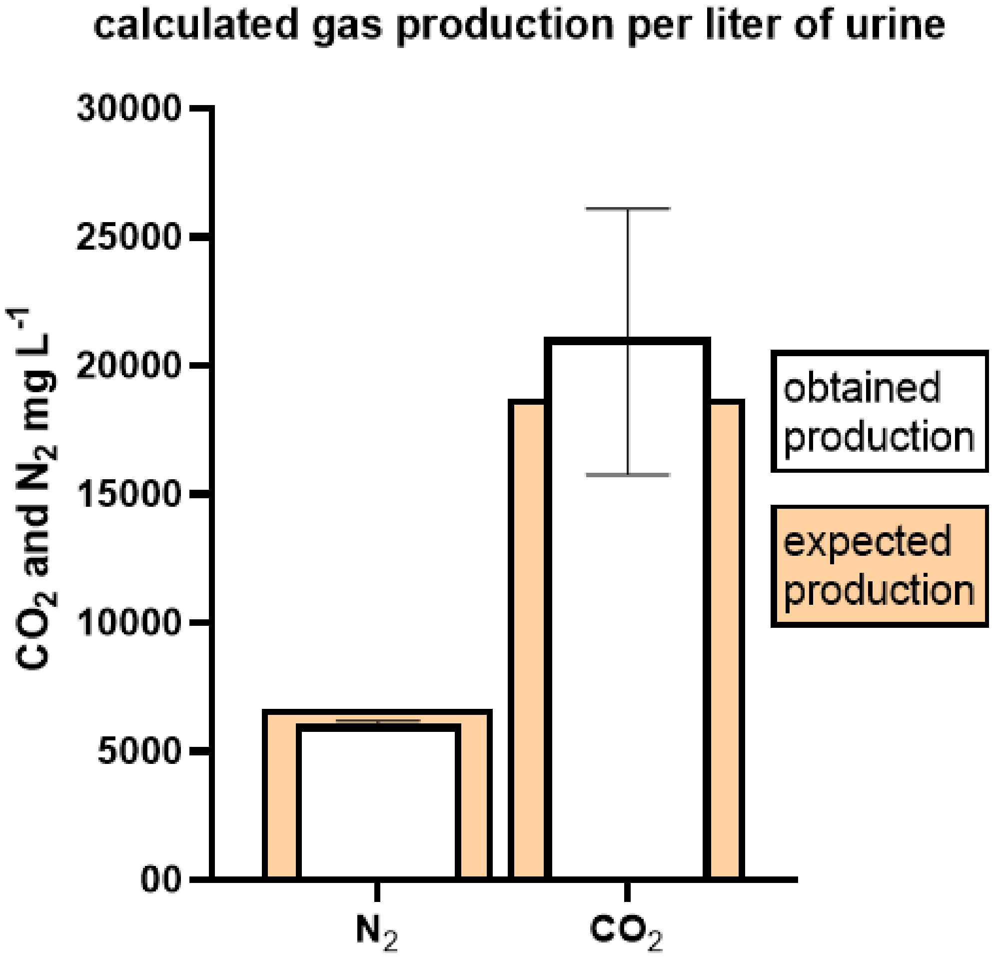
N_2-membrane extraction & analysis for mass balancing: How?



Gas and liquid measurements for each condition (>8 replicates)
Measurement campaign started after a week operation in a condition (HRT=1 day)

- **Confirm N_2 and CO_2-production**

- Side product formation



N_2: expected 6700-7800 mg N L^{-1}

> 6000 mg N L^{-1} urine of extracted N_2 gas

80-95 %

CO_2: expected 17500-19300 mg L^{-1}

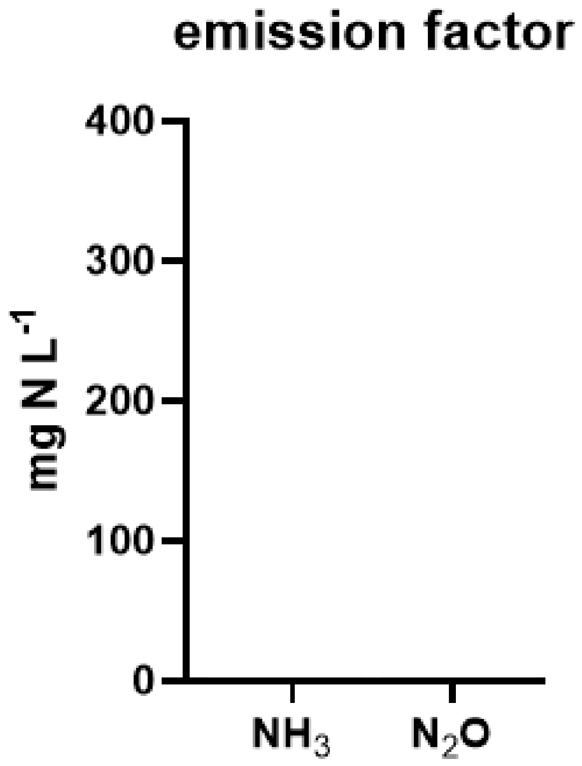
20800 +/- 4000 mg CO_2 L^{-1}

90-130 %

According to expectations, organic carbon removal need for water reuse

- Confirm N_2 and CO_2-production

- **Side product formation**



NH_3

0.6 mg NH_3-N L^{-1} urine

0.1 %

Acceptable, well below SMAC: 3 ppm

N_2O

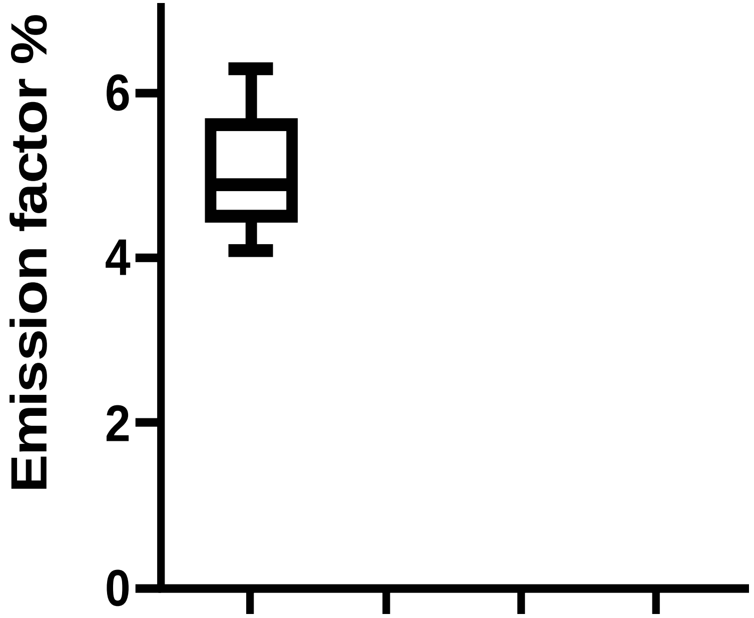
300 mg N_2O-N L^{-1} urine

4-6 %

Not-acceptable, within range for N_2O emissions, above SMAC: 18 ppm

N_2O emission factor under different conditions

Vacuum pressure	0.1	**1**	0.1	0.1	atm
Nitrogen load	100	100	**120**	100	%
Aeration time	100	100	100	**120**	%



Without vacuum → strong reduction N_2O emission

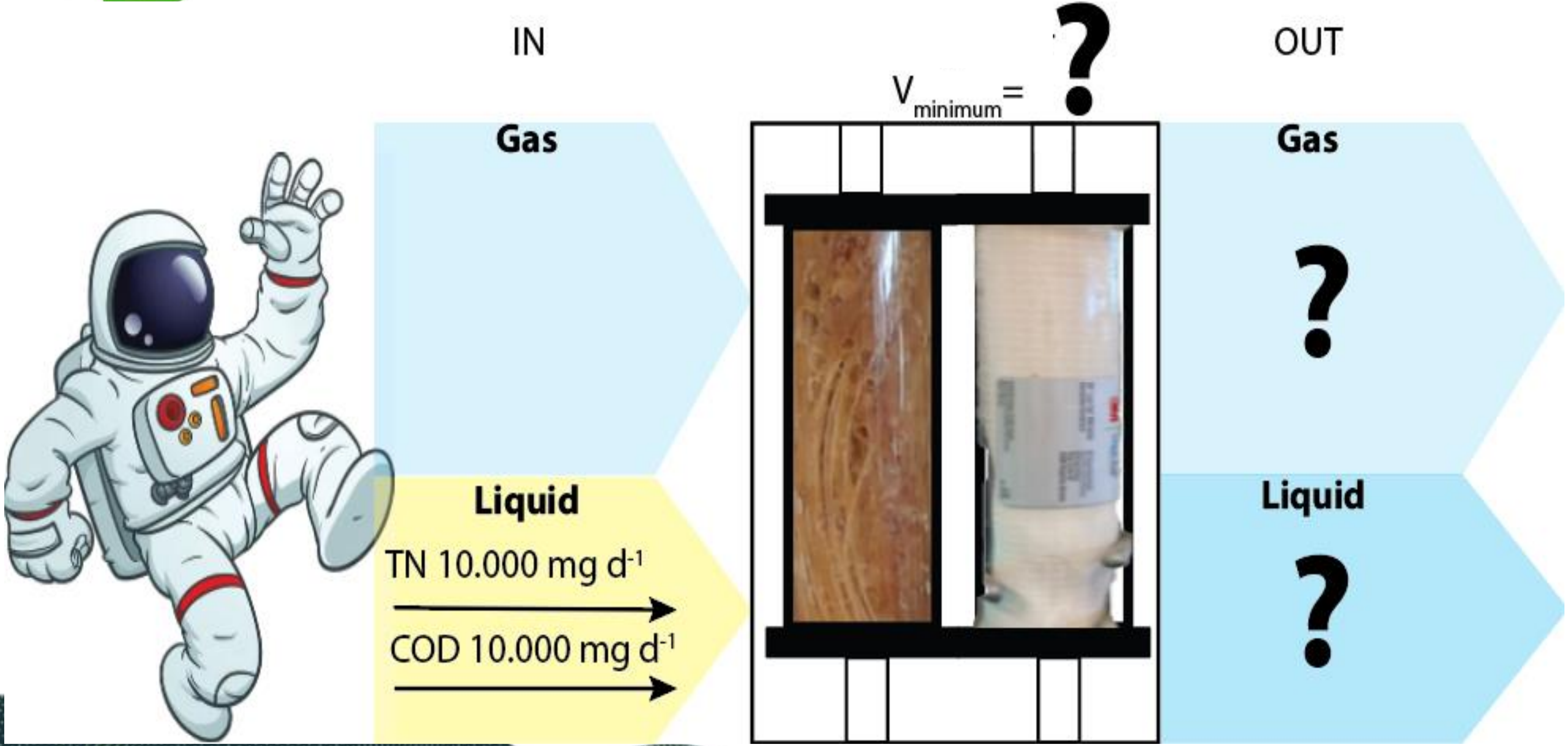
Overloading → strong reduction N_2O

Extra aeration → strong reduction N_2O

Thus, N_2O emission is strongly dependent on operational conditions

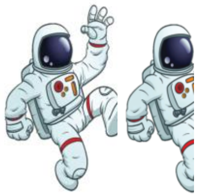
3. Mass balances

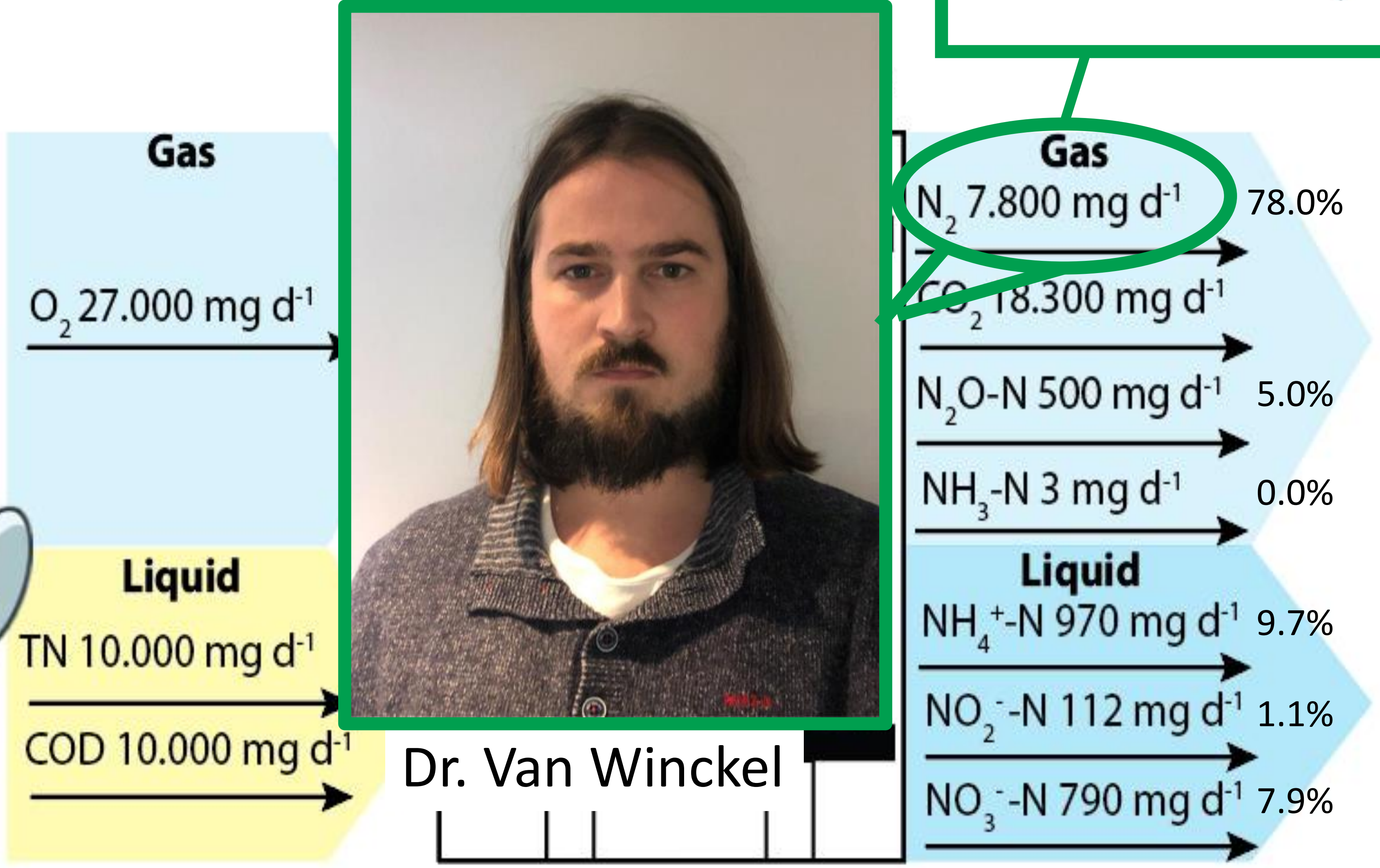
Mass balance per astronaut



Mass balance per astronaut

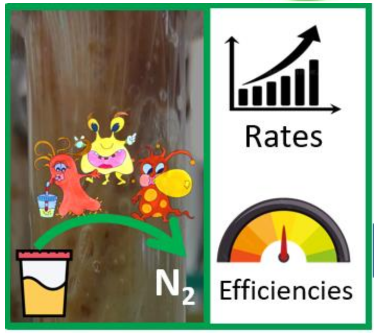
Needed: 13.000 mg N_2 per day in Orion DST *(Goodliff 2017)*





Dr. Van Winckel

Take home messages



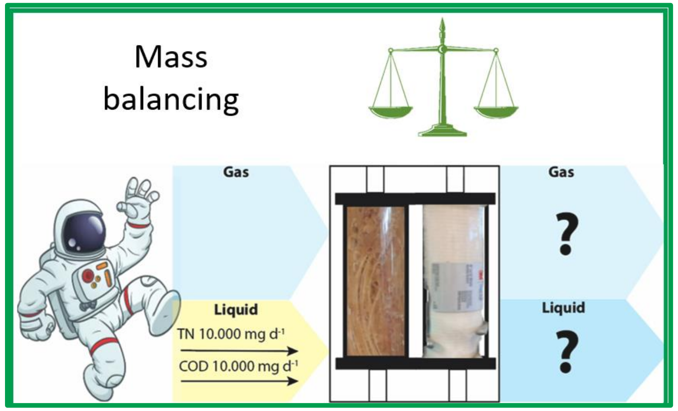
Yes we can: Successfully established N_2 production from urine

Optimum at 1000 mg N L^{-1} d^{-1}, 80-95%

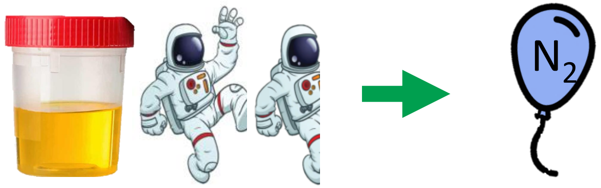
Gas extraction was **succesfully established**

N_2-gas production confirmed

N_2O: clues for minimization→ operational conditions



Urine from <2 astronauts completely offset gas-losses Orion DST



Simultaneous cleaner water for easier reuse

Further research done

TN_{in}
6000 mg N L^{-1}

Undiluted urine + PN/A in MABR

Background

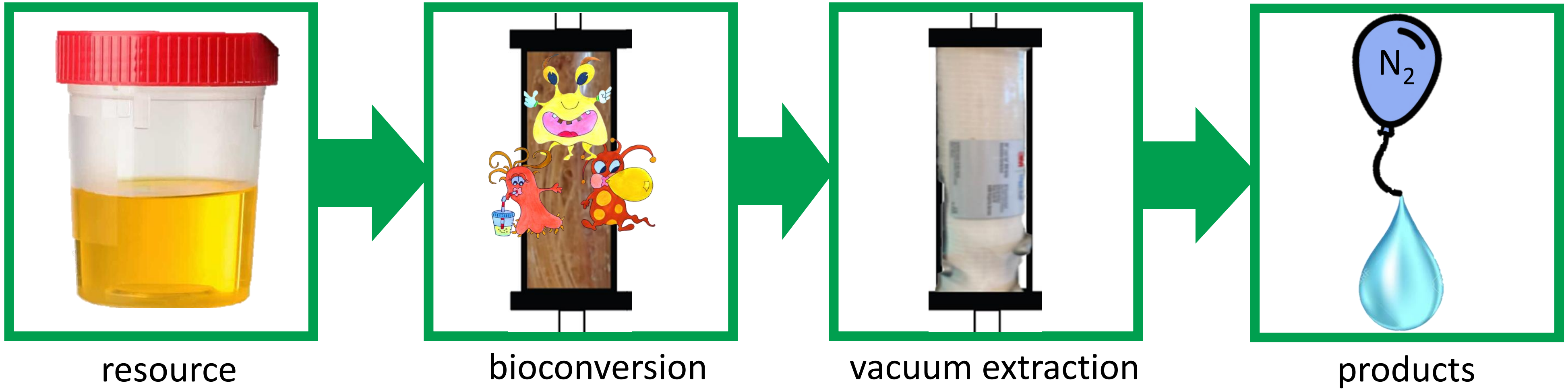
PN/A on undiluted urine always failed due to inhibition& washout (Schielke-Jenni, 2015)

Main findings

- No loss of performance
- Nitrogen removal rates stable
- Removal efficiency increased to 95+%!
- Shielding effect biofilm + fixation might prevent washout of inhibited AnAOB

Nitrogen gas production and extraction from urine to compensate for gas losses in Space

MELiSSA



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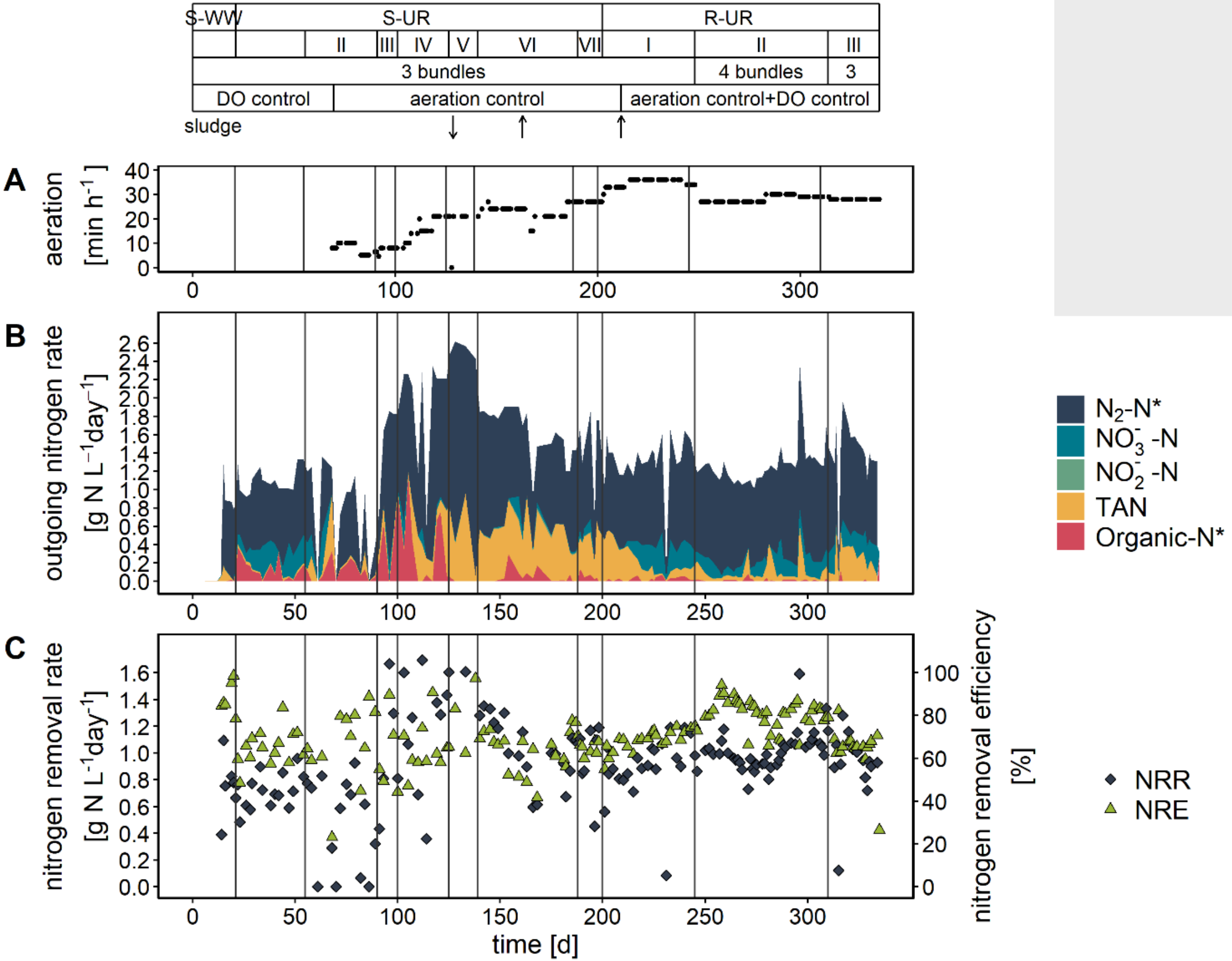

S-WW
S-UR
R-UR
II
III
IV
V
VI
VII
I
II
III
3 bundles
4 bundles
3
DO control
aeration control
aeration control+DO control
sludge
A
aeration [min h-1]
B
outgoing nitrogen rate [g N L-1day-1]
N2-N*
NO3- -N
NO2- -N
TAN
Organic-N*
C
nitrogen removal rate [g N L-1day-1]
nitrogen removal efficiency [%]
NRR
NRE
time [d]