SIWW 2022

Accelerated Startup of PN/A Biofilm in ZeeNAMMOX^{TM} without Anammox Inoculation

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4/19/2022

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Summary

1. **MABR Refresher**
   Process Basics/ZeeLung/Current Use
2. **PN/A Refresher**
   PN/A vs. Conv. SND / PN/A in Sidestream/
   PN/A w MABR
3. **ZeeNAMMOX Process**
   Pilots Overview/Pilots Startup Results/
   Biowin Simulation

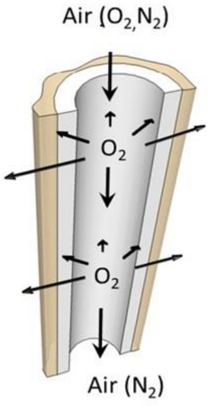
1.

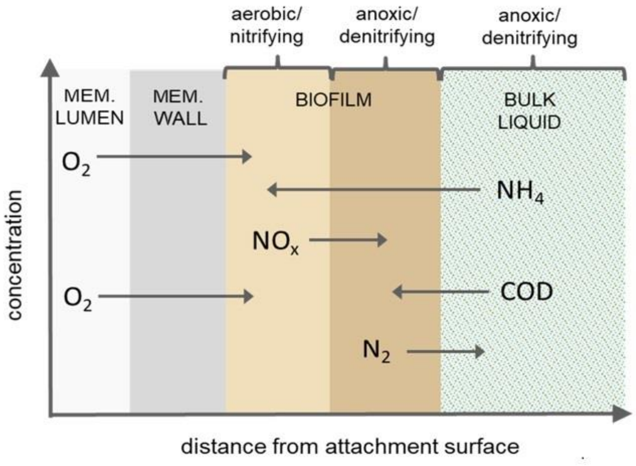
MABR Refresher

Process Basics/ZeeLung/Current Use

MABR Refresher

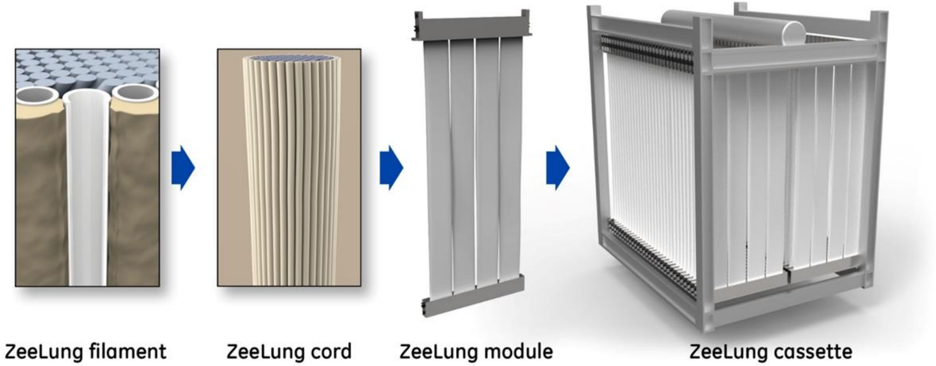
Process Basics

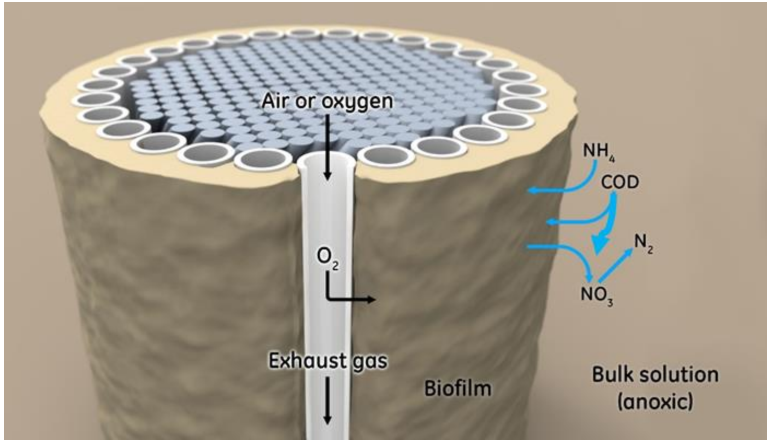




- membrane aerated biofilm reactor - MABR
- media-supported biofilm with its own built-in O_2 supply
- counter-diffusional biofilm
- Aerobic capabilities in anoxic conditions - SND

MABR Refresher
ZeeLung



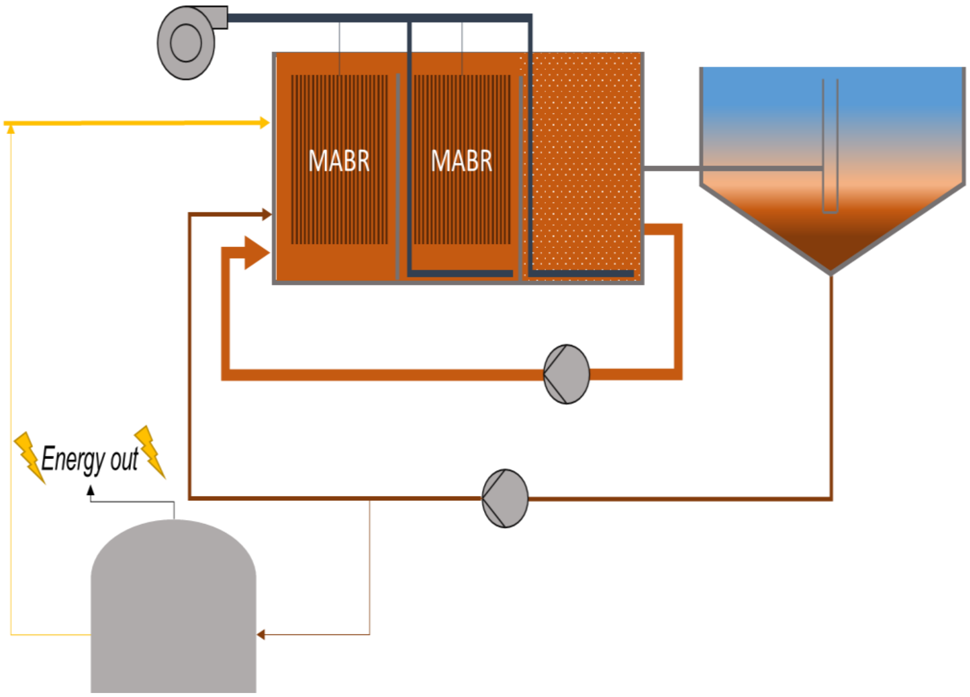


Highest efficiency of O_2 transfer by Diffusion into a biofilm

MABR Refresher

Current Use

- MABR – mainstream - energy efficient intensification
- Increase of biomass inventory
- simultaneous nitrification & denitrification (SND)
- limiting or eliminating internal recycle
- Mainstream MABR kinetics – driven by NH_3 limitation within the biofilm



2.

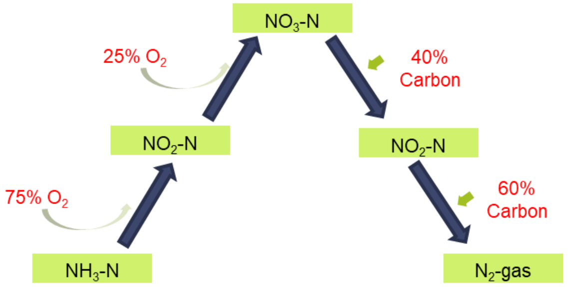
PN/A Refresher

PN/A vs. Conv. SND / PN/A w MABR

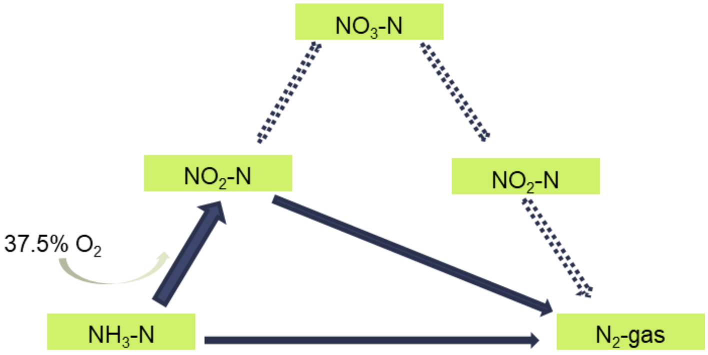
PN/A Refresher

PN/A vs. Conventional SND

- Conventional Nitrification/Denitrification Cycle: **PAIN**
  - N removal requires large bioreactor volumes… high capex
  - N removal is energy intensive (O_2) & requires carbon...high opex



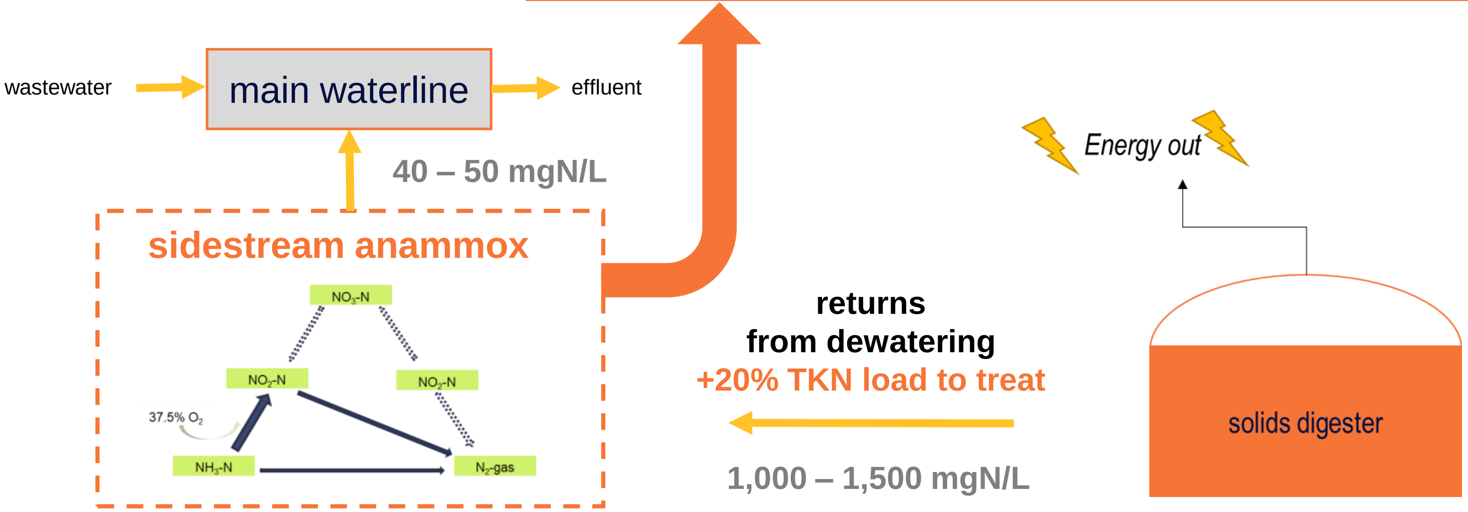
- Partial nitritation & deammonification: **GAIN**
  - N removal in reduced reactor volume…lower capex
  - N removal with reduced energy & C demand….lower opex
  - Simplicity & reliability



PN/A Refresher

PN/A in Sidestream

- **20% reduction** of nitrogen load <u>on mainstream waterline</u>
- lower energy cost (**-10 to -15% WWTP aeration energy** for nitrogen removal)
- improve & **secure nitrogen discharge** compliancy with anaerobic digestion



But

— Existing Technologies

- efficient Pathway
- **inefficient oxygen delivery**
- **complex operation & control**

ZeeNAMMOX process
principle & benefits

Benefits

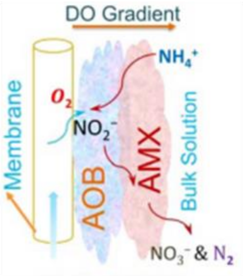
Energy efficiency

Gas control analyzers
- reliable and accurate
- strong NOB repression

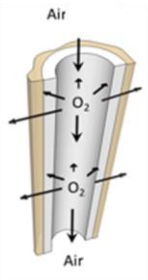
Simple process control
- direct supply of oxygen to biofilm - (no influence of poor centrate quality)
- reliable lever for NOB suppression
- minimal intervention required

Flow through with high TSS resiliency

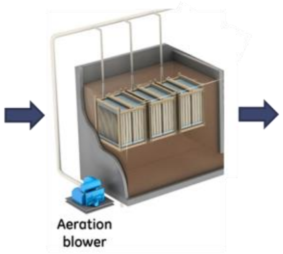
Principle



counter-diffusion biofilm favours growth of AOB and AMX in biofilm



low-energy O_2 transfer via gas-transfer membrane



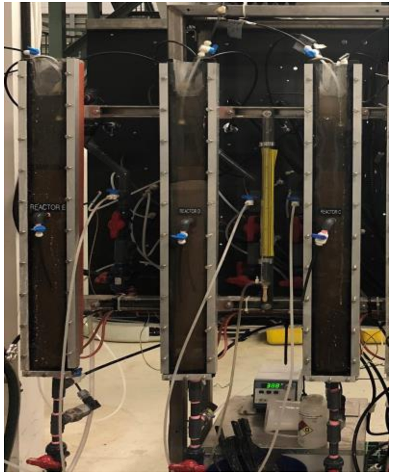
simple one-stage process

3.

ZeeNAMMOX Process

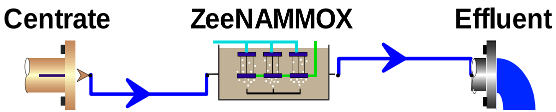
Pilots Overview/Pilots Startup Results/Biowin Simulation

ZeeNAMMOX Process
Pilots Overview



Lab-scale ZeeNAMMOX Pilots:
R1, R2, R3

Full-scale ZeeNAMMOX Demo



Model in Biowin

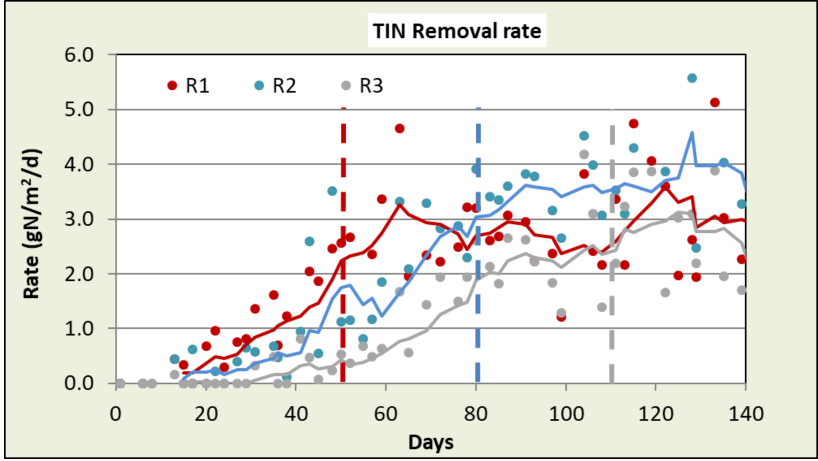
- Lab-scale Pilots (>3 years):
  - 3 reactors in parallel for concept proof
- Full-scale Demo (startup):
  - Validate concept using full-scale system under field conditions
- Simulation in Biowin:
  - Dynamic simulation of pilot systems, sensitivity study, and process design

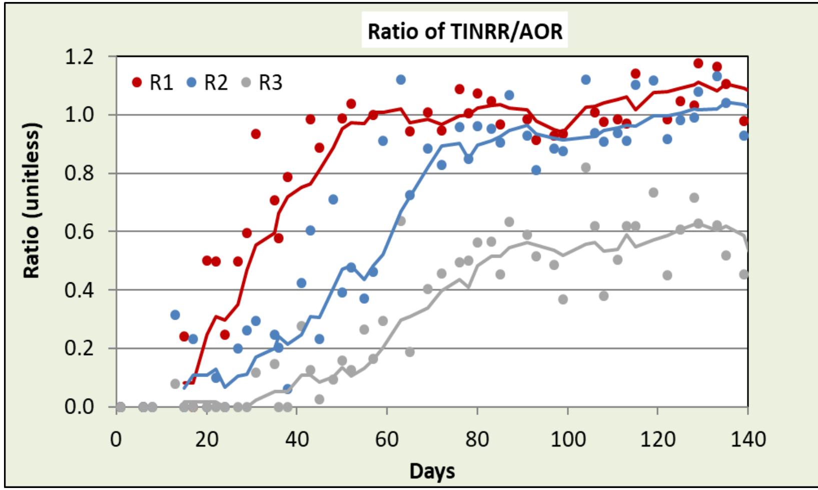
ZeeNAMMOX Process

Lab Pilot Results

Reactor	Startup (days)	TINRR after startup ($gN/m^2/d$)	TINRR/AOR ratio after startup
R1	50	2.9	1
R2	80	3.7	0.98
R3	110	2.8	0.59

- Only nitrifying sludge was seeded at the beginning of the startup.
- Only oxygen supply conditions were different.



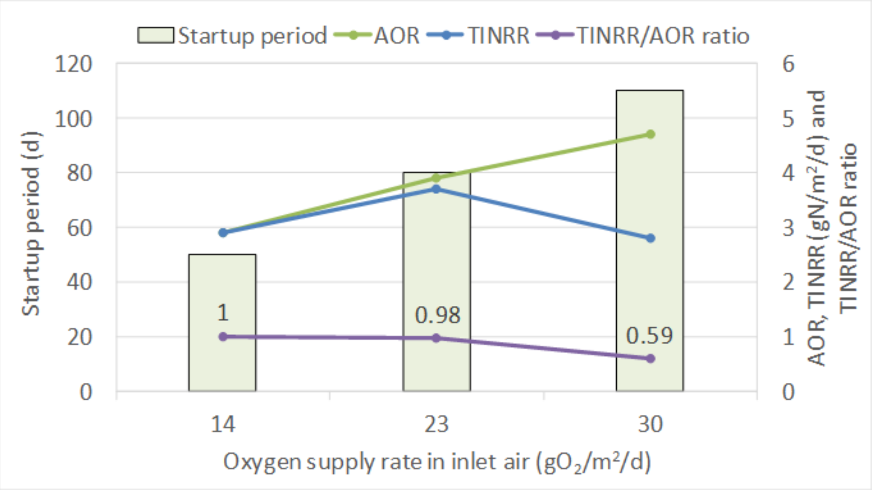


Quick Startup, high rate removals at 100% NOB suppression

ZeeNAMMOX process

Lab Pilot Results

How Oxygen Supply Rate Impacts Startup Period

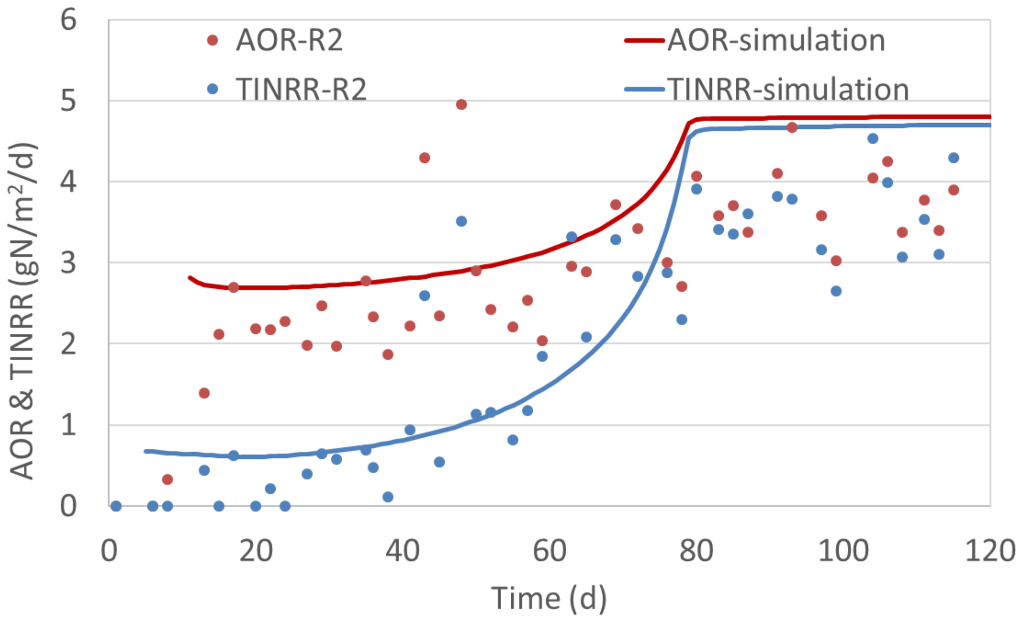


- **Startup period is shorter** at lower oxygen supply rate (OSR)
- **Lower OSR** results in shorter O_2 penetration depth
- Shorter O_2 penetration would lead to **better Anammox growth**
- **AOR increases** with Mass-inlet-O_2
- TINRR reaches a peak within the same range of M-inlet-O_2
- Optimal M-inlet-O_2 might be higher than 23 $gO_2/m^2/d$

ZeeNAMMOX Process

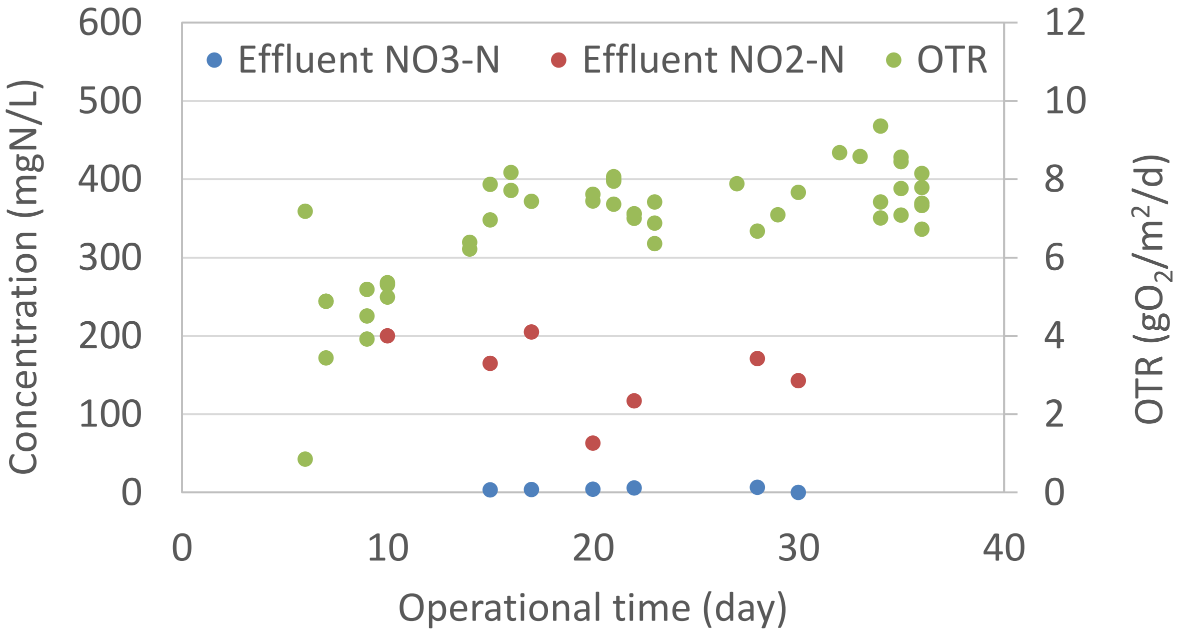
Simulation in Biowin

Accelerated Startup without Anammox Seeding in R2



- Simulation conditions:
  - Anammox in influent: default value
  - μ_{max} : 0.05 1/d
  - Boundary thickness: 200 µm
  - Detachment: default value
  - Other parameters: minor changes

PUB ZeeNAMMOX demo startup… showing strong NOB repression…



- **Startup performance**:
  - **gradual increase in OTR**
  - **rapid establishment of AOB biofilm**
  - **complete NOB suppression**
  - Anammox activity to be established…

ZeeNAMMOX process
Summary

- **PN/A is well established** for N removal in side-stream application
- Existing solutions are **more complex to operate and control**, use **inefficient O_2 delivery**, show fragilities
- MABR enabled PN/A is **simple & super energy-efficient** (ZeeNAMMOX)
- Lab scale pilot & simulation
  - **ZeeNAMMOX allows to speed-up anammox biomass growth**
  - **50 days start-up was achieved with ZeeNAMMOX without Anammox inoculation**
  - **gas control** of oxygen supply rate (OSR) makes ZeeNAMMOX **a unique solution to speed-up** sidestream anammox growth

Demo Scale ZeeNAMMOX plant is under start-up stage at PUB site

ZeeNAMMOX process

Value Proposition

- ⇛ **ENERGY << 70% COMPARED TO GRANULAR & MBBR….LOWER OPEX**
- ⇛ **BIOREACTOR VOLUME >20% SMALLER THAN GRANULAR….. LOWER CAPEX**
- ⇛ **SIMPLE PROCESS… O_2 SUPPLY PROVIDES SELECTION PRESSURE**
- ⇛ **RESILIENT PROCESS… ANAMMOX BACTERIA RETAINED IN BIOFILM**
- ⇛ **N_2O REDUCTION… POTENTIALLY UP TO 90% LESS THAN OTHER PN/A TECHNOLOGIES**
- ⇛ **START-UP WITHOUT ANAMMOX SEEDING EXPECTED BETWEEN 50 – 90 DAYS**

	Granular	MBBR	ZeeNAMMOX
energy, kWh/kg-$N_{removed}$	1.4	1.5	**0.4**
volume, kg-$N_{removed}$/m^3/d	0.4-0.8*	0.5-1.0*	**1.0**

*reported ranges

THANK YOU

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