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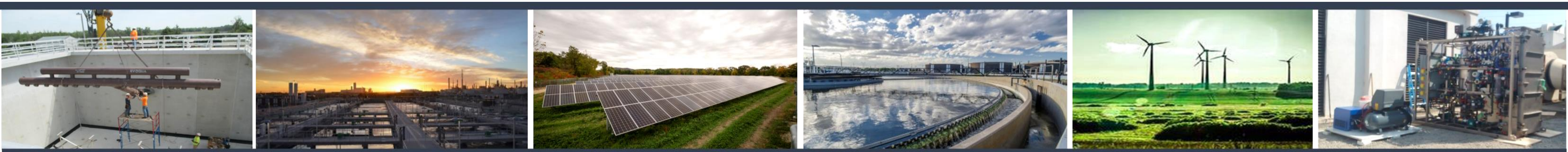
We will begin our presentation in a few minutes…



Leadership and Excellence in Environmental Engineering and Science

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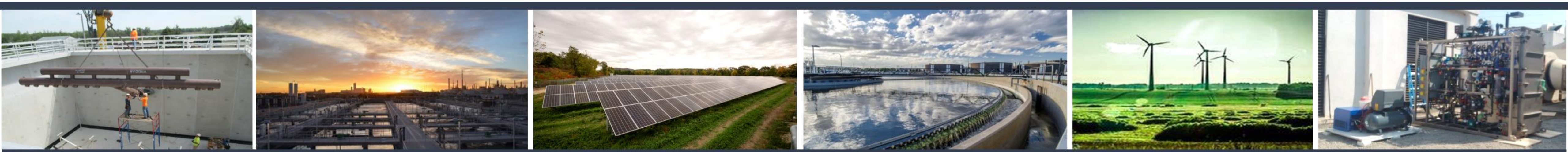
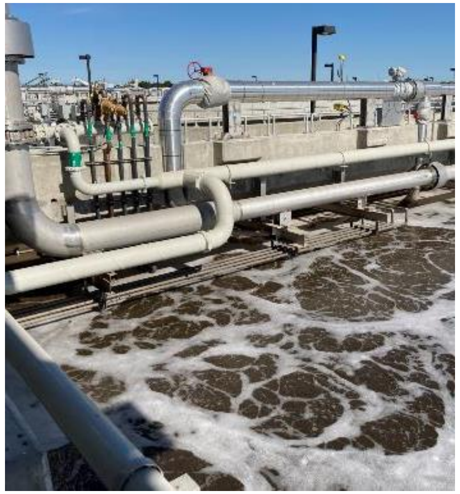
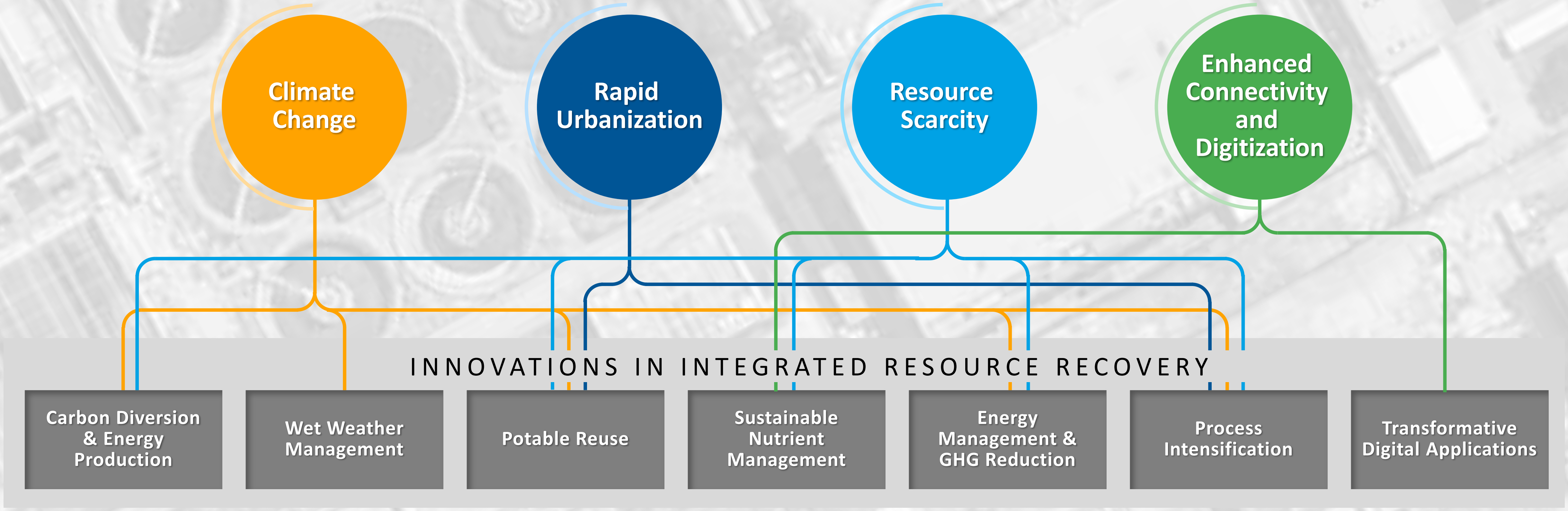


Leadership and Excellence in Environmental Engineering and Science

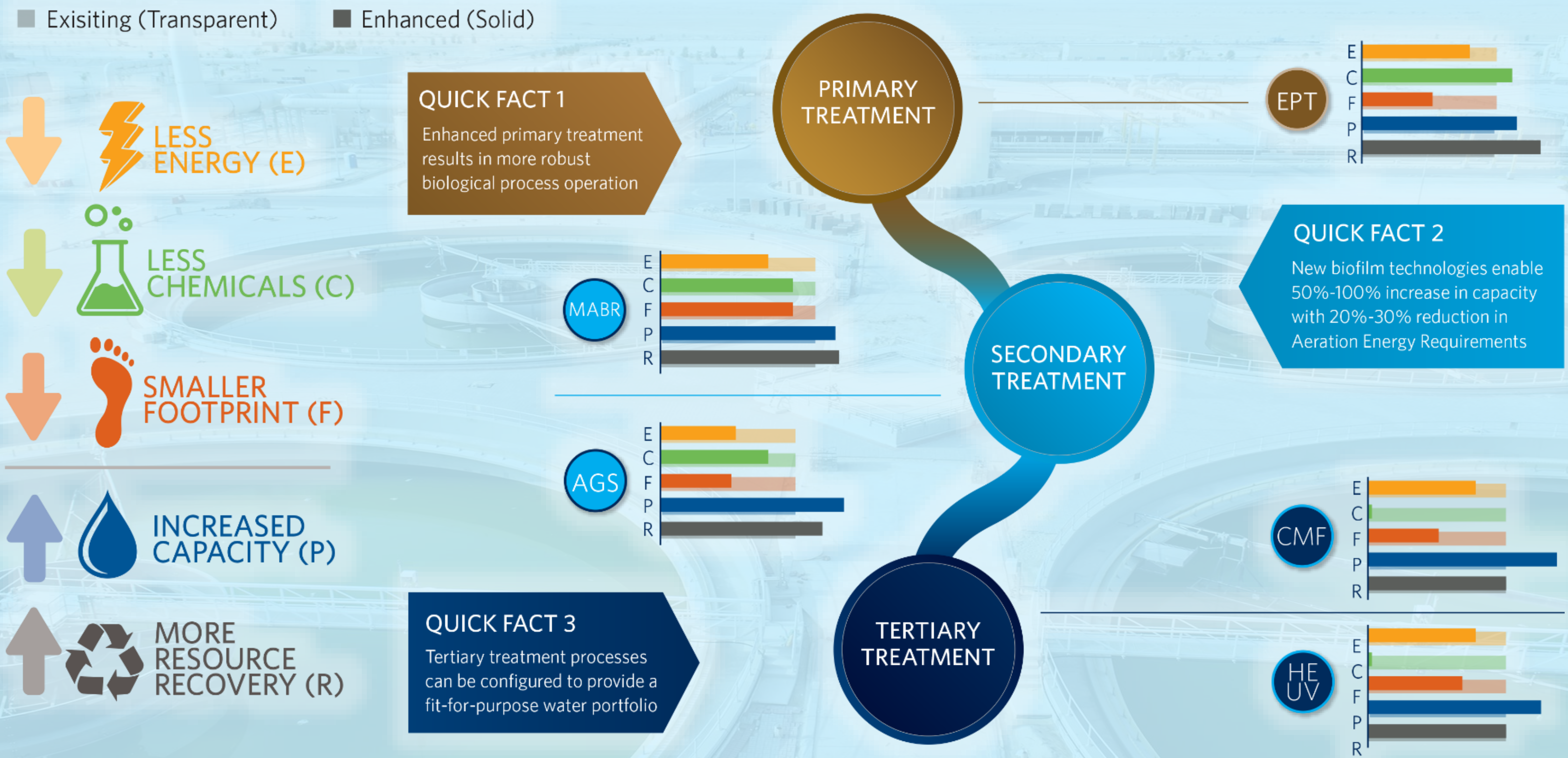
Innovative, Sustainable, Integrated Resource Recovery



Sandeep Sathyamoorthy
Global Practice & Technology Leader
Black & Veatch


Climate Change
Rapid Urbanization
Resource Scarcity
Enhanced Connectivity and Digitization
INNOVATIONS IN INTEGRATED RESOURCE RECOVERY
Carbon Diversion & Energy Production
Wet Weather Management
Potable Reuse
Sustainable Nutrient Management
Energy Management & GHG Reduction
Process Intensification
Transformative Digital Applications

Process Intensification: Doing More with Less



Intensified Nutrient Management Technologies

Suspended Growth

(e.g., NAS, MLE) w/ SND or ABAC

PN-A
PD-N-A

Biofilm Systems

Co-diffusional (IFAS, MBBR,MOB)

Counter-diffusional (MABR)

AGS

Biocatalyst

Encapsulation (Microvi, Lentikat)

Intensified Solids Separation

Hydrocyclone (INDense)

MBR

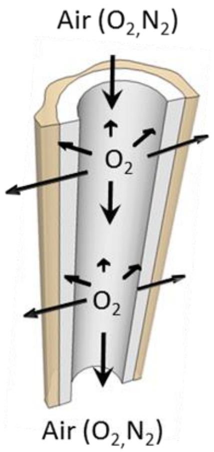
Integration of sidestream and mainstream deammonification

An MABR is…

MEMBRANES

- *Dense, hydrophobic material*
- *Hollow fiber or flat sheet configuration*

AIR DELIVERY

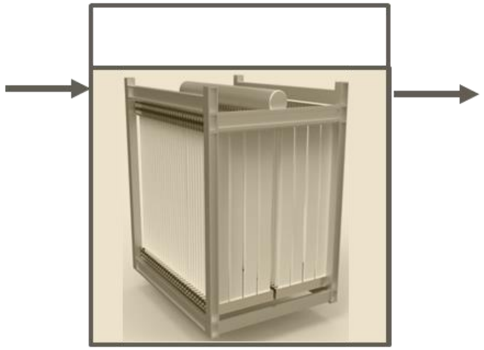


Air flows through intramembrane lumen and diffuses through membrane wall to biofilm

SUBSTRATE

Membrane cassettes are submerged in MLSS

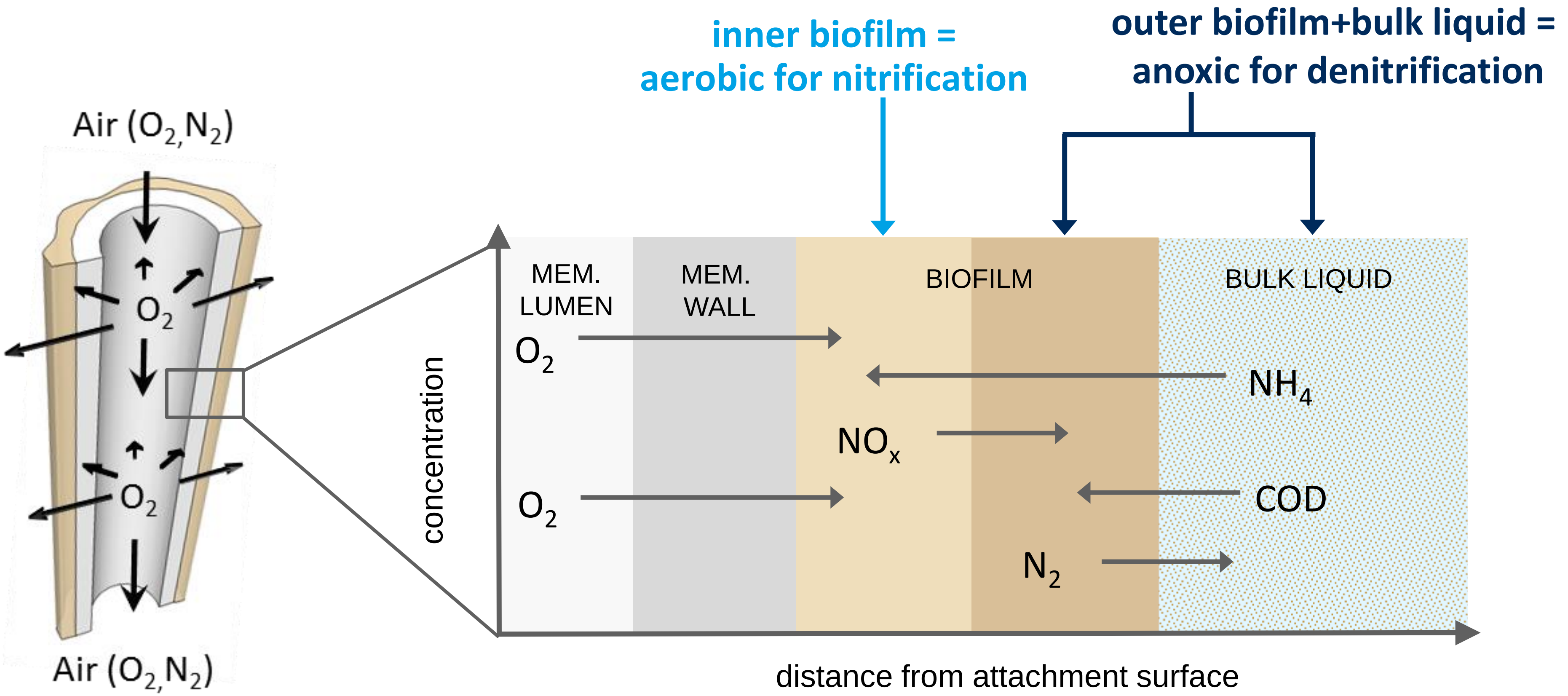
- *COD*
- *Ammonia (NH_4-N)*



"Breathing" Biofilms

Passive delivery of oxygen results in high oxygen transfer efficiencies.

The MABR supports counter-diffusional substrate delivery.



Counter-diffusional substrate delivery supports total nitrogen removal in a single biofilm and basin.

Benefits of an MABR

a Bubbleless Aeration Device

- Fine aeration control

&

a Biofilm Technology

- Intensified treatment
- Support slow growing organisms

SYNERGY

- Efficient aeration driven by biofilm activity
- High abundance of nitrifying organisms in biofilm
- Total nitrogen removal in a single reactor

Value Proposition of MABR Technology

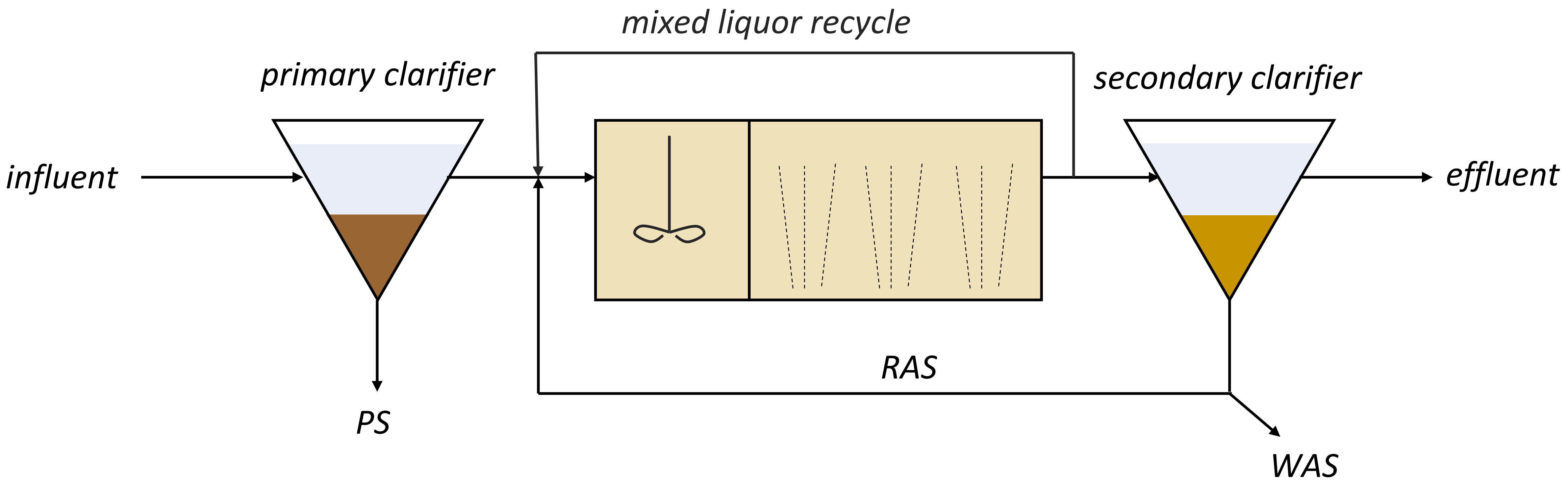
- Support **total nitrogen removal** in the **same tank**
- **Retrofit existing aeration tanks** and achieve **process intensification**

Reduce CAPEX

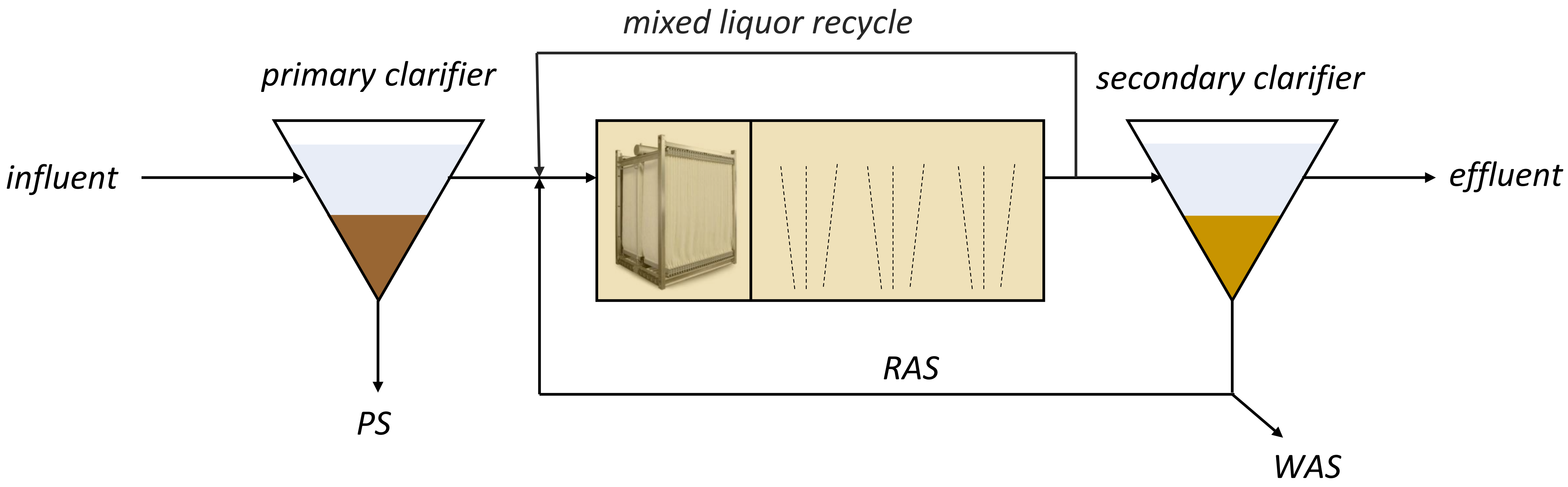
- Achieve efficient oxygen transfer rates
- Reduce internal recycle pumping
- Reduce **supplemental** biodegradable organic **carbon requirements** for denitrification

Reduce CAPEX AND OPEX

MABR achieves nitrification/denitrification in the anoxic zone.

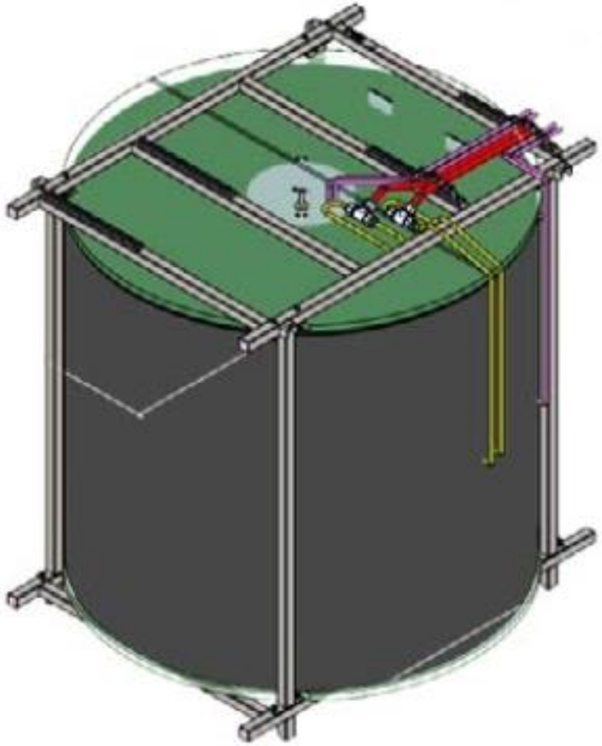


MABR achieves nitrification/denitrification in the anoxic zone.



Technology Providers

fluence



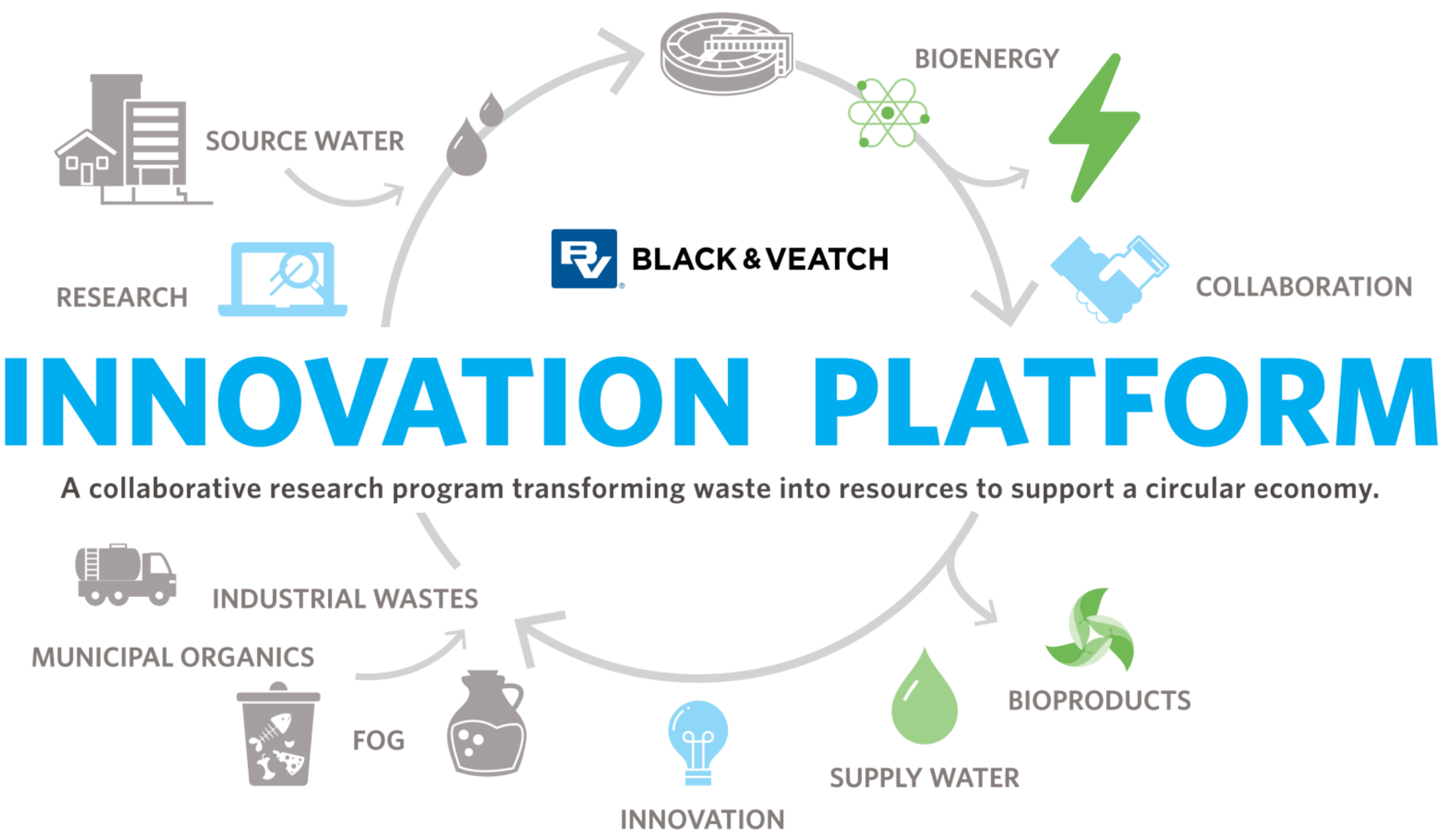
suez

DUPONT

Knowledge Gaps of MABR

Fundamental Understanding	Operational Challenges	Scale up Challenges
• Microbial Community Structure • AOB/NOB ratio	• Optimal SRT • Impact of C:N ratio • Biofilm Management	• No of cassettes • Nitrification Rate

Nutrient Removal Intensification Using MABRs: Pilot Study at Hayward WPCF



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HAYWARD

suez environnement

Black & Veatch: Sandeep Sathyamoorthy
Yueyun Tse
Kelly Gordon

Suez: Dwight Houweling
Dan Coutts

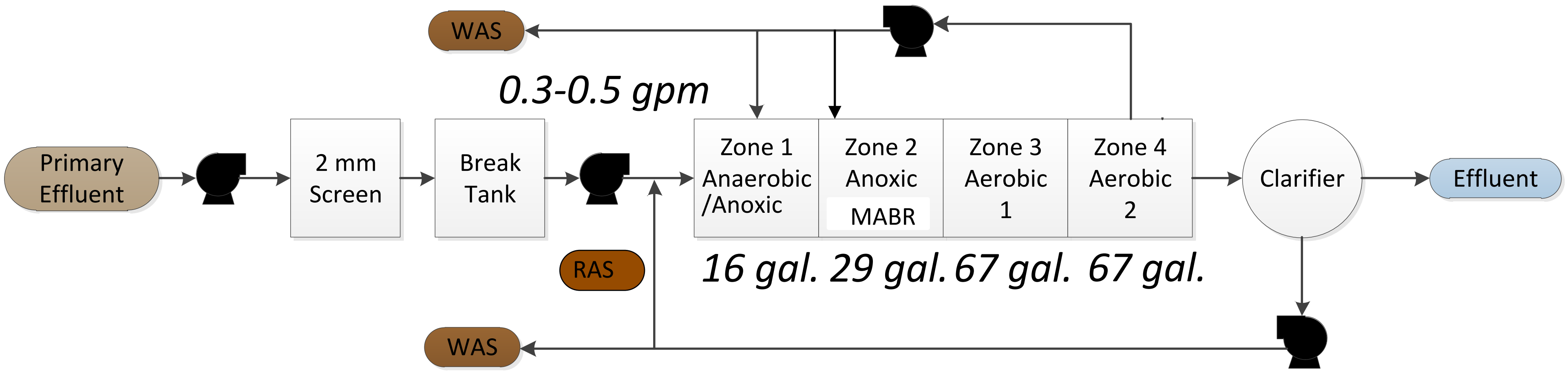
Hayward: David Donovon
Farid Ramezanzadeh

MABR Pilot @ Hayward WPCF

~10 MGD

Primary Sed > Trickling Filter > Solids Contact > Chlorine Disinfection

Pilot Overview

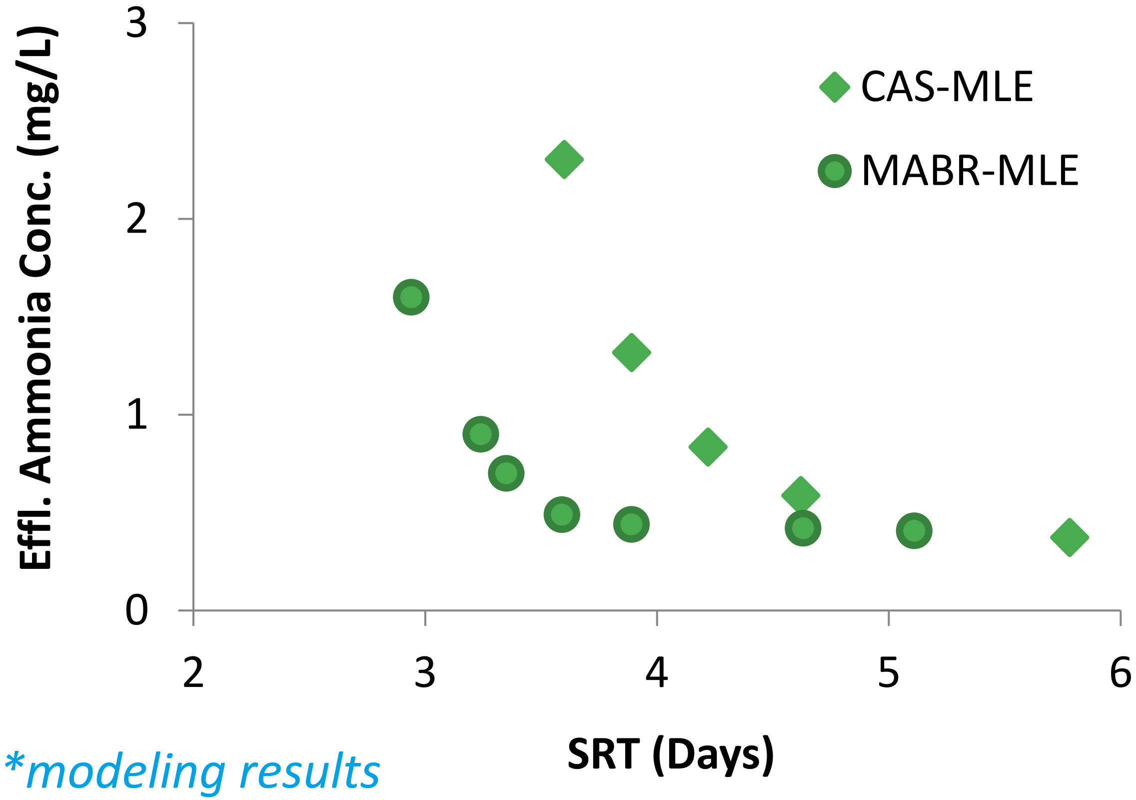


Use the research to fill knowledge gaps related to three main question

Question 1	Question 2	Question 3
Can use of MABR reduce the volume requirements for BNR?	What nitrification rate can be used for the MABR?	Is the performance of an MABR the same for all types of influents?

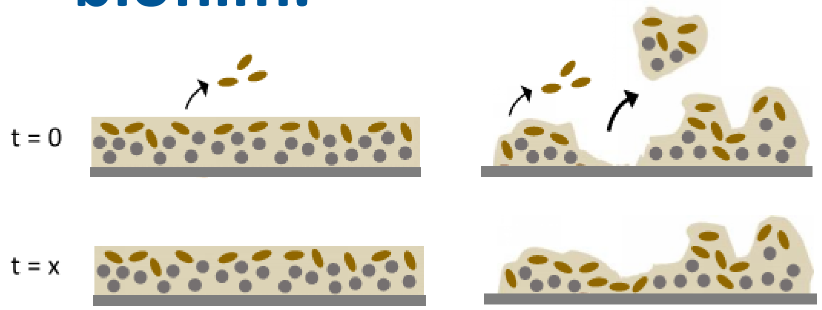
MABR Pilot Research Question # 1

*Evaluate the **aerobic solids retention time (SRT)** required to achieve **nitrification** in an **MABR** configuration compared with a **Suspended Growth BNR** configuration*

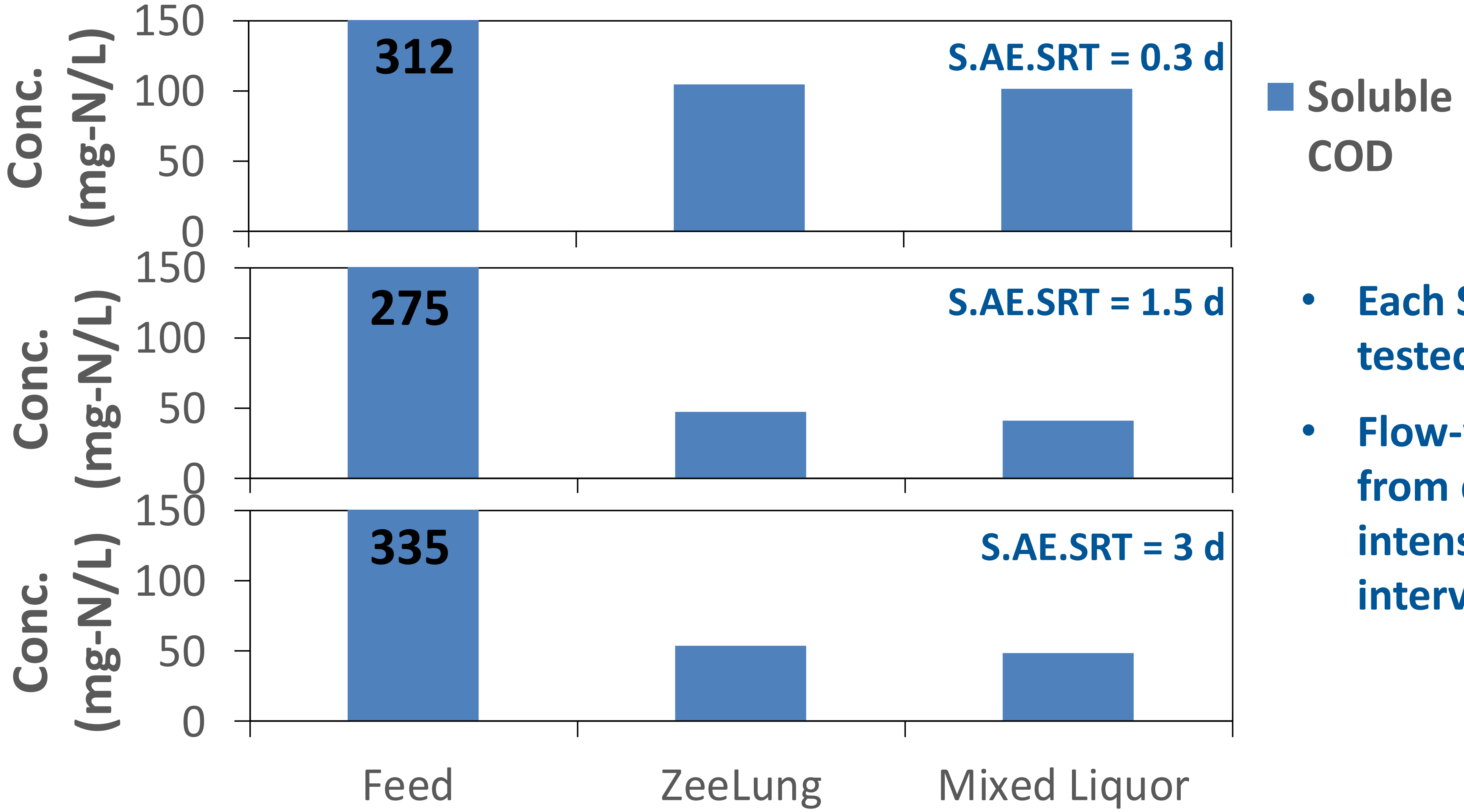


**modeling results*

1. **Lower nitrification "work" required by suspended sludge**
2. **"Seeding" effect by the biofilm.**

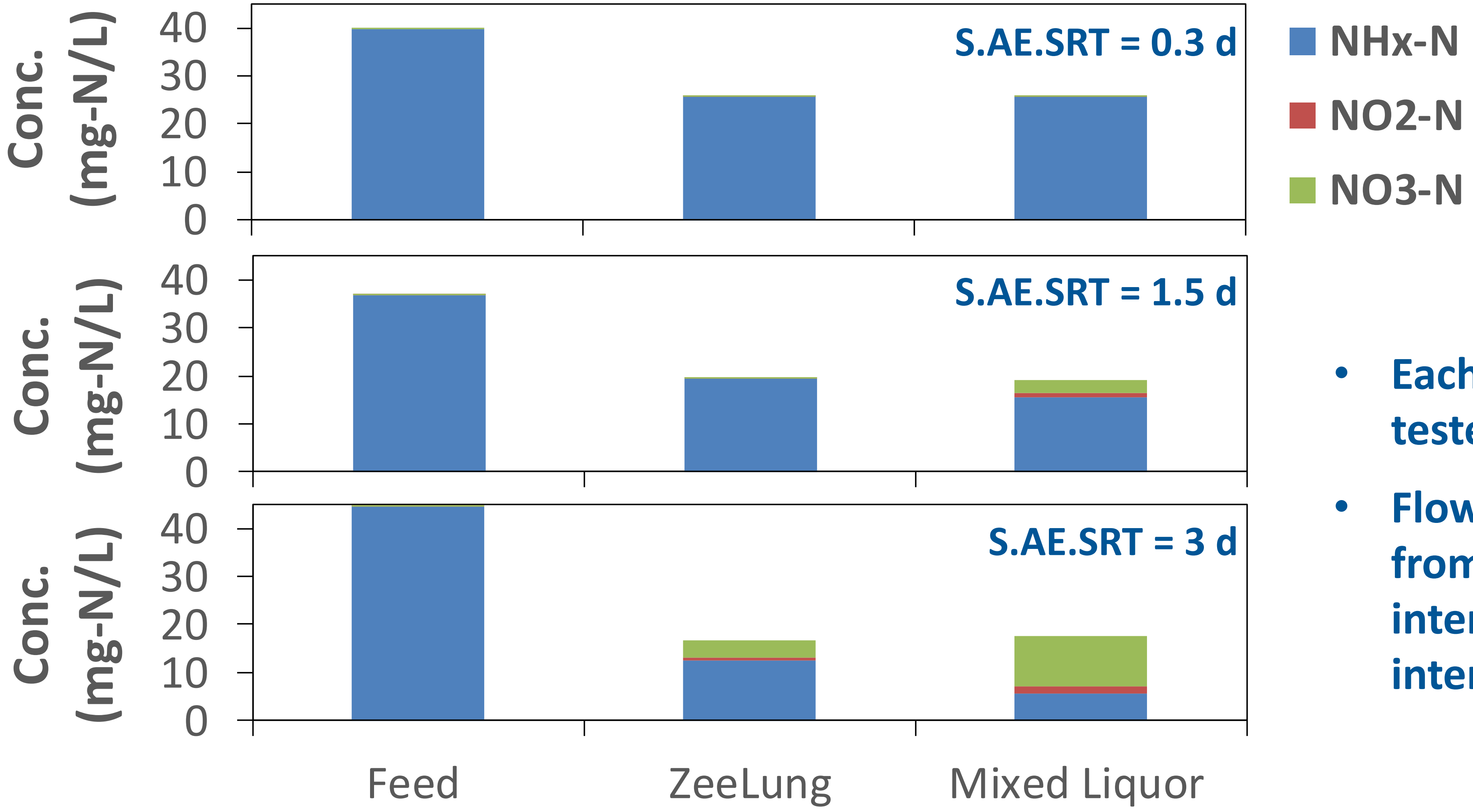


Pilot (MABR+ Sus. Growth) Performance At Different SRTs



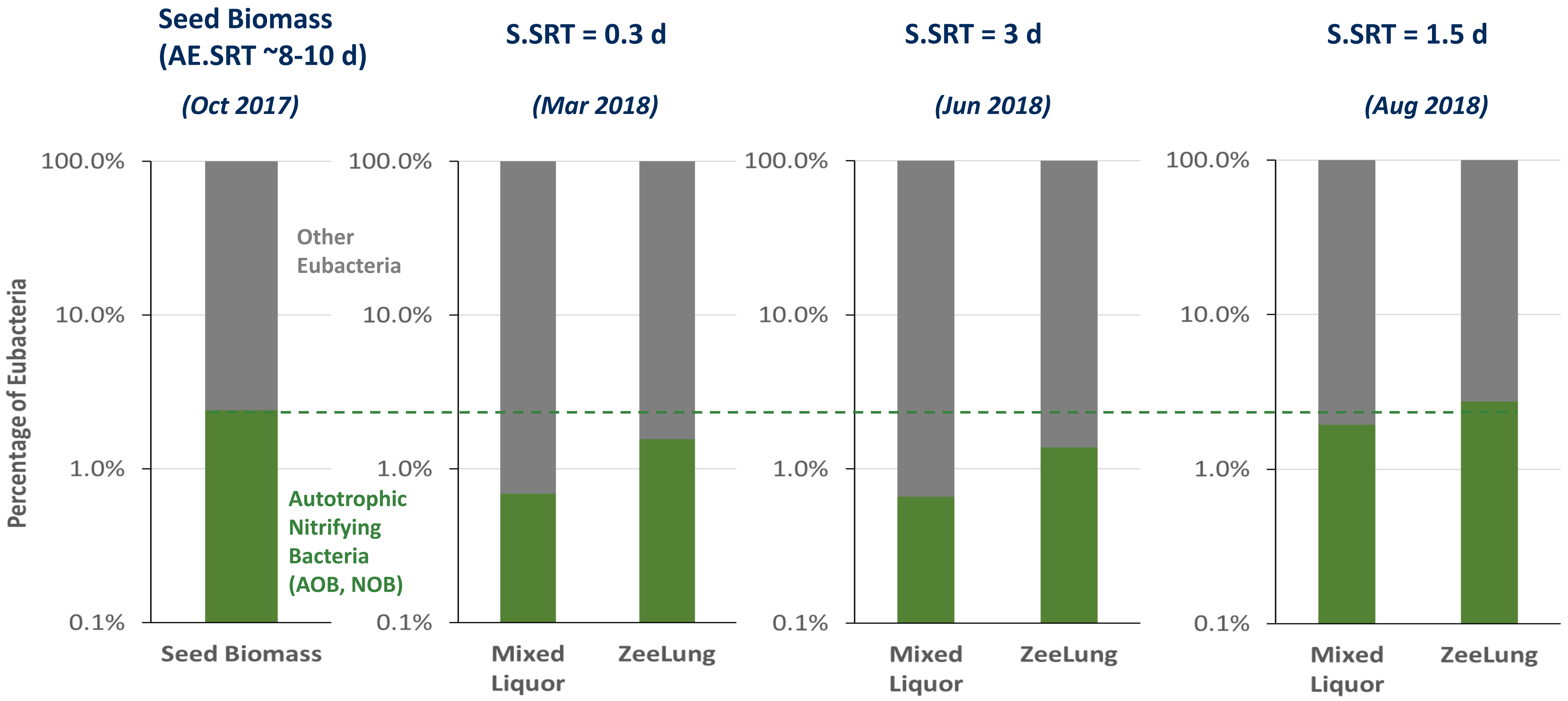
- Each SRT Condition tested for > 5X SRT
- Flow-weighted average from duplicate 24-h intensive sampling (2h interval) results

Pilot (MABR+ Sus. Growth) Performance At Different SRTs



- Each SRT Condition tested for > 5X SRT
- Flow-weighted average from duplicate 24-h intensive sampling (2h interval) results

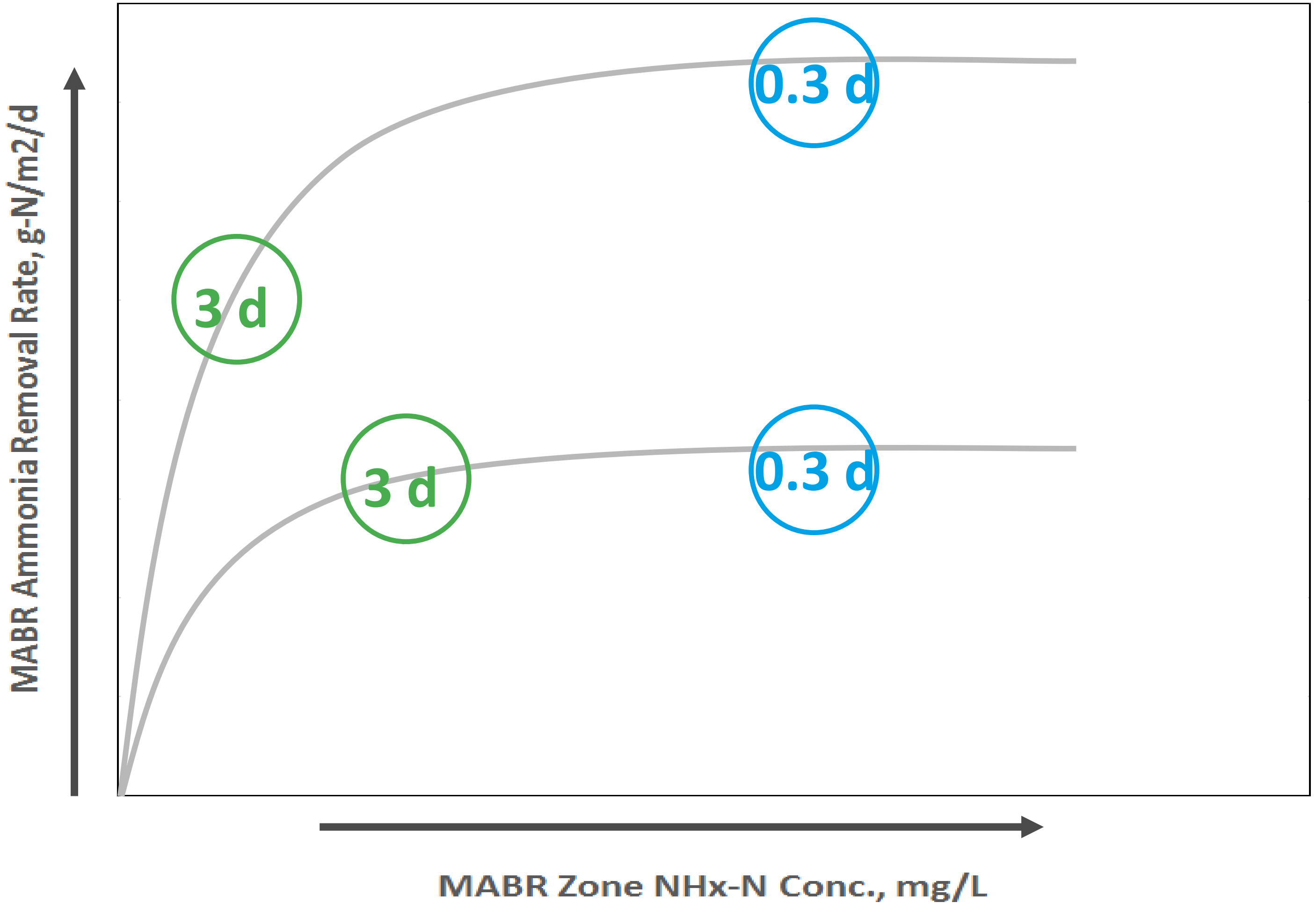
Looking at the Nitrifying Fraction of the overall biomass



Calculated using qPCR & assumptions related to gene copies in specific phyla
qPCR data from Chandran lab (Columbia University)

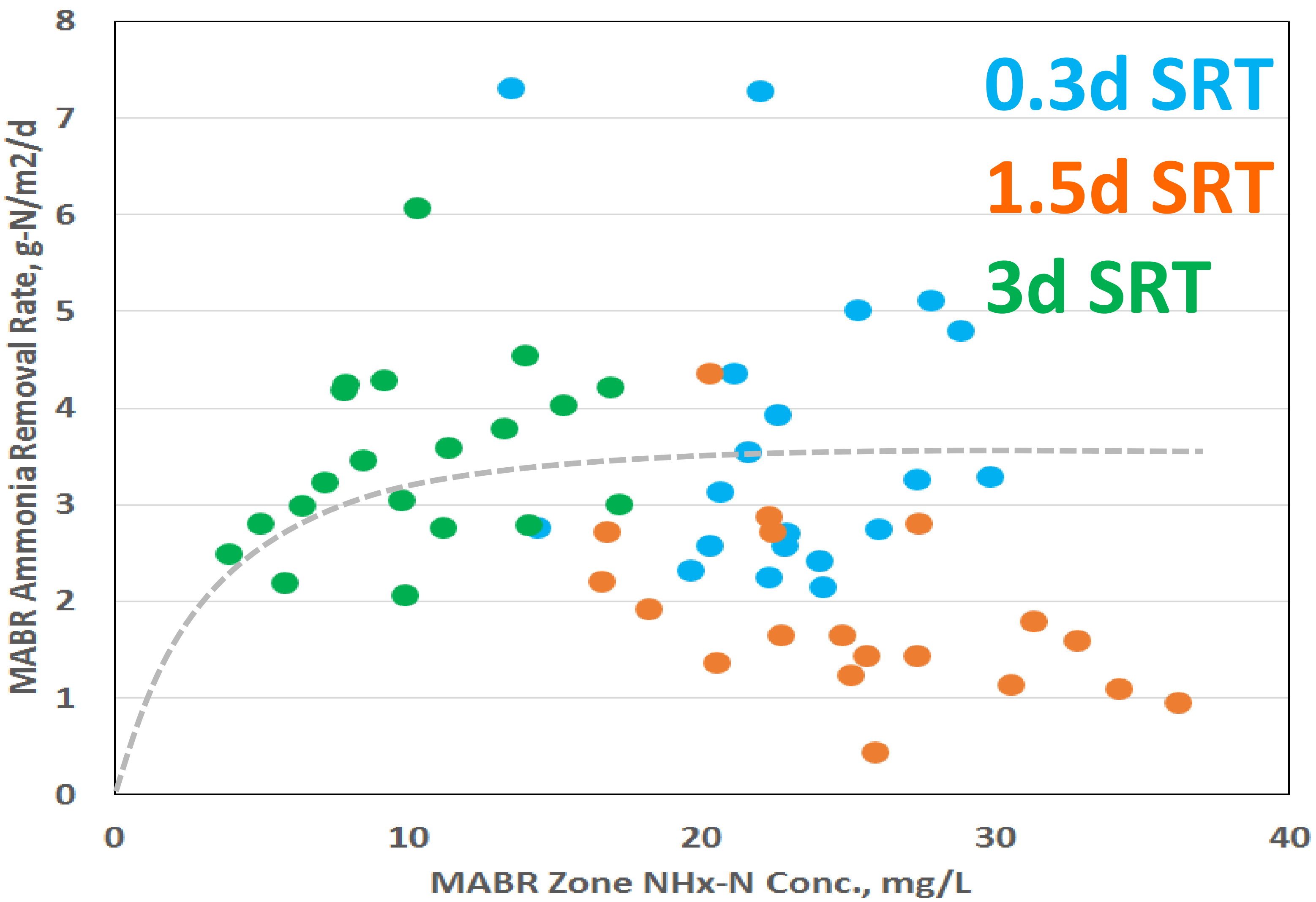
MABR Pilot Research Question #2

*How does **Suspended Growth AE SRT** impact **Nitrification Rate** (g-N/d/m²) of MABR Biofilm?*



- Key Design Parameter
- Longer Suspended Growth AE SRT should lead to **lower NHx-N Concentration** in MABR Zone

MABR Ammonia Removal/Nitrification Rate



3d SRT v.s. **0.3d SRT**

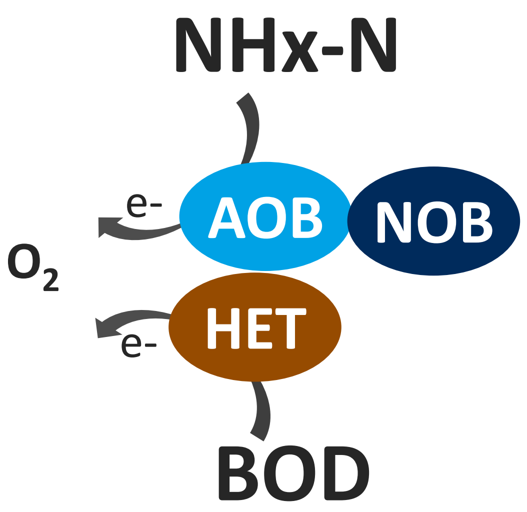
- Nitrification Rate increased from ~3 to ~4 g-N/m^2/d as suspended growth AE SRT decreased from 3 to 0.3d.

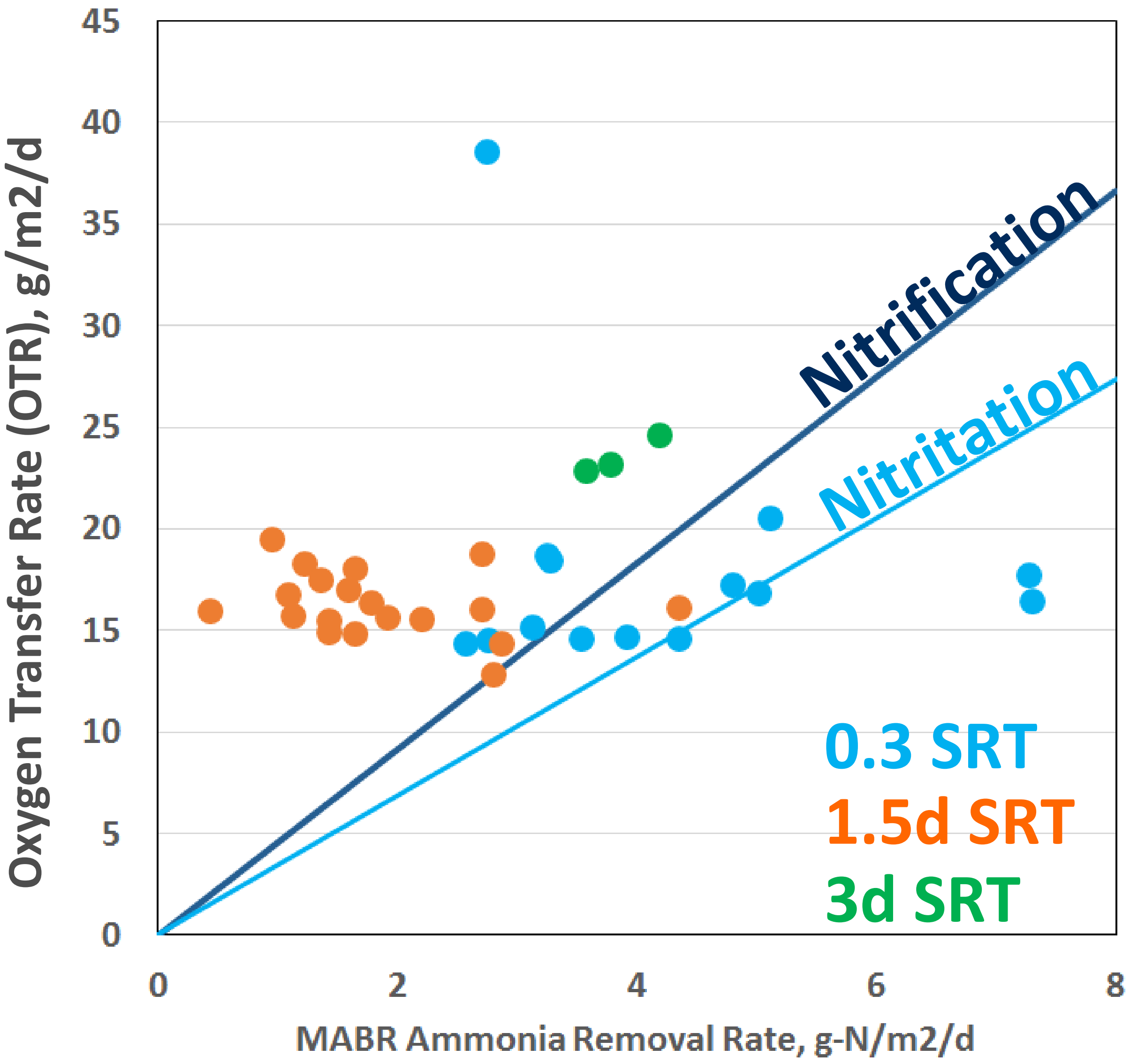
3d SRT v.s. **1.5d SRT**

- lower rate at higher NHx-N conc.?

Low Nitrification Rate @ High Ammonia Conc.?

- Similar OTR but different nitrification rate
- lower rates are a result of oxygen used for other activities (e.g. BOD oxidation)



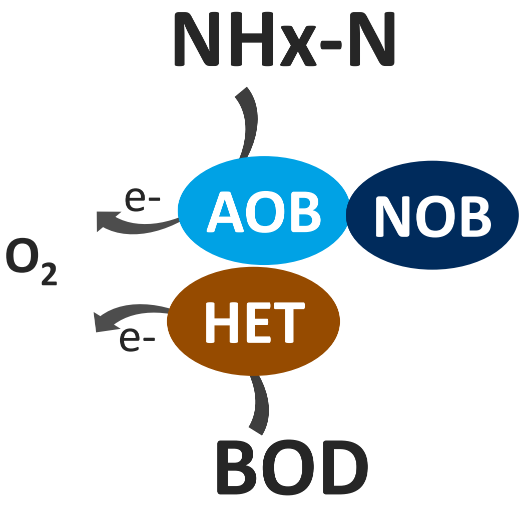


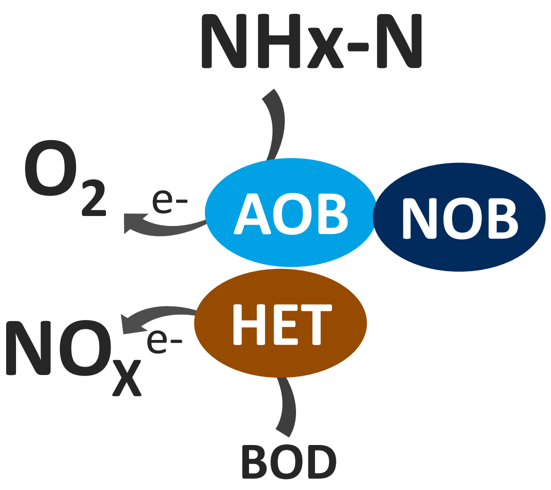
Lower Nitrification Rate @ Higher Ammonia Conc.?

Hypothesis 1:

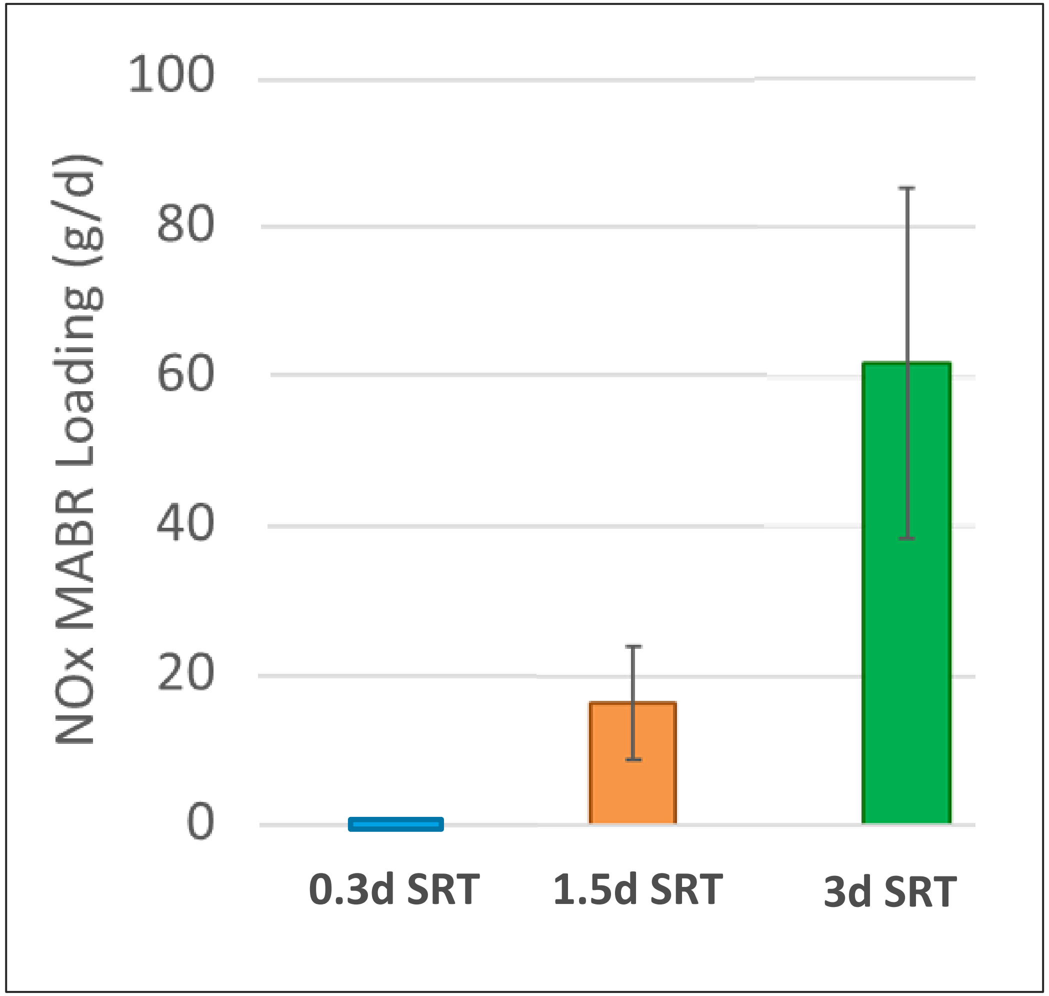
- SRT influence O2 availability for nitrification

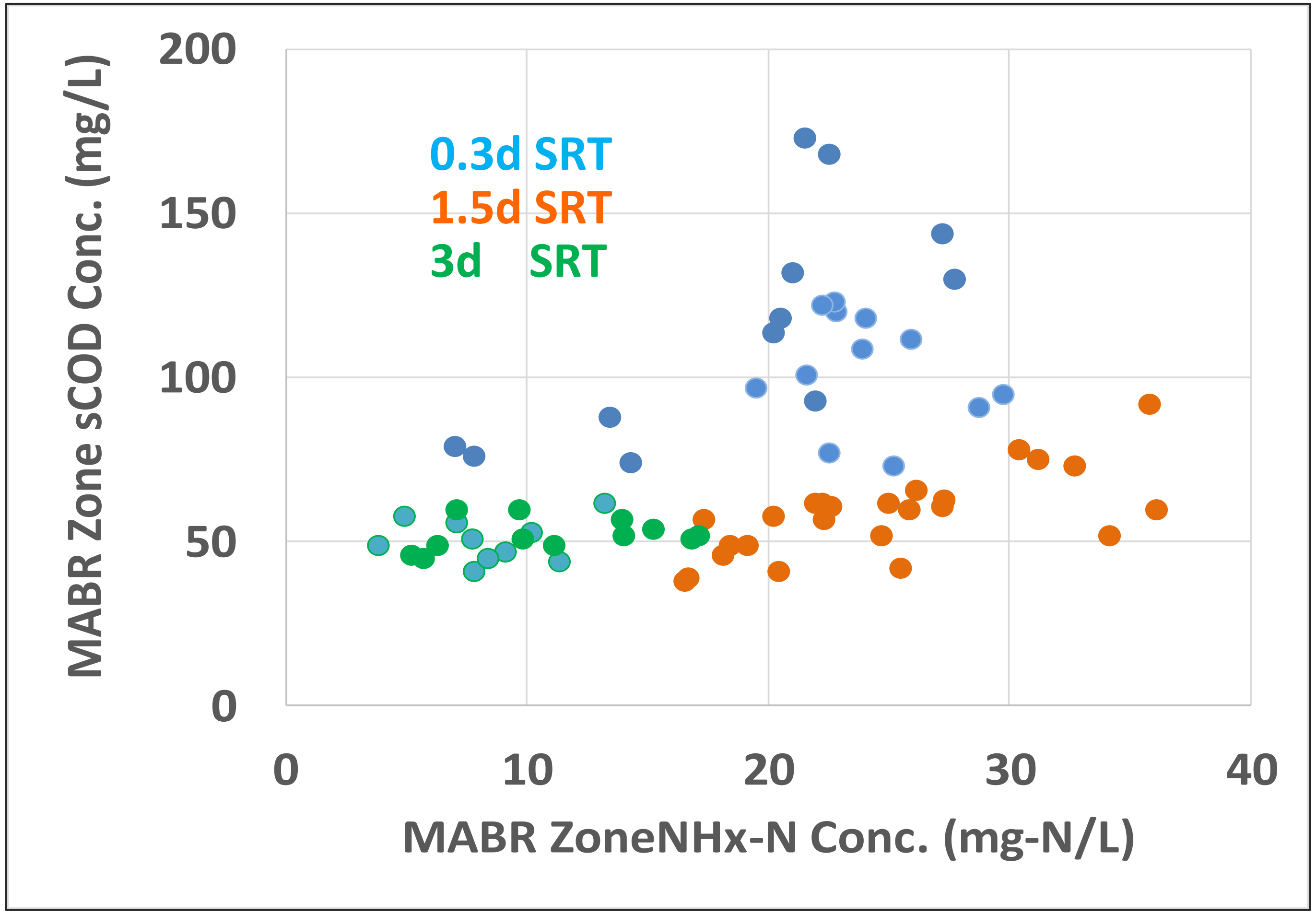
Increase BOD Conc. ⟵ **Shorter SRT** ⟶ **Reduce NOx Returned**



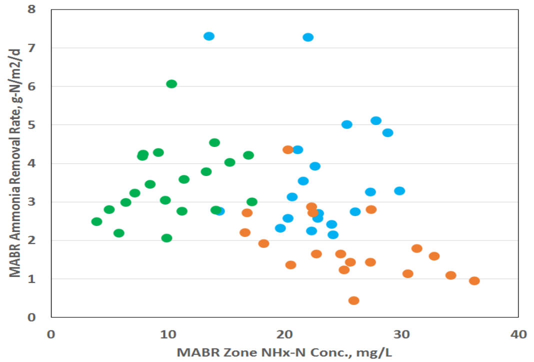


SRT Decrease->
Less NOx Return & Increased COD Conc.





Low Nitrification Rate @ High Ammonia Conc.?



Hypothesis 2:

- lower rates are a result of changes in the biofilm microbial ecology over time and the order of the experiments

Feb, 2018	March-July, 2018	July-Sept, 2018
0.3d SRT	3d SRT	1.5d SRT

MABR Pilot Research Question # 3

Assess the impact of the ***organic carbon to nitrogen loading rates (C/N)*** *on MABR performance.*

- Biofilm **Function**--C:N ratio affects competition between heterotrophs and nitrifying organisms for **oxygen**.
- Biofilm **Structure--** C:N ratio affects competition between **heterotrophs and nitrifying organisms** for space in the biofilm
- Biofilm **Thickness**--Excessive carbon loads can result in thick biofilms and diffusional limitation.

Different C/N Ratio->Different *Structures* of Biofilm

"high-C/N biofilm"

Typical	Primary Effluent
sCOD/NHx-N	**7**
NHx-N, mg/L	41
tCOD, mg/L	545
sCOD, mg/L	302

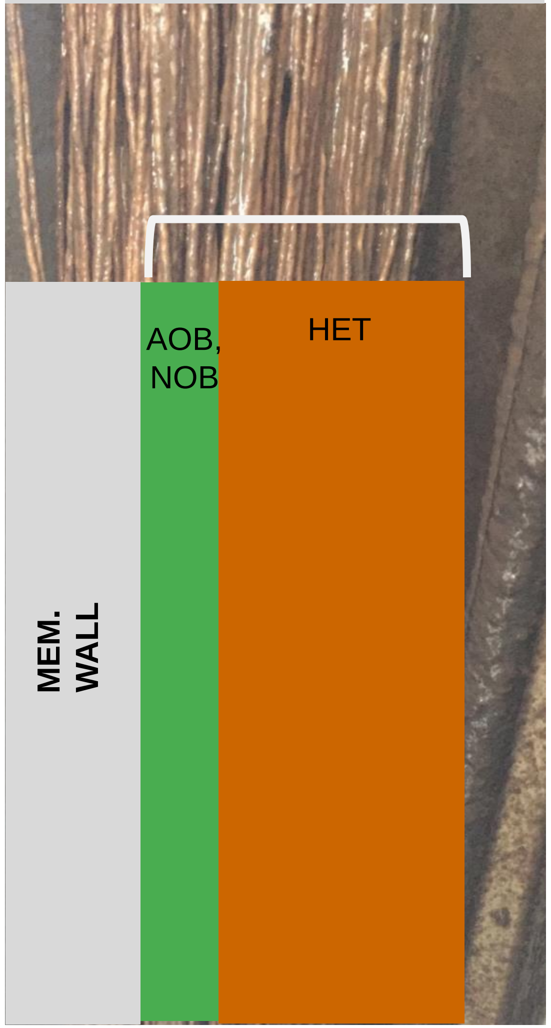
"low-C/N biofilm"

Typical	TF Effluent
sCOD/NHx-N	**2.5**
NHx-N, mg/L	34
tCOD, mg/L	280
sCOD, mg/L	85

Different C/N Ratio->Different *Structures* of Biofilm

Typical	Primary Effluent
sCOD/NHx-N	**7**
NHx-N, mg/L	41
tCOD, mg/L	545
sCOD, mg/L	302

“high-C/N biofilm”



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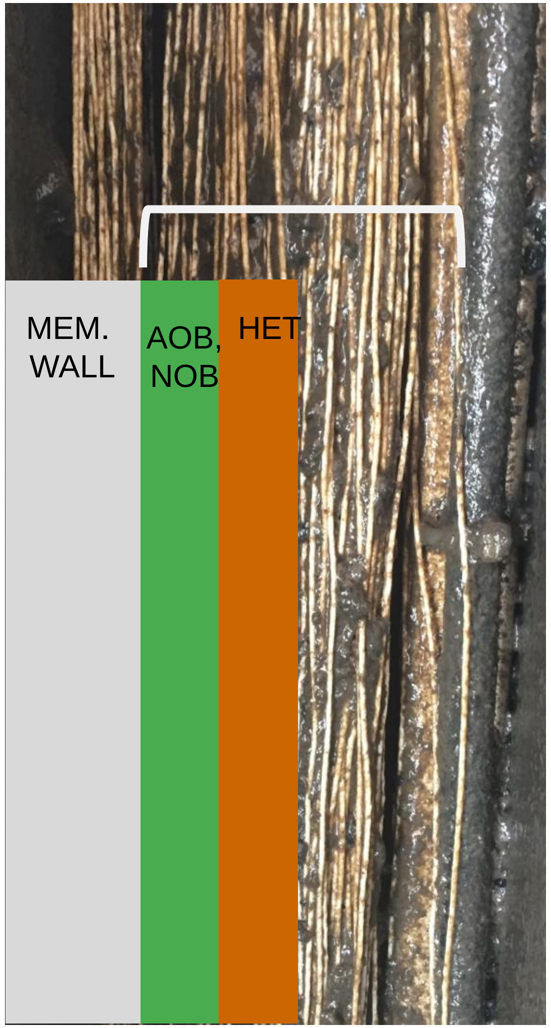
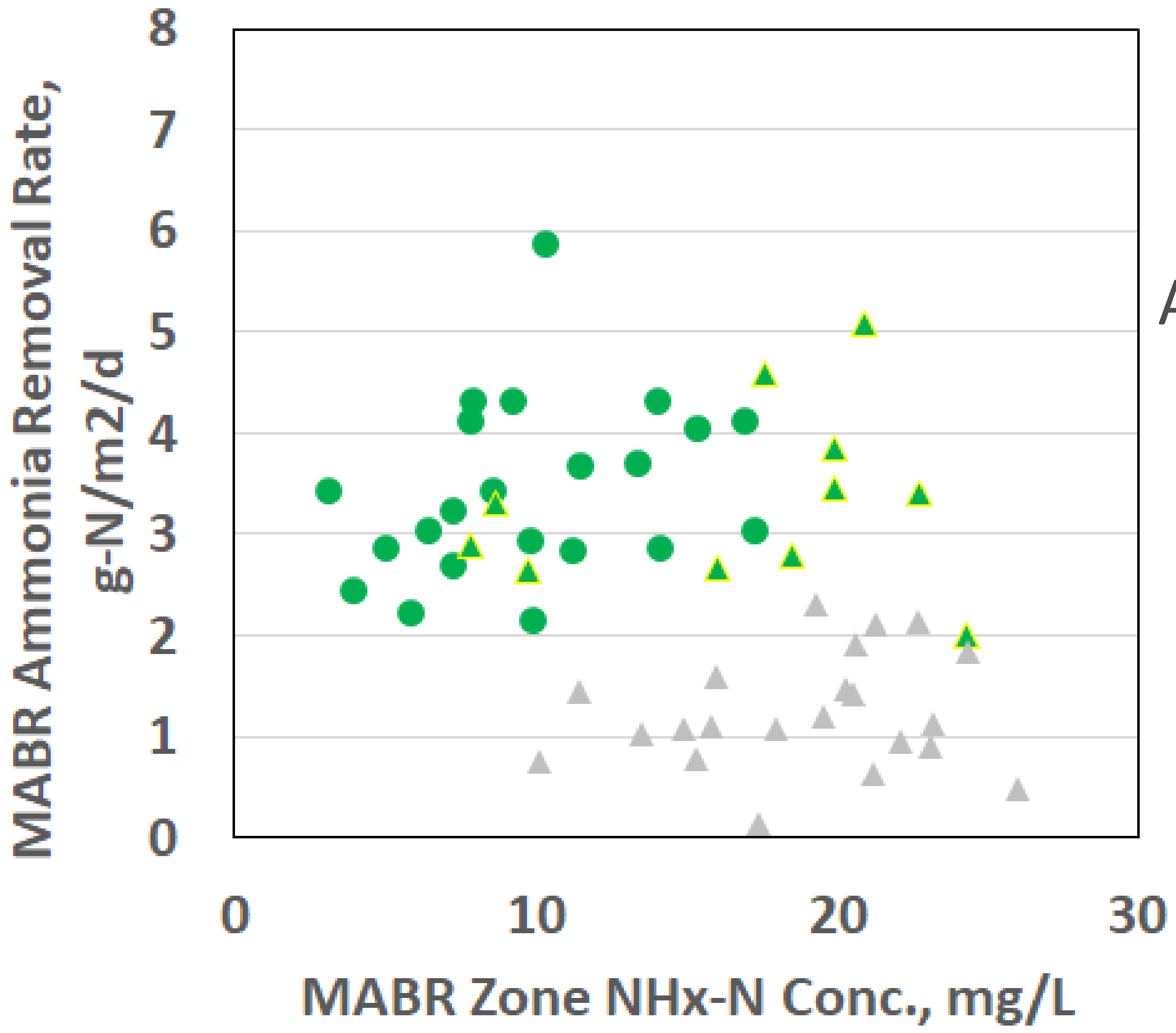


Different Biofilm *Structures*-> Different Ammonia Removal Rates



All Tested at 3d aerobic S.SRT

Biofilm Built in PE

Biofilm Built in TFE

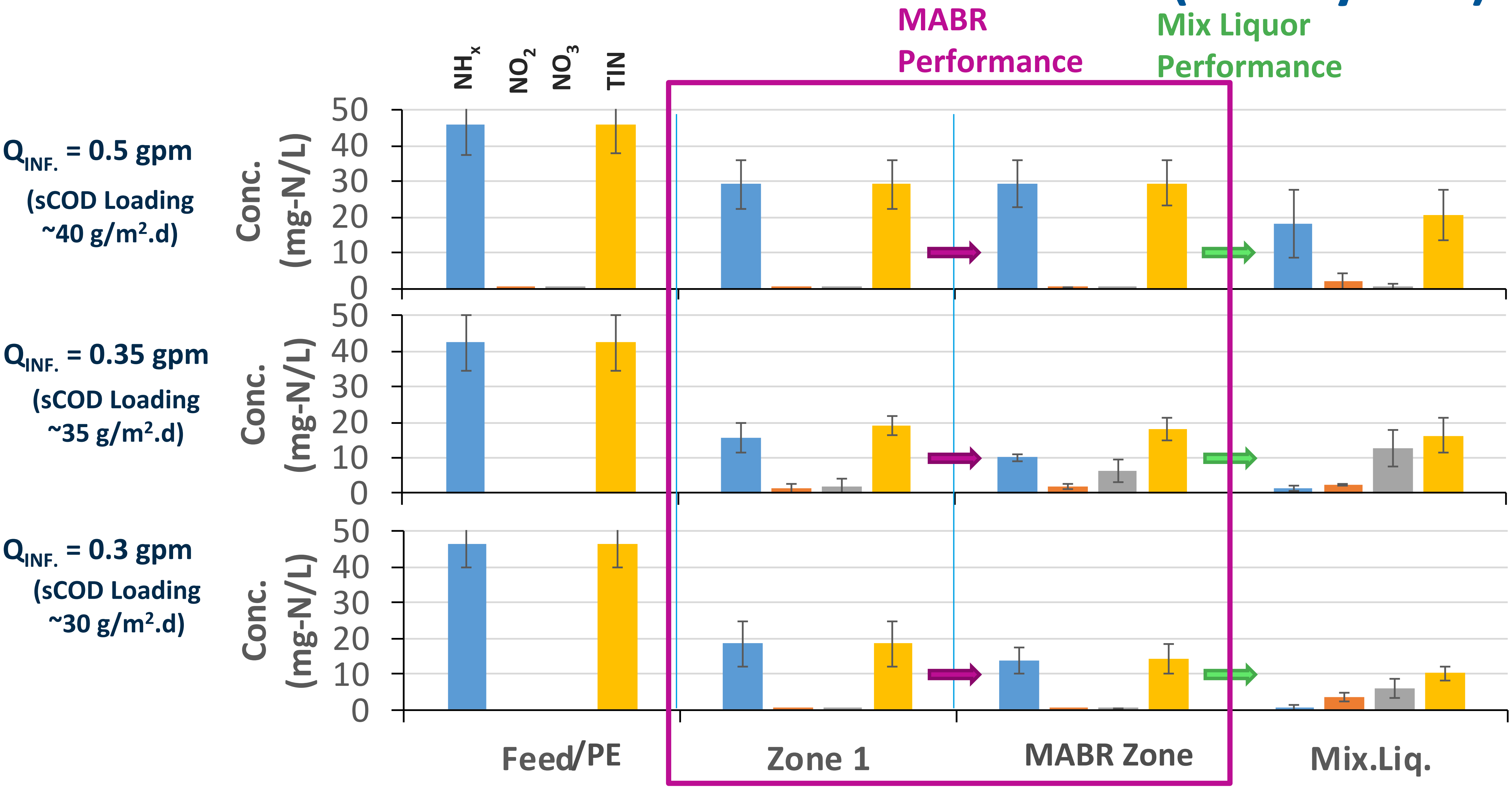
- ● PE as Pilot Influent
- ▲ TFE as Pilot Influent

What happens when COD loading is too high

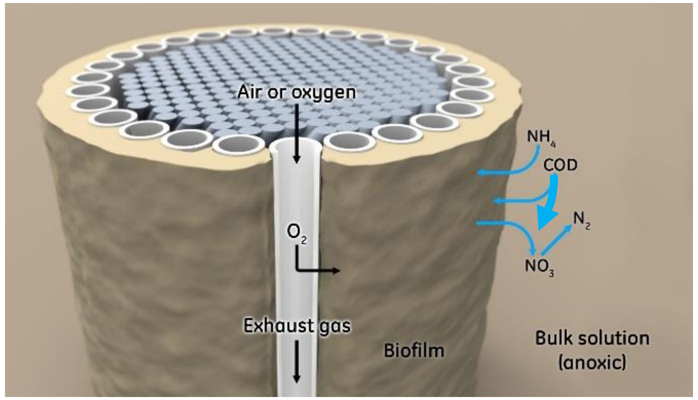
HIGHER LOADING CONDITIONS
(sCOD Loading ~60 g/m².d)

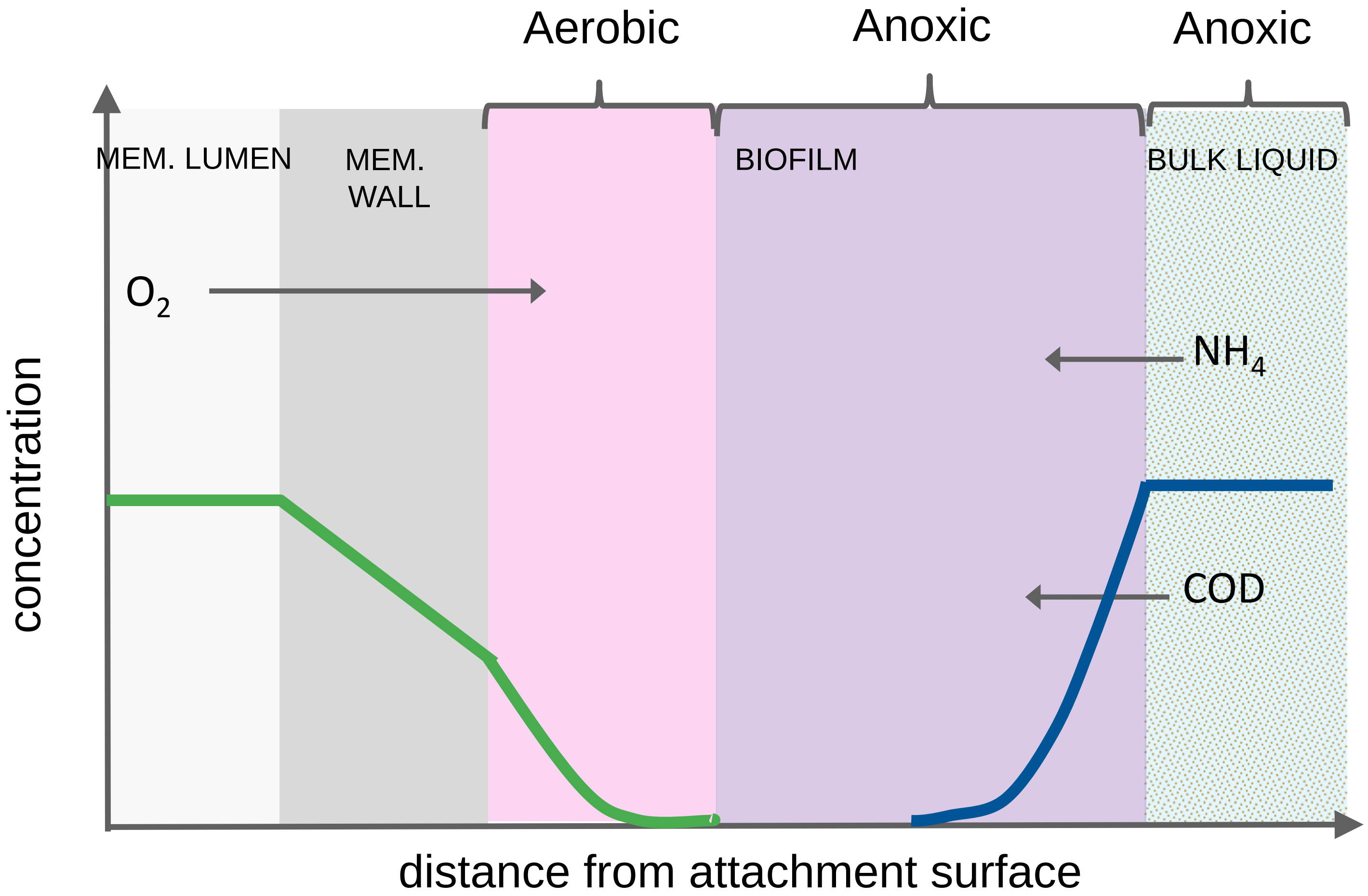
LOWER LOADING CONDITIONS
(sCOD Loading ~20 g/m².d)

Pilot Performance Under Different Flow Rate (~3 day SRT)

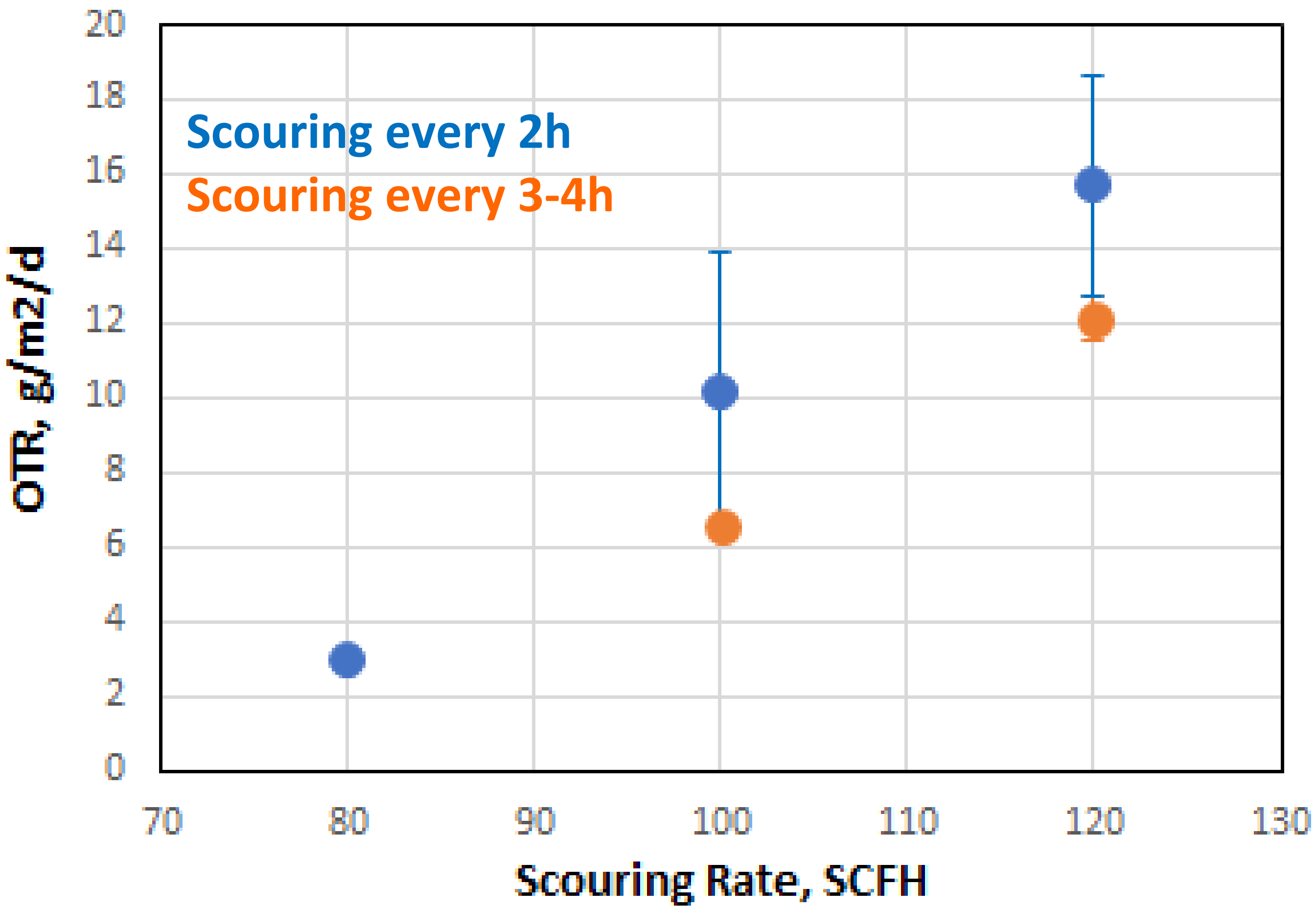


Biofilm Management is Critical





Biofilm Management is Critical for Oxygen Transfer

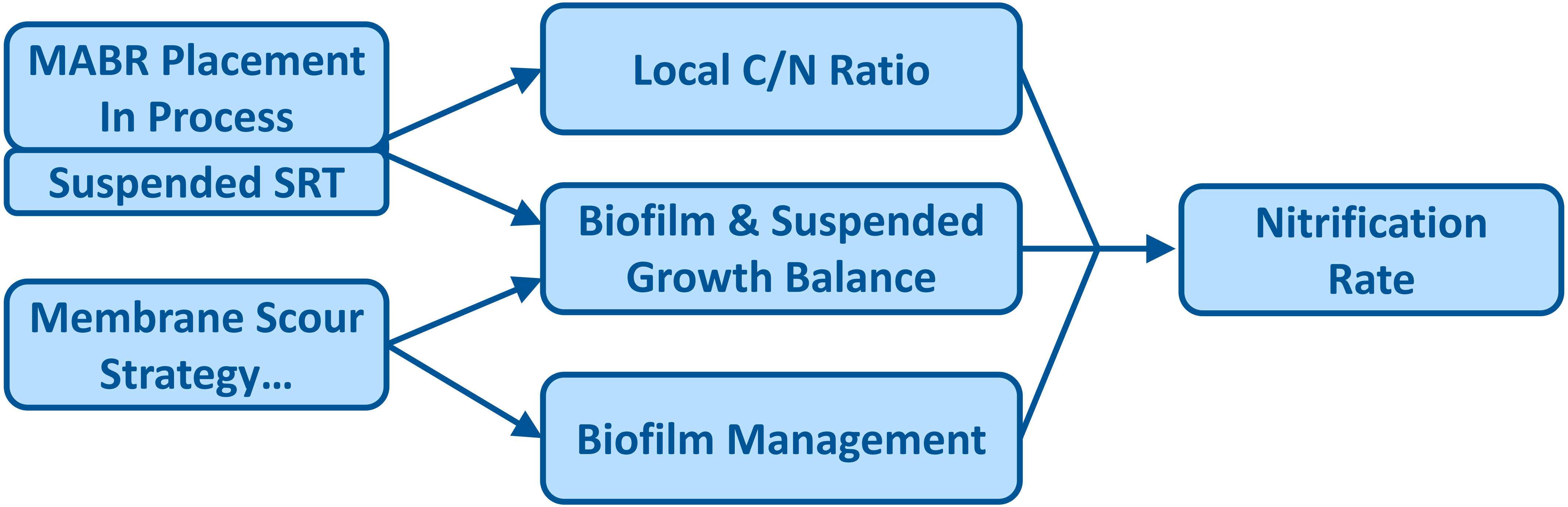


- Scouring Intensity/Rate
- Scouring Frequency/Interval
- Scouring Duration

Takeaways from MABR Research

- The **counter-diffusional** substrate delivery scheme leads to **TN removal in one Tank**.
- TN removal can be achieved at suspended **SRTs** lower than conventionally required/designed through MABR intensification
- **Biofilm Management**, **C/N Ratio**, **Balance between Biofilm** and **Suspended Growth** are critical to maintain high nitrification rate and efficient MABR performance

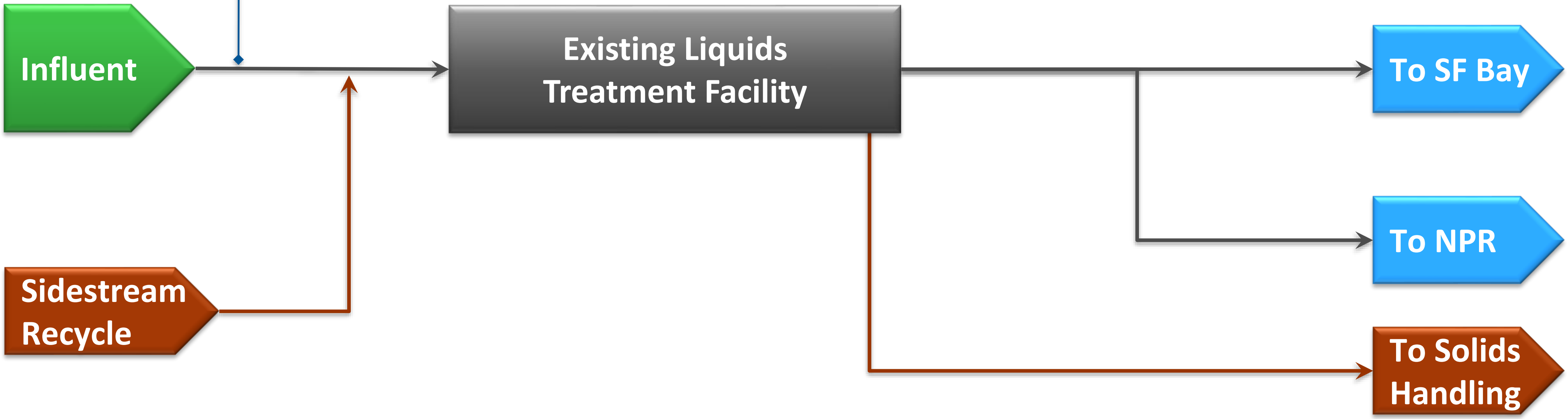
Key Factors to Consider for MABR Design



Consider expansion of an existing WRRF at an adjacent site

	Q MGD	NHx, mg-N/L	sTN, mg-N/L
AA	22	24	~35-36
MM	28	22	~33-34

- Aging facility
- Low reliability, robustness



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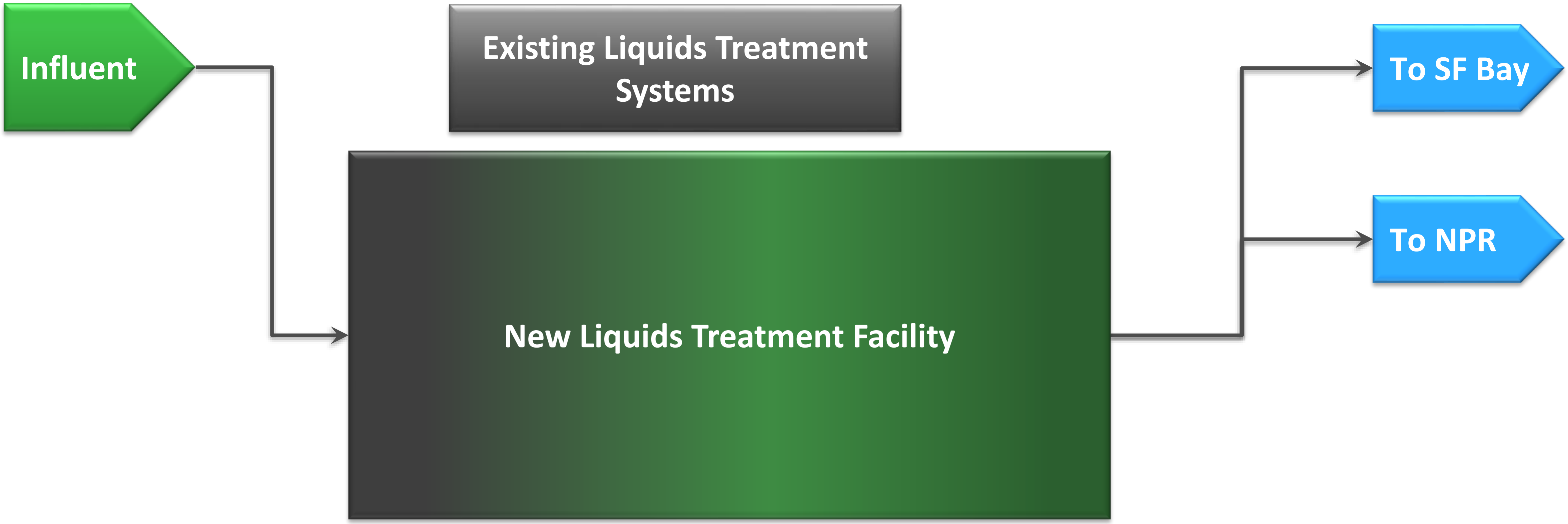
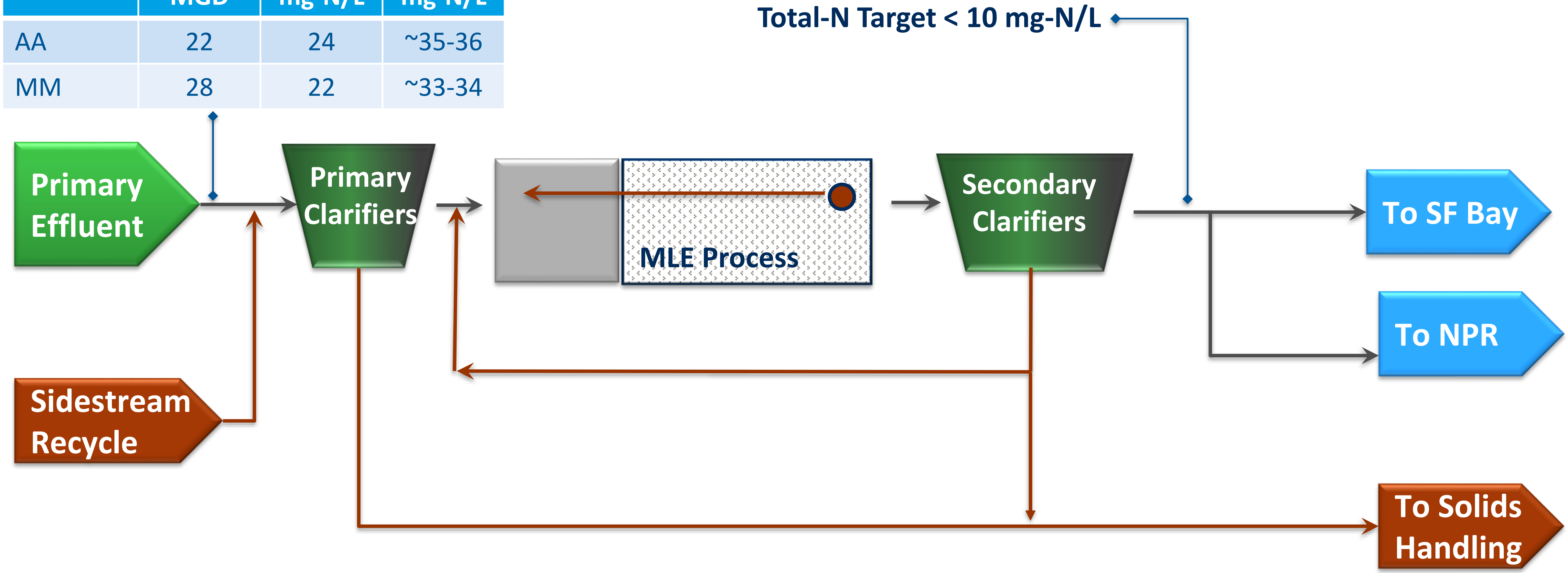
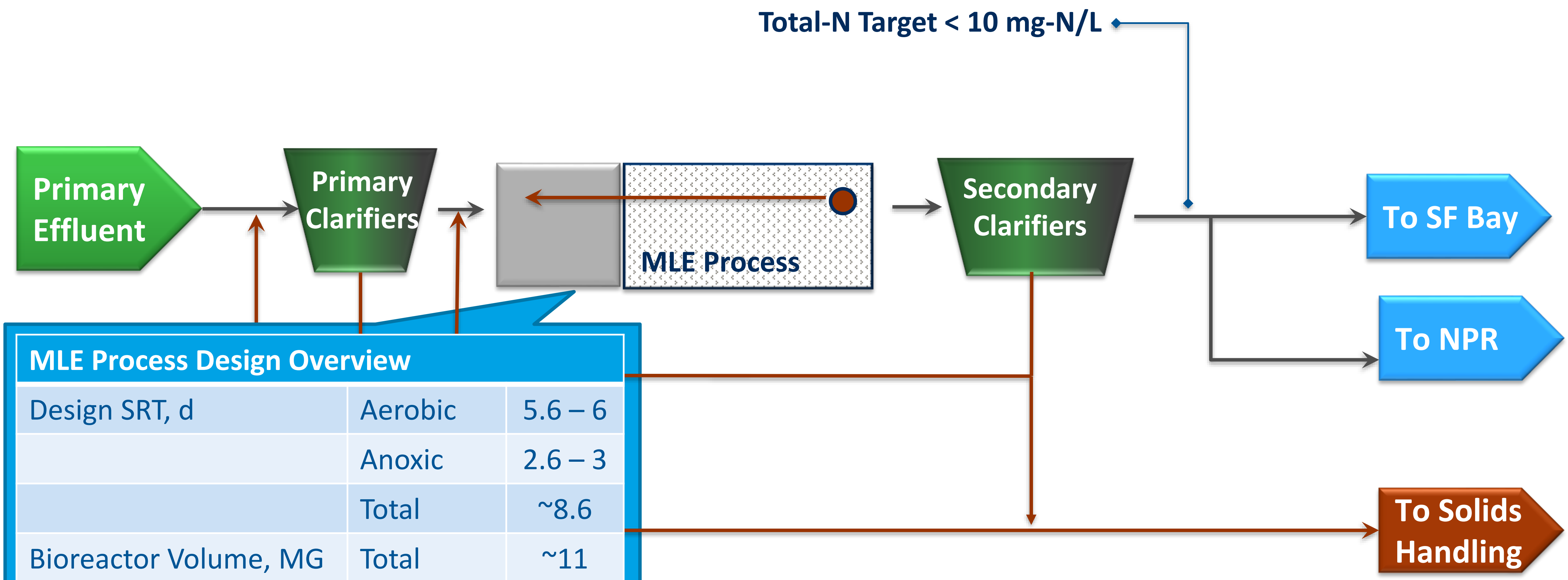


New WRRF Design (at "greenfield" site)

	Q MGD	NHx, mg-N/L	sTN, mg-N/L
AA	22	24	~35-36
MM	28	22	~33-34



New WRRF Design (at "greenfield" site)
Process Design Summary



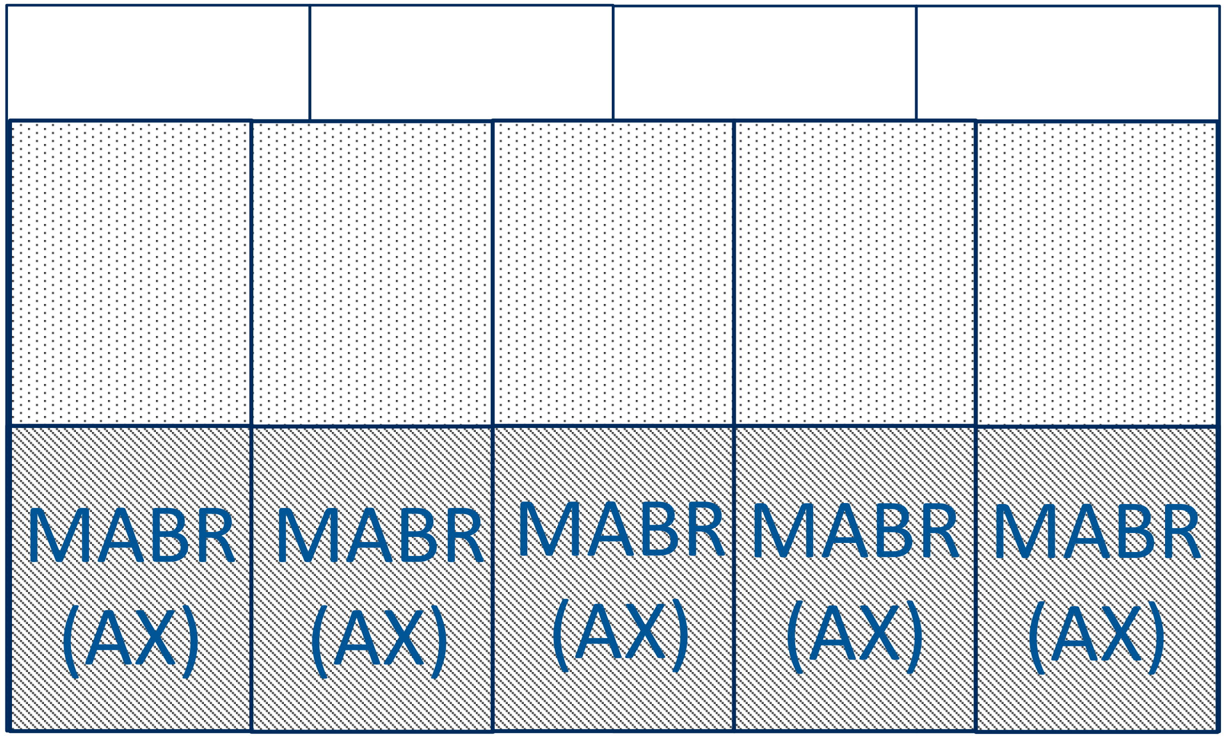
MLE Process Design Overview		
Design SRT, d	Aerobic	5.6 – 6
	Anoxic	2.6 – 3
	Total	~8.6
Bioreactor Volume, MG	Total	~11
Side Water Depth, ft		25
Target MLSS, mg/L		~2,500

Can Process Intensification Help Enhance the Process Design?

- What is the potential suspended SRT (and resulting volume) reduction?

- What are some trade-offs to consider?

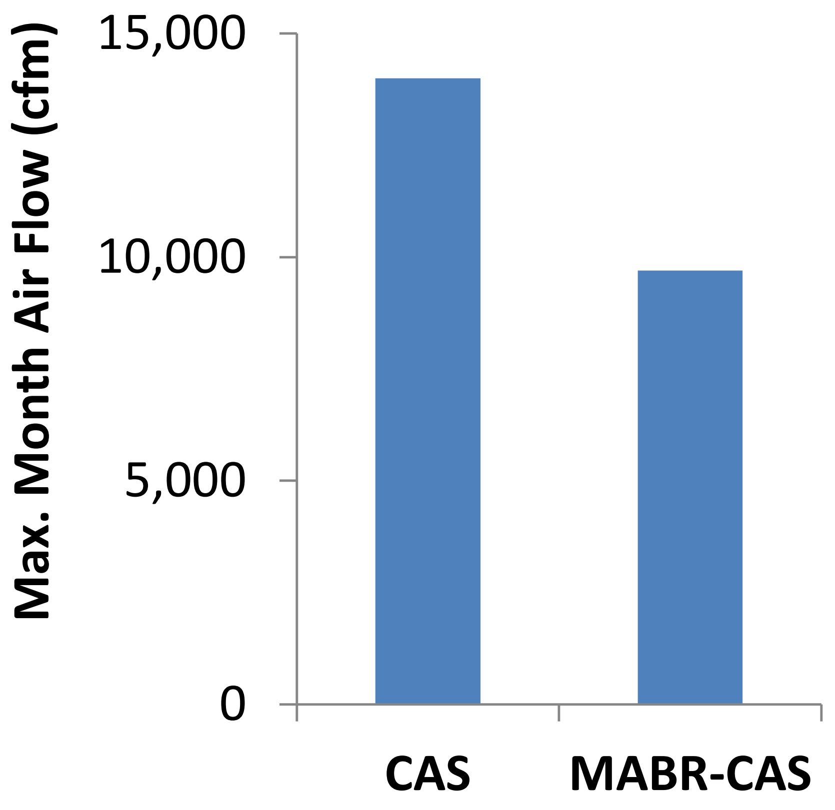
Incorporation of MABRs into the MLE design

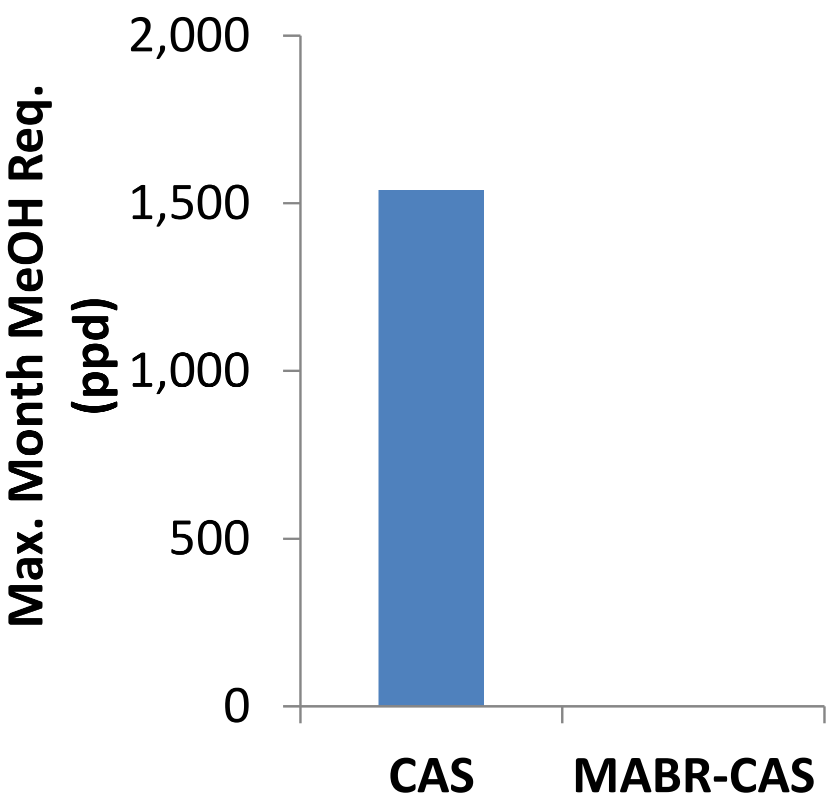


- **Current CAS Design**
  - ~ 11 MG
  - ~35% AX, 65% AE
  - $MLSS_{MAX.MONTH}$ ~ 2,500 mg/L

- **MABR-AS Design**
  - ~ 8 MG
  - ~ 50% AX
  - $MLSS_{MAX.MONTH}$ ~ 2,500 mg/L

Aeration & Chemical Use Benefits



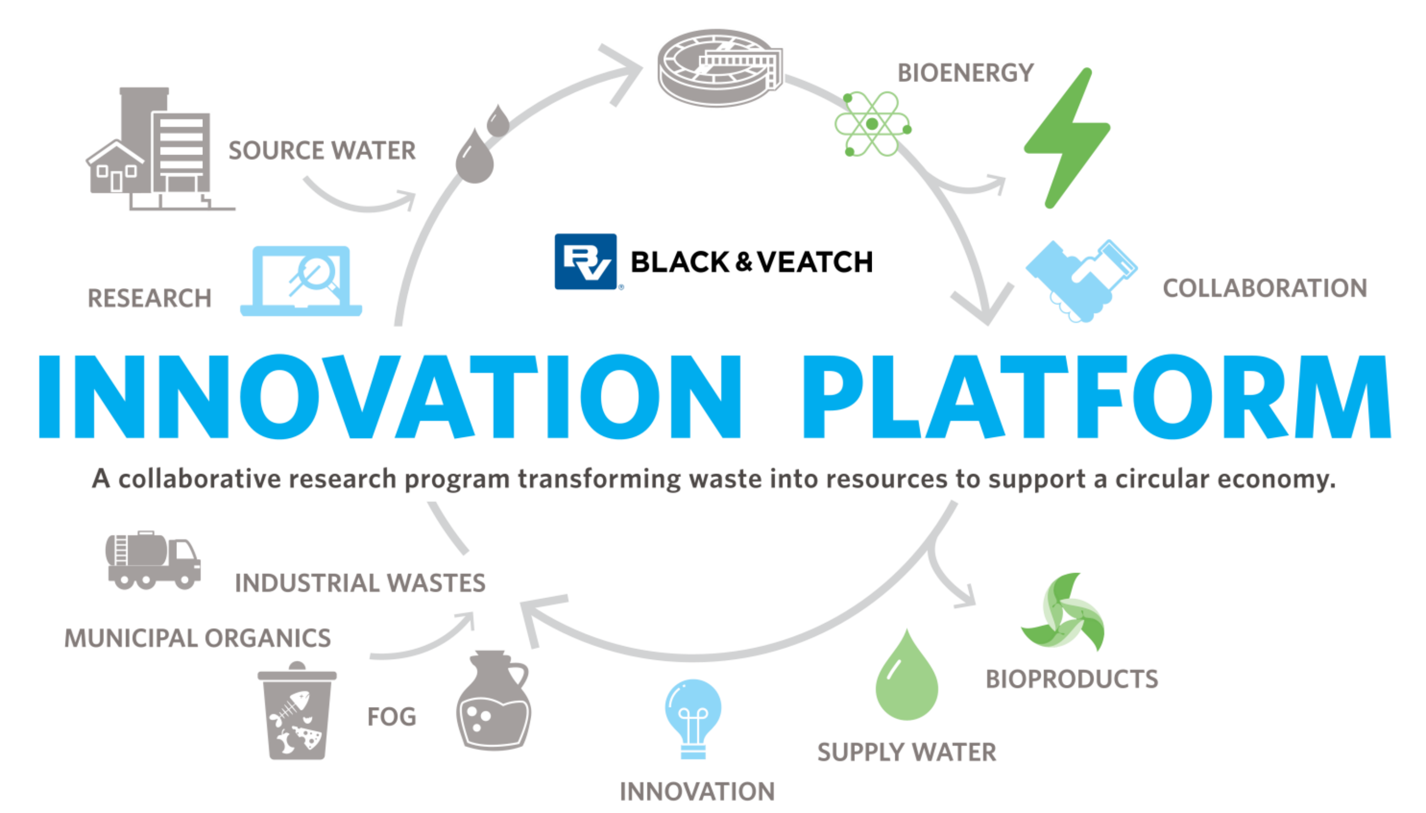


Tradeoffs

- Replacing potentially expensive concrete with equipment
  - More detailed tradeoff analyses required – including LCA, etc.
- But – there are benefits to reducing overall tank depth
  - Safety, operability, etc.

- Can this not be planned for as part of a future “plug-and-play” solution?
  - Yes…& No
  - Overall plant design/integration and system design are critical
    - (any) technology needs to be “best positioned” for success
    - For MABRs – hydraulics are key: shortcuiting, bypassing, best use of membrane area, etc.

BUILDING A WORLD OF DIFFERENCE



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