Jacobs In the kNOW

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We encourage you to submit questions in the chat.

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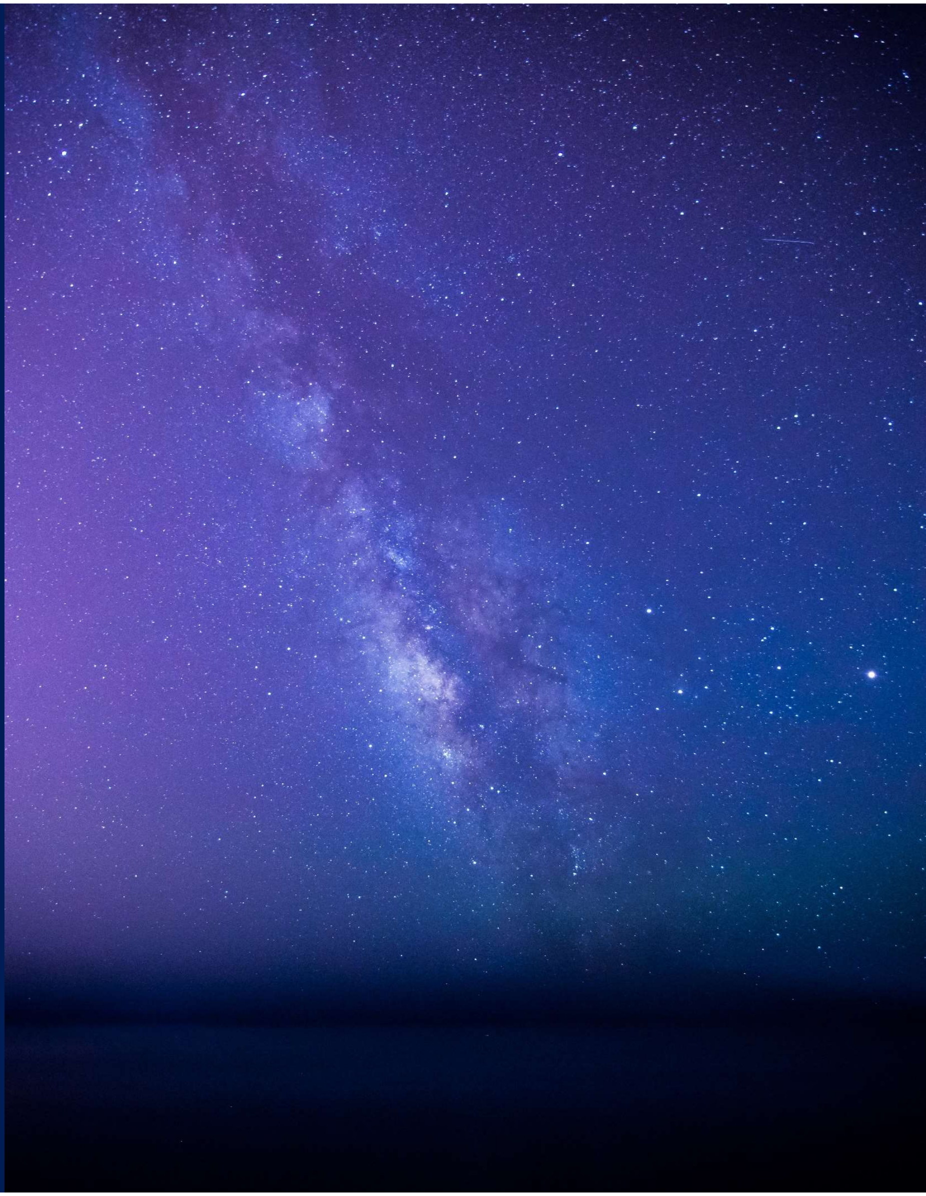

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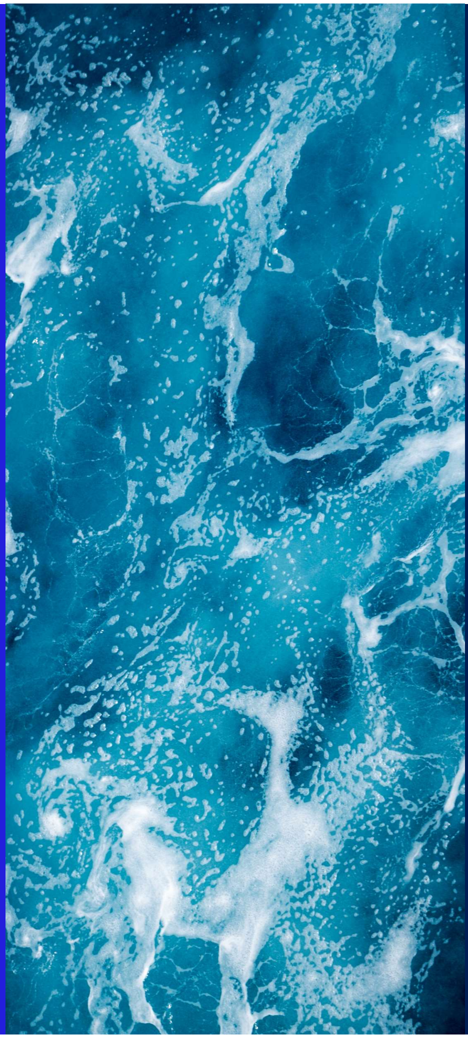
MABR technology:

The New “~~Double~~ Triple Threat” for Energy, Capacity, and N_2O Emission Benefits

In the kNOW Webinar Series

Mar 2, 2023



Agenda

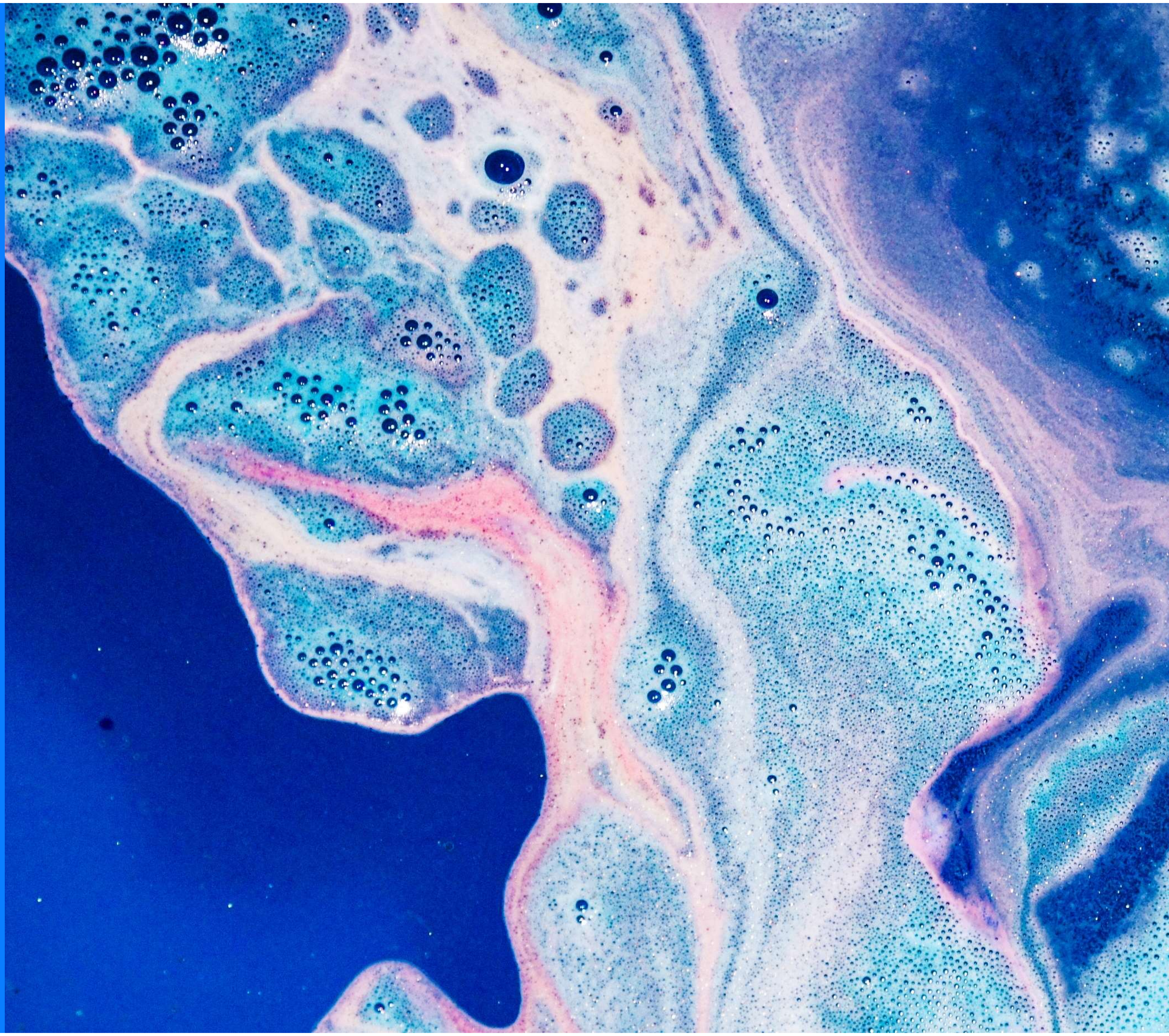
Introductions

MABR Technology:
Applications and Benefits

Case Study #1
Ejby Mølle WRRF, Denmark

Case Study #2
Elmira WWTP, Canada

Live Q&A



Introduction

Colin Newbery

About Jacobs In the kNOW webinars

Introduction

Delivers the latest information on the hottest topics trending in the water sector. Each webinar includes case studies and firsthand experiences with the featured topics presented by the foremost water industry experts.

The webinar series was launched to provide a platform to connect with the water sector, share innovations and offer professional development credits.

Visit: www.jacobs.com/webinars/in-the-know

Identifying Smarter Solutions to Infrastructure Challenges Using Optimization

Infrastructure projects are becoming more challenging as we address aging infrastructure, capacity issues, climate change, population growth and conflicts with other existing infrastructure. Optimization technology employs sophisticated algorithms, enhanced computation and automation to assist water utilities in finding solutions to these complex infrastructure problems that maximize benefits and minimize costs. In this webinar, we will present examples from Anglian Water's Strategic Pipeline Alliance, a CSO Long-Term Control Plan and others with our partner Optimatics.

Climate Change: How Should Water Utilities Respond to the IPCC's Call to Action?

While we respond to other pressing global challenges, climate change remains one of the biggest threats to life on this planet as we know it. As anchor institutions embedded in nearly every community, water systems have an opportunity to accelerate our progress, playing an even bigger role in delivering decarbonization and resilience measures against climate change. In this webinar we will present the key findings of the recent IPCC AR6 'Physical Science Basis' report of greatest relevance to the Water sector. We will help identify the potential vulnerabilities and make practical recommendations for resilience actions that can be taken to pro-actively manage them.

The Water Sector and Hydrogen: Green for Go

This "In the kNOW" webinar examines hydrogen from the perspective of the water sector as a potential producer and user of hydrogen. We identify pathways for hydrogen production at Water Resource Recovery Facilities, highlighting synergies and trade-offs with day-to-day treatment, and exploring hydrogen's possible contribution to the water sector's Net Zero carbon emissions targets.

Speakers

Meet our presenters

Facilitator

Speakers

Colin Newbery, P. Eng

Jacobs Technical
Director, Water, Asia

Tim Constantine P. Eng

Jacobs Global Principal for
Wastewater Treatment

Adrienne Willoughby, P. Eng

Jacobs Process Engineer,
Canada

Our speakers

Meet our presenters

Tim Constantine, P.Eng.

Global Principal
Wastewater Treatment

- 28 years experience
- Global leadership in Process Engineering at Jacobs
- Studies and designs for over 300 treatment plants globally
- Two US Patents
- MABR technical leadership
  - Ejby Mølle WRRF (Denmark)
  - Elmira WWTP (Canada)
  - Numerous technology evaluations

Adrienne Willoughby, P.Eng.

Senior Process Engineer

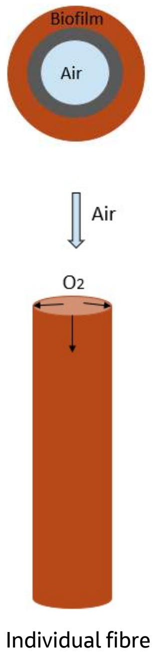
- 12 years experience
- Process leadership with technologies including MABR, InDENSE, others
- Process engineer and Design Manager for MABR implementation in Elmira, Canada
- MABR process modelling expertise

MABR

Applications and benefits

MABR Background – What is it??

- **M**embrane **A**erated **B**iofilm **R**eactor
- Bundles of hollow fibre gas permeable membranes through which air/O_2 is passed



- Biofilm growth on exterior of fibre
- Microbiology respires directly from lumen surface

MABR Background – Who are the Manufacturers?

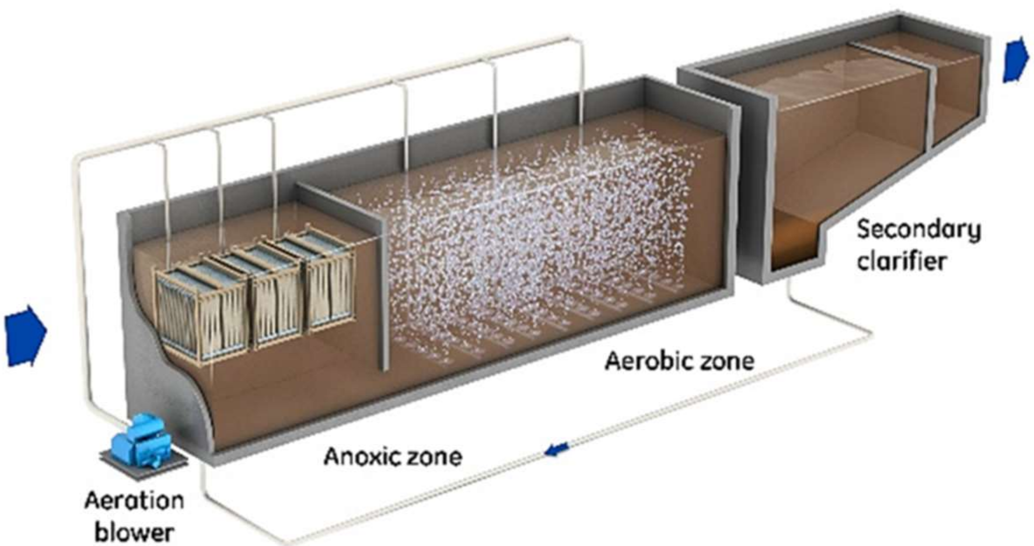
- Veolia Water Technologies and Solutions (previously SUEZ)
  - Product name: ZeeLung

- Dupont Water Solutions (previously OxyMem™)
  - Product name: OxyFAS and OxyFILM

- Fluence (previously Emefcy)
  - Product name: Aspiral and Subre

MABR Background – How is it typically applied?

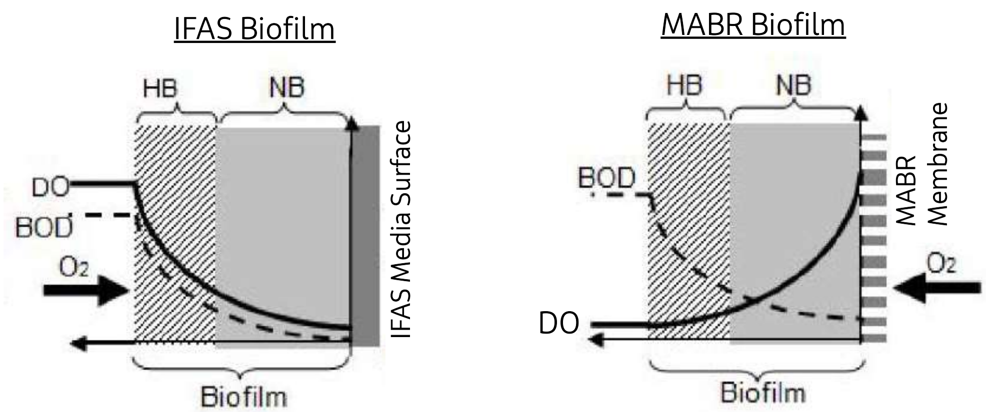
- Typically installed in anoxic/anaerobic zones in "hybrid" configuration
  - MABR biofilm operates in concert with suspended growth activated sludge
- MABRs most cost effectively target nitrification
- Configuration allow simultaneous nitrification/denitrification in anoxic zone



Courtesy Veolia Water Technologies and Solutions

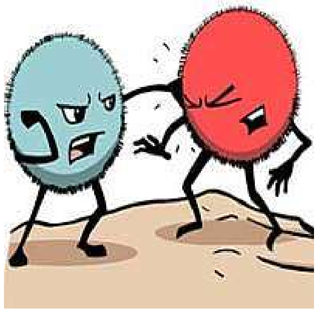
MABR Background – How it works and what are the Benefits

- Technology is very analogous to integrated fixed film activated sludge (IFAS), but with key differences:
  - Countercurrent vs. co-current biofilm
  - O_2 delivered to nitrifying biomass with MABR
  - MABR biofilm can better target nitrifying biomass growth



HB = Heterotrophic Bacteria NB = Nitrifying Bacteria

- MABR Benefits:
  - Very high oxygen transfer efficiency
  - Increased process capacity compared to conventional activated sludge
  - Lower greenhouse gas (GHG) emissions, particularly N_2O



MABR Benefits – Oxygen Transfer Efficiency

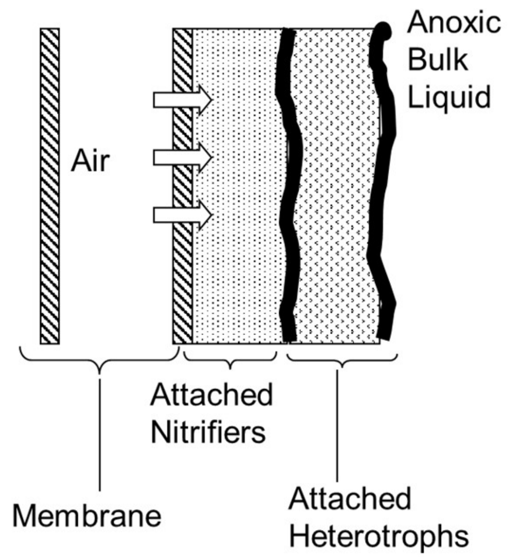
- Let's first look at the efficiency of conventional aeration

Often 50% of energy costs!

- Oxygen transfer efficiency (OTE) only 10 – 15%
- Most O_2 unutilized
- Delivery point is at the bottom of tank (relatively high pressure = high energy)
- High energy demands

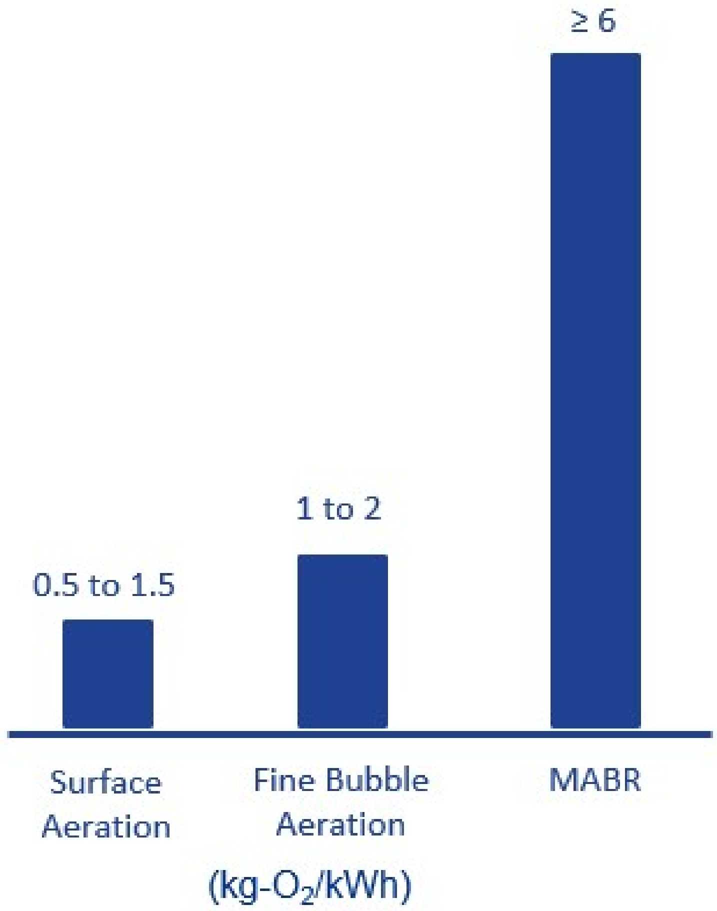
MABR Benefits – Oxygen Transfer Efficiency

- High specific surface area allows O_2 to be delivered directly to biomass
- Theoretically up to 100% OTE
- In practice, up to ~40 -50% OTE
  - Requires purge to maintain driving force for O_2 transfer
  - High OTE is independent of tank depth
- Backpressure is low (much less than tank depth)
- Low energy consumption
- High O_2 transfer per unit energy



MABR Benefits – Oxygen Transfer Efficiency

- Conventional aeration is inefficient and usually the largest energy consumer
- MABR aeration efficiency is 3 or 4 times better than fine bubble aeration



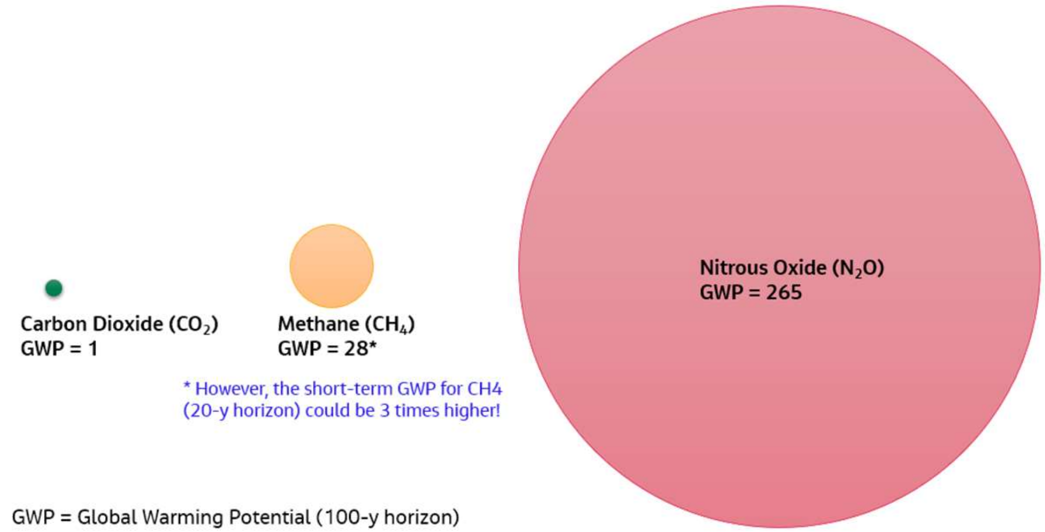
MABR Benefits – Increased Process Capacity

- MABRs operate on the same principle as other hybrid technologies such as IFAS
- Conventional systems typically require a minimum solids retention time (SRT) to maintain growth of nitrifying organisms
  - Greater bioreactor volume ($$)
- With hybrid/MABR systems, nitrifiers grow on media, then slough off to MLSS
- Hybrid systems require less suspended growth SRT, meaning less bioreactor volume
- Potentially 50% less bioreactor volume

MABR Benefits – Reduced GHG Emissions

- Energy efficiency of MABR can assist in reducing Scope 2 emissions
  - Depends upon electricity generation method (e.g., fossil fuel or "green")
- Nitrification and denitrification have been found to include pathways for significant N_2O emissions
- In general, N_2O emissions higher when:
  - Nitrification instability occurs
  - During transition from unaerated (anoxic) to aerated (aerobic) zones
- MABRs studies showing lower N_2O emissions
  - Underlying rationale still being investigated

- **Scope 1:** Direct emissions from facility (e.g., methane, N_2O)
- **Scope 2:** Indirect emissions from electricity use
- **Scope 3:** Chemicals; biosolids beneficial reuse, 'embodied carbon' in existing (and new) infrastructure

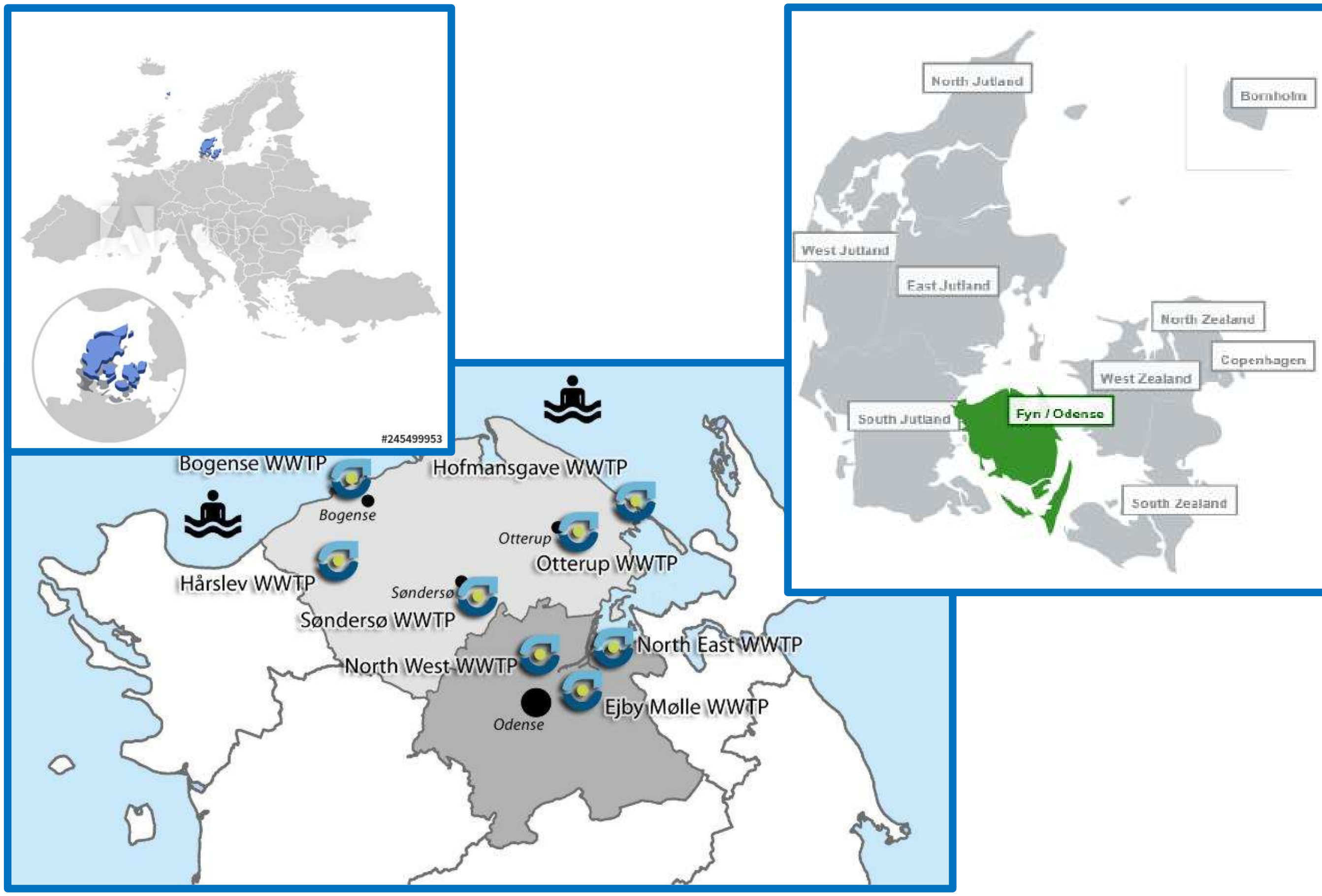


Case Study:

Ejby Mølle WRRF
Full-scale Demonstration

Background on VCS Denmark

- VCS Denmark est. 1853
- Staff of 200+ providing water supply and wastewater conveyance/treatment, treatment for pop. >400,000
- Operate:
  - 6 WTPs
  - 8 WRRFs
  - 3,400 km of conveyance



Background on Ejby Mølle WRRF – Journey to Energy Self Sufficiency

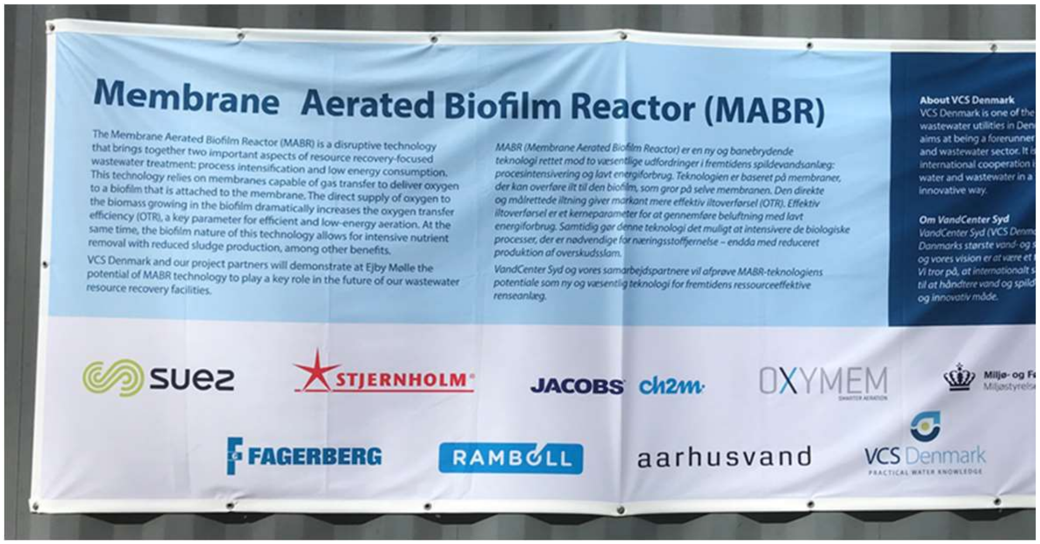
- 415,000 population equivalent facility
- Advanced BNR facility (Bio-P and N-removal)
- 76% energy self-sufficient in 2011
- By 2018:
  - Above 110% electricity energy self-sufficiency
  - Above 180% energy self-sufficiency (incl. Heat recovery)

VCS Denmark Imperatives and Constraints

- Automated facilities, mostly without onsite operations personnel
- Energy Efficient
- High wet weather flows, low temperatures
- Strict effluent requirements, resource recovery, footprint

<u>MABR</u> seen as a High Potential Technology to Assist in Achieving Goals

Three Year Demonstration Study Initiated in Summer 2018



VCS Denmark

Jacobs

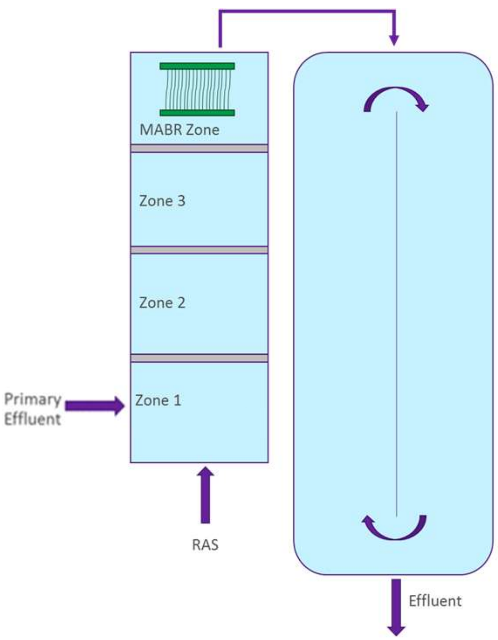
aarhusvand

OXYMEM → DUPONT Water Solutions

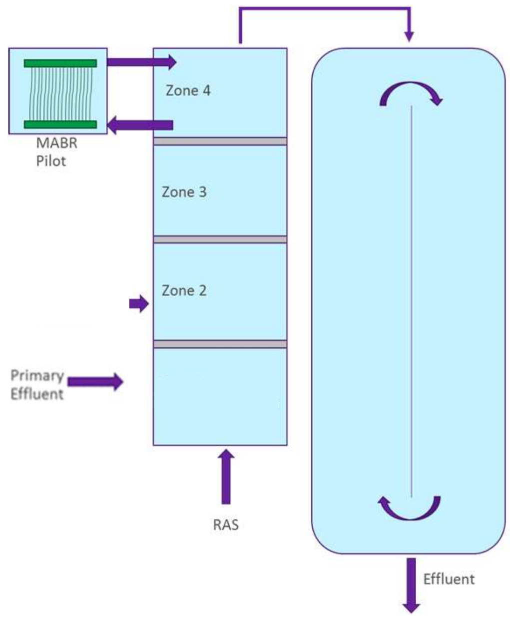
suez → VEOLIA WATER

Demonstration Setup: Two configurations – Two vendors

In Basin



Sidestream Tank



VEOLIA WATER

DUPONT Water Solutions

Demonstration Setup

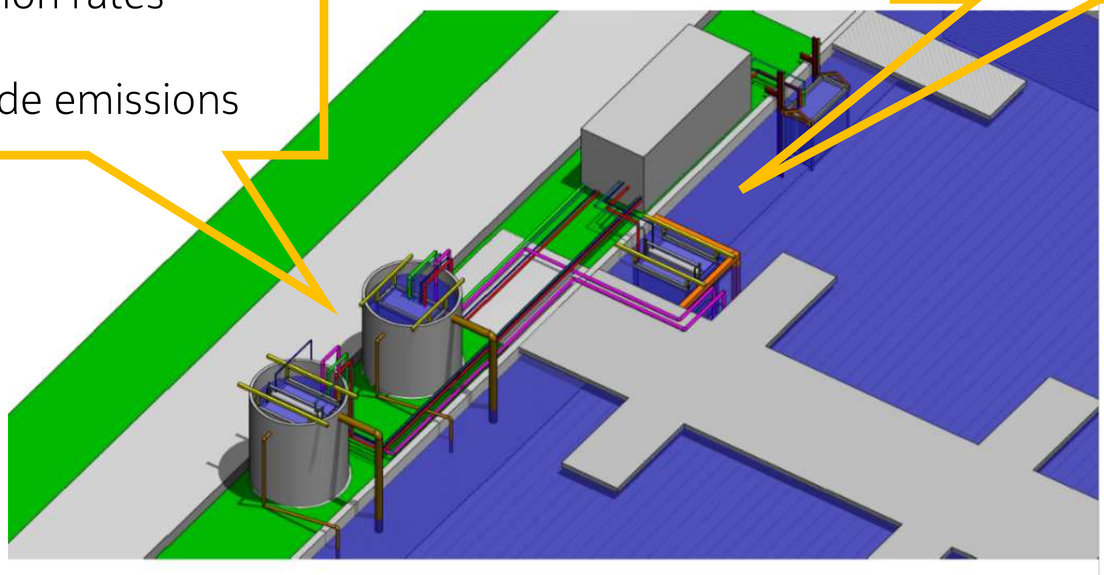
Demonstration Setup allowed for Continuous Data Collection

In Basin

Biofilm- debris
OTR
Nitrous oxide emissions

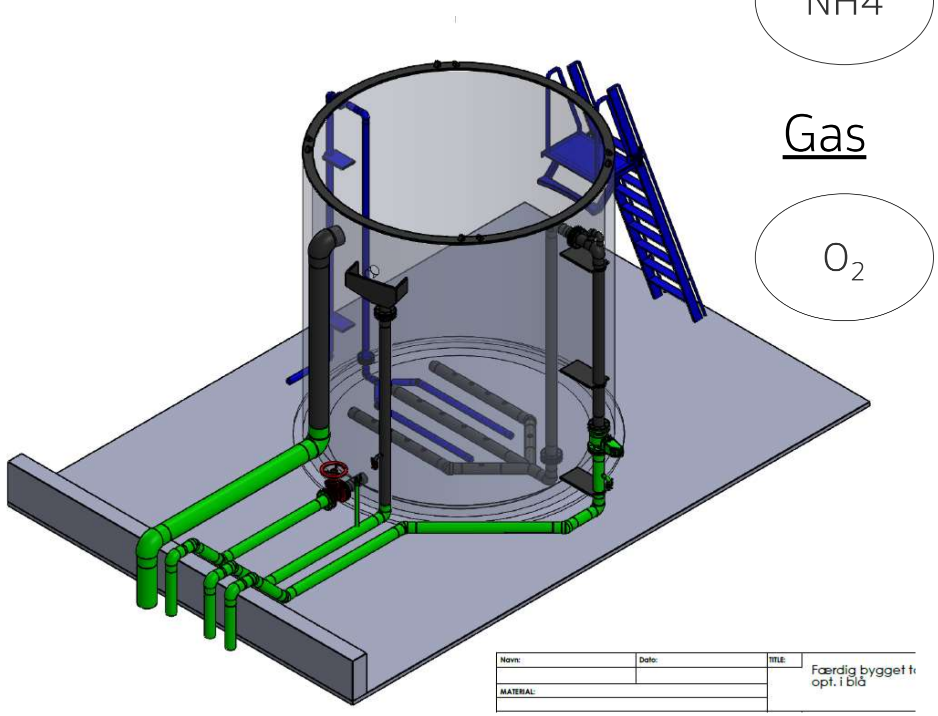
Sidestream Tank

Nitrification rates
Denitrification rates
OTR
Nitrous oxide emissions



+ Biweekly laboratory analyses
+ Biofilm sampling

Demonstration Setup allowed for Continuous Data Collection



Liquid

NH4 | ORP | N_2O

Gas

O_2 | CO_2 | N_2O

Ease of Implementation was Important

Interference of the deeply anaerobic conditions of the feed!

Chemical analysis confirms precipitation:

- Copious amounts of Iron (and suspected high levels of S (FeS)
- Marginal amounts of P, Ca, Mg, Al, Zn

Solution: For Demonstration, Control ORP to more "typical" levels

- Implement fine bubble aeration to control ORP to approximately ~-200 mV, typical of BNR systems (September 2019)
- With modules scaled, suppliers worked with different approaches to bring demonstration back on track

SUEZ

- Complete replacement of modules
- Fall 2019
- Excellent results thereafter

OxyMem

- Retain existing cassettes and "clean"
- COVID foiled plans of cleaning in early 2020
- June 2020 cleaning
- Excellent results thereafter

Summary of Later Studies and Successful Operation

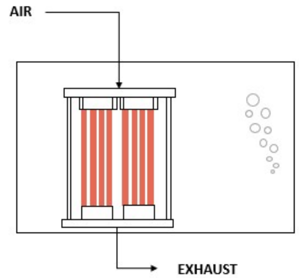
Debris Accumulation – Minimal Considering Conditions

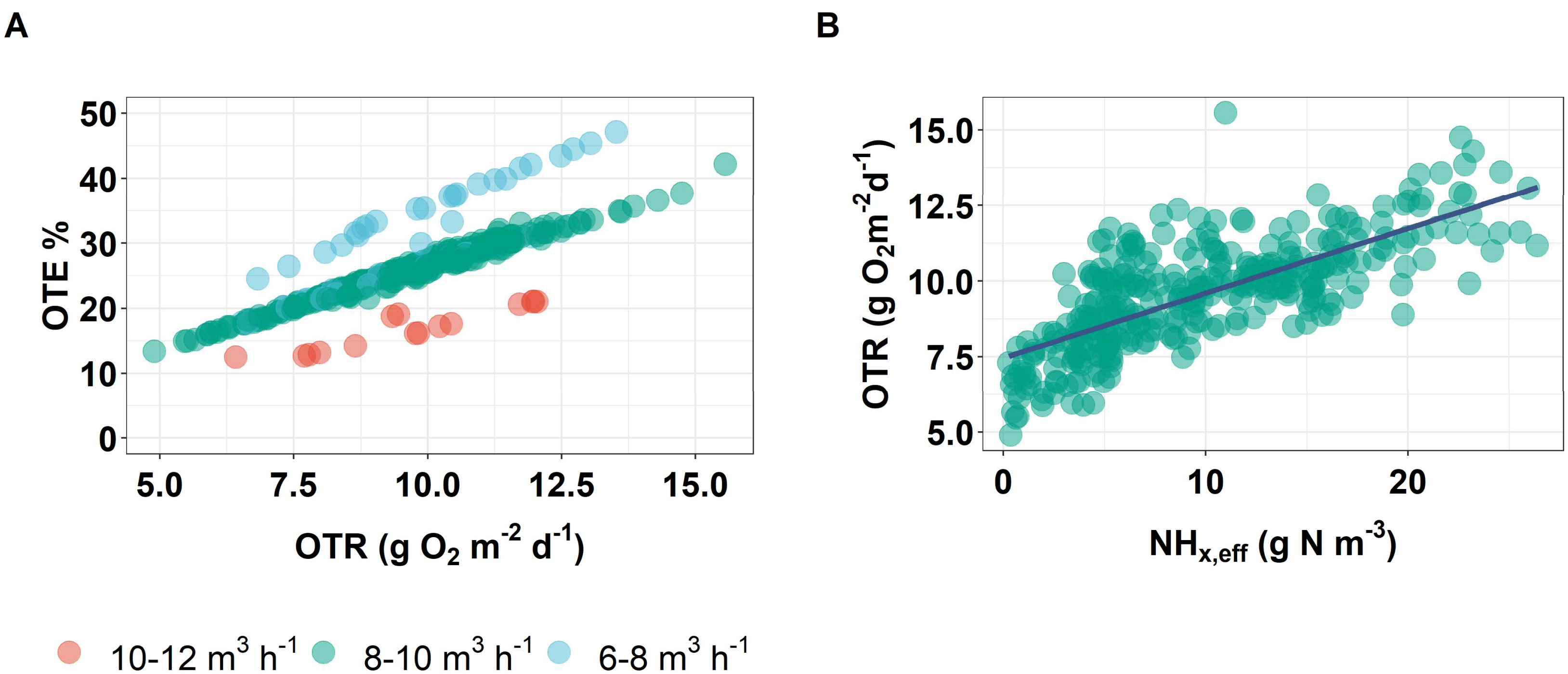
- Detailed visual inspection carried out after ~18 months of operation
- Challenging conditions:
  - Influent screening non-ideal
  - Large open tanks at treatment plant
  - Facility surrounded by forest

SUEZ

OxyMem

Oxygen Transfer – Benchmark Results





Uri-carreño, N., Nielsen, P.H., Gernaey, K. V, Flores-alsina, X., 2021. Science of the Total Environment Long-term operation assessment of a full-scale membrane-aerated bio fi lm reactor under Nordic conditions. Sci. Total Environ. 779, 146366. https://doi.org/10.1016/j.scitotenv.2021.146366

Nitrous Oxide Emissions

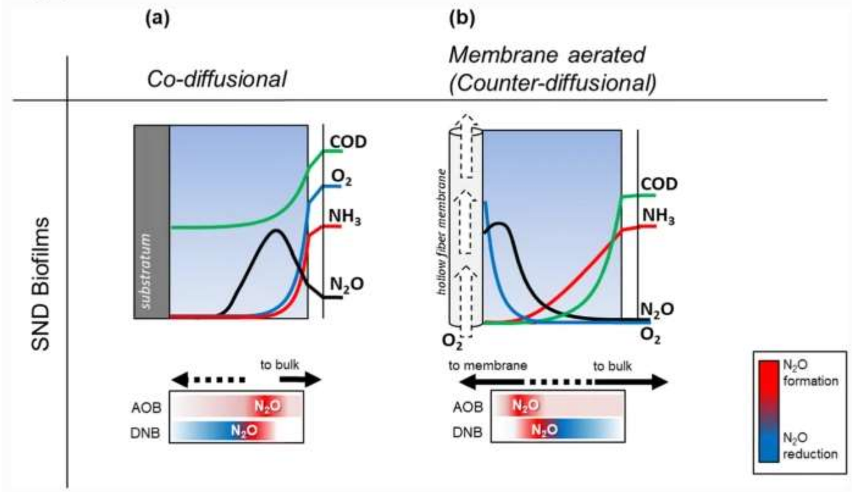
- Previous studies indicate MABR has substantially lower N_2O generation compared to other biofilm-based technologies (i.e., MBBR)
- However, previous study <u>only</u> looked at liquid side dissolved N_2O generation and <u>not</u> possible back diffusion of N_2O into offgas

Water Research 124 (2017) 363–371
Contents lists available at ScienceDirect
Water Research
journal homepage: www.elsevier.com/locate/watres

Counter-diffusion biofilms have lower N_2O emissions than co-diffusion biofilms during simultaneous nitrification and denitrification: Insights from depth-profile analysis

Co Thi Kinh [a], Toshikazu Suenaga [a], Tomoyuki Hori [b], Shohei Riya [a], Masaaki Hosomi [a], Barth F. Smets [c], Akihiko Terada [a, *]
[a] Department of Chemical Engineering, Tokyo University of Agriculture and Technology, Naka 2-24-16, Koganei, Tokyo, 184-8588, Japan
[b] Institute for Environmental Management Technology, National Institute of Advanced Industrial Science and Technology (AIST), Onogawa 16-1, Tsukuba, Ibaraki, 305-8569, Japan
[c] Department of Environmental Engineering, Technical University of Denmark, Miljoevej, 2800, Lyngby, Denmark

Fig. 7



N_2O formation in combined nitrifying/denitrifying biofilms. **a** Co-diffusional and **b** counter-diffusional. Solid black arrow indicates N_2O loss towards either bulk or membrane lumen; dashed black arrow indicates reduction within the biofilm depth. NO_2^- and NO are not shown for clarity

From: Sabba, F., Terada, A., Wells, G., Smets, B. F., & Nerenberg, R. (2018). Nitrous oxide emissions from biofilm processes for wastewater treatment. *Applied Microbiology and Biotechnology*, *102*(22), 9815–9829. https://doi.org/10.1007/s00253-018-9332-7

Nitrous Oxide Emissions – Ejby Mølle WRRF Demonstration

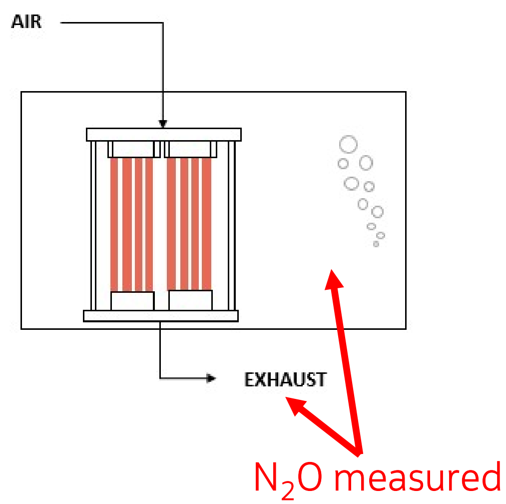


Table 4. Average N_2O emissions from the MABR reactors from January to June 2019.

	Temp	HRT	N_2O emissions	
	Celsius	h	% N Load	% N removal
Mixed Liquor	13	3	0,11 ± 0,30	0,47 ± 0,96
Exhaust gas			0,17 ± 0,10	0,77 ± 1,58

Uri Carreño, N., Nielsen, P. H., & Almind-Jørgensen, N. (2020). N2O Emissions from Ejby Mølle. In *The Danish Environmental Protection Agency* (Issue August).

- Analyses show approx. 1% of N-removal is through N_2O pathway
- Uri Carreño et al (2020) summarized measured N_2O production from Ejby Mølle WRRF bioreactors, and indicates 7-8 times greater production compared to MABR

Case Study:

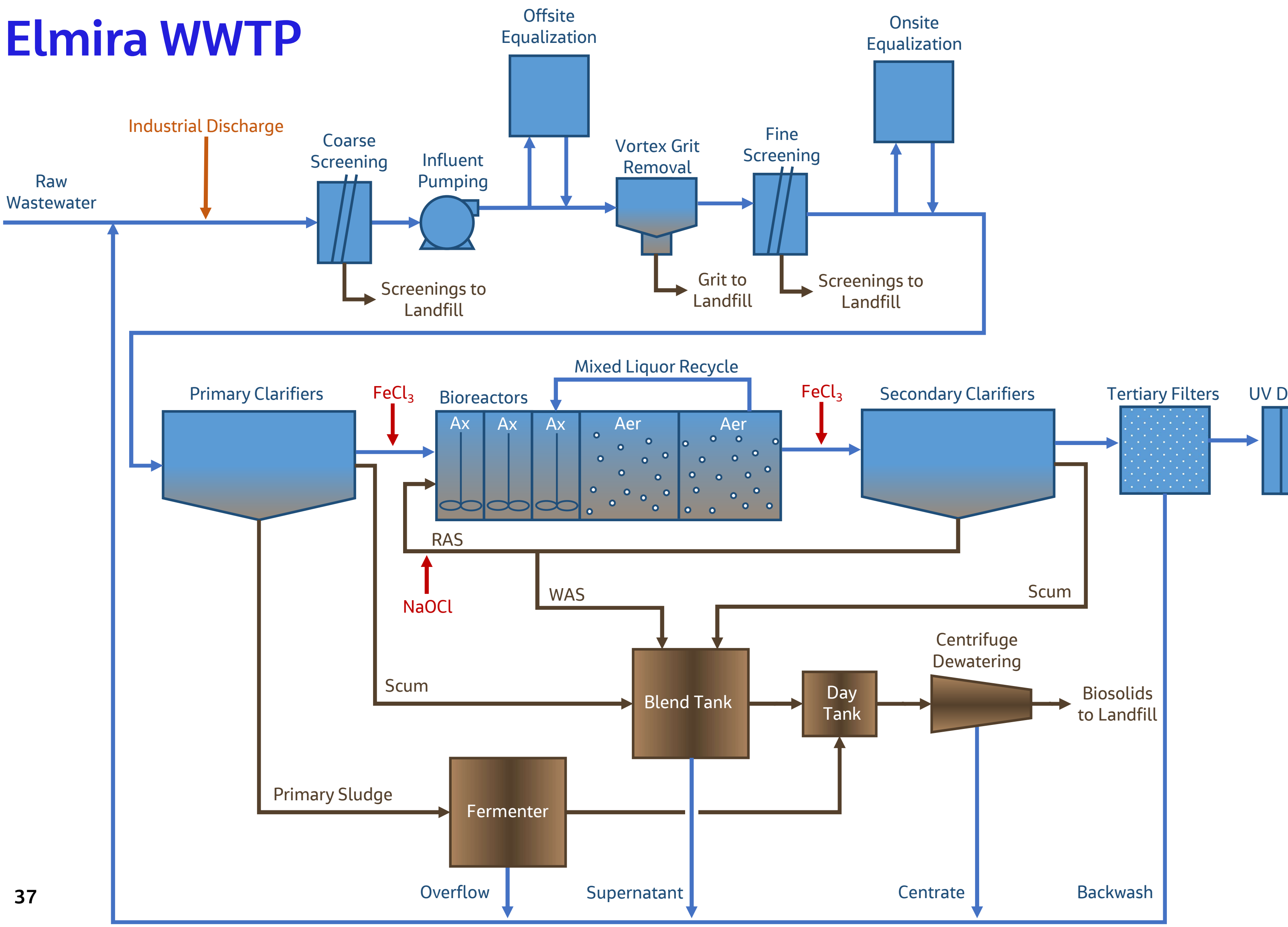
Elmira WWTP Full Scale Implementation

Elmira Wastewater Treatment Plant

- Waterloo, Ontario, Canada
- Currently serves population of ~12,000
- Rated flow capacity:
  - Average: 7,800 m^3/d
  - Peak: 19,500 m^3/d (2.5 PF)
- Unique raw wastewater characteristics:
  - High industrial contributions
  - High I&I

Region of Waterloo

Elmira WWTP



Effluent Objectives:	
$cBOD_5$	5.0 mg/L
TSS	5.0 mg/L
TP	0.2 mg/L
TAN	0.4 mg/L (summer) 1.0 mg/L (winter)

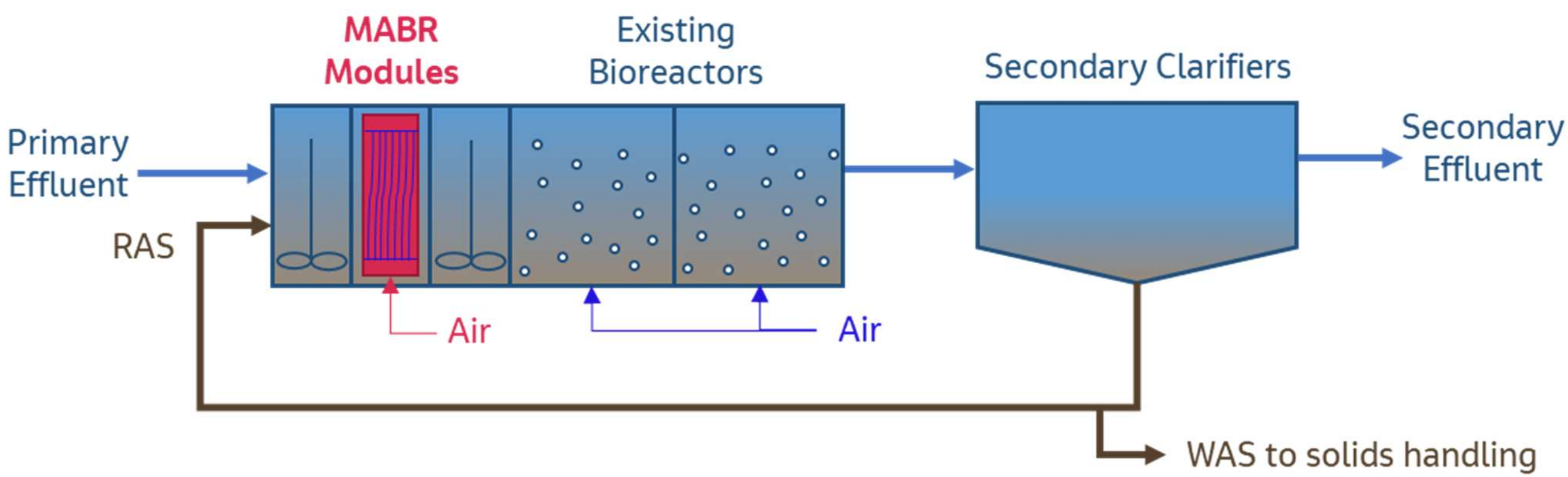
Project Driver: Secondary Treatment Capacity Limitations

- Raw wastewater characteristics differ from the plant's original design basis:
  - Raw wastewater is highly concentrated due to local industries
  - Extreme peak flows due to inflow and infiltration exceed secondary treatment capacity
- These characteristics limit the capacity of the existing secondary treatment system to approximately 4,000 m^3/d
- Secondary treatment upgrades needed to restore treatment capacity (7,800 m^3/d) and provide reliable treatment
- **MABR** was identified as the preferred strategy
- Due to supply chain issues (MCC), commissioning is expected in April/May 2023…

Dupont OxyFAS MABRs were pre-purchased (competitive)

MABR Benefits at Elmira WWTP

- Increase nitrification capacity and performance due to the retention of attached nitrifiers in the MABR biofilm
- Increase secondary treatment capacity by allowing the system to operate at lower mixed liquor concentrations, as a result of lowering the required suspended growth solids retention time (SRT) to achieve complete nitrification
- MABRs will be installed in second anoxic zone of existing bioreactors

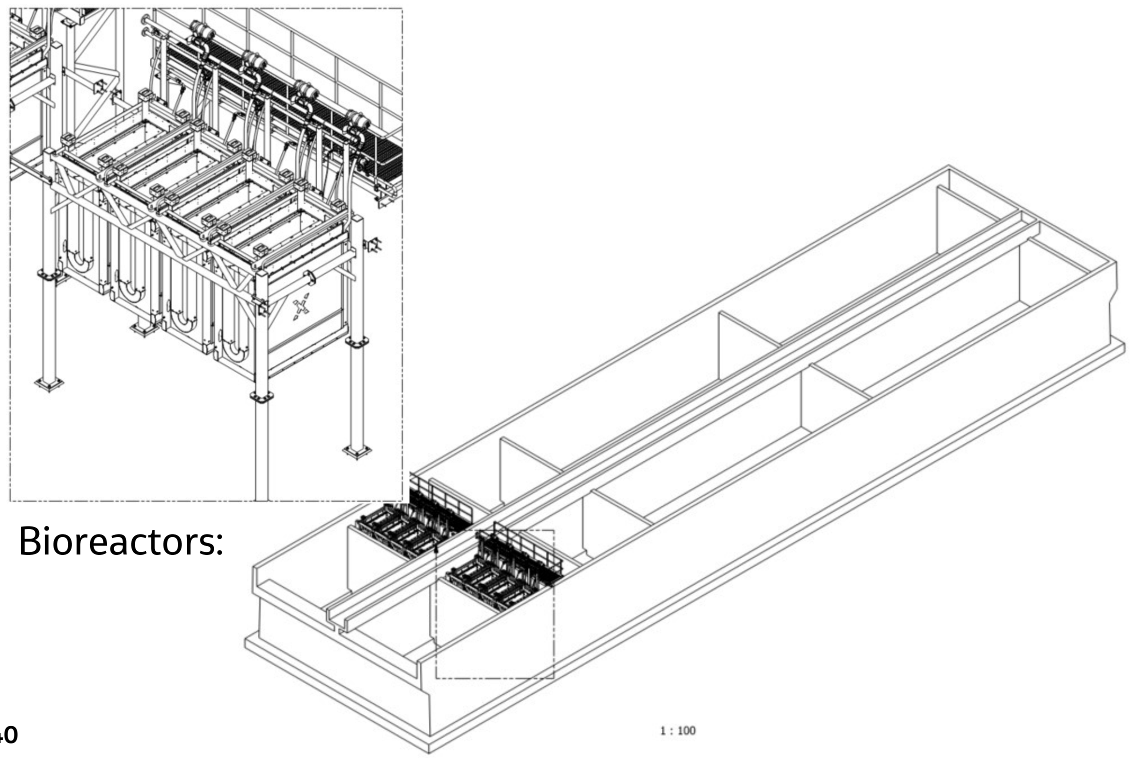


Scope of Work – Upgrades in Bioreactor and Blower Building

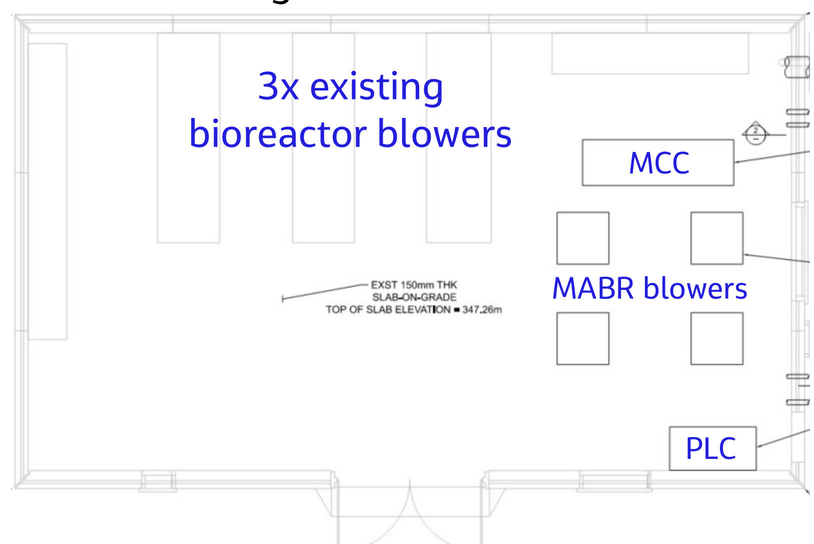
- Eight MABR modules (four per tank), support frames, access walkways
- Provision to add two more modules in future
- New anoxic zone mixers (end-of-life replacement)

- Four new MABR blowers
  - Two process air blowers
  - Two scour air blowers
- New MCC and PLC

Bioreactors:

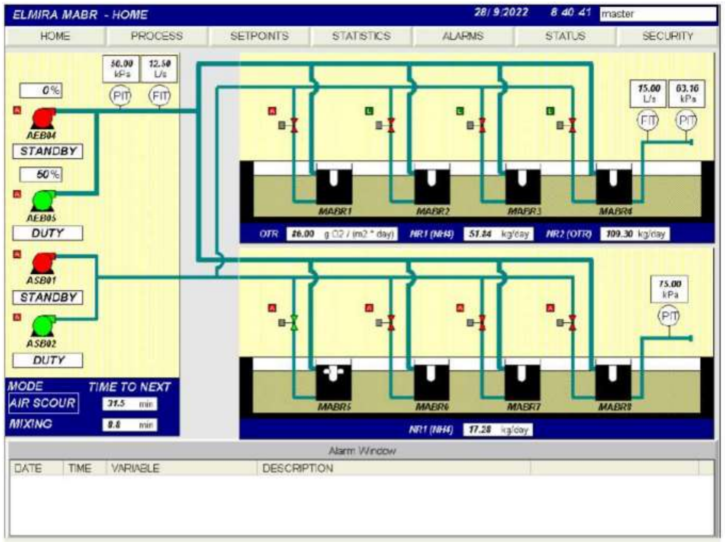


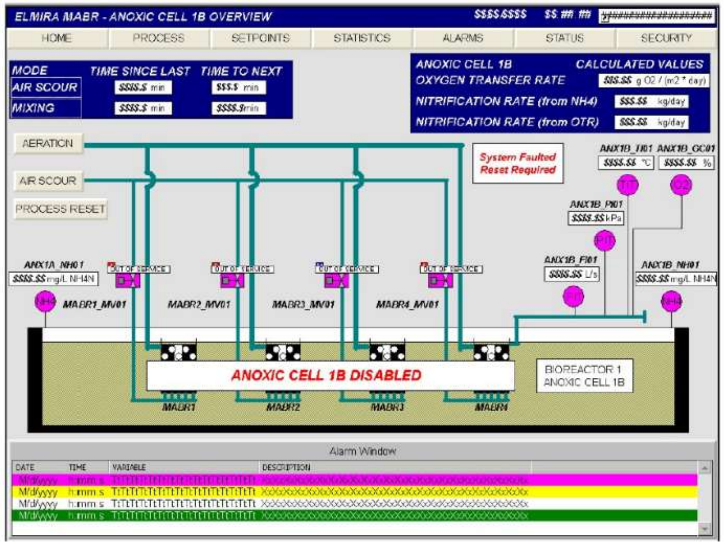
Blower building:



Process Operation and Control

- MABR designed to remove ~23% of raw wastewater ammonia load
- Process control:
  - Process air blower operates continuously; speed based on no. MABRs in service (VFD)
  - Scour air blower operates intermittently to control biofilm thickness (constant speed)
  - Off-gas and airlift are used for mixing within module
- Performance monitoring:
  - Mixed liquor ammonia concentration is monitored upstream/downstream of MABRs
  - MABR off-gas oxygen concentration is monitored





MABR Support Structure, Access Walkway, and Piping Manifold

Courtesy of OxyMem

Ready for MABR Installation…

MABR Cassettes

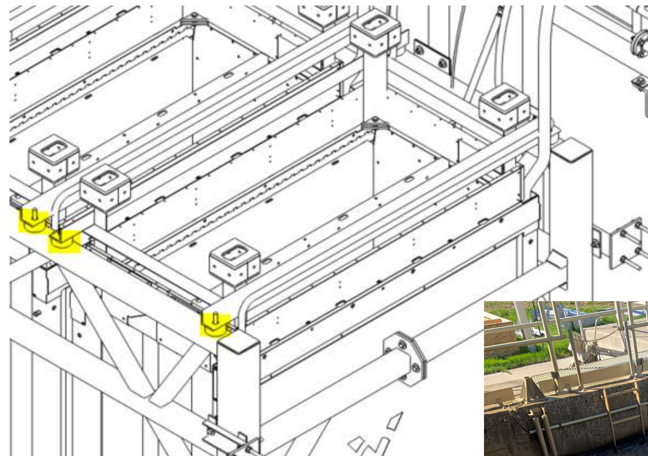
- 2.1m high x 2.2 m long x 1.15m wide
- Gas-permeable silicone membranes
- 510 μm inner diameter
- 1,450 m^2 membrane surface area per module

MABR Blowers

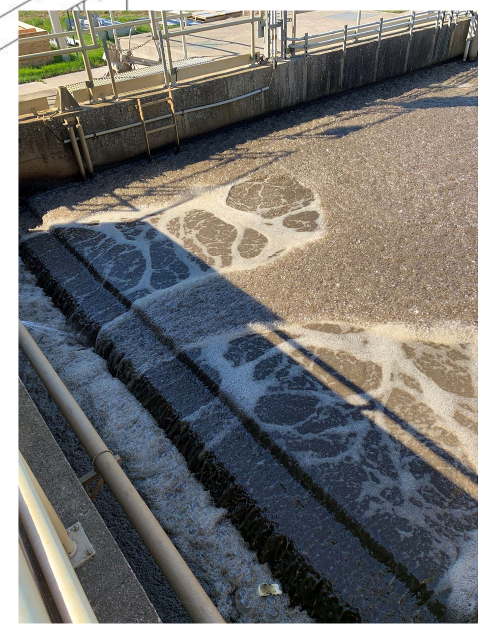
- Two 5 kW positive displacement Aerzen **process air** blowers (duty/standby)
- Two 5 kW positive displacement Aerzen **scour air** blowers (duty/standby)
- Dedicated MABR blowers will provide opportunity for aeration energy optimization

Lesson Learned: Understanding Hydraulic Gradeline is Important

- Knowing the range of water surface elevations is key to determine MABR installation elevation in the tank
- To achieve desired water level relative to MABR installation:
  - Proper levelling required for frame installation
  - “Spacers” included with MABR frame to adjust MABR heigh during installation
  - Bioreactor effluent weir adjustment was required
- …this lesson learned is specific to the OxyMem MABR design



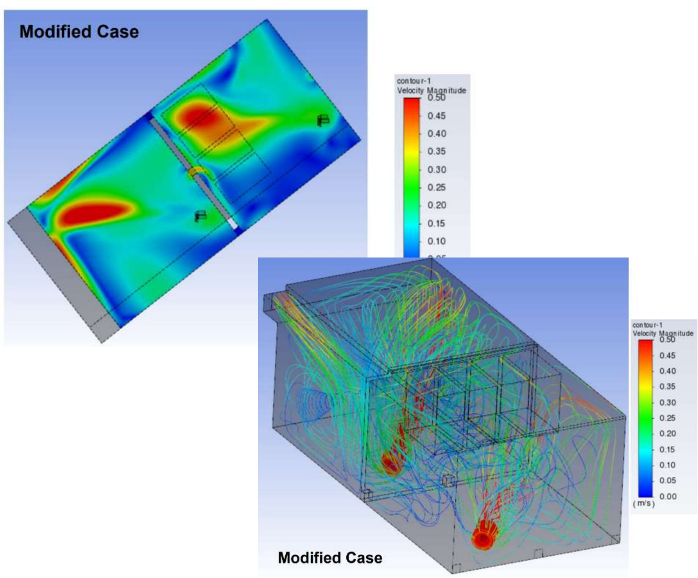
Spacers at top of MABR frame



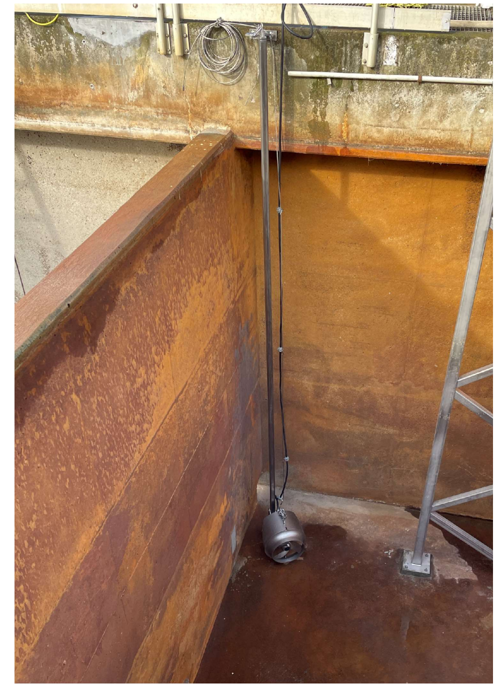
New effluent weir

Lesson Learned: Mixing in MABR Zone is Critical

- Anoxic zone mixers were replaced (end-of-life)
- CFD modelling verified new mixers in MABR zone provide adequate flow distribution
- Orifices at the bottom of baffle walls were sealed to prevent flow short-circuiting



Sealed orifices



New mixer

Other Project Takeaways…

- Bioreactor condition assessment was completed to understand structural/mechanical deficiencies and minimize risk during construction
- Equipment pre-purchase is beneficial:
  - Helped to define the limits of vendor supplied equipment for confident, complete delivery
  - No surprises during tender period means high quality, complete proposals
  - Well established relationships heading into the 60% design phase
- Heat tracing is required for MABR off-gas (… in Canada)

Commissioning Approach

Acceptance testing will be completed in two phases to demonstrate the efficiency of a full-scale installation side by side with the unmodified bioreactor

MABR Train 1

- 90-day biological acclimation period coinciding with cold weather operation (1-Oct)
- 14-day performance test period
- Temporary removal of MABR for inspection and debris check

MABR Train 2

- 60-day biological acclimation period coinciding with cold weather operation
- 14-day performance test period

Composite Samplers

- Upstream and downstream of each anoxic/MABR zone
- Samples will be analyzed for Ammonia, Nitrate, Nitrite, sBOD, Soluble Phosphorous, Soluble TKN, sCOD

Instrumentation and Plant Data

- online ammonia analyzers
- raw sewage flows and loads
- RAS flow and MLSS, ORP, temperature
- Blower airflow, MABR exhaust oxygen

Summary

- MABR is a market disruptive technology
- Technology allows for:
  - Increased process capacity
  - Reduced energy associated with aeration
  - Lower N2O emissions and GHGs in general
- Now being implemented at a number of locations worldwide
- While installations to date have been relatively small, larger facilities now being contemplated

Thank You!

Jacobs

Challenging today.
Reinventing tomorrow.