

MBRs are more cost effective than ever before!

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Water Environment Federation
the water quality people®

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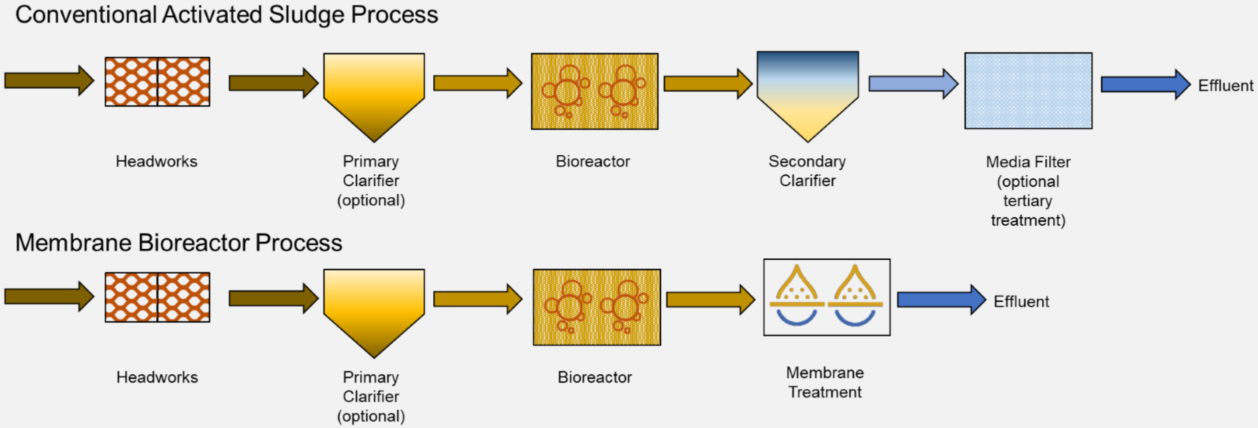
Outline

- Introduction
  - *MBR 101*
  - *Overview*
- Background
- Methodology
- Results
- Conclusions

MBR 101 Refresher
What is an MBR?



WW Trends MBR can help Address

- Water recycling
- Resilient treatment design
- Process intensification
- Data analytics
- Cost of Ownership

Drivers for Use
Advantages of MBR

Footprint
- Typical MBRs are ~1/3rd the footprint of CAS for the same flow
- Modular design allows for easy retrofit in existing tanks

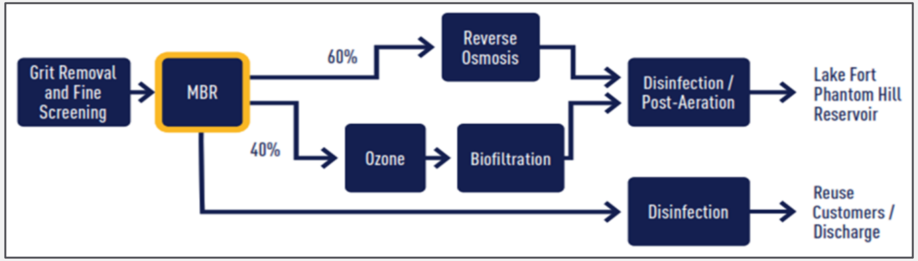
Reliability
- Physical barrier that consistently produces high quality effluent regardless of influent water quality or process upsets

Quality
- Treated water meets or exceeds toughest regulatory requirements in the world
- Perfect for direct & indirect potable reuse

Economics
- Lower total cost of ownership for comparable treatment objectives vs. conventional

CAS vs. MBR Footprint

Irvine Ranch, California
- MBR built in 2013 occupies only 40% of CAS footprint per MLD
- 41.3 MLD MBR added to 37.8 MLD CAS plant



Hamby WRF, Texas Flowsheet
- 2016 WateReuse Large Project of the Year award winner
- Largest MBR in Texas at 70.8 MLD average daily flow

MBRs are more cost effective than ever before!

Overview

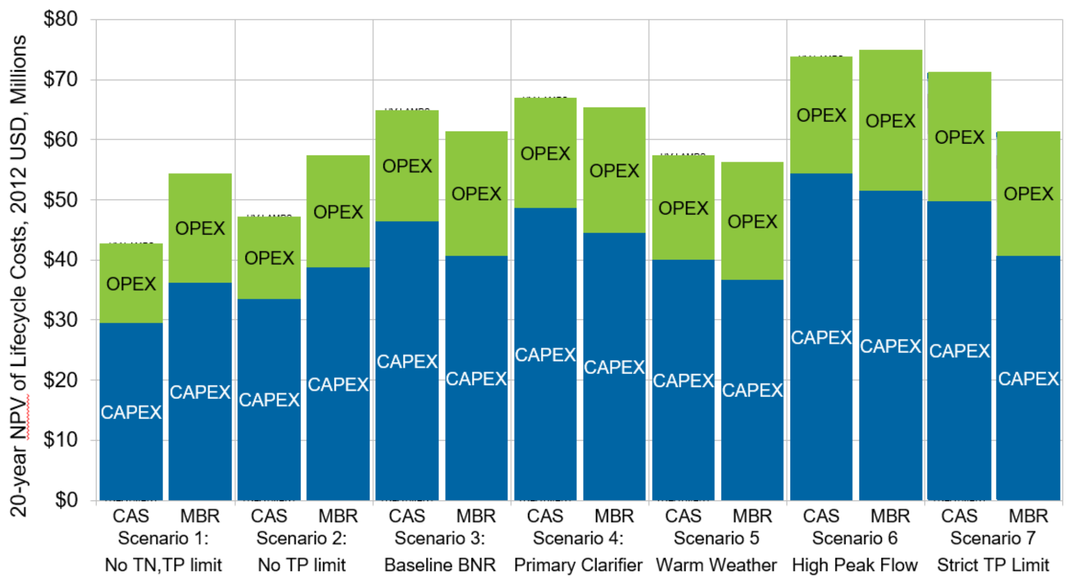
- When first commercialized in the early 90's, MBR was a niche technology that was cost-competitive only in particular conditions
- Capital and Operating Cost Comparison presented at WEFTEC 2012 showed MBRs to be cost-competitive or lower cost than CAS for many applications
- Design innovations introduced over the past decade have further reduced the capital and operating costs of MBRs
- Goal of this presentation is to quantify the impact of design advances on the relative capital and operating costs of MBRs vs. CAS by updating and expanding the 2012 cost estimating tool

Brightwater MBR, USA
175 MLD MDF
12 years in operation

*Based on 20 MLD treatment capacity as compared to conventional secondary treatment with moderate treatment goals. Preliminary 2022 results including 500EV. 200MLD example being developed now.

Background

- 2012 cost model looked at 20-year lifecycle cost of 18.9 MLD (5.0 mgd) greenfield WRRF
- Both CAS and MBR concept designs were developed and costed for 7 different operating scenarios
- 2012 report conclusions:
  - O&M costs for MBR typically greater than comparable CAS; however, overall lifecycle cost for MBR were less for many scenarios is lower due to lower capital costs
  - CAS had lower capital and lifecycle costs when tertiary treatment was not required
  - MBR had lower capital and lifecycle costs when tertiary treatment was required



Why revisit this 10 years later?

Much has changed over the past decade which influences some of the core design assumptions of the original cost model, including:

1. Membrane air scour
2. Cassette packing density
3. Permeation approach
4. Chemical cleaning regime
5. Membrane life
6. EBPR
7. Filtration technology

In addition, inflation has increased the costs of raw materials, chemicals, equipment fabrication, and construction and operating labor.

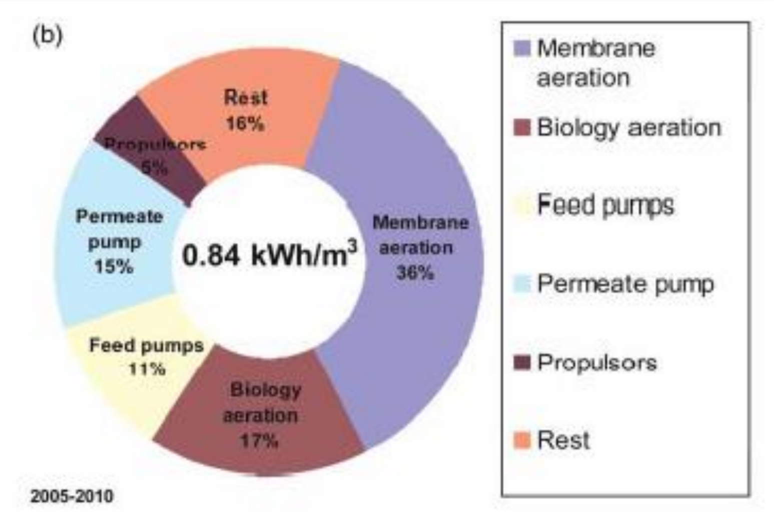
Membrane Air Scour

Membrane manufacturers have moved from sequential coarse bubble aeration to gas sparging diffused aeration, reducing air scour energy for membrane cleaning by 30% (Young et al, 2017).

Coarse bubble air scour
Source: GE Water (2011)

Gas sparging air scour
Source: GE Water (2011)

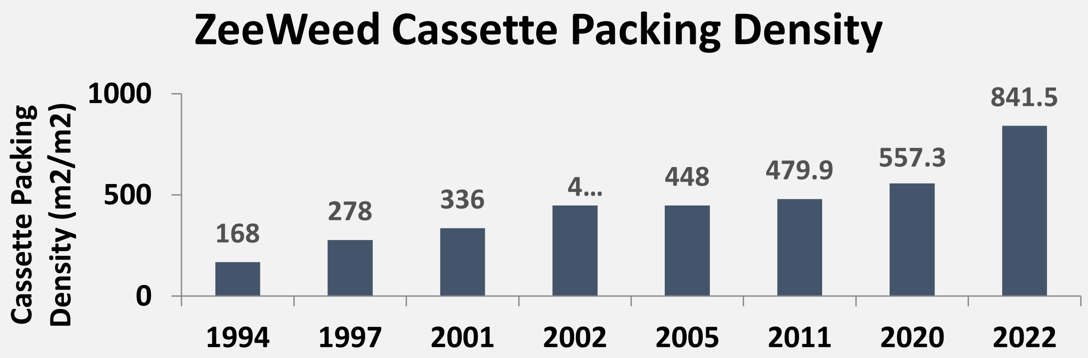
Membrane aeration was traditionally the largest energy use in MBR systems.



Source: Kreminski et al (2012) – Varsseveld MBR

Cassette Packing Density

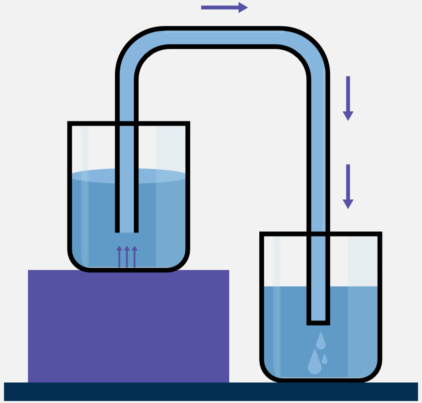
Membrane manufacturers have increased the density of membrane modules per cassette, **allowing greater surface area for treatment in a smaller space.**



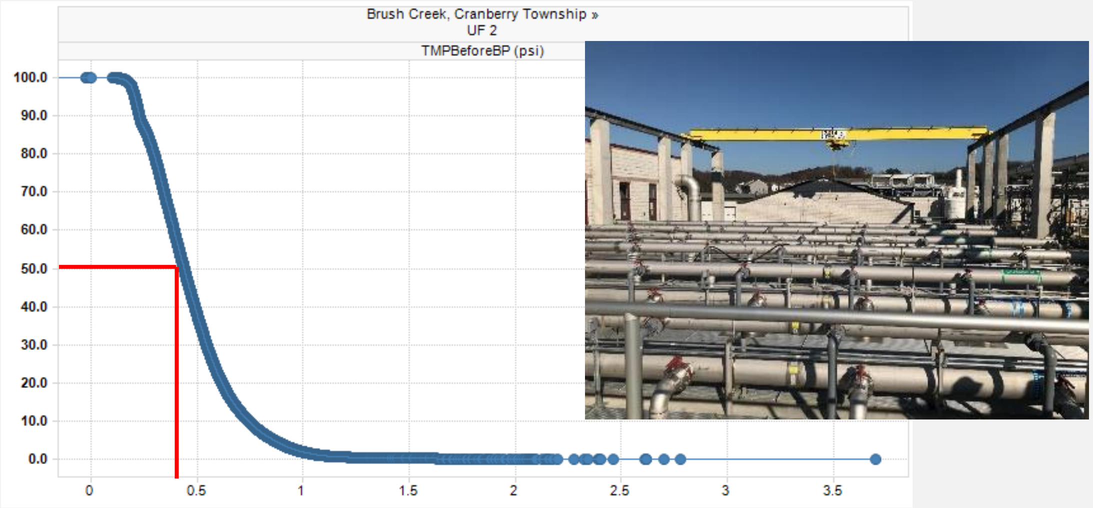
For example, the next generation ZeeWeed 500EV ultrafiltration membrane cassette from Veolia has **88% greater surface area** than the same 500D cassette had in 2012**.**

Permeate Approach

Where hydraulic conditions allow, drawing permeate through the membranes by gravity siphon under lower trans-membrane pressure conditions has gained traction as a means to **reduce average energy use** (Young et al, 2022)



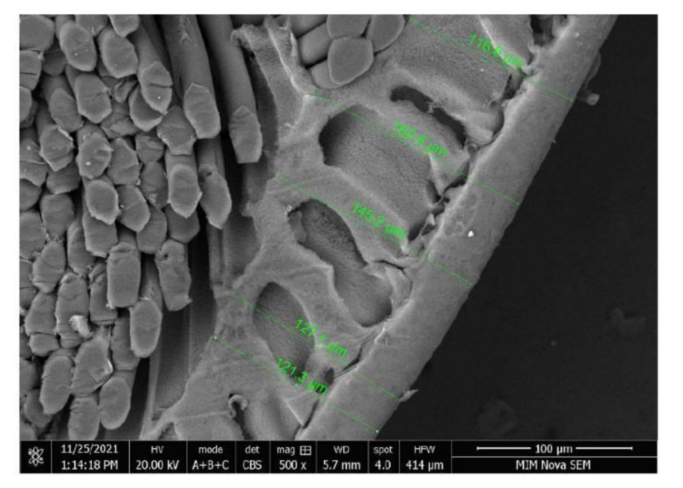
Brush Creek WPCF in Cranberry, PA permeates by gravity over 99% of the time with average TMP < 0.04 bar (0.5 psi)



Chemical Cleaning Regime

Membranes have been shown to retain functionality for **longer durations** before replacement even with **less frequent chemical cleaning** than was previously accepted (Sears et al, 2022)

Electron microscope scan of 13 year old membranes at City of Brandon MBR reveals little degradation (Sears et al, 2022)



Membrane Life

Experienced membranes manufacturers have improved materials of construction and design of modules and cassettes over the last three decades. Even under challenging operational conditions, some municipal membranes can achieve very long operational life.

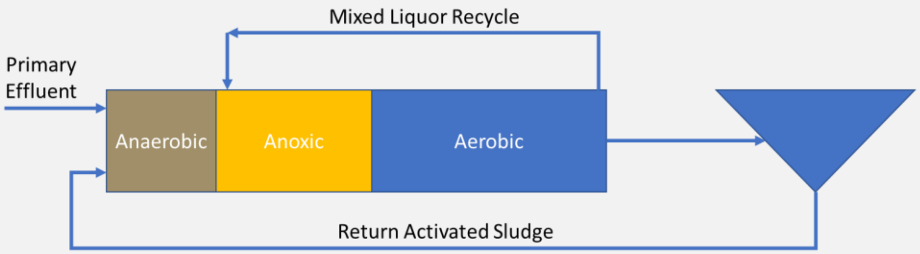
Example of Municipal ZeeWeed 500 applications with long membrane operational life

Project	Commissioned	ADF (m3/day)	MDF (m3/day)	Demonstrated Life (years)
Thetis Lake WWTP	1995	26.5	45.4	21
Powell River WWTP	1998	4,180	4,180	20
American Canyon WWTP	1999	11,360	18,930	13
Port McNicoll, WWTP	2001	2,500	5,400	20
Corona WWTP	2001	4,540	4,540	17
Brescia WWTP	2002	48,000	48,000	14
Nordkanal WWTP	2003	16,000	45,000	16
Rubes Creek WRP	2003	9,500	16,300	11
City of Redlands WWTP	2004	27,255	27,255	16
Traverse City WWTP	2004	27,300	38,600	16
Duvall WWTP	2005	3,785	7,190	11
Viareggio WWTP	2005	6,000	7,680	16
ADM Decatur WWTP	2005	25,510	25,510	15
Marco Island WWTP	2006	11,360	18,930	14
Mysore WWTP	2007	3,000	3,000	14
Pune WWTP	2007	2,000	2,000	14
Oxford PCP	2008	13,620	25,880	16*
City of Brandon WWTP	2009	19,000	24,000	13
Brightwater WWTP	2011	87,500	175,000	13*

*Original membranes still in operation

EBPR

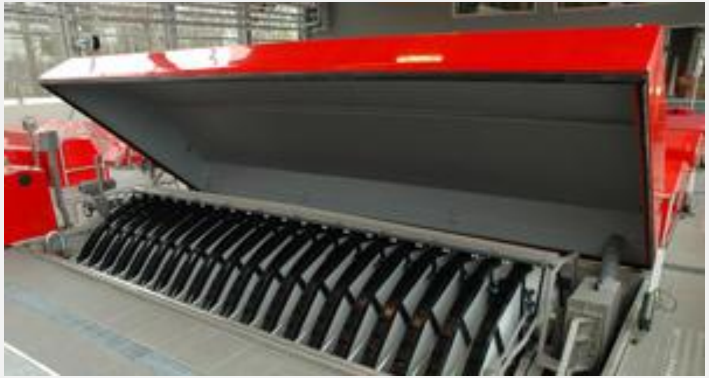
Use of EBPR, in combination with biological nitrogen removal, has become **more prevalent** as utilities seek to reduce operating costs and make operations more sustainable.

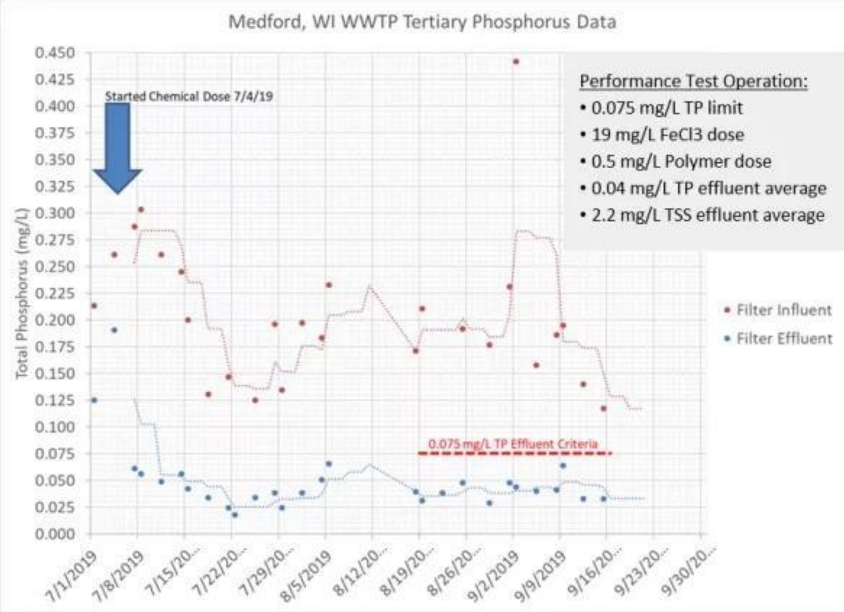


Original cost model assumed all chemical P removal.

Filtration Technology

Disc filtration has replaced sand filtration or tertiary membranes as the preferred technology for achieving low effluent phosphorus concentrations when nitrogen reduction is accomplished through upstream biological processes.





The City of Medford, WI WWTP upgraded their sand filters to a Hydrotech Discfilter system to meet a TP < 0.075 mg/L. The system treats 1.5 MGD ADF and peaks at 3.66 MGD with 2 duty + 1 standby filter.

https://www.veoliawatertech.com/en/case-studies/achieving-ultra-low-phosphorus-performance

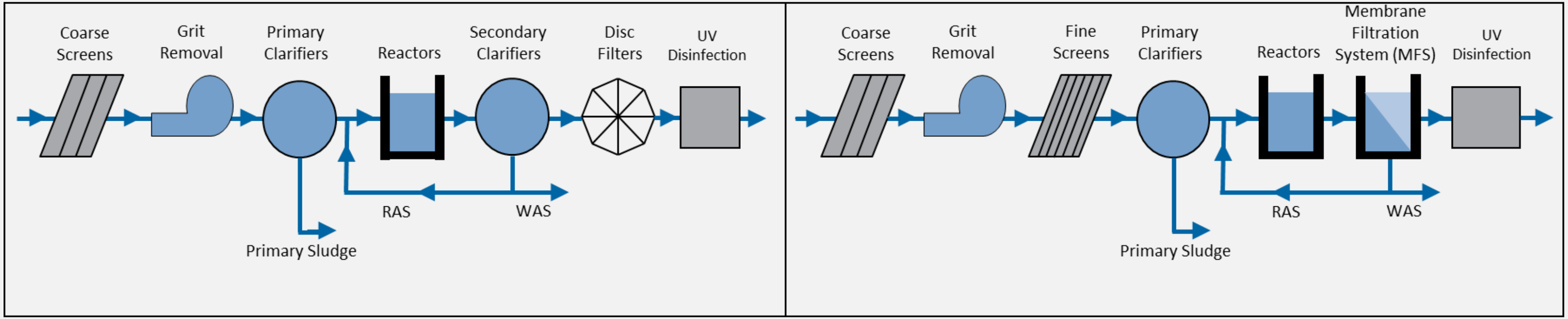
Methodology

- Concept designs were developed for the liquid treatment train of a greenfield municipal WRRF for **6 design scenarios at 2 different capacities (20 and 200 MLD)**
- For each scenario, both a CAS and MBR based concept design was developed using the same set of influent and effluent assumptions

Scenario	Flow Peaking Factor	Effluent Concentrations (mg/L)				Secondary Treatment Approach	Solids Separation Approach
		BOD	SS	TN	TP		
1	2x	30	30	N/A	N/A	Nitrifying A/S	Clarifiers for CAS; Membranes for MBR
2	2x	30	30	N/A	1	Nitrifying A/S with chem P	Same as above
3	2x	10	10	10	1	A2/O	Same as above
4	2x	10	10	10	0.1	A2/O	Above plus Disc Filters for CAS
5	2x	10	10	3	0.1	5-stage Bardenpho	Same as above
6	3x	10	10	3	0.1	5-stage Bardenpho	Same as above

Methodology (continued)

- Temperature: 12 deg C
- Primary clarification for 200 MLD scenarios only
- Assume all scenarios are fully nitrifying year-round (effluent NH3-N < 1 mg/L)
- Assume mainstream EBPR, with supplemental alum added as required to meet 0.1 TP limits
- Assume disc filters for CAS scenarios with < 1.0 mg/L TP limits
- Assume year-round disinfection required for all scenarios (even MBR)
- Solids treatment train not be modeled (assume sidestream treatment provided as required for recycle load management)

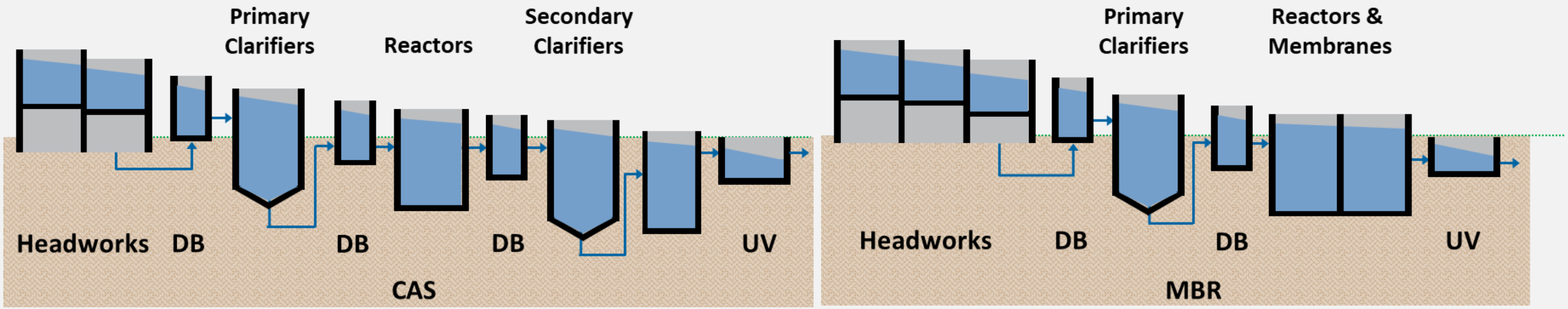


Methodology (continued)

A flat site was assumed for all scenarios, with differences in construction above grade or excavation below grade accounted for in the cost model

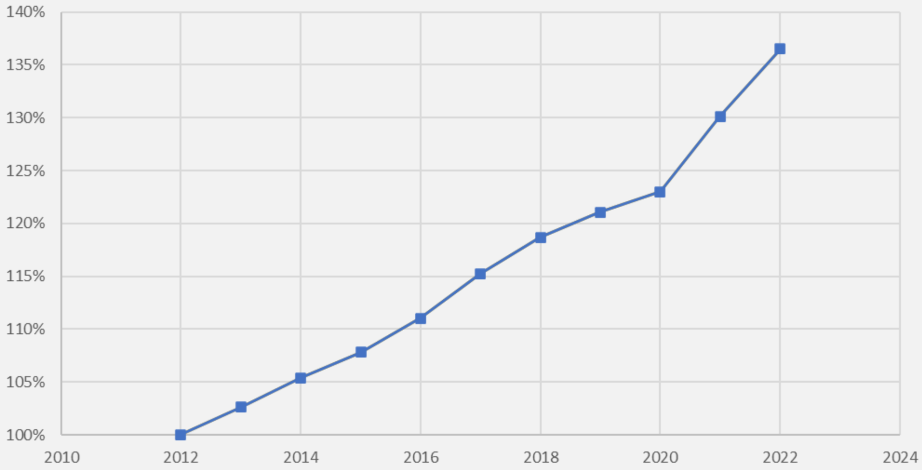
Influent hydraulic grade was set at the same elevation for both CAS and MBR scenarios

Where sufficient head exists in the hydraulic profile, gravity membrane permeation is during normal operating conditions (92% of the time) and pumped during peak flow conditions



Methodology (continued)

- Equipment costs were based on 2022 manufacturer's quotations and similar project examples, escalation included per ENR CCI
- Materials costs were obtained from Quarter 1, 2022 RS Means Data (Facilities Construction) for Cleveland, Ohio which is representative of the US average
- Labor costs were developed based on the New England Interstate Water Pollution Control Commission (NEIWPCC) Guide for Estimating Staffing at Publicly and Privately Owned Wastewater Treatment Plants



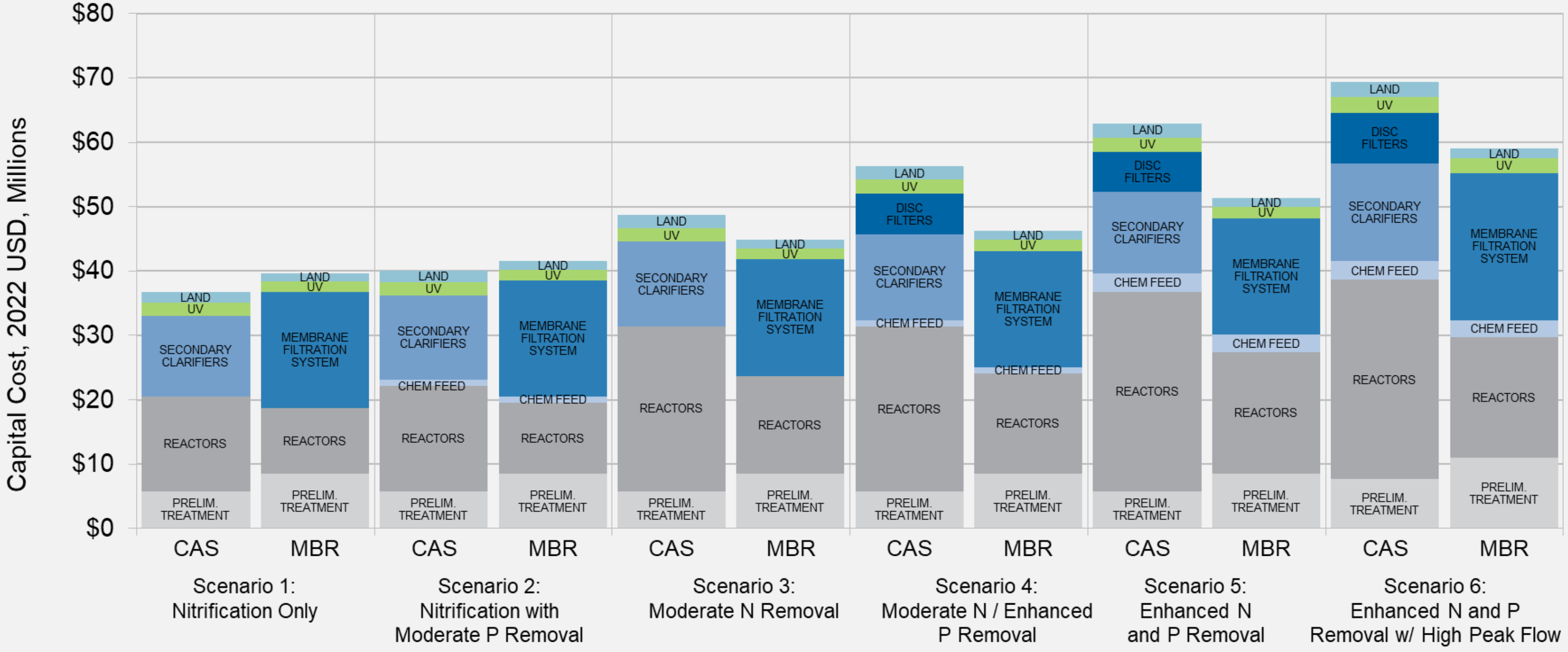
- ENR CCI aggregate inflation from 2012 to April 2022 was 137%

Changes between 2012 and 2022

- Increase in plant size from 5 MGD (18.9 MLD) to 20 MLD
- Influent pumping now constant across all scenarios
- Deleted Administration Building across all scenarios
- Removed caustic addition from all alum dosing scenarios (assumed influent alkalinity is not limiting)
- Scenario 6 peak hour flow factor changed from 4 to 3
- Intermediate Pumping deleted from CAS scenarios
- Sand filters in CAS scenarios were replaced with disc filters
- MBR scenarios consider permeating by gravity for 92 percent of an average day
- Scenario 3/4/5 configured for EBPR (A2O or 5-stage Bardenpho)
- TN limit changed from 10 mg/L to 3 mg/L for Scenarios 5 and 6, requiring post-anoxic zone
- MBR membrane replacement prorated based on 50% replacement at 15 years service life

Baseline Cost Comparison

20 MLD model capital cost results



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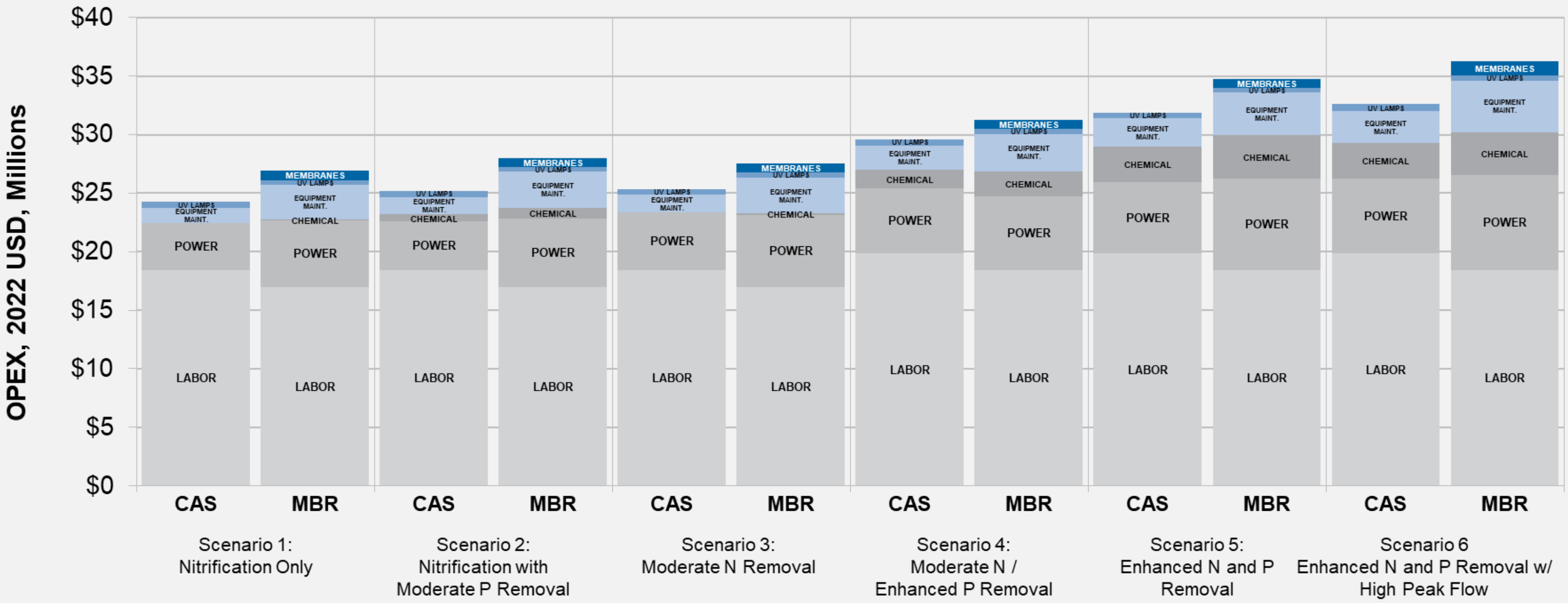
Baseline Cost Comparison

20 MLD model O&M cost comparison



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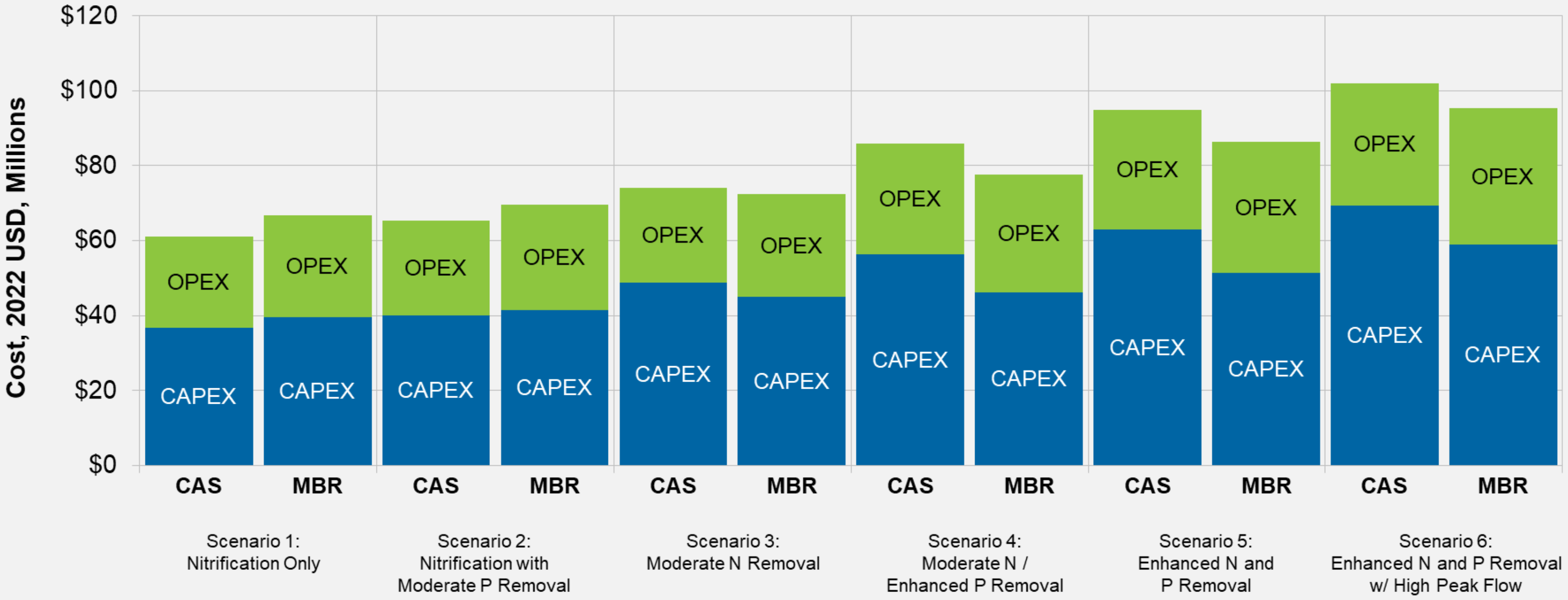
Baseline Cost Comparison

20 MLD model Lifecycle cost comparison



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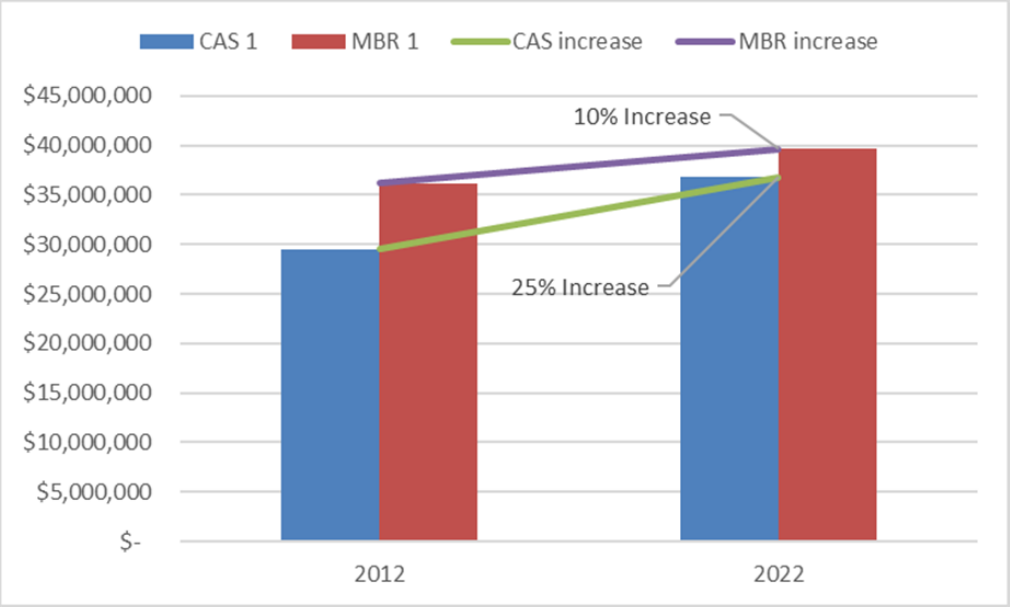
20 MLD Model Results

20-year present worth lifecycle costs for MBR technology are:

- Greater than CAS for Scenarios 1 and 2 (Nitrification only or Nitrification with moderate phosphorus removal)
- Slightly lower than CAS for Scenario 3 (Moderate nitrogen removal)
- Less than CAS for Scenarios 4 through 6 (Enhanced phosphorus and/or nitrogen removal)

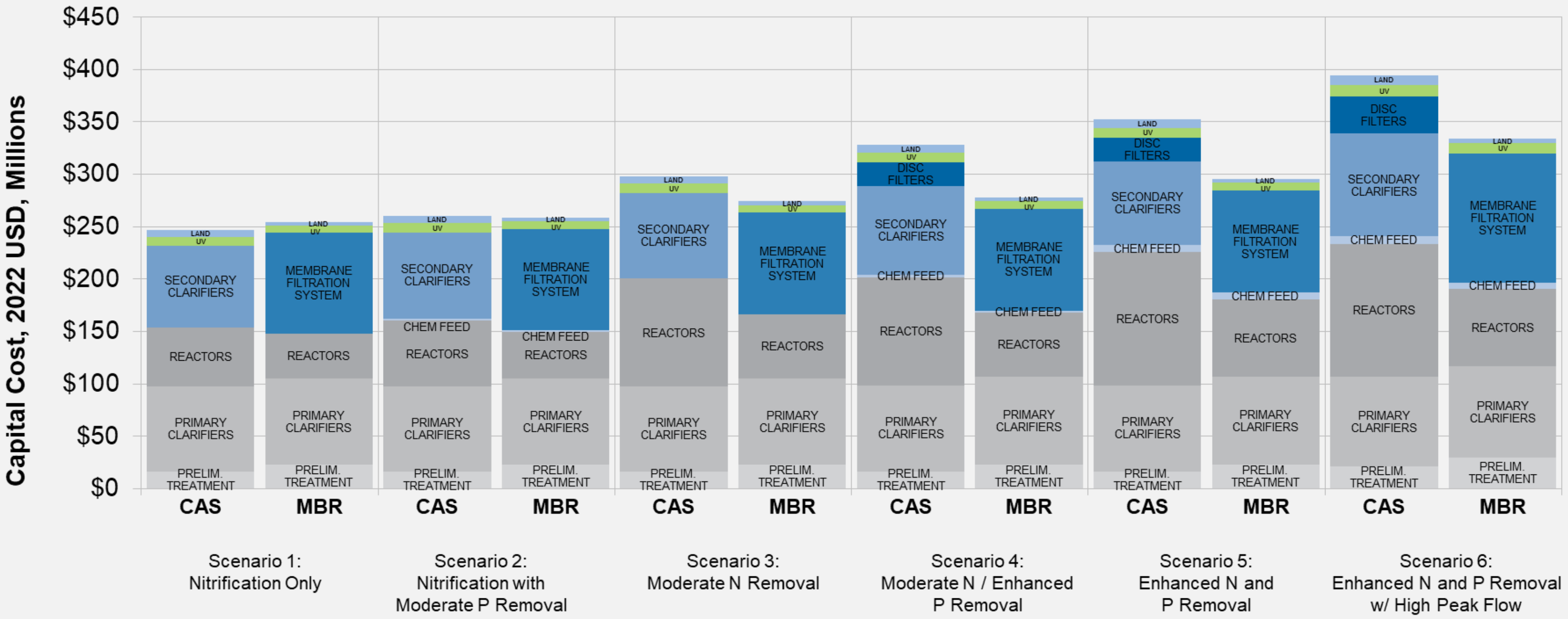
Compared to the 2012 analysis:

- Cost premium for MBR treatment compared to CAS treatment for Scenario 1 (Nitrification only) reduced from 28% to 9.1%
- Cost advantage of MBR treatment compared to CAS for Scenario 4 (Moderate nitrogen and enhanced phosphorus removal) increased from 4% to 11%



Baseline Cost Comparison

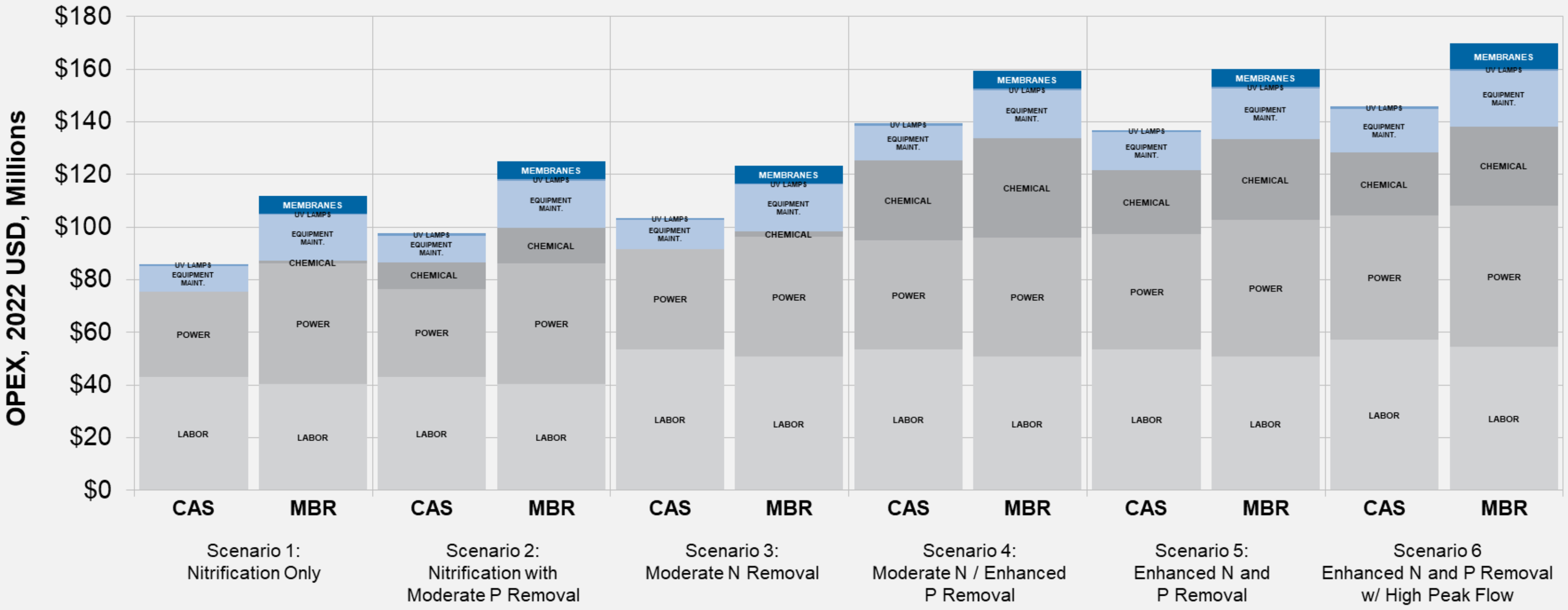
200 MLD model capital cost results



MBRs are more cost effective than ever before!

Baseline Cost Comparison

200 MLD model O&M cost comparison



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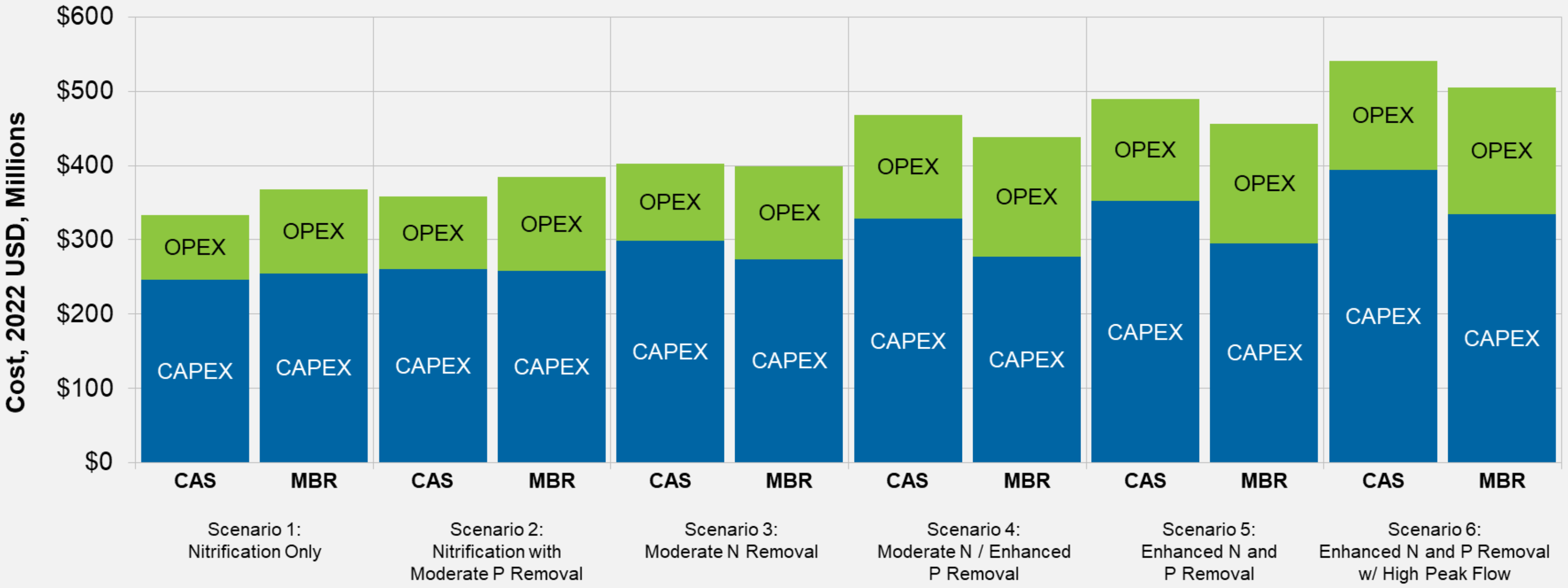
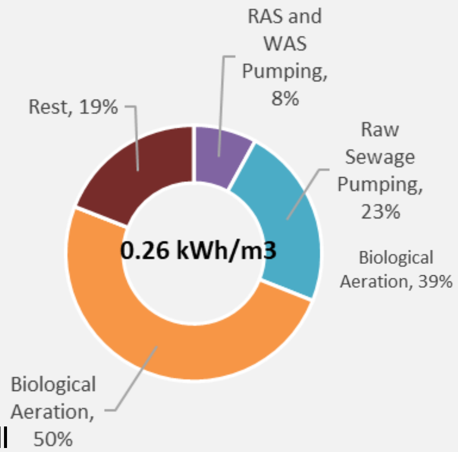
Baseline Cost Comparison
200 MLD model Lifecycle cost comparison

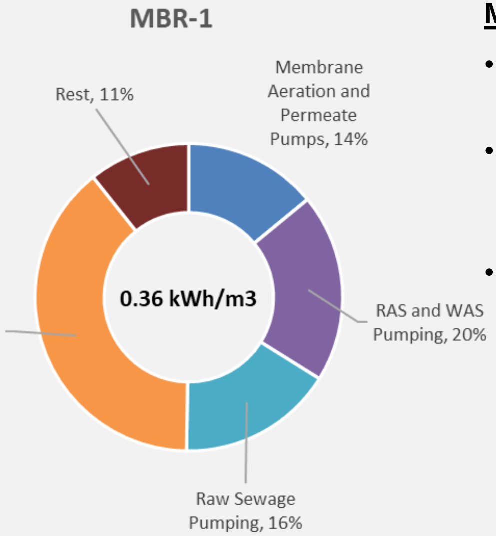


Energy Use – Limited Nutrient Removal
Scenario 1 | Nitrification Only | 30/30/NL/NL

CAS Plant

- Aeration energy use at 50%
- RAS and WAS pumping relatively small at 8%
- Raw sewage pumping is defined common starting elevation for each scenario
- Rest includes UV disinfection, chemical dosing, preliminary treatment, and other small motor loads





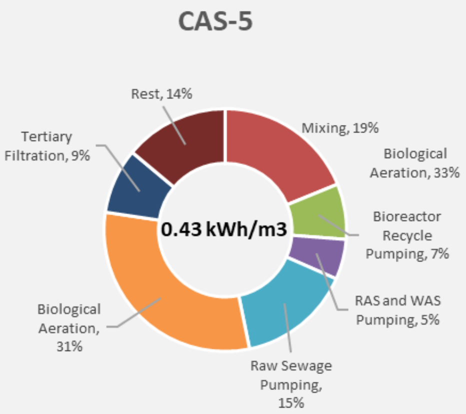
MBR Plant

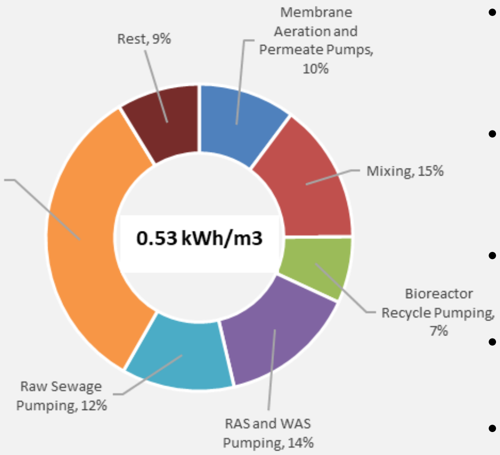
- Total energy usage 38% higher than CAS Plant
- Membrane aeration and permeate pumping energy use at 14%
- RAS and WAS much higher than CAS at 20% due to higher RAS rates

Energy Use – Enhanced Nutrient Removal
Scenario 5 | Enhanced N and P Removal | 10/10/3/0.1

CAS Plant

- 65% increase in energy use versus Scenario 1 CAS Plant
- Aeration and mixing energy use at 50%
- RAS and WAS pumping at 5%
- Bioreactor internal recycle pumping at 7%
- Tertiary Filtration at 9%





MBR Plant

- Total energy usage 23% higher than CAS Plant versus 38% higher in Scenario 1
- Membrane aeration and permeate pumping energy use at 10%
- RAS and WAS much higher than CAS at 14%
- Similar internal recycle pumping at 7%
- Mixing energy at 15%, smaller tanks

Energy Use – MBR Then and Now

Scenario 1 | Nitrification Only | 30/30/NL/NL

- Overall CAS facility energy use has slightly decreased from 0.27 kWh/m3 in 2012 to 0.26 kWh/m3 in 2022
- Overall MBR facility energy use has decreased from 0.41 kWh/m3 in 2012 to 0.36 kWh/m3 in 2022
  - Membrane specific energy use decreased from 0.092 kWh/m3 to 0.052 kWh/m3
  - Some of this is attributable to permeating by gravity assumption and the remainder includes MBR aeration efficiency improvements
- Overall MBR energy use premium has decreased from +52 percent in 2012 to +38 percent in 2022
- Varies for different treatment scenarios depending on effluent limits

Conclusions… 10 years later

- CAS still has a lower 20-year present worth lifecycle cost than MBR for greenfield facilities without TN removal requirements or low effluent TP limits
  - MBR may still be more suitable if there are space constraints or other considerations
- MBR has slightly lower lifecycle cost than CAS when moderate TN removal is required
  - Local costs for construction and power could impact the preferred technology selection
- MBR has lower lifecycle cost than CAS when low effluent TN or TP limits are required
  - Similar results would be expected for facilities producing reuse quality effluent
- Compared to the 2012 analysis, the cost premium for MBR treatment compared to CAS treatment for Scenario 1 (Nitrification only) reduced from 28% to 9.1%, while the cost advantage of MBR treatment compared to CAS for Scenario 4 (Moderate nitrogen and enhanced phosphorus removal) increased from 4% to 11%
  - MBR operational costs have reduced but are still higher than CAS, balanced by savings in initial construction cost
- Scale does not have a significant impact on the cost comparison between CAS and MBR technology
- Compared to 2012 the energy cost premium has reduced by 14 percent

HENRIKSDAL
BUILDING THE WORLD'S LARGEST MBR

Challenge: Upgrade existing plant that is built into rock formation with residential buildings built on top

Solution: Biology reconfigured to include phosphorous and nitrogen removal + membrane system installed into existing secondary clarifiers

City of Stockholm, Sweden turns to MBR technology for doubling of capacity & meeting effluent requirements

Henriksdal WWTP
Start-up: 2021

- City is growing and needs to add treatment capacity
- Commitments to Baltic Sea Action Plan and EU Water Directives
- Existing infrastructure requires upgrade
- Facility built inside a rock mountain

HAMBY
POTABLE REUSE IN ACTION

Challenge: Reservoirs in drought stricken area hitting critically low levels.

Solution: Introducing a sustainable source of water to replenish.

City of Abilene, USA turns to indirect potable reuse to maintain reservoirs
Hamby WRF **Start-up: 2015** • Region experiencing chronic draught and population growth putting area reservoirs at 30% capacity • Residents under strict water use restrictions due to drought • Discharges more than 7 million gallons of advanced treated wastewater effluent a day into Lake Fort Phantom Hill reservoir • Awarded the 2016 WateReuse Large Project of the Year

BRESCIA
NEW LIFE FOR OLD INFRASTRUCTURE

Challenge: Insufficient quality water for irrigation and human consumption.

Solution: Purify wastewater for irrigation, use fresh water for drinking.

City of Brescia, Italy uses MBR to future proof wastewater treatment

Brescia WWTP
Start-up: 2002, 2015 membrane replacement

- Capacity expanded 4x in the same footprint with Ultrafiltration
- 42 million liters per day of continuous flow
- Effluent quality dramatically increased to meet new discharge regulations
- Replaced conventional technology

MBR is no longer a niche technology or only cost-competitive in particular conditions. It is a proven solution for small to very large treatment plants and especially effective in conventional retrofits.

Before: Clarifiers

Henriksdal WWTP, Sweden. CAS to MBR conversion with 864 million liters per day when upgrade is complete.

Questions?

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