NEW WATER RESOURCES BROUGHT BY MEMBRANE TECHNOLOGIES

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ABSTRACT

Keywords: Membranes, Microfiltration (MF), Ultrafiltration (UF), Nanofiltration (NF), Reverse Osmosis (RO), Desalination

Introduction

Membrane treatment has become more prevalent in water recycling, water reuse, and salinity management, and all four major membrane categories (Microfiltration (MF), Ultrafiltration (UF), Nanofiltration (NF) and Reverse Osmosis (RO)) are commercially available. Although membranes have been used extensively in the private sector, they are considered cutting edge technology in the public water recycling, salinity management, water reuse, and desalination arena.

When water scarcity occurs, three major additional water sources are considered:

- water conservation
- recycling
- desalination

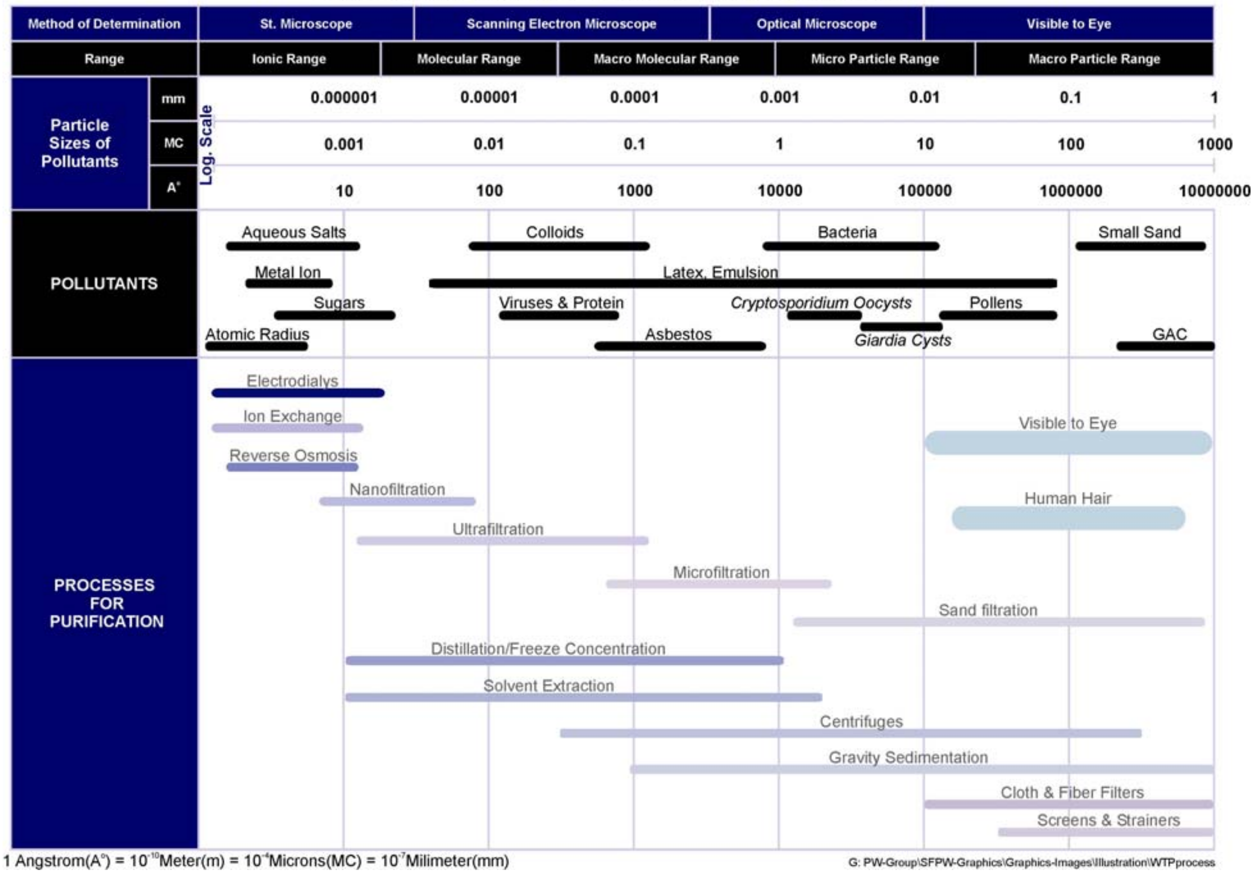
Because water conservation has its limits, recycling and desalination have become the most cost-effective alternatives for obtaining an additional water source, with membranes providing the best solution. In particular, the low pressure membranes used in bioreactors (MBR) are perceived as offering significant benefits for both new wastewater treatment facilities and for upgrades or retrofits of existing wastewater treatment facilities compared to more traditional treatment processes. When addressing recycling water salinity, MBR is a reliable pretreatment for Reverse Osmosis (RO) because it does not require any additional equipment. Moreover, membranes can play an even larger role in water recycling, water reuse, and salinity management by increasing reuse water quality; removing new constituents of concern such as pharmaceutically active compounds (PhACs), personal care products (PCPs) and endocrine disrupters (EDCs); and meeting new regulations such as Total Maximum Daily Loads (TMDLs).

Membranes are becoming important commodities in water treatment. Four major membranes categories sorted by membrane pore sizes are commercially used at the present time:

- Microfiltration (MF) - screens particles from 0.1 to 0.5 microns.
- Ultrafiltration (UF) - screens particles from 0.005 to 0.05 microns.
- Nanofiltration (NF) - screens particles from 0.0005 to 0.001 microns.
- Reverse Osmosis (RO) - ranging molecular size down to 10 MWCO.

The appropriate membrane treatment process for removal of different constituents from water can be traced in the chart below. All membrane categories are commonly used in water treatment to achieve the goals of the Drinking Water Guidelines and Standards as well as producing desalted and/or Ultra Pure Water (UPW) for different industrial and other needs, such as power plant make up water, electronic ships manufacturing, the food industry, pharmaceutical, medical, and others.

Water Treatment Processes Depending on Water Characteristics



The use of membranes in wastewater treatment lagged behind their use in water treatment; however, this market area is growing rapidly, building on the experience and technology issues overcome in water applications.

Although all four membrane categories can be found in wastewater treatment and water reuse, Microfiltration (MF) and Reverse Osmosis (RO) are the most representative in this area.

The fastest growing membranes markets are wastewater treatment by Membrane Bio-Reactor MBR, which utilizes mainly Microfiltration MF or Ultrafiltration UF membranes,; and Desalination, which mainly utilizes RO membranes.

Membrane Shape Types:

- Spiral Wound

- Hollow Fiber
- Flat Sheet

Membrane Type depending on driven pressure:

- Pressure Driven (MF, UF, NF and RO)
- Immersed, Vacuum Driven (MF and UF)

Membranes have found their place in nearly all water and wastewater business sectors:

- Municipal Water Treatment:

  - Drinking Water including Desalination

- Municipal Wastewater Treatment:

  - Biological Wastewater Treatment with Membrane Separation

  - Tertiary Treatment & Recycling Water Treatment

- Industrial Water Treatment:

  - Power Plants make-up and DI water

  - Semiconductors

  - Pharmaceutical

  - Food & Beverage

  - Medical and many others.

- Industrial Wastewater Treatment:

  - Power plants: Cooling Tower blow-down water treatment & recycling

  - Metals concentration and water recycling.

  - On-board systems (ships, boats)

- Military and Emergency systems
- Agricultural irrigation and recycling systems

Membranes occupy a strong position in all three major areas of treatment: desalination, water treatment, and wastewater treatment and reuse for both municipal and industrial applications.

DESALINATION

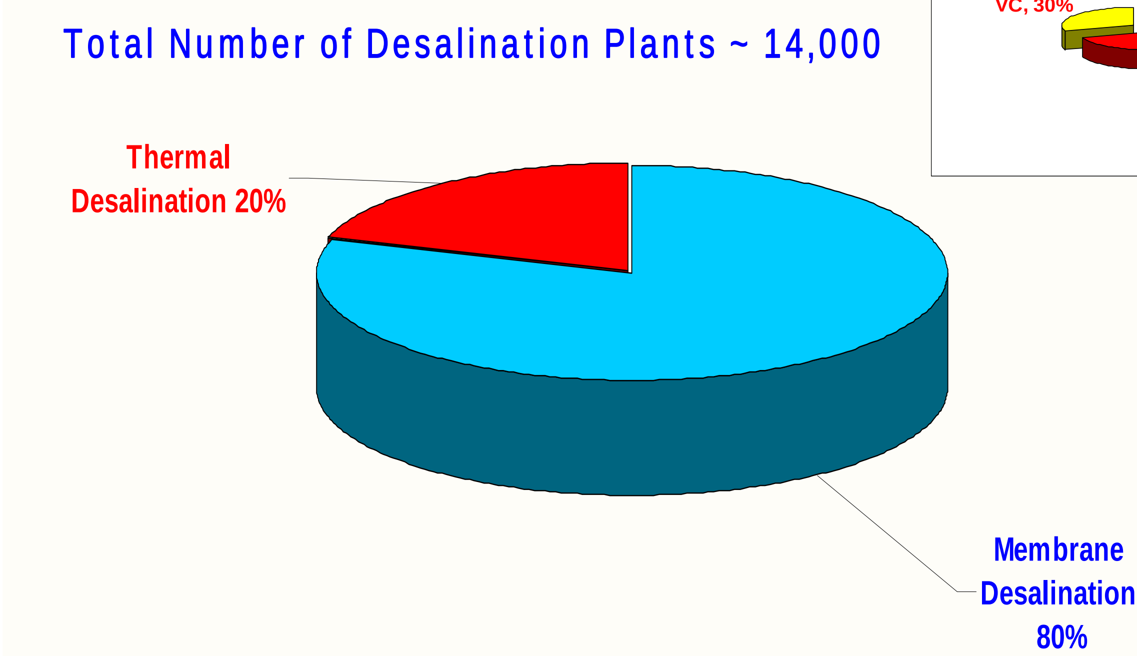
The first RO desalination membranes were developed in the early 1960s. Desalination by RO entered the commercial market in the early 1970s when the membrane manufacturing process became efficient enough to produce desalted water that was competitive with thermal processes, and when the technological process for RO desalination was established.

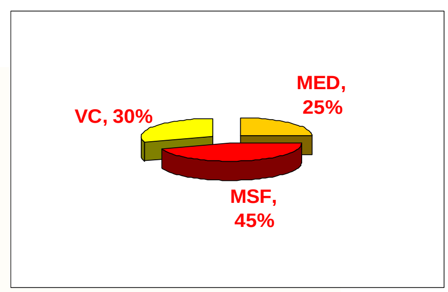
The major thread, which prevented widespread use of membrane desalination was high energy demand for the process, which was mainly affected by the water salinity (TDS) and water temperature.

Development and implementation of efficient energy recovery devices in the reverse osmosis desalination technologies boosted the growth of RO plants worldwide:

- Energy Recovery Turbines (ERT) (Pelton Wheel, Francis type) are cost effective for higher feed pressures, with typical energy savings of over 30%
- Double Work Exchanger Energy Recovery (DWEER), with typical energy recovery of over 90% of the concentrate stream
- Hydraulic turbo-charger
- Pressure/Work Exchanger: piston-type system to boost feed pressure

Due to the utilization of energy recovery, improved membrane properties, and lower membrane elements cost, desalination by membranes (SWRO) is beginning to dominate the current and future desalination markets. As seen in the chart below, the number of membrane desalination installations is close to 80% of all desalination facilities.





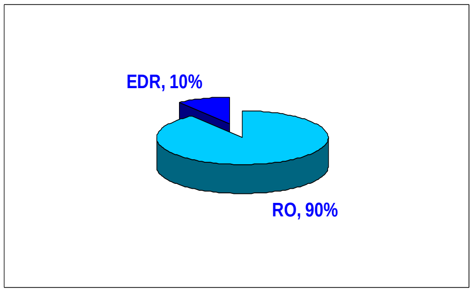


Figure 2: Number of desalination plants worldwide. RO - Reverse Osmosis, EDR - Electro Dialysis Reversal, MSF - Multi Stage Flash, MED - Multi Effect Distillation, VC - Vapor Compression

Although leading in number of installations, membrane desalination by RO still provides only a comparable capacity to the thermal processes:

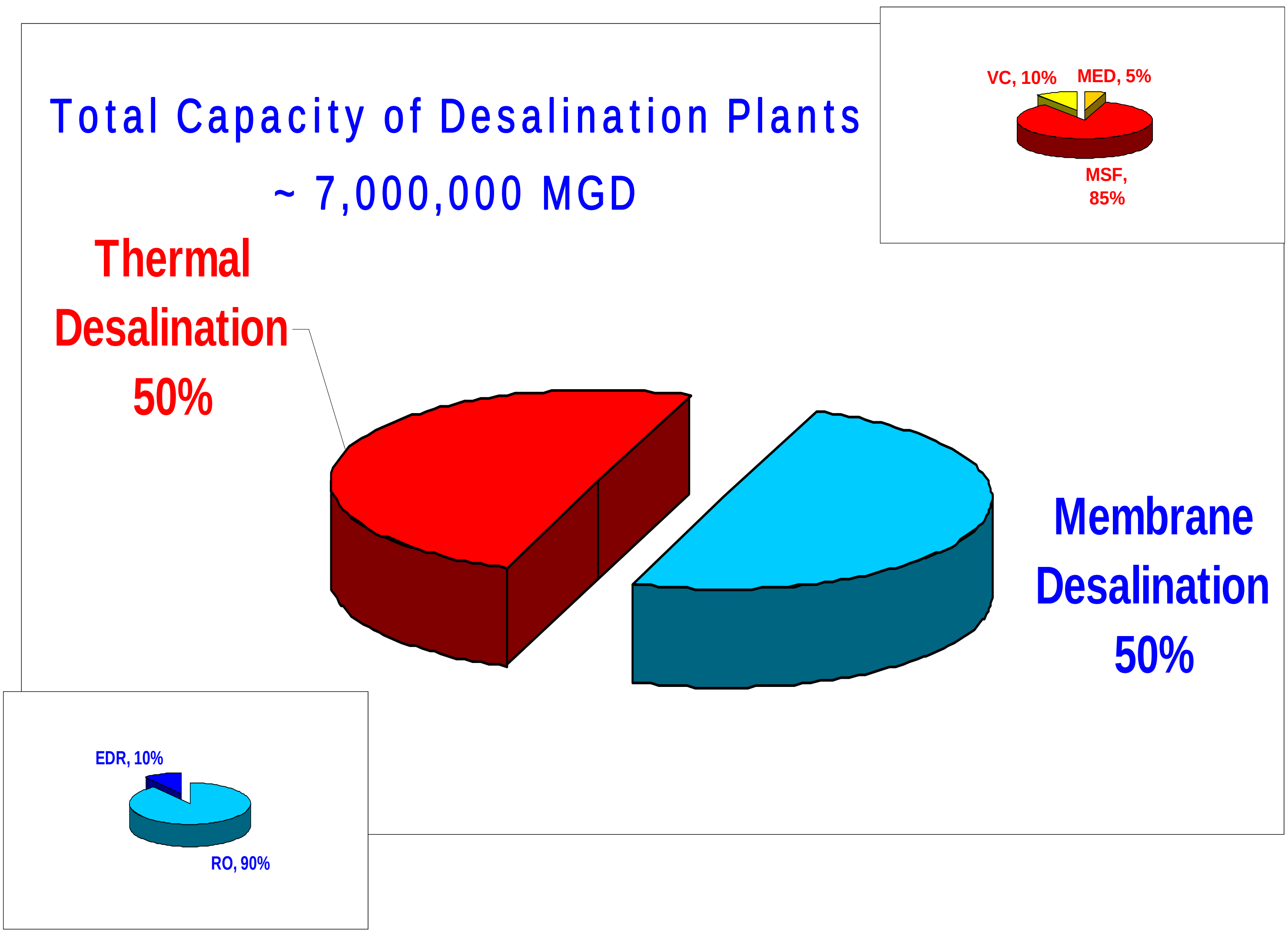


Figure 3: Desalination Capacity Worldwide. RO - Reverse Osmosis, EDR - Electro Dialysis Reversal, MSF - Multi Stage Flash, MED - Multi Effect Distillation, VC - Vapor Compression

The lack of correlation between the number of installations and overall capacities can be explained by the history of desalination. Thermal processes have been on the market more than five decades and most of them provide relatively high capacities. However, this ratio is expected to change significantly because most of the desalination systems which are being currently designed, constructed, and considered for construction are based on membrane technology. For example, the largest membrane desalination plant in the U.S. is the Tampa Bay SWRO, with a capacity of 25 MGD (and provision for expansion up to 35 MGD). The plant went into the operation in 2003. A much larger membrane desalination facility in Israel, the Ashkelon SWRO, was designed with a capacity of 44 MGD and expanded to 88 MGD in 2005. Two large SWRO desalination plants with a capacity of 50 MGD each are being considered in Huntington Beach and Carlsbad in Southern California.

When different technologies, including thermo processes, were evaluated for these large desalination facilities, membrane desalination SWRO provided the most cost-effective solution for all considerations: capital expenditures, O&M, and cost per 1,000 gallons of treated water based on 20 – 30 years of operation.

As positive results, such as cost-effectiveness, emerge from large SWRO facilities in operation, they will provide more security and confidence in building SWRO plants with larger capacities.

WATER TREATMENT

Microfiltration MF and Ultrafiltration UF technologies became commercialized in the late eighties and early nineties. The major issues in MF and NF developments are:

- Increase membrane flux
- Decrease trans-membrane pressure
- Increase particles rejection
- Extend membrane lifetime
- Improve operational process including back-wash technique and CIP cleaning
- Improve membrane manufacturing process

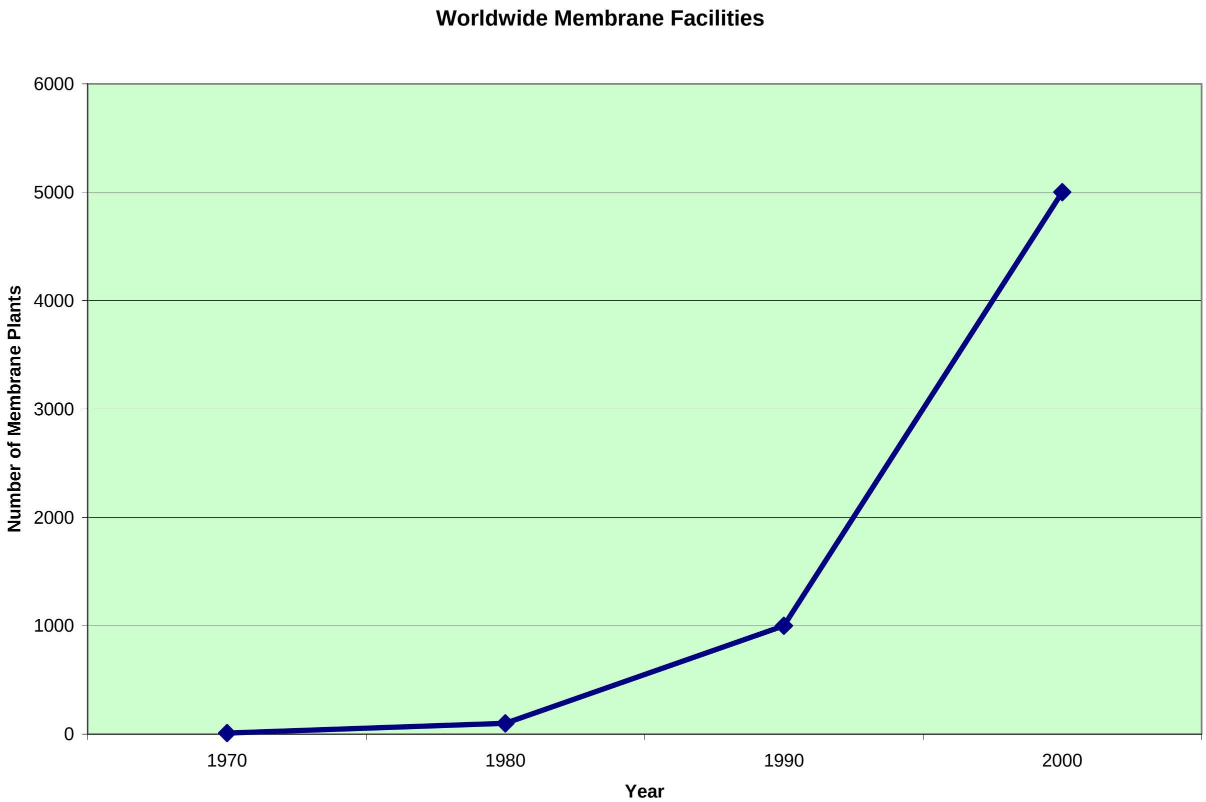
To address the above-listed major membrane targeted characteristics, to improve membrane performance, and to bring membrane applications to a new level, the following membrane characteristics and parameters are subjects of current and future research and developments:

- Improving pores shape, uniformity and distribution

- Upgrading hydrophilic properties
- Increasing membranes overall porosivity
- Developing more sophisticated and cost-effective membrane materials

During the past ten to twenty years, the availability, efficiency and reliability of membrane systems have significantly increased, while the capital and operational costs of these systems have declined considerably. This has resulted in worldwide exponential growth of membrane treatment plants. The latest AMTA information on the number of membrane plants worldwide (not including desalination systems) is provided in the chart below:

Worldwide Low Pressure Membrane Facilities (<u>not including Desalination</u>)



As competition in the membrane business grew, more and more membrane providers came into the market. As a result there has been a noticeable tendency for prices reductions in membranes during the last decade.

In water applications, low pressure membranes, MF and UF, have successfully replaced conventional clarifiers and media filters (Mono- and Multi-Media) providing product water of higher quality than conventional treatment. Low pressure membranes can be operated at a wide range of pH = 2 – 12, and all chemicals used in water treatment can be safely applied to adjust water quality if required. Coagulants can be used to upgrade operational performance, and enhanced coagulation combined with membrane filtration is a proven technique to reduce total organic carbon and color in the water.

When water is further treated for industrial use, the high pressure membranes NF and RO are successfully replacing conventional softening and ion exchange technologies based on all types of ion-exchange resins: strong acid cation (SAC), weak acid cation (WAC), strong base anion (SBA), and weak base anion (WBA).

To get ultra pure water, the revolutionary electro-deionization (EDI) technology is successfully replacing mixed beds polishers, providing consistent water resistivity in the range of 18 Mohm-cm, which meets the strictest industrial standards for semiconductor, power, pharmaceutical, medical, and other industries.

WASTEWATER TREATMENT AND REUSE

Membranes found their place in wastewater treatment in the early 1990s, making wastewater treatment by membranes the youngest membrane treatment technology and the most recently growing. The growth of wastewater treatment by membranes is predicted to experience stable growth, exceeding 15% annually up to the year 2010.

The major wastewater/water reuse membrane types of applications are:

- Membrane Bio-Reactors (MBR):

  - liquor (MLSS) separation from the supernate using pressure or immersed (vacuum) membranes.

  - supernate separation from the residual particles.

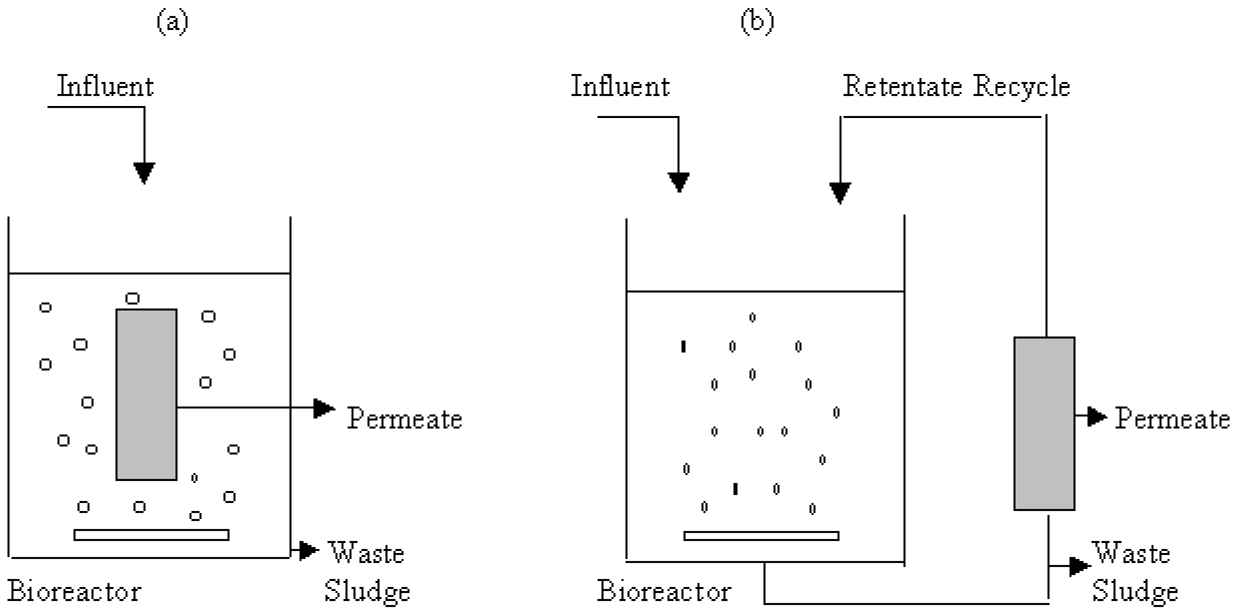
- Reuse/Recycling water:

  - solids (TSS/TDS) removal from the biologically treated water (MF/UF followed by NF/RO).

Membrane technologies can be a stand alone process and/or used in combination with the traditional conventional technologies. The best approach in process selection has to be based on the wastewater chemistry, the requirements of the treated effluent and system capacity, as well as operational requirements and specific needs of each individual site and project.

When selecting the type of MBR technology for a given project, the major performance features and economics have to be considered.

Submerged MBR configuration with membrane unit integrated into the bioreactor.	Side stream MBR configuration with a separate membrane filtration unit



Comparison of MBR configurations.

Parameter	Immersed Membrane MBR	Side-stream MBR (pressure)
Flux	Lower	Higher
Footprint	Larger	Smaller
Aeration Cost	Higher (>90%)	Lower (>20%)
Permeate Discharge/Pumping Cost	Lower (up to 30%)	Higher (up to 80%)
CIP Frequency	Lower	Higher
Capital Cost	Higher	Lower
O&M Cost	Lower	Higher

The major characteristics of Membrane Bio-Reactors using Microfiltration or Ultrafiltration Membranes are summarized in the table below.

Wastewater Treatment Parameter	MBR Value, Metric	MBR Value, US	Conventional Treatment Value, Metric	Conventional Treatment Value, US

Wastewater Treatment Parameter	MBR Value, Metric	MBR Value, US	Conventional Treatment Value, Metric	Conventional Treatment Value, US
Transmembrane Pressure (Immersed Membranes), TMP	10 – 50 kPa	1.5 – 7.5 psi	NA*	NA
Flux	15 – 25 l/m2 x hr	9 – 15 GFD	NA	NA
Energy Consumption, TOTAL	1 – 3.5 kW-hr/m3	5.0 – 17.5 HP-hr/1,000 gal	0.9 – 2.9 kW-hr/m3	4.5 – 14.5 HP-hr/1,000 gal
Energy Consumption, aeration	0.9 – 3.2 kW-hr/m3	4.5 – 16.0 HP-hr/1,000 gal	0.9 – 2.9 kW-hr/m3	4.5 – 14.5 HP-hr/1,000 gal
Energy Consumption, permeate discharge	0.1 – 0.3 kW-hr/m3	0.5 – 1. 5 HP-hr/1,000 gal	NA	NA
MLSS	10 – 25 gr/liter	80 - 200 lbs/1,000 gal	3.5 – 6.0 gr/liter	28 - 48 lbs/1,000 gal
Hydraulic Retention Time, Average	12 hrs	12 hrs	24 hrs	24 hrs
Sludge age	20 – 60 days	20 -60 days	17 – 20 days	17 – 20 days
BOD Removal	95 – 99%	95 – 99%	90 – 95%	90 – 95%
COD Removal	95 – 99%	95 – 99%	90 – 95%	90 – 95%
TKN Removal	40 – 95 %	40 – 95 %	40 – 80%	40 – 80%
Membrane Warranty	5 – 8 years (prorated up to 10)	5 – 8 years (prorated up to 10)	NA	NA
Membrane Module Price	50 – 100 US$/m2	5 – 10 US$/ft2	NA	NA

NA* - Not Applicable

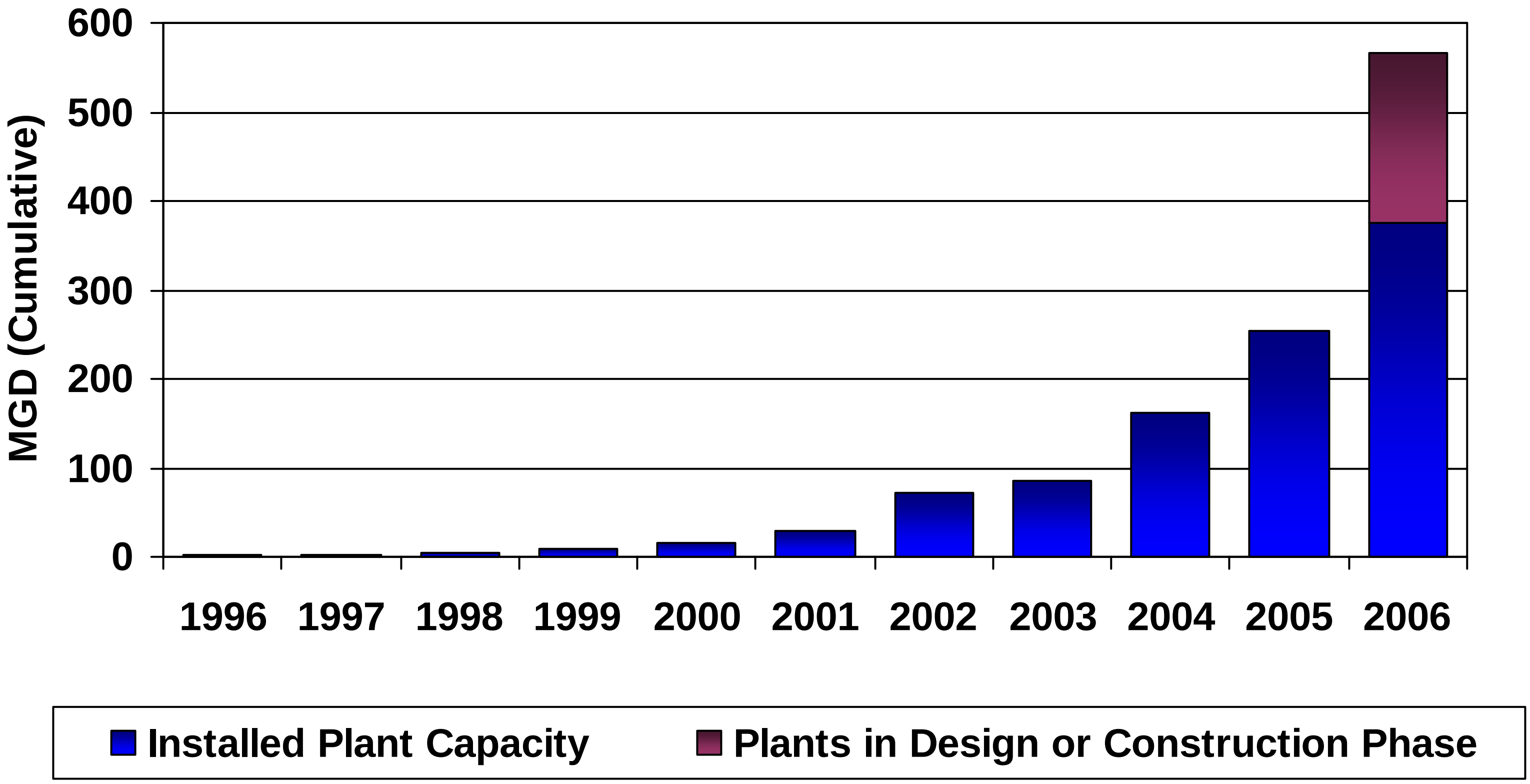
MBR performance compared to conventional biological treatment.

Parameter of effluent	Conventional typical	MBR guaranteed	MBR typical
BOD5	10 – 30 ppm	< 5.0 ppm	< 0.4 ppm
TSS	10 - 30 ppm	< 5.0 ppm	< 3.0 ppm
Turbidity	10 - 20 NTU	< 0.2 NTU	< 0.2 NTU
NH3-N	< 5 ppm	< 1 ppm	< 0.5 ppm
TN	< 10 ppm	< 10 ppm	< 5 ppm
TP	< 1.0 ppm	< 0.5 ppm	< 0.2 ppm

Two decades ago at the beginning of the commercial low pressure membrane era, the typical membrane warranty was provided for no more than 3 years. Currently, most manufacturers provide a 5 year warranty and some suppliers provide a prorated warranty of 8 years and up to 10 years.

One of the main characteristics of MBR technology is the ability of membranes to remove pathogenic organisms, while providing disinfection of the effluent at the same time.

MBR installations have grown exponentially. For example, ZENON reports accelerated demand in MBRs as represented in the chart below.



Membranes provide a number of significant benefits and have become cost effective for many water and wastewater treatment applications, replacing conventional traditional processes while benefiting new constructions and upgrades and retrofits of existing facilities.

<u>Ten Technical Reasons to Select Membranes:</u>

1. Absolute barrier for treatment/removal
2. Smaller footprint/Layout
3. Product water is not affected by the feed water hydraulic and contaminant overloads, spikes, and fluctuations
4. Less or no chemicals required
5. Minimal or no pre-treatment required
6. Single step process
7. Modular expandability (for future expansions)
8. Less volume of discharged wastes (including sludge and chemicals)
9. Simplicity of operation with remote monitoring
10. Lower post-disinfection demand in chlorine, UV intensity.

<u>Five Commercial Reasons to Select Membranes:</u>

1. Provide more effective substitution to all water/wastewater treatments
2. Cost competitive for water applications, especially for mid and large size facilities (> 1 MGD);
3. Cost competitive for wastewater applications, especially for high discharge criteria and reuse
4. The best cost-effective solution for upgrades in water/wastewater
5. Minimal labor requirements for O&M (much less than conventional)

The chart below can be a directional guideline for the membrane selection process for different treatment needs. Each individual project has to be evaluated for feed water quality, requirements for the treated effluent water, size of the system, capital and operational cost, as well as for the project specific conditions.

Membrane Conversion Chart

Water Source	Major Characteristics	Recommended Conventional Treatment	Membrane Treatment Alternative
River	TSS > 100 ppm	Clarifier + Media Filter	MF or UF
	TSS = 50-100 ppm	Clarifier + Media Filter	MF or UF
	TSS < 50 ppm	Multi-Media Filter	MF or UF
Lake or Large Pond	Hard Water + TOC .	Enhanced Coagulation + Lime Softening + Clarifier + Media Filter	Enhanced Coagulation + MF or UF
	TSS > 100 ppm .	Enhanced Coagulation + Clarifier +Media Filter	Enhanced Coagulation + MF or UF
	TSS = 50-100 ppm .	Coagulation + Clarifier +Media Filter	MF or UF .
	TSS < 50 ppm	Coagulation +Media Filter	MF or UF
Well	Iron & Manganese	Greensand Filter	MF or UF
	Hardness	Filter + Softener	MF or UF + NF
	TSS > 10 ppm	Media Filter	MF or UF or UF
	TSS = 5-10 ppm	Media Filter	MF or UF or UF
	TSS < 5 ppm	Double Cartridge Filters	MF or UF or UF
Sea/Ocean Water	TSS > 100 ppm .	Clarifier + Media Filter + Desalination	MF or UF + RO .
	TSS = 50-100 ppm .	Clarifier + Media Filter + Desalination	MF or UF + RO .
	TSS < 50 ppm	Double Media Filter + Desalination	MF or UF + RO
Ultra Pure Water (UPW)	Product requirements Resistivity 18 MOhm-cm	Mixed Beds	EDI
Wastewater	All wastewater	Full Biological Treatment process	MBR

	characteristics	based on Activated Sludge	
Tertiary Effluent	All characteristics	Coagulation + Media Filter	MF or UF

SUMMARY

Membranes have become an important commodity in water and wastewater treatment as it finds more and more applications and replaces traditional conventional technologies. Used in combination with different technologies, membranes may address removal of mineral and organic compounds in the water, including volatile type compounds such as endocrine disruptors (EDCs) (42 found in the U.S.A.) pharmaceutically active compounds (PhACs), and personal care products (PCPs).