Awwa Research Foundation

Advancing the Science of Water®

Advancing the Science of Water: AwwaRF and Membrane Processes

The 1986 Amendments to the Safe Drinking Water Act spawned a number of federal regulations, some addressing competing water quality objectives that test the capabilities of conventional treatment practices. In order to meet these new regulatory requirements, water suppliers have been compelled to consider alternative treatment technologies over the past two decades.

Membrane processes, among the most promising and most popular of the innovative technologies, are now being used worldwide to achieve a range of water treatment goals, including removing pathogens, other particles, and organic matter from traditional supplies; desalting lower-quality sources such as brackish groundwater and seawater; and treating municipal wastewater for nonpotable reuse.

At its most basic level, membrane technology is a separation process in which a pressure-driven liquid crosses a semipermeable membrane that separates the solution's components according to their physical and chemical properties. The membranes most commonly used in drinking water treatment are low-pressure or high-pressure products that are permeable to water but act as barriers to contaminants of assorted sizes.

"Membranes can't oxidize anything or force a chemical reaction, but they provide a physical barrier of various nominal pore sizes that can remove almost all drinking water contaminants," said James S. Taylor of the University of Central Florida. "Although there is no such phenomenon as complete contaminant removal, membranes are the most universally capable process available for drinking water treatment."

High-pressure membranes—reverse osmosis (RO) and nanofiltration (NF)—have significantly smaller sized pores than low-pressure membranes. RO membranes are used primarily to remove salts and other dissolved solids. NF membranes generally reject substances in the size range of a nanometer—for example, natural and synthetic organic compounds. Low-pressure membrane processes, often called ultrafiltration (UF) or microfiltration (MF), are used primarily to remove pathogens—including the chlorine-resistant protozoan *Cryptosporidium*—and as a pretreatment step to extend the life of high-pressure membrane systems.

Using Membranes to Treat Drinking Water

AwwaRF funded its first membrane-related project in 1988, just two years after passage of the 1986 Amendments. Since that study, which established a blueprint for membrane research related to treating potable water, AwwaRF has funded more than 50 membrane projects valued at more than $25 million.

"When AwwaRF started funding membrane research, high-pressure membranes were more developed as an alternative treatment process," said Joe Jacangelo, a vice-president of MWH (formerly James M. Montgomery Consulting Engineers). "But little to nothing had been done in terms of studying low-pressure membranes. AwwaRF had the foresight to see that membranes offered a huge benefit for drinking water purveyors as well as overall public health."

In addition to expanding water suppliers' knowledge of the capabilities of low-pressure and high-pressure membrane systems, AwwaRF studies have elucidated operational considerations such as fouling, membrane integrity, and concentrate disposal. AwwaRF has also played a leading role in outlining membrane research needs and providing data for developing water quality regulations.

AwwaRF's fundamental contributions to the acceptance of membrane processes as viable water treatment technologies include:

- Helping to define the international agenda for membrane research;
- Proving that low-pressure membranes reject particles in drinking water;
- Documenting the effectiveness of low-pressure membranes at removing pathogens, including protozoa, bacteria, and some viruses;
- Verifying the ability of high-pressure membranes to remove pathogenic microorganisms, particularly viruses;
- Demonstrating the efficacy of high-pressure membranes for removing pesticides, trace organics, and inorganic solutes;
- Confirming the feasibility of using membranes not only as stand-alone processes but also in integrated water treatment systems;
- Evaluating techniques for monitoring membrane integrity during operation;
- Characterizing membrane concentrate and addressing requirements for its disposal;
- Identifying the factors that influence membrane fouling and delineating methods to minimize its effect on performance;
- Compiling statistics on membrane applications and installations worldwide, including information on geographic location, water quality considerations, plant design, permitting requirements, product procurement, operations, and costs; and
- Providing data for use in the development of federal water quality regulations.

Defining the Research Agenda

AwwaRF's role in defining the agenda for membrane research began with its first membrane project, in which Taylor identified the research needs related to using membranes to treat drinking water ("Assessment of Potable Water Membrane Applications and Research Needs," Project 424, funded 1988, published 1989, order number 90564). Since then, AwwaRF has followed up with two workshops that convened groups of experts to determine research needs—the first in Bar Harbor, Maine, in 1995; the second in Golden, Colorado, in 2000.

"The Bar Harbor gathering was the first time membrane experts from all over the world came together," said Taylor. "About 20 of us, including researchers and manufacturers, spent a week discussing the questions that needed to be addressed through research projects."

"AwwaRF was consistent in identifying the issues that needed to be addressed and in getting answers to these questions," said Samer Adham, also a vice-president of MWH.

Determining the Capabilities of Low-Pressure Membranes

Particle Removal. AwwaRF's first research on the feasibility of using membrane processes to treat drinking water was a groundbreaking pilot study of low-pressure membranes conducted with United Water in Boise, Idaho, and directed by Jacangelo ("Low Pressure Membrane Filtration for Particle Removal," Project 506, funded 1989, published 1992, order number 90603). The project evaluated the performance of three UF membranes—two hollow-fiber models and one spiral-wound product—under real-world conditions and demonstrated that these membranes were capable not only of meeting but exceeding the Surface Water Treatment Rule requirements for removing microorganisms.

"This study showed that low-pressure membranes could produce very high water quality, and it examined some of the parameters that governed operation and contributed to fouling and fouling prevention," said Jacangelo. "We didn't have a lot of knowledge about fouling and fouling control then. Today, we're light-years ahead in our understanding of fouling, and a lot of this is attributable to AwwaRF projects."

"The early work in Boise was an eye-opener for me in terms of the potential viability of these technologies," said James Lozier, a vice-president of CH2M Hill. "When AwwaRF started funding membrane research, there was little information in the United States on how to apply membrane technologies in our industry. Very little was happening in terms of pilot testing or constructing facilities. AwwaRF was a pioneer in funding research on membrane technologies when most people hadn't even heard of them or had heard of them only for other applications.

"The Boise study gave us a much better understanding of how these 'new' technologies performed in this particle removal application and how they performed relative to each other," Lozier continued. "Prior to the market for low-pressure membranes, we had RO, and all the products for this process were interchangeable—the membranes all fit into the same housing and pretty much worked the same. With the advent of the UF/MF marketplace, the whole landscape changed because these membranes were proprietary products—one developed in Australia, one in the United States, one in France. Now we had to understand how these products operated and how to compare them functionally. This study helped me understand that these membranes had different properties—they don't backwash the same; they aren't cleaned in the same way. With low-pressure membranes, writing procurement documents and evaluating costs became much more complicated."

Pathogen Removal. A subsequent AwwaRF project documented the effectiveness of low-pressure membranes at rejecting microorganisms ("Membrane Filtration for Microbial Removal," Project 817, funded 1992, published 1996, order number 90715). Conducted by Jacangelo and Adham, the study evaluated six membranes at bench scale and four at pilot scale and tested seven techniques for monitoring membrane integrity.

"This study may have been as groundbreaking as the Boise study," said Lozier. "The Boise study showed that low-pressure membranes were effective at particle removal, but this study examined how well they control pathogens, which was—and still is—their principal value."

All the membranes that Jacangelo and Adham tested removed *Giardia, Cryptosporidium,* and selected bacteria to below detection limits, but their ability to remove the MS2 virus varied. The air-pressure hold test proved to be the most sensitive direct method for monitoring membrane integrity, and particle counting was the most sensitive indirect method. But even when a membrane fiber was compromised, the membranes still achieved substantial removal of *Giardia* and *Cryptosporidium*.

"The early studies of low-pressure membranes showed that these membranes could be used to control microorganisms and remove turbidity," said Jacangelo. "This had never been done before on a drinking water scale; most applications at this time were at pharmaceutical companies and other settings involving small flows. These studies made a huge difference because they demonstrated that membranes could be used on a much larger scale. Later studies produced more incremental changes. Big studies with a global impact have diminished because the field has matured."

Differentiating Low-Pressure Membranes. In a more recent AwwaRF study, Jacangelo developed a method for characterizing low-pressure membranes according to their ability to directly remove microorganisms rather than relying on nominal pore size to predict their removal capabilities ("Micro-and Ultrafiltration Performance Specifications Based on Microbial Removal," Project 2683, funded 2000, published 2006, order number 91089). Jacangelo believes this approach to characterizing low-pressure membranes is needed because he thinks the terms UF and MF, which the drinking water profession adopted from the pharmaceutical industry, are inappropriate for drinking water applications.

"In the drinking water community, MF has gotten a bad name because it's been associated with being unable to remove viruses," Jacangelo said. "Some manufacturers simply began calling their membranes UF without making any changes to the membranes because there were no guidelines and no standard terminology delineating what UF and

MF meant. I've contended that that we should come up with a standardized protocol for characterizing these membranes. I don't think we should distinguish between MF and UF; we should use the term low-pressure membranes for both"

Examining High-Pressure Membranes

AwwaRF funded a breakthrough study of high-pressure membranes in 1994 with its Dutch research partner, Kiwa Water Research. With Taylor as principal investigator, the study demonstrated the ability of RO membranes to remove pesticides, total organic contaminants, and inorganic solutes from drinking water ("Flat Sheet, Bench, and Pilot Testing for Pesticide Removal Using Reverse Osmosis," Project 170, funded 1994, published 2000, order number 90808).

The project was undertaken because the U.S. Safe Drinking Water Act, the European Community Standards, and the World Health Organization Guidelines for Drinking Water Quality specified maximum allowable concentrations of specific pesticides in drinking water and, at the time, little information was available on pesticide rejection at the concentrations specified in these regulations. The study also produced a model for predicting pesticide removal by these diffusion-controlled membranes.

A more recent study funded by AwwaRF and Kiwa showed that NF could also remove trace organic contaminants under a range of experimental conditions ("Nanofiltration Retention Models for Organic Contaminants," Project 2945, funded 2003, to be published in 2007, order number 2945). In addition, the study produced a model to predict NF's ability to reject trace organic compounds at full scale.

Integrating Membranes With Other Treatment Processes

Applying membrane technology to drinking water treatment in the United States went through several stages, according to Adham. "Initially, membranes were applied primarily to relatively contaminant-free water sources just for filtering out microorganisms. Their use originated in France and Australia, where they were considered a polishing step," Adham said. "The success of these early membrane installations made other utilities envious, but many of them had more challenging water sources containing other contaminants such as organic material. At this point, utilities started combining membranes with pretreatment processes in order to meet multiple water quality challenges. AwwaRF was at the forefront of this trend. It was instrumental in ensuring the wider application of membrane technology."

AwwaRF and the U.S. Environmental Protection Agency (USEPA) co-sponsored the first project to investigate the feasibility of combining membrane processes with other types of treatment ("Integrated Membrane Systems," Project 264, funded 1995, published 2004, order number 90899). Led by Jan Schippers at Kiwa, the project involved six water utilities from the United States and Europe and included both pilot- and full-scale studies.

"This was the first project to look at the integration of membrane processes," said Taylor, another of the project's principal investigators. "It showed that membranes were not simply isolated stand-alone processes but could be used with other treatment technologies—for example, removing pesticides by applying membranes prior to granular activated carbon treatment to extend the life of the carbon, using coagulation before RO, or using coagulation and replacing sand filtration with UF or MF."

Although both low-pressure and high-pressure membranes can remove microorganisms, only RO and NF can remove the trace organics that become precursors to disinfection by-product (DBP) formation—but these diffusion-controlled processes require some type of pretreatment to control fouling. This study examined six treatment systems that integrated membrane processes and various types of pretreatment—slow sand filtration, soil passage (e.g., riverbank filtration or canal infiltration), coagulation–sedimentation–filtration, MF, and UF. By integrating low-pressure and high-pressure membranes, the study also demonstrated the synergistic ability of staged membranes processes to remove both microbiological and organic contaminants.

"The Schippers study was groundbreaking in scope because it showed us how to apply membrane processes in a broader context," said Lozier. "Till that time, most people were just using membranes as an independent process for particle removal. This study showed there is a much bigger universe in which we can consider applying membranes to meet a host of water quality needs."

All the integrated membrane systems tested in this study produced biologically stable water that satisfied regulatory requirements for removing pathogens and DBP precursors. This finding was significant because it showed that RO and NF can be used to treat surface water, provided these processes are preceded by appropriate pretreatment and fouling is controlled by cleaning at acceptable frequencies.

"When you use MF or UF as a pretreatment to prevent fouling, this removes the particles and leaves the RO to do what it's designed to do, which is to remove salts," said Lozier.

Subsequent projects have continued to explore integrating membrane technologies into existing and planned water treatment facilities. In a tailored collaboration with the Kansas City (Missouri) Water Services Department, Gil Crozes of Carollo Engineers investigated two retrofit strategies for the utility's 240-mgd lime softening plant ("Integrating Membrane Treatment in Large Water Utilities," Project 2876, funded 2002, published 2004, order number 91045F).

Both retrofit scenarios involved integrating low-pressure membrane systems with granular media filters. Results of a six-month pilot study enabled the researchers to develop design criteria and cost estimates for each scenario. Although both scenarios proved feasible, membrane module and system characteristics dictated their practicality, and their performance depended heavily on the physical and hydraulic constraints imposed by typical filter bed designs. Cost predictions ranged from $0.364/gpd to

$0.395/gpd, significantly lower than unit costs of the largest low-pressure membrane systems in place at the time.

Another alternative treatment scheme integrates membranes and biological treatment, with the membrane serving as a bioreactor. Adham and Bruce Rittmann of Northwestern University examined the efficacy of this technology for removing specific groundwater contaminants at pilot scale and defined the operating conditions required for full-scale application ("Membrane Biofilm Reactor Process for Nitrate and Perchlorate Removal," Project 2804, funded 2001, published 2004, order number 91004F).

Compiling Membrane Data

In an early effort to synthesize the data on membrane treatment of drinking water, AwwaRF collaborated on a handbook on membrane processes in the early 1990s ("Water Treatment Membrane Processes," Project 826, funded 1992, published 1996, order number 90716). The book was compiled by three leading researchers—Joel Mallevialle from France, Peter Odendaal from South Africa, and Mark Wiesner from the United States—who attributed what they described as the "relatively recent global increase in the use of membranes in environmental engineering applications" to three factors: regulatory pressures, increased demand for water, and market forces surrounding the development and commercialization of membrane technologies.

In discussing regulatory pressures, the handbook's editors noted that new regulations had "generated considerable interest in the use of membrane processes for particle removal, for the removal of organic materials that may be precursors to disinfection by-products, and for membrane disinfection."

Envisioning that membrane processes could play a role in mitigating water scarcity, the editors predicted that membranes might allow us to use water sources previously considered impractical because of "technical or economic considerations." As examples, they cited the use of RO to treat seawater and the use of NF, "or 'softening' membranes," to treat shallow groundwater containing "high concentrations of hardness (calcium and magnesium) as well as high concentrations of natural organic matter."

Observing that indirect potable reuse and direct industrial reuse had become "attractive means of extending existing water supplies," the editors pointed out that these processes also provided opportunities for incorporating membrane technologies. Among the market forces discussed were the use of membranes to treat water used for kidney dialysis and the burgeoning market for membrane products in other countries, particularly Japan.

Individual chapters of the handbook covered a variety of topics, including the principles of rejection in pressure-driven membranes, specific characteristics and capabilities of RO, NF, UF, and MF membranes, field evaluation and pilot testing, biofouling, and membrane bioreactors.

A more recent project funded by AwwaRF and the U.S. Bureau of Reclamation consolidated a great deal of dispersed information about current low-pressure membrane installations across the globe ("Development of a Microfiltration and Ultrafiltration Knowledge Base," Project 2763, funded 2001, published 2005, order number 91059; report includes a searchable CD-ROM). Led by Adham, the researchers conducted a literature survey, a survey of membrane vendors, and a survey of membrane plant owners and operators, then compiled a comprehensive database on MF/UF drinking water plants, reclaimed water plants, and desalination plants using MF/UF as pretreatment.

The vendor survey identified 450 MF/UF facilities with capacities ranging from 0.1 mgd to 100 mgd. The plants were located in 38 countries. As of 2004, according to Adham, North America was home to almost half (48 percent) of the total installed MF/UF capacity; a third (32 percent) was located in Europe; and the remainder was in Asia, Australia, and the Pacific islands.

"As a practical project, this was an important study," said Lozier. "By bringing together valuable information that wasn't easily accessible before, the study helped consultants and utilities better understand what others were doing with membrane technology and uncovered some of the issues that had cropped up as these processes were operated."

The survey of plant owners and operators yielded guidance on topics as varied as pilot testing, water quality, plant design, permitting, procurement, operation, integrity monitoring, residuals handling, and costs. The lessons learned by these owners and operators should help water suppliers and consultants select membrane products, streamline the regulatory approval process, optimize operations, and minimize costs.

Addressing Operational Concerns

The first full-scale low-pressure membrane plant in the United States—a 5-mgd MF system at the San Jose (California) Water Company's Saratoga plant—went on line in 1994. Before this pivotal event, AwwaRF funded a number of studies during the early 1990s to address operational considerations such as membrane integrity, concentrate disposal, and fouling.

Monitoring Integrity. In addition to the integrity tests conducted during the Boise study, membrane integrity was a topic of investigation in several subsequent AwwaRF projects.

In research funded by AwwaRF and the U.S. Bureau of Reclamation, Lozier and Benito Mariñas of the University of Illinois monitored the integrity of high-pressure membranes ("Microbial Removal and Integrity Monitoring of High-Pressure Membranes," Project 435, funded 1997, published 2003, order number 90942F). "We spiked samples with a variety of virus-removal indicators," said Lozier. "The most practical was Rhodamine WT, a large-molecule fluorescent dye, but it ends up in concentrate because it's highly rejected, and this of course has regulatory implications. The study gave us a better understanding of the effects of different types of membrane defects, but we didn't get to the Holy Grail, which would have been the ability to say 'Here's something you can purchase inexpensively and apply with no environmental downside.'"

In a collaborative effort sponsored by AwwaRF and the U.K. Drinking Water Inspectorate, Crozes evaluated the effectiveness of existing methods for measuring the integrity of low-pressure membranes and recommended improvements ("Assessment and Development of Low-Pressure Membrane Integrity Monitoring Tests," Project 2681, funded 2000, published 2004, order number 91032). The most reliable methods were the pressure decay test, a microbial challenge test, and—particularly for UF systems—high-sensitivity particle counters.

Concentrate Disposal. In pressure-driven membrane systems, the portion of the feed solution that passes through the membranes is called the permeate. The reject stream, or concentrate, is a waste product that must ultimately be disposed of.

As early as 1990, AwwaRF funded the definitive study on membrane concentrate disposal ("Membrane Concentrate Disposal," Project 607, funded 1990, published 1993, order number 90637). For this project, Mike Mickley and his colleagues at Mickley & Associates surveyed U.S. drinking water utilities to identify every treatment plant in the country that was using any type of membrane process. With data gleaned from this survey and a worldwide literature review, they described the chemical characteristics of concentrate and discussed concentrate management and disposal methods and their costs. The study also incorporated a state-by-state review of regulations and permits that applied to various disposal options including surface water discharge and underground injection.

"Desalination processes were in place prior to AwwaRF's projects, but concentrate disposal wasn't receiving much attention," Mickley said. "It's only been in the past few years that utilities have felt the need to solve concentrate disposal problems. That's because of more stringent regulations, more membrane installations, larger plant sizes, and more public awareness of environmental issues."

"I still use Mickley's report on concentrate disposal," said Lozier. "It was an important study because it pulled together a lot of information from diverse sources and made it accessible in one place for the first time. When the report was published, concentrate disposal wasn't as big an issue as it is today, but it's become the major issue related to applying desalination technologies anywhere away from the coast."

Mickley points out that the project's survey of U.S. membrane plants provided baseline information for tracking the growth of the membrane industry, as well as the location and size of plants, operation trends, and concentrate disposal practices. He adds that data from this study were also used by the Joint Water Reuse and Desalination Task Force, an alliance of six national research organizations—AwwaRF, the U.S. Bureau of Reclamation, the Water Environment Research Foundation, WateReuse Foundation, National Water Research Institute, and the Sandia National Laboratories—to create a "desalination roadmap." Originally published in 2003 and currently being updated, this document maps out a research agenda related to water reclamation, reuse, recycling, salinity management, and desalination issues. "These groups wanted to collaborate on a research agenda to avoid overlapping projects," Mickley said.

A subsequent Mickley study produced models to predict the occurrence and causes of ion toxicity in concentrate and reviewed potential technical and regulatory options for dealing with it ("Major Ion Toxicity in Membrane Concentrate," Project 290, funded 1995, published 2000, order number 90824).

Controlling Fouling. "AwwaRF also led the attack on membrane fouling," said Taylor. After Jacangelo's particle removal study, which examined fouling and fouling control in low-pressure membrane systems (Project 506, discussed earlier), AwwaRF funded a study to evaluate the impact of fouling on high-pressure membranes ("Biological Fouling of Separation Membranes Used in Water Treatment Applications," Project 904, funded 1993, published 2003, available only to subscribers via order number 904). Conducted by Harry Ridgway of Orange County (California) Water District, the study identified the physico-chemical and biological factors that influence bacterial attachment to various membrane materials and correlated biofilm growth kinetics with membrane performance.

Influencing Federal Regulations

Several of the projects discussed in this report have had direct bearing on federal water quality regulations. "AwwaRF's contributions in the area of membranes have influenced regulations in a positive manner for foundation subscribers," said Jacangelo.

Lozier notes that without the Boise study on particle removal (Project 506), "we wouldn't have had the basis to consider low-pressure membranes for clients and to say that membranes can meet the Surface Water Treatment Rule [SWTR] requirements more effectively than other technologies."

The subsequent study on pathogen removal (Project 817) is considered equally important in terms of meeting the suite of regulations related to the SWTR. "Research on the removal of pathogens documented how successfully membrane processes could remove microorganisms and supported the regulatory standards by establishing the log removal credits in the Surface Water Treatment Rule," said Mickley. "The primary use of membrane technology now is for *Cryptosporidium* removal to meet the Long Term 2 Enhanced Surface Water Treatment Rule [LT2ESWTR]," said Adham.

The AwwaRF study on RO removal of pesticides (Project 170) caught the attention of USEPA regulators, who asked if AwwaRF would design a protocol for the membrane treatment studies required under the Information Collection Rule (ICR). The ICR was a short-term regulation under which almost 300 U.S. utilities collected monitoring data to support decision-making for regulations to control DBPs and pathogens in drinking water. Utilities meeting certain criteria were also required to conduct pilot studies to evaluate the feasibility of removing DBP precursor material by treatment with granular activated carbon or membrane processes.

"We wrote protocols for membrane pilot-testing techniques that could be used to meet the ICR requirements or by anyone else doing membrane pilot studies," said Taylor. Developed as an outgrowth of Project 170, the protocols were published in a separate report ("Development and Verification of ICR Membrane Protocol for Bench and Pilot Studies, order number 90809), and USEPA adopted them. "AwwaRF was solely responsible for these protocols," Taylor said.

Jacangelo's study on characterizing membranes in relation to their ability to remove microorganisms (Project 2683) also had a beneficial effect on regulatory standards. "The LT2 Rule says utilities can use membranes to remove *Cryptosporidium* and other microorganisms, and USEPA's guidance manual for this rule stipulates how membranes can be used," said Jacangelo. "But there was no provision for bench-scale evaluations of membranes; everything had to be done at pilot scale or larger. We developed a protocol demonstrating that these membranes can be evaluated at bench scale. The protocol is not complicated, and it stands up to scientific scrutiny. The LT2 team at USEPA reviewed it several times, and so did some 600 external experts, including the National Sanitation Association, the states, and manufacturers. USEPA eventually included bench-scale evaluation in the guidance manual, which now refers to this protocol as an example that can be used for compliance."

Current Membrane Use

Since that 5-mgd MF plant went on line in California in 1994, membrane installations for treating potable water have increased dramatically in number and scale. Several factors have contributed to this explosive growth—more stringent water quality regulations, inadequate water resources, increased emphasis on water reuse to stretch available supplies, and technological advances that have lowered both the capital and operations and maintenance costs of membrane installations.

"As membranes became cheaper and the technology grew more prevalent and people saw that it worked, it became an accepted alternative," Lozier said. "We consider it for almost every project now."

In a review of filtration processes published in the 125th anniversary issue of *Journal AWWA* in March 2006, Gary Logsdon and his co-authors wrote: "Low-pressure membrane filtration radically changed the drinking water industry in the 1990s. Such plants produce low-turbidity water, can require less on-site maintenance than conventional coagulation–filtration plants, have a compact footprint, and use modular equipment that can help defer capital expenditures until additional capacity is needed."

The Future of Membranes

All of the researchers interviewed for this report predict continued growth in the use of membrane processes to treat drinking water.

"The future of membranes is very bright," said Lozier. "MF/UF is established, and its market will continue to grow; it will eat into the market of granular media filtration. Big membrane plants are here now—Minneapolis has a 70-mgd plant and a second 94-mgd plant in the works; the 96-mgd Lakeview plant in the Toronto metropolitan area is nearing startup; and San Diego County is constructing a 100-mgd plant, the largest to date for drinking water treatment. The market will include upgrading older plants. Particularly in the Northeast and Midwest, we'll see conversions of granular media filter plants to membrane plants; current examples are in Thornton, Colorado, and Salmon, Idaho."

Lozier believes the market for high-pressure membranes will also grow, though he says it won't be huge. "High-pressure membranes will become more commonplace because of the need for additional water sources—whether the new source is brackish groundwater, reuse effluent, or seawater," he said. "The use of membranes in situations where we have to use degraded, low-quality, or impaired water sources has to grow. We can't invent freshwater."

Mickley concurs. "Freshwater resources are already overtapped," he said. "Where do we find additional resources? Of course we'll fix leaks and implement conservation programs, but the most logical new resource is lower-quality water, primarily groundwater—not superficial freshwater aquifers but lower aquifers, which typically have higher salinity. The need for a drought-proof source of water is a driving force for groundwater desalination, and membranes are the treatment of choice for treating higher salinity water sources."

Treating Water for Reuse. The use of membranes to treat reclaimed water is also expected to increase. "Water reuse is the fastest growing area of water supply in the country," said Taylor.

"Membrane filtration for indirect potable water reuse is less expensive than seawater desalination," Lozier points out. "You can implement reuse anywhere, provided you can overcome the psychological barriers and convince customers to drink this water, but to desalinate seawater, you have to be by an ocean."

"Lower salinity wastewater effluent treated for reuse will probably rely on low-pressure membranes," said Mickley. "In situations where salinity is higher, utilities will probably use desalting membranes. The increased use of these membranes is occurring because of population growth. More than half the desalination plants in the United States are in Florida, but the use of desalting is spreading; more states are considering it all the time. The state with the second largest number of desalting plants is California, and Texas is third. These are all high-population states. In Europe most desalination plants treat seawater; in the United States, they usually treat brackish groundwater."

Jacangelo also foresees more desalination because of limited water supplies, particularly in the West. He says water agencies are beginning to address the issue of supply with what he calls "a total water portfolio." Purveyors that adopt this approach "will be looking at their natural water supply, plus reuse water, desalted water, and water supplies that become available through conservation," he explained. "They need a portfolio of water supplies because a single supply may not be adequate at any given time. Most reclaimed surface water is currently used in nonpotable applications, but recharged and desalted water are treated for potable use. Planned indirect potable reuse is not as widespread as it could be."

The Evolving Membrane Market. The expanding market for membranes is expected to bring changes that are both evolutionary and revolutionary. "We'll see larger and larger installations," Adham predicts. "Because treating surface supplies is becoming more challenging, we'll see more new and retrofit installations that combine membrane filtration with other treatment processes. We'll also see low-pressure membrane installations for pretreating seawater before RO desalination," he said.

"Membrane bioreactors are one of the treatment processes of the future, especially for treating water for reclamation and reuse," Adham continued. Jacangelo agrees. "I think membrane bioreactors will ultimately be the most frequently employed process for reuse," he said.

"We'll also see vendors develop new technologies—for example, more robust membrane materials that are more durable and can withstand more aggressive water conditions," said Adham. "It would be nice to have environmentally friendly membranes that would disintegrate by themselves after a few years. Fifty years from now, what will we do with all the worn-out membranes? It would be better to have membranes that last 50 years rather than having to replace them after five to seven years."

Considering Costs. Of course, longer membrane life also means lower capital and life-cycle costs. Jacangelo says membrane costs have decreased so much that in some applications—for example, a new conventional water treatment plant versus a new membrane plant—the membrane plant is actually less expensive now. "Retrofits, however, are a different matter," he says.

Taylor believes we should consider costs more broadly. "Everyone now understands that membranes are the most universal treatment process available to the drinking water profession," he says. "But when we evaluate cost-effectiveness, we need to look at the cost of illnesses and deaths caused by waterborne disease outbreaks. If Milwaukee had had MF or UF, the 1993 crypto outbreak would not have happened."

Taylor also points out the value of producing high-quality water, not only the economic benefits achieved by reducing sickness but also the advantage of people feeling comfortable about the area where they live. "It's like having good schools," he says. "People don't evaluate the cost–benefit ratio of having good schools, but having high-quality drinking water is equally good for a local area's economy, even though we don't put a dollar value on it."

