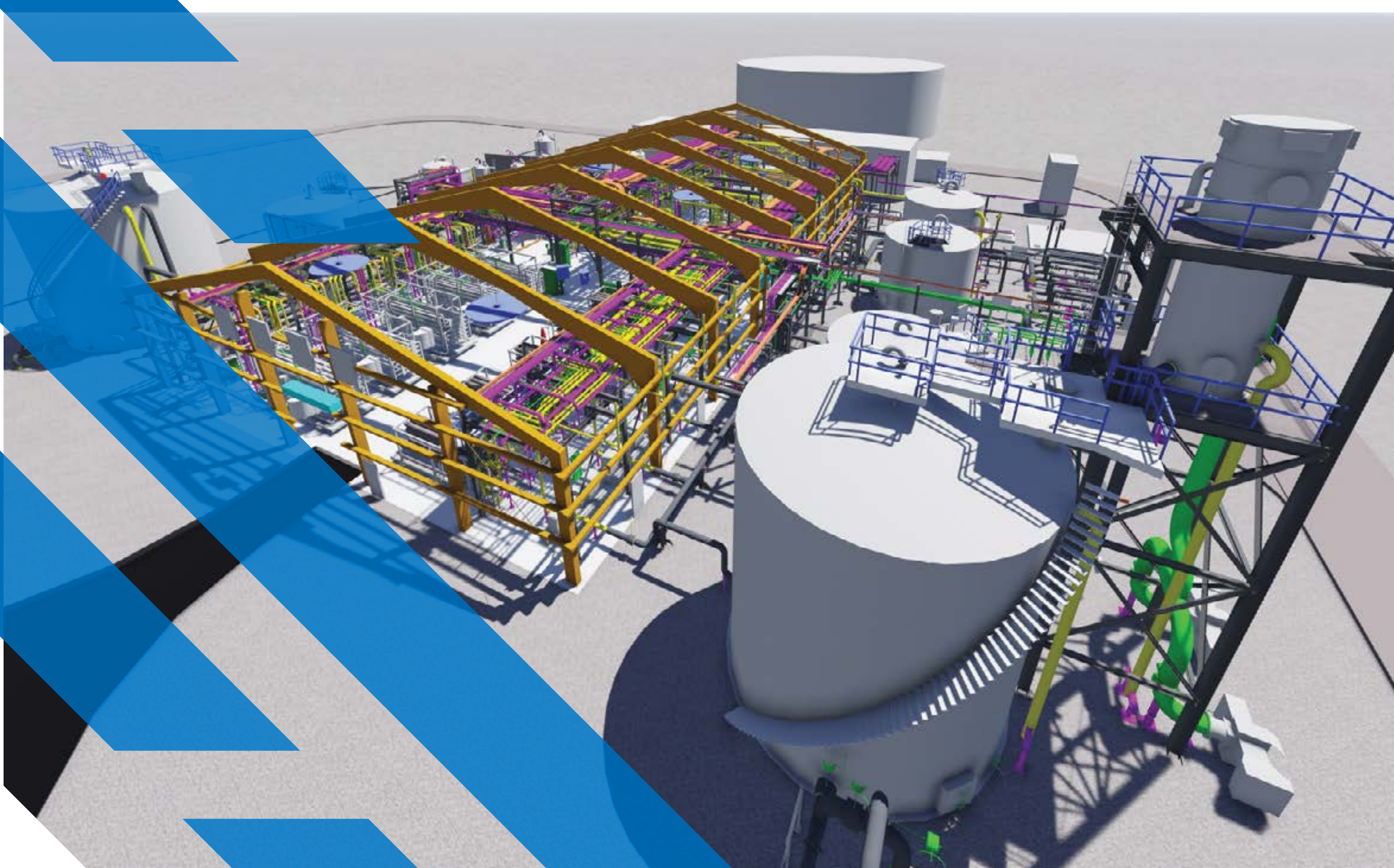
WHITE PAPER / **WATER AND WASTEWATER REUSE**

MORE WATER RESTRICTIONS MEET MORE OPTIONS

BY Larry Close, PE

Refineries in drought-stricken locations across the U.S. face increasing water supply costs and potential water restrictions. After decades of facing these issues, many refineries have found that new water treatment technologies have opened the door to greater solutions that increase process efficiency and reduce water demand.



The story of one Midwest refinery facing drastic water restrictions highlights current conditions and explores future solutions. The case study reflects water issues many areas in the United States face and demonstrates the approach one refinery took to meet the challenge. Water issues are here to stay, but refineries have more options to overcome the issues than ever before.

BACKGROUND

The oil and gas market and water demand are inextricably linked. Considerable amounts of water are used to improve production, especially fracking, and in refining for removing impurities and increasing process efficiencies. A number of factors around the world make the relationship, frequently referred to as the water-energy nexus, the focus of long-term planning by intergovernmental agencies at the global level down to the municipality attempting to deal with water stress, whether from scarcity, increased need or competition. Water stress impact on stakeholders in southern and western regions of the United States varies in severity, but the issues and solutions shared in this paper potentially serve as examples for other regions in the nation and around the world.

A significant portion of the water intensity — the ratio of water withdrawn and returned or consumed to the unit of energy that is produced — is attributed to secondary sources that are predominant in U.S. production. Producing crude from these sources is more difficult than from primary sources and requires more water.This paper focuses on the refining market specifically, while noting the production water intensity is worth acknowledging.

Water is the "other" liquid in refining. It is required for cooling and for steam in refining processes to improve process efficiency. (See Figure 1.)

Significant water use traditionally occurs during the refining process due to demand from the cooling towers, boilers and desalters. This water use has decreased due to enhanced efficiencies developed during the last few decades, largely in response to factors that include environmental legislation and water scarcity.

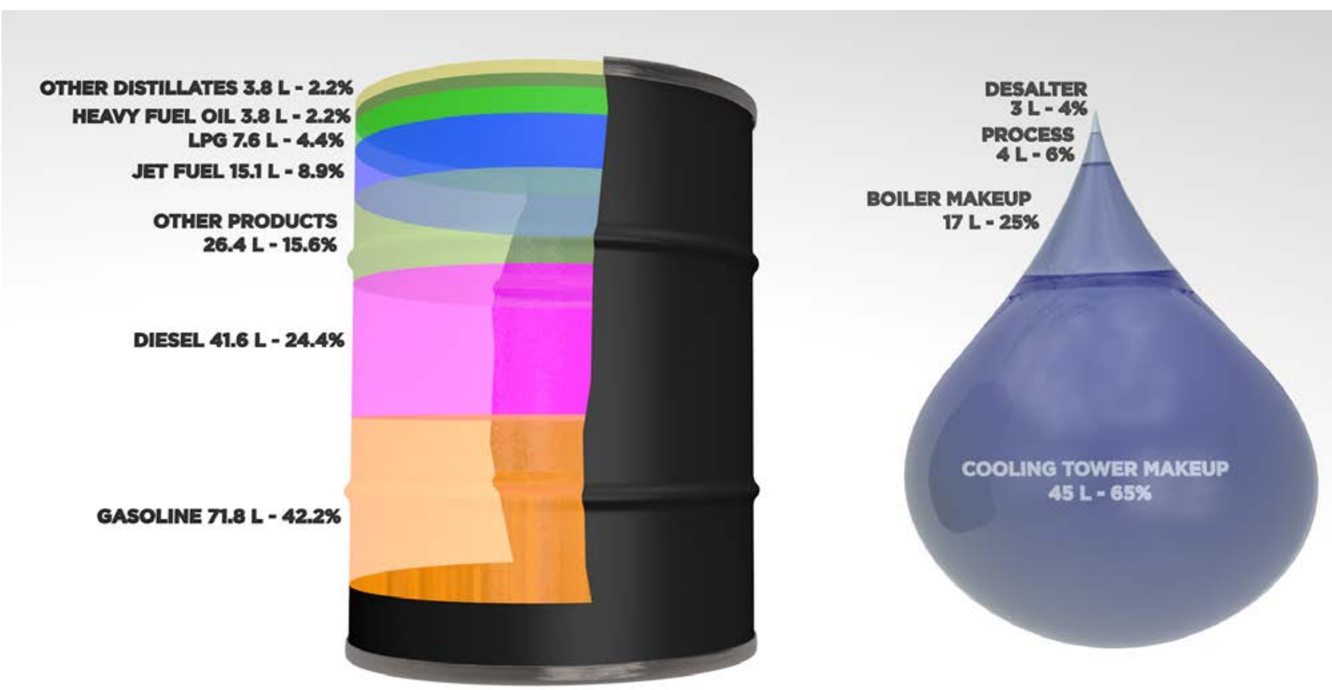


FIGURE 1: *Water required for refined products per barrel of crude.*

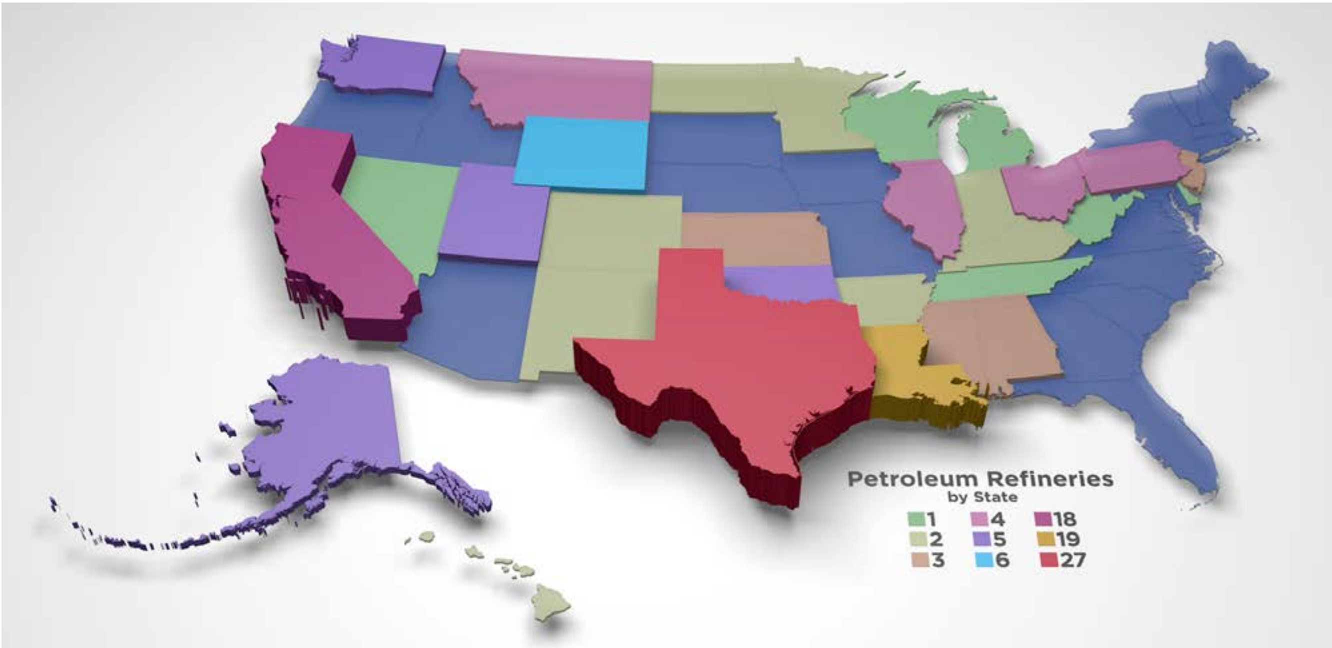


FIGURE 2: *Number of refineries by state.*

The water-refining relationship, frequently evaluated as part of the larger water-energy nexus, is driven by water concerns at all levels. Due to the water-energy relationship, water access issues, scarcity and competition occur at local, state, regional and national levels. This has the potential to significantly affect the refining market. Droughts typically dominate national news; most conference attendees are likely aware of the droughts in Texas and California. However, many organizations outside of those states are equally concerned with looming water issues in the near future. (See Figure 2.) The interest demonstrated by the American Fuel and Petrochemical Manufacturers (AFPM) in exploring water restriction issues is a good example as the organization devotes time and resources to researching this topic.

Outside the United States, organizations are focused on water as well — the World Economic Forum (Forum); Qatar Foundation, a leading learning institution in OPEC member Qatar; the World Bank; and the United Nations all have devoted resources to water. The World Economic Forum has listed water on the top 10 global risk list in recent years. Although water was not on the most recent edition (2016), climate change was on the list. According to a lecture given at the 2016 Forum in Davos, climate change exacerbates the water crisis. The Forum's list is a perspective of nearly 750 experts around the world and highlights the risks with the greatest potential to adversely affect the world in the next decade. The Qatar Foundation has dedicated considerable resources to studying water and published an article in 2013 declaring water the most precious resource. The World Bank, through its Water Global Practice, and United Nations' water research strive to understand water crises around the world.

Water issues in Texas and California have been and continue to be national news. Nearly one-third of the refineries in the United States are located in California and Texas — two states that are experiencing or have experienced drought conditions in the last five years. Texas had the driest year on record in 2011 while in the worst drought since 1950. In response to the extreme conditions, one Texas city began a "Toilet to Tap" wastewater reuse system during the highest drought stage. The negative connotation with such programs has prevented their widespread acceptance despite available water treatment technologies. Droughts drive difficult decisions that affect many stakeholders: farmers, industries, cities, states and even countries. The same city cited above experienced a water rights dispute, sending a wake-up call to several stakeholders, including local industry. In that dispute, a group of farmers sued the

Texas Commission on Environmental Quality (TCEQ) over a judgment on junior water rights. In short, TCEQ applied perceived authority to judge preferentially between stakeholders with junior rights. The Texas court ruled in favor of the farmers.

In 2011, multiple Texas refineries and petrochemical plants temporarily shut down because of power grid reliability issues. Power outages in the region were directly related to the Texas drought conditions. The impact of California's drought on refineries hasn't been as significant as in Texas yet, but some refineries are curtailing water usage in response to the regional drought conditions. One would expect that if the drought persists, the ripple effects through the California water-energy nexus and measures to restrict water usage will follow those seen in Texas. However, the entire state is still in abnormally dry conditions, according to the U.S. drought monitor, although the El Niño weather pattern has brought much-needed moisture to the area in recent months of 2015-16. One hopes the positive inflection point in the weather will continue. Yet, like Texas, California faces potential complications in demographics that could hamper the turnaround or at a minimum suggest a "new" normal in water consumption and demand. According to U.S. Census Bureau data on population projections, the South and West regions of the United States will represent the majority of population growth through 2030 — more people require more energy and more water (i.e., the water-energy nexus).

For the refineries affected by Texas and California drought, comprehensive sustainable water solutions are already a reality. Those in other regions can proactively look to them for solutions to problems that may be on the horizon. In a 2013 report by the U.S. Government Accountability Office (GAO), 40 state water managers expect regional water shortages under average conditions during the next 10 years. (See Figure 3.)

Although challenges always appear daunting, innovative applications of new technologies holds promise. Similar to the way closed-loop cooling systems in the 1970s reduced wastewater production in response to market drivers, technologies to enhance water minimization, use alternative water supplies and allow wastewater reuse are part of the answer to today's water concerns.

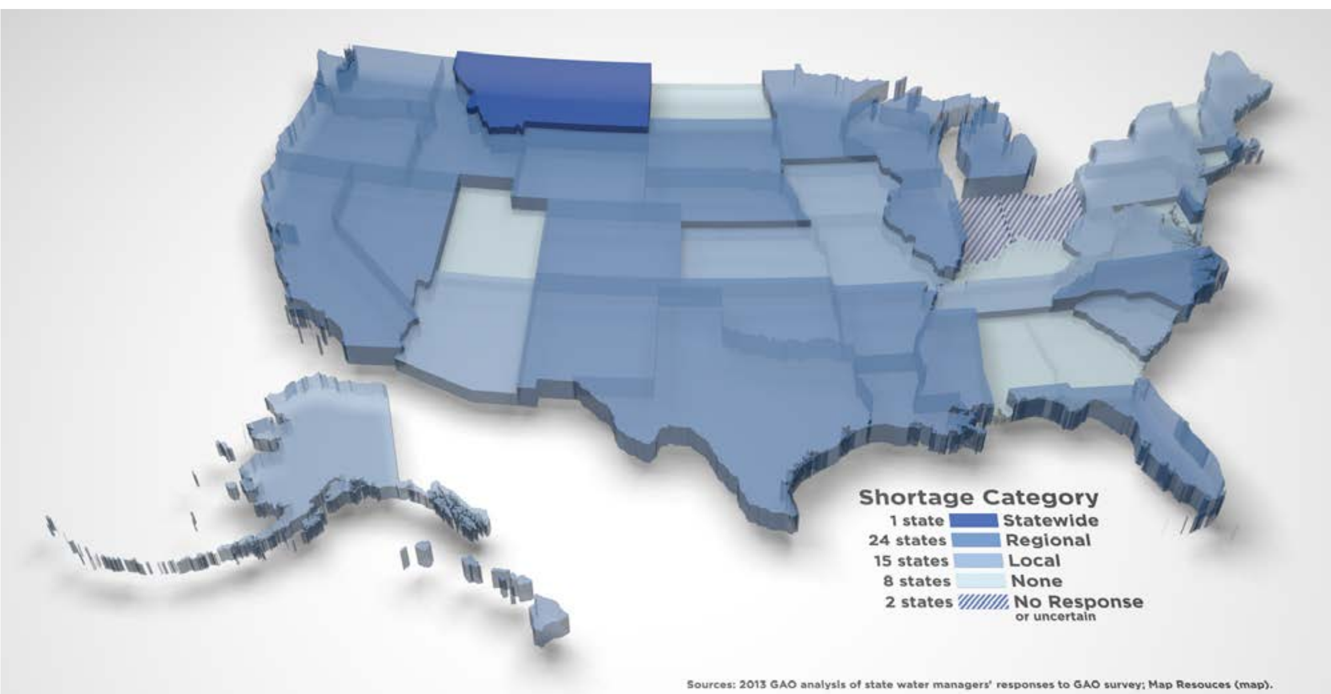


FIGURE 3: *Water concerns across the nation.*

WATER REUSE OPPORTUNITIES IN REFINERIES

In light of these water concerns, refineries have used best practices to minimize water use and minimize wastewater production, including by recycling wastewater. The primary sources of reuse water are noncontaminated stormwater, stripped sour water, vacuum and crude tower overhead water and wastewater (refinery and municipal sources). Primary reuse opportunities are the desalter, boiler feed water (BFW) and cooling tower makeup water (CTW). Identification of appropriate source water and reuse opportunity is based on many factors, including required water treatment, interconnecting piping, reliability risk to refinery process units, and risk to the refinery wastewater treatment plant.

Recycling water from process to process, for example stripped sour water for a desalter wash water, can offset refinery water demand, but it also complicates operation. In the stripped sour water example, the water may require treatment prior to desalter use and could adversely affect the refinery wastewater treatment plant. Type of crude processed at the refinery must be considered in a water reuse evaluation. Based on our experience, recycling between processes is not common because of factors like those described.

The common practice is reusing municipal or refinery wastewater for significant process water users. Source water and reuse opportunities drive the type of treatment required to achieve the minimum water quality (total suspended solids, total dissolved solids, hydrogen sulfide, ammonia, etc.). Boilers and cooling towers are low-hanging fruit for water reuse because offsetting their water demand has a big impact on total refinery water use. Water treatment, starting from a wastewater treatment plant effluent, typically includes filtration technologies from a traditional sand filter to polymeric-based membranes.

COMMON TREATMENT TECHNOLOGIES AND REUSE OPPORTUNITY

Treatment Technologies	Reuse Opportunity
Media sand filtration	Utility water, emergency fire water, cooling tower makeup water
Microfiltration, ultrafiltration	Utility water, emergency fire water, cooling tower makeup water
Microfiltration, ultrafiltration and reverse osmosis or nanofiltration	Utility water, emergency fire water, cooling tower makeup water and boiler feed water
Ion exchange	Utility water, emergency fire water, cooling tower makeup water and boiler feed water

To achieve reuse quality, wastewater treatment plant effluent passes through a series of filtration processes, referred to as a treatment train. A typical treatment train is shown in Figure 4.

The water quality from this type of treatment train is suitable for reuse to meet or supplement water demand for BFW and CTW, although not all reuse purposes require that level of water quality. As depicted in Figure 4, the treatment train can accommodate partially treated water to be routed as a side stream for other purposes. Driven by water concerns, refineries are evaluating wastewater reuse as a method to offset water demand. Feasibility of water reuse is improving because of reduced cost of technologies, improved efficiencies and proven operational experience. One example is highlighted in the following case study.

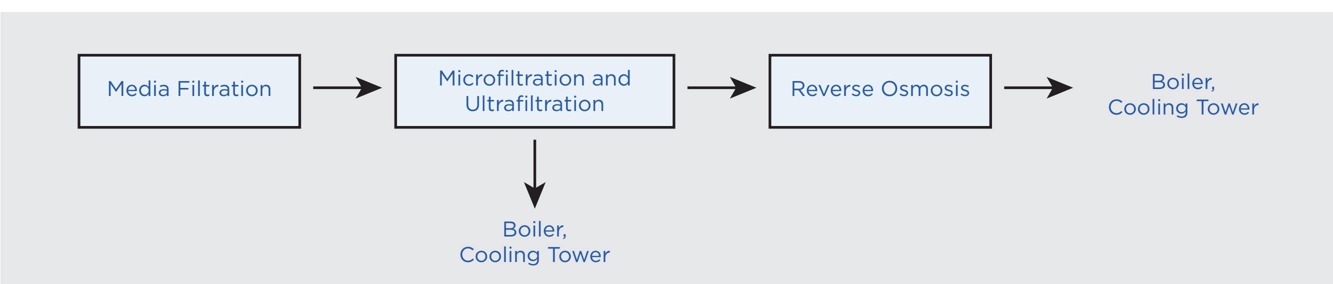


FIGURE 4: *Typical filtration technologies in a treatment train.*

CASE STUDY: REFINERY REUSES AND BLENDS WATER SOURCES FOR PRODUCTION OPERATIONS

A Midwestern refinery needed an innovative design solution to solve a challenging industrial water issue. This solution also serves as a design model to help solve other critical water issues discussed earlier in this paper.

This refinery includes multiple cooling water towers and a boiler system for steam production, both critical to the refining process. Both systems require on-site treatment prior to use of the water in the BFW and CTW systems, both of which require massive amounts of water for the production process. Ultimately, two of the most significant goals of this project were to conserve water and minimize environmental impact. Reusing waste streams and maximizing water recovery combine to achieve these goals and were significant drivers for the project.

The refinery uses millions of gallons of water a day and needed to reduce the amount of water being drawn from the region's aquifer. The refinery initially conducted feasibility studies to determine if the city's wastewater could be used as a water source. The studies verified the wastewater can be purified to the necessary standards to be used for the cooling towers. For several years, the refinery had been using a water treatment process with leased trailers, but the owner recognized a permanent solution was needed.

The refinery owner demonstrated its commitment to being a steward of the environment by building an integrated membrane facility and the treatment of multiple water sources on the refinery's site. The treatment facility effectively reuses municipal wastewater effluent and water from chloride remediation wells with finished water from these sources treated to a very high level.

Two distinct treatment processes are used: Microfiltration (MF)/Reverse Osmosis (RO) and Microfiltration (MF)/Nanofiltration (NF). By blending and using multiple water sources, this refinery reduced the draw from the region's aquifer by an estimated 1.5 million gallons of water per day.

Primary objectives of the project were to:

1. install a permanent water treatment plant facility to replace leased water treatment trailers;
2. resolve finished water quality issues; and
3. address concerns about further dewatering of the region's water aquifer.

To begin solving the refinery's needs, several water sources are blended and routed to the new treatment facility. These include existing refinery wells, chloride remediation wells (installed to mitigate the potential impact of improperly injected waste), refinery wastewater, potable water and graywater sources. This system will provide finished water at two water qualities: a lesser quality for CTW and higher-quality permeate for BFW.

Key factors taken into consideration in meeting the needs of the refinery:

1. This treatment facility will serve the entire refinery, providing both makeup water to the existing cooling towers and BFW to the boiler house.
2. The process design is based upon water treatment technology including MF, NF and RO systems.
3. A microfiltration backwash reuse system will be installed to treat MF backwash, thereby improving system recovery.

SUMMARY

The design and operation of this integrated membrane facility offers an innovative and effective model that can be used in other industrial and wastewater applications. The project demonstrates viable solutions to several critical water issues:

- Wastewater reuse: it demonstrates many potential implications from potable water treatment to industrial uses.
- The effective blending of multiple water sources with varying water qualities and the design of a treatment system that is flexible enough to treat this variation.
- Increased water demands for people and industry will require implementing similar projects, such as blending of multiple water sources, reuse and advanced treatment.

This project serves as a model by showing the possibilities that advanced water treatment processes can provide. An integrated membrane treatment facility, one that also combines both NF and RO membrane elements operating in parallel, is a great example of advancements in the water treatment industry. As existing water sources around the globe become stressed in terms of availability and potential contamination, the need to explore advanced treatment technologies and processes will become increasingly important. This project effectively demonstrates that such unique treatment solutions aiding in overcoming the water issues are not only possible but within reach.

BIOGRAPHY

LARRY CLOSE, PE, is a process engineer specializing in water and wastewater treatment at Burns & McDonnell. He has 11 years of experience in the company's industrial water and wastewater group and is a registered professional engineer in Kansas. His experience is in treatment feasibility studies, pilot studies and final design related to oil/water separation, metals removal and biological treatment. He earned his Bachelor of Science and Master of Science in civil engineering from Kansas State University.

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