CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Water and Energy Savings Using Innovative Forward Osmosis Systems for Irrigation and Indirect Potable Reuse

October 2021 | CEC-500-2021-046

PREPARED BY:

Primary Authors:
Olgica Bakajin, Jennifer Klare, Erik Desormeaux, Charles Benton, James Lalikos, Alexandria Rinella, Alyssa May

Porifera Inc.
1575 Alvarado Street
San Leandro, California 94577
510 695 2777
www.porifera.com

Contract Number: EPC-14-063

PREPARED FOR:
California Energy Commission

Kevin Mori, PE
Project Manager

Virginia Lew
Office Manager
ENERGY EFFICIENCY RESEARCH OFFICE

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGEMENTS

This project was made possible through the California Energy Commission's (CEC) Electric Program Investment Charge program that provided funding for advancing energy efficiency in California's food and beverage manufacturing industry. Support from the California Energy Commission provides companies like Porifera the opportunity to bring cutting-edge research to commercial scale where benefits can be realized for private industry and the public.

Partnerships created through the program provide small companies with the chance to collaborate with industry to explore research concepts. This collaboration enables discovery of practical solutions for industry and lends brand-name credibility to the innovations of small businesses.

Porifera is thankful to the following partners, each of whom demonstrated professionalism and persistence throughout the project:

- Jackson Family Wines – Erich Kroll, Julien Gervreau, and Roque Flores
- Ale Industries – Morgan Cox and Mike Shaefer
- Dr. Bronner's All-One – Darcy Shiber-Knowles, Liz Schwartz, and Jose Pacheco
- CDM Smith – Carl Lundin, Randy Smith and Perry Ng

Porifera is grateful for the opportunities provided by the CEC to promote the development of this technology for wide-ranging commercial use. This project provided the engineering team the chance to define and solve processing challenges and discover solutions applicable across industries.

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Water and Energy Savings Using Innovative Forward Osmosis Systems for Irrigation and Indirect Potable Reuse is the final report for the Advance Wastewater Treatment Using Forward Osmosis to Produce High Quality Water project (Contract Number: EPC-14-063) conducted by Porifera Inc. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at ERDD@energy.ca.gov.

ABSTRACT

Industrial-scale water treatment systems can save energy, reduce wastewater volumes, and generate pure water streams on site. Many industrial wastewaters are very difficult to treat, however, since they contain high levels of dissolved and suspended solids that make low-cost treatment with membrane-based systems ineffective. As a result, industrial wastewater is often not reused but rather disposed of off-site or treated on site with expensive methods (membrane bioreactors, combinations of many unit processes or, in some cases, thermal for near zero liquid discharge projects) that are complex, energy intensive, and generate greenhouse gases. New membrane-based water purification technologies and systems are needed to cost-effectively treat water for onsite reuse, with reduced carbon dioxide emissions and increased energy savings. Porifera conducted pilot testing of the proprietary forward-osmosis (PFO) recycler to demonstrate energy savings for high-purity reuse of hard-to-treat industrial wastewater at three different site locations.

The first site location was a Jackson Family Wines facility near Santa Rosa, California. Data indicated that the PFO recycler could save 20 percent energy at 70 percent recovery and save 40 percent energy at 90 percent recovery compared to competing processes. Porifera installed a PFO recycler to treat wastewater for irrigation and industrial reuse. The second site was Ale Industries, a microbrewery in Oakland, California. Porifera installed a PFO recycler to reduce the wastewater volume from brewing and generate clean water for reuse using 10 times less energy than a competing evaporator. The third site was Dr. Bronner’s Magic Soaps in Vista, California. Porifera recycled wastewater for reuse, reducing the current treatment and disposal regimen and using 90 percent less energy than an evaporator and while reducing carbon dioxide emissions compared to the current trucking used to dispose of the waste.

Porifera collaborated with engineering firm CDM Smith, which provided independent measurement and verification of energy savings at each location. These representative pilots demonstrated the potential of the PFO recycler to achieve substantial energy and cost savings for customers while generating pure water streams for onsite reuse. As a result, the technology demonstrated in this project is ready to be scaled up and sold to early adopters for commercial use.

Keywords: water reuse, waste minimization

Please use the following citation for this report:

Bakajin, Olgica, Jennifer Klare, Erik Desormeaux, Charles Benton, James Lalikos, Alexandria Rinella, and Alyssa May. 2021. *Water and Energy Savings Using Innovative Forward Osmosis Systems for Irrigation and Indirect Potable Reuse*. California Energy Commission. Publication Number: CEC-500-2021-046.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

California's industries struggle with increasing water scarcity and energy demands. California remains dry and still faces "moderate drought" to "severe drought" conditions. According to the California Energy Commission's (CEC) third assessment on climate change, water scarcity will worsen. Adequate allocation of resources, combined with the adoption of innovative technologies and judicious environmental regulations, are recommended for efficient management of water-energy resources.

A technology developed by Porifera Inc. provides cost-effective onsite reuse of energy-intensive waste streams that are expensive to treat with current technologies. Affordable water reuse is a "pain point" for industrial water users such as food and beverage manufacturers, especially in water-stressed areas like southern and central California with rising waste-disposal and water-sourcing expenses. Manufacturers are seeking solutions to offset these rising costs to remain competitive in their respective markets. The Porifera proprietary forward-osmosis recycler, a water reuse solution, will help manufacturers do that. Piloting the system in a real-world environment demonstrated the benefits of the technology to end-users and will accelerate its commercial adoption and use. The recycler turns customer wastewater into clean water for reuse and creates a waste concentrate that can be reused as biomass feedstock and for ethanol production. This reduces waste disposal fees, increases water availability, and reduces energy use by 20 percent to 40 percent.

Historically, forward osmosis technology has had limited use in wastewater processing because forward osmosis membranes did not perform well and were not economically competitive. Porifera's technological breakthroughs in membrane development and system design enable substantial energy savings and reductions in water use and energy footprint that will bring forward osmosis processing into the mainstream. The recycler demonstrated in this project combines the company's proprietary forward osmosis membrane element and reverse osmosis technology.

Project Purpose

The purpose of this project was to demonstrate energy savings and increased water reuse at sufficient scale for commercial evaluation. The data generated will be shared with other businesses in California and elsewhere to provide more confidence for companies to implement the technology, resulting in water and energy savings.

The objectives of the project were to:

- Demonstrate the proprietary forward-osmosis recycler system as a reliable, cost-effective technology to reuse water.
- Demonstrate energy savings and increased water volumes for reuse.
- Demonstrate that the water produced from the process is of high quality, free from minerals and chemicals, and reusable for various onsite processes (washdown, sterilization, boiler feed, and so forth).

The main goal of this project was to demonstrate the benefits of the recycler technology for reuse of hard-to-treat wastewater, including energy savings and increased water for reuse.

Successful demonstration at sufficient scale work will accelerate recycler technology adoption across California. Broad technology adoption will result in energy savings and more water reuse, benefiting California ratepayers and society at large.

Project Approach

The project was tailored to demonstrate the recycler in three applications that are relevant to and representative of three different large sectors of California's industry, with pilot partners highly respected in their industry sector:

1. Winery wastewater reuse at Jackson Family Wines
    - Jackson Family Wines is one of the world's largest wine producers and is committed to handcrafting fine wines with an added passion for sustainability.
2. Brewery wastewater reuse at Ale Industries
    - Ale Industries is an environmentally conscious craft brewery located in Oakland, California. The brewery pioneers brewing technologies to save energy and reduce waste because they understand that investing in the environment will nurture the communities they care about, allowing them to flourish and grow.
3. Hard-to-treat manufacturing wastewater reuse at Dr. Bronner's All-One
    - Dr. Bronner's All-One is a producer of organic soap and personal care products headquartered in Escondido, California. Dr. Bronner's is committed to near-zero waste solutions.

Porifera's project approach began with exploratory laboratory work to understand process and equipment requirements, design parameters, and potential added value of the technology for the customer. The researchers collected samples from the sites and performed bench-scale tests using forward osmosis membrane or elements to determine the target water recovery, flux rate, and draw solution for the pilot-scale tests. This step minimized the onsite effort and reduced the burden on the pilot partner resources. Laboratory and pilot-scale tests at Porifera's facility allowed Porifera to plan the pilots to maximize benefits within pilot partner operational constraints.

Following the exploratory phase for each application, Porifera designed and built pilot systems at the size needed to treat the waste streams present and to best mimic a commercial solution. With the pilot systems, Porifera conducted onsite testing to assess efficiency in achieve pilot partner goals. To generate independent data, Porifera worked with a measurement and verification partner, CDM Smith. Energy use, water quantity, and produced water quality data were measured and analyzed.

Project Results

Winery Wastewater Reuse at Jackson Family Wines

The project demonstrated energy savings and higher recovery (that is, more water for reuse) with a proprietary forward osmosis recycler compared with other reuse options to produce similar water quality. The project also demonstrated that the technology has flexibility to treat highly variable source waters producing superior water recovery compared to other membrane processes. Process water was demonstrated to have excellent soil absorption ratio, making it desirable for irrigation. Soil absorption ratio is a calculated ratio of sodium to mineral content (calcium and magnesium) in water.

When comparing different energy use options, data indicated that the recycler could save on the order of 20 percent energy compared to a competing process at 70 percent recovery, and use 40 percent less energy than competing processes at 90 percent recovery, thus demonstrating that the recycler technology enables more water to be reused using less energy.

Brewery Wastewater Reuse at Ale Industries

The Porifera team demonstrated that the recycler was able to treat a small brewery's challenging (high organics and biologically active) and highly variable wastewater and produce high purity water for reuse. The project also showed that the recycler could reuse more water (70 percent) with less energy compared to a membrane bioreactor plus reverse osmosis.

A key takeaway from this demonstration was the minimal maintenance required for a wastewater application that would typically require frequent maintenance. While the system did not continue to perform at the highest energy efficiency target during the entire study, the efficiency was considered sufficient for the pilot partner and was impressive given the minimal maintenance required to reliably produce clean water for reuse. Minimal maintenance can be exceptionally valuable to small businesses like microbreweries that generate challenging wastewaters but would still like to reuse as much water as possible while focusing primarily on core business activities. The pilot data indicated excellent rejection of organics, hardness, and other key constituents that would allow onsite reuse of the water for many activities. Disinfection and polishing may be needed for sanitary use, but this is the case with any reuse stream.

Hard-to-Treat Manufacturing Wastewater Reuse at Dr. Dr. Bronner's All-One

The Porifera team demonstrated that challenging high-organic-content wastewater could be recycled into high-purity water for reuse. It also showed that the recycler could reuse more water than other membrane systems and use 10 times less energy than an evaporator. Due to space constraints, the recycler is likely the only technology considered that could reliably reuse water at this site.

The pilot study data indicated that the pilot operated sustainably on this source water after upgrading the system to operate at high velocity to keep solids suspended, with spacerless elements to reduce clogging of the flow channels, and that higher pH cleanings were key to restore membrane performance.

The pilot data indicates that the recycler could save on the order of 90 percent energy compared to evaporators and reduce carbon dioxide emissions compared to the current trucking used to dispose of the waste.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

To gain acceptance into the marketplace, it is imperative to share the successes at commercial sites that validate the recycler's capabilities across the industry. Demonstrations occurred at sites with recognized brand cachet within their industry. This makes them marketing "influencers" for their peer group and increases the likelihood of technology adoption amongst their peers. These installations are an invaluable reference base of established energy and wastewater reuse savings. The primary beneficiaries of the forward osmosis water reuse technology are manufacturers that currently experience water scarcity issues.

This market need is global, and large enough to provide a rewarding opportunity for the growth of forward osmosis technology over the long-term. Outreach and educational tools and materials have been designed to increase the speed and penetration of innovative energy efficient technologies into the marketplace. Porifera has and plans to continue to publish papers and articles in industry trade publications to inform the industry on the cost-savings associated with forward osmosis technology implementation.

Porifera demonstrated the forward osmosis-based technology innovations to reduce energy and maximize value while also increasing manufacturing capabilities, reducing manufacturing costs, improving system designs, and integrating lessons learned into design and control protocols. As a result, the technology demonstrated in this project is sufficiently ready to be scaled up and sold to early adopters for commercial use. The proprietary forward osmosis elements and remaining components are integrated into plug-and-play type recycler systems that require minimal site modifications to integrate into existing facilities. Commercial interest indicates that the recycler can provide benefits in terms of organics removal, reduced maintenance, and low energy; however, cost reduction is a key driver in being able to compete for all potential water reuse opportunities that are a good fit for this technology.

Benefits to California

Employing this technology will empower California companies be more drought resilient and remain competitive and operational even during high demand periods on local and statewide water resources.

California's manufacturers require solutions that will help offset rising energy and water costs to remain competitive. This project demonstrates that Recycler technology has the potential to address these challenges in several high-energy and water consuming industries. The pilot demonstrations performed set groundwork for commercial scale demonstration projects.

Implementing Porifera's recycler technology for water reuse at California industrial users will reduce energy and water resource demands throughout the state. The energy savings will occur primarily in reduced energy needed for purification, pumping, and heating and reheating of water at industrial sites as well as reduced pumping necessary to transfer water to the Central Valley and Southern California assuming reduced industrial and agricultural demands.

On average, the researchers expect the technology to save between 1 and 5 kilowatt-hours (kWh) per 1,000 gallons reused for most industrial applications and that the technology could be an attractive solution for more than two-thirds of industrial wastewater in California. Assuming a third of the 180,000 acre-feet per year (58 billion gallons per year) of new industrial water is reused in California the near future and 3 kWh per 1,000 gallons of energy savings on average per project, the total energy savings would equate to approximately 53,000 megawatt-hours per year.

CHAPTER 1: Introduction

Porifera Company Overview

Porifera is a San Leandro, California-based company which manufactures proprietary forward osmosis membranes and provides process solutions to a variety of industries. Porifera's forward osmosis solutions enable industries to remove water and retain valuable components of their products.

Porifera Technology Overview

Introduction to Forward Osmosis

Forward Osmosis has unique advantages for food and beverage (F&B) applications because it can operate reliably when processing challenging liquids that quickly clog or foul other types of membrane processes, such as reverse osmosis (RO).

Forward osmosis (FO) is the osmotically-driven purification of water or concentration of products using a semi-permeable membrane. Water molecules migrate across the membrane by diffusion into a salt (draw) solution. This process does not require any input of energy. Porifera's solutions combine forward osmosis technology with reverse osmosis (RO) for recovery of the draw solution. Although FO has been studied for decades, it has only recently obtained broader commercial adoption. FO has unique advantages for F&B applications because it can operate reliably when processing challenging liquids that quickly clog or foul other types of membranes such as RO. Previous versions of FO technology were large and expensive systems that did not operate efficiently. Porifera has made advancements in membrane development and module design which address the cost, footprint, and performance constraints of existing treatment technologies.

Porifera's proprietary forward osmosis (PFO) innovations are unique in that PFO can:

- Operate reliably on challenging liquids with high solids, pulps, free and emulsified oils and greases, high chemical oxygen demand (COD), high biological oxygen demand (BOD). Porifera is the only provider of "spacerless" FO elements (membrane elements with the spacer material removed to create open feed channels) suited to these applications.
- Achieve higher membrane flux, rejection, and efficiencies than competing FO technologies using the same osmotic driving force.
- Operate at high rejection and high efficiencies using a "draw solution" (that is, table salt) that is easily recyclable using RO. Competing FO technologies require toxic draw solutions or allow too much leakage of the draw salt into the product.
- Operate at temperatures up to 176^{o}F (80^{o}C). Standard FO & RO membranes cannot exceed 113^{o}F (45^{o}C), which negates potential energy savings in high temperature reuse applications (for example, boiler feed, sterilization, or when reheating is required).
- Operate at a wide range of pH (2-11), expanding the applicability of FO-based solutions, which in the past could not operate at low pH levels.

- The PFO Recycler has multiple advantages over other advanced treatment technologies as described in Table 1.

Table 1: Proprietary Forward Osmosis Recycler versus Competing Technologies for Hard-to-Treat Wastewater

Technology	Reliability	Water Purity for Reuse	Limits & Notes
Pretreatment +Nanofiltration	Not reliable	Poor. Small molecules such as sugars pass through the membrane so water will be unfit for reuse.	COD[1]: <10 mg/L Oils & grease:<0.1 mg/L Temp: <45°C Not reliable when starch and sugars are present
Ultrafiltration + RO	Poor, frequent cleanings	Fair. RO water is usually extremely high quality. However, the COD may be over 10 mg/L, exceeding the reuse target for water used in food processing equipment.	COD: <60 mg/L Oils & grease: <2.0 mg/L Temp: <45°C Not reliable when starch and sugars are present.
Membrane Bioreactor + RO	Moderate, high maintenance and semi-frequent cleanings	High. Biological step reduces BOD to a more manageable concentration for RO than UF. Additional treatment steps required for reliable reuse.	Better than UF+RO for high BOD[2] and starchy wastes; four additional treatment steps needed at Frito-Lay to reuse water
Evaporators + distillers	Poor to moderate	Poor. Volatile Organic Compounds (VOCs) remain in the condensate.	Expensive, poor solution for high starch, BOD, and COD wastes
Porifera's PFO Recycler	High, target is unmanned operation with infrequent cleanings	High. Two barriers for all contaminants. UVAOP not likely required.	COD: >100,000 mg/L Oils and grease: >50 mg/L Temp: <80°C for PFO step

1 COD = Chemical Oxygen Demand. A measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as Ammonia and nitrite.

2 BOD = Biological Oxygen Demand. The amount of dissolved oxygen demand needed by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. The BOD value is often used as a surrogate of the degree of bioactive organic pollution of water.

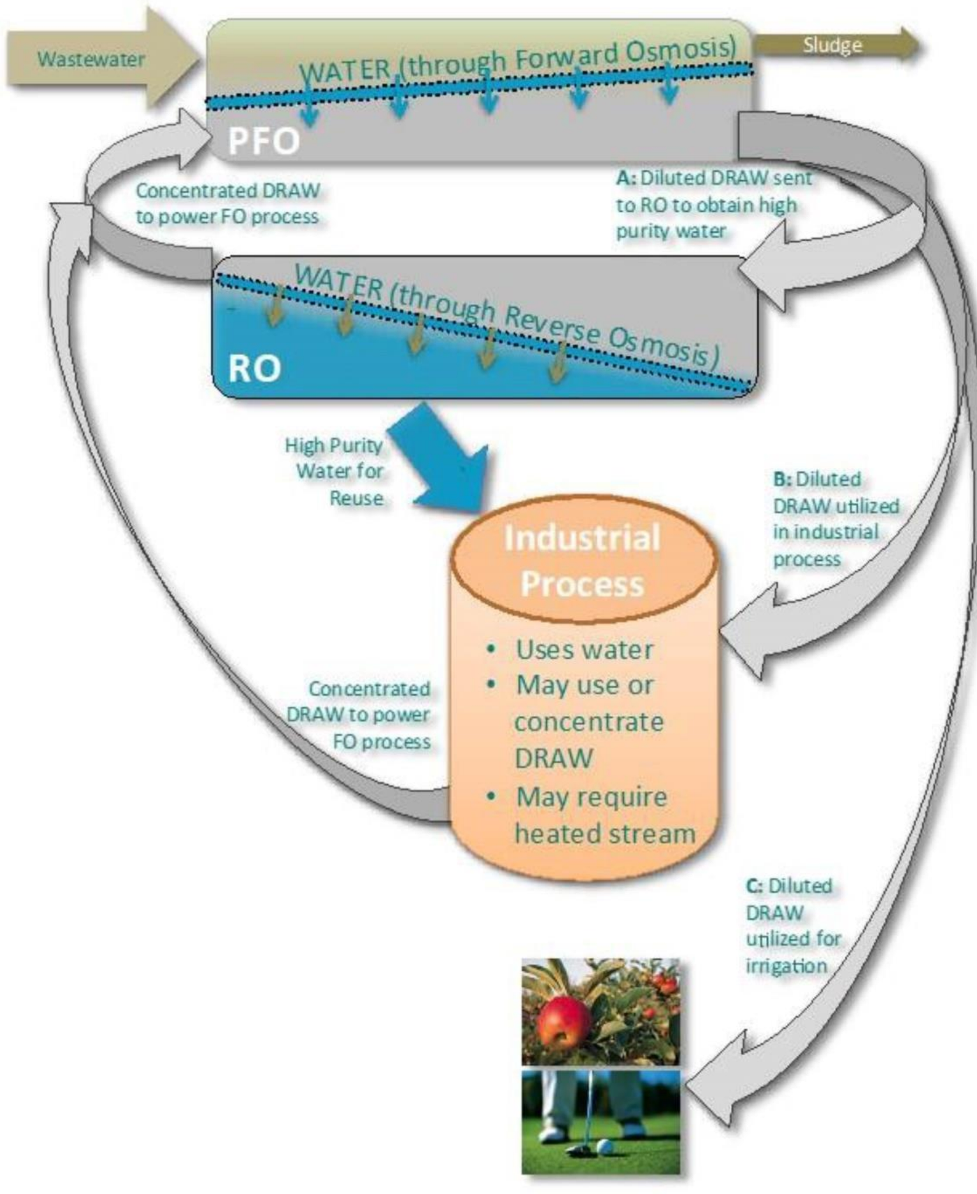
Source: Porifera Inc.

The advantages of this technology allow Porifera to combine FO and RO in a PFO Recycler system that can process highly fouling and variable quality waters that RO alone cannot achieve.

Porifera Forward Osmosis Recycler

As shown in Figure 1, Porifera's Recycler combines the company's PFO and RO technology to achieve treatment of hard-to-treat water of variable-quality. PFO membrane technology allows the system to treat much harder to treat waters than conventional RO can do on its own.

Figure 1: Recycler Water Reuse Applications



Schematic illustrating potential water reuse applications for the Porifera's PFO Recycler.

Source: Porifera Inc.

Draw solution selection for the PFO Recycler typically is determined by cost and water quality considerations and is very application and site specific. However, in general, simple sodium and magnesium salts are selected for PFO Recycler technology.

Draw Solution Selection

There are many potential draw solutions mentioned in research papers; however, Porifera has tried many promising candidate-draw solutions and there are numerous research papers that compare FO membrane performance with different draw solutions. Conclusions indicate in the researchers' expert opinion that simple, cheap salts often yield the best performance and this is especially the case when RO is used for draw regeneration. Data also indicates that RO is currently the cheapest form of draw regeneration ready for commercial implementation.

Previous studies and the data in this report confirm that if cost is the primary consideration directing decisions for a project and all water quality goals can be met, then table salt (sodium chloride) is the typically chosen as the draw solution for PFO Recycler pilot test and commercial systems.

Furthermore, since FO (which has a similar pore size and contaminant rejection as RO) removes the types of foulants and scalants that quickly foul RO membranes, such that FO essentially becomes excellent pretreatment prior to RO. Since RO is used to recycle a draw solution with higher osmotic pressure than the wastewater, it does use more energy than RO only. However, as described in this report, PFO Recycler technology can still use less energy than competing technologies for challenging wastewaters.

Some customers desire extremely low concentrations of sodium or chloride in the reuse water and in this case other salts may be preferred. For example, when the water is reused for agricultural irrigation water, then using a magnesium salt can provide many benefits over sodium salts. This is because having a certain magnesium (or calcium) to sodium ratio can be beneficial in restoring soil that has been degraded by the buildup of sodium, which lowers ability of soil to adsorb water. As described in more detail in later chapters, using a magnesium salt can improve a water quality parameter known as soil adsorption ratio, which in turn suggests that the reused water can improve and restore a soil instead of degrading it, which is a concern with some reuse waters.

The second most common draw solution used in a PFO Recycler is magnesium chloride ($MgCl_2$; road salt), which increases the total cost (considering both capital and operating costs) of treated water by 5-15 percent compared to a sodium chloride draw depending on the design of the system. In most cases, this increased cost is cheaper than adding magnesium to the final reuse water directly, so the increased cost is often not as important as the water quality goal of soil restoration and the impact of crop yields or the ability to achieve some regulatory discharge requirement.

Magnesium sulfate ($MgSO_4$; Epsom salt) may also be considered; however, it increases treatment costs on the order of 15-30 percent compared to a sodium chloride draw; therefore, it is often cheaper to use other draw solutions and add an extra RO polishing step unless an extremely low chloride limit cannot be achieved using a more cost-effective approach.

Costs in Water Reuse Applications

In terms of overall cost considerations, it should be noted that it is often difficult to compare the costs for reuse technologies on hard-to-treat applications such as the ones included in this report because the solutions are often proprietary and the customers have often not found a competing solution that will achieve their reuse goals to provide an accurate comparison. It is, however, useful to discuss general cost competitiveness compared to state-of-the-art technologies.

Within the water reuse field, the most common technology used for high purity water reuse applications is the combination of ultrafiltration (or microfiltration which is very similar) and

RO. This often provides the most competitive combination of upfront capital expense and long-term operations and maintenance costs. For hard-to-treat waters with moderate to high concentrations of organics like the applications in this report, combinations of membrane bioreactors and RO is often considered a potential alternative; however, many customers do not consider this a desirable option when the maintenance requirement for the RO system is deemed onerous due to frequent membrane fouling and cleaning. Therefore, some customers consider sewer discharge and/or thermal evaporation as the only potential options for disposal of their wastewater. Since thermal evaporation is so expensive and energy intensive, many customers do not consider high purity reuse to be an option until a technology like the PFO Recycler can show acceptable cost estimates and maintenance requirements treating the actual waste stream at pilot scale.

Based on this introduction, the overall costs of implementing PFO Recycler technology will be compared in general to the cost of implementing UF+RO, MBR+RO and thermal evaporators. PFO Recycler technology is currently in a cost point where it can be competitive and at times up to 25 percent cheaper than MBR+RO systems and over 50 percent cheaper than thermal evaporators in terms of capital and operating expenses and will also have fewer maintenance requirements for waste streams that are considered too challenging for UF+RO. As demand increases and production costs decrease for PFO membranes, it is expected that the PFO Recycler will be cost competitive with industry leading UF+RO solutions and would be able to compete on most high purity reuse projects and has the potential to be a very cost attractive option for wastes considered too challenging for UF+RO.

The cost impacts related to the selection between sodium and magnesium salts for the draw solution and use of other chemicals such as antiscalants, biocides, or cleaning chemicals are often negligible because the costs associated with these chemicals are typically similar or more expensive than with PFO Recycler technology.

Pilot Partner Sites Overview

1. Winery Wastewater Reuse at Jackson Family Wines (JFW)
    - JFW bottling facility in Santa Rosa, California
2. Brewery Wastewater Reuse at Ale Industries (AI)
    - AI brewery and taproom in Oakland, California
3. Hard-to-treat Manufacturing Wastewater Reuse at Dr. Bronner’s All-One
    - Dr. Bronner’s All-One manufacturing facility in Escondido, California

Measurement and Verification Partner

Porifera engaged CDM Smith as a measurement and verification partner. CDM’s role was to perform independent measurement and verification for the pilots.

CDM Smith is an engineering and construction company that provides solutions in water, energy, transportation, and facilities projects for government and private clients. The employee-owned CDM Smith has been operating since 1947 and has more than 5,000 employees world-wide.

Project Goals and Objectives

The goals of this project were to:

- Demonstrate the system for industrial and irrigation reuse
- Demonstrate the benefits of the PFO Recycler
- Demonstrate the production of high purity water for virtually any reuse
- Demonstrate energy savings and increased water reuse at sufficient scale for commercial evaluation.

The expectation was to conduct testing of the PFO Recycler technology and demonstrate the energy savings in comparison to current technologies for recycling water at industrial facilities.

The objectives of this project were to:

- Demonstrate the PFO Recycler system as a reliable, cost effective technology to reuse water.
- Demonstrate both energy savings and increased water volumes for reuse.
- Demonstrate that the water produced from this process has high water quality content, free from minerals and chemicals and can be reused for various onsite processes (for example, washdown, sterilization, boiler feed, and so on).

Onsite pilot testing of the PFO Recycler system was designed to demonstrate 20-40 percent lower energy use for high purity reuse of hard-to-treat industrial wastewater. The PFO Recycler is an energy efficient hybrid FO+RO system that generates purified water streams for reuse as process water or irrigation.

CHAPTER 2: Water Reuse at Jackson Family Wines Blending Facility

Purpose

The purpose of the pilot project for Jackson Family Wines (Figure 2) (JFW) was to demonstrate energy savings, high purity water, and other benefits associated with treating a challenging waste stream using the PFO Recycler. More specifically, the primary purpose was to demonstrate more water for reuse with less energy, while also reducing the volume of their wastewater ponds and providing high quality water to reduce maintenance associated with mechanical systems (for example, cooling towers and boilers) that would utilize the recycled water.

Figure 2: Proprietary Forward Osmosis Recycler Pilot at Jackson Family Wines Site

Picture of Porifera PFO Recycler Pilot

Source: Porifera, Inc.

Cost and Energy Saving Strategies

PFO Recycler technology can reduce energy use and increase water reuse at wineries and other industrial facilities in at least two ways. First, it can recover more water from challenging waste streams with less energy than competing processes. Second, it can handle higher temperatures than competing membrane technologies to reduce the need of cooling and reheating water prior to reuse in boilers, reducing energy use.

Goals and Objective

The primary objective of the testing was to demonstrate energy savings and water quality in a way that would benefit wineries and other industrial facilities throughout California.

Therefore, the goals for this pilot demonstration were to:

1. Demonstrate energy savings with a PFO Recycler by demonstrating:
    - Less energy than competing reuse options to produce similar water quality
    - Higher recovery (that is, more water for reuse) than competing reuse technologies
2. Demonstrate that PFO technology offers benefits over alternative processes
    - Flexibility to treat highly variable source waters

- Superior water recovery compared to other membrane processes

3. Provide an example of reducing energy needed to reuse water from challenging wastes to reduce current and future energy use in the state of California

Approach

Wastewater streams at wineries and other food and beverage processing facilities are highly variable in terms of water quality parameters. Therefore, the Porifera team worked collaboratively with the Pilot Partner to identify representative streams to use for pilot demonstrations. JFW identified two potential waste streams for reuse with the intent of reducing storage needed in onsite ponds. The two streams selected were significantly different in terms of salinity, solids loading, temperature and other variables and both streams were variable over time. Upon stream selection Porifera staff performed site demonstrations with the Recycler equipment used to treat both streams.

To minimize onsite optimizations and minimize requirements for Pilot Partner's resources, the approach was to first perform laboratory tests to understand treatment requirements and set water recovery goals based on estimated salinity, fouling potential and other characteristics of water streams. Next, these results were presented to pilot partner staff and the Porifera team collaborated to select the waste streams for pilot scale testing that would achieve both Porifera's goals to show energy savings as well as the pilot partner's goals for increased water reuse.

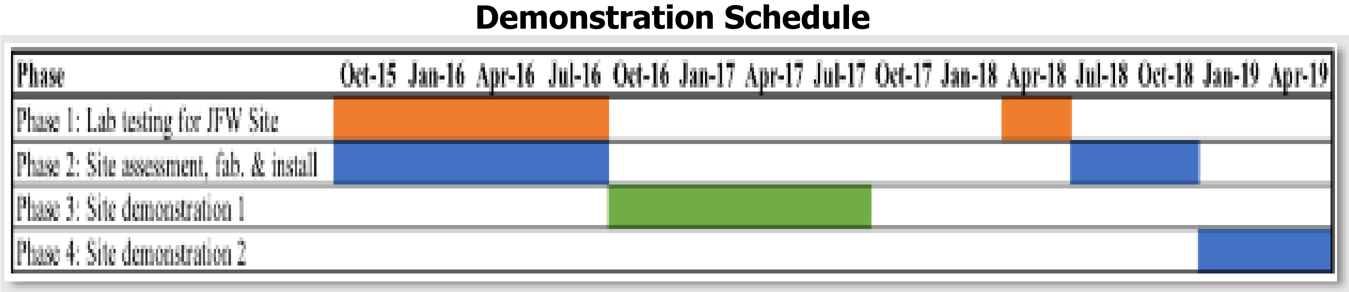
The following sections summarize this approach in more detail including the test phases, location, equipment used and note the key changes in equipment or approach as the project progressed.

Test Phases and Schedule

The testing occurred in the following phases as described in Figure 3:

1. Phase 1: Preliminary lab testing 10/1/15 to 10/1/16 and 04/01/18 to 07/01/18
2. Phase 2: Site assessment, pilot system fabrication and installation 10/1/15 to 10/1/16 and 07/01/18 to 01/01/18
3. Phase 3: Site demonstration on Feed 1 12/1/16 to 6/15/17
4. Phase 4: Site demonstration on Feed 2 1/28/19 to 4/10/19

Figure 3: Jackson Family Wines Blending Facility Wastewater Reuse Demonstration Schedule



Source: Porifera, Inc.

Location: Jackson Family Wines Blending and Bottling Facility in Windsor, California

The testing occurred at two main locations. The first location was Porifera's laboratory where preliminary laboratory testing, equipment design, and manufacture occurred. The second location was the JFW blending facility located near Sonoma, California (Figure 4).

Figure 4: Site Location and Map of California Wineries

Site Location and Map of Breweries and Brewpubs in North Central California

Source: America's Beer Trail Website California Breweries and Brewpubs Map. https://www.brewtrail.com/ california-breweries/

Equipment and Materials

The equipment and materials used for testing were different for each phase of the test and is summarized in the following subsections. The main components needed for testing were as follows:

- PFO laboratory scale and pilot-scale test system at Porifera lab
- Pond and tank building feed solutions (that is, waste streams selected by pilot partner)
- Pond and sump feed water pumps and supply systems
- Draw solution (for example, NaCl – table salt and $MgCl_2$ – road salt)
- Tankless FO+RO system 1 with sand filter prefiltration equipment

- FO+RO system 2 with tanks, Spiral Water prefiltration equipment (spiralwater.com) and biocide addition
- Miscellaneous disinfection and cleaning chemicals
- Miscellaneous piping, electrical, and containment work to install and operate pilot
- Sample containers suitable for water quality testing

The test equipment, treatment process, and site modifications were designed, installed and operated by Porifera, the feed solution was provided by the pilot partner, and draw solution and other chemicals were supplied by Porifera.

Phase 1: Preliminary Laboratory Testing

Initial tests were performed using Porifera's small custom laboratory setup referred to as the membrane coupon test setup. Using this data, additional tests were performed using Porifera's custom membrane element test setup.

Phases 2 and 3

Following the preliminary lab tests, Porifera designed and constructed the PFO Recycler 1 pilot system. This system was designed to have an extremely small footprint to fit within a small storage trailer, which fit within the allotted space next to a wastewater pond at the site (Figure 5).

Figure 5: Proprietary Forward Osmosis Recycler Pilot Systems 1 and 2

Pictures of the PFO Recycler 1 Skid (Left) and PFO Recycler 2 Skid 2 (Middle) and Spiral Water (Skid Right)

Source: Porifera, Inc.

The PFO Recycler 1 pilot was configured to run on:

- FO: one or two PFO6S modules with 6 PFO-100 elements each (42 m^2 per module).
- RO: up to six 2.5-inch diameter by 40-inch-long Dow SW elements (2540's)
- Tankless design: no feed or draw tanks were needed; only a small draw dose tank
- Table salt (NaCl) draw and magnesium chloride ($MgCl_2$)

A unique aspect of this pilot system was that it was designed to operate without a draw storage tank. This means that the draw out of the RO system would flow directly into the FO draw inlet and the dilute draw from the FO would feed directly into the RO pump suction without any draw storage. While this can have many benefits in terms of small footprint and small draw volumes, it does change the system starts and stops and the system becomes more difficult to control when there are rapid changes in feed water salinity and/or temperature.

During Phase 3, a submersible pump was installed in the pond to pump water directly into the FO modules. Once algae and other biogrowth began to clog the piping, instruments and FO modules, different types of pre-filters were tested between the sump pump and FO modules. Finally, backwashing dual-media filters (anthracite and sand) were sufficient to keep the feed supply system running with less maintenance. In addition, PFO elements both with and without spacers were used during testing to determine which would be better for the solids loading observed during testing.

Phase 4

Following Phase 3, new data and requests from JFW led to a new feed stream and a need for additional piloting. A significant amount of BOD and certain other constituents, such as suspended solids, rinse water containing wine, and cleaning chemicals were entering the wastewater from their tank storage building. Therefore, if it were possible to recycle this waste stream prior to it mixing with other streams in their ponds, the water quality would improve in the main pond used for irrigation reuse and it would reduce storage in other ponds.

Based on an assessment of this new feed, the PFO Recycler process would need to be configured to be able to treat rapid changes in feed water temperature and quality. With this new information, Porifera designed and constructed the PFO Recycler 2 pilot system, which was designed to include 1) a draw storage tank, 2) biocide addition, and 3) a 20-micron prefilter (Figure 5).

The PFO Recycler 2 pilot was configured to run on:

- FO: one or two PFO9S modules with 9 PFO-100 elements each (63 m^2 per module)
- RO: up to ten 2.5-inch diameter by 40-inch-long Dow SW elements (2540's)
- Tank design: no feed tank was used, but did include draw storage and dose tanks
- Table salt (NaCl) draw and magnesium chloride ($MgCl_2$)
- Biocides:
    - Continuous chlorine dioxide (ClO_2)
    - Intermittent peracetic acid (PAA)

During Phase 4, a jet type submersible pump was installed in the tank building drainage sump, which had a water level 15-20 feet below grade. The sump location is in a small shrubbery lined median in the middle of a larger parking lot between JFW's tank and barrel buildings. Due to this central location, there were no utility connections within 200 feet, thus a connection was made to their existing sump pump panel and a transformer were added to the pilot system to create the required voltage. Additionally, an auxiliary clean water tank was used to start the system and was refilled with system permeate to provide makeup water and flush water for membrane cleanings or system maintenance. A 12 square foot plastic berm was deployed under the system to contain any spills that might end up in the parking lot and return them to the sump. The system and berm also had to be covered with a plastic 12 foot by 20 feet car port framed covering to protect the system from rain and the berm from filling with rain water.

A Spiral Water® Automatic Self-Cleaning Filter with a 20-micron wedgewire mesh was installed between the sump pump and FO modules to remove particulates and biocide dosing systems were installed to dose the biocide prior to the Spiral Water® based on the challenging feed water conditions observed during startup.

Project Data and Results

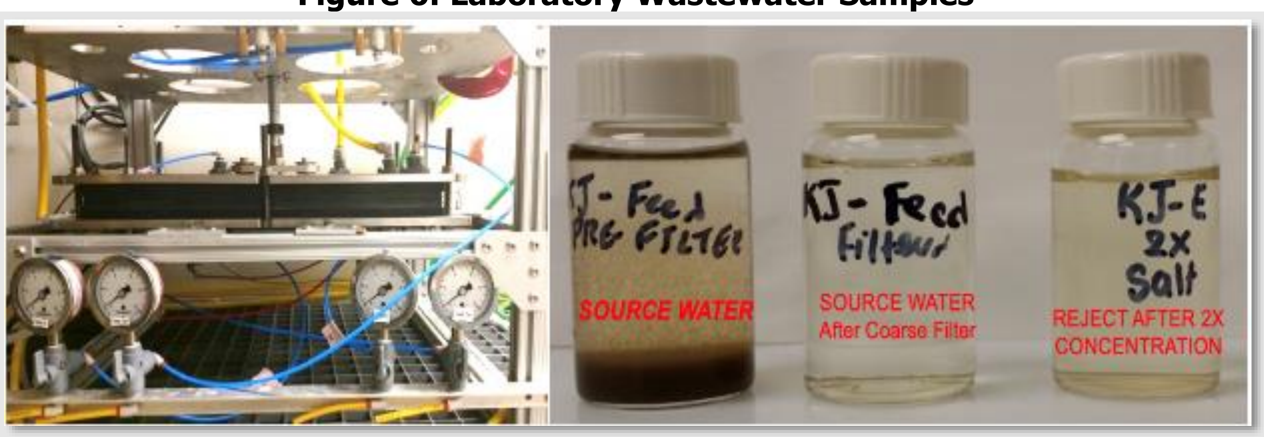
This section includes a summary of the data and results for each test and phase of the project.

Phase 1: Preliminary Laboratory Testing

Laboratory coupon and element tests were performed on wastewater from an onsite pond to evaluate the customer's wastewater and design an optimal solution for this site. Initially, JFW was targeting only 50 percent water recovery so that the water quality in the FO concentrate would not exceed municipal limitations.

At lab scale, Porifera's FO membrane was able to achieve between 50-85 percent reuse at an acceptable flux rate (>14 lmh) and a low draw salinity. Pictures of the source water and resulting FO concentrate are shown in Figure 6.

Figure 6: Laboratory Wastewater Samples



Picture of the samples including the waste stream feeds and resulting concentrates with salt and/or anti-fouling draw solutions

Source: Porifera, Inc.

Phase 2: Site Assessment, Pilot System Fabrication, and Installation

After presenting the results from Phase 1 to JFW site staff, it was determined that the pilot would treat water from the same wastewater ponds at the site that the samples were collected from for Phase 1. Multiple site trips were performed to confirm the available utilities at the site and to determine the optimal location. The system was designed, fabricated, and tested at Porifera. Then it was transported in a trailer customized for the system. Porifera then installed the system at the site with support from the JFW staff. Later as discussed for Phase 4, a second site was identified and the activities in phase 2 were repeated for the second site.

Phase 3: Site Demonstration on Pond Wastewater (Feed 1, Site 1)

The wastewater from the pond alternated between not so challenging (low suspended solids and BOD) to extremely challenging (high suspended solids, high BOD, and algal blooms) and its temperature (40-90^{o}F) varied significantly due to changing weather conditions. The submersible pumped was located near the middle of the pond and positioned to pull water from approximately mid-depth (Figure 7).

Figure 7: Selected Pilot Sites

Photographs of the pilot sites selected for testing. Site 1 near existing pond (left) and Site 2 near the tank building (right)

Source: Porifera, Inc.

Pilot system 1 was designed to maintain a target feed rate determined by a setpoint in the touchscreen and increase the draw salinity to maintain a target recovery setpoint of 50 percent input in the touchscreen. The feed rate into the system was constant and the draw salinity was used as a gas pedal to speed up the system if necessary, to maintain stable recovery. Because there was no draw storage tank, a very small amount of draw could be wasted to rapidly slow the system down if necessary; however, this rarely occurred because it would happen only if system recover exceeded >65 percent recovery as a setpoint.

During winter months, the spikes in suspended solids and organics were moderate and easily treated by the PFO Recycler system without pretreatment. Once the weather began to warm up, algae growth in the pond could become excessive and would clog the feed pump, feed piping, and feed channels within the FO module, which required the installation of pretreatment for stable operation. More detail on these different periods is summarized below and the key operating and water quality parameters are summarized in Tables 2 and 3.

The initial plan was to operate the PFO Recycler at 50 percent recovery, with a NaCl draw, and without pretreatment and compare PFO elements with and without spacers to determine the necessity of pretreatment. During initial winter months, the system ran well both with and without spacers. There was some noticeable clogging of the element spacer during this time which was observed due to increased differential pressure (DP) between the entry and exit of the FO module. Performing a clean water flush and high pH clean-in-place both reduced the DP buildup; however, it would increase more quickly after the initial clogging than when the module was new. The spacerless elements performed better in terms of DP but did operate at an approximately 15-20 percent lower normalized flux rate when operating at an equivalent driving force when compared to the elements with spacers on the feed side of every membrane.

The estimated clean-in-place (CIP) frequency of the FO membranes was estimated at once per 3-4 months with spacerless elements and without pretreatment, which was determined to be acceptable based on the foulants in the source water, which typically would require more frequent cleanings of competing membrane treatment processes.

As the weather began to warm, there was noticeable algae growth in the source water pond. While this did not immediately impact the pilot, the Porifera team did begin to notice that the system pumps were using more energy to get water into the FO module and the draw recovery pump began to use more energy to maintain 50 percent recovery. The source water supply system was evaluated and a FO element was autopsied to determine the cause. It was clear that the algae loading in the source water was too high to keep the system from clogging and it was determined that pretreatment was needed to keep the system running without frequent cleans. Figure 8 shows a picture of the source water pond and the submersible pump clogged with algae.

Figure 8: Source Water Pond and Clogged Pumps

Photograph of source water pond (Left) and clogged feed submersible pump (right)

Source: Porifera, Inc.

An auto-backwashing dual-media (anthracite and sand) filter was installed to remove most of the suspended solids prior to entering the FO module, which provided much better performance of the PFO Recycler system, although frequent maintenance (once or twice per week) was required to keep the source water submersible pump and piping (before the sand filter) clean. Also, the backwash frequency of the sand filters was frequent (increased to once per every 2-6 hours instead of once per day on average) during spikes in algae growth, meaning it was probably not the most ideal pretreatment solution. However, it was suitable for maintaining adequate pretreatment for the PFO Recycler. It should be noted that was is referred to as “frequent maintenance” was the result of a simple, low-cost temporary water supply system and that a commercial system would be designed to provide source water from a depth that would minimize algae intake.

The estimated CIP frequency of the FO membranes was estimated at once per every 1-3 weeks during this period before pretreatment was added regardless of element type. The CIP frequency was estimated at once every 3-6 weeks with pretreatment during high algae growth periods. It was also determined that the source water piping would need to be cleaned 1-2 times per month unless site improvements could provide access to the water before it entered the pond. While this would reduce algae, it was noted that it would increase biochemical oxygen demand (BOD) and other challenges.

Optimized Operation and Conclusions

After it was determined that the pretreatment was adequate for stable pilot operation, water quality sampling was performed to assess the pilot system's ability to meet site reuse quality goals. The data shown in Table 3 (presented later in this section) indicated that it met initial goals and produced very high-quality water, exceeding the target water quality.

Porifera performed additional testing to determine the system's ability to improve the soil adsorption ratio (SAR) factor of the permeate. SAR is a calculated ratio of sodium to mineral content (calcium and magnesium) in a water. A high ratio (a higher ratio of sodium to mineral content even if total sodium is low) may degrade the soil by reducing soil water adsorption. A low ratio indicates the water may restore the soil. Typically, a SAR of less than 3 is considered acceptable with no restrictions on the use of recycled water for crops or ornamental plants. A SAR of 3-9 is considered moderate with soil monitoring, non-sensitive crop selection and soil amendment (for example, adding gypsum) recommended with SARs between 6-9. A SAR of greater than 9 is considered unacceptable for most plants and is not recommended for irrigation use.

Magnesium chloride ($MgCl_2$) was determined from this analysis to be an attractive draw solution for testing because it would increase the magnesium in the recycled water and reduce the sodium compared using a sodium chloride (NaCl) draw solution. Therefore, during the final phase of testing, the pilot was operated using a $MgCl_2$ draw solution. $MgCl_2$ showed a positive impact because the feedwater entering the pilot had a moderate SAR, while the SAR of the pilot permeate was consistently below 2 when operating with a $MgCl_2$ draw solution compared to moderate to high when using a NaCl draw solution.

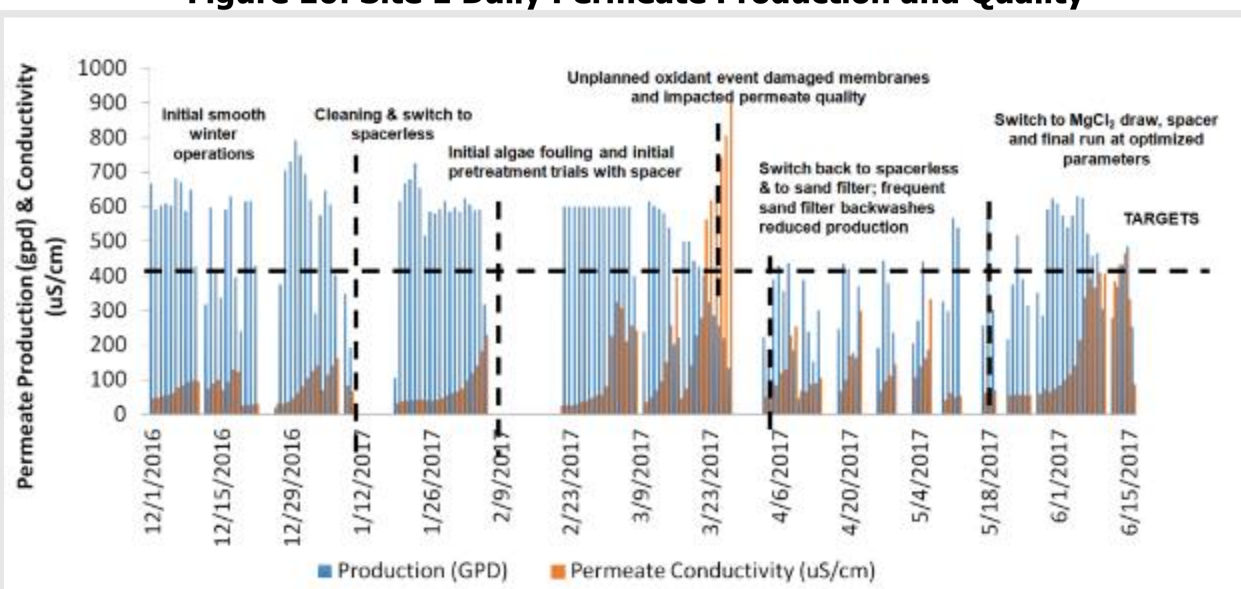
Final performance, energy use numbers, and design parameters were assessed. Figure 9 shows a photograph of the source water and recycled water coming into and going out of the PFO Recycler pilot. Figure 10 shows an overview of run time with bars showing how the permeate achieve 50 percent recovery production and conductivity goals.

Figure 9: Site 1 Source Stream and Permeate Stream

Picture of pilot permeate stream (left) and source water stream into FO module (right)

Source: Porifera, Inc.

Figure 10: Site 1 Daily Permeate Production and Quality



Data graph showing timeline of daily production, permeate quality, target values, and key events

Source: Porifera, Inc.

Phase 4: Site Demonstration on Tank Building Wastewater (Feed 2)

The pilot partner reassessed the ideal location for pilot testing after Phase 3 and determined that it could be better to reuse the water prior to it entering the ponds and reusing it directly as boiler feed, cooling tower feed, and potentially other uses. By selecting the right waste stream and location, it could improve operation of mechanical equipment, improve water quality that goes into the pond, improve discharge water quality, and improve water quality used for irrigation. Based on discussions with the pilot partner, there were two potential locations (the barrel building and tank building). A different technology (vibratory RO) was being installed to recycle water from the barrel building, so the pilot partner selected the tank building for the PFO Recycler pilot trial. The barrel building water was higher in suspended solids, while the tank building water was higher in organic loading, temperature variability, and certain constituents that would be better to discharge without putting into the pond.

A submersible pump was positioned approximately mid-depth in the "catch-all" drainage sump located in the parking lot next to the tank building (Figure 11). A large sump pump would pump this wastewater directly from the sump into the pond once a high level was reached, so the water quality in the sump was highly influenced by the inflow.

Figure 11: Site 2 Source Sump

Pictures of source water sump and clogging of sump pump feeding pilot

Source: Porifera, Inc.

The tank building includes over 8 million gallons of tank space and the wastewater changes often due to frequent cleaning of tanks, moving wine, and filtering wine that can occur at any time of the day for any period. This variability was visually evident (Figure 12) and would be characterized as extremely challenging due to rapid temperature fluctuations, rapid changes in free chlorine and oxidation and reduction potential (ORP) from cleaning chemicals, and rapid changes in color, odor organics and solids loading.

Figure 12: Site 2 Source Water Quality Variability in Same Day

Pictures of changes in source water stream within a 30-minute period

Source: Porifera, Inc.

Like pilot system 1, pilot system 2 was designed to maintain a target feed rate determined by a setpoint in the touchscreen and increase the draw salinity to maintain a target recovery setpoint of >65 percent input in the touchscreen. However, pilot system 2 was designed to include pretreatment, feed chemical addition, and to operate with a draw tank. The feed rate into the system was constant and the draw salinity was used as a gas pedal to speed up the system if necessary, to maintain recovery. However, if the recovery exceeded the setpoint, then the draw recovery RO system would slowly adjust to stabilize recovery. During this time the level in the draw tank would rise, but programming was sufficient to operate the RO system as needed to maintain operation even with the rapid changes in feed water quality that would impact the osmotic driving force, which impacts system recovery. The pretreatment system was a Spiral Water™ auto-backwashing 20-micron stainless steel wedge-wire type filter. The PFO elements used contained spacers and the initial draw solution was NaCl but was changed to $MgCl_2$ before the end of the test.

During startup, the entire feed side of the system clogged within 12 hours including the piping, pre-filter, and FO modules. The source water supply system was evaluated and a FO element was autopsied to determine the cause and it was visually evident that rapid biogrowth had grown on every available surface on the feed side of the system (see Figure 13).

Figure 13: Site 2 Bio-Growth During Startup and Before Biocide Addition

Pictures of biogrowth that clogged feed pipe (left) and pre-strainer (right)

Source: Porifera, Inc.

While this was initially disheartening, the system had been designed to allow for addition of chemicals upstream of the prefilter if needed. One chemical dosing system allowed for a constant dose of ClO_2 into the feedwater to keep bacteria from growing (varied between 1-5 mg/L; system programmed to maintain 0.2 mg/L in FO reject), while a second dosing system would intermittently inject PAA (instantaneous shock dose of 2,000 mg/L once per 30-600 minutes depending on DP increase) into the feed to remove biogrowth and other foulants that had been able to grow in the system. This immediately improved operation and began to remove bacterial growth and other deposited material from mechanical equipment and PFO element spacers that could not be completely cleaned with chemicals or other methods following the initial clogging. Both the pilot partner and the project team were impressed that it worked after seeing rapid fouling during startup. After this, the system ran consistently except for minor shutdowns when the submersible pump clogged (Figure 10).

Key operating and water quality parameters are summarized in Tables 2 and 3.

Table 2: Representative Key Pilot Operating Parameters at Sites 1 and 2

	Feed in	Feed Reject/ Concentrate Out	Concentrate Draw to FO	Dilute Draw to RO	Permeate
Flow (gpm)	S1: 0.8 S2: 2.8	S1: 0.4 S2: 0.3-0.8	S1: 0.5 S2: 2.0	S1: 0.9 S2: 4.2	S1: 0.4 S2: 2.0-2.5
Water recovery (%)	N/A	N/A	N/A	N/A	S1: 50% S2: 70-90%
Pressure (psi)	S1: 3-8 S2: 8-18 Varied with FO DP increase	S1: 1-4 S2: 2-3	S1: 1-4 S2: 5	S1: 250-550 S2: 180-800 Varied per FO & RO flux, fouling & feed quality	S1: <15 S2: <15
Conductivity (mS/cm)	(proprietary)	N/A	S1: 20-35 S2: 18-45	S1: 15-25 S2: 9-22	S1: 0.03-0.3 S2: <0.3
Temperature (^{o}C)	S1: 54-82^{o}F (12-28^{o}C) S2: 77-176^{o}F (25-80^{o}C)	Not logged	Not logged	S1: Not logged S2: 82-185^{o}F (28-85^{o}C)	S1: 59-86^{o}F (15-30^{o}C) S2: 81-187^{o}F (27-86^{o}C)
Energy use (Wh/gallon)	N/A	N/A	N/A	N/A	S1: 3.5-7.6 S2: 2.5-10

Source: Porifera Inc.

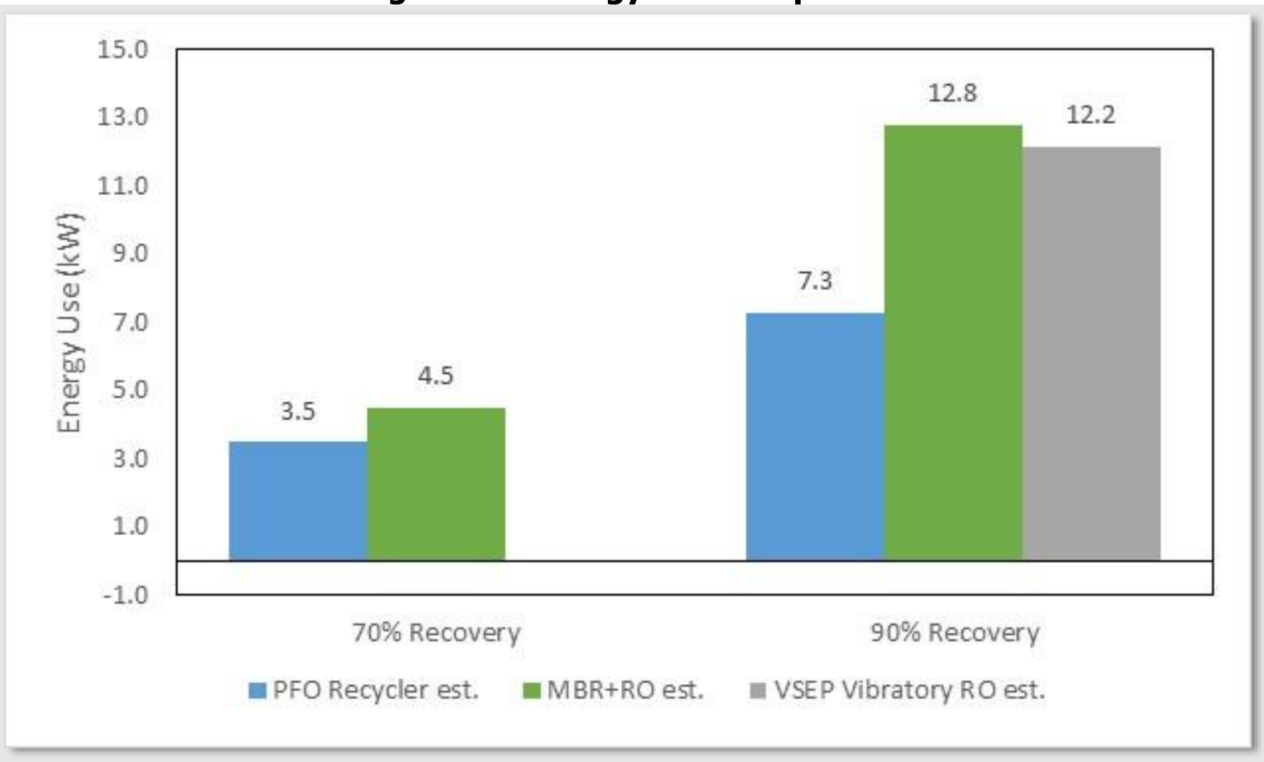
Table 3: Summary of Key Pilot Water Quality Analysis Data at Sites 1 and 2

Parameter	Units	Feed	Pilot Permeate With $MgCl_2$ draw
BOD	mg/L	S1: 200-280	S1: ND
COD	mg/L	S1: 300-520 S2: > 4,000	S1: ND S2: 150
TSS	mg/L	(proprietary)	S1: < 1 S2: < 1
Algae	#/mL	(proprietary)	S2: ND
Chloride	mg/L	S1: 12 S2: 20	S1: 6 S2: 39
Sodium	mg/L	S1: 20-30 S2: 10	S1: 5 S2: 2.5
Conductivity	uS/cm	(proprietary)	S1: 30-50 S2: < 250
Total Dissolved Solids (TDS)	mg/L	S1: 800 S2: 280	S1: < 25 S2: 130
Hardness	mg/L as $CaCO_3$	S1: 110-180 S2: 100	S1: < 25 S2: < 25
Alkalinity	mg/L as $CaCO_3$	S1: 470-580 S2: 45	S1: < 5 S2: < 5
Calcium	mg/L as $CaCO_3$	S1: 21-33 S2: 14	S1: ND S2: 0.1
Magnesium	mg/L as $CaCO_3$	S1: 15-24 S2: 15	S1: 6 S2: 5.5
pH	pH Units	S1: 8 S2: 5.5-8.5	S1: 6 S2: 4.4-7.0
Color	Color units	(proprietary)	S2: ND (< 2)

Source: Porifera Inc.

The data shows that the pilot system unit average energy at 50 percent recovery when treating water at the ponds was 3.5-6.5 kilowatt-hours (kWh) per 1,000 gallons at site 1. At site 2, the total energy use was approximately increased to 4-6 kWh/1,000 gallons at 70 percent total recovery and 7-10 kWh/1,000 gallons at 90 percent total recovery (Figure 14).

Figure 14: Energy Use Comparison



Comparison of unit energy use. PFO Recycler data was measured at the Site 2 and competing process energy use are estimates based on published values. VSEP is the name of the type of vibratory RO also pilot tested at this site.

Source: Porifera Inc.

Based on the data, the following three items were observed in terms of energy use:

1. The energy use numbers are for the PFO Recycler treatment process only. When adding in the source water pumping from the pond or sump through pretreatment, the auxiliary air compressor and other axillary systems, so the PFO Recycler energy use was approximately 30-90 percent of the total at any given time depending on what other pumps, air compressors, and so forth were running at the time. The impact of these auxiliary loads would be much lower for a commercial scale system due to scale and the energy needed for source water supply would be similar to that for competing treatment processes.
2. Instantaneous energy use at site 2 was highly dependent on the efficiency of the pumps as the RO system would speed up and slow down rapidly with rapid swings in feed water quality (primarily temperature and conductivity). A commercial scale system designed to maximize pump efficiency with these variations would be able to achieve better energy use numbers than demonstrated by the pilot.
3. The energy use and RO feed pressure at site 2 would noticeably increase after periods when the RO membranes operated at temperatures higher than 140°F (60°C), which is over the max recommended temperature of 113°F (45°C). This is a known common result at high temperatures and a commercial scale system could include a heat exchanger to mitigate this “hot water penalty” (since this wastewater flow rate is relatively small compared to clean water use and the clean water is at a low temperature). Or if this warm permeate was used as boiler feed water, the added

energy savings from reduced heating may be worth the relatively small amount of energy needed to increase RO pressure for reuse.

Based on these realizations, the energy use estimates for a commercial PFO Recycler system optimized for this site as described later in this section would be 3.3 kWh/1,000 gallons for 50 percent recovery from the pond at site 1, 3.8 kWh/1,000 gallons for 70 percent recovery and 7.3 kWh/1,000 gallons for 90 percent recovery at the tank building (site 2). Note that more energy is required to reduce waste volume from ~3 times reduction at 70 percent recovery to 10 times reduction at 90 percent recovery.

While these energy numbers may initially appear high when looking at just the TDS, the impact of organics and variability should not be discounted as there are few competing technologies that would be considered for these types of challenging waste streams.

A vibratory shear enhanced process (VSEP) RO system treating water from the barrel building at the same site is estimated to use 12.1 kWh/1,000 gallons at 90 percent recovery (Loge and Rupiper, 2019), but the unit energy use is not known for 70 percent recovery. It is also currently unknown how the VSEP and PFO Recycler would compare in terms of price for this project; however, based on analysis by other Porifera industrial customers that evaluated both technologies, the cost and footprint would be expected to be in the same ballpark at this time with the PFO Recycler pricing and space requirements becoming significantly more attractive as PFO elements are scaled to larger sizes.

Another option would be to consider a membrane bioreactor (MBR); however, there are multiple practical considerations that would make it difficult to utilize a MBR at this site. First, a MBR sized for this organics loading is estimated to be 3-5 times larger than a PFO Recycler in terms of footprint and footprint is at a premium at this site. Second, a MBR would not reject dissolved contaminants or ions for high purity reuse that the PFO Recycler would unless a RO system were added after the MBR to provide high purity water. So, an MBR+RO process would be needed for an apples-to-apples comparison. Recent estimates from the literature for a MBR process range between 2.4 and 9 kWh/kgal (Loge and Rupiper, 2019) with higher numbers being reported in Europe with higher recoveries. It was estimated for this analysis that an MBR+RO process that could achieve 70 percent overall recovery (assumes 85 percent recovery from MBR and 83 percent recovery from RO) would need approximately 2.5 kWh/kgal for the MBR and 2.0 kWh/kgal for the RO. It was also estimated for this analysis that an MBR+RO process that could achieve 90 percent overall recovery (assumes 95 percent recovery from MBR and 95 percent recovery from RO) would need approximately 8.5 kWh/kgal for the MBR and 4.3 kWh/kgal for the RO.

Also, the energy used needed for onsite reuse would be less energy than needed to import Delta water to wine regions in southern California and other parts of California.

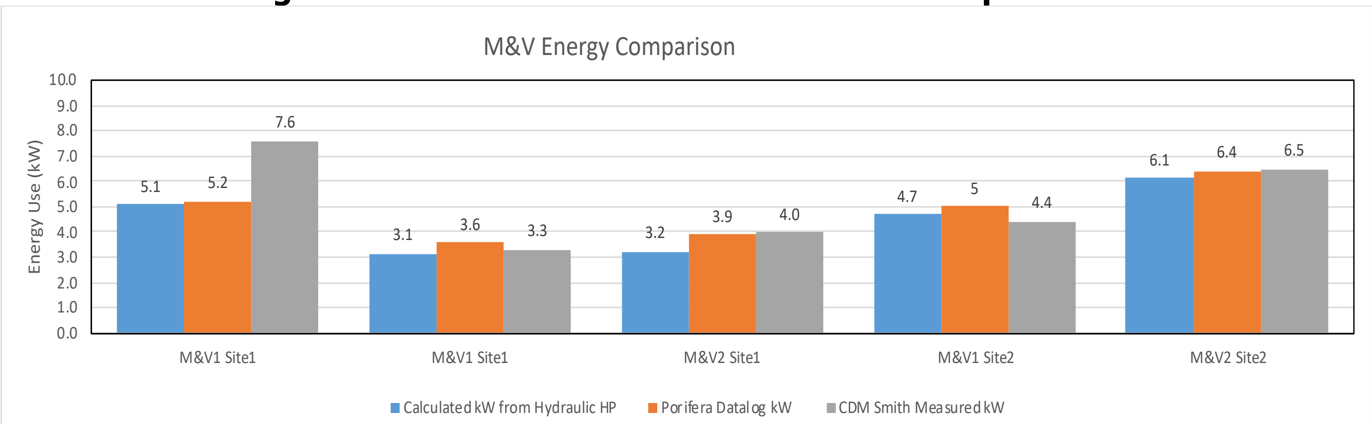
When comparing these different energy use options, this data indicates that the PFO Recycler could save on the order of 20 percent energy compared to a competing MBR+RO process at 70 percent recovery and 40 percent less energy than MBR+RO or vibratory RO at 90 percent recovery, thus backing up the claim of more water reused with less energy.

Summary of Independent Measurement and Verification Data

CDM Smith was the measurement and verification partner for this project and visited the site multiple times. The graphs below compare their independent readings with Porifera's readings shown at that time on the touchscreen, which is the same data used for data logging and creating data graphs shown in this section and Appendix A.

The calculated unit energy use from M&V measurements was approximately 3.3-7.6 kWh/1,000 gallons at site 1 and 2.6-4.0 kWh/1,000 gallons at site 2 using the total pilot energy numbers, which included all pumps, controls, and components that used energy in the PFO Recycler system (Figure 15). More details are provided in Appendix A.

Figure 15: Measurement and Verification Comparison



Energy use verification by CDM.

Source: Porifera Inc.

Commercial Scale-up Assumptions from Pilot Results

The JFW site has a need for approximately 30 gpm of high purity reuse water, which is approximately 70 percent of the estimated 43 gpm of total clean water used onsite and this JFW facility accounts for approximately 2 percent of all the wine produced in the state of California.

Site Test Conclusions and Recommendations

More Water with Less Energy

Overall, the pilot study results showed that this challenging and highly variable wastewater could be recycled into high purity water for reuse. It also showed that the PFO Recycler could reuse more water (90 percent) with less energy than MBR+RO or VSEP vibratory RO, which are other options being considered for the site.

Pretreatment Needed

The pilot study data indicated that the pilot operated sustainably on this source water after installing sand filters and site 1 and a 20-micron screen upstream at site 2 to reduce impacts of onsite maintenance activities. Some additional analysis would need to be performed to determine if a different pretreatment could be used if water was reused right before entering the ponds. Also, the use of chlorine dioxide as a biocide and polyacrylic acid as a maintenance biocide was confirmed and demonstrated to be necessary for treating water with high organics, yeast, and other fermentation byproducts at site 2. The biocides have the added benefit of providing high-quality water that already has residual disinfectant to minimize downstream bio-growth.

Energy Use

The pilot data indicates that the PFO Recycler could save on the order of 20 percent energy at 70 percent water recovery and 40 percent energy at 90 percent water recovery. The energy savings for water reuse are highly dependent on the water quality, particularly salinity.

Recommendations

This technology should be recommended for additional support and demonstrations to reuse challenging and highly variable wastewaters. The fact that the system could run reliably on the water at Site 2 without any sort of microbiological process will be a gamechanger for industrial facilities that either cannot afford or do not have the space for an MBR.

CHAPTER 3: Brewery Wastewater Reuse at Ale Industries

Purpose

The purpose of the pilot project for AI (Figure 16) was to demonstrate energy savings, high purity water, and other benefits associated with treating a challenging waste stream using the PFO Recycler. More specifically, the primary purpose was to demonstrate more water for reuse with less energy, while also reducing fresh water use by reusing the water to flush toilets.

Figure 16: Proprietary Forward Osmosis Recycler Pilot at Ale Industries Site

Picture of Porifera PFO Recycler Pilot

Source: Porifera, Inc.

Cost and Energy Saving Strategies

PFO Recycler technology can reduce energy use and increase water reuse at breweries and other industrial facilities in at least two ways. First, it can reuse more water from challenging waste streams with less energy than competing processes. Second, it can handle higher temperatures than competing membrane technologies to reduce the need of cooling and reheating water prior to reuse in boilers, which use less energy with warm water.

Goals and Objective

The primary objective of the testing was to demonstrate energy savings and water quality in way that would benefit breweries and other industrial facilities throughout California.

Therefore, the goals for this pilot demonstration were to:

1. Demonstrate energy savings with a PFO Recycler by demonstrating:
    - Less energy than competing reuse options to produce similar water quality
    - Higher recovery (that is, more water for reuse) than competing reuse technologies
2. Demonstrate that PFO technology offers benefits over alternative processes
    - Flexibility to treat highly variable source waters
    - Superior water recovery compared to other membrane processes
3. Provide an example of reducing energy needed to reuse water from challenging wastes to reduce current and future energy use in the state of California

Approach

Wastewater streams at breweries and other food and beverage processing facilities are highly variable in terms of water quality parameters. Therefore, the Porifera team worked collaboratively with the pilot partner to identify representative streams for piloting. Pilot partner staff identified the hot wastewater from the kettle mash/wort as the ideal stream to reuse on site. Wort is the liquid extracted from the mashing of grain during the brewing of beer. Wort contains the sugars, including maltose and maltotriose, which are fermented by brewing yeast to produce alcohol.

Initial lab tests during Phase 1 indicated that no pretreatment would be necessary to achieve between 50 and 70 percent recovery. Since AI is located near Porifera's facility, it was determined that a PFO Recycler pilot would be installed and additional assessment and optimization could be performed on site.

As with most microbreweries, the generation of wastewater is more sporadic than larger breweries such that feed wastewater for the pilot was not available every day and volumes were insufficient to keep the pilot running overnight. The protocol was for pilot partner staff to let Porifera know when wastewater was available and then Porifera staff would come to initiate a run and the system would run at setpoints on the control panel until the wastewater feed was treated. The resulting concentrate was discharged to the sewer and the resulting permeate water was initially also sent to the sewer but was later reused for toilet flush water until site construction required changes to existing plumbing.

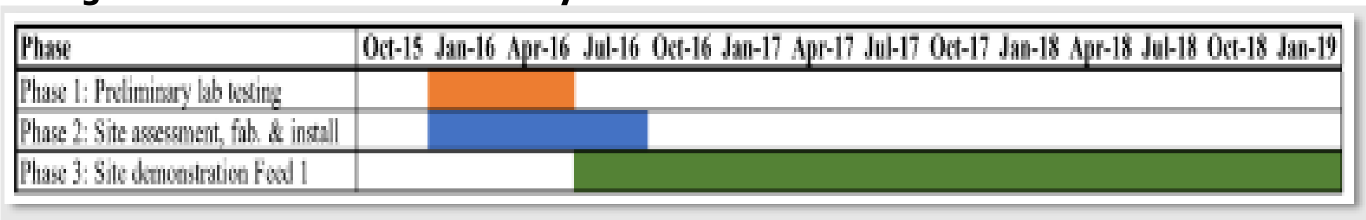
The system was simple to operate so pilot partner staff took over operations and no longer called Porifera staff to operate the system. Porifera would check the data and confirm performance; however, the pilot partner asked that no maintenance or adjustments be made to the process to confirm that it was a low maintenance treatment option. During this time, the FO and RO membranes were not cleaned for over a year. While some fouling occurred (shown by reduced recovery) the pilot system continued to run and produce excellent water quality. The recovery eventually stabilized and the system continued to operate until the system had to be moved to accommodate construction and facility upgrade activities during which time the pilot was not able to operate. After construction was complete, the membranes and tanks were cleaned and the system was restarted with only one additional cleaning at the end of the pilot test to determine how the clean would restore performance.

Test Phases and Schedule

The testing occurred in the following phases (Figure 17):

1. Phase 1: Preliminary lab testing, 01/01/2016 – 07/01/2016
2. Phase 2: Site assessment, pilot system fabrication and installation, 01/01/2016 – 07/31/2016
3. Phase 3: Site demonstration on wastewater feed, 07/01/2016-02/28/2019

Figure 17: Ale Industries Facility Wastewater Reuse Demonstration Schedule



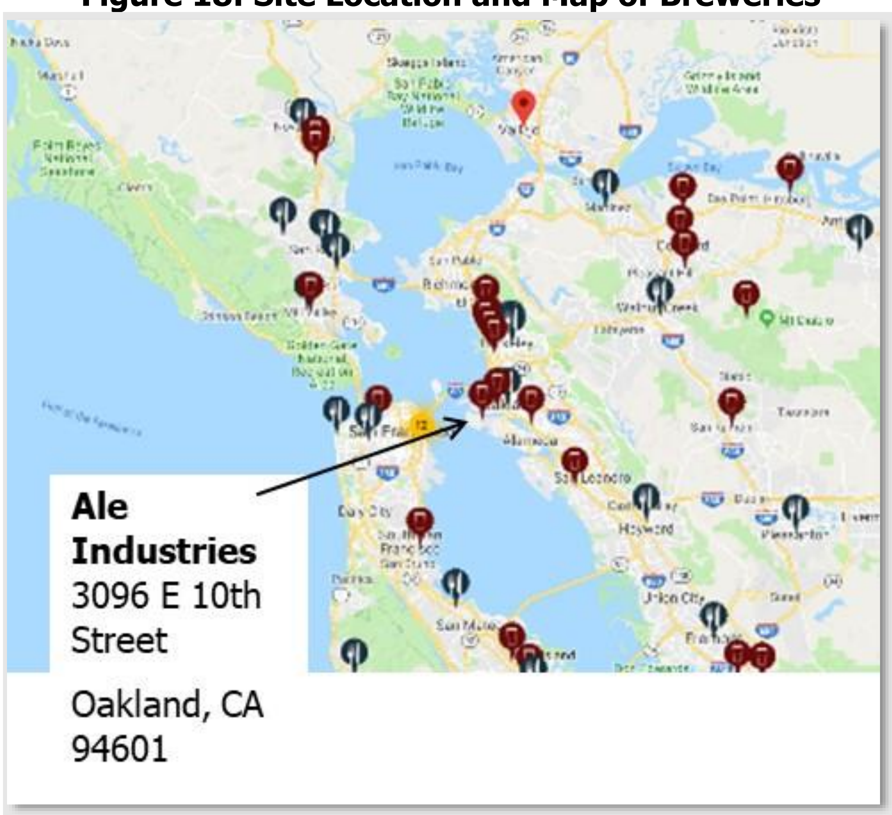
Demonstration Schedule for Ale Industries Pilot

Source: Porifera Inc.

Location: Ale Industries, Oakland, California

The testing occurred at two main locations. The first location was Porifera's laboratory where preliminary laboratory testing, equipment design and manufacture occurred. The second location was the Ale Industries microbrewery located in Oakland, California (Figure 18).

Figure 18: Site Location and Map of Breweries



Site Location and Map of Breweries and Brewpubs in North Central California

Source: America's Beer Trail Website California Breweries and Brewpubs Map https://www.brewtrail.com/california-breweries/

Equipment and Materials

The equipment and materials used for testing was different for each phase of the test and is summarized in the following subsections. The main components needed for testing were as follows:

- PFO laboratory scale and pilot-scale test system at Porifera lab
- Wort tank wash water feed
- Feed water pumps and tank to supply feed from the wort tank to the pilot
- Draw solution (for example, NaCl - table salt and MgCl2 - road salt)
- Tankless FO+RO system 1 with sand filter prefiltration equipment
- Generation 1 PFO Recycler system with draw storage and dose tanks
- High pH and low pH non-proprietary RO safe cleaning chemicals
- Miscellaneous piping, electrical, and containment work to install and operate pilot
- Sample containers suitable for water quality testing

The test equipment, treatment process, and site modifications were designed, installed and by Porifera. The draw solution and other chemicals were supplied by Porifera. The feed solution and some pilot operations were provided by the pilot partner.

Phase 1: Preliminary Laboratory Testing

Initial tests were performed at coupon scale using Porifera's custom membrane coupon test setup. Using this data, additional tests were performed using Porifera's custom membrane element test setup (shown in Figure 6).

Phases 2 and 3: Site Demonstration

Following the preliminary lab tests, Porifera designed and constructed the PFO Recycler pilot system. This system was designed to have an extremely small footprint to fit within a small open area at the site. The PFO Recycler pilot was configured to run on:

- FO: one PFO-20 element (1 m^2).
- RO: one 2.5-inch diameter by 21-inch-long Dow SW element (2521)
- Table salt (NaCl) draw

A photograph of the system is shown in Figure 19. This system was designed to operate at a given feed and permeate flow setpoint. Unlike later pilots used for this project, it did not auto adjust to changes in feed water quality, fouling or temperature. If fouling or changes in water quality occurred, the result would be a change in the FO flux rate which would be seen in the data as a change in the overall recovery. The RO system operated independently and thus would not run all the time. It would turn on when a certain level in the draw storage tank was achieved and turn off once that tank hit a low level.

This means that the resulting data did not generate typical performance trends that could be easily compared with performance at a later date. Instead, it generated data that was are highly dependent on the type of beer that was being made and the washdown procedures and temperatures used on those days. These parameters were used to try to normalize performance trends to osmotic pressure and temperature. However, it was easier to compare data from runs on wastewater from the same product than from different products. Typically, the recovery would start very high since the feed water was very warm and decrease as the temperature of the feed dropped over time since FO and RO flux rates are highly temperature dependent.

Figure 19: Proprietary Forward Osmosis Recycler Pilot System

Pictures of the PFO Recycler Skid

Source: Porifera, Inc.

Project Data and Results

This section includes a summary of the data and results for each test and phase of the project.

Phase 1: Preliminary Laboratory Testing

Laboratory coupon and element tests were performed on wastewater collected on site to evaluate the customer's wastewater and design an optimal solution for this site. Initially, Ale Industries did not have a specific water recovery target in mind, only that the water quality be sufficient for toilet flushing at a minimum and for other washdown if possible.

At laboratory scale, Porifera's FO membrane was able to achieve 50 percent recovery at average flux of 10 lmh FO flux and 80 percent reuse at average flux of 5 lmh using a draw solution with an average of 25,000 mg/L NaCl. Photographs of the source water, resulting FO concentrate, and dilute FO draw solution are shown in Figure 20.

Figure 20: Laboratory Wastewater Samples

Picture of the Dilute draw (left), feed (left center), FO concentrate at 50 percent recovery (right center) & 80 percent recovery (right)

Source: Porifera, Inc.

Phase 2: Site Assessment, Pilot System Fabrication, and Installation

After presenting the results from Phase 1 to pilot partner staff, it was determined that the pilot would treat water from the same wastewater at the site where the samples were collected from for Phase 1. Multiple site trips were performed to confirm the available utilities at the site and to determine the optimal location.

Phase 3: Site Demonstration

The wastewater alternated between warm (30-45°C) and very warm (45-70°C) and varied with different beer products. However, the bioactive waste was typically high in both organics and yeasts. While this would normally be a significant challenge for membrane processing because temperature, water quality and osmotic pressure of the wastewater changed significantly from one run to the next, Porifera found the PFO Recycler was able to treat this waste with ease. One reason the Recycler was able to easily operate in this challenging condition is that the hot water may have helped to open sufficient flow paths for osmosis to occur, despite significant bio-growth. And while there was some observed reduction in performance in terms of water recovery, this was acceptable to the pilot partner in exchange for not having to perform maintenance (for example, membrane cleaning).

The system (Figure 21) operated intermittently on site for over 2 years with virtually no modifications or treatment process related maintenance (for example, membrane cleaning or draw salinity increases). Porifera did have to perform minor equipment replacement as needed to keep the system operational. The team ended up replacing pressure sensors or other mechanical items that stopped working and calibrating sensors. This maintenance would be necessary with any water treatment system and was not considered process specific maintenance. The data shows that recovery did initially decrease without membrane cleaning, but it eventually stabilized and was maintained without cleaning. After 2 years, the system was cleaned to assess recovery of performance.

Figure 21: Installation at Pilot Site

Pictures of the pilot being moved into site location and the mash tank where feed was pump from.

Source: Porifera, Inc.

Conductivity and odor were used to determine water quality during continuous operation and water sampling was performed to confirm suitability for reuse in toilets and miscellaneous washdown activities. Additional water quality samples were collected after the final cleaning to determine the cleaning's effective to restore performance. key operating and water quality parameters are summarized in Table 4 and Table 5.

The data in Table 5 shows excellent COD and TDS rejection even though the system had been running intermittently for over 12 months without a cleaning. One observation is that certain constituents (for example, sulfate) slowly build up in the draw over time when membrane cleaning and draw maintenance are not performed. These constituents not likely from the salt used to make the draw, but likely enter the draw slowly over time. Once these constituents enter the draw they are then rejected by FO and RO membranes until some equilibrium concentration is achieved.

Table 4: Representative Key Pilot Operating Parameters

	Feed in	Feed Reject/ Concentrate Out	Concentrate Draw to FO	Dilute Draw to RO	Permeate
Flow (gpm)	0.1-1	0.02-0.67	0.6	0.8	0.03-0.8
Water recovery (%)	N/A	N/A	N/A	N/A	33-80%
Pressure (psi)	<3	<2	<3	400-550 typical (200-800) depending on feed mS, temp. and fouling	<10
Conductivity (mS/cm)	8 average (0.8-30 depending on product)	2-20	20-50	16-45	0.07-0.7
Temperature (^oC)	15-73^oC	15-70^oC	15-71^oC	15-70^oC	16-72^oC
Energy use (Wh/gallon)	N/A	N/A	N/A	N/A	50-200 depending on feed mS, temp. and fouling

Source: Porifera Inc.

Table 5: Representative Key Pilot Operating Parameters

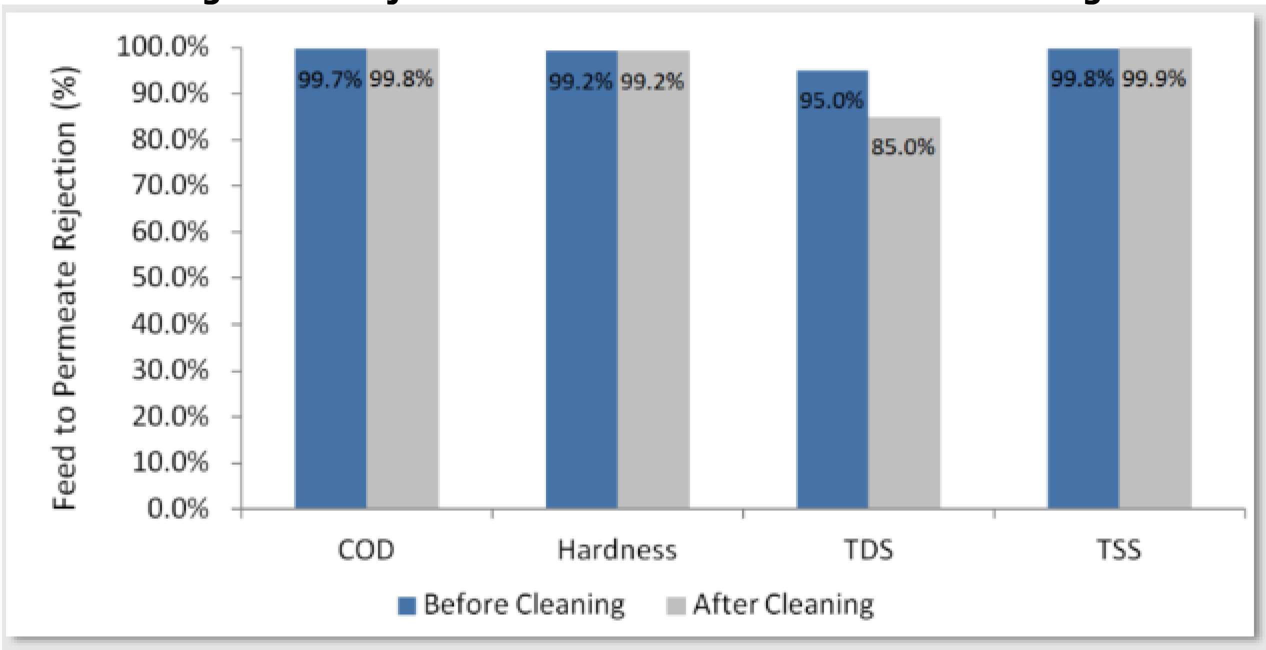
Parameter	Units	Feed	FO Reject to Sewer	Dilute Draw to RO	Pilot Permeate
COD	mg/L	BC: 20,000 AC: 15,000	BC: 25,000–60,000 AC: 24,000	BC: NM AC: 1,900	BC: 61 AC: 37
TSS	mg/L	AC: 500 AC: 700	BC: 350–1,000 AC: 750	BC: 1 AC: 2	BC: ND (<1) AC: ND (<1)
TDS	mg/L	BC: 5,000–12,900 AC: 3,700	BC: 16,000–25,000 AC: 16,500	BC: 20,000–30,000 AC: 28,000	BC: 500–700 AC: 500
Hardness	mg/L as $CaCO_3$	BC: 130 AC: 85	BC: 150–380 AC: 190	BC: 55 AC: ND (<5)	BC: ND (<5) AC: ND (<5)
Calcium	mg/L	BC: ND (<5) AC: ND (<5)	BC: ND (<5) AC: 17	BC: 15 AC: ND (<5)	BC: ND (<1) AC: ND (<1)
Magnesium	mg/L	BC: 28 AC: 21	BC: 31 AC: 35	BC: 4 AC: ND (<5)	BC: ND (<1) AC: ND (<1)
Sodium	mg/L	BC: 30 AC: 36	BC: 72–120 AC: 690	BC: 12,000–13,000 AC: 12,000	BC: 24–100 AC: 220
Sulfate	mg/L	BC: 46 AC: 36	BC: 56–80 AC: 690	BC: 2,000–2,300 AC: 12,000	BC: 60 AC: 25
pH	pH unit	BC: 4.0 AC: 3.7	BC: 4.2 AC: 3.9	BC: 4.0 AC: 3.6	AC: 3.3 BC: 3.1

Source: Porifera Inc.

The FO membranes were cleaned and the draw solution was refreshed prior to a second sampling round to determine impact of these maintenance tasks on performance and water quality. There were slight improvements and changes in terms of permeate water quality and it appeared that the sulfate concentration in the draw had not reached equilibrium levels. However, rejection of some other constituents was lower after the cleaning indicating the fouling that had built up on the FO and RO membranes had likely provided some impact on rejection as well.

Figure 22 shows rejection data from analysis immediately before and a day after the final membrane clean performed at the end of testing.

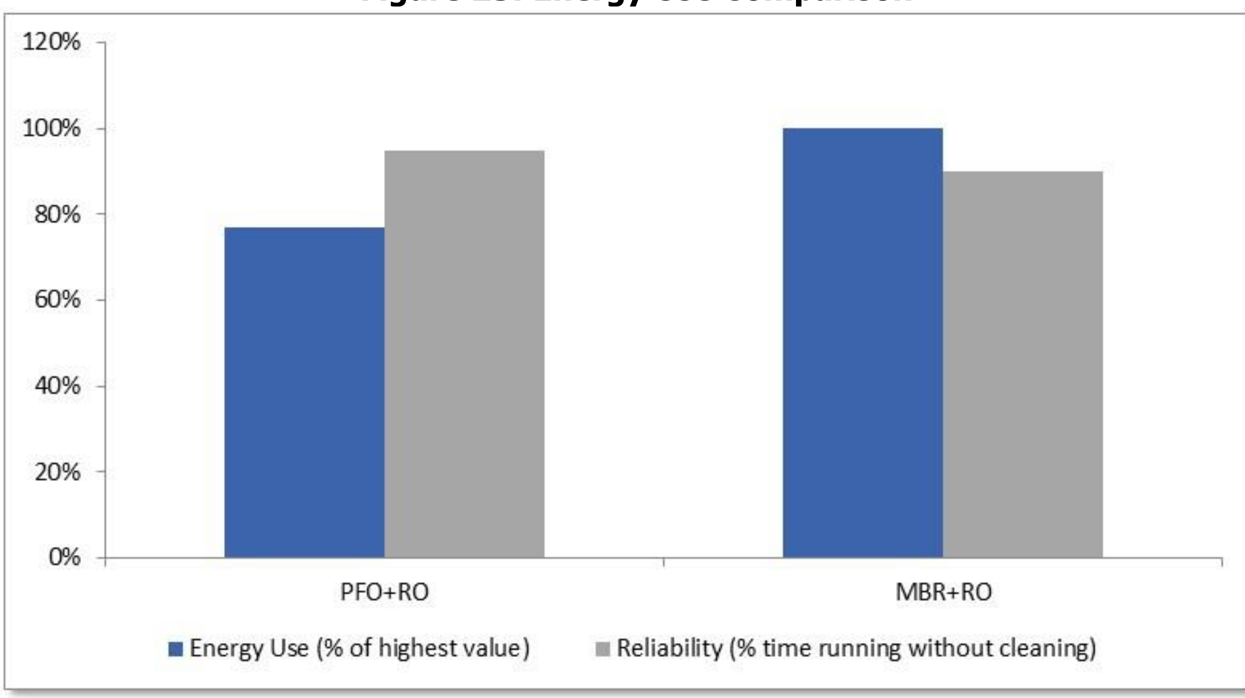
Figure 22: Rejection Before and After Membrane Cleaning



Graph of rejection of key water quality parameters before and after PFO and RO membrane cleaning

Source: Porifera Inc.

Figure 23: Energy Use Comparison



Comparison of unit energy and reliability for PFO Recycler and a competing technology

Source: Porifera Inc.

The data shows (Figure 23) that the pilot system unit average energy at 50-70 kWh/1,000 gallons when the FO and RO membranes were new operating at >70 percent recovery with an increase into the range of 80-200 kWh/1,000 gallons when the membranes were operated over 3 months without a cleaning. While these numbers are quite high, it's important to note that this system:

- Did not include an energy recovery device (ERD) on the RO system and operated at RO recoveries of <20 percent due to equipment restrictions. This recovery point is extremely inefficient without an ERD (an ERD would have decreased pilot energy use to <10 kWh/1,000 gallons) and not representative of commercial systems, which operate at a higher recovery rate or include an ERD.
- Utilized only one FO membrane and one RO membrane due to the low flow rates, which at times resulted in operating at less-than-optimal flow rates and pressures needed to minimize the energy needed primarily in the RO system.
- Operated at temperatures >60oC, which is higher than the limit for RO membranes of 45oC and likely increased the pilot energy use as described for the Phase 4 JFW pilot.

Based on these realizations and assuming that the feedwater would not be treated until the temperature dropped below 60°C, the energy use estimates for a commercial PFO Recycler system optimized for this site would be approximately 3.5 kWh/1,000 gallons operating at 70 percent recovery with cleanings every 2-3 months as recommended and between 4 and 7 at 30-60 percent recovery if the elements are not cleaned in over a year (acceptable based on data, but not recommended).

While these energy numbers are significant when looking at just the TDS, the impact of organics, temperature, and variability should not be discounted as there are few competing technologies that would be considered for these types of challenging waste streams.

The other technology considered for this site was a MBR which was estimated to be over ten times larger than a PFO Recycler in terms of footprint, which is at a premium at this site. Second, an MBR would not reject dissolved contaminants or ions for high purity reuse that the PFO Recycler would unless a RO system were added after the MBR to provide high purity water. So, an MBR+RO process would be needed for an apples-to-apples comparison. Recent estimates from the literature for a MBR process range between 2.4 and 9 kWh/kgal with higher numbers being reported in Europe with higher recoveries. It is was estimated for this analysis that an MBR+RO process that could achieve 70 percent overall recovery (assumes 85 percent recovery from MBR and 83 percent recovery from RO) for a total would need approximately 2.5 kWh/kgal for the MBR and 2.0 kWh/kgal for the RO. However, the MBR process may use more energy depending on how the process operates.

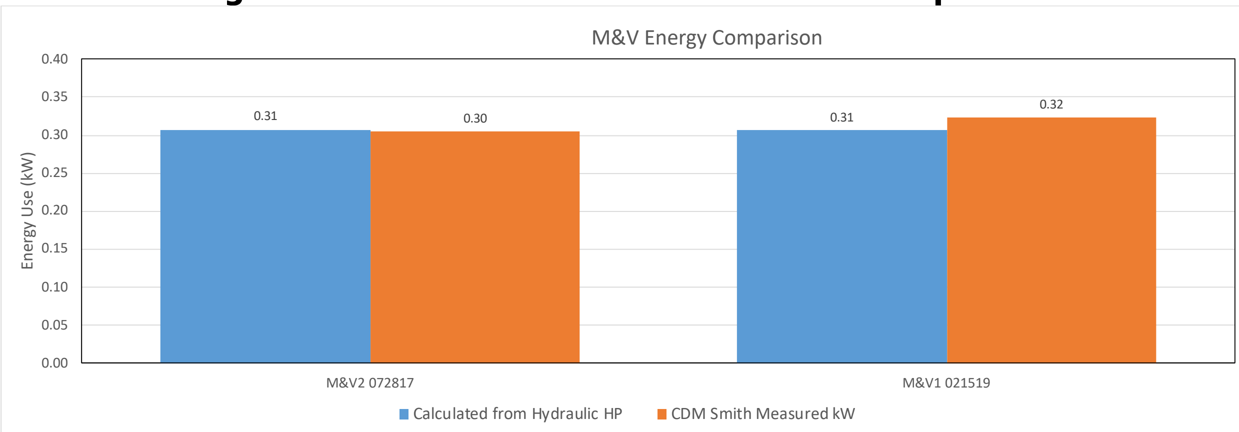
When comparing these different energy use options, this data indicates that the PFO Recycler could save 22 percent energy compared to a competing MBR+RO process at 70 percent recovery.

Summary of Independent Measurement and Verification Data

CDM Smith was the measurement and verification partner for this project and visited the site multiple times. Figure 24 compares their independent readings with Porifera's readings shown at that time via data logging.

The calculated unit energy use from the measurements was approximately 150-190 kWh/1,000 gallons using the total pilot energy numbers, which included all pumps, controls, and components that used energy in the PFO Recycler system. Again, energy use at these same conditions would have been <10 kWh/1,000 gallons if the pilot had been large enough to include common energy recovery devices. More M&V data is provided in Appendix A.

Figure 24: Measurement and Verification Comparison



Energy use verification by CDM Smith.

Source: Porifera Inc.

Commercial Scale-up Assumptions from Pilot Results

While the total wastewater flow at this site was less than 1 gallon per minute on average, there are many breweries in California and many are growing and expanding, which can stress the local municipality's ability to supply sufficient water and accept the high organics waste stream, especially in more rural areas. Based on industry experience and input from the project team, it was estimated that the average small microbrewery could utilize a 5-gpm system, while larger breweries could use a 50-100 gpm size. While their waste stream may not always be this large, there advantages to having a larger system that can process a large volume in a short period of time in terms of site logistics and in terms of operating during off-peak demand hours to reduce energy costs.

Site Test Conclusions and Recommendations

More Water with Less Energy

Overall, the pilot study results showed that this challenging and highly variable wastewater could be recycled into high purity water for reuse. It also showed that the PFO Recycler could reuse more water (70 percent) with less energy compared to MBR+RO.

Low Maintenance even without Pretreatment

A key takeaway from this demonstration was the minimal maintenance required for a wastewater application that would typically require intensive upkeep. While the system did not continue to perform at peak efficiency; the efficiency was considered sufficient for the pilot partner and was impressive from a process engineering point of view. This flexibility helps small wastewater intensive businesses like microbreweries reuse more water by alleviating concerns over maintenance, so that the end user can focus on their core business activities.

High Purity Water

The pilot data indicated excellent rejection of organics, hardness, and other key constituents that would allow onsite reuse of the water for many activities. Disinfection and polishing may be needed for sanitary use, but this is often the case with any reuse stream.

Recommendations

This technology should be recommended for additional support and demonstrations to reuse challenging and highly variable wastewaters. The fact that the system could run reliably with minimal maintenance without pretreatment or a microbiological process will be a gamechanger for industrial facilities that either cannot afford or do not have the space for an MBR.

CHAPTER 4:
Dr. Bronner's Magic Soap Water Reuse

Purpose

The purpose of the pilot project for Dr. Bronner's Magic Soap was to demonstrate energy savings, high purity water production, and other benefits associated with treating a challenging waste stream using the PFO Recycler (Figure 25). More specifically, the primary purpose was to demonstrate more water for reuse with less energy, while also reducing the volume of wastewater transported for disposal.

Figure 25: PFO Recycler Pilot System

Picture of Porifera PFO Recycler Pilot

Source: Porifera, Inc.

Cost and Energy Saving Strategies

PFO Recycler technology can reduce energy use and increase water reuse at manufacturing facilities in at least two ways. First, it can reuse more water from challenging waste streams with less energy than competing processes. Second, it can handle higher temperatures than competing membrane technologies to reduce the need of cooling and reheating water prior to reuse in boilers, which use less energy with warm water.

Goals and Objective

The primary objective of the testing was to demonstrate energy savings and water quality in way that would benefit industrial facilities throughout California.

Therefore, the goals for this pilot demonstration were to:

1. Demonstrate energy savings with a PFO Recycler by demonstrating:
    - Less energy than competing reuse options to produce similar water quality
    - Higher recovery (that is, more water for reuse) than competing reuse technologies
2. Demonstrate that PFO technology offers benefits over alternative processes:
    - Flexibility to treat highly variable source waters
    - Superior water recovery compared to other membrane processes
3. Provide an example of reducing energy needed to reuse water from challenging wastes to reduce current and future energy use in the state of California

Approach

Wastewater streams at industrial facilities can be very challenging to recycle. The primary challenges with Dr. Bronner's streams are that they contain a complex mixture of oils, surfactants, and other constituents that are very difficult to treat with membranes, biological treatment processes and evaporation. For Dr. Bronner's, the PFO Recycler system would not only reduce the volume of wastewater but also generate a stream of clean water for reuse. With Dr. Bronner's commitment to manufacturing their product as sustainably as possible, onsite water reuse using less energy is a high priority.

There were numerous waste streams at this facility and the approach was to work collaboratively with the pilot partner to identify representative streams for piloting. Dr. Bronner's identified three potential waste streams for reuse with the intent of reducing the waste volume and generating clean water.

After the feeds were selected, the approach was to first perform laboratory tests to understand treatment requirements and set water recovery goals based on estimated osmotic pressure, fouling potential, and other characteristics of water streams.

Unfortunately, pilot testing started much later than anticipated due delays resulting from contracting and site construction. Therefore, the plan had to be modified at multiple points to generate data useful to the pilot partner, Porifera, and to fulfill the goals of the grant funding. This included performing additional tests at the Porifera facility. The testing at Porifera's facility was performed with an energy efficient system with improved flow controls that was representative of a commercial system for this feed water.

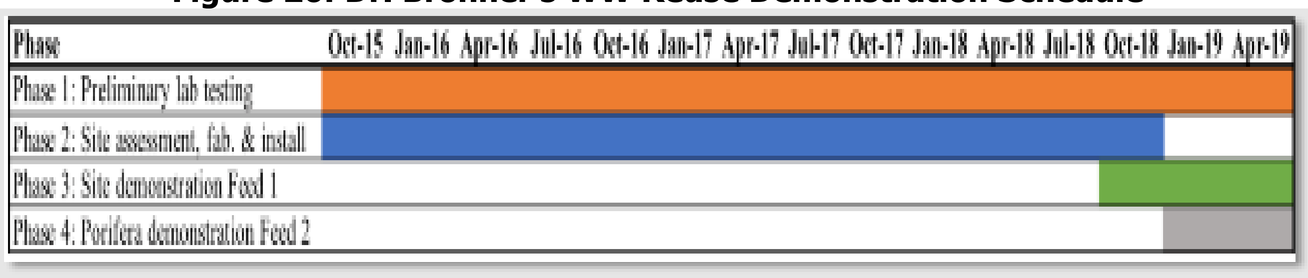
The following sections summarize this approach in more detail including the test phases, location, equipment used, and key changes in equipment or approach as the project progressed.

Test Phases and Schedule

The testing occurred in the following phases (Figure 26):

1. Phase 1: Preliminary lab testing, 09/01/2015 – 03/31/2019
2. Phase 2: Site assessment, pilot system fabrication, and installation, 09/01/2015 – 12/31/2018
3. Phase 3: Site demonstration on wastewater feed, 12/01/2018 – 03/31/2019
4. Phase 4: Porifera facility demonstration on wastewater feed, 02/01/2019 – 03/31/2019

Figure 26: Dr. Bronner's WW Reuse Demonstration Schedule



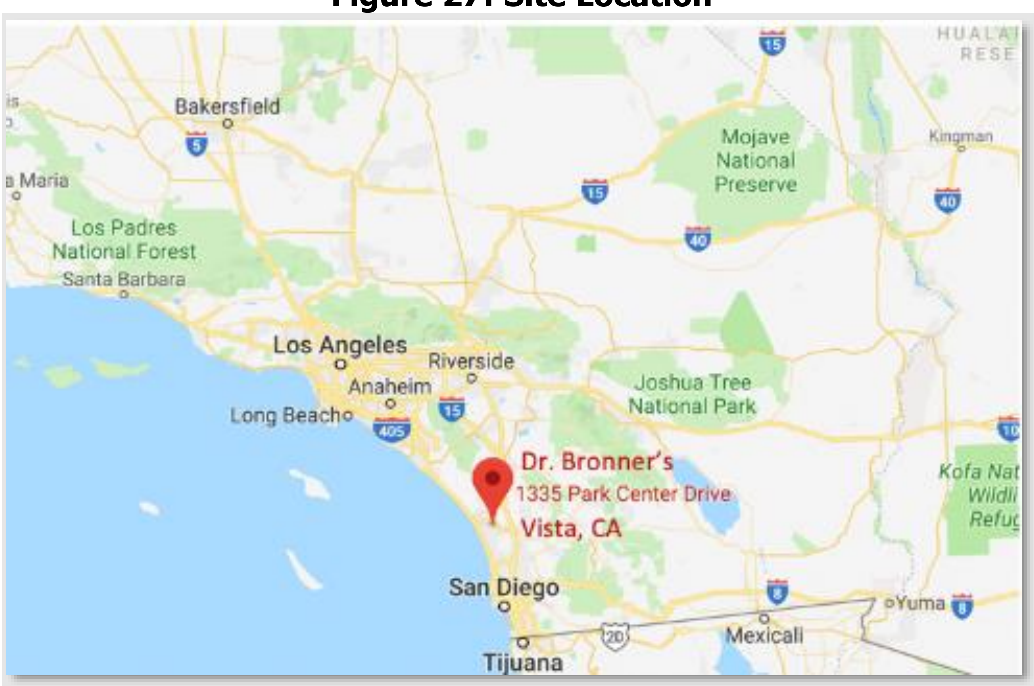
Demonstration Schedule for pilot at Dr. Bronner's facility.

Source: Porifera Inc.

Location: Dr. Bronner's Magic Soaps, Vista, California

The testing occurred at two main locations. The first location was Porifera's laboratory where preliminary laboratory testing, equipment design and manufacture occurred. The second location was the Dr. Bronner's manufacturing facility located in Vista, California (Figure 27).

Figure 27: Site Location



Map of Dr. Bronner's Site

Source: Google Maps

Equipment and Materials

The equipment and materials used for testing was different for each phase of the test and is summarized in the following subsections. The main components needed for testing were as follows:

- PFO laboratory scale and pilot-scale test system at Porifera lab
- Final mixed wastewater in totes (that is, waste stream selected by pilot partner)
- Feed water pumps and supply systems
- Draw solution: glycerol based
- FO+RO system 1 with 80- and 120-micron pre-strainers
- FO+RO system 2 with 120-micron pre-strainer
- Miscellaneous cleaning chemicals
- Miscellaneous piping, electrical, and containment work to install and operate pilot
- Sample containers suitable for water quality testing

The test equipment, treatment process, and site modifications were designed, installed and operated by Porifera, the feed solution was provided by the pilot partner, and draw solution and other chemicals were supplied by Porifera.

Phase 1: Preliminary Laboratory Testing

Initial tests were performed using Porifera's custom laboratory membrane coupon test setup. Then additional tests were performed using Porifera's larger laboratory-scale custom membrane element test setup shown in Figure 28.

Figure 28: Proprietary Forward Osmosis Element Testing

Photographs of a preliminary testing on Feed 1 (left) and the element being testing (right)

Source: Porifera, Inc.

Phases 2 and 3

Following the preliminary lab tests, Porifera designed and constructed the PFO Recycler 1 pilot system. This system was designed to have an extremely small footprint to fit within a small space at the facility. PFO Recycler 1 treated water from both Feed 1 and Feed 2.

The PFO Recycler 1 pilot was configured to run on:

- FO: 1-2 PFO-100 elements (7 m^2 per element).
- RO: one 2.5-inch diameter by 40-inch-long Dow SW element (2540)
- Draw storage tank and dose tank
- Feed, concentrate, and permeate totes
- Glycerol draw solution

A unique aspect of this pilot system was that it was designed to operate with a non-salt draw solution. This was selected based on performance during the lab-scale tests and to also mitigate water quality concerns for Dr. Bronner's manufacturing process. Pictures of PFO Recycler 1 at the site are shown in Figure 29.

Figure 29: Proprietary Forward Osmosis Recycler Pilot Systems 1 at Dr. Bronner Site

Pictures of the PFO Recycler 1 Skid

Source: Porifera, Inc.

Phase 4

Flow rates and water quality at the site were different than originally anticipated and multiple modifications were made to the PFO Recycler 1 to attain useful and representative data. However, there was still some uncertainty in terms of both energy use, water quality, and fouling rates due to low flow considerations that were of concern to the pilot partner and Porifera.

Therefore, a second PFO Recycler was tested at Porifera's facility to incorporate lessons learned from Phase 3, operate at commercial scale design parameters, and to answer the outstanding questions of the project team. Feed 2 (275 gallons) was shipped to Porifera's facility for a multiple day test and a 120-micron pre-strainer was also used. A picture of PFO Recycler 2 is shown in Figure 30. Feed 2 was tested at Porifera because there was insufficient space at the site due to ongoing construction activities.

The PFO Recycler 2 pilot was configured to run on:

- FO: one or two PFO9S modules with 9 PFO-100 elements each (63 m^2 per module).
- RO: up to ten 2.5-inch diameter by 40-inch-long Dow SW elements (2540's)
- Tank design: no feed tank was used, but did include draw storage and dose tanks
- Glycerol draw

Figure 30: Proprietary Forward Osmosis Recycler Pilot Systems 2 at Porifera

Pictures of the PFO Recycler 2 Skid

Source: Porifera, Inc.

Project Data and Results

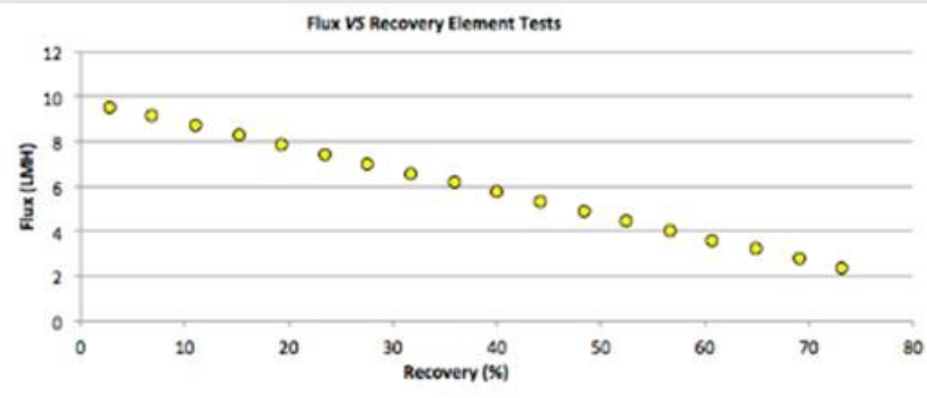
This section includes a summary of the data and results for each test and phase of the project.

Phase 1: Preliminary Laboratory Testing

Laboratory coupon and element tests were performed on Feed 1 to evaluate the customer's wastewater and design an optimal solution for this site. Dr. Bronner's was interested in maximizing recovery and evaluating reusing the water for either industrial use, irrigation, or both.

At laboratory scale, Porifera's FO membrane was able to achieve approximately 80 percent recovery at an average flux rate of 4 lmh. Both salt and glycerol-based draw solutions were evaluated and glycerol was identified as the preferred draw at the site due to its similarity to ingredients already present at the site. A graph showing flux vs. recovery data and pictures of the source water and resulting FO concentrate are shown in Figure 31.

Figure 31: Laboratory Wastewater Samples



Data graph and picture of the samples including the waste stream feeds and resulting concentrate.

Source: Porifera, Inc.

Phase 2: Site Assessment, Pilot System Fabrication, and Installation

After presenting the results from Phase 1 to pilot partner staff, it was determined that the pilot would treat the wastewater tested in Phase 1. The site was assessed to determine the and the utilities, location, space allotments, and other factors necessary to install the pilot. The pilot system was then designed and fabricated at Porifera. Initial I/O (Input/Output) and leak checks were performed to validate the system operations. It was then packaged and transported to the site in a trailer. The site was prepared by Dr. Bronner's with the required inputs for the system ready upon the system's arrival. Installation was performed with flushing and initial water testing.

Phase 3: Site Demonstration (Feeds 1 and 2)

The feeds were brought to the pilot in individual totes for testing. The pilot was configured to perform with a minimal flow rate to maintain a feasible tote replacement period. Two other totes were located next to the pilot to store the FO reject and FO permeate streams.

During Phase 3, testing began on Feed 1 and there were multiple modifications to the pilot treatment process to optimize and improve the treatment process. First, the system frequently shutdown on nuisance alarms because 1) the 80-micron pre-strainer would rapidly foul with solids that looked like coconut oils and 2) air would enter the feed supply line from bubble formation in the tanks (Figure 32). The team increased the strainer mesh size to 120 micron and piping was modified so that any flow into tanks and totes occurred in a submersed manner (that is, liquids entered below the water line instead of splashing into the tank which created bubbles).

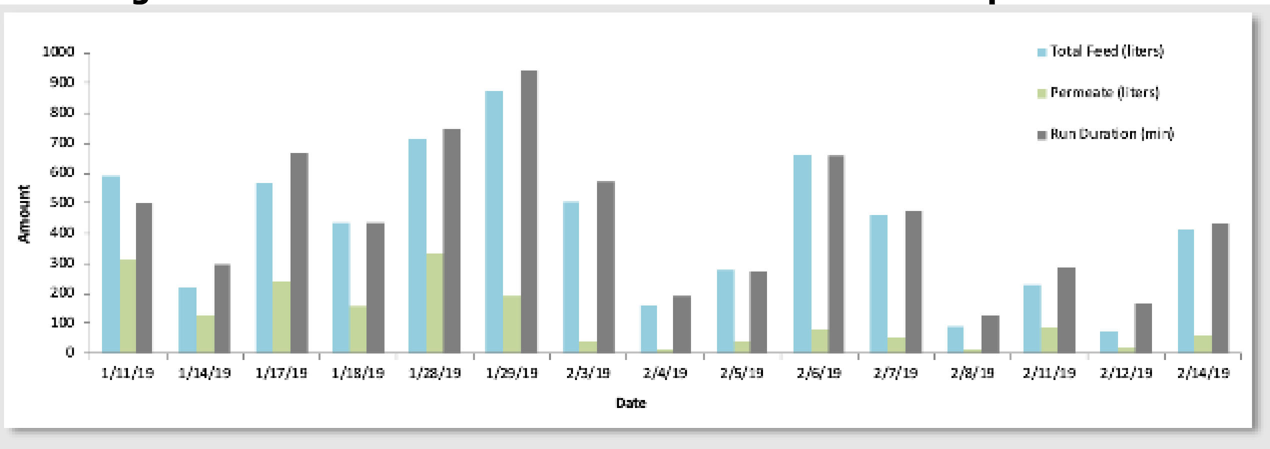
Figure 32: Proprietary Forward Osmosis Recycler Pilot Systems 1 and 2

Photographs of the foamy Feed 1 (left) and the strainer (right) clogged with organics.

Source: Porifera, Inc.

While these changes addressed nuisance alarms, the next hurdle was the congealing and precipitation of solids in the feed tank, pipes, pumps, and FO elements. As shown in Figure 33 and Figure 34 the initial water recovery was over 60 percent but began to drop over days. The tanks, pipes, and FO elements were cleaned (shown in upticks in recovery); however, element autopsies indicated that oil and grease type solids were precipitating and getting stuck in the element spacers.

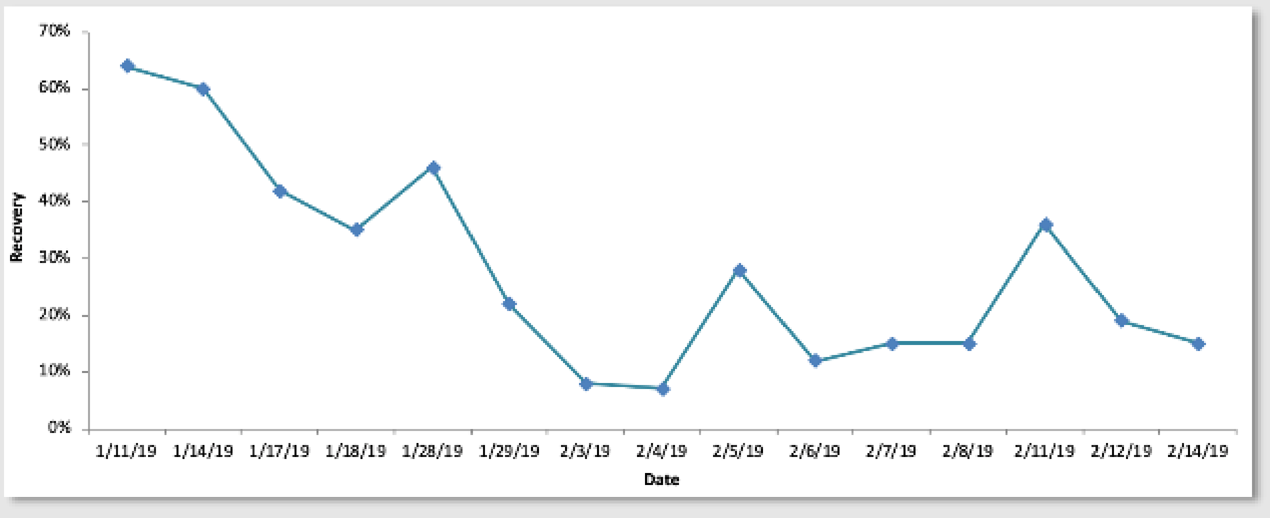
Figure 33: Total Feed and Permeate Volumes Prior to Optimization



Total feed and permeate volumes prior to optimization.

Source: Porifera Inc.

Figure 34: Proprietary Forward Osmosis Recycler 1 Recovery Prior to Optimization



System recovery prior to optimization.

Source: Porifera Inc.

New FO elements were installed and the feed was switched to Feed 2 during the remainder of February; however, performance did not improve to acceptable values.

Therefore, troubleshooting efforts were performed during to assess if there were pretreatment or other solutions that could improve recovery. Multiple different types of pre-filters were evaluated but would clog more quickly than the FO elements and were difficult to clean. Chemical options evaluated included dispersants and alternative cleaning chemicals, which indicated that the cleaning pH should be above 11.5 to regain performance of the FO membrane. Also, the TSS of Feeds 1 and 2 was evaluated and it was determined that Feed 2 could improve PFO Recycler performance because it had slightly reduced suspended solids that could aggregate increase clogging during concentration.

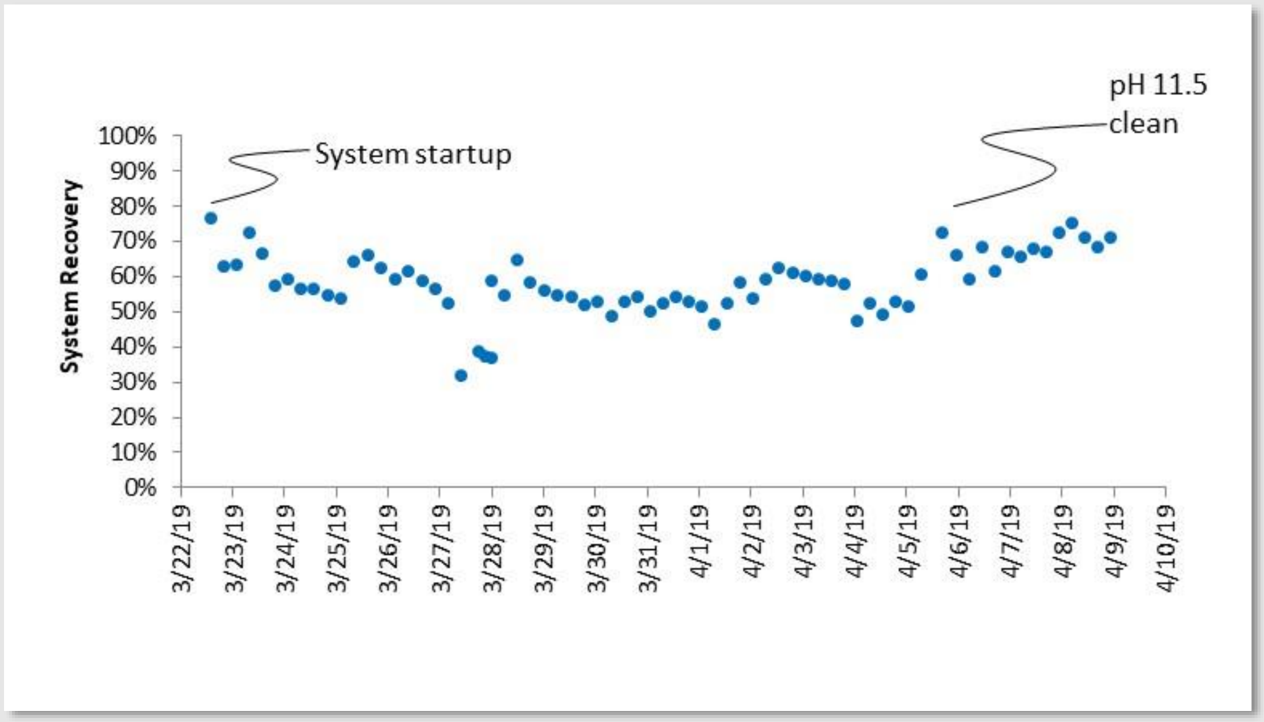
The approach that worked the best was a combination of the following adjustments:

1. Installing a spacerless element instead of spacered element.
2. Increasing the flow rate inside the element using enhanced circulation.

3. Mixing the permeate and reject back into the feed tank overnight so the system did not stop and allow the feedwater to become stagnant.
4. Feed 2 was used as the feed during the remainder of testing.

Implementing these changes increased cleaning periods from once every 2-5 days to once every 2-4 weeks to maintain a water recovery of over 60 percent as shown in Figure 35. More detail on these different periods is summarized below and the key operating and water quality parameters are summarized in Tables 6 and 7.

Figure 35: Proprietary Forward Osmosis Recycler 1 Recovery Post Optimization



System recovery after optimization.

Source: Porifera Inc.

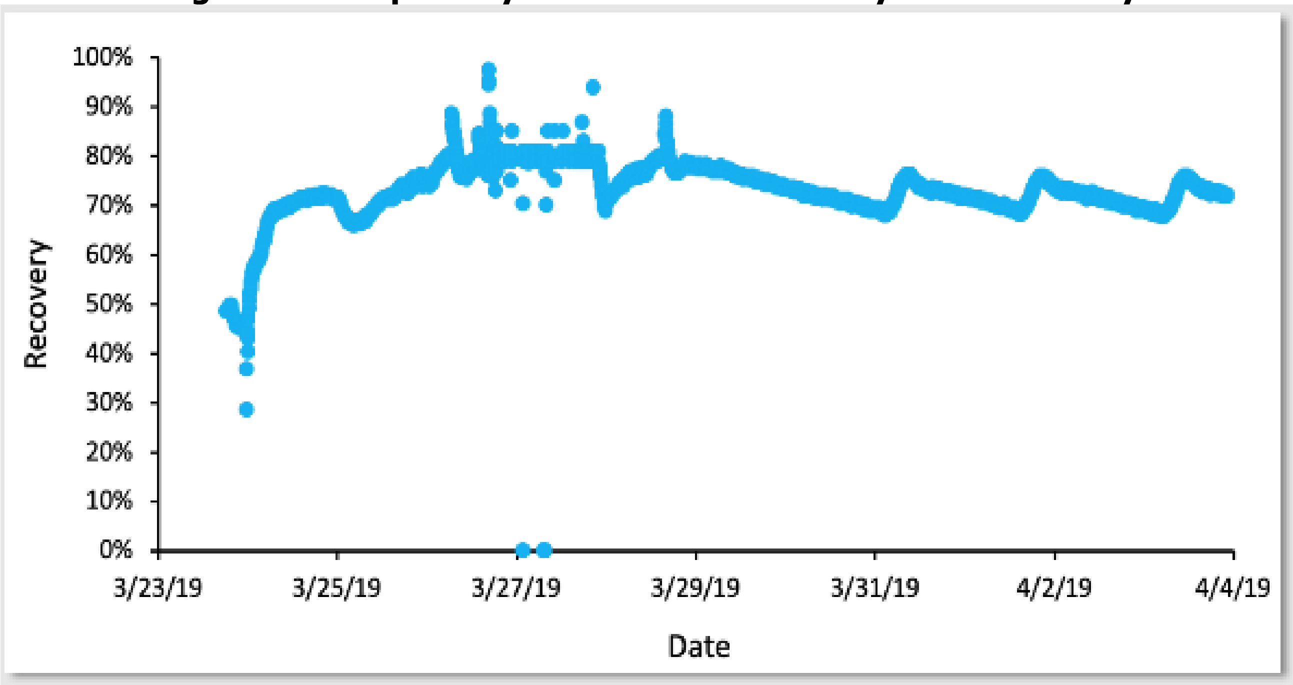
Phase 4: Site Demonstration on Tank Building Wastewater (Feed 2 only)

Additional testing was performed at Porifera's facility with Feed 2. The PFO Recycler 2, a larger and more efficient Recycler system, treated this wastewater during a two-week trial. The system produced a very high quality permeate (<60 mg/L TDS) with significantly reduced energy consumption (<14.1 kWh/1,000 gallons of permeate) compared to the smaller PFO Recycler 1 system (~40 kWh/1,000 gallons) that did not operate at efficient design points, did not include an energy recovery device (ERD) on the RO pump (the flow rates were too small for a ERD), and did not allow for flow controls and velocities needed to improve performance with this type of feedwater that wanted to congeal and precipitate at low velocities. The permeate and reject streams were mixed back together into the feed for a week and then the feed was changed to a new tote.

Figure 36 shows the improved water recovery (70-80 percent) during Phase 4 and without any cleaning. The draw concentration was modified to increase or maintain recovery and you can see the draw dosing create a small uptick in recovery creating a sawtooth pattern.

Key operating and water quality parameters are summarized in Table 6 and Table 7.

Figure 36: Proprietary Forward Osmosis Recycler 2 Recovery



Optimized System Recovery

Source: Porifera Inc.

Table 6: Representative Key Pilot Operating Parameters for Phases 3 & 4

	Feed in	Feed Reject/ Concentrate Out	Concen-trate Draw to FO	Dilute Draw to RO	Permeate
Flow (gpm)	P3: 0.11 P4: 1.43	P3: 0.033–0.043 P4: 0.33–0.43	P3: 0.06 P4: 1.0	P3: 1.3 P4: 2.0	P3: 0.067–0.077 P4: 1.0-1.1
Water recovery (%)	N/A	N/A	N/A	N/A	P3: 60–70% P4: 70–77%
Pressure (psi)	P3: 3-6 P4: 8	P3: <3 P4: <3	P3: <4 P4: <6	P3: 400–800 P4: 400–800	P3: <10 P4: <10
Temperature (°C)	P3: 22°C P4: 19.5°C	P3: NM P4: NM	P3: NM P4: NM	P3: 35°C P4: 21°C	P3: 35°C P4: 21°C
Energy use (Wh/gallon)	N/A	N/A	N/A	N/A	P3: 40 P4: 10–14

Source: Porifera Inc.

Table 7: Summary of Key Pilot Water Quality Analysis Data for Phases 3 & 4

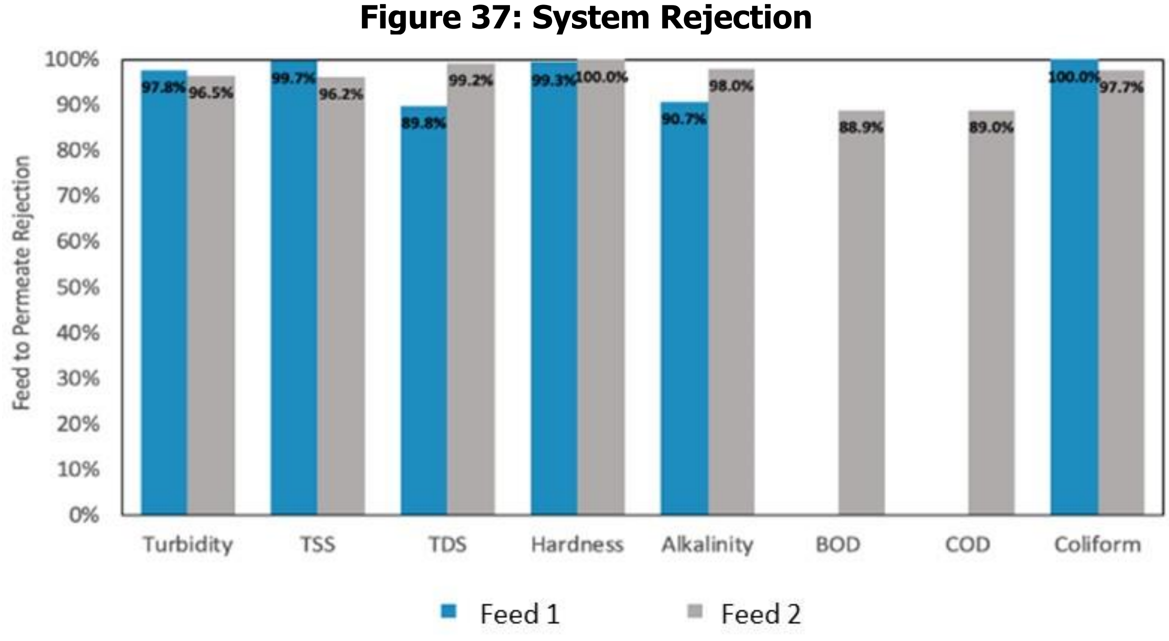
Parameter	Units	P3: Feed 1 P4: Feed 2	Pilot Permeate
BOD	mg/L	P3: 3,500 P4: 3,600	P3: — P4: 400
COD	mg/L	P3: 9,000 P4: 6,900	P3: — P4: 760
TSS	mg/L	P3: 300 P4: 2.6	P3: ND (<1.0) P4: ND (<0.1)
Turbidity	NTU	P3: 58 P4: 2.8	P3: 1.3 P4: 0.1
TDS	mg/L	P3: 4,500 P4: 7,400	P3: 460 P4: 59
Hardness	mg/L as $CaCO_3$	P3: 720 P4: 1500	P3: ND (<5) P4: 0.2
Alkalinity	mg/L as $CaCO_3$	P3: 270 P4: 325	P3: ND (<25) P4: 6.6
pH	pH Units	P3: 9.0 P4:6.8	P3: 7.7 P4: 5.3
Total Coliform*	MPN/100 mL	(proprietary)	(proprietary)

Notes: P3: feed 1, P4: feed 2, ND – not detected above the detection limit, *not a sanitary system and no disinfectants used

Source: Porifera Inc.

Figure 37 shows excellent rejection of key water quality constituents from analysis.

Figure 37: System Rejection



System Rejection

Source: Porifera Inc.

The data shows that the PFO Recycler Pilot 1 system unit energy at 70 percent recovery was approximately 395 kWh/1,000 gallons on Feed 2 post-modifications. PFO Recycler Pilot 2, the unit energy use was approximately 13-14 kWh/1,000 gallons at 70 percent recovery and 14-15 kWh/1,000 gallons at 80 percent recovery based on data-logged values that recorded energy use on the pilot. However, this data may be higher than actual because estimates based on hydraulic horsepower were 12-13 kWh /1,000 gallons at 70 percent recovery and CDM Smith recorded lower numbers of 10-12 kWh/1,000 gallons at 70 percent recovery when measuring real-time watts used by the treatment process.

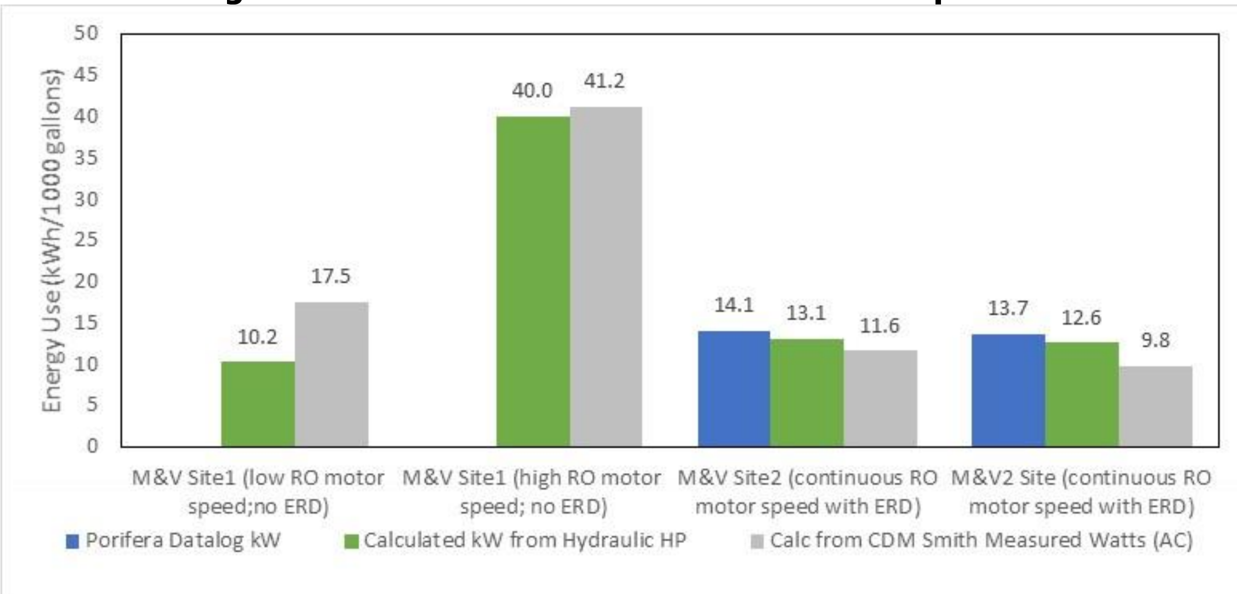
Comparing energy use for this project to other alternatives is difficult due to the nature of the organics in the water. CDM Smith did not recommend typical MF+RO or MBR+RO reuse options for this water due to the surfactants and oils present. Porifera staff contacted a couple of evaporator companies to assess suitability for this project and it was mentioned that this would be a very difficult project to implement due to the extremely small space constraints and water quality. The type of evaporator suggested would use more than 200 kWh equivalent per 1,000 gallons of water reused. Even if the evaporator were able to increase recovery, it would still be expected to use more than 10 times more kWh/1,000 gallons than the PFO Recycler.

Summary of Independent Measurement and Verification Data

CDM Smith was the measurement and verification (M&V) partner for this project and visited the site and Porifera's facility to perform M&V measurements. The graph below compares their independent readings with Porifera's readings shown at that time on the touchscreen, which is the same data used for data logging and creating data graphs shown in this section and the Appendix.

The calculated unit energy use from M&V measurements (Figure 38) was approximately 41 kWh/1,000 gallons for PFO Recycler 1 at the site and 10-12 kWh/1,000 gallons for the PFO Recycler 2 at Porifera using the total pilot energy numbers, which included pumps, controls, and components that used energy in the PFO Recycler system. More details are provided in Appendix A.

Figure 38: Measurement and Verification Comparison



Measurement and verification comparison between Porifera data log, calculation and CDM Smith verification.

Source: Porifera Inc.

Commercial Scale-Up Assumptions from Pilot Results

The Dr. Bronner's site generated approximately (proprietary) gallons per day of wastewater and pilot data showed that 70 percent could be reused with a 2- to 3-week cleaning interval. However, this total will increase once current facility upgrades are completed. The assumed system size for the site would be approximately 1-2 gpm of permeate, which is the size of the PFO Recycler 2 used for this project. This size system could fit at the site post-construction.

Site Test Conclusions and Recommendations

More Water with Less Energy

Overall, the pilot study results showed that this challenging waste stream could be recycled into high purity water for reuse. It also showed that the PFO Recycler could reuse more water than other membrane systems and use 10 times less energy than an evaporator. Due to space constraints, the PFO Recycler is likely the only technology considered that could reliably reuse water at this site.

High-Velocity, Spacerless Elements, and High pH Cleaning Chemistry Needed

The pilot study data indicated that the pilot operated sustainably on this source water after installing upgrading the system to operate at high velocity to keep solids suspended, with spacerless elements to reduce clogging of the flow channels, and that higher pH cleanings were key to restore membrane performance.

Energy Use

The pilot data indicates that the PFO Recycler could save on the order of 90 percent energy compared to evaporators and would reduce CO_2 emissions compared to the current trucking used to dispose of the waste.

Recommendations

These results and lessons learned are promising for future reuse of high COD, oily and surfactant laden wastes. Commercial scale demonstration is recommended to demonstrate possibilities for reuse where reuse was not previously considered a realistic option.

CHAPTER 5: Path to Commercialization

Production Readiness Summary

The goal of this project was to clearly demonstrate the benefits of the PFO Recycler technology at industrial scale and accelerate its adoption across California while saving energy and reusing more water. The PFO Recycler is an energy efficient FO+RO system that generates purified water for reuse while concentrating the feed water. When designed and implemented correctly, the PFO Recycler will save customers' energy and money and produce significant amounts of excellent quality water for reuse.

While the PFO Recycler technology had already been developed, patent protected, and used for small commercial demonstrations, there was insufficient nonconfidential pilot-scale or commercial data demonstrating the technology's effectiveness to grow demand. Furthermore, the FO market at the time of this project award was virtually non-existent with insufficient demand to drive technology growth or investment in scaling up manufacturing to reduce cost.

With the support of this project, Porifera was able to demonstrate the FO-based technology innovations to reduce energy and maximize value while also increasing manufacturing capabilities, reducing manufacturing costs, improving system designs, and integrating lessons learned into design and control protocols. As a result, the technology demonstrated in this project is sufficiently ready to be scaled up and sold to early adopters for commercial use.

The key component of the PFO Recycler System is the high specific flux PFO element, which is manufactured in Hayward, California. Early in the project, the team was able to improve efficiency of manufacturing PFO elements while decreasing costs. This was accomplished by improving automation to increase production speed and reduce defects. Direct project results were a reduction in assembly time of roughly of 11 times per element and an element cost reduction of 86 percent. Achieving faster and cheaper PFO element production through automation will help accelerate commercialization and capabilities to meet growing market demand.

The PFO elements and remaining components are integrated into plug-and-play type PFO Recycler systems, which require minimal site modifications to integrate into existing facilities. Multiple pilot systems were designed and demonstrated for a variety of feeds and site conditions during this project. Key design modifications and lessons learned related to design, operation, and controls have already been included in the design of commercial systems.

Note: While useful pilot operation data was obtained and goals were demonstrated, no patentable inventions were conceived or reduced to practice during the project term.

Next Steps

The project allowed Porifera to demonstrate the technology at three customer's sites. The sites included water from a winery, a craft brewery, and a soap manufacturing facility. The operational data and independent measurement and verification data from these pilots is not confidential and will be used to create case studies, presentations and other marketing materials that will allow market professionals and customers to assess the technology for their needs and to promote future adoption of the technology.

Other steps include performing additional pilot and demonstration tests at customer sites, selling and installing commercial systems to grow our installation list, and continuing to invest in manufacturing to reduce the price of our core products, FO membrane element and module. Commercial interest indicates that the PFO Recycler can provide benefits in terms of organics removal, reduced maintenance, and low energy; however, cost reduction is a key driver in being able to compete for all potential water reuse opportunities that are a good fit for this technology.

CHAPTER 6: Technology and Market Transfer Activities

The scope of this project included the development of a technology transfer plan and technology transfer activities.

Technology Transfer Plan Summary

The goal of the knowledge and technology transfer plan was to disseminate the knowledge gained, experimental results and lessons learned available to policymakers and industry decision-makers. For this solution to have a significant impact on California's industrial energy use, the technology needs to be publicized because without the knowledge transfer component, the benefits of this technology cannot be realized. The findings of the demonstrations should be made available to advance and promote the adoption of new technology.

Understanding the technical feasibility of process integration and potential value to the industry is crucial to initiate adoption of the technology. Until recently, forward osmosis has had limited use in food and beverage processing. This is because FO membranes did not perform well, making them economically unattractive. Porifera's technological breakthroughs in membrane development and system design demonstrated in these projects will introduce FO technology into the mainstream. These innovations allow significant energy savings, the potential for onsite water reuse, and reduction in system size and infrastructure requirements.

This plan encompasses a multipronged approach to share the results and to lay the groundwork for widespread adoption that included passive and active information sharing activities which have been made available to all stakeholder groups.

Target Market

The primary beneficiaries of forward osmosis concentration technology are manufacturers that currently experience water scarcity issues. California's industrial users face increasing water scarcity and energy demands. California is still unseasonably dry and the state continues to face "moderate drought" to "severe drought" conditions. According to the California Energy Commission's third assessment on climate change (Moser, 2012), water scarcity is projected to get worse. Adequate allocation of resources, combined with the adoption of innovative technologies, and judicious adoption of environmental regulation are recommended in the report for efficient management of water-energy resources.

Porifera's technology allows for cost-effective onsite reuse of waste streams that are energy intensive and therefore expensive to treat with current technologies. Affordable water reuse is a pain-point for industrial users including food and beverage manufacturers, especially in water-stressed areas like Southern and Central California. Their waste disposal costs are rising, and their water sourcing expenses are increasing. Manufacturers are looking for solutions that will offset these rising costs and allow them to remain market competitive.

These demonstrations have allowed Porifera to developments that bring forward osmosis technology closer to commercialization.

This market need is global, and large enough to provide a rewarding opportunity for the growth of forward osmosis technology over the long-term.

To gain acceptance into the marketplace, it is imperative to share the successes at commercial sites that validate the PFO Recycler's capabilities across the industry. Demonstrations occurred at sites with recognized brand cachet within their industry. This makes them become marketing "influencers" for their peer group and increases the likelihood of technology adoption amongst their peers. These installations are an invaluable reference base for demonstrated energy savings and water reuse.

Industry Influencers

CDM Smith, a "technology-neutral" engineering firm, served as the measurement and verification partner on this project. CDM Smith has qualified personnel that have assisted companies in evaluating advanced technologies for product processing, water reuse, and other industrial uses.

Porifera has also engaged with several influential industry associations including the International Food Technologists (IFT), California League of Food Processors (CLFP), and the Food Processing Suppliers Association (FPSA) to provide education on the potential of forward osmosis for California's industry.

Technology Transfer Activities

The technology transfer activities performed during this project were passive and active in nature and are summarized in the sections below.

Passive Information Sharing

Outreach and educational tools and materials have been designed to increase the speed and penetration of innovative energy efficient technologies into the marketplace. Porifera has and plans to continue to publish papers and articles in industry trade publications to inform the industry on the cost-savings associated with forward osmosis technology implementation.

Porifera has also revamped the company website for the purpose of providing information and benefits that are being realized by the demonstration of the technology into various markets. Porifera's website provides a location to post case studies and product specification documents for access by target audiences from the various market sectors. The site includes sections specific to several different markets to which the technology is applicable as well as case studies and specifications of systems and products.

The pilot demonstrations funded under this project provide an invaluable reference base for data on energy savings and increased water reuse. The case studies developed from these demonstrations provide manufacturers with information crucial for implementation of the technology and benefits to the market. Manufacturers value this helpful "third-party" perspective. Case studies are available to the public, policy makers and industry professionals regarding the status and effectiveness of the projects.

Active Information Sharing

Porifera has participated in several industry showcases, presentations and exhibits to expand the sphere of outreach to additional industry professionals. Below are some key information sharing mediums where the results and lessons learned from this project were and will be presented:

Completed Passive Information Sharing Activities

- Publication: IFT Magazine Article: Advantages and Applications of Forward Osmosis, March 2017.
- Publication: CSIRO Website: Forward Osmosis for the Food Industry, 2017.

Links to these and future publications are available at https://www.porifera.com/news-events.

Completed Active Information Sharing Activities

- Oral presentation: EPIC Symposium: Sacramento, California, February 2017
- Booth exhibit: California League of Food Processors: Sacramento, California, February 2018
- Booth exhibit: Institute of Food Technologists Conference: Chicago, IL, June 2018
- Oral presentation: International Water Association: 2017
- Booth exhibit: California League of Food Processors: Sacramento, California, February 2019
- Oral presentation: EPIC Symposium: Sacramento, California, February 2019
- Oral presentation: California WateReuse Symposium: Garden Grove, California, March 2019
- Booth exhibit: Institute of Food Technologists Conference: New Orleans, LA, June 2019
- Oral presentation: Membrane Technology Forum: Minneapolis, MN, June 2019

Porifera plans to continue outreach efforts to share project results and discuss future potential opportunities.

Planned Activities

Planned Passive Information Sharing Activities

- Case study: Water Reuse at Jackson Family Wines: Porifera website, industry trade publications
- Case study: Wastewater Reuse at Ale Industries: Porifera website, industry trade publications
- Case study: Wastewater Reuse at Dr. Bronner's: Porifera website, industry trade publications
- Press release on project results: News distribution websites, industry trade publications
- Article: Project description and results: FO Tech website for industry professionals

CHAPTER 7: Conclusions and Recommendations

Conclusions

Porifera's PFO Recycler technology was demonstrated in three distinct and representative California industries. In each case, the demonstration was tailored to showcase the capability of the technology for the customer and to also measure the energy savings and potential benefits to the state of California.

In general, the results indicated that sodium chloride draw solution would be the cheapest option when implementing PFO Recycler technology for their application. However, it was noted for the Jackson Family Wine application that using a magnesium chloride draw solution would be preferred when using the water for irrigation since the magnesium in the reuse water would be more beneficial to the soil than sodium.

Winery Wastewater Reuse

The pilot results at JFW demonstrated 50-90 percent reuse depending on the request of the customer. The results showed that the pilot system could continue to produce high quality water even with extreme variation in the organics loading, temperature and other water quality parameters that are typically too difficult for conventional and other advanced treatment system to handle.

The data also indicated that the PFO Recycler provided the following:

- **Excellent rejection suitable for boiler feed reuse**. Draw solution pH adjustment or polishing is necessary to increase COD rejection by the RO step during COD spikes in the feed to always attain boiler feed quality.
- **Reuse warm water to reduce heating when used as boiler feed water**. The pilot produced excellent water quality even at temperatures between 60 and 85^{o}C. Reusing this warm water would require significantly less heating than heating ambient temperature City water or local groundwater. Operating at these warm temperatures did decrease the energy efficiency of the RO membranes as expected indicating that letting the water cool to lower than 65^{o}C would be preferred depending on RO pressure at the time.
- **Reuse of high organics water that typically require biological treatment** by using biocides to keep rapid biofouling from clogging the membranes, pumps and piping.
- **Sustainable, low maintenance operation** with acceptable cleaning intervals with the appropriate pretreatment, which depends on the source of the water.
- **Energy savings** on the order of 20 percent energy at 70 percent water recovery and 40 percent energy at 90 percent water recovery.
- **Space savings** on the order 2-5 times smaller footprint compared to MBR systems.

Brewery Wastewater Reuse

The pilot results at Ale Industries demonstrated 30-80 percent water reuse depending on the beer being made and the level of cleaning maintenance being performed. The results showed that the pilot system could continue to produce high quality water even when the membranes were not cleaned over a year and had exceeded recommended cleaning triggers after 3 months. This indicated that the system could produce excellent water quality with little to no maintenance and with only a minimal unit energy increase if that is an important selling point to the end use.

The data also indicated that the PFO Recycler provided the following:

- **Excellent rejection suitable for boiler feed reuse**. Draw solution pH adjustment or polishing is necessary to increase COD rejection by the RO step during COD spikes in the feed to always attain boiler feed quality.
- **Reuse warm water to reduce heating when used as boiler feed water**. The pilot produced excellent water quality even at temperatures up to 70^{o}C. Reusing this warm water would require significantly less heating than heating ambient temperature City water or local groundwater. Operating at these warm temperatures did decrease the energy efficiency of the RO membranes as expected indicating that letting the water cool to lower than 65^{o}C would be preferred depending on RO pressure at the time.
- **Reuse of high organics water that typically require biological treatment** without the use of pretreatment (other than a coarse screen) or biocides.
- **Sustainable, low maintenance operation even when not cleaned as recommended.**
- **Energy savings** on the order of 22 percent energy at 70 percent water recovery.

Industrial High Chemical Oxygen Demand (Oils and Surfactants) Wastewater Reuse

The pilot results at Dr. Bronner's demonstrated >70 percent water reuse once the process was optimized and the proper cleaning and maintenance regimen was implemented. This type of wastewater is especially difficult to treat with conventional and other advanced treatment technologies because the oils and other contaminants precipitate and congeal during concentration and are difficult to remove once this occurs.

The data also indicated that the PFO Recycler provided the following:

- **Excellent rejection suitable for boiler feed reuse**. Draw solution pH adjustment or polishing is necessary to increase COD rejection by the RO step during COD spikes in the feed to always attain boiler feed quality.
- **Reuse of high organics water with surfactants that is usually not possible to reuse**
- **Energy savings** on the order of 10X when compared to evaporation, which was the only other treatment technology considered feasible for this waste stream.

Recommendations

This technology should be supported and marketed for additional demonstrations to reuse challenging and highly variable wastewaters. The fact that the system could run reliably with minimal maintenance without pretreatment or a microbiological process will be a gamechanger for industrial facilities that either cannot afford or do not have the space for an MBR. It also was able to reuse a high organic waste with oils and surfactants that are typically not feasible with competing advanced treatment reuse technologies.

The next step for the PFO Recycler is to expand the use of the technology commercially. With the success of the pilot demonstrations, the technology is ready for commercial installations for applications directly derived from these pilot demonstrations.

For other applications, more research may be needed to demonstrate that the water quality and maintenance requirements are suitable for customer’s needs. To achieve commercial expansion, Porifera will partner with early adopters and work with them on customizing the PFO Recycler to overcome their reuse challenges and use more water with less energy.

CHAPTER 8: Benefits to Ratepayers

Introduction

This project demonstrated that the PFO Recycler can:

- Reuse more water with less energy than competing processes for challenging high organic wastes including wastes with rapid changes in temperature and salinity (JFW)
- Continue to run with little to no maintenance and produce high quality water for reuse (Ale Industries)
- Reuse water from high COD and surfactant feeds that cannot be treated with other membrane technologies (Dr. Bronner's)
- Provide a new option to reuse water when footprint is a key consideration (all)

While the pilot-scale results indicated energy savings for these specific applications, the potential energy savings that would result from full implementation of PFO Recycler technology are larger than these applications. For example:

1. Like JFW, many food and beverage related processors have challenging wastes with challenges due to organics, salinity, and so on that are also near agricultural sites and need a reuse solution to reduce costs, increase drought resiliency and restore local soil
2. Like Ale Industries, there are many microbreweries, roasters and small businesses that would consider reusing more water if it did not create maintenance headaches
3. Like Dr. Bronner's, there are numerous facilities that truck away or evaporate high COD wastes because there is no other cost-effective or feasible option
4. Like all these sites, there are industries that are evaluating reusing more water, but do not have the space for current options, especially when variability would require very large MBR's or evaporators to provide a year-round solution

It is difficult to estimate the potential savings for all the potential applications, so assumptions are needed to estimate the applicability and potential savings is a certain percentage of target industry were to adopt and utilize the technology.

Also, the benefits to ratepayers will be both direct and indirect. Direct benefits include the potential for lower cost of power and water. Indirect benefits will be in terms of jobs, increased revenue and/or other advantages for California businesses, and associated increases in local, state and federal tax income.

Note that key assumptions for energy and emissions calculations are based on the relevant results and conclusions sections for each pilot test.

Energy and Emissions Savings for California Industry

The pilot studies funded by this project demonstrated energy savings at each site. Potential statewide energy savings have been estimated in two different ways (top down and bottom up) to provide a range of potential savings based on industry adoption and assumptions listed below.

Based on these two approaches, it is anticipated that 273 MWh/year of energy could be saved from early adoption and on the order of 53,000 MWh/year assuming widespread adoption.

Estimate 1: Top-Down Approach for Industrial Reuse in California

Implementing Porifera's Recycler technology for water reuse at California industrial users will reduce energy and water resource demands throughout the state. The energy savings will occur primarily in reduced energy needed for purification, pumping, and heating/re-heating of water both at industrial sites as well as reduced pumping necessary to transfer water to the Central Valley and Southern California assuming reduced industrial and agricultural demands.

The Natural Resources Defense Council and the Pacific Institute estimated for California "that the water reuse potential…ranges from 1.9 million to 2.5 million acre-feet per year. Approximately 64 percent of the water reuse potential is from residences; the remainder is from commercial businesses and institutions (21 percent) and industry (15 percent). Some of this reuse is already occurring. According to a recent state survey, recycled water use in California is 670,000 acre-feet per year. Thus, the potential for additional water reuse in California today is 1.2 million to 1.8 million acre-feet per year."[1] Fifteen percent of 1.2 million acre-feet equals 180,000 acre-feet of industrial wastewater that was not reused at the time of the survey.

Based on the results from this project and after performing calculations to consider the typical ranges of salinity, temperature, and organics in industrial wastewaters, we expect our technology to save between 1-5 kWh per every 1,000 gallons reused for most industrial applications and 3 kWh per 1,000 gallons on average. If we assume that a third (33 percent) of the 180,000 acre-ft./year (58 billion gallons/year) of new industrial water is reused in California the near future and 3 kwh/1,000 gal of energy savings on average per project, then the total energy savings would equate to approximately 53,000 MWh/year.

Estimate 2: Bottom-Up Approach for One Industrial Sector in California

The second approach is to make assumptions about industry adoption based on the largest target of industrial users, the California food and beverage industry. Within this market, impacted market segments can be subdivided into the following industry subgroup in Table 8.[2]

[1] Water Reuse Potential in California. Natural Resources Defense Council & Pacific Institute. June 2014. IB:14-05-e. http://www.nrdc.org/water/files/ca-water-supply-solutions-reuse-IB.pdf

[2] Industry definitions and data obtained from: Food Manufacturing in California. 2010. Prepared by the Northern California Center of Excellence and the Office of Economic Development at Cerritos College.

Table 8: California's Food Processing Industry Sub Groups

Sub Group	# of Companies	Size (#Jobs)
Beverage Product	1,485	47,915
Other Food	549	25,825
Fruit & Vegetable/Specialty	419	36,930
Dairy Product	284	17,200
Sugar & Confectionary	222	7,359
Total	**2,959**	**135,229**

Source: Porifera Inc.

Based on conversations with industry experts including CDM Smith, we assume that (1) over 70 percent of these companies discharge a wastewater that is challenging to reuse in terms of organics or salt content, (2) the technology would be attractive to more than 50 percent of these companies, and (3) 15 percent of these companies will implement a drought mitigation project in the next 10 years.

Table 9 summarizes the anticipated energy and CO_2 emissions savings if 15 percent of these California companies with challenging wastewaters implemented a PFO Recycler instead of a much more energy intensive reuse system. Assumptions are summarized after the table.

Table 9: Summary of Estimated Energy and Water Saving Benefits to Ratepayers

Number of F&B Companies in CA	Percent to Implement a Reuse Project	Average Reuse Capacity	Savings with PFO Recycler vs. Current State of the Art	Expected Annual Savings
2959	15% = 443 companies	250,000 gallons per day	20-40% energy savings per 1,000 gallons reused (1-5 kWh/kgal)	274 MWh and 91 metric tons of CO_2 emissions

Source: Porifera Inc.

Underlying Assumptions for Bottom-Up Energy Savings

Assumptions for supporting our projected growth rates include:

- PFO Recycler would save 3 kWh per 1,000 gallons reused vs. competing technologies
- 250,000 gallons per day would be reused 365 days per year. 3 kWh times 250 units of 1,000 gallons per day times 365 = 274,000 kWh/year = 274 MWh/year.
- Emissions factor (CO2): 0.73 lbs CO2 saved per kWh saved and 2204 lbs. per metric ton.
- There is increasing economic pressure to conserve water & energy resources.
- Strategic partnering with a large company will accelerate market penetration.
- The PFO Recycler will function as expected based on pilot results and lessons learned.

Benefits and Conclusions

The benefits for implementing PFO Recycler technology at scale in the three piloted applications are summarized in the following sections and are based on the following assumptions.

Underlying Assumptions for Benefits and Conclusions

- Lower drought related costs.
  Assumption: more water reused = greater water sustainability and lower statewide costs.
- Lower costs for new water and wastewater infrastructure.
  Assumption: more water reused = lower projected future water demand.
- Lower costs for new or expanded power plants and distribution systems
  Assumption: reduced electricity demand = lower projected future demand

Benefits Related to Reducing Energy and Reusing Water at California Wineries

California's wine industry not only generates billions[3] in revenue but is also a rapidly growing industry that requires significant energy infrastructure throughout the state. According to the U.S. Census Bureau, the U.S. had 1,956 wineries in 2007, where 971 of the wineries were in California and produced about 85 percent of all U.S. wine. More recent estimates indicate that there were 4,653 wineries in California out of the 11,496 in the US (wineinstitute.org).

According to a Lawrence Berkeley National Laboratory (LBNL) study (Wu, 2013), the California winemaking industry consumes over 400 Gigawatt-hours (GWh)of electricity annually, the second largest electricity consuming food industry in California, after fruit and vegetable processing. Furthermore, UC Davis estimated that California wineries use approximately 670,000 acre-ft. of water per year and 322 gallons of water per gallon of wine produced (Sumner, 2016). Thus, the wine industry is considered an excellent target for application of energy and water saving innovations.

Direct benefits to ratepayers would be reduced electrical and water demand which can lead to a lower cost of power and water. This reduction would have the most impact at peak usage times, which in turn reduces cost and improves reliability of energy and water infrastructure. Recent studies indicate that the energy used for water supply and wastewater treatment is approximately 3 percent of the total energy use or 12 GWh/year; however, this demand is expected to grow as high purity reuse becomes more common and implementing PFO Recycler will curb a sharp increase in demand which is especially important in rural areas where it would be expensive to increase both water resources and energy production and transmission. Additionally, if warm wastewater (113-140^{o}F) can be treated to boiler feed quality, then the demand for natural gas can also be reduced as less heat would be needed to heat the water prior to entering the boiler.

As Porifera technology increasingly gains adoption within the wine industry, the qualitative and intangible benefits to California ratepayers will correspondingly grow including:

---

[3] The state shipped a record 38 million cases with retail value of $34.1 billion in 2016. http://www.wineinstitute.org/resources/pressroom/05012017

- Improved quality of irrigation water to reverse the trend of harmful salt buildup in valuable soil resources
- Reduced water pumping from local overtaxed aquifers
- More jobs from a strengthened wine industry as a result of improved drought resiliency and a lower cost of water and power
- Improved reliability of water and power infrastructure through decreased reliance on local municipalities and reduced peak demands
- Improved reliability of water and wastewater infrastructure from reduced irrigation and washdown demand especially during droughts

Benefits Related to Reducing Energy and Reusing Water at California Breweries

A typical craft brewery uses 7 gallons of water to make 1 gallon of beer and California has more craft breweries—small, independent beer makers that use traditional ingredients—than any other state. In 2015, more than 570 were in operation and another 240 were slated to open, according to the California Craft Brewers Association. Craft breweries contributed $6.5 billion to the state economy in 2014, producing 3.5 million barrels. Many of these breweries are being asked to cut back on water use by local or regional municipalities to meet the previous state mandate, which aims to reduce California's overall urban water use by 25 percent compared to 2013 (Watson, 2015).

Inside the average brewhouse, cleaning uses the most water—three to eight gallons per gallon of beer—and additional water is needed for cooling and packaging. Much of the water used in breweries is lost to evaporation or is simply sent down the drain. The PFO Recycler creates water ideal for cleaning, cooling, and packaging and can create high purity water from challenging brewery wastes with little to no maintenance as shown during pilot testing.

Direct benefits to ratepayers would be reduced electrical and water demand which can lead to a lower cost of power and water. This reduction would have the most impact at peak usage times, which in turn reduces cost and improves reliability of energy and water infrastructure. For example, recent EPA data indicates that the energy used for boilers is approximately 5 percent of electricity demand at breweries and a much larger percentage of natural gas demand. Since most brewhouses operate during peak energy and water use periods, reusing warm wastewater (113-140^{o}F) treated to boiler feed quality, would decrease this significant energy demand by reducing heating to water prior to entering the boiler.

As Porifera technology increasingly gains adoption for reusing industrial wastewater at breweries, the qualitative and intangible benefits to California ratepayers will correspondingly grow including:

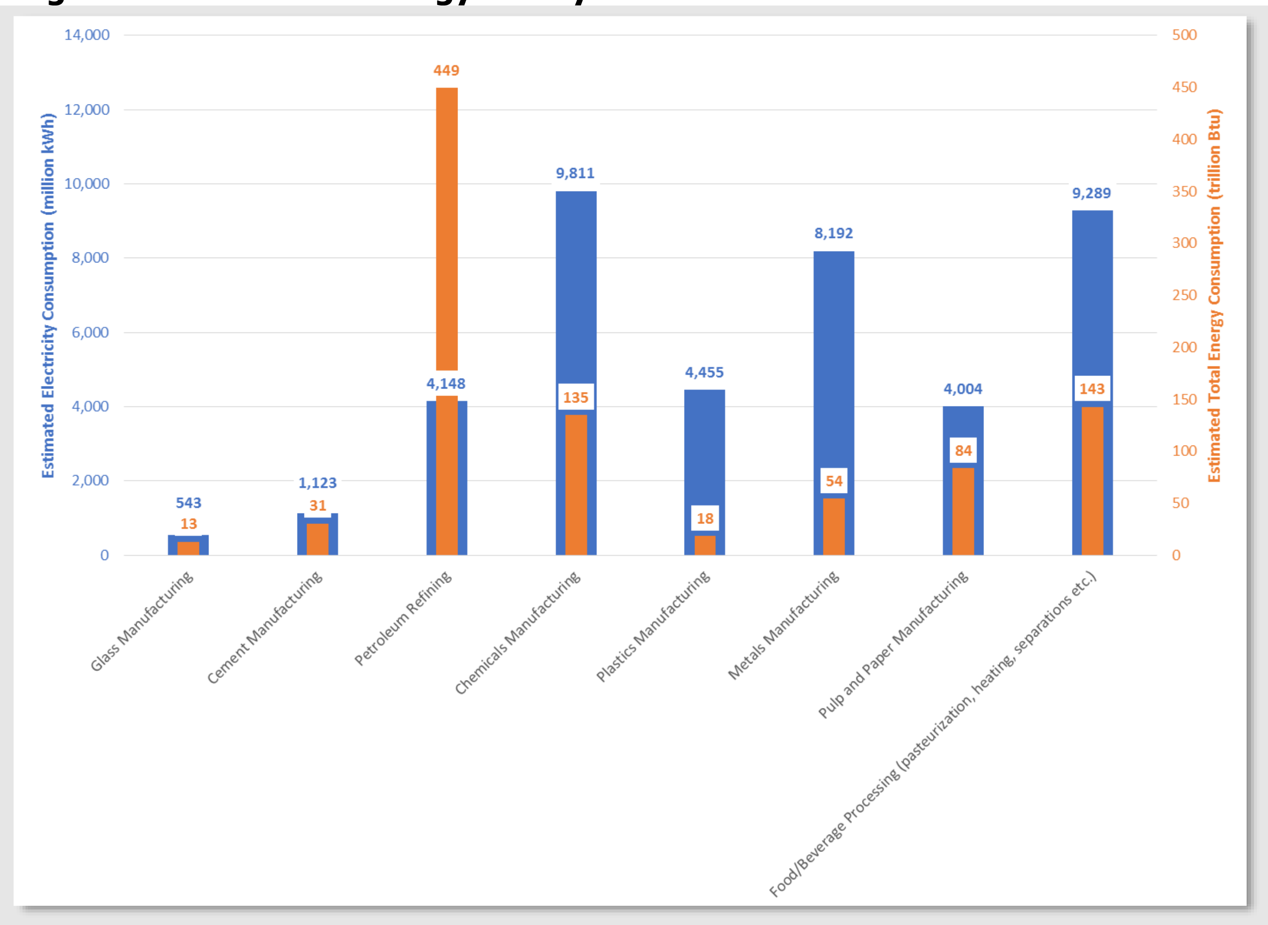
- Reduced urban water use to meet statewide goals, reducing burden on residential users
- Reduced water pumping from local overtaxed aquifers
- Potentially more jobs from a strengthened brewery industry because of improved drought resiliency and a lower cost of water and power
- Improved reliability of water and power infrastructure through decreased reliance on local municipalities and reduced peak demands

- Improved reliability of water and wastewater infrastructure from reduced irrigation and washdown demand especially during droughts

Benefits Related to Reducing Energy and Reusing Water at Caliornia Industry

Industrial users in California consume significant amounts of energy. A February 2019 CEC study estimates total energy use within different industrial sectors in California as shown in Figure 39 (CEC, 2019). Of these industries, the results from the Dr. Bronner's pilot are especially applicable to the chemicals, plastics, metals and pulp and paper manufacturing industries which often have challenging wastes with oils, greases, or surfactants that are difficult to treat with conventional and membrane reuse systems.

Figure 39: Estimated Energy Use by Industrial Sector in California 2014 Data



Estimated electrical and total energy consumption in California for certain sectors, referencing federal and county data, 2014

Sources: EIA 2014 (MECS), U.S. Census Bureau 2014a (ASM), U.S. Census Bureau 2014b (CBP), and U.S. Census Bureau 2014c (NAICS definitions)

Based on the totals in Figure 38, implementing Porifera's PFO Recycler technology within California industrial users and reducing the total energy demand by even a small percentage will both reduce total and peak energy loads and reduce natural gas demand, which in turn reduces the cost of electricity and improves reliability of energy infrastructure. It also reduces rural and urban water use, which would be especially helpful when these sites include boilers, cooling towers, or are near sites with irrigation demand to reduce the demand on local wells and water supplies.

As Porifera technology increasingly gains adoption with industrial users, the qualitative and intangible benefits to California ratepayers will correspondingly grow including:

- Reduced urban water use to meet statewide goals, reducing burden on residential users
- Reduced rural water use, reducing burden on agricultural users
- Reduced water pumping from local overtaxed aquifers
- Potentially more jobs from a strengthened industry because of improved drought resiliency and a lower cost of water and power
- Improved reliability of water and power infrastructure through decreased reliance on local municipalities and reduced peak demands
- Improved reliability of water and wastewater infrastructure from reduced irrigation and washdown demand especially during droughts

LIST OF ACRONYMS

Term/Acronym	Definition
AI	Ale Industries
Brix	The sugar content of an aqueous solution
BOD	Biological oxygen demand
C	Celsius
CLFP	California League of Food Processors
COD	Chemical oxygen demand
EPIC	Electric Program Investment Charge
ERD	Energy recovery device
F	Fahrenheit
FO	Forward osmosis
FPSA	Food Processing Suppliers Association
Gal	Gallons
gpm	Gallons per minute
GWh	Gigawatt hours
IFT	International Food Technologists
JFW	Jackson Family Wines
kg/l	Kilograms per liter
kWh	Kilowatt hours
Lb	pounds
LMH	Liters per square meters per hour
MBR	Membrane Bioreactor
M&V	Measurement and Verification
m^2	Meter squared
mg/L	Milligrams per liter
mS	Microsiemens
mS/cm	Microsiemens per centimeter
$MTCO_2$	Metric Tons of Carbon Dioxide
ORP	Oxidation and reduction potential
psi	Pounds per square inch
PAA	Peracetic acid
PFO	Proprietary forward-osmosis
RO	Reverse osmosis
RSF	Reverse Salt Flux

Term/Acronym	Definition
SAR	Soil adsorption ratio
Therms	A unit of heat equivalent to 100,000 Btu
TDS	Total dissolved solids (used as a measure of salinity)
TSS	Total suspended solids (used as a measure of solids loading)
UF	Ultrafiltration
V	Volt
VOC	Volatile organic compounds
VFD	Variable frequency drive
VSEP	Vibratory shear enhanced processing
Wh	Watt hours
Wh/gal	Watt hours per gallon
Wt%	Weight%age
ZLD	Zero liquid discharge

REFERENCES

Brewers Association Energy Usage, GHG Reduction, Efficiency and Load Management Manual. https://www.brewersassociation.org/attachments/0001/1530/Sustainability_Energy_Manual.pdf

California Energy Commission. 2019. Research Roadmap for Advancing Technologies in California's Industrial, Agriculture and Water Sectors

Loge, F., and Rupiper, A. 2019. Energy and Water Savings From Onsite Water Reuse in the Wine Industry, EPIC Symposium Poster.

Moser,S., Ekstrom, J., and Franco, G. 2012. CEC Publication # CEC-500-2012-007

Sumner, D. 2016. Water into Wine in California: Economic Perspectives. University of California Agricultural Issues Center and Department of Agricultural and Resource Economics, UC Davis. https://aic.ucdavis.edu/publications/Economic%20wine%20and%20water.pdf

Watson, J. 2015. California craft beer brewers balance drafts and drought. http://www.cadrought.com/california-craft-beer-brewers-balance-drafts-and-drought/

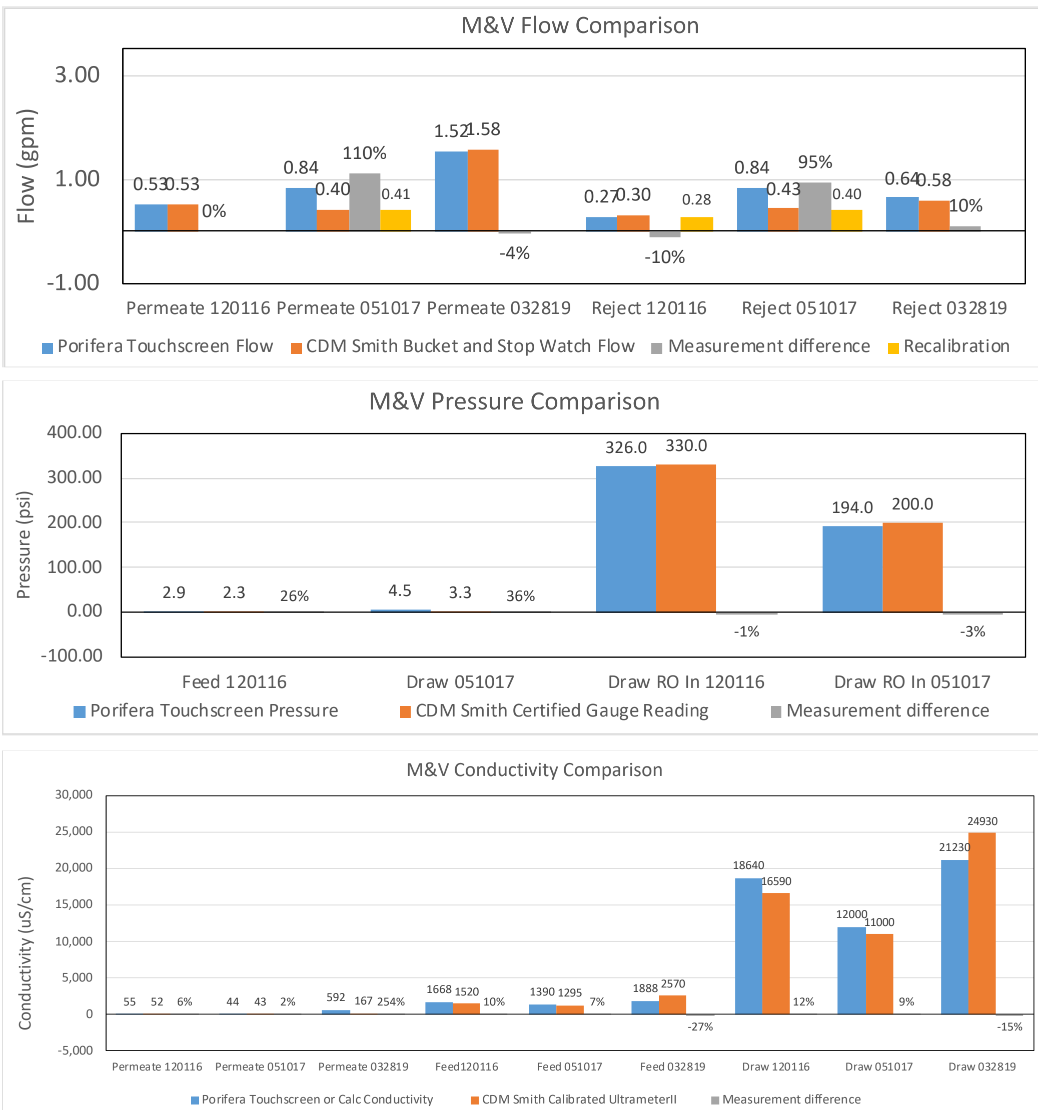
Wu, Y.Y., Chow, S., Ganji, A.R. 2013. Energy Efficiency Opportunities in Wineries for Retrofit and New Concentration Projects. Berkeley Applied Science and Engineering; Industrial Energy Technology Conference.

APPENDIX A: Additional Supporting Data

The figures in this section summarize the additional measurement and verification data collected by CDM Smith. Note that majority of measurements were within typical variations based on the specified accuracy of the instrument except for the feed and permeate conductivity meters which had to be re-calibrated multiple times throughout testing.

Figure A-1: Measurement and Verification Data Comparison, Jackson Family Wines provides measurement and verification readings at the JFW site. While most of the readings were within standard tolerances within the measured range for the water quality or other instruments, some instruments were recalibrated and placed on a recalibration schedule to improve data accuracy.

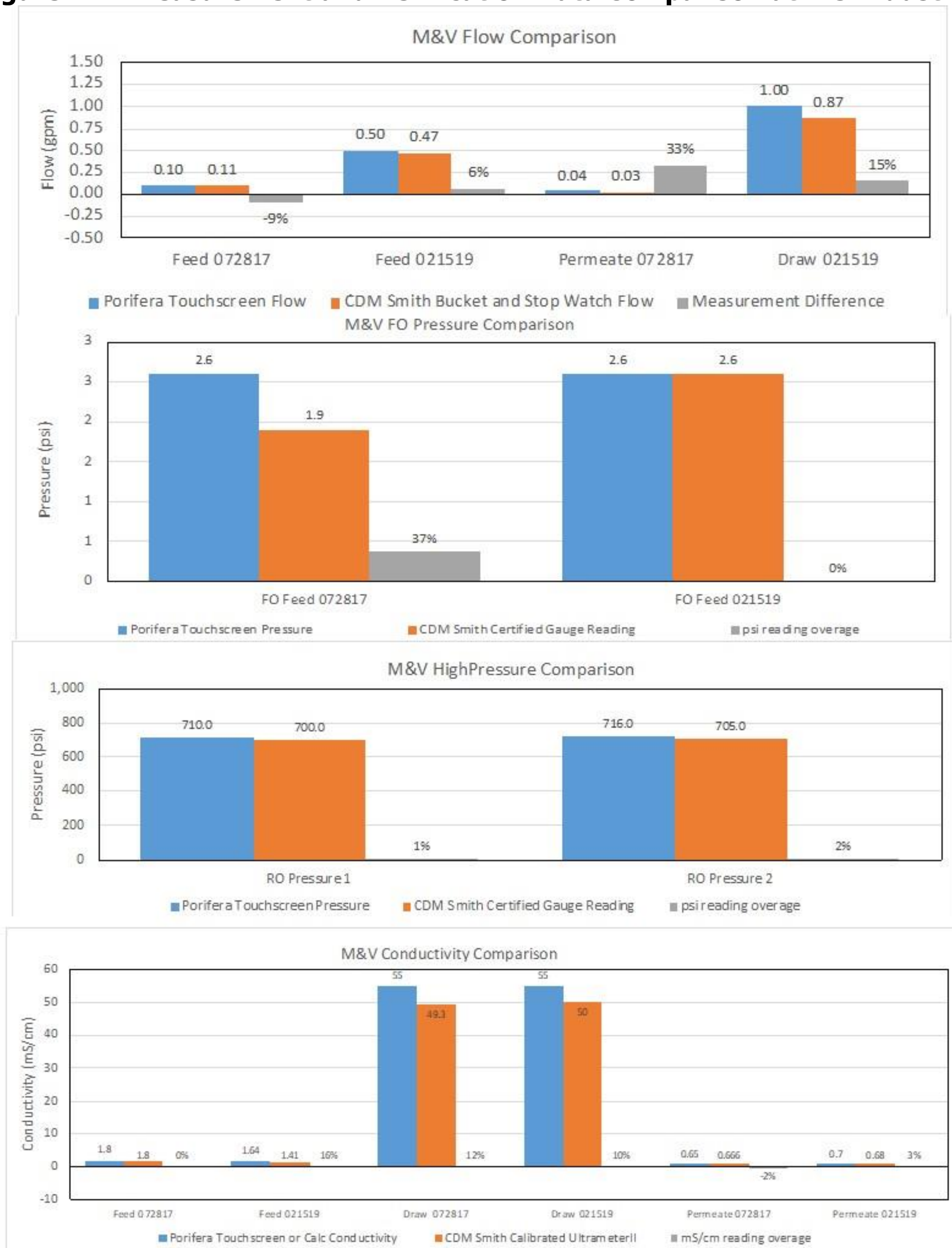
Figure A-1: Measurement and Verification Data Comparison, Jackson Family Wines



Source: Porifera, Inc.

Figure A-2 provides measurement and verification for Ale Industries. While the majority of the readings were within standard tolerances within the measured range for the water quality or other instruments, some instruments were recalibrated and placed on a recalibration schedule to improve data accuracy.

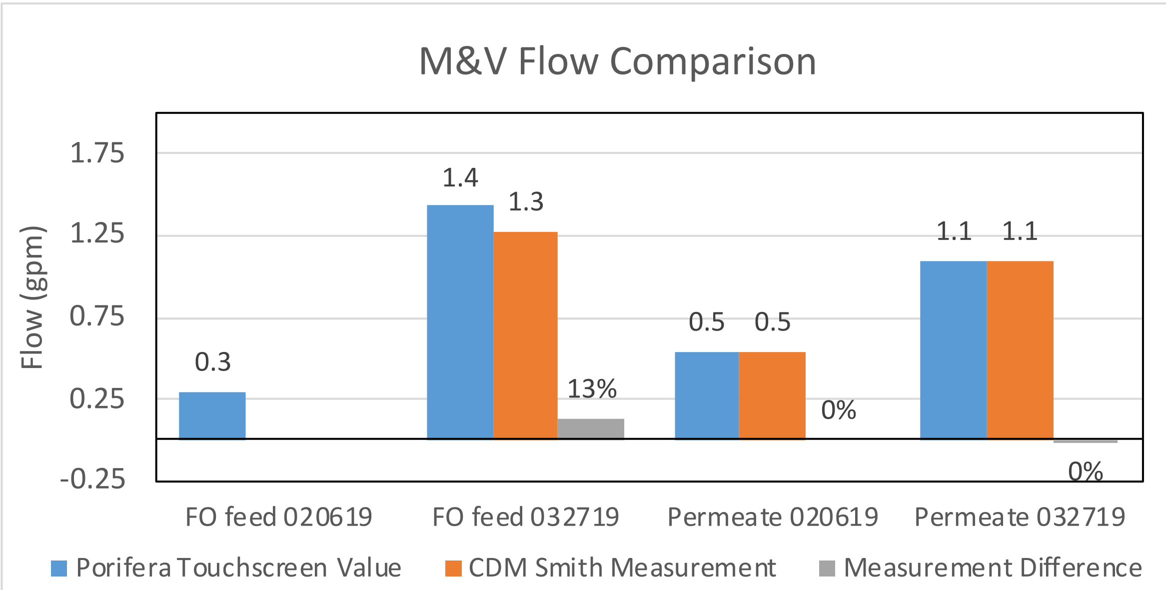
Figure A-2: Measurement and Verification Data Comparison at Ale Industries

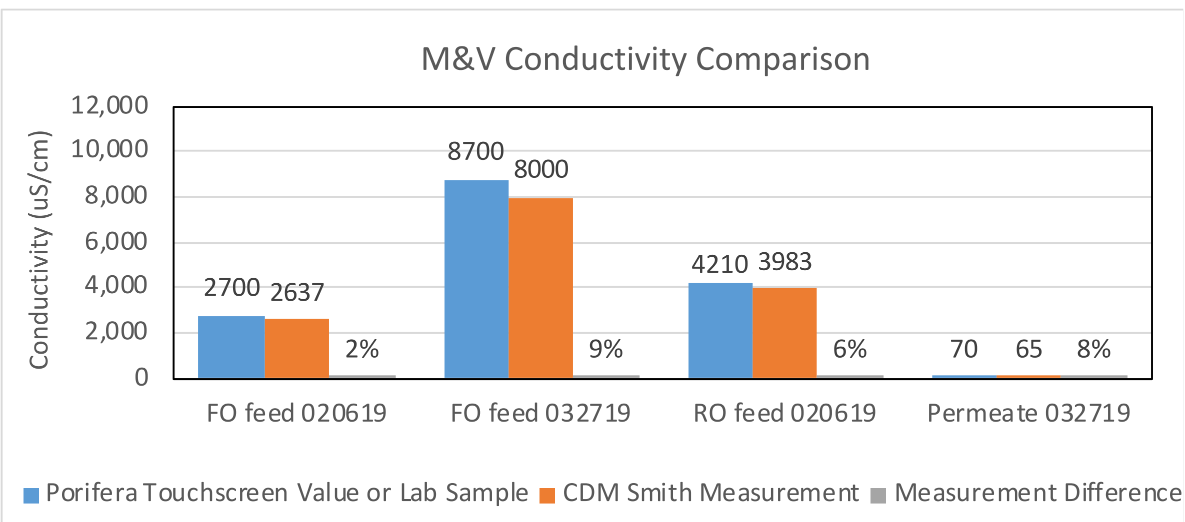


Source: Porifera, Inc.

Figure A-3 provides measurement and verification readings for the flow values at the JFW site. While the majority of the readings were within standard tolerances within the measured range for the water quality or other instruments, some instruments were recalibrated and placed on a recalibration schedule to improve data accuracy.

Figure A-3: Measurement and Verification Data Comparison for Dr. B





Source: Porifera, Inc.