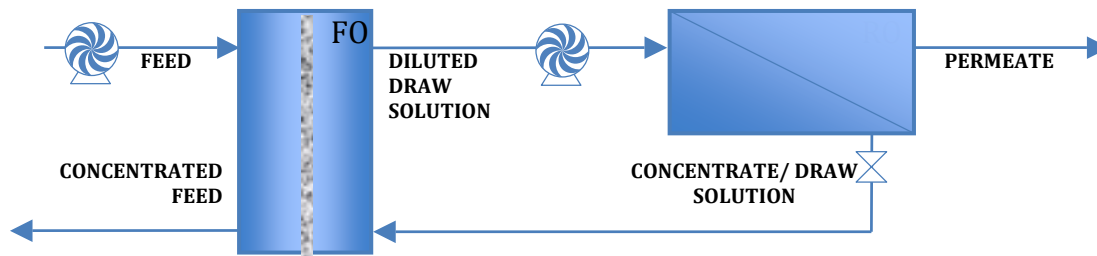


## FO/RO Hybrid System

Synergistically coupling forward osmosis (FO) with reverse osmosis (RO) produces an exceptionally robust, multi-barrier system for treating water with TDS ranging from 500 to 35,000 mg/L. FO process uses the natural chemical potential difference between a highly saline draw solution and a feed stream to induce natural osmosis through a semipermeable membrane (see FO webpage). An FO process may be viewed as a pretreatment for downstream unit processes, especially for water with high scaling or fouling propensity. During this process the feed is concentrated while the draw solution becomes dilute. Thus, engineered applications of FO require the continuous reconcentration of the draw solution in a closed loop. One prominent method for reconcentrating the draw solution is to use RO (see RO webpage). Reconcentration with RO is a viable option for concentrated brines because the FO membrane effectively removes scale-forming solutes and membrane foulants. Recent studies have demonstrated the efficiency of the hybrid FO/RO systems in treating secondary wastewater effluent, landfill leachate, and brackish water brines. Employing a very selective RO membrane for the reconcentration stage will ensure high NaCl rejection. Recent research suggests that water recovery in FO/RO system may exceed 96%.



### Summary of technical assessment of hybrid FO/RO system.

Criteria	Description/Rationale
Industrial status	One pilot-scale test on secondary effluent from a municipal wastewater treatment plant. No previous utilization for CBM produced water treatment.
Feed water quality bins	The estimated TDS application range is between 500 and 35,000 mg/L. High removals of monovalent and divalent ions, metals, and organics is expected.
Product water quality	The quality of permeate depends on feed water salinity and operating conditions. Pilot-scale studies report greater than 99% rejection of TDS.
Production efficiency (recovery)	Product water recovery is shown to exceed 96% in some studies
Energy consumption	Energy requirements are estimated between 5.7 and 11.4 kWh/kgal (0.24 to 0.48 kWh/bbl)
Chemicals	Chemical cleaning frequency depends on feed water quality. Membrane cleaning is triggered when certain operating conditions are exceeded, and may require the use of NaOH, Na <sub>4</sub> EDTA, or HCl.
Life cycle	No data is currently available for hybrid system; however, RO elements will likely require replacement between 3 and 7 years of operation.

**Summary of technical assessment of hybrid FO/RO system.**

<b>Criteria</b>	<b>Description/Rationale</b>
Infrastructure considerations	<p>This treatment process will require a larger footprint than conventional RO systems. Chemical storage will be required, in addition to a FO membrane bank.</p> <p>System mobility is reduced compared to conventional RO systems.</p>
O&M considerations	<p>Monitoring and control required for flow rates, chemical dosing, and RO element pressure.</p> <p>System may require substantial oversight to ensure proper operation of integrated system.</p> <p>Level of flexibility: highly flexible to alterations in feed water quality.</p> <p>Level of robustness: TFC RO membranes have high pH tolerance, but cannot be exposed to feed temperatures in excess of 113°F (45°C). FO membranes are typically composed of <i>cellulose acetate</i> and are more resistant to oxidants than TFC membranes, but less resistant to low or high pH operation.</p> <p>Level of reliability: RO systems operate semi-continuously with automated, short duration chemical rinses or osmotic backwashing cycles (for RO). FO systems may operate semi-continuously with short duration, high flow rate mechanical cleanings.</p> <p>Types of energy required: electrical.</p>
Overall costs	Capital costs for FO/RO systems are currently unknown.
Pre-treatment	Process may require pretreatment options including antiscalant and acid addition.
Post-treatment	<p>Product water may require pH adjustment and/or remineralization. This may be achieved by lime bed contacting or by blending small amounts of filtered and sterilized feed water with permeate.</p> <p>The concentrated feed stream may require additional post treatment or disposal consideration.</p>
Concentrate management or waste disposal	No special concentrate treatment is required. Relatively high recovery rates exceeding 96% generate very small volume of concentrated brine.
Applicability for produced water treatment	Moderate to good – FO provides an excellent pretreatment option for the RO stage; however, FO membrane elements are not yet optimized for use in water treatment.
Note: 1 barrel = 42 US gallon	