Membranes vs. Conventional Technology
What’s on the mind of Utility Engineers?

- **Water** scarcity
- Changing **water** characteristics
- **Water** discharge limits
- Overall cost of operation
- Makeup **water** quality – impact to equipment
- Makeup **water** quality – impact to equipment and operational costs
- Manpower requirements
Understand your water source

• How it can vary over time – mineral content
• It’s organic and turbidity variability (organic slippage)
• Biological aspects
• How will sludges be handled and their respective costs
• Defining the “dirt” loading that would be allowable to a pretreatment system
  – Ion exchange typically an SDI of 3-5 and suspended solids no greater then 10 ppm
  – Membranes typically an SDI of <3 and zero suspended solids
Solids Removal
Pretreatment approaches

- Clarification
- Hot or cold lime clarification
- Media filtering
- Membrane filtering
- With or without chlorination
- Do nothing
Impurity Removal Processes

Electrodialysis Reversal

0.045 µm
Table Work - 1

What is the primary pretreatment system in place at your plant?

What are the components in this system?
## Typical Raw Water

<table>
<thead>
<tr>
<th>Particle Size (microns)</th>
<th>Particles per mL</th>
<th>% of Total Particles</th>
<th>Volume ppm</th>
<th>% of Total Volume</th>
<th>Particle Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5-1.0</td>
<td>48309.0</td>
<td>94.7%</td>
<td>0.0671</td>
<td>0.37%</td>
<td>669709.6</td>
</tr>
<tr>
<td>1.0-2.0</td>
<td>22580.0</td>
<td>4.4%</td>
<td>0.0261</td>
<td>0.15%</td>
<td>260253.7</td>
</tr>
<tr>
<td>2.0-4.0</td>
<td>2320.0</td>
<td>0.5%</td>
<td>0.0277</td>
<td>0.15%</td>
<td>276706.1</td>
</tr>
<tr>
<td>4.0-6.0</td>
<td>560.0</td>
<td>0.1%</td>
<td>0.0361</td>
<td>0.20%</td>
<td>361249.6</td>
</tr>
<tr>
<td>6.0-8.0</td>
<td>300.0</td>
<td>0.1%</td>
<td>0.0533</td>
<td>0.30%</td>
<td>533428.8</td>
</tr>
<tr>
<td>8.0-10.0</td>
<td>210.0</td>
<td>0.0%</td>
<td>0.0819</td>
<td>0.46%</td>
<td>818574.7</td>
</tr>
<tr>
<td>10-15.0</td>
<td>290.0</td>
<td>0.1%</td>
<td>0.2881</td>
<td>1.61%</td>
<td>2881549</td>
</tr>
<tr>
<td>15.0-20.0</td>
<td>130.0</td>
<td>0.0%</td>
<td>0.3227</td>
<td>1.80%</td>
<td>3227948</td>
</tr>
<tr>
<td>20.0-30.0</td>
<td>300.0</td>
<td>0.1%</td>
<td>2.2484</td>
<td>12.54%</td>
<td>22488635</td>
</tr>
<tr>
<td>30.0-40.0</td>
<td>80.0</td>
<td>0.0%</td>
<td>1.9380</td>
<td>10.81%</td>
<td>19383420</td>
</tr>
<tr>
<td>40.0-50.0</td>
<td>20.0</td>
<td>0.0%</td>
<td>0.7038</td>
<td>3.92%</td>
<td>7039321</td>
</tr>
<tr>
<td>50-100</td>
<td>90.0</td>
<td>0.0%</td>
<td>12.1412</td>
<td>67.70%</td>
<td>1.21E+08</td>
</tr>
<tr>
<td>100-200</td>
<td>0.0</td>
<td>0.0%</td>
<td>0.0000</td>
<td>0.00%</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>509889.0</strong></td>
<td><strong>100%</strong></td>
<td><strong>17.9345</strong></td>
<td><strong>100%</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Raw Water**

![Graph of Raw Water](image)
Clarifier

TOTAL COST
Clarifier

**Function:**
- Removal of suspended solids via sedimentation.
- Separation can be assisted via chemical addition (coagulation, flocculation) to improve settling time and components removed.

**Operation:**
- Used for influents with >50-100 ppm TSS.

**Limitations:**
- Large Footprint
- Difficult to control under variable conditions
- Not complete suspended solid removal
- Carry over

**Strengths:**
- Works with high suspended solids loads
- Low operating cost based on volumetric flow rate
Clarification
## Filtration

<table>
<thead>
<tr>
<th>Technology</th>
<th>Function</th>
<th>Effluent Quality</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity – mixed media Filters</td>
<td>Suspended Solids Removal</td>
<td>Low Turbidity Water</td>
<td>Simple Maintenance. Lowest cost when TSS removal efficiency is not stringent. Carry through can be significant.</td>
</tr>
<tr>
<td>Pressure Filters</td>
<td>Hot or Cold Process Filtration</td>
<td>Low Turbidity Water</td>
<td>Improved control over turbidity. Channeling and caking can occur.</td>
</tr>
<tr>
<td>Cartridge Filters</td>
<td>Disposable - Solids Removal</td>
<td>Micron size selected by user</td>
<td>Very high operating costs even if suspended solids are low.</td>
</tr>
</tbody>
</table>
Gravity - Mixed Media Filter

Most multi media filters rated at around 5 GPM/ft²

Above 6 or 7 GPM/ft², see quality of effluent decrease

Low flow rates can cause channeling

Avoid sudden rate changes on a dirty filter
Particle Size Analysis effluent from a MMF with Coagulant feed
Pressure Filter

**Advantages**

- Eliminates the need for repumping of filtered water
- Permits High Temperature Operation i.e. Hot Lime
- Prevents heat losses from the system

**Limitations**

- Applicable when dealing with solids above 15 micron
- Hot Water required for filter backwash
# Membranes vs. Conventional Technology

<table>
<thead>
<tr>
<th>Membrane Treatment</th>
<th>Conventional Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Membrane Treatment Image" /></td>
<td><img src="image2.png" alt="Conventional Treatment Image" /></td>
</tr>
<tr>
<td>Modern and continuously improving</td>
<td>Technology</td>
</tr>
<tr>
<td>Extremely compact</td>
<td>Footprint</td>
</tr>
<tr>
<td>Physical barrier = reliable filtration</td>
<td>Separation Process</td>
</tr>
<tr>
<td>Fully automated with minimal chemical use</td>
<td>Operation</td>
</tr>
<tr>
<td></td>
<td>Developed in the 1800’s</td>
</tr>
<tr>
<td></td>
<td>Large land requirement</td>
</tr>
<tr>
<td></td>
<td>Gravity driven with coarse filtration</td>
</tr>
<tr>
<td></td>
<td>Labor and chemical intensive</td>
</tr>
</tbody>
</table>

- Technology: Developed in the 1800’s
- Footprint: Large land requirement
- Separation Process: Gravity driven with coarse filtration
- Operation: Labor and chemical intensive
UF – Hollow Fiber

**Advantages**
- Small Pores – 0.1 μm absolute, 0.04 μm nominal
- Single step superior Particle Removal
- Handles suspended solids better than MMF
- Absolute Barrier allows for Micro-organism removal
- Highly Reliability
- Lower Operating cost than pressure filtration.
- Low capital cost due to footprint.

**Limitations**
- No free oil or grease
- pH between 5 – 9.5
- Temperature <40 C
- Maximum Chlorine 1000 ppm continuous (0.5M ppm-hrs)
- Max TSS 10,000 ppm for direct filtration
UF - Hollow Fiber

Hollow strands of porous plastic fibers with billions of microscopic pores on the surface

The pores are thousands of times smaller in diameter than a human hair

Pores form a physical barrier to impurities but allow pure water molecules to pass

Clean water is drawn to the inside of fiber by a gentle suction

Electron microscope view of membrane surface
Hollow Fiber Configurations

**Immersed**
- Open tank configuration, loosely packed fibers for easier solids removal
- Low pressure, vacuum-driven operation
- Simpler scale-up for larger systems

**Pressurized**
- More difficult to remove solids from confined pressure vessels, tightly packed fibers
- Use higher pressures as membranes become fouled
- Expensive pressure vessel required for each unit
Capital Cost--Immersed vs. Pressure UF

Table 1 – Capital Cost per Gallon

<table>
<thead>
<tr>
<th></th>
<th>Very Large – Large ($/ gall)</th>
<th>Medium ($/ gall)</th>
<th>Small ($/ gall)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>$0.368 - $0.407</td>
<td>$0.442 - $0.460</td>
<td>$0.725 - $1.72</td>
</tr>
<tr>
<td>Submerged</td>
<td>$0.232 - $0.254</td>
<td>$0.300 - $0.400</td>
<td>$0.469 - $0.733</td>
</tr>
<tr>
<td>Cost Difference</td>
<td>$0.136 - $0.153</td>
<td>$0.060 - $0.142</td>
<td>$0.256 - $0.987</td>
</tr>
<tr>
<td>Percentage</td>
<td>37% - 38%</td>
<td>14% - 30%</td>
<td>35% - 57%</td>
</tr>
</tbody>
</table>

Immersed systems have lower capital cost

Energy Costs-Immersion vs. Pressure UF

**Table 2 – Energy Cost per 1000 Gallons**

<table>
<thead>
<tr>
<th></th>
<th>Very Large – Large ($/ 1000 gall)</th>
<th>Medium ($/ 1000 gall)</th>
<th>Small ($/ 1000 gall)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>$0.020 - $0.028</td>
<td>$0.022 - $0.026</td>
<td>$0.031 - $0.105</td>
</tr>
<tr>
<td>Submerged</td>
<td>$0.012 - $0.024</td>
<td>$0.012 - $0.014</td>
<td>$0.013 - $0.015</td>
</tr>
<tr>
<td>Cost Difference</td>
<td>$0.004 - $0.008</td>
<td>$0.010 - $0.012</td>
<td>$0.018 - $0.090</td>
</tr>
<tr>
<td>Percentage</td>
<td>20% - 29%</td>
<td>45% - 46%</td>
<td>58% +</td>
</tr>
</tbody>
</table>

**Immersed systems have lower energy demand**

Dissolved Solids Removal
What type of dissolved solids removal systems do you use today and for which systems (Demin, RO, Softener, etc)?

Estimate the cost to operate each system on a $/gal basis?
## Ion Exchange

<table>
<thead>
<tr>
<th>Technology</th>
<th>Function</th>
<th>Effluent Quality</th>
<th>Capital Costs</th>
<th>O&amp;M Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Zeolite Softening</td>
<td>Hardness Removal</td>
<td>0.2 – 1.0 ppm hardness</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Hot Zeolite Softening</td>
<td>Hot process water softening</td>
<td>0.2 – 1.0 ppm hardness Some alkalinity, silica and TDS removal</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Demineralization</td>
<td>Removal of all dissolved solids</td>
<td>&lt;10 umho Conductivity &lt;200 ppm Silica</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Chloride Anion Dealkalization</td>
<td>Reduction of alkalinity</td>
<td>50 to 90% Alkalinity reduction</td>
<td>Low-Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Starvation Dealkalization</td>
<td>Reduction of alkalinity, hardness and some TDS</td>
<td>50 to 90% Alkalinity reduction</td>
<td>Moderate</td>
<td>Low</td>
</tr>
</tbody>
</table>
Sodium Zeolite Softening

**Advantages**
- Inexpensive – Capital & operating costs
- Simple-to-operate
- Durable
- Safe & inexpensive sodium chloride regenerant

**Limitations**
- No reduction in total dissolved solids (TDS)
- Limited Resin life due to fouling and oxidizer attack
- No silica reduction
- No alkalinity reduction without dealkalizer
Hot Zeolite Softening

**Advantages**
- Softening under process temperatures (100 – 115 C)
- Softening reactions go to completion
- Typically good silica reduction as well through absorption of silica on the magnesium hydroxide precipitate
- Some TDS reduction

**Limitations**
- Clogging or improper spray pattern can prevent proper heating of water
- Lime feed is always a pain
- Sludge handling concerns
# Demineralization

## Advantages
- Reduction in all dissolved solids
- Enables high cycles operation
- Suitable for high-pressure boilers
- Can tailor to specific purity needs
- Excellent silica rejection
- Excellent alkalinity/CO2 rejection

## Limitations
- Strong acid/caustic required for regeneration
- Caustic costs high & variable
- Limited anion resin life
- Silica and sodium leakage
- Manpower intensive
- Operating costs directly proportional to TDS
## Chloride Anion Dealkalization

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Inexpensive – Capital &amp; operating costs</td>
<td>• No reduction in total dissolved solids (TDS)</td>
</tr>
<tr>
<td>• Simple-to-operate</td>
<td>• FW quality can limit boiler cycles</td>
</tr>
<tr>
<td>• Durable</td>
<td>• Not suitable for high-pressure boiler operation (&gt; 900 psig)</td>
</tr>
<tr>
<td>• Safe &amp; inexpensive sodium chloride regenerant</td>
<td>• No silica reduction</td>
</tr>
<tr>
<td></td>
<td>• No alkalinity reduction without dealkalizer</td>
</tr>
</tbody>
</table>
Starvation Dealkalization

**Advantages**
- Reduction of 80-90% alkalinity
- Reduction of hardness to <0.1 ppm
- Some reduction of TDS
- Efficient use of regenerants
- Low water wastage

**Limitations**
- Waste is not readily reusable
- Handling of acids
- Neutralization of waste required
- No silica reduction
# Membrane Systems

<table>
<thead>
<tr>
<th>Technology</th>
<th>Function</th>
<th>Effluent Quality</th>
<th>Capital Costs</th>
<th>O&amp;M Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse Osmosis</td>
<td>Separation of all dissolved solids</td>
<td>Typically 98% TDS reduction</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Electrodialysis Reversal (EDR)</td>
<td>Dissolved Solids Removal via electrical field</td>
<td>Typically 75% TDS reduction but high water recovery</td>
<td>Moderate-High</td>
<td>Low</td>
</tr>
<tr>
<td>Ultrafiltration – Hollow Fiber</td>
<td>Suspended Solids Removal</td>
<td>Reduced Suspended Solids. No TDS Removal</td>
<td>Moderate-High</td>
<td>Low</td>
</tr>
<tr>
<td>Electrodeionization EDI (E-Cell)</td>
<td>Functions like a mixed bed</td>
<td>&lt;10 ppb SiO2 16+ Megohm</td>
<td>Moderate</td>
<td>Low</td>
</tr>
</tbody>
</table>
What is a Membrane?

Two classes of membranes:
- Porous (UF, MF)
- Non-porous (RO, NF)

Non-porous membranes typically comprise a thin film on a support.
Reverse Osmosis

**Advantages**
- Rejection of all dissolved solids
- Operating costs not directly dependant on TDS
- Enables high cycle boiler operation
- Requires no chemical regenerants (acid/caustic)
- Not labor intensive
- Versatile pairings with resin-based systems
- Ideal for mobile applications

**Limitations**
- Not meant for Suspended Solids removal
- Higher electrical costs than resin-based systems (high-pressure pumps)
- Generates significant reject stream (typically 20 – 30% of input stream)
- Does not reject CO2
- Maximum Temperature – 80C
Electrodialysis Reversal (EDR)

**Advantages**
- Self-Cleaning Electrodes
- High resistance to organic fouling
- Inorganic scaling resistance
- No silica rejection
- Very high water recovery

**Limitations**
- ~75-90% removal of TDS
- Best for brackish water feed
- Polarization (Temp, TDS fluctuations)
- Maximum and minimum Total Dissolved Solids
- Maximum Temperature 35C
EDR Technology

Electrodialysis (ED):
- Electrically-driven ion removal process, using voltage to draw ions through membranes
- Ions permeate, not water

Electrodialysis Reversal (EDR):
- An ED process, where the polarity of the electrodes, and the concentrate and dilute streams, reverse every 15 to 20 minutes.
- Reversal removes & flushes freshly precipitated scale
Purification Evolution

1940’s
- Pretreatment
- Cation IX
- Anion IX
- Mixed Bed
- Caustic

1990’s
- Pretreatment
- R.O.
- Mixed Bed
- Caustic
- Acid

2000+
- Zeeweed Pretreatment
- R.O.
- EDI
Selected Experiences

Shell AOSD—River water, UF, RO, MB

Southern Company – Plant Harris—River water, UF, RO, MB

Petro Canada + Edmonton Gold Bar
Muni WWT Plant—UF, RO
Shell AOSD Plant PFD

North Saskatchewan River

3 mm Screen

Ferric Chloride

Sodium Hypochlorite

Heat Exchanger

Bisulphite

Anti-Scalant

2 x 50% ZeeWeed® Ultrafilters

2 x 50% ZeeWeed® Reject

Caustic

Acid

Neutralization Tank

Neutralized Regenerant

Spent Regenerant

Forced Draft Degasifier

2 x 100% Mixed Bed Ion Exchangers

2 x 50% Reverse Osmosis Units

RO Reject

Demin Boiler Feed Water
390 m³/h
(1700 USGPM)

Boiler

Neutralized Regenerant

Spent Regenerant

2 x 100% Mixed Bed Ion Exchangers

2 x 50% Reverse Osmosis Units

RO Reject

Neutralization Tank

Neutralized Regenerant

Spent Regenerant

Forced Draft Degasifier

2 x 100% Mixed Bed Ion Exchangers

2 x 50% Reverse Osmosis Units

RO Reject

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2 x 100% Mixed Bed Ion Exchangers

2 x 50% Reverse Osmosis Units

RO Reject

Neutralization Tank

Neutralized Regenerant

Spent Regenerant

Forced Draft Degasifier

2 x 100% Mixed Bed Ion Exchangers

2 x 50% Reverse Osmosis Units

RO Reject

Neutralization Tank

Neutralized Regenerant

Spent Regenerant

Forced Draft Degasifier

2 x 100% Mixed Bed Ion Exchangers

2 x 50% Reverse Osmosis Units

RO Reject

Neutralization Tank

Neutralized Regenerant

Spent Regenerant

Forced Draft Degasifier

2 x 100% Mixed Bed Ion Exchangers

2 x 50% Reverse Osmosis Units

RO Reject

Neutralization Tank

Neutralized Regenerant

Spent Regenerant

Forced Draft Degasifier

2 x 100% Mixed Bed Ion Exchangers

2 x 50% Reverse Osmosis Units

RO Reject

Neutralization Tank

Neutralized Regenerant

Spent Regenerant

Forced Draft Degasifier

2 x 100% Mixed Bed Ion Exchangers

2 x 50% Reverse Osmosis Units

RO Reject

Neutralization Tank

Neutralized Regenerant

Spent Regenerant
Southern Co Plant Harris
Edmonton, Alberta
Gold Bar Municipal WWT Plant

1.3 MGD Muni Effl to UF to RO for Boiler/Cooling Makeup
Effluent Quality Gold Bar UF

Silt Density Index
Nov’06-Mar’07

Influent Conductivity
Nov’06-Mar’07

Phosphate
April’06 - March ’07 In ppm

- 6
- 5
- 4
- 3
- 2
- 1
- 0
- 1
- 2
- 3
- 4
- 5
- 6

1 23 45 67 89 111 133 155 177 199 221 243 265 287
Operating Scenarios
Potential Membrane Solutions for Boiler Process Systems

1. RO in front of existing demineralizers
2. RO in front of, or to replace existing softeners
3. New plant—RO/MB or Demin/MB?
4. 2 pass RO/EDI to replace resin-based demineralizer - Mixed-bed quality train
5. Ultrafiltration in front of demin. or RO to replace traditional filtration/clarification
Potential Operating Systems
Boiler Feedwater / High Purity Water System

Membrane Pre-treatment

Reverse Osmosis System

Ion Exchange System Or E-Cell

GE imagination at work
ZeeWeed® & RO – The Ideal Partnership

Ensure RO reliability
Superior RO system protection
Silt density index (SDI) < 2
Process simplification
Higher RO flux rates
Experience – > 90 UF/RO plants

Reduced capital and operating costs
Minimal downtime means virtually no production or process interruptions
$ The biggest bang for your buck $
Addition of RO ahead of Existing Demin

Reduced acid & caustic regenerant costs
  – 85 – 90% reduction in regenerant usage is typical

10 to 15% more feedwater production each month

90% less high TDS regenerant waste

Extended ion exchange resin life
  – 40 – 50% extension in resin life typical
  – Much longer regen. cycles & reduced iron/organic fouling

Improved feedwater & steam quality
  – Sodium & silica slippage & breaks reduced
**Benefits of RO:**
- Reduced acid and caustic costs
- Improved Demin water quality
- Reduced labor required
- Reduced chemical discharge
- Extended ion exchange resin life
RO preceding Demineralizer
Example with relatively inexpensive water and sewerage
RO cost justified above approx. 230 ppm TDS

RO to precede Demin. $0.50/kgal raw water / $0.50/kgal waste

Demin.

Capital and operating cost of RO included
Logical candidates for analysis
Softener and/or Dealkalizer to RO

- Boiler cycles limited to 20 or less (5% or more blowdown)
- High alkalinity and/or high silica waters - cycles limiting or scale-forming
- Steam treatment costs excessive due to high alkalinity make-up
- Steam purity is critical – turbines; steam contact with process; clean steam generators
- Amine feed is not permitted or desired
- Systems without blowdown heat recovery (or inoperable/inefficient blowdown HX)
HPI Facility with High TDS Well Water using Dealkalizer and NaZ Softener

**Basis**

BD BTU compared to 90F water ("free process preheat"), no BD heat recovery

$8.00 per mill BTU

85% incremental fired heater efficiency

Condensate return = 20%
Base Situation Flow Balance

600 psi Boiler Systems
Basic Flow Diagrams for Boiler Feedwater Pretreatment
BaseCase
Current Feedwater Pretreatment

570 gpm out with 618 in
Waste 48 usgpm
Impact of UF, RO on Flow Balance

Basic Flow Diagrams for Boiler Feedwater Pretreatment
Feedwater Pretreatment with UltraFiltration and Reverse Osmosis—Higher Cycles

516 gpm out with 728 in
Waste 37 usgpm
Conversion from Softened to RO make-up

- **Improved steam purity**
  > Process/Turbine

- **Improved condensate corrosion control**
  > High-alkalinity waters

- **Minimizes operating and maintenance expenses**
  > Boiler waterside and steamside failures

- **Maintains optimal thermal performance**
  > Boiler and steam heat transfer efficiency

- **Reduced chemical treatment costs**
  > Higher cycles operation – less wastage
  > Lower steam system treatment requirements
RO to precede NaZ

**Basis**

- **Raw water cost, $/1000 usg**: $0.25
- **Sewer cost, $/1000 usg**: $0.25
- **Electricity cost, $ / Kwh**: $0.06
- **Fuel Cost, $/MM BTU**: $8.00
- **Boiler efficiency, %**: 85.0%
- **Salt $/lb**: $0.04
- **Acid 100% $/lb**: $0.05
- **Caustic 100% $/lb**: $0.24
## Summary-Options for Well Water Treatment

<table>
<thead>
<tr>
<th>Option</th>
<th>BaseCase</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing Configuration, WAC, Decarb., Na Zeolite</td>
<td>Filtration, Demin, WAC, SAC, Decarb., SBA</td>
<td>Iron Oxidation, Filtration, RO, Na Zeolite</td>
<td>Iron Oxidation, Ultrafiltration, RO, Na Zeolite</td>
</tr>
<tr>
<td>Flows, gpm, ave</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Well Water In</td>
<td>618</td>
<td>686</td>
<td>804</td>
<td>804</td>
</tr>
<tr>
<td>Produced Water to BFW</td>
<td>570</td>
<td>570</td>
<td>570</td>
<td>570</td>
</tr>
<tr>
<td>Regen Waters to Waste</td>
<td>48</td>
<td>89</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>RO Reject to Waste</td>
<td></td>
<td></td>
<td>193</td>
<td>193</td>
</tr>
<tr>
<td>MMF reject to Waste</td>
<td></td>
<td>27</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>UF Reject to Waste</td>
<td></td>
<td></td>
<td></td>
<td>32</td>
</tr>
<tr>
<td>Characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDS to BFW, ppm (includes condn rt) =</td>
<td>157</td>
<td>&lt;3</td>
<td>&lt;12</td>
<td>&lt;12</td>
</tr>
<tr>
<td>Silica to BFW, ppm</td>
<td>11.1</td>
<td>0.1</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Boiler Cycles Based on Silica</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 psi at 40 ppm</td>
<td>3.6</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>450 psi at 90 ppm</td>
<td>8</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>120,50 psi at 150 ppm</td>
<td>14</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Option</td>
<td>BaseCase</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>----------</td>
<td>------------</td>
<td>------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td></td>
<td>Existing</td>
<td>Filtration, Demin, WAC, SAC, Decarb., SBA</td>
<td>Iron Oxidation, Filtration, RO, Na Zeolite</td>
<td>Iron Oxidation, Ultrafiltration, RO, Na Zeolite</td>
</tr>
<tr>
<td>Operating Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ion Exchange Operating Costs, $ per kgal produced</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prefilter Polymer</td>
<td></td>
<td>$0.05</td>
<td>$0.06</td>
<td>$0.02</td>
</tr>
<tr>
<td>Salt at $.04/lb, 6 lb/ft³, 3.5x/day</td>
<td></td>
<td>$0.06</td>
<td></td>
<td>$0.02</td>
</tr>
<tr>
<td>Acid at $.05/lb, 4 lb/ft³, 3.7x/day</td>
<td></td>
<td>$0.14</td>
<td>$0.18</td>
<td></td>
</tr>
<tr>
<td>Caustic at $.24/lb 100%</td>
<td></td>
<td></td>
<td>$0.64</td>
<td></td>
</tr>
<tr>
<td>Neutralisation Caustic at $.24/lb 100%</td>
<td></td>
<td>$0.29</td>
<td>$0.01</td>
<td></td>
</tr>
<tr>
<td>Raw water at $.25/kgal</td>
<td></td>
<td>$0.27</td>
<td>$0.30</td>
<td>$0.35</td>
</tr>
<tr>
<td>WWT at $.25/kgal</td>
<td></td>
<td>$0.02</td>
<td>$0.05</td>
<td>$0.10</td>
</tr>
<tr>
<td>Resin Replacement, 7 yr life</td>
<td></td>
<td>$0.05</td>
<td>$0.08</td>
<td>$0.02</td>
</tr>
<tr>
<td>Resin cleaner estimation $15,000/year</td>
<td></td>
<td>$0.05</td>
<td></td>
<td>$0.00</td>
</tr>
<tr>
<td>Decarbonator (Power + NaOH)</td>
<td></td>
<td>$0.05</td>
<td>$0.05</td>
<td>$0.04</td>
</tr>
<tr>
<td><strong>RO, UF Costs, $ per kgal produced</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemicals, cleaning, antiscalant,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dechlor</td>
<td></td>
<td></td>
<td></td>
<td>$0.23</td>
</tr>
<tr>
<td>RO Power cost at $.06/kwh</td>
<td></td>
<td></td>
<td></td>
<td>$0.24</td>
</tr>
<tr>
<td>RO membrane &amp; cartridge replacement cost</td>
<td></td>
<td></td>
<td></td>
<td>$0.16</td>
</tr>
<tr>
<td><strong>Total Operating Costs, per kgal of prod</strong></td>
<td></td>
<td>$0.93</td>
<td>$1.37</td>
<td>$1.21</td>
</tr>
<tr>
<td><strong>$ per year, 570 gpm product</strong></td>
<td></td>
<td>$277,690</td>
<td>$409,536</td>
<td>$363,552</td>
</tr>
<tr>
<td><strong>$ per year at required BFW rate</strong></td>
<td></td>
<td>$277,690</td>
<td>$370,738</td>
<td>$329,110</td>
</tr>
</tbody>
</table>
# Blowdown Rate and Heat Savings Available

## BaseCase

<table>
<thead>
<tr>
<th>Steam Pressure (psi)</th>
<th>Steam Rate (lb/hr)</th>
<th>BaseCase Cycles</th>
<th>% BD</th>
<th>FW (lb/hr)</th>
<th>BD (lb/hr)</th>
<th>LiqBTU (Btu/lb)</th>
<th>BD Heat Lost (BTU/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>10,000</td>
<td>3.6</td>
<td>28%</td>
<td>13,846</td>
<td>3,846</td>
<td>475</td>
<td>1,603,846</td>
</tr>
<tr>
<td>450</td>
<td>80,000</td>
<td>8</td>
<td>13%</td>
<td>91,429</td>
<td>11,429</td>
<td>441</td>
<td>4,377,143</td>
</tr>
<tr>
<td>120</td>
<td>190,000</td>
<td>14</td>
<td>7%</td>
<td>204,615</td>
<td>14,615</td>
<td>321</td>
<td>3,843,846</td>
</tr>
<tr>
<td>50</td>
<td>52,000</td>
<td>14</td>
<td>7%</td>
<td>56,000</td>
<td>4,000</td>
<td>267</td>
<td>836,000</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td></td>
<td><strong>365,890</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>10,660,835</strong></td>
</tr>
</tbody>
</table>

$\$/yr $878,955$

## High Cycles w RO, NaZ

<table>
<thead>
<tr>
<th>Steam Pressure (psi)</th>
<th>Steam Rate (lb/hr)</th>
<th>BaseCase Cycles</th>
<th>% BD</th>
<th>FW (lb/hr)</th>
<th>BD (lb/hr)</th>
<th>LiqBTU (Btu/lb)</th>
<th>BD Heat Lost (BTU/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>10,000</td>
<td>50</td>
<td>2%</td>
<td>10,204</td>
<td>204</td>
<td>475</td>
<td>85,102</td>
</tr>
<tr>
<td>450</td>
<td>80,000</td>
<td>50</td>
<td>2%</td>
<td>81,633</td>
<td>1,633</td>
<td>441</td>
<td>625,306</td>
</tr>
<tr>
<td>120</td>
<td>190,000</td>
<td>50</td>
<td>2%</td>
<td>193,878</td>
<td>3,878</td>
<td>321</td>
<td>1,019,796</td>
</tr>
<tr>
<td>50</td>
<td>52,000</td>
<td>50</td>
<td>2%</td>
<td>53,061</td>
<td>1,061</td>
<td>267</td>
<td>221,796</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td></td>
<td><strong>338,776</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1,952,000</strong></td>
</tr>
</tbody>
</table>

$\$/yr $160,937$

---

### Feedwater Savings

\[
\text{Savings} = 27,115 \text{ lb/hr} \times 54 \text{ gpm}
\]

\[
\text{Savings} = \frac{27,115 \times 54}{2080} \approx 718,018 \text{ per year}
\]

### Blowdown Heat Savings

\[
\text{Savings} = 718,018 \text{ per year}
\]
Additional benefits of RO-quality make-up water to boilers

**Improved steam purity for process and turbomachinery**
- Greatly reduced dissolved solids reduce carryover potential
- Greatly reduced loading on blowdown heat recovery system

**Improved boiler efficiency & reliability**
- Reduced potential for scale deposits
- Reduced potential for boiler tube failure due to scale/overheating

**Reduced corrosivity of steam to processing equipment**
- Reduced carbonic acid loading and amine demand
- Reduced carryover potential from alkalinity
GE Water & Process Technologies

Economic Models

Presented by
GE
Water & Process Technologies
3 New powerful tools for quick evaluation providing value to our customers

Cost evaluation RO in front of existing demin

Cost evaluation RO with existing Softener

Operating Cost evaluation UF/RO with existing Softener VS Hot Lime Softener
Tools benefits:
Calculate operating cost of existing system
Calculate and compare operating cost using RO technology
Calculate pay-back time in years
Provide hard and soft saving
Single tool quickly and accurately evaluates project potential
Operating Cost evaluation RO in front of New Softener versus Existing Dealkaliser

Please select the unit system you want to use:

1 = US or 2 = Metric

Please enter the water analyses into the yellow cells

<table>
<thead>
<tr>
<th>Raw Water</th>
<th>Feed water contaminant</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPM as CaCO3</td>
<td>PPM</td>
</tr>
<tr>
<td>Hardness</td>
<td>284</td>
</tr>
<tr>
<td>M alkalinity</td>
<td>22</td>
</tr>
<tr>
<td>Silica</td>
<td>13</td>
</tr>
<tr>
<td>Conductivity</td>
<td>270</td>
</tr>
<tr>
<td>Iron</td>
<td>0.1</td>
</tr>
<tr>
<td>pH</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Please enter the Plant operation conditions & Assumptions

| Operating days per year | 365 |
| Stear rate average, lbs/hr | 334,500.0 |
| Boilers pressure, systems vary from 50 to 600 psi | 50 to 600 psi |
| Estimated % Make-up | 77.5% |
| Make-up water usgpm (calculated) | 570.01 |
| Dearator Pressure, psig | 7.3 |
| Feedwater Dissolved Oxygen (ppb) | 7 |
| Raw water cost, $/1000 usg | 0.250 |
| Sewer cost, $/1000 usg | 0.250 |
| Electricity cost, $/Kwh | 0.06 |
| Fuel Cost, $/MM BTU | 6.50 |
| Heat recovery system installed and working | 0 |
| Boiler efficiency, % | 80% |

Dealkalizer / Softener operation

| Salt dosage, lbs/ft | 6 |
| Salt - acid unit cost, $/lb | 0.04 |
| Resin expected live in years | 8 |
| Resin SAC estimated cost, $/cft | $50 |
| Resin capacity, kgr/ft3 | 20.69 |
| Resin cleaners estimated yearly cost | 15,000 |
| WAC | $70 |

RO information input

| Average water temperature | 90.0 F |

Boiler system Operating conditions (cycles)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>min</th>
<th>max</th>
<th>average</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>2,500</td>
<td>3,000</td>
<td>2,750</td>
<td>12.8</td>
</tr>
<tr>
<td>M Alkalinity</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>17.6</td>
</tr>
<tr>
<td>Silica</td>
<td>90</td>
<td>150</td>
<td>120</td>
<td>10.8</td>
</tr>
<tr>
<td>Sulfite residual</td>
<td>20</td>
<td>40</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RO Pump inlet pressure</th>
<th>30.0 psi</th>
<th>RO Pump outlet pressure</th>
<th>280.0 psi</th>
<th>PSI increase</th>
<th>250.00 psi</th>
<th>% Recovery</th>
<th>75%</th>
<th>Pump efficiency %</th>
<th>65%</th>
<th>Motor efficiency %</th>
<th>95%</th>
</tr>
</thead>
</table>
### Operating Systems comparison

<table>
<thead>
<tr>
<th></th>
<th>With Dealkaliser</th>
<th>With RO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make-up water required, usgpm</td>
<td>570.0</td>
<td>515.8</td>
</tr>
<tr>
<td>Daily make-up water, usg/day</td>
<td>820,821.0</td>
<td>742,699.9</td>
</tr>
<tr>
<td>Boiler Cycles of Concentration (average)</td>
<td>10.841</td>
<td>50,000</td>
</tr>
<tr>
<td>% Boiler blowdown</td>
<td>9.2%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Boiler Blowdown, lbs/hr</td>
<td>33,990.7</td>
<td>6,826.5</td>
</tr>
<tr>
<td>Treatment Cost, $/MM lbs steam (estimated)</td>
<td>$120.23 $</td>
<td>$37.20</td>
</tr>
</tbody>
</table>

### Economic Comparison with annual operating cost

<table>
<thead>
<tr>
<th></th>
<th>Existing Dealkaliser</th>
<th>RO in front of New Softener system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regeneration cost salt, acid, NaOH, Power</td>
<td>160,000 $</td>
<td>15,390 $</td>
</tr>
<tr>
<td>Resin cleaners cost</td>
<td>15,000 $</td>
<td>0 $</td>
</tr>
<tr>
<td>Resin replacement cost</td>
<td>14,410 $</td>
<td>5,432 $</td>
</tr>
<tr>
<td>Boiler Treatment Chemicals cost (estimated)</td>
<td>352,000 $</td>
<td>109,000 $</td>
</tr>
<tr>
<td>Fuel Cost Associated with Blowdown</td>
<td>879,000 $</td>
<td>161,000 $</td>
</tr>
<tr>
<td>Raw water cost total</td>
<td>78,947 $</td>
<td>95,604 $</td>
</tr>
<tr>
<td>Sewer cost total</td>
<td>9,334 $</td>
<td>27,802 $</td>
</tr>
<tr>
<td>RO operating cost (electricity, chemicals, cleaning,</td>
<td>181,438 $</td>
<td></td>
</tr>
<tr>
<td>membranes &amp; filters replacement)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total operating cost</td>
<td>1,508,690 $</td>
<td>595,666 $</td>
</tr>
<tr>
<td>Annual saving</td>
<td></td>
<td>913,024 $</td>
</tr>
</tbody>
</table>

Other annual saving considering water and steam quality improvement: 110,000 $

Annualized RO Equipment Total Project Cost: 1,690,000 $

Pay back time in years based on finance period: 1.65
Tools partitions – soft saving section

**Other Benefits of RO quality BFW make-up to that can possibly be translated into annual savings**

Savings must be validated to specific Customer conditions, all may or may not apply.

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$25,000</td>
<td>Improved steam purity, less foaming and carry over.</td>
</tr>
<tr>
<td>$0</td>
<td>Improved purity of products/processes contacted by steam</td>
</tr>
<tr>
<td>$15,000</td>
<td>Improved steam equipment reliability and efficiency (especially steam turbines)</td>
</tr>
<tr>
<td>$0</td>
<td>Improved steam heat transfer and turbine efficiency</td>
</tr>
<tr>
<td>$0</td>
<td>Improved safety – reduced chance of catastrophic failure</td>
</tr>
<tr>
<td>$0</td>
<td>Reduced potential for scale deposits: extended equipment life</td>
</tr>
</tbody>
</table>

Improved boiler efficiency, **KEY SAVINGS POTENTIAL**. If Boiler tubes have deposits it can be calculated as % efficiency gain, estimation of 1% efficiency for this account 1% is equivalent to: $90,300 annual saving

| $45,000 | ecomagination - less fuel burned = less "Green House Gases"                |
| $5,000  | ecomagination - less "CO2 Emission" you can estimate $10 per ton of CO2 reduction |
| $0      | You can enter here others benefits that are not listed                      |
| $0      | You can enter here others benefits that are not listed                      |

Maintenance cost reduction on condensate return lines and traps

| $20,000 | Typically a 10 to 20% cost reduction savings on existing maintenance.       |
| $110,000| **Total** $ claimed for other annual benefits                               |
3 New powerful tools for quick evaluation providing value to our customers

GE Water & Process Technologies

Customer: XYZ Plant
Date: 24-Feb-07
Consultant: M. Joe Blow

Cost evaluation RO in front of existing demin

Cost evaluation RO with existing Softener

Operating Cost evaluation UF/RO with existing Softener VS Hot Lime Softener
Summary

Membrane systems can save you money and potentially water for utility applications

New systems are predominately moving to an all-membrane approach

The green approach!!