WestVirginiaUniversity

Produced Water and Waste Heat-aided Blowdown Water Treatment: Using Chemical and Energy Synergisms for Value Creation

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West Virginia University

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Research Objective & Expected Outcome

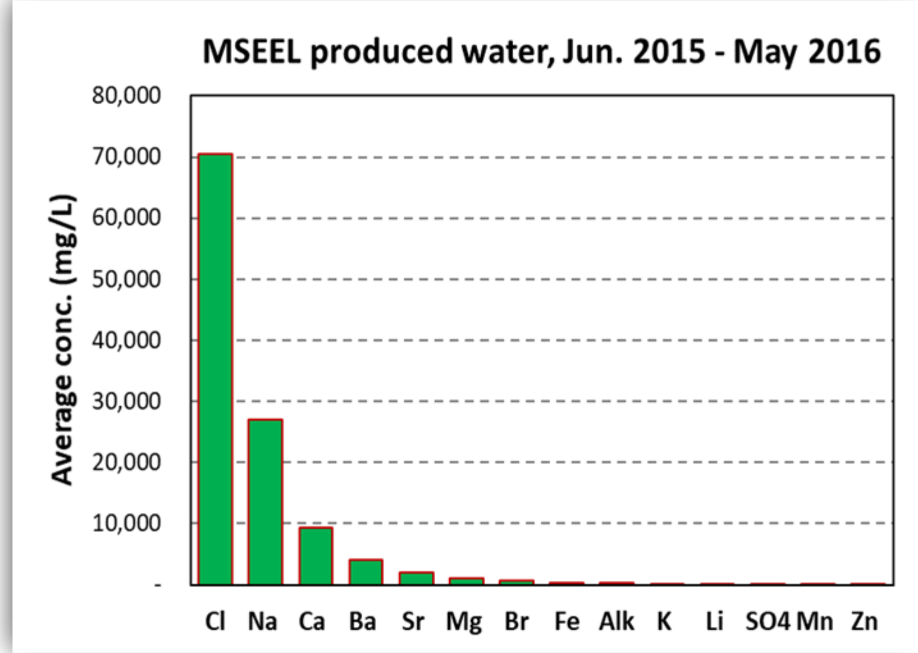
- **Objective:**
  To develop a blowdown (BD) water treatment process utilizing produced water (PW) and waste heat

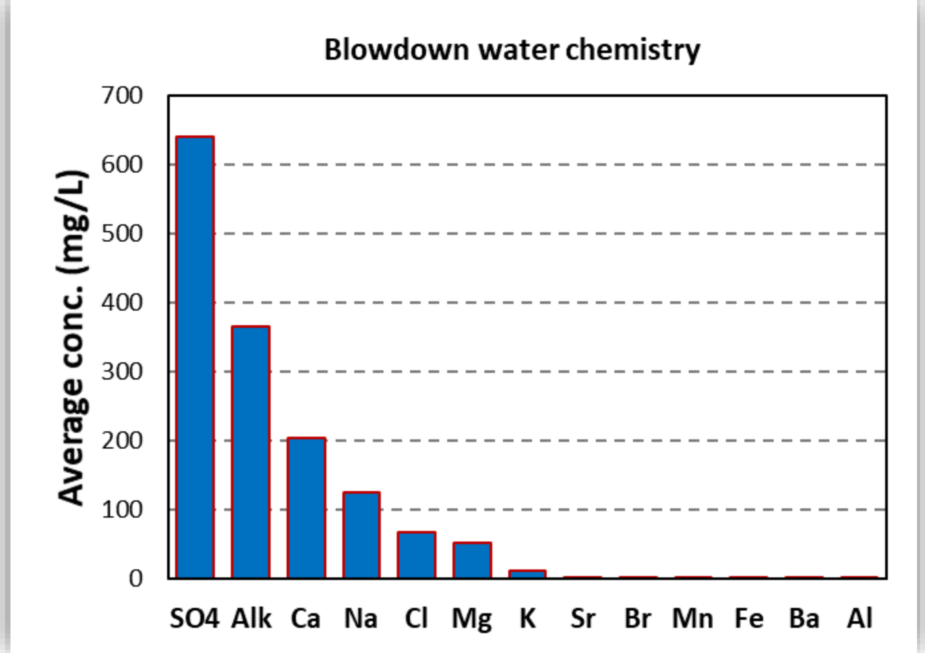
- **Expected Outcome:**
  Maximization of water reuse and saleable by-product generation while achieving a step-improvement of chemical and energy footprints of the treatment

Complementary Chemistry of BD and PW

- **High TDS concentration of produced water**
  Increase the TDS concentration of feed stream to RO treatment

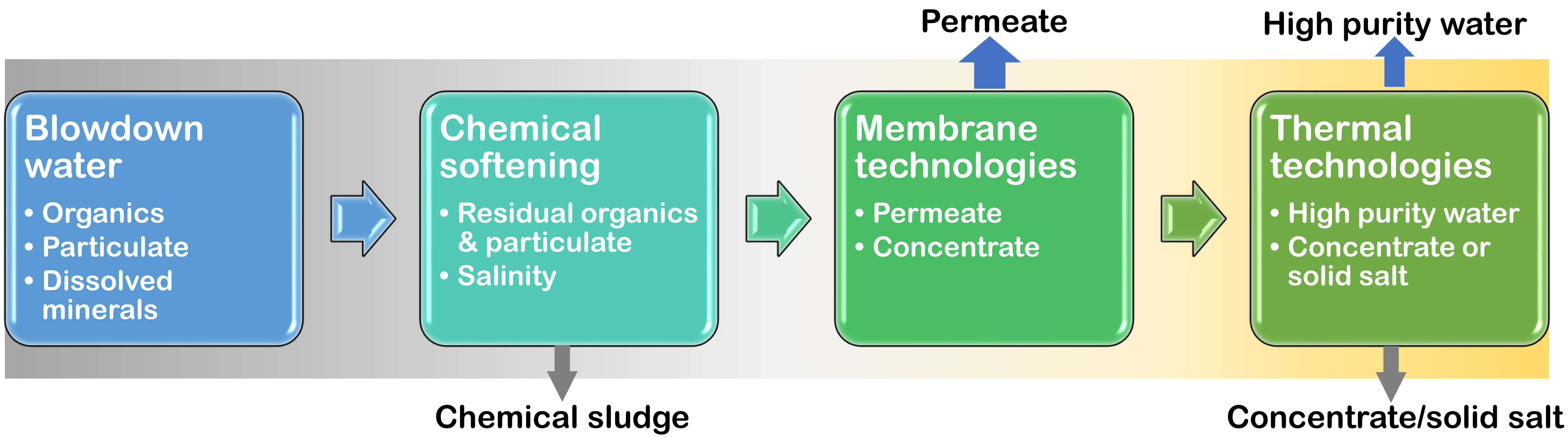
- **High sulfate and carbonate concentration of blowdown water**
  Form chemical precipitation with scale-forming cation in the PW (e.g., Ca^{2+}, Ba^{2+}, Sr^{2+})

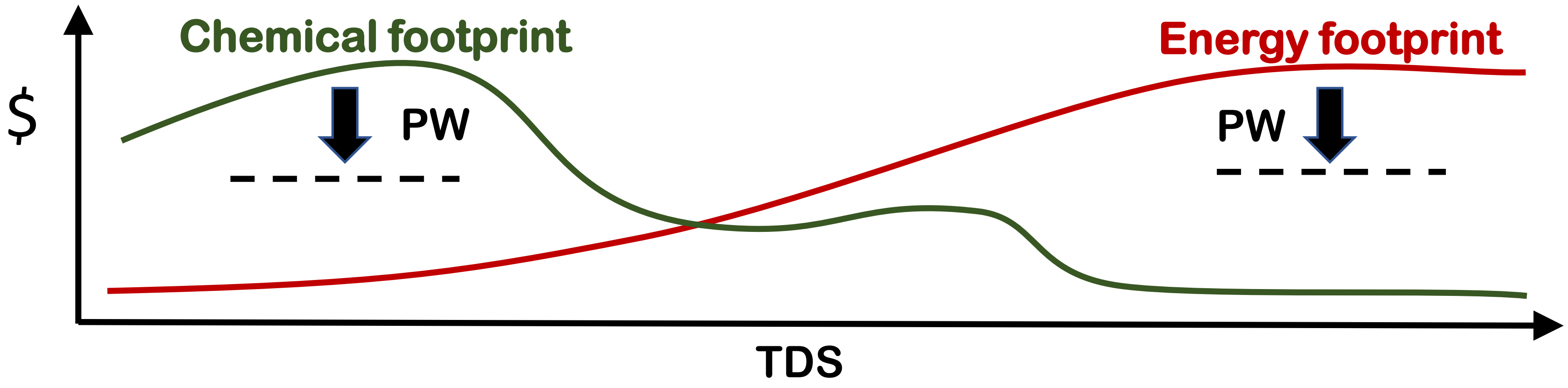




WVU Marcellus Shale Energy and Environment Laboratory (MSEEL) production well

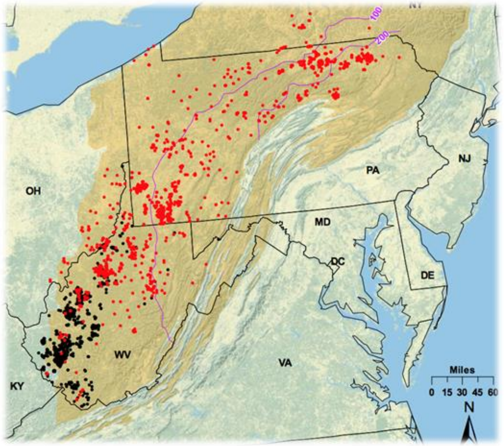
Baseline and Produced Water (PW)-aided Treatment

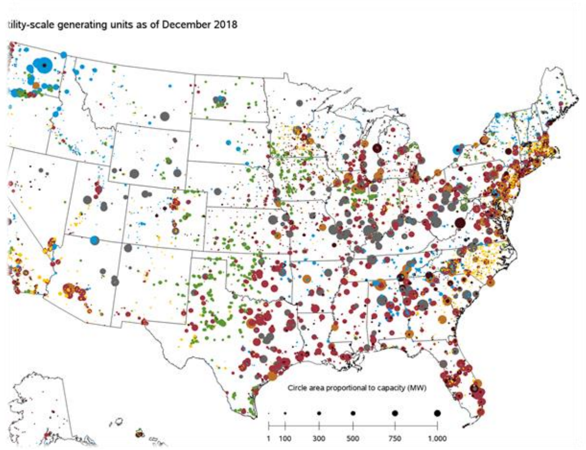


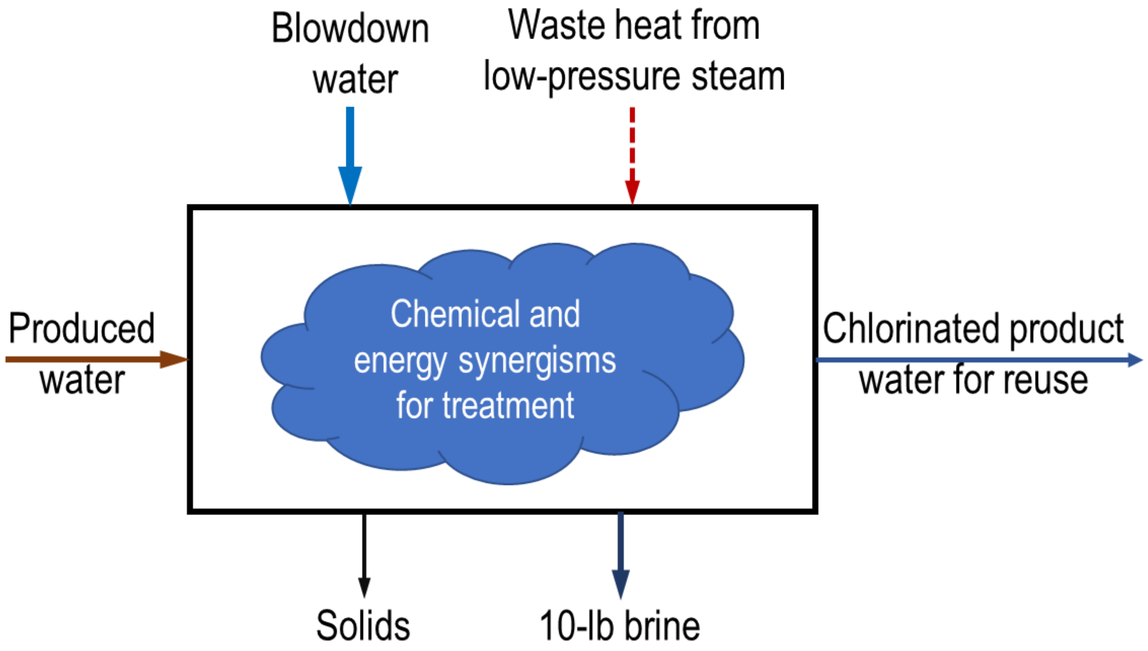


A Regional Solution

- Innovative approach for co-management of PW and BD water
- Chemical and energy synergisms
- Useful products
  - RO permeate for cooling makeup
  - 10-lb brine as saleable product
  - NaOH and Cl_2 generation







Co-treatment Process

1. Mixing

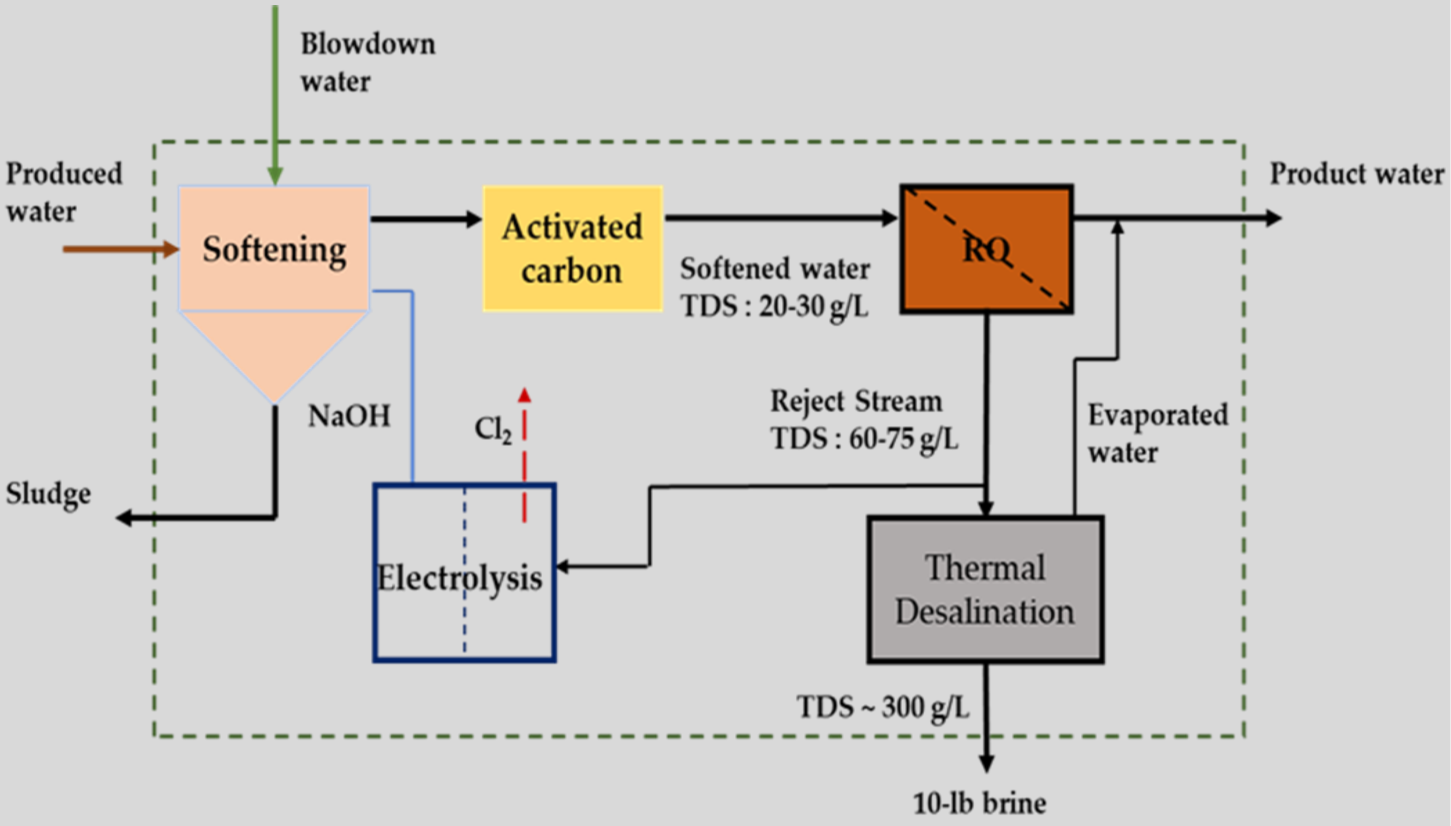
2. Chemical softening

3. Activated carbon filtration

4. Reverse osmosis
   - permeate and concentrate

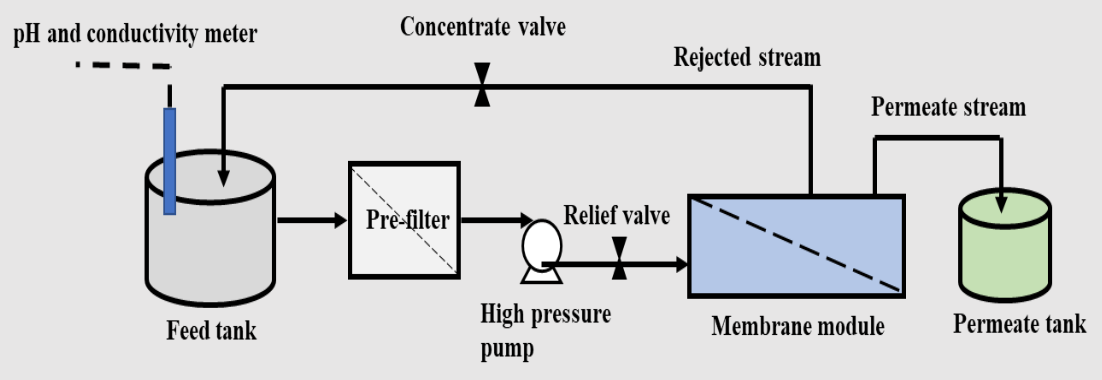
5. Thermal desalination
   - 10-lb brine

6. Brine electrolysis
   - NaOH and Cl_2 generation



Treatment Units

1. Mixing and softening
2. Activated carbon filtration
3. Reverse osmosis (RO)



Mixing and Softening

Parameters	PW	BD	Mix(10:1)*	Softening
pH	5.7	7.3	6.9	12.1
Sulfate (mg/L)	<0.01	700	215 (70%)	225
Calcium (Ca, mg/L)	14,000	160	1900	2.3 (100%)
Magnesium (Mg, mg/L)	1600	50	200	0.16 (100%)
Barium(Ba, mg/L)	11,000	0.1	100 (90%)	2.0 (98%)
Strontium (Sr, mg/L)	4800	1.6	480	6.0 (99%)
Iron (Fe, mg/L)	80	<0.01	4.0	0.2 (95%)
Silicon (Si, mg/L)	10.5	9.0	18	7.0 (60%)
Lithium (Li, mg/L)	30	<0.048	6.0	5.8

Note: percentages in parentheses are percent removal as a result of the treatment unit
*Volumetric Mixing ratio of BD to PW is 10 to 1

Activated Carbon Filtration

Parameters	PW	BD	Mix (10:1)	Activated Carbon
TDS (g/L)	230	1.8	23	20
TOC (mg/L)	13	16	14.5	<3 (90%)
Calcium (Ca, mg/L)	14,000	160	1900	0.04 (98%)
Magnesium (Mg, mg/L)	1600	50	200	0.02 (88%)
Barium(Ba, mg/L)	11,000	0.1	100	<0.02 (100%)
Strontium (Sr, mg/L)	4800	1.6	480	<0.01 (100%)
Iron (Fe, mg/L)	80	<0.01	4.0	0.17 (15%)
Lithium (Li, mg/L)	38	<0.048	6.0	2.9 (50%)

Note: percentages in parentheses are percent removal as a result of the treatment unit
*Volumetric Mixing ratio of BD to PW is 10 to 1

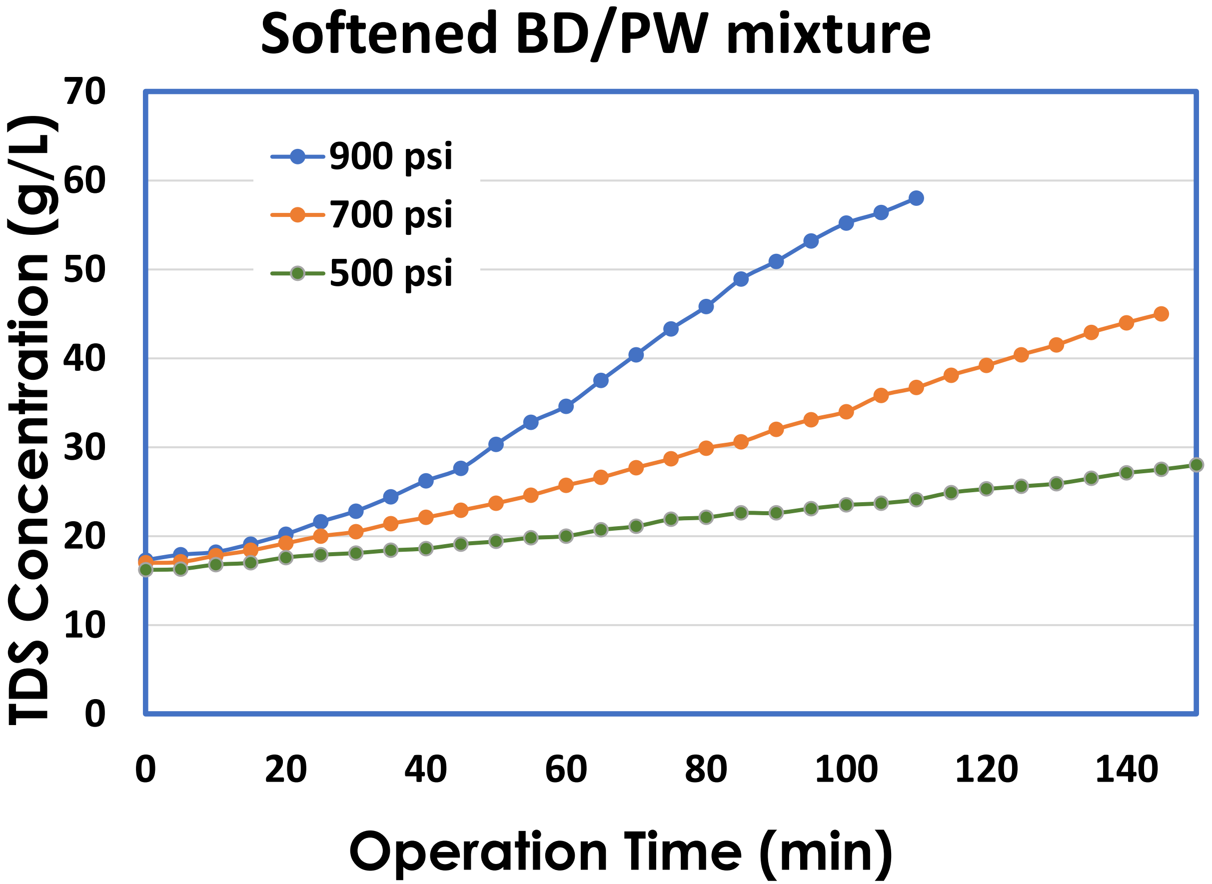
Reverse Osmosis (Batch Treatment)

- **Softened BD/PW mixture**
  Initial Volume : ~70L
  Initial TDS: ~17 g/L
  Initial pH: 10.5 and 8.5

- RO treatment continued until the permeate flow rate decreased to as low as ~0.15 L/min

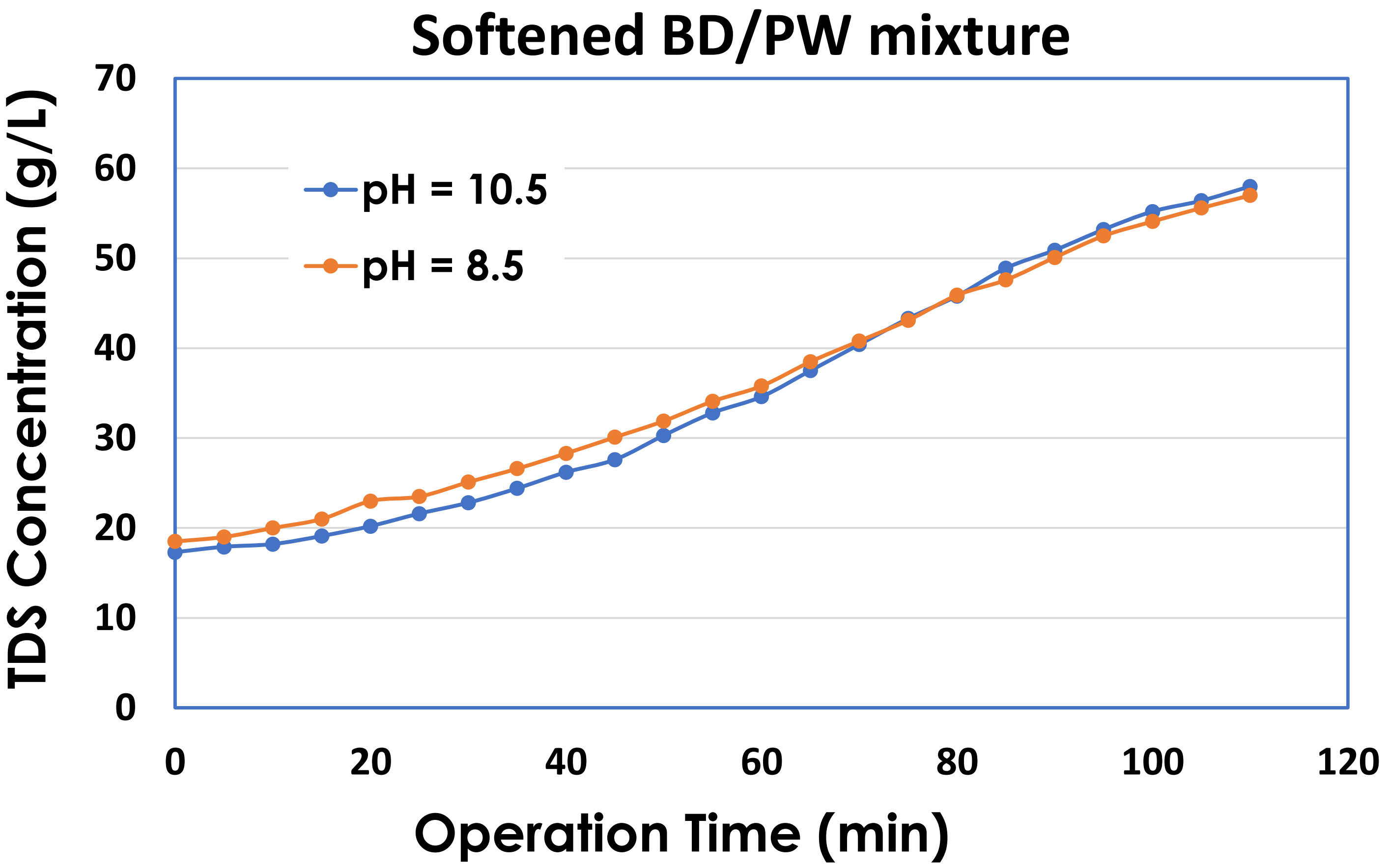
- RO treatment
  - >65% water recovery
  - 99% salt rejection

Reverse Osmosis (Batch Treatment)



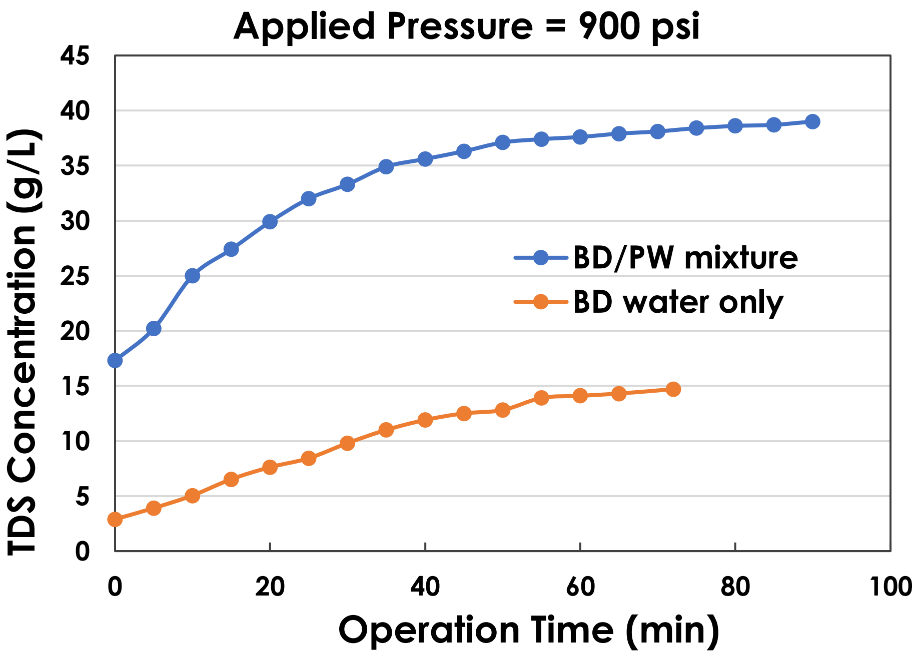
	Applied Pressure		
	500 psi	700 psi	900 psi
Water Recovery	48%	71%	79%
Unit Energy (kWh/L)	0.06	0.05	0.04
Permeate TDS (g/L)	0.6	0.7	0.7

Reverse Osmosis (Batch Treatment)



Permeate flow rate was in the same range for both initial pH

Integrated Process (mixing, softening, AC, RO)

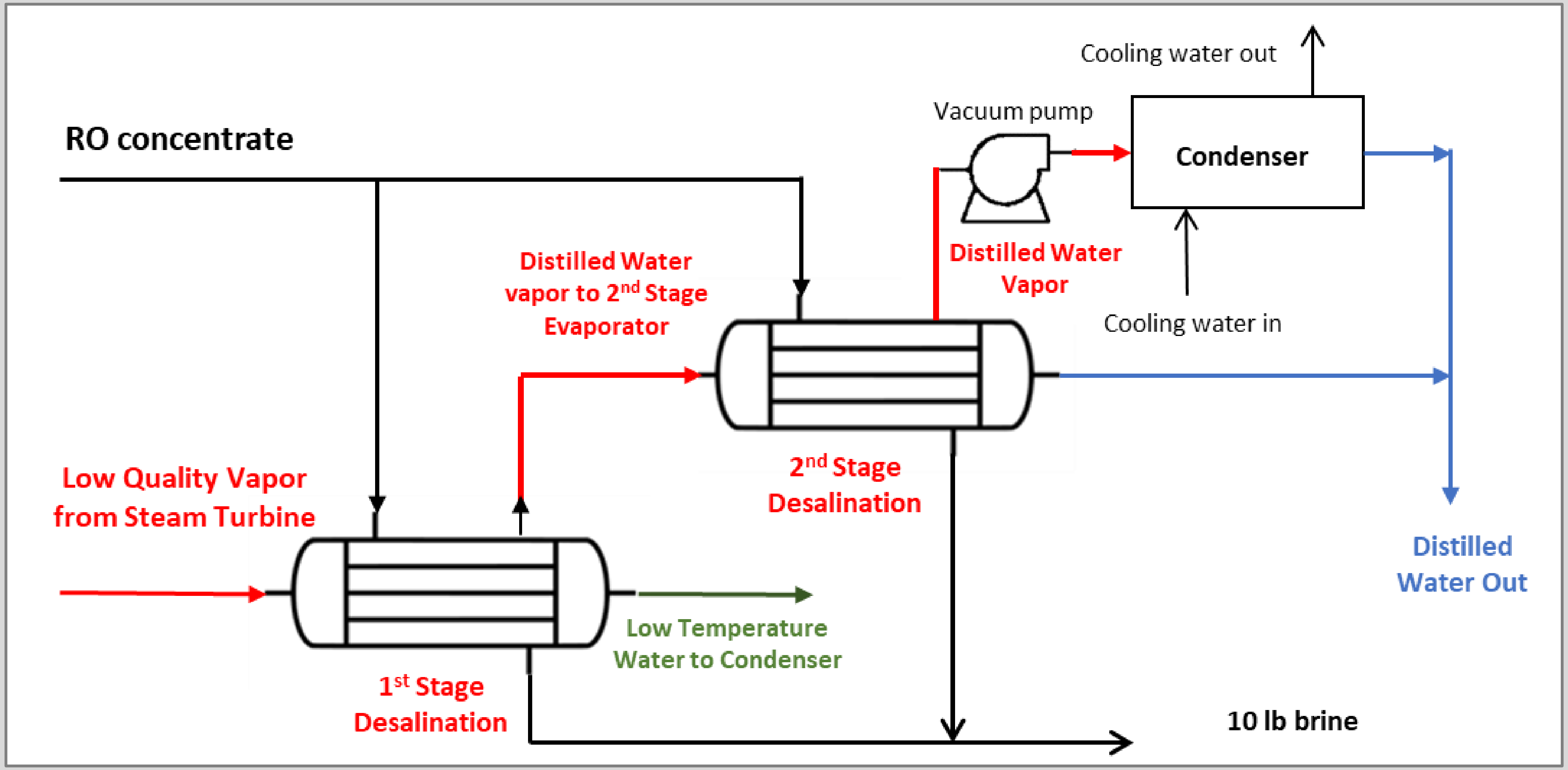


	BD/PW (10:1) Mixture	BD water alone	PW alone	BD+PW (10:1)
Na_2CO_3 (kg/L)	0.006	0.0006	0.1	0.01
NaOH (5M, L/L)	0.01	0.0045	0.2	0.022

	BD/PW (10:1) Mixture	BD water alone	PW alone
Water Recovery	67%	94%	Not feasible w/ RO
Unit Energy (kWh/L)	0.04	0.02	N/A
Permeate TDS (g/L)	0.7	0.2	N/A

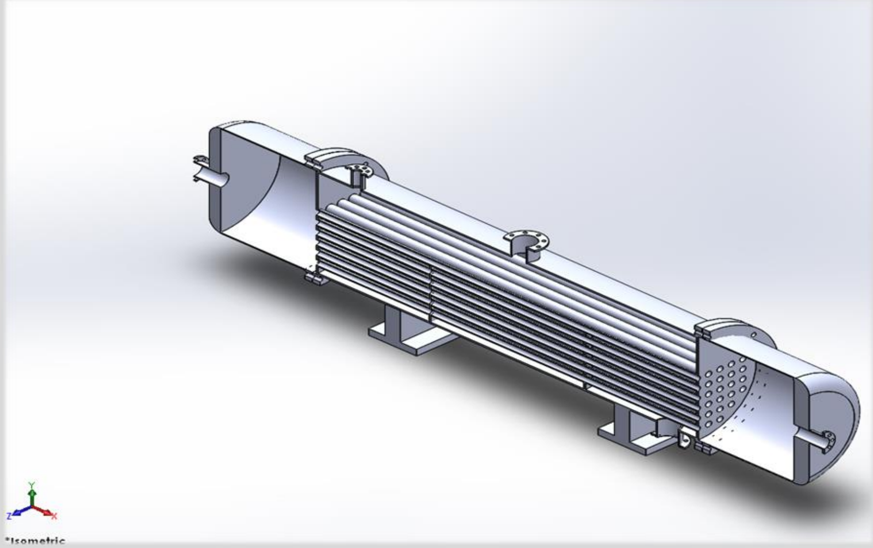
Thermal Desalination

Two-Stage Thermal Desalination System Using Low Quality Vapor from Steam Turbine

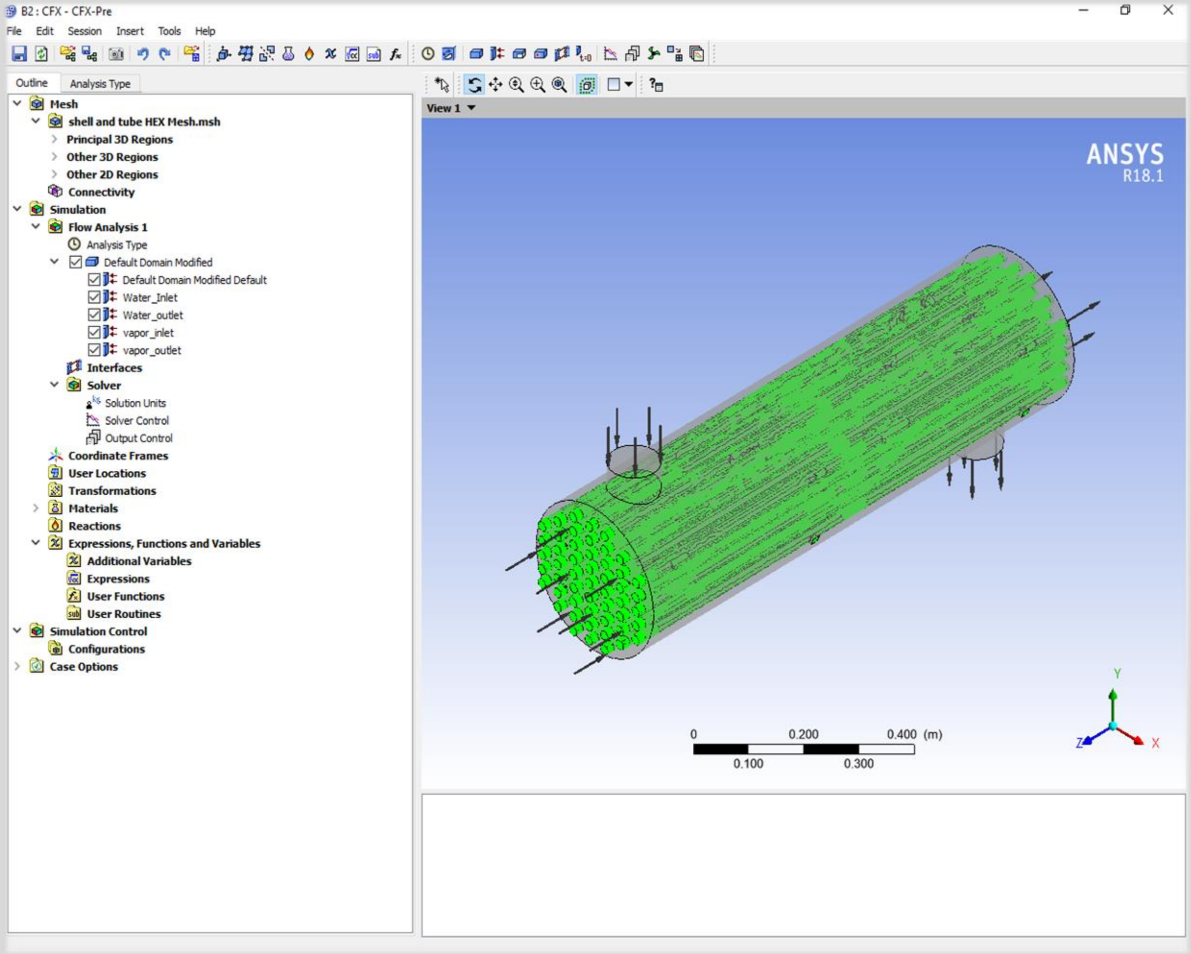


Thermal Desalination

- **Shell-and-Tube design**
  Shell diameter: 0.35 m, length: 1.2 m
  Number of tubes: 50
  Tube material: Copper
  Tube length: 1.07 m
  Tube Inner Diameter: 10 mm
  Tube Out Diameter: 16 mm



- CFD simulations

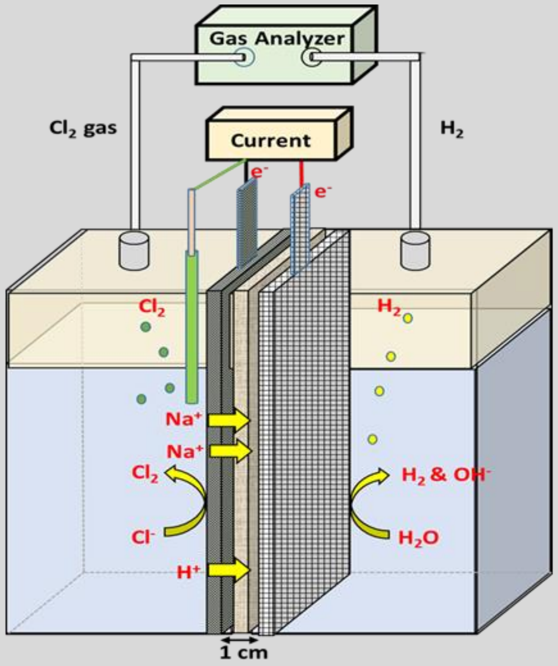


Brine Electrolysis

- Electrolysis of brine

Cathode: $2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-$ or $O_2(g) + 2H_2O + 4e^- \rightarrow 4OH^-$

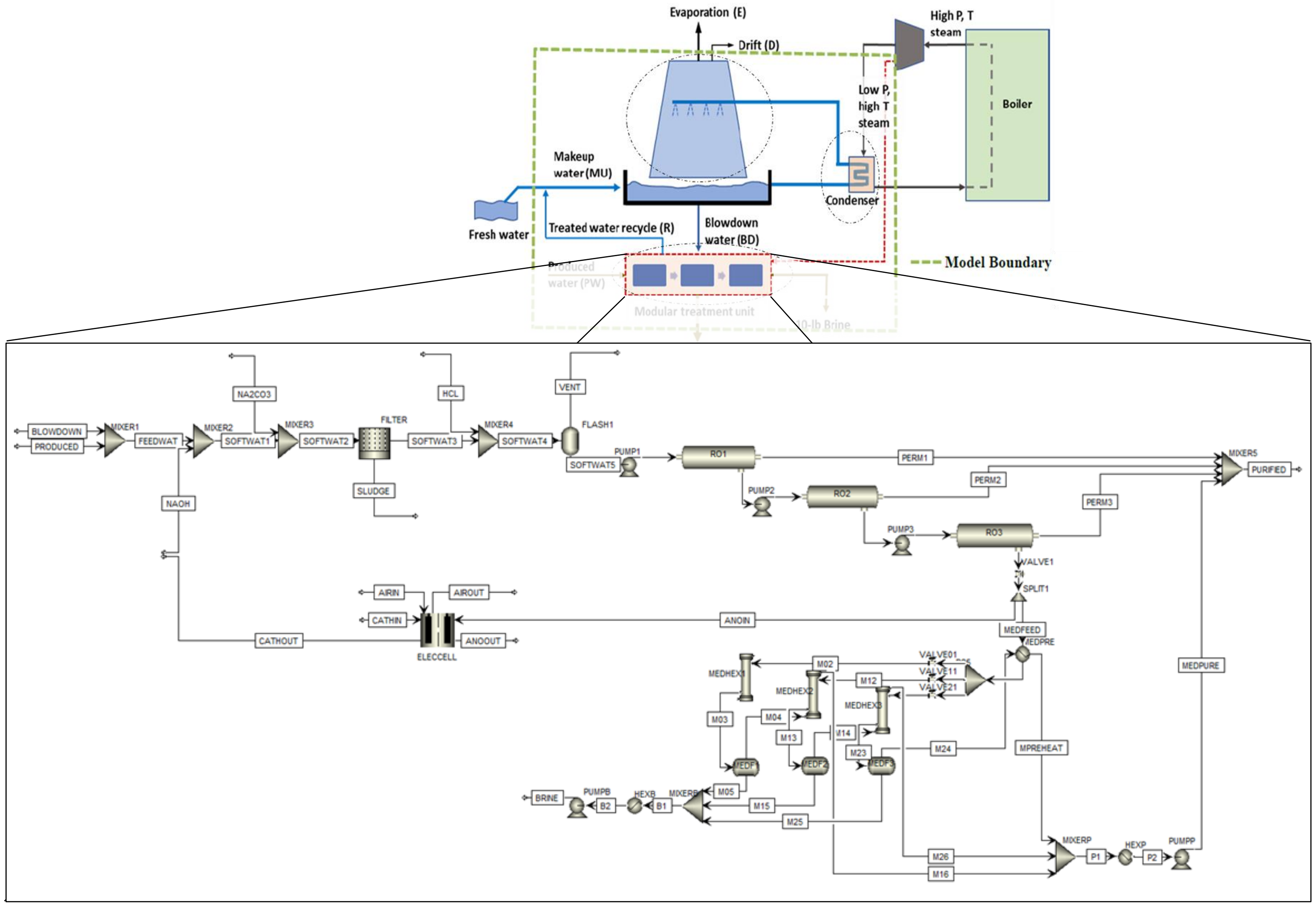
Anode: $2Cl^- \rightarrow Cl_2 + 2e^-$ and $Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^-$



- With NaCl solution (0.5M), current 10 mA/cm^2:
  - Cathodlyte: NaOH (pH > 12, faradic efficiency 93%)
  - Anode: Chlorine (faradic efficiency 32%)

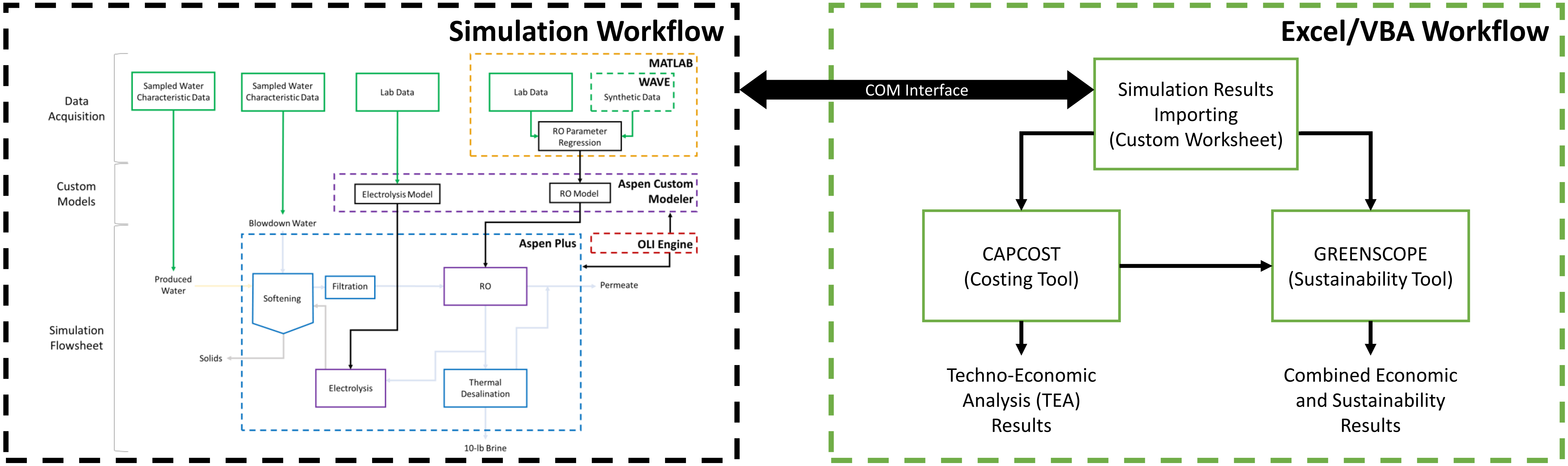
Process Modeling and Simulations

- Simulation flowsheet created in **Aspen Plus** with supplementary imported software models and calculations
- Completed rigorous simulation of the modular treatment unit
    - **OLI Engine** used for thermodynamic calculations
    - **Aspen Custom** models developed for **reverse osmosis** (RO) and **brine electrolysis** units
    - Simulation results are comparable to experimental values



Framework for Simulation and Optimization

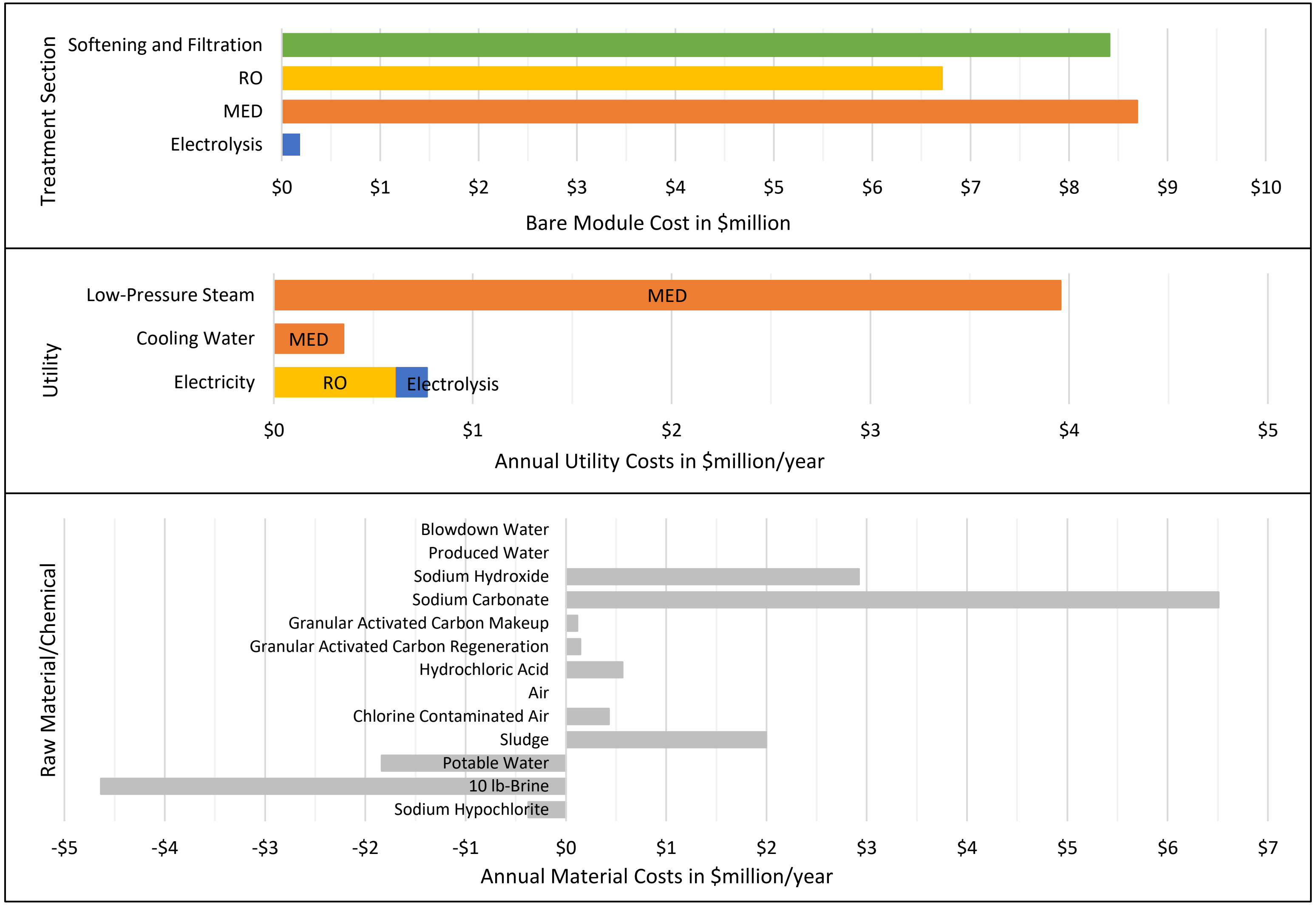
- In the simulation workflow, Aspen Plus uses experimental data, established model results and imported custom models from multiple software platforms
- Ongoing development of a **Visual Basic for Applications (VBA) optimization framework**
  - Aspen operation and importing automated using a component object model (COM) interface
  - Excel tools used for comprehensive techno-economic (**CAPCOST**[1]) and sustainability (**GREENSCOPE**[2]) analyses



[1] Turton, R., et al. (2017). CAPCOST software as part of: Analysis, Synthesis, and Design of Chemical Processes.
[2] Ruiz-Mercado, G. J., et al. (2012). Sustainability indicators for chemical processes: I. Taxonomy.

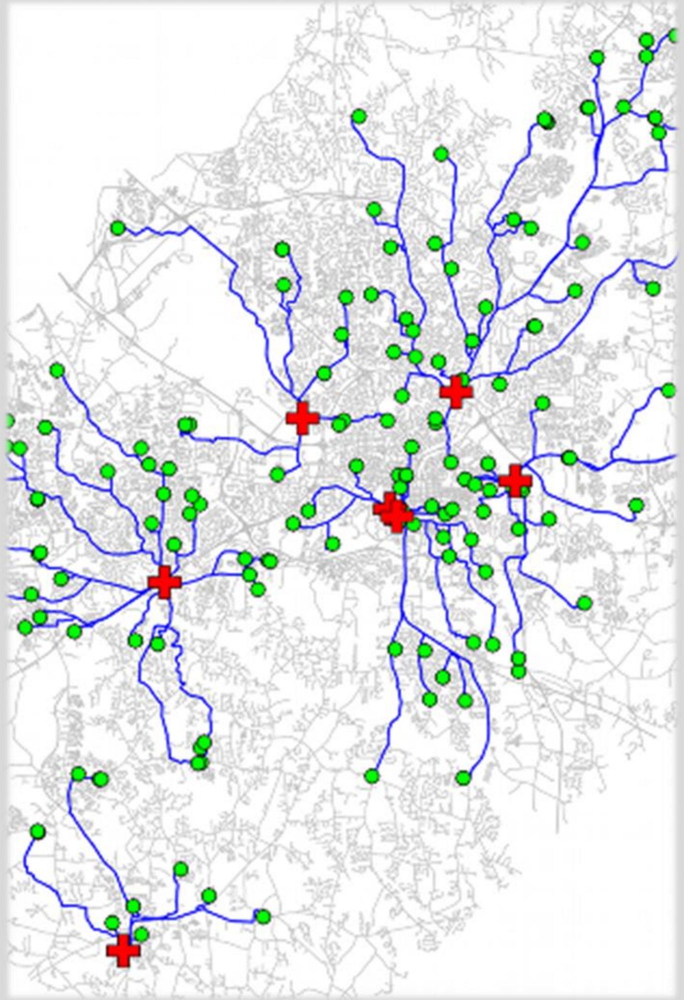
Integrated Treatment Process Cost Distribution

- Preliminary TEA performed for a base case simulation with following design parameters
  - 5:1 blowdown (BD) to produced (PW) water ratio
  - 2.5 MGD (millions of gallons per day) of combined feed flow
  - 3-Stage reverse osmosis (RO)
  - 3-Stage multi-effect distillation (MED)
  - Increased concentration of NaOH for softening by 65 g/L with electrolysis



Future Work

- Integrate the thermal desalination unit
- Quantify chemical and energy demands
- Techno-economic analysis
  - Revenue scenarios
  - CapEX/OpEX implications for material, transportation, waste generation and disposal



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