Evaluating Chemical Softening and Electrocoagulation for Brine Pretreatment

By: Abdiel Lugo, EIT

New Mexico State College of Engineering

Department of Civil Engineering, New Mexico State University, Las Cruces, NM

NAWI
National Alliance for Water Innovation

NREL
Transforming ENERGY

NM STATE

U.S. DEPARTMENT OF ENERGY

SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

BE BOLD. Shape the Future.

New Mexico State University

NMSU – WaterTAP Collaboration

- WaterTAP model development from NMSU as deliverables:
  - Chemical Softening – Lime and Soda Ash ★
  - Electrocoagulation ★
    (Currently available in WaterTAP library as a ZO model)
  - Air Stripping ★
  - Brine Electrodialysis Concentrator 🕒
    (In progress)
  - Bipolar Electrodialysis 🕒
    (In progress)
  - Electrodialysis Metathesis 🕒
    (In progress – Collaboration with Dr. Shane Walker (Texas Tech) and UTEP)

U.S. DEPARTMENT OF ENERGY

NREL Transforming ENERGY

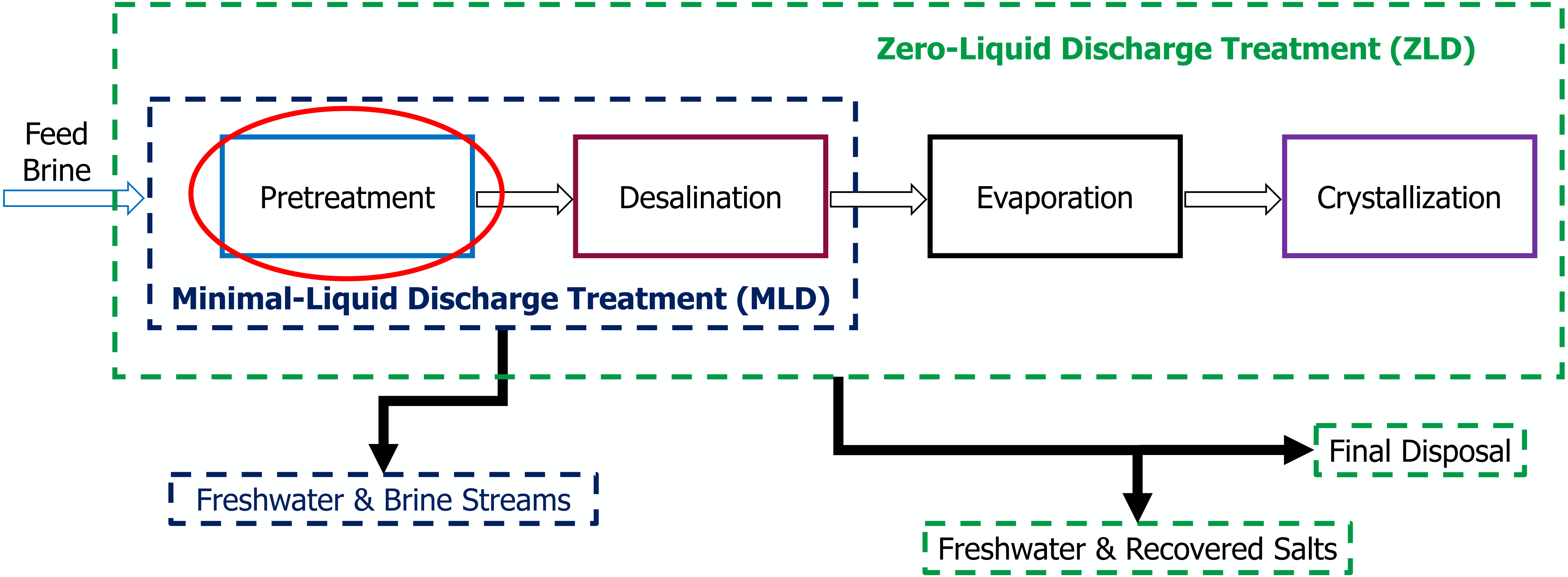
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

Water TAP

NAWI National Alliance for Water Innovation

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

Overview



Zero-Liquid Discharge Treatment (ZLD)

Feed Brine

Pretreatment

Desalination

Evaporation

Crystallization

Minimal-Liquid Discharge Treatment (MLD)

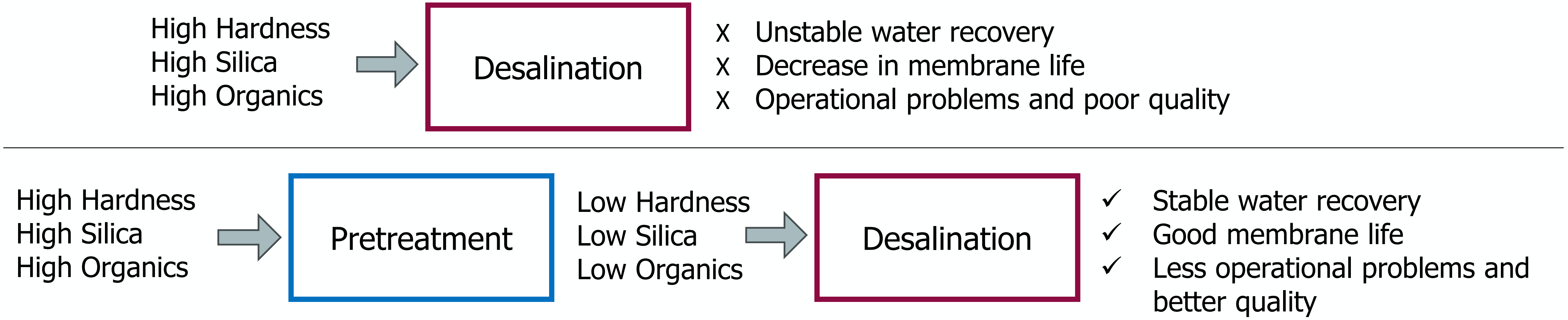
Freshwater & Brine Streams

Final Disposal

Freshwater & Recovered Salts

Goal and Importance of Pretreatment

- An effective pretreatment system should reduce the different fouling and scaling constituents of predominance to effectively operate subsequent treatment systems without any potential operational limitations due to the input water source.



High Hardness
High Silica
High Organics

→ **Desalination**

X Unstable water recovery
X Decrease in membrane life
X Operational problems and poor quality

High Hardness
High Silica
High Organics

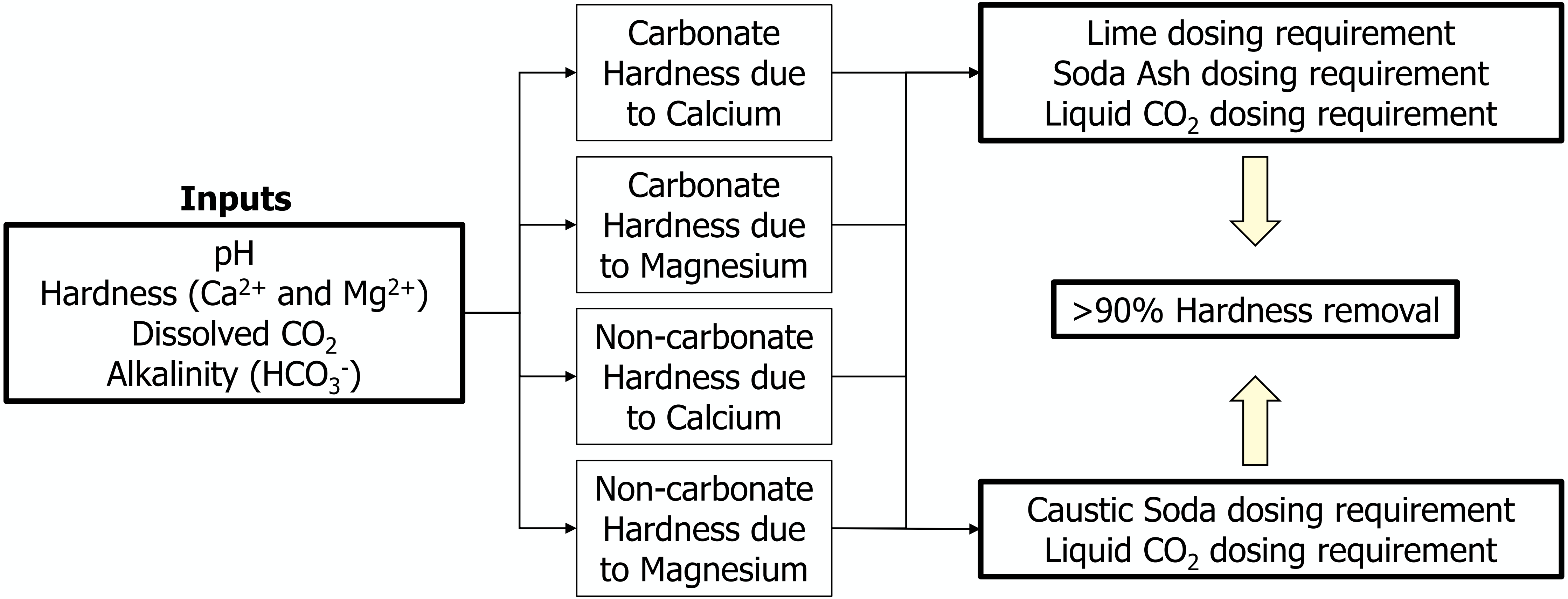
→ **Pretreatment**

Low Hardness
Low Silica
Low Organics

→ **Desalination**

✓ Stable water recovery
✓ Good membrane life
✓ Less operational problems and better quality

Chemical Softening



Inputs

pH
Hardness (Ca^{2+} and Mg^{2+})
Dissolved CO_2
Alkalinity (HCO_3^-)

Carbonate Hardness due to Calcium

Carbonate Hardness due to Magnesium

Non-carbonate Hardness due to Calcium

Non-carbonate Hardness due to Magnesium

Lime dosing requirement
Soda Ash dosing requirement
Liquid CO_2 dosing requirement

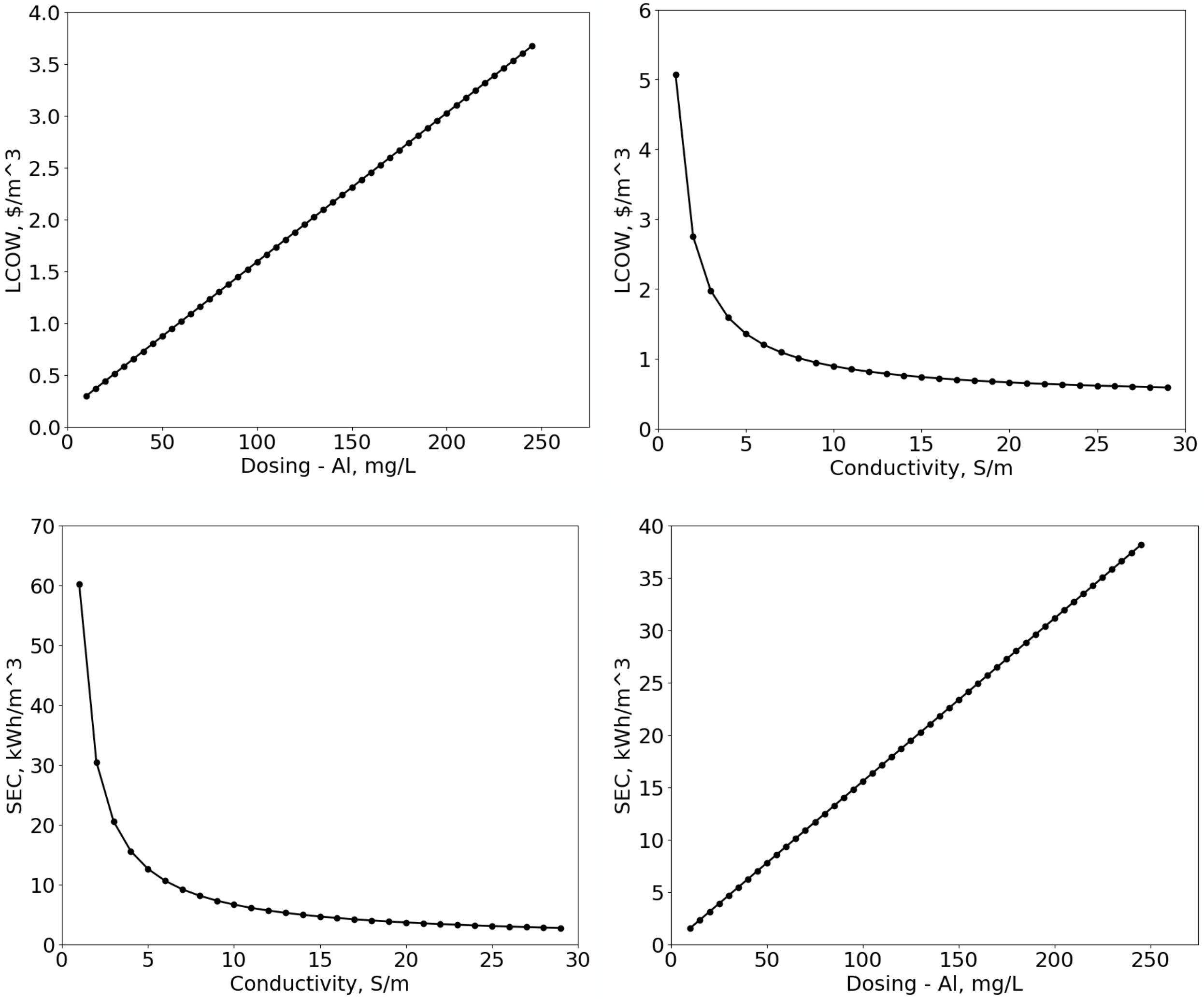
>90% Hardness removal

Caustic Soda dosing requirement
Liquid CO_2 dosing requirement

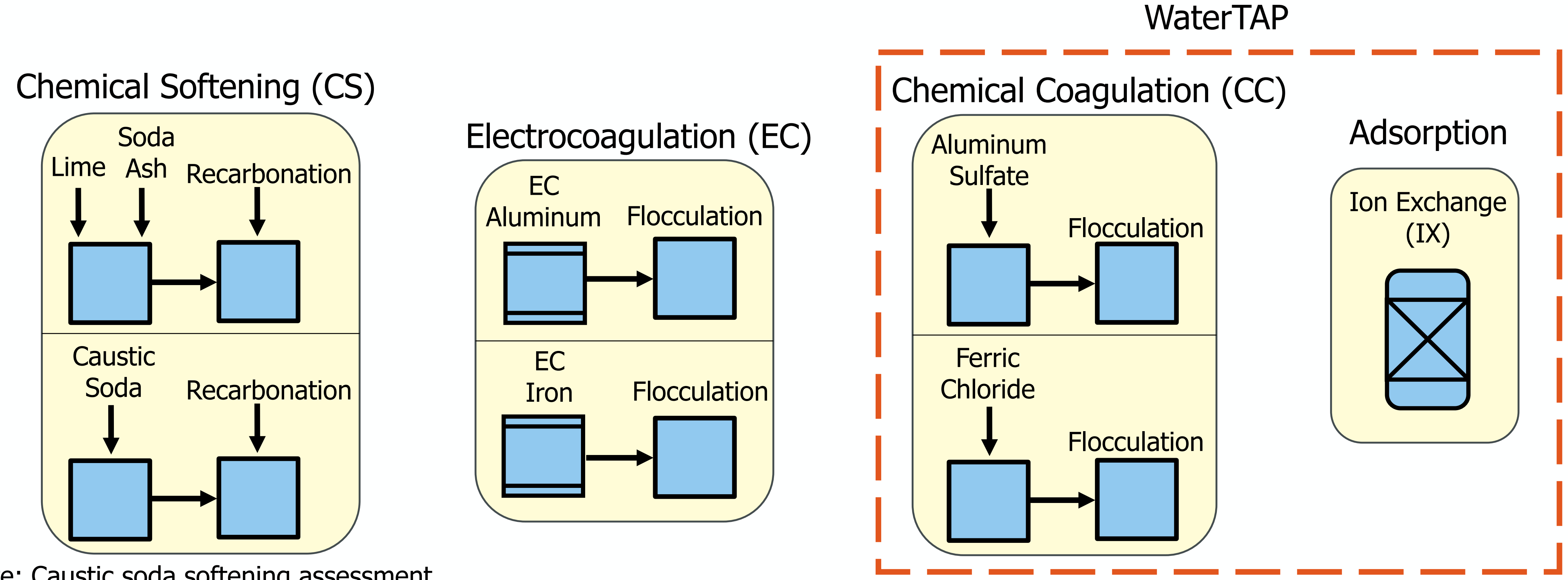
Electrocoagulation

- Electrocoagulation has been explored as a viable pretreatment alternative for saline streams, such as brine, before membrane or thermal desalination processes.

- One of the advantages of the application of electrocoagulation in high salinity brines is the high electrical conductivity of the stream, which leads to low electrical resistance and no need for the addition of any supporting electrolyte.



Pretreatment Units



Note: Caustic soda softening assessment performed using a modified CS model and experimental work by NMSU team.

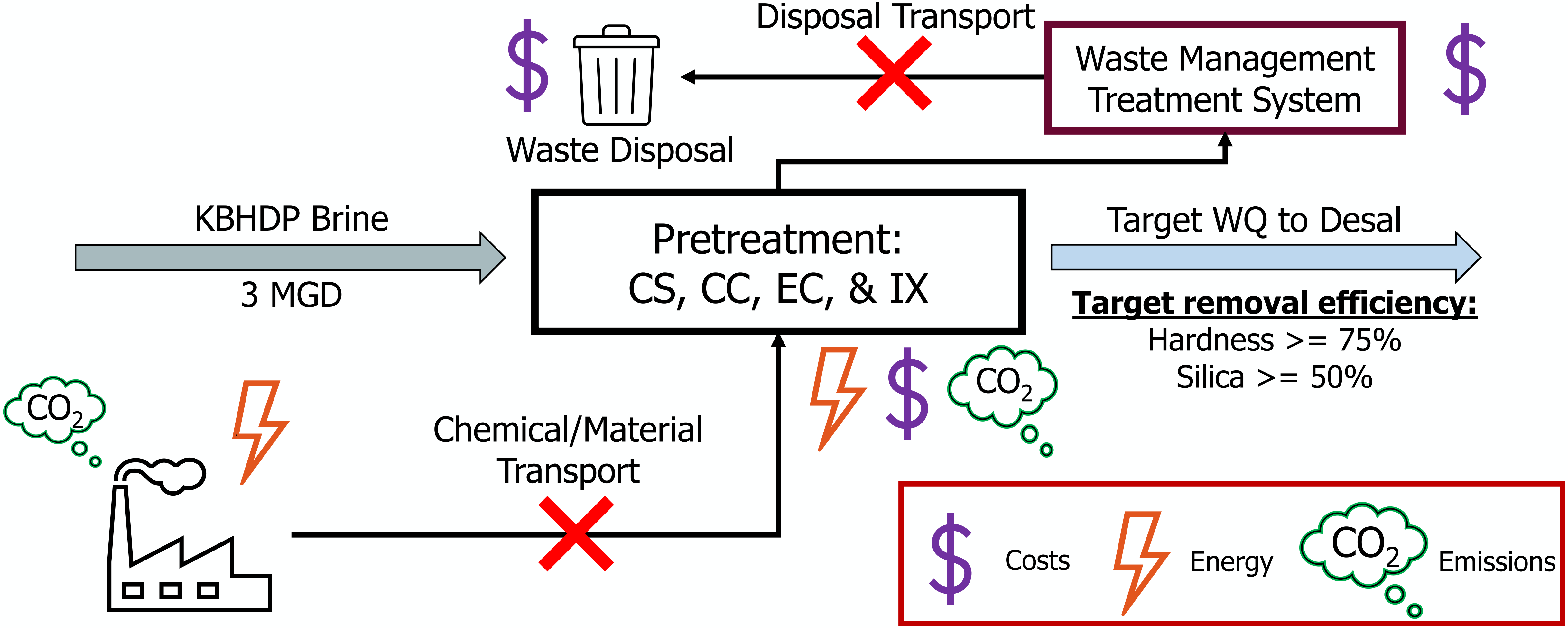
Case Study

Kay Bailey Hutchinson Desalination Plant (KBHDP) Brine

- TDS = 11,000 mg/L
- Calcium = 610 mg/L
- Magnesium = 161 mg/L
- Hardness = 2,300 mg/L as $CaCO_3$
- Silica = 130 mg/L
- Total Organic Carbon = 8 mg/L

Ref: (El Paso Water, 2020)

Considerations in Assessment



Disposal Transport

Waste Disposal

Waste Management Treatment System

KBHDP Brine

3 MGD

Pretreatment:
CS, CC, EC, & IX

Target WQ to Desal

Target removal efficiency:
Hardness >= 75%
Silica >= 50%

Chemical/Material Transport

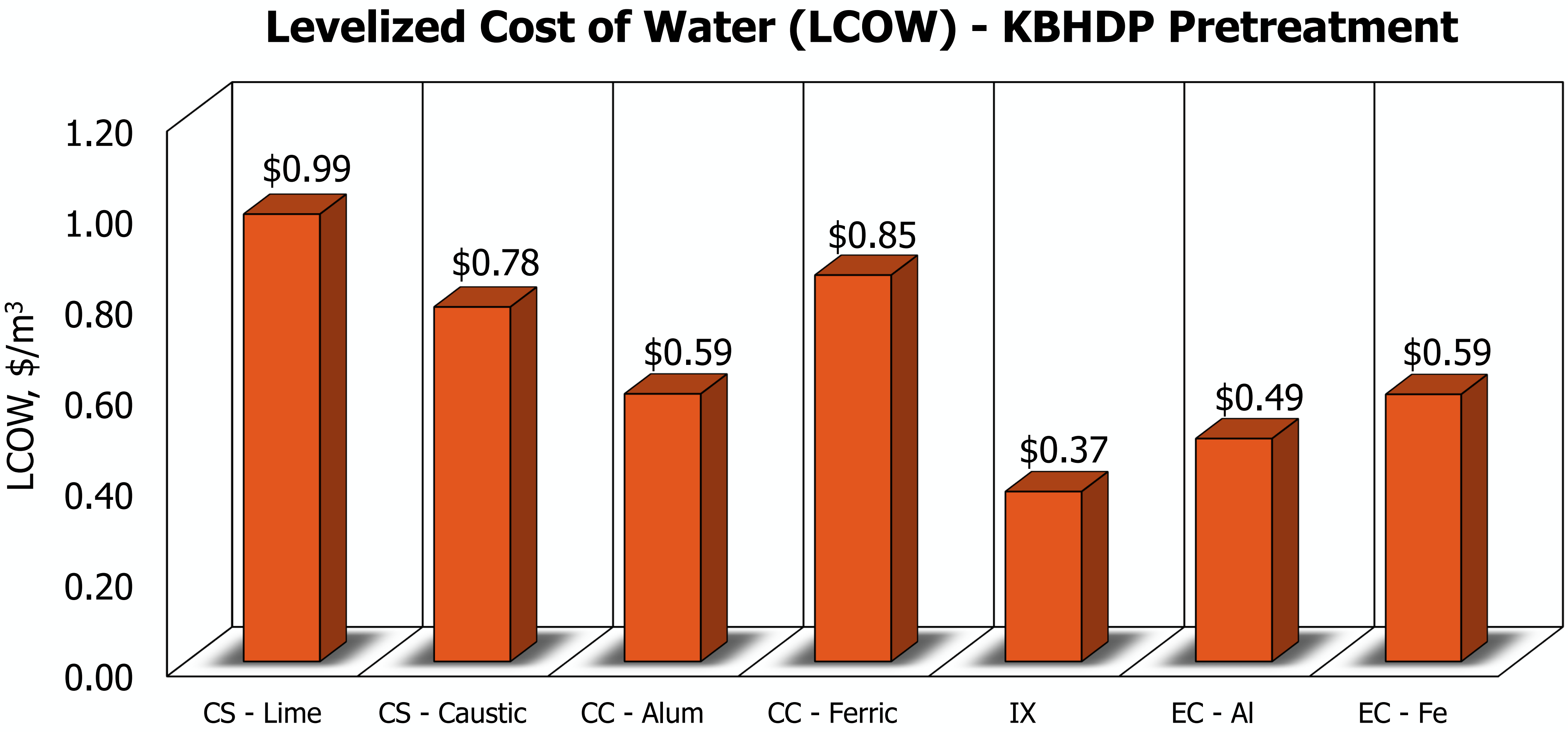
CO_2

$ Costs
⚡ Energy
CO_2 Emissions

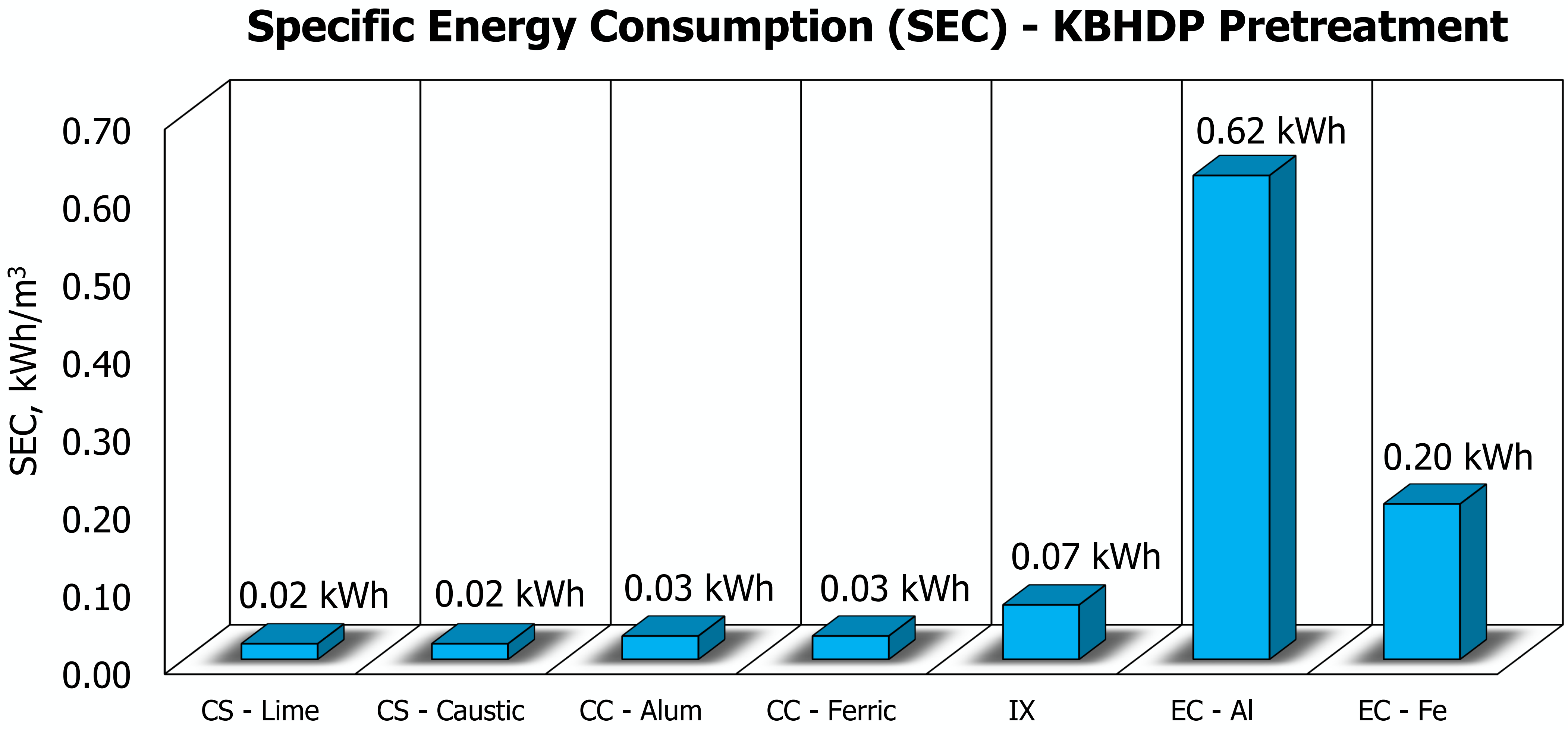
Considerations in Assessment

- Evaluation metrics:
  - Costs → levelized cost of water (LCOW, $\$/m^3$ of brine) - 2023
  - Energy → specific energy consumption (SEC, kWh/m^3 of brine)
  - Greenhouse emissions → carbon dioxide emissions (CO_2, kg CO_2/m^3 of brine)
- Implemented WaterTAP default cost factors
- Cost of chemical purchase, sludge management units (filter press and thickener), and sludge/waste disposal.
- Default removal efficiencies of target constituents considered in ZO models.

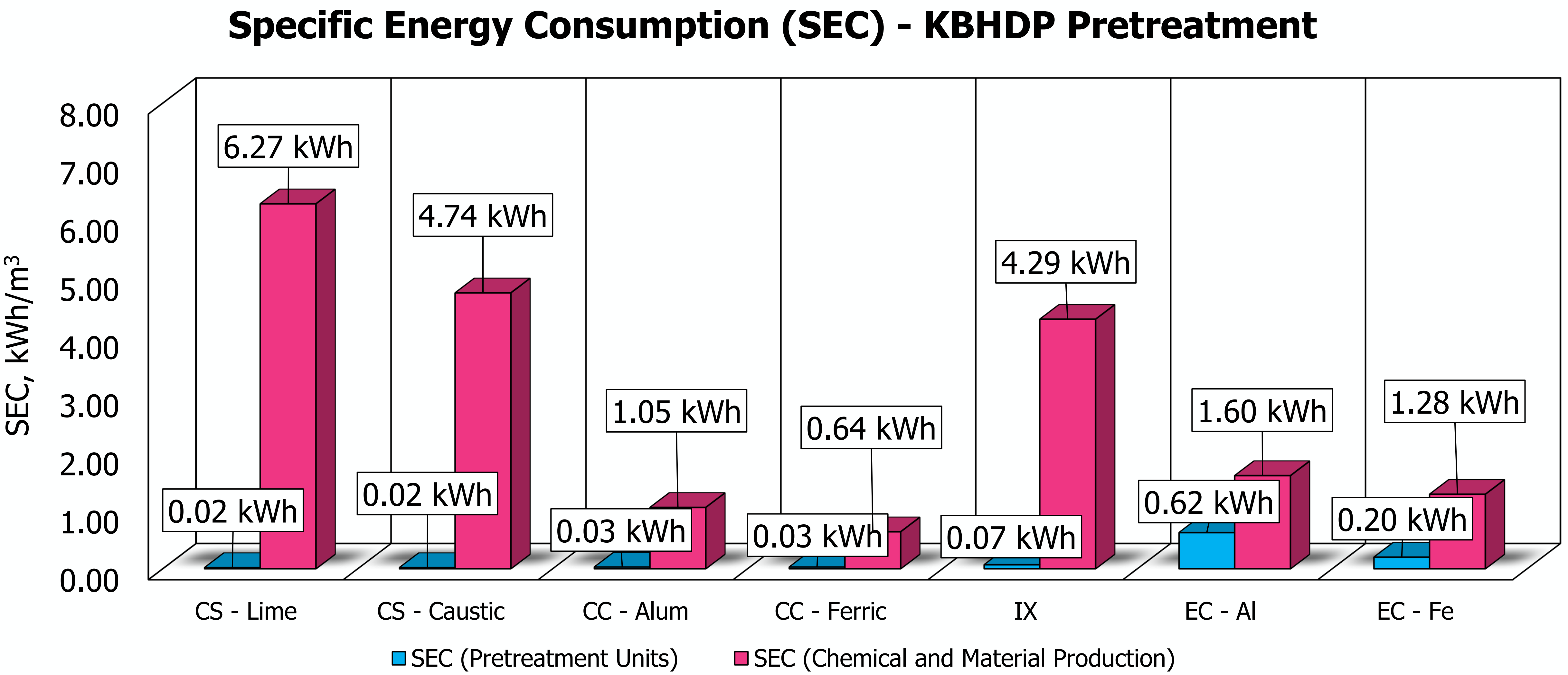
Results


Levelized Cost of Water (LCOW) - KBHDP Pretreatment
LCOW, \$/m³
1.20
1.00
0.80
0.60
0.40
0.20
0.00
\$0.99
\$0.78
\$0.59
\$0.85
\$0.37
\$0.49
\$0.59
CS - Lime
CS - Caustic
CC - Alum
CC - Ferric
IX
EC - Al
EC - Fe

Results

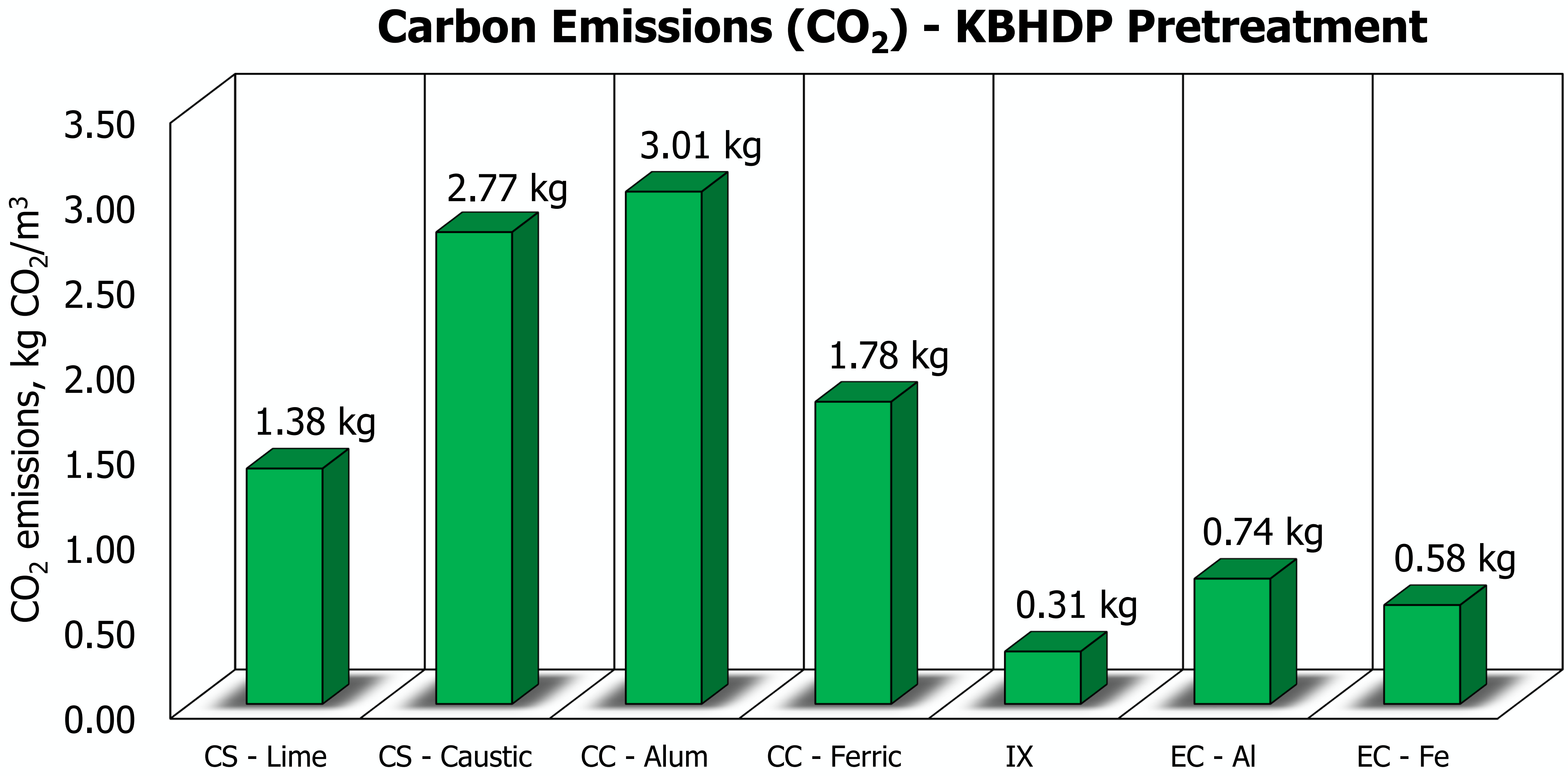

Specific Energy Consumption (SEC) - KBHDP Pretreatment
SEC, kWh/m^3
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.02 kWh
0.02 kWh
0.03 kWh
0.03 kWh
0.07 kWh
0.62 kWh
0.20 kWh
CS - Lime
CS - Caustic
CC - Alum
CC - Ferric
IX
EC - Al
EC - Fe

Results



Specific Energy Consumption (SEC) - KBHDP Pretreatment
SEC, kWh/m^3
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
6.27 kWh
0.02 kWh
4.74 kWh
0.02 kWh
1.05 kWh
0.03 kWh
0.64 kWh
0.03 kWh
4.29 kWh
0.07 kWh
1.60 kWh
0.62 kWh
1.28 kWh
0.20 kWh
CS - Lime
CS - Caustic
CC - Alum
CC - Ferric
IX
EC - Al
EC - Fe
SEC (Pretreatment Units)
SEC (Chemical and Material Production)

Results


Carbon Emissions (CO_2) - KBHDP Pretreatment
CO_2 emissions, kg CO_2/m^3
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1.38 kg
2.77 kg
3.01 kg
1.78 kg
0.31 kg
0.74 kg
0.58 kg
CS - Lime
CS - Caustic
CC - Alum
CC - Ferric
IX
EC - Al
EC - Fe

Summary

- WaterTAP provides a powerful and efficient tool for the evaluation of water treatment systems on their respective application scenarios.
- For the RO concentrate case study, high chemical usage leads to a high overall impact in all evaluation metrics in the pretreatment applications.
- IX showed to be one of the best pretreatment alternatives in almost all evaluation metrics:
  - In real-scale applications, IX as a pre-treatment is normally focused on solely hardness removal.
  - Combining IX with another pretreatment unit that mitigates silica (such as EC) can prove to be beneficial.
  - IX WaterTAP model considers only a single solute in solution; the effect of the KBHDP brine’s ionic may not be fully accounted for.

Summary

- CS demonstrated to be an expensive pretreatment alternative due to its high chemical usage, while EC was the second lowest of the considered units for pretreatment application.
- The incorporation of mineral precipitation and scaling with OLI will provide a very integral component as to the complete evaluation of these pretreatment options in high salinity MLD or ZLD.
- Optimization on these units is much more plausible through the understanding of water quality predictions and the scaling potential before and after the pretreatment.
- This work demonstrated the importance of accounting for an adequate cost assessment of pretreatment units needed in high salinity brines as these can represent a significant part of the overall cost of the MLD or ZLD.

Thank you so much for your attention!

Special thanks to the collaborators:

Pei Xu, Huiyao Wang, Zachary Stoll, Carolina Mejía-Saucedo,
Punhasa Senanayake, Kurban Sitterley, Parthiv Kurup

Backup Slides

Notable Limitations

The optimal choice of pretreatment may be subject to rigorous field testing and experimental analysis for efficient applications depending on the type of water and chemicals of concern for downstream processes.

The use of unit models can only provide approximations to real-scale applications, as there are many factors that go into the field application of these pretreatment systems that may not be accounted for in the models.

Uncertainty in the use of literature-based energy and emission factors to estimate the SEC and CO_2 emissions of the different pretreatment system may lead to possible additional discrepancy to the actual values of these.

Oversaturated chemical species present in the KBHDP brine and their change when considering an additional 60% water recovery on the brine.

Minerals – KBHDP	Saturation Index	Saturation Index (Additional 60% recovery)
Aragonite ($CaCO_3$)	1.61	2.48
Calcite ($CaCO_3$)	1.76	2.63
Chalcedony (SiO_2)	0.90	1.31
Chrysotile ($Mg_3Si_2O_5(OH)_4$)	3.52	8.27
Dolomite ($CaMg(CO_3)_2$)	3.29	5.05
Sepiolite ($Mg_4Si_6O_{15}(OH)_2 \cdot 6H_2O$)	3.63	7.48
Silica quartz (SiO_2)	1.33	1.74
Strontianite ($SrCO_3$)	0.68	1.55
Talc ($Mg_3Si_4O_{10}(OH)_2$)	9.02	14.61