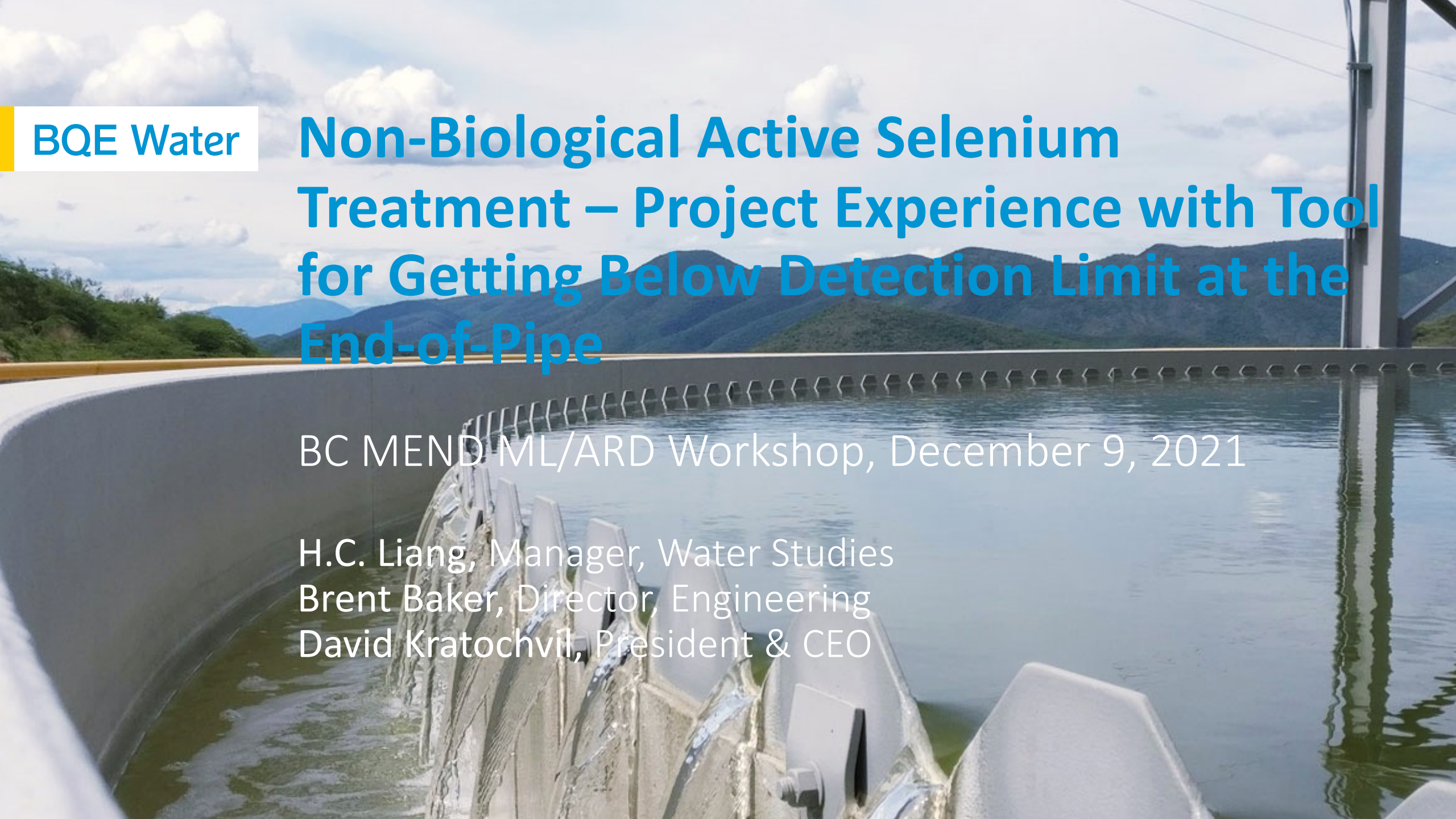


BQE Water

Non-Biological Active Selenium Treatment – Project Experience with Tool for Getting Below Detection Limit at the End-of-Pipe

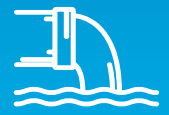
BC MEND ML/ARD Workshop, December 9, 2021

H.C. Liang, Manager, Water Studies
Brent Baker, Director, Engineering
David Kratochvil, President & CEO

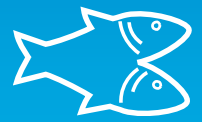
Agenda

1. Review of Non-Biological Selenium Treatment – Selen-IX™
2. Selen-IX™ Plants: From Lab to Pilot to Full-Scale
3. New Full-Scale Applications
4. Lake Koocanusa Conundrum – Challenges of Trans-Boundary Lake

Why Non-Biological Treatment for Selenium?

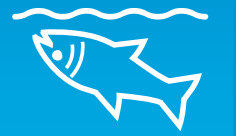


Reach end-of-pipe selenium concentration < 0.5 µg/L



Avoid organoselenium issues & chronic effects

Stable refractory residue with off-take potential



Avoid bio treatment issues: nutrient add, COD/BOD, TSS

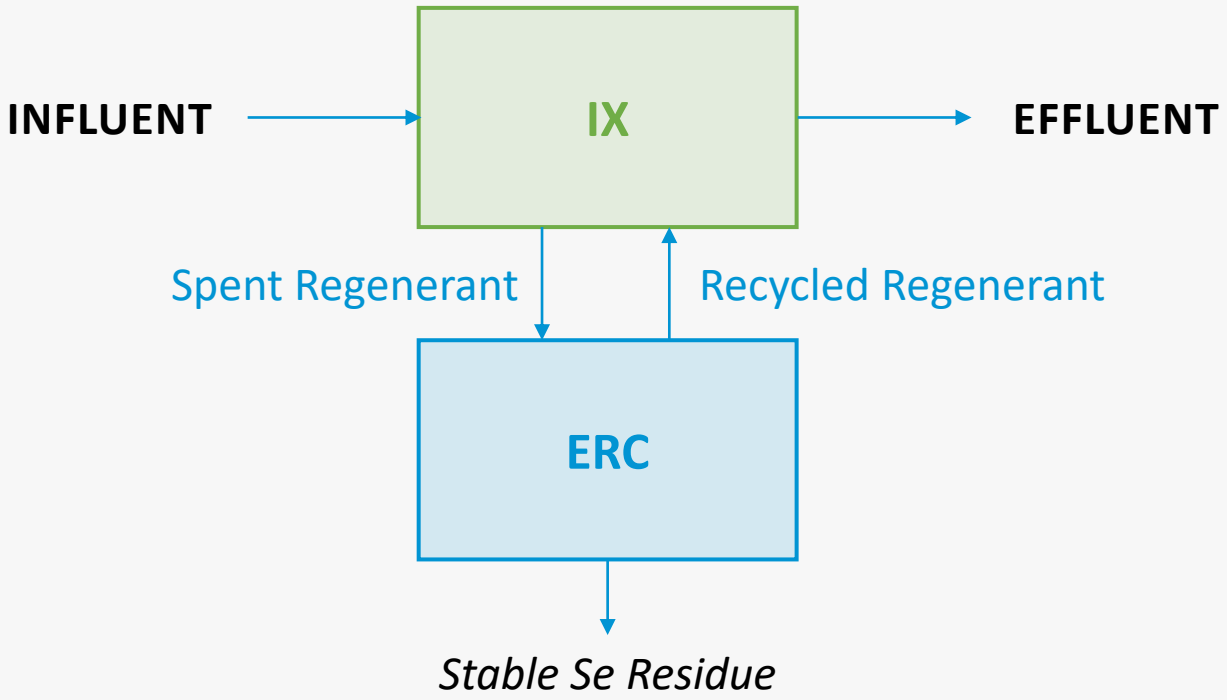
Handle large fluctuations in flow and mass loading and temperature

Provide seasonal or intermittent treatment

Selen-IX™ Plants – From Lab to Pilot to Full-Scale

Selen-IX™ = IX + ERC for Selective Se Removal

Selectively remove selenium to < 0.5 µg/L while fixing selenium into small quantity of stable inorganic solid residue

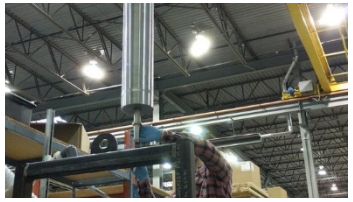


- Selective removal of Se from impacted mine water
- Produce treated water with Se < 0.5 µg/L
- Pre-concentrate Se by factor of 20 to 2000x

- Remove Se from pre-concentrated brine solution from IX regeneration
  Stabilize Se into non-toxic inorganic residue suitable for re-use

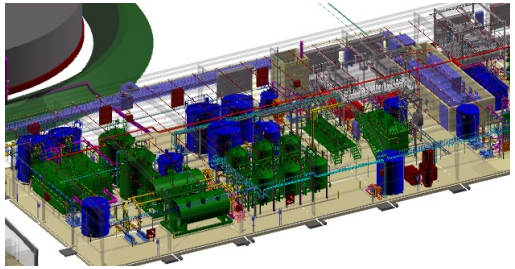
Selen-IX™ Commercialization Timeline

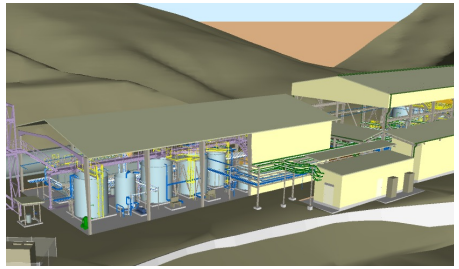
2012 – 2017: Lab & Pilots

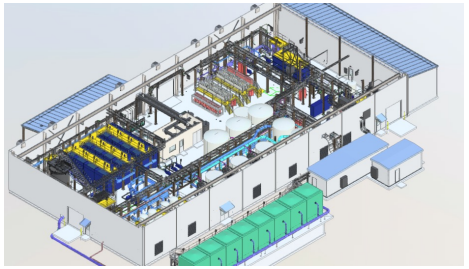


2018: Industrial Demonstration
Consortium of Major Miners

2019-2020: 1st Full-Scale Plant

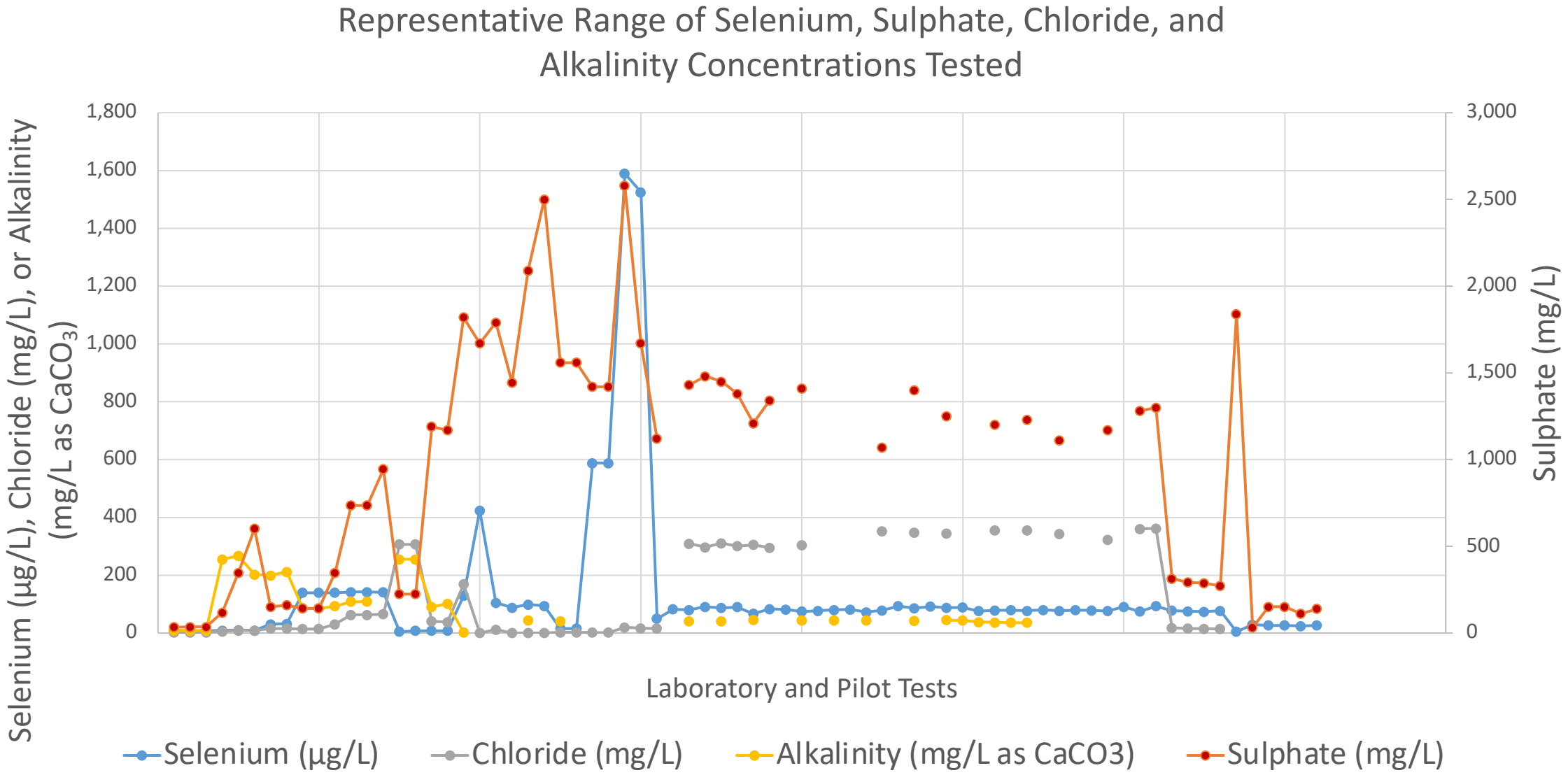






2020-2022: 2nd, 3rd & 4th
Full-Scale Plants

Selen-IX™ Wide Range of Feed Water Characteristics Tested

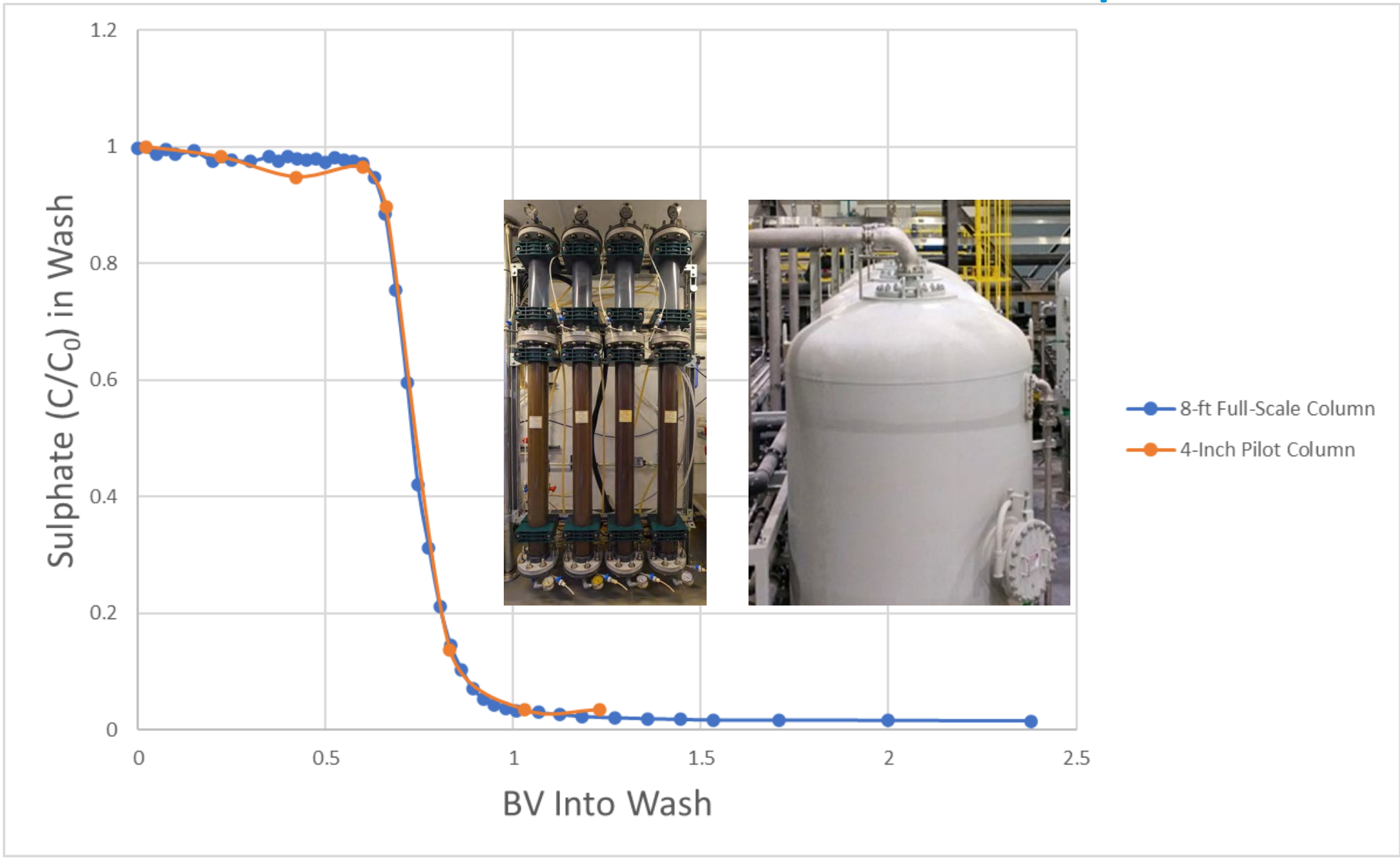


Effect of Sulphate on Selen-IX™ Efficiency

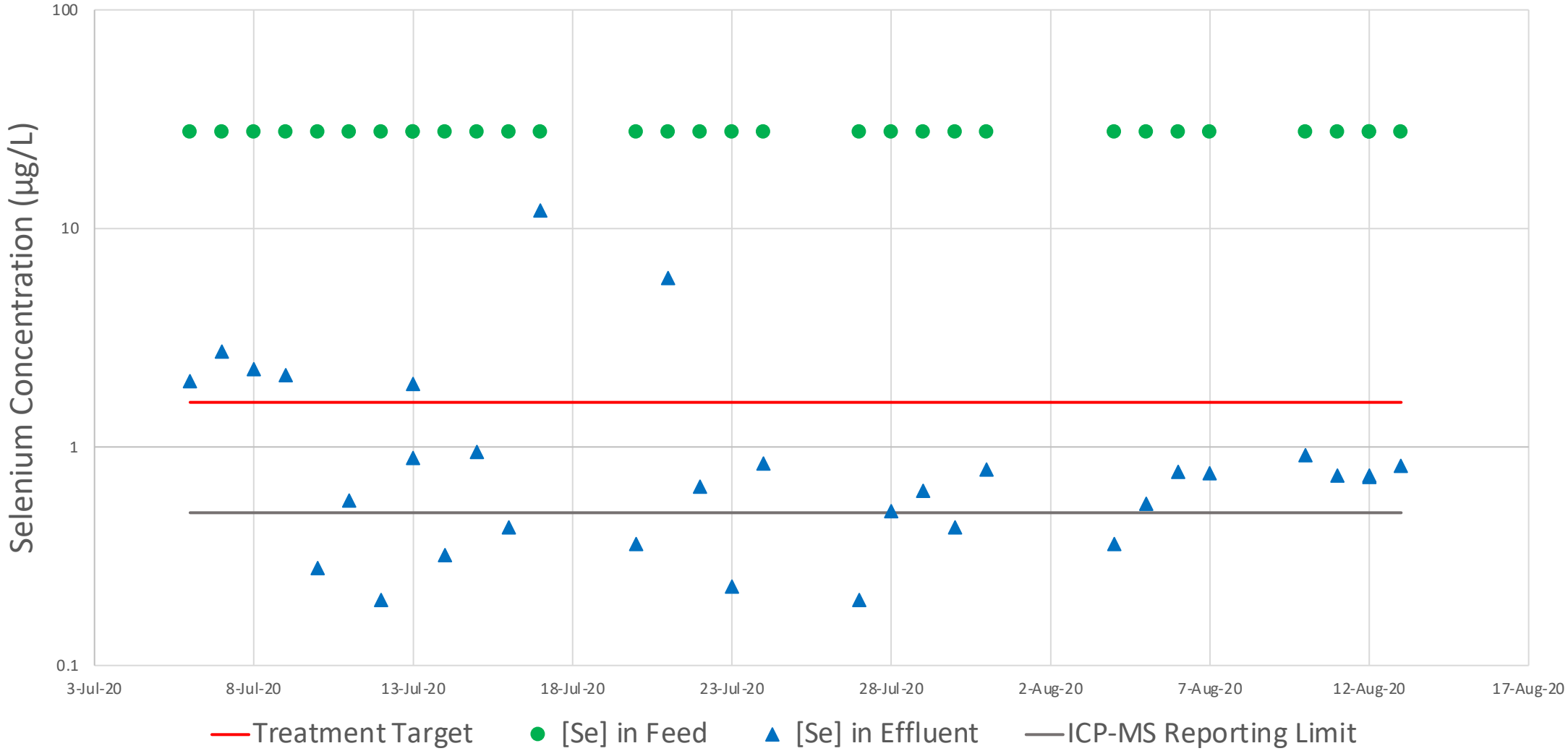
- IX resin capacity increases with decreasing [SO_4^{2-}]
- Treating water with 75 mg/L SO_4^{2-} much more efficient compared to 2,000 mg/L SO_4^{2-}
- End-of-pipe [Se] not sensitive to influent selenium concentrations
- Treating higher flowrate more efficient in some cases

How Well Does Selen-IX™ Scale Up?

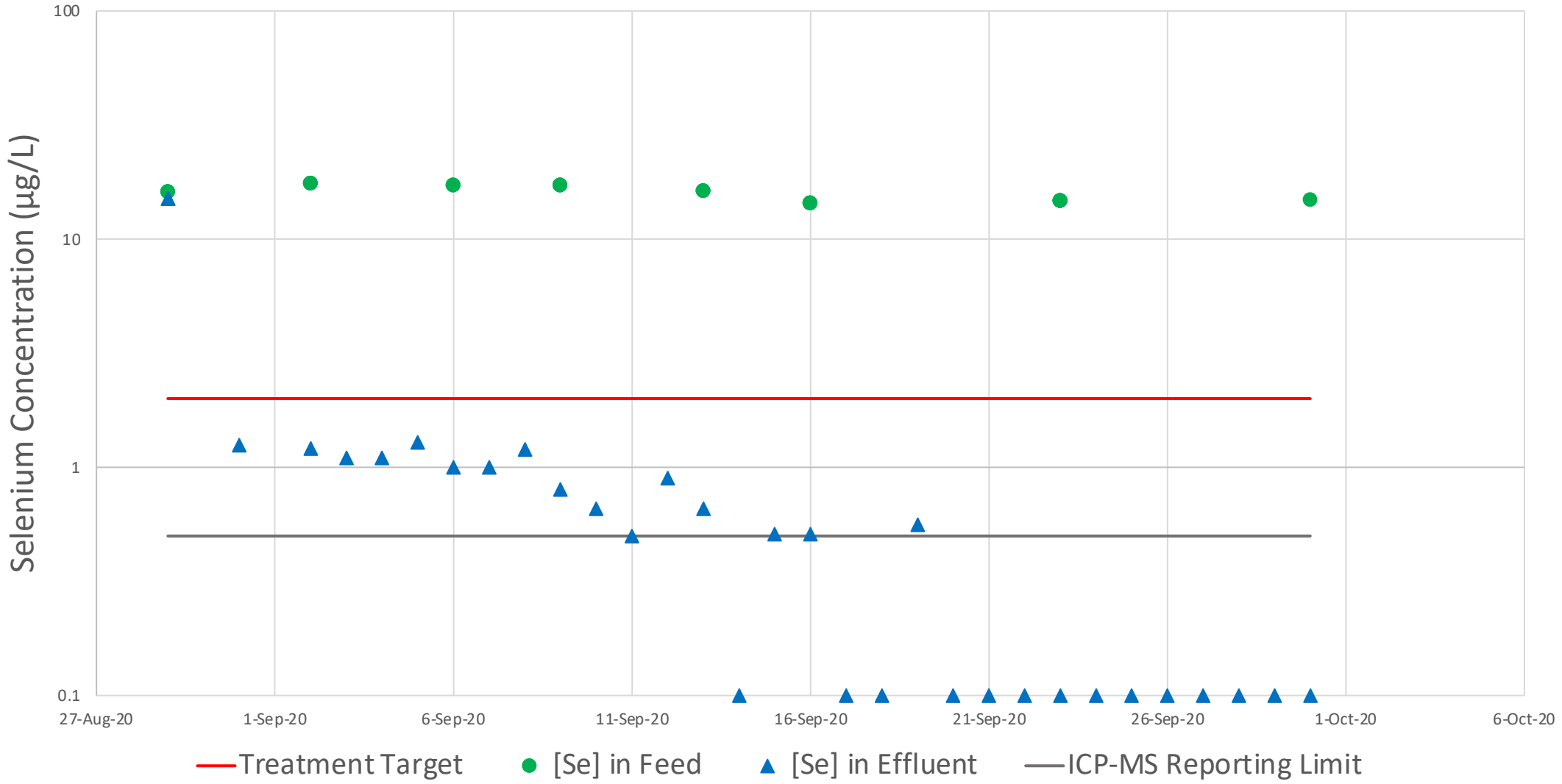
Wash Curves for Pilot and Full-Scale Operations



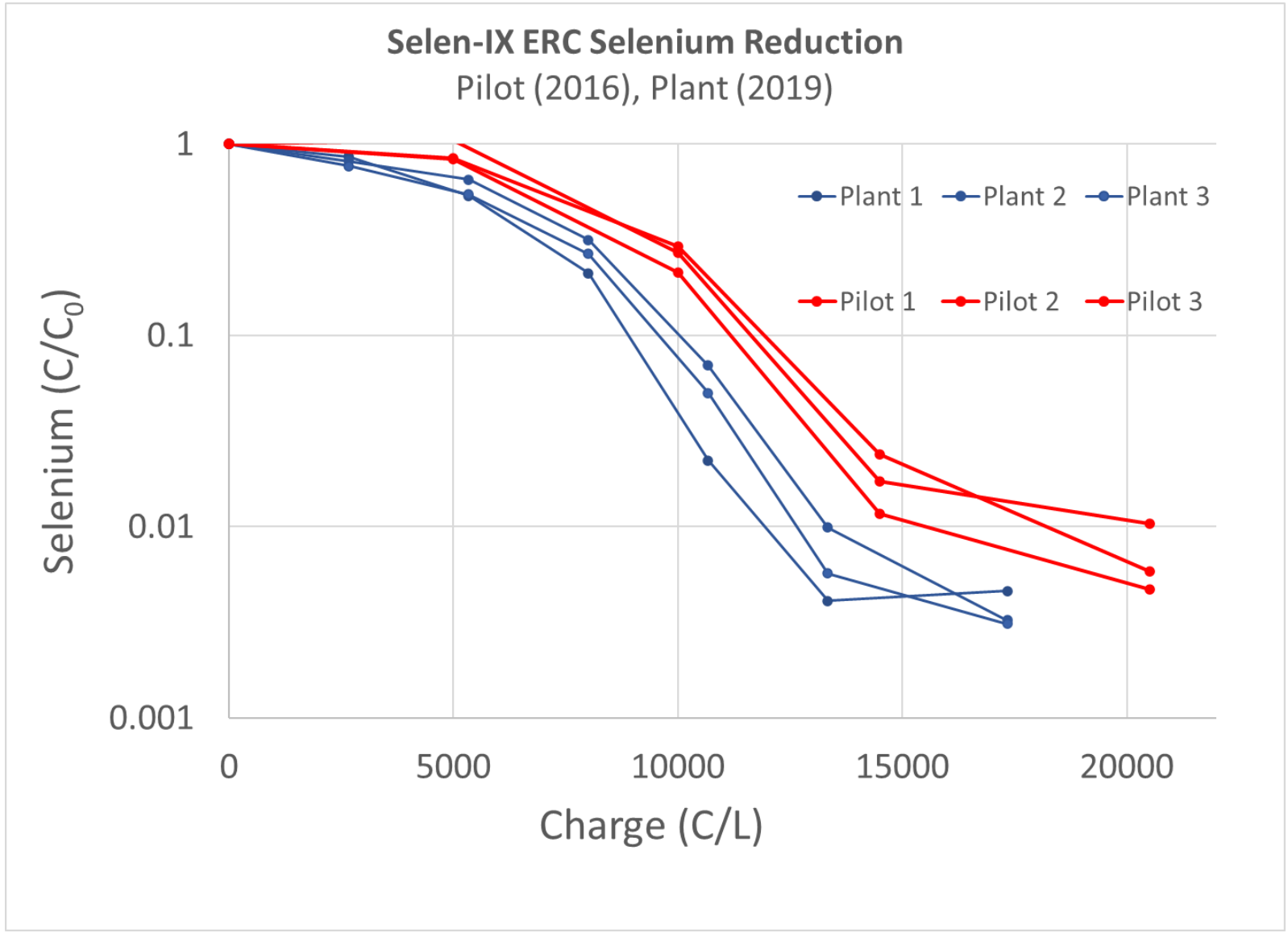
Selenium Removal by IX in Pilot Plant



Selenium Removal by IX in Full-Scale Plant



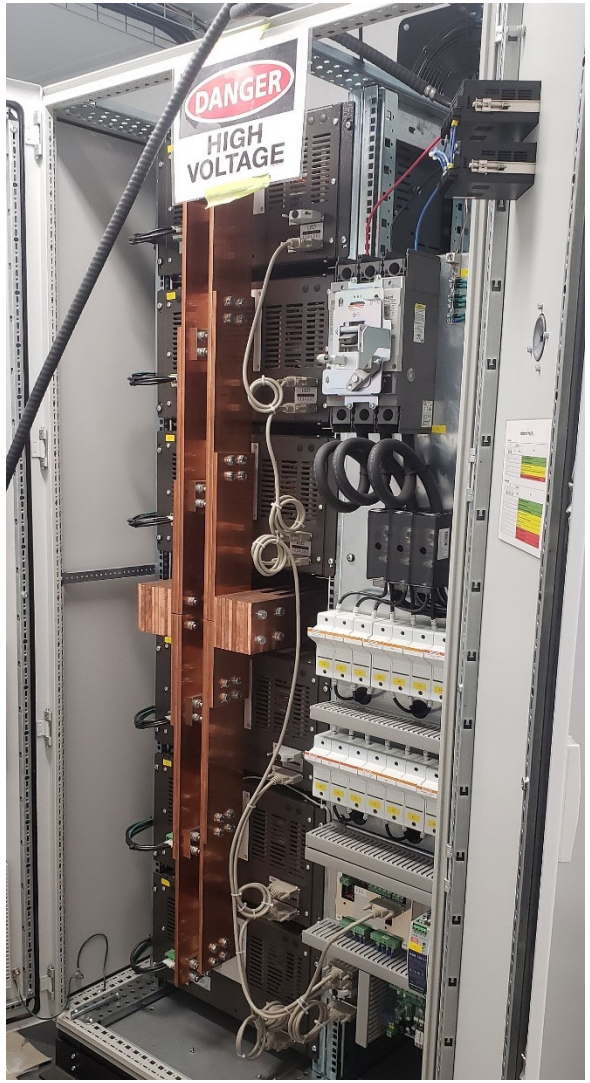
Selenium Reduction in ERC – Pilot and Full-Scale



Cell Operating Voltage

Plant	Pilot Test	Demonstration	Full-Scale WTP
Voltage (V/cell)	1.31	2.03	2.75

Rectifiers



Technical Data:

Input voltage:	480V, 3Ph, 50-60Hz + GND
Input current:	223A
Power factor:	> 0.94
DC output voltage:	**20 V**
DC output current:	**7500 A**
Duty factor:	100 %
Ripple:	< 3 % across full range of control
Adjustment:	1 - 100 %
Control:	constant current and voltage control
Control accuracy:	< 1 % of rated output
Cooling:	Air-Cooled
Ambient temperature:	**up to 100 °F**
Site altitude:	**up to 5200 feet above sea level**
Dimensions:	39/ 32/ 79 (W/ D/ H) inches (+ 4 inch base)

Key Lessons from Scale-Up

Full-Scale Performance Predictable from Good Pilot Testing Data:

- **IX**
  - Flow distribution
  - Treated water selenium concentrations
- **ERC**
  - Selenium reduction
  - Operating voltage

Cautionary Tale:

- **Rectifiers** – Work with vendors with good understanding of specifications

Full-Scale Selen-IX™ Facilities

Kemess Selen-IX™ Plant – BC, Canada

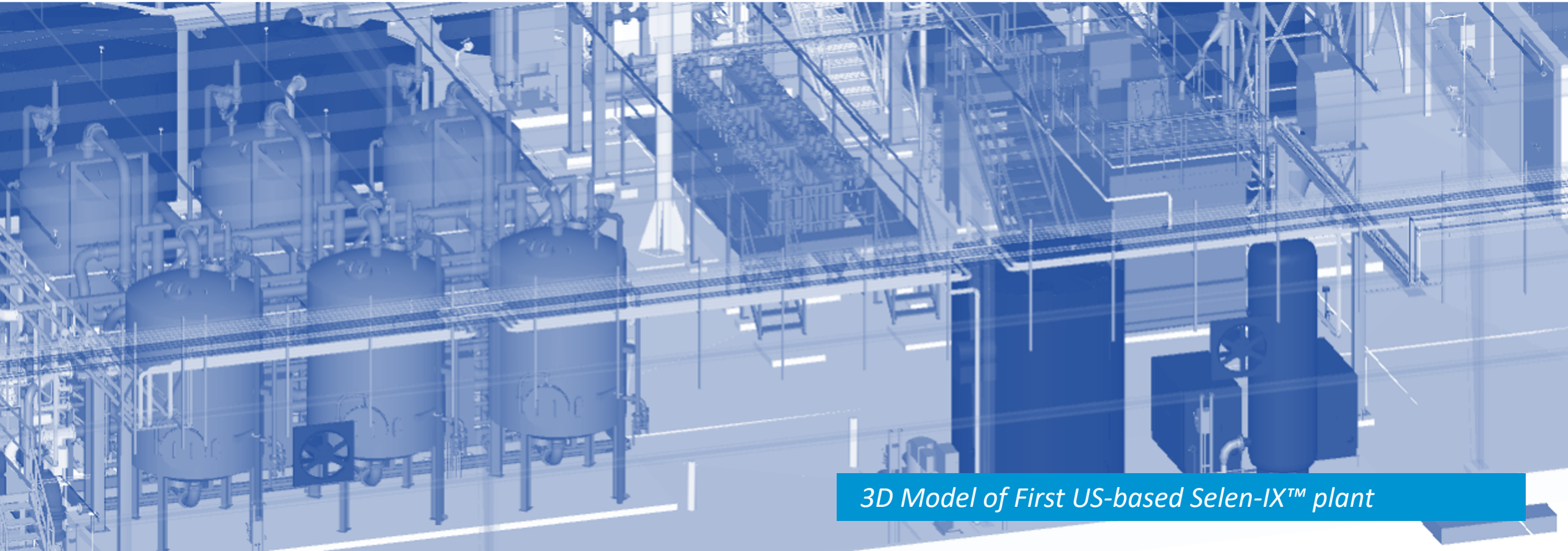
Project Drivers	Design Parameters	
Remove selenium to < 2 µg/L and fix into stable residue for tailings disposal	*Flow rate*: 1,200 gpm (6,500 m^3/d) *Se discharge limit*: 0.002 mg/L (BC WQG)	*IX Columns Residence time*: 18 mins *ERC Power*: 500 kW *Residue*: Max ~ 4 t/d filter cake

Interior of first full-scale Selen-IX™ plant, Northern BC

Products of Kemess WTP

Coal Ash Pond Selen-IX™ WTP – Eastern USA

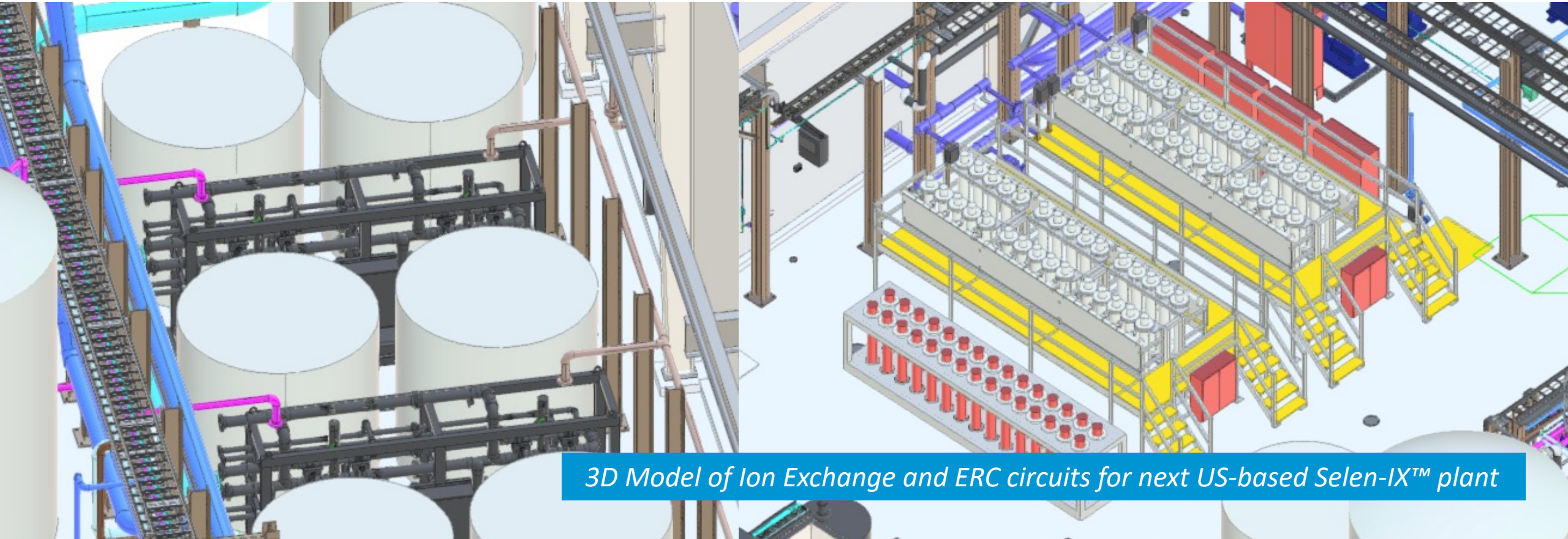
Project Drivers	Design Parameters	
Intermittent operation with fast ramp up/down to reliably remove selenate to < 5 µg/L, fixed to stable residue	*Operations:* 9 hrs/d, 5 d/wk *Flow rate*: 2,000 gpm (4,000 m^3/d) *Se discharge limit*: 0.005 mg/L	*IX Column Residence Time*: 6 mins *ERC Power*: 100 kW *Residue*: Max ~ 900 lbs/d filter cake



3D Model of First US-based Selen-IX™ plant

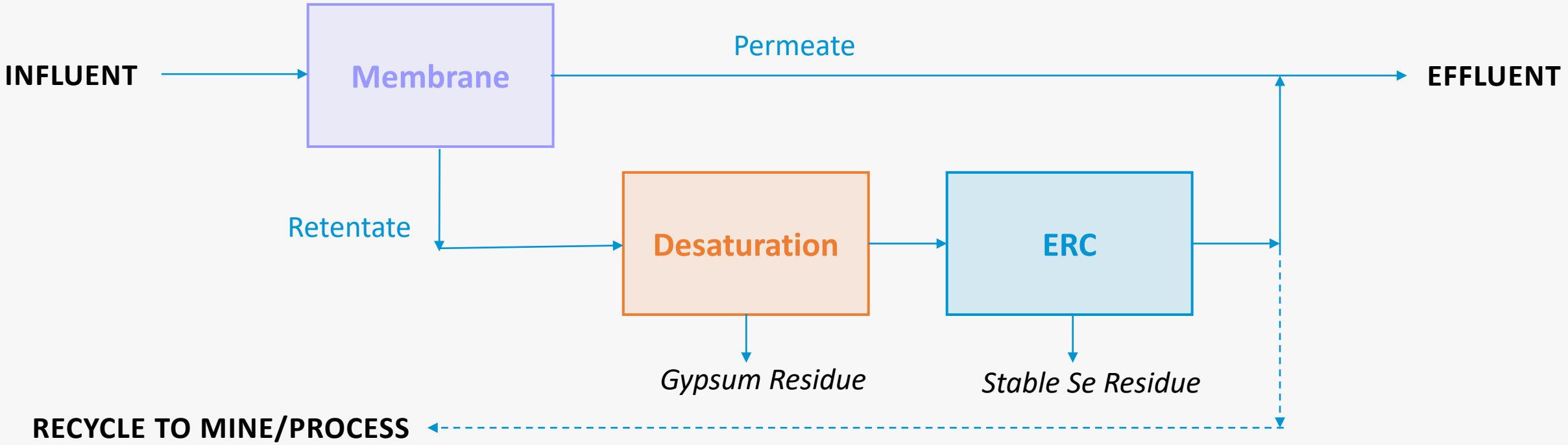
Copper Mine Selen-IX™ WTP – Western USA

Project Drivers	Design Parameters	
Remove selenate to less than 1.6 part per billion, along with upstream metals removal for Cd, Cr, Cu, Zn, As	*Flow rate*: 2,000 gpm (4,000 m^3/d) *Se discharge limit*: 0.0016 mg/L	*IX Column Residence Time*: 3 mins *ERC Power*: 200 kW *Residue*: Max ~ 3 t/d filter cake



3D Model of Ion Exchange and ERC circuits for next US-based Selen-IX™ plant

NF/RO + ERC for Selenium and Sulphate Removal



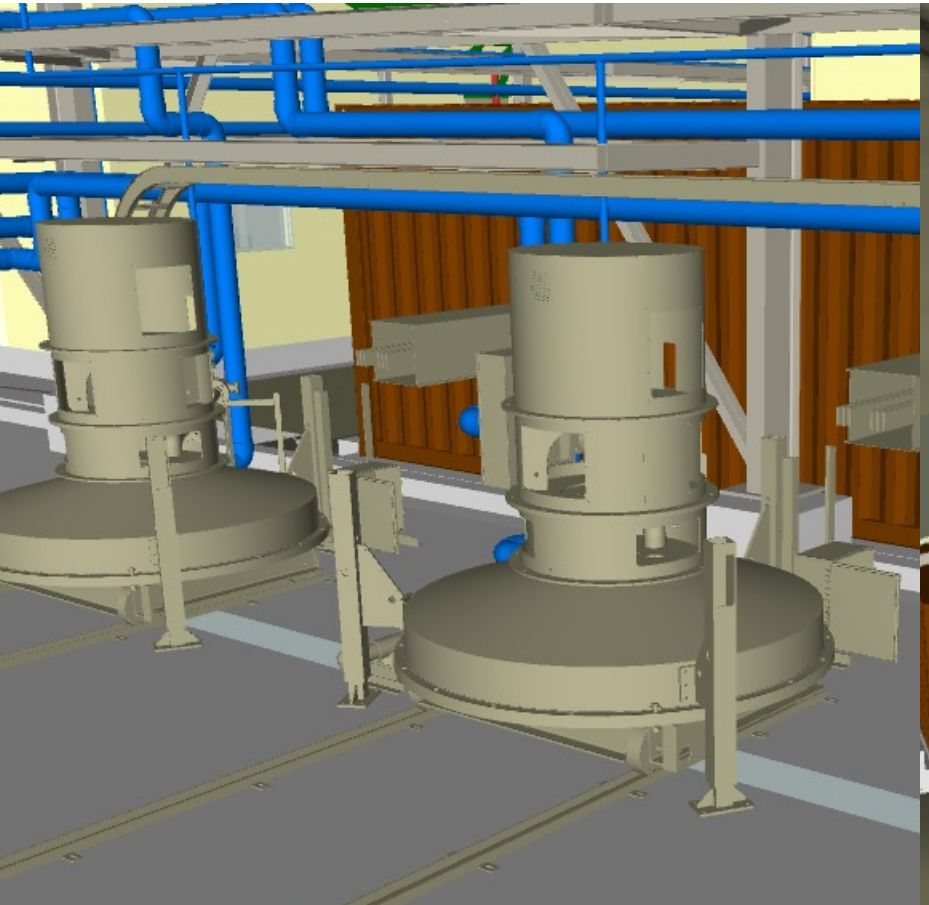
- Produce treated water with Se & SO_4^{2-} complying with discharge limits
- Pre-concentrate Se & create $CaSO_4 \cdot 2H_2O$ supersaturation

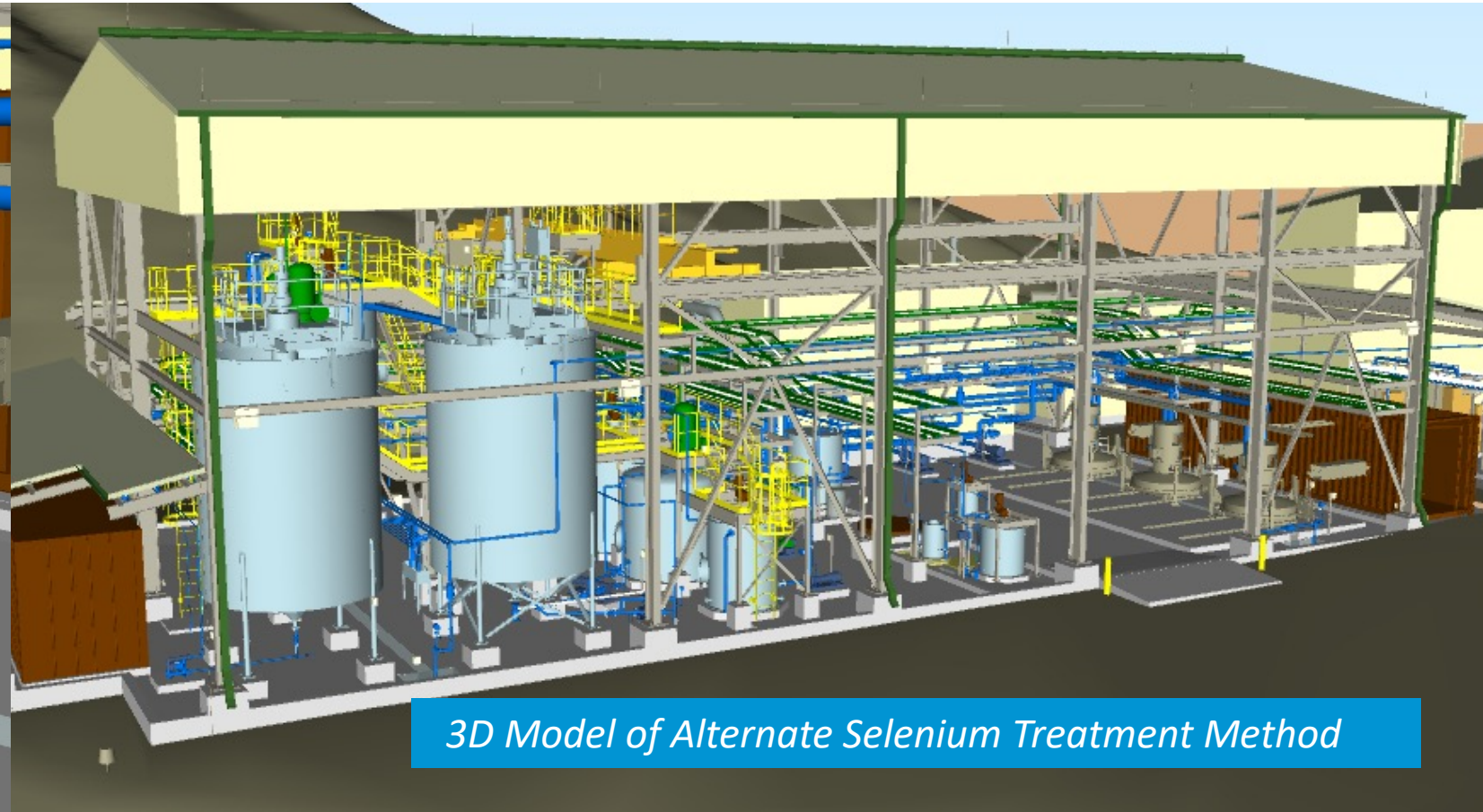
- Remove SO_4^{2-} by relieving $CaSO_4 \cdot 2H_2O$ supersaturation
- Produce clean gypsum

- Remove Se from pre-concentrated solution to eliminate brine from membranes
- Stabilize Se into non-toxic inorganic residue suitable for re-use

NF/ERC WTP Under Construction – Western USA

Project Drivers	Design Parameters	
Small footprint brownfield addition to existing facility. Comply with Se & SO_4^{2-} discharge limits for chronic WET on *Ceridaphnia dubia*	*Flow rate*: 150 gpm (800 m^3/d) *Se discharge limit*: 0.0016 mg/L *SO_4^{2-} discharge limit*: 720 – 900 mg/L	*ERC Power*: 300 kW *Residue*: Max ~ 6 t/d filter cake





3D Model of Alternate Selenium Treatment Method

NF/ERC WTP Under Construction – Western USA

Possible Application for Lake Koocanusa to Meet 0.8 µg/L Selenium Standard

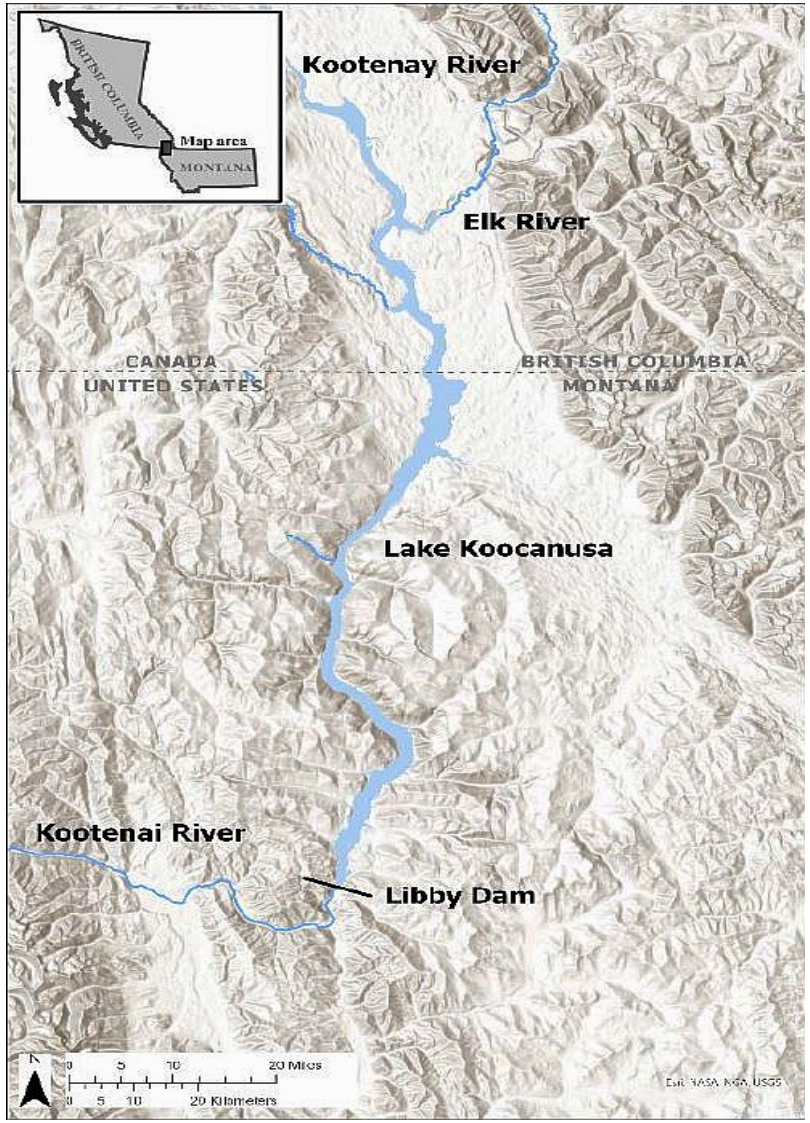
Cross-Boundary Quandary: Dual Selenium Standard

Lake Koocanusa (Libby Reservoir)

- Lake Koocanusa shared by Canada and USA
- BC WQG for selenium is 2 µg/L
- Montana has set 0.8 µg/L site-specific selenium standard in Lake Koocanusa
- Current average selenium concentration is ~1 µg/L

Picture from AP News: https://apnews.com/article/mt-state-wire-id-state-wire-montana-canada-lifestyle-9d39d3999c64478297b4c474d61f8d3f

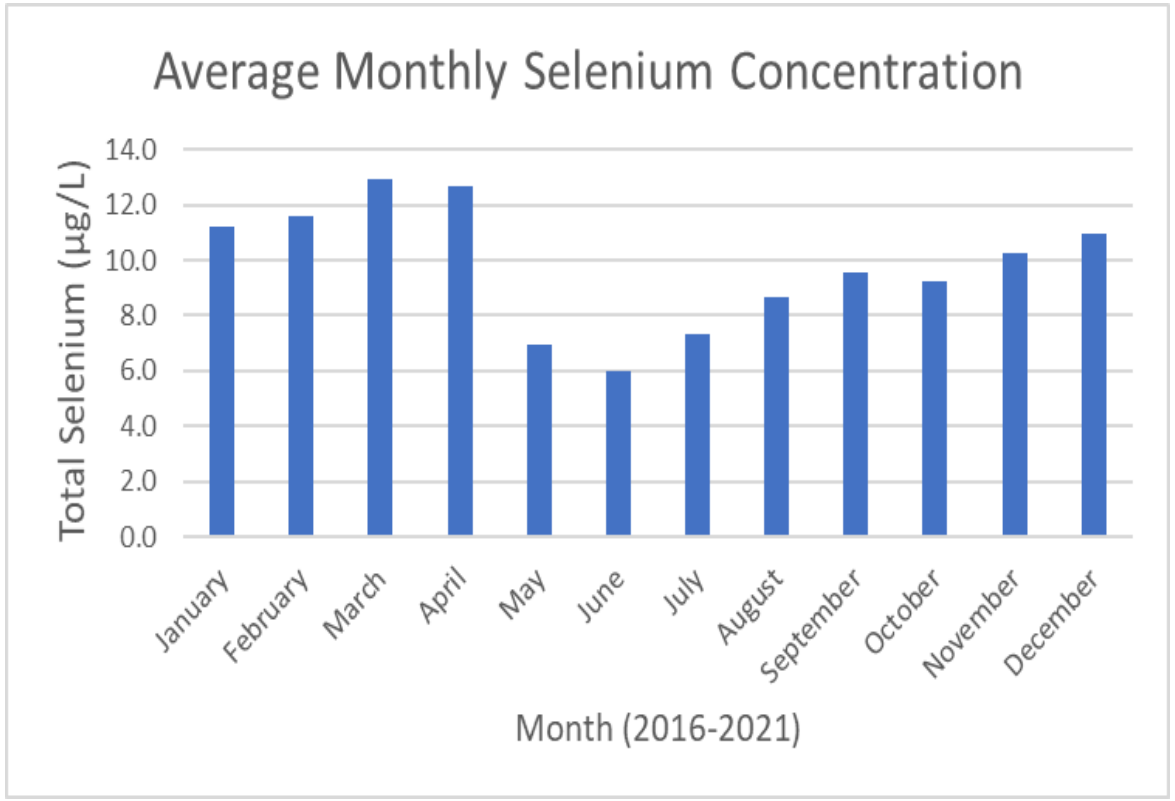
Lake Koocanusa (Libby Reservoir)

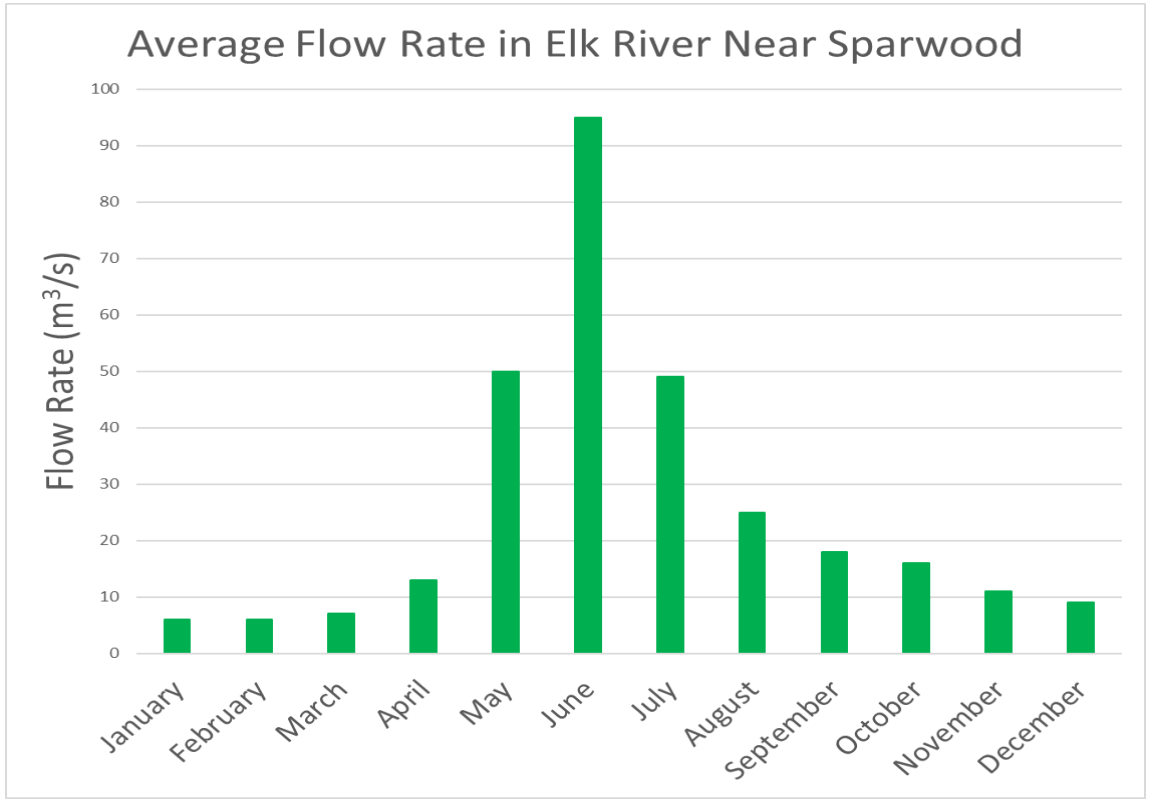


- Kootenay, Bull, and Elk Rivers flow into Lake Koocanusa
- Elk River: ~1/4 of flow into Lake Koocanusa
- >95% of selenium loading from Elk River

Map adapted from Montana DEQ's "Derivation of a Site-Specific Water Column Selenium Standard for Lake Koocanusa" (2020)

Elk River Selenium Concentrations and Flows





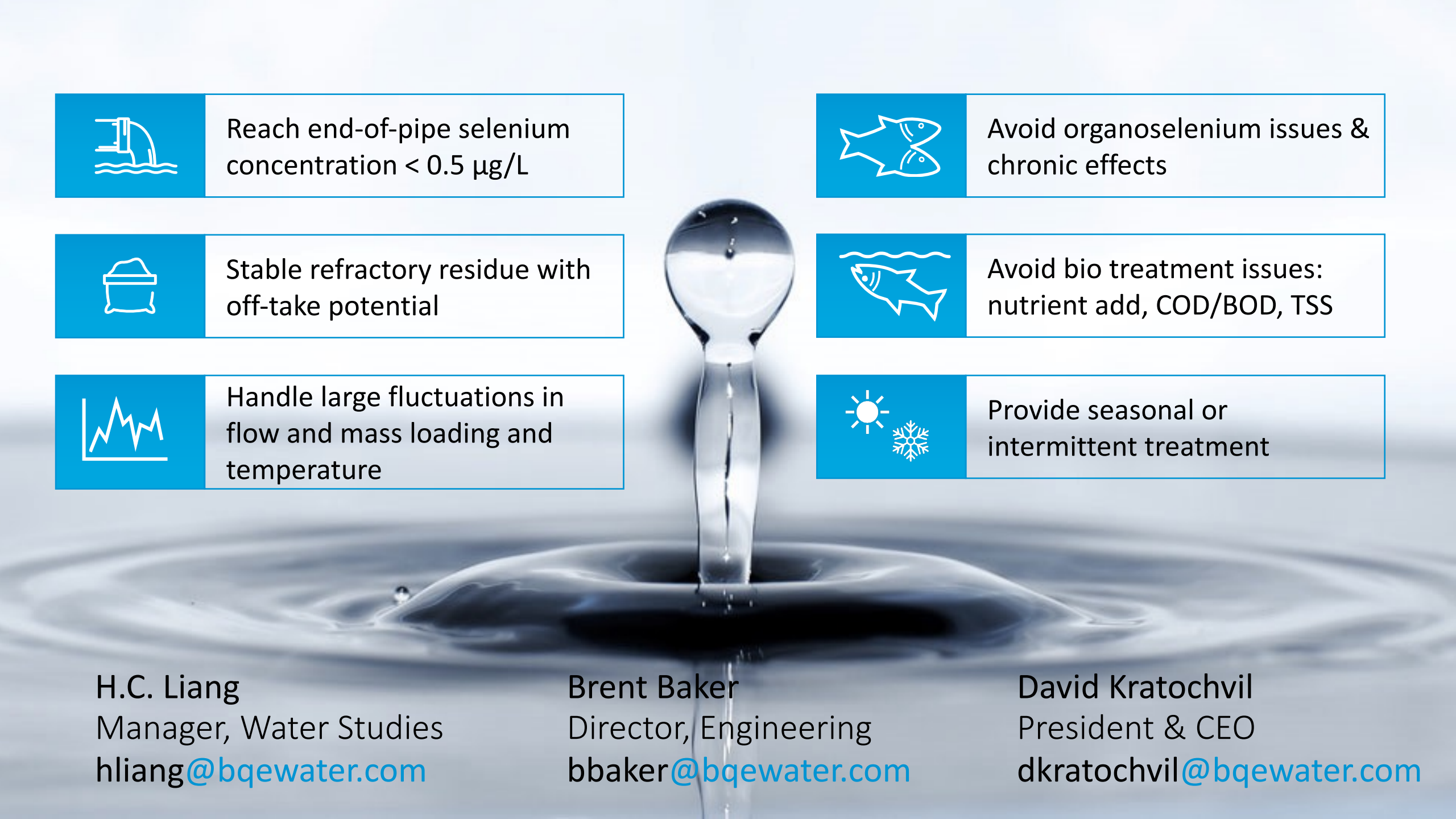
Data from https://aquatic.pyr.ec.gc.ca

Selenium Filtration Plant to Reduce Selenium Load to Lake Koocanusa

- Raw water quality:
  - [Se] ~10 µg/L avg
  - [SO_4^{2-}] ~75 mg/L avg
- Design flowrate 7 m^3/s (605,000 m^3/d) removes ~1/3 selenium loading
- Concrete basins
- Can help reach compliance with U.S. 0.8 µg/L selenium standard

Potential Solution to Cross-Boundary Conundrum

- Technology exists to solve problem
- Non-biological selenium treatment of portion of Elk River (~2-3% of total inflow to Lake Koocanusa)
- Remove ~1/3 of selenium loading into Lake Koocanusa
- Could yield results within < 1 year of commencement
- Solids generated per year would be ~0.01 to 0.04% weight of annual coal production in area



- Reach end-of-pipe selenium concentration < 0.5 µg/L
- Stable refractory residue with off-take potential
- Handle large fluctuations in flow and mass loading and temperature
- Avoid organoselenium issues & chronic effects
- Avoid bio treatment issues: nutrient add, COD/BOD, TSS
- Provide seasonal or intermittent treatment

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