Electrodeionization (EDI)

Outline

- Process Principles
- EDI History
- Applications and Benefits
- Performance
- Feed Water Requirements and Pretreatment

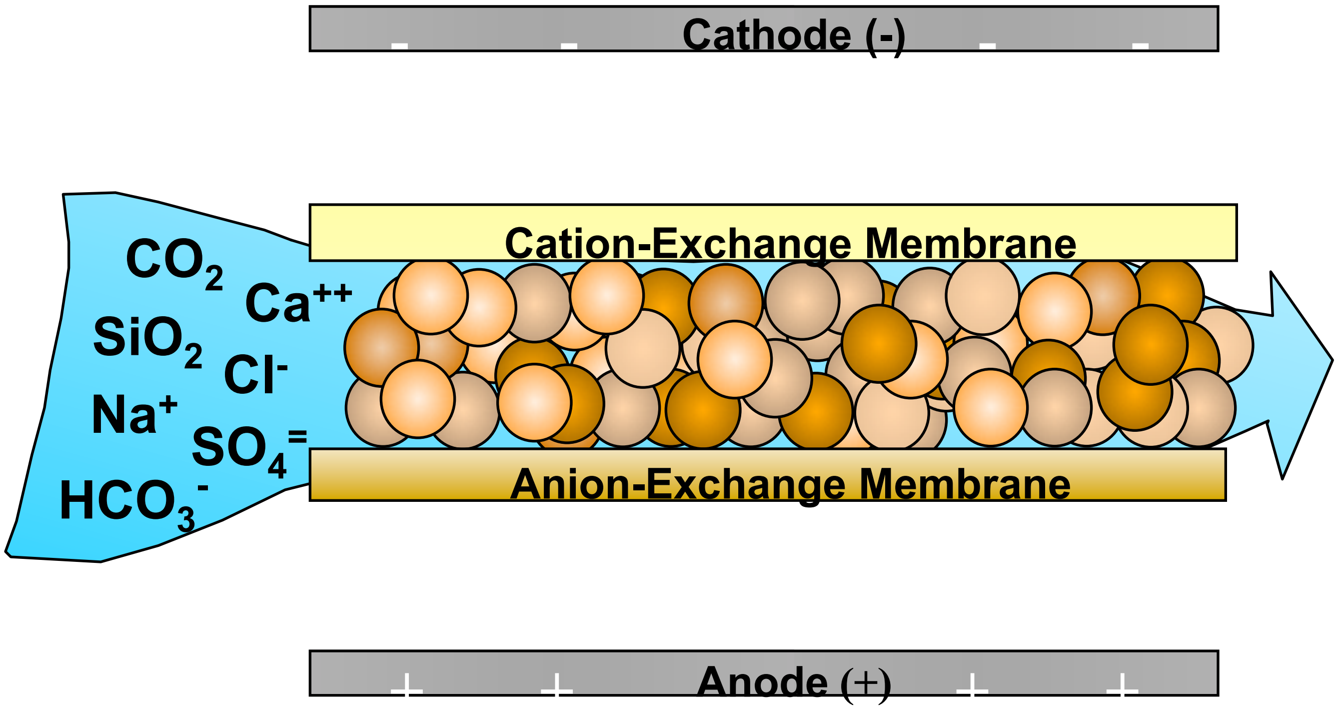
Process Principles

Process Principles

Device

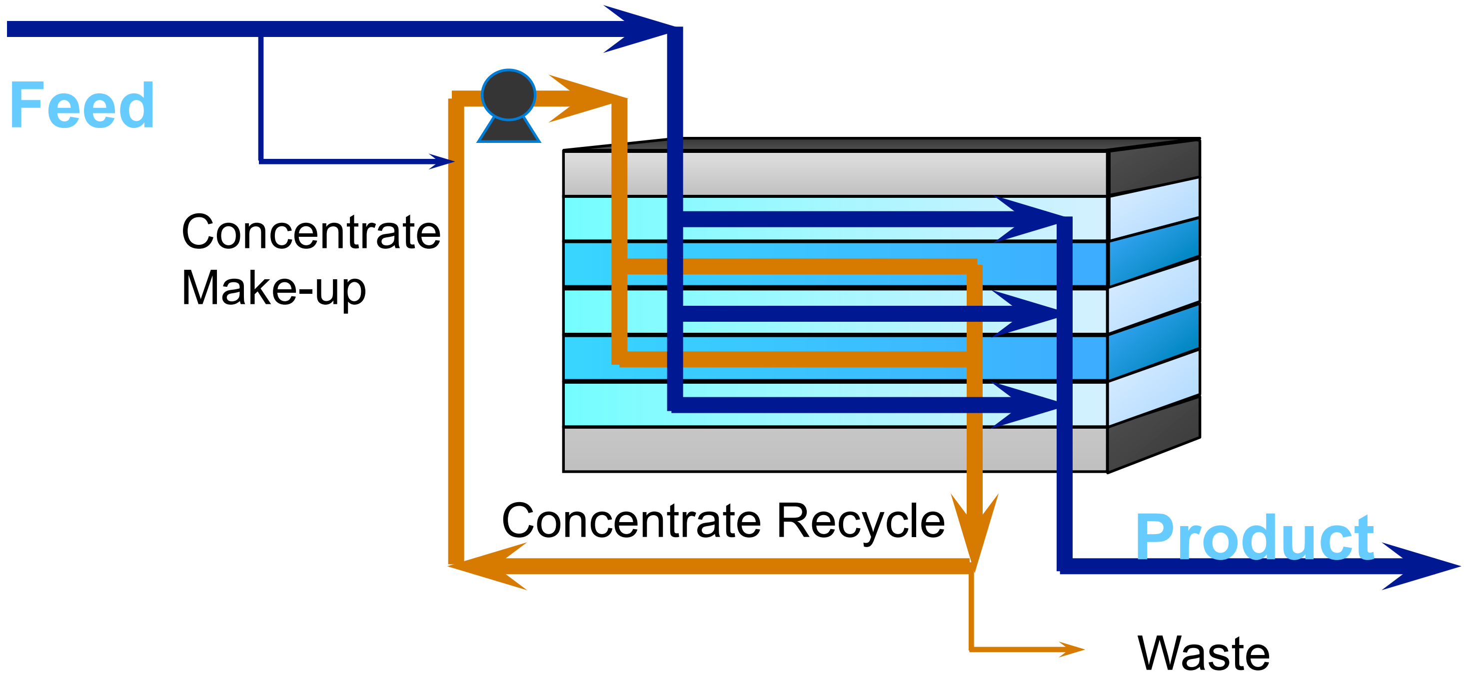
- Cation exchange membrane
- Anion exchange membrane
- Spacers
- Electrodes
- Ion exchange resin

Process Principles



Process Principles

EDI System



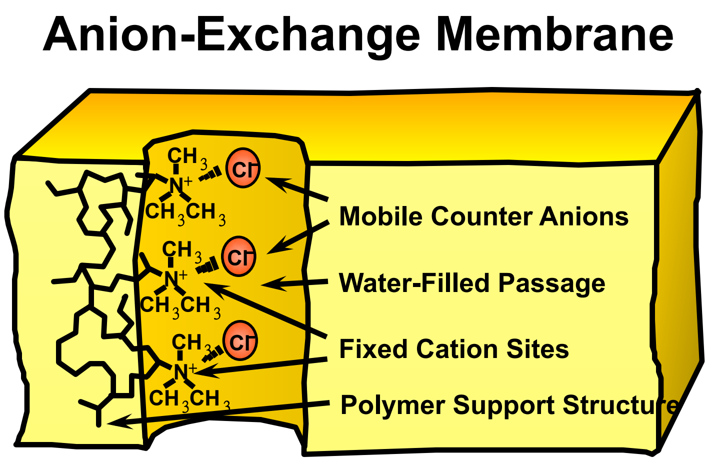
Process Principles

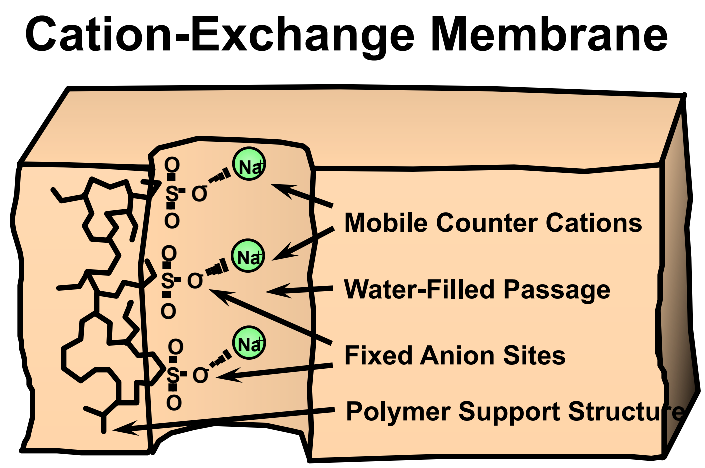
How does EDI work?

- Enhanced transfer regime (high salinity)
  - Remove strong ions from water
- Electroregeneration regime (low salinity)
  - Remove ionizable species (weak acids or weak bases) from water

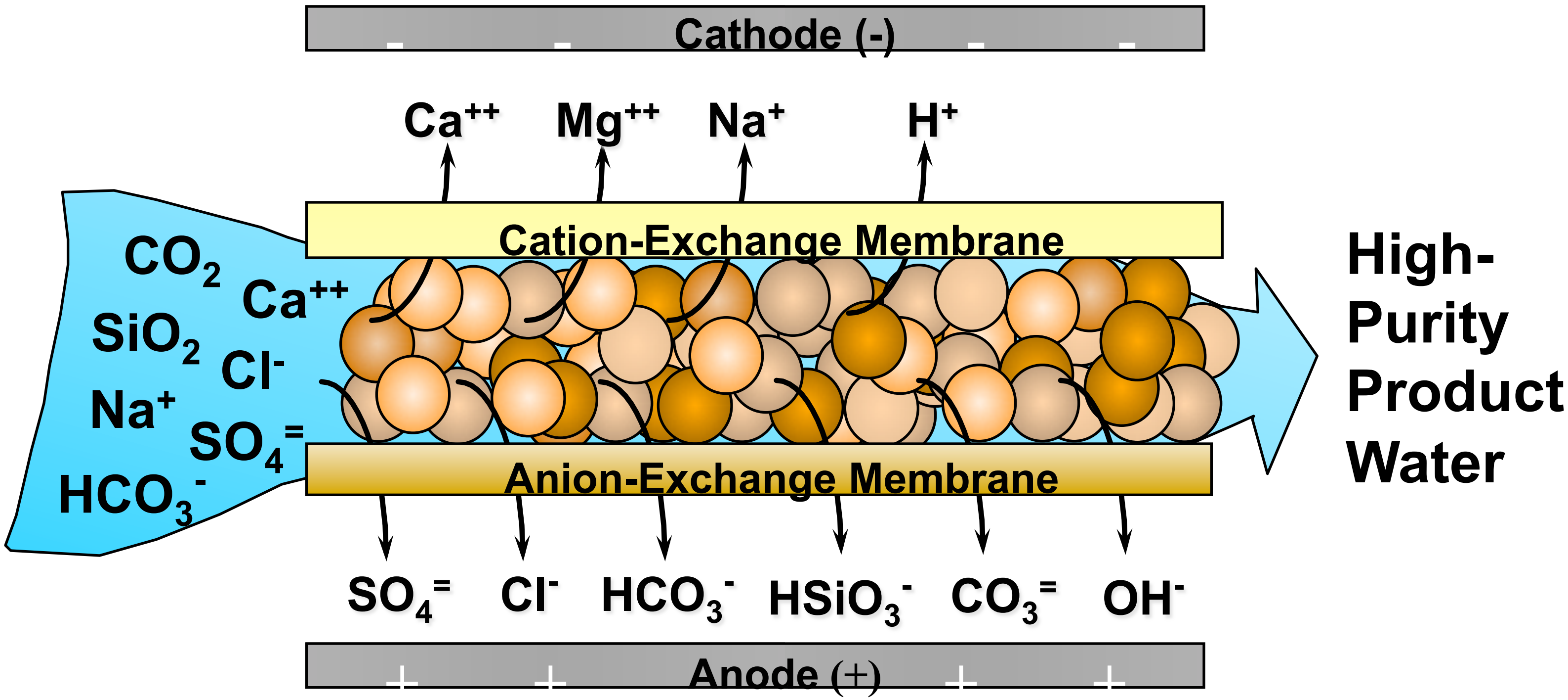
PROCESS PRINCIPLES

Ion-Exchange Membrane





Process Principles



Process Principles

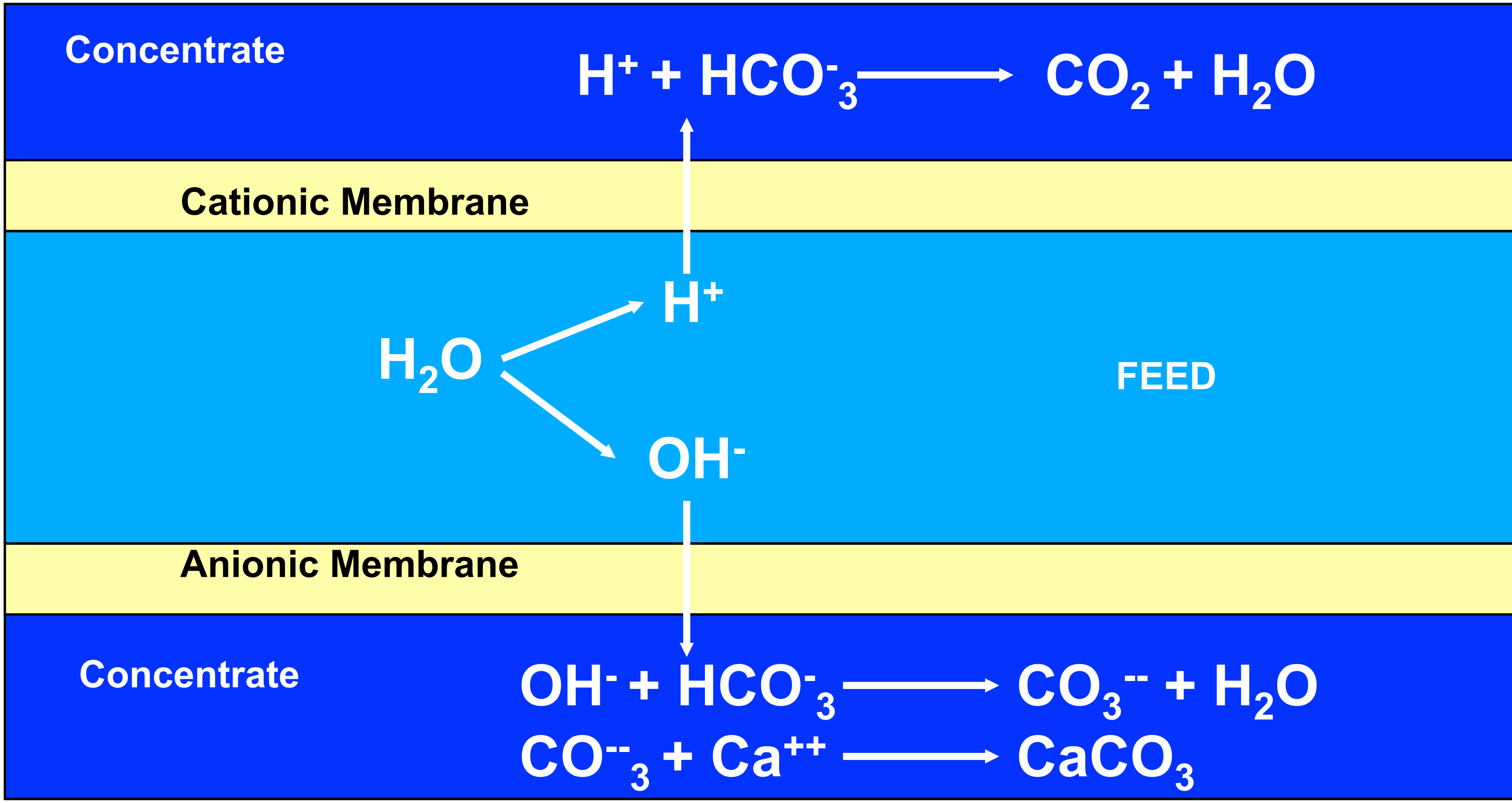
Enhanced transfer regime

Ions are transferred from solution to resins by diffusion.

Ions move inside resins by means of electricity

Ions reach the membranes and pass to the brine flow.

Polarization

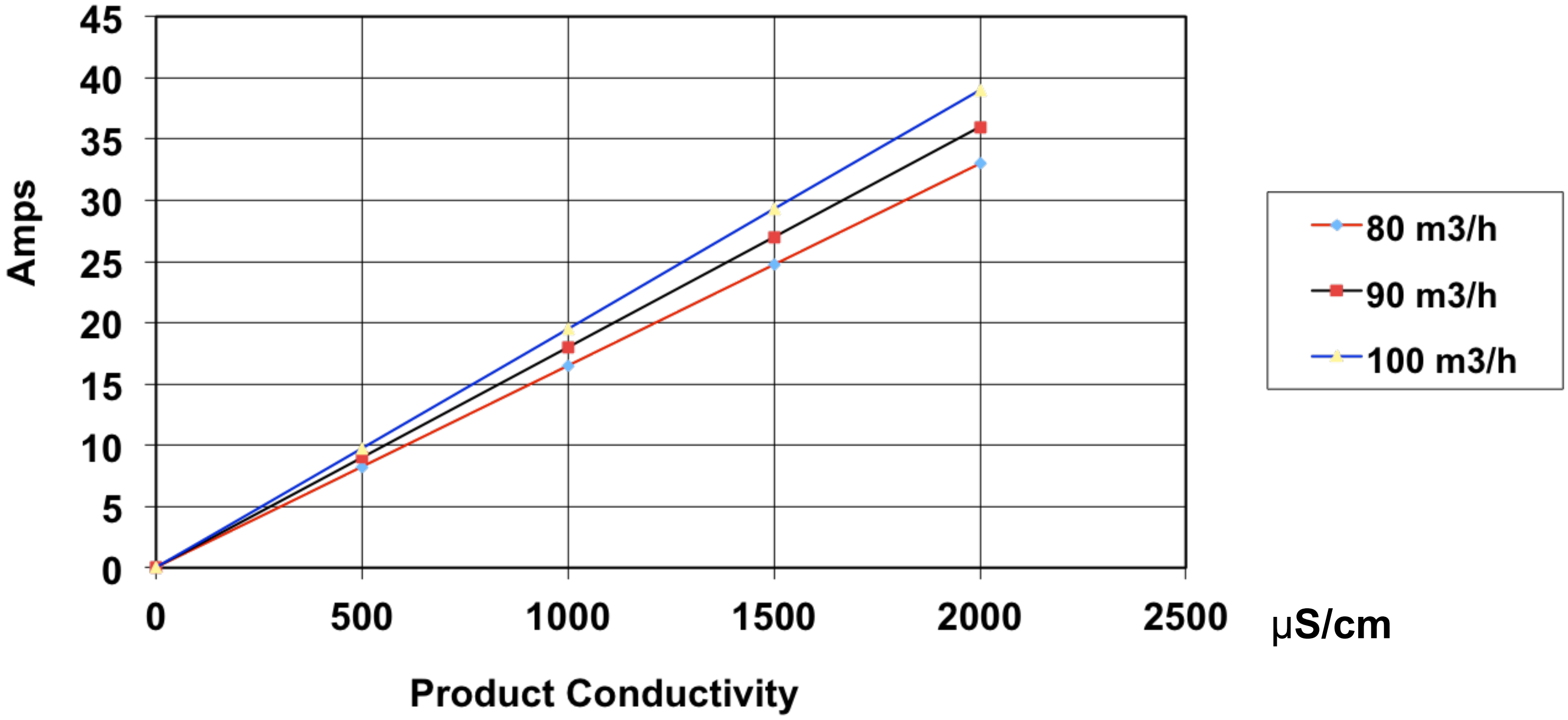


Process Principles

Electro regeneration Regime

- Resin in hydrogen and hydroxide forms
- Removal of weakly ionized compounds by ionization reactions
  - $CO_2 + OH^- \longrightarrow HCO_3^-$ pKa = 6.4
  - $HCO_3^- + OH^- \longrightarrow CO_3^{=}$ pKa =10.3
  - $SiO_2 + OH^- \longrightarrow HSiO_3^-$ pKa = 9.8
  - $H_3BO_3 + OH^- \longrightarrow B(OH)_4^-$ pKa = 9.2
  - $NH_3 + H^+ \longrightarrow NH_4^+$ pKa = 9.2

Polarization



EDI History

EDI Technology History

- 1955 - Walters et al, work with periodic electro-regeneration of ion exchange resin in stack.
- 1957 - Kollsman patent on basic EDI method and apparatus.
- 1959 - Gluekauf, early EDI experimental data and theory.
- 1960's - Early Ionics EDI experiments.
- 1987 - Millipore Commercialized EDI - "CDI".

Applications and Benefits

EDI Applications

- Microelectronics
- Power Generation
- Boiler Feed
- Pharmaceutical
- Industrial
- Others

Technology Benefits

- Continuous process with constant stable product quality.
- No acid or caustic regenerants required
- No upsets or downtime from regeneration
- No need for high purity water rinse and backwash
- Produces high purity water with high water recovery (95%).

Additional Technology Benefits

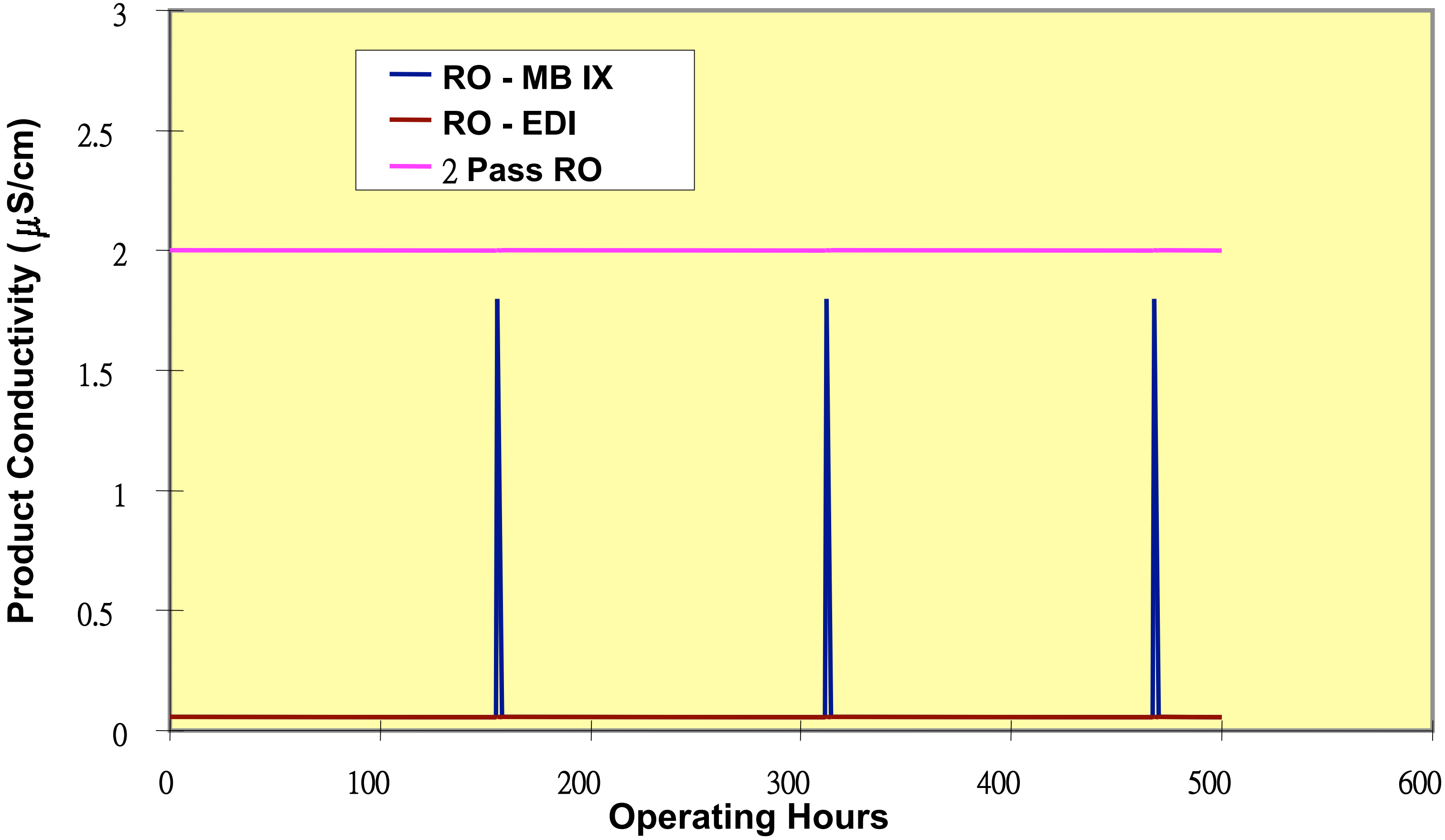
- No regeneration waste
- Eliminates need for a waste treatment plant
- Eliminates acid and caustic storage tank
- Eliminates acid and caustic dilution skid
- Reduced floor space
- Safe and reliable (No chemical handling)

Additional Technology Benefits

- Minimizing on-going O&M costs
  - essentially no chemical usage
  - minimal maintenance
- Easy to install
  - lower installation costs than with conventional ion-exchange
  - on-line quicker
- Provide consistent high percentage boron rejection

Weakly Ionized Species Removal By EDI

Product Quality Comparison



Boron Removal by EDI

- Boron present at very low concentrations in many waters
- Presence of Boron often unchecked
- Boron can cause problems in semiconductor manufacturing

Boron Removal by RO

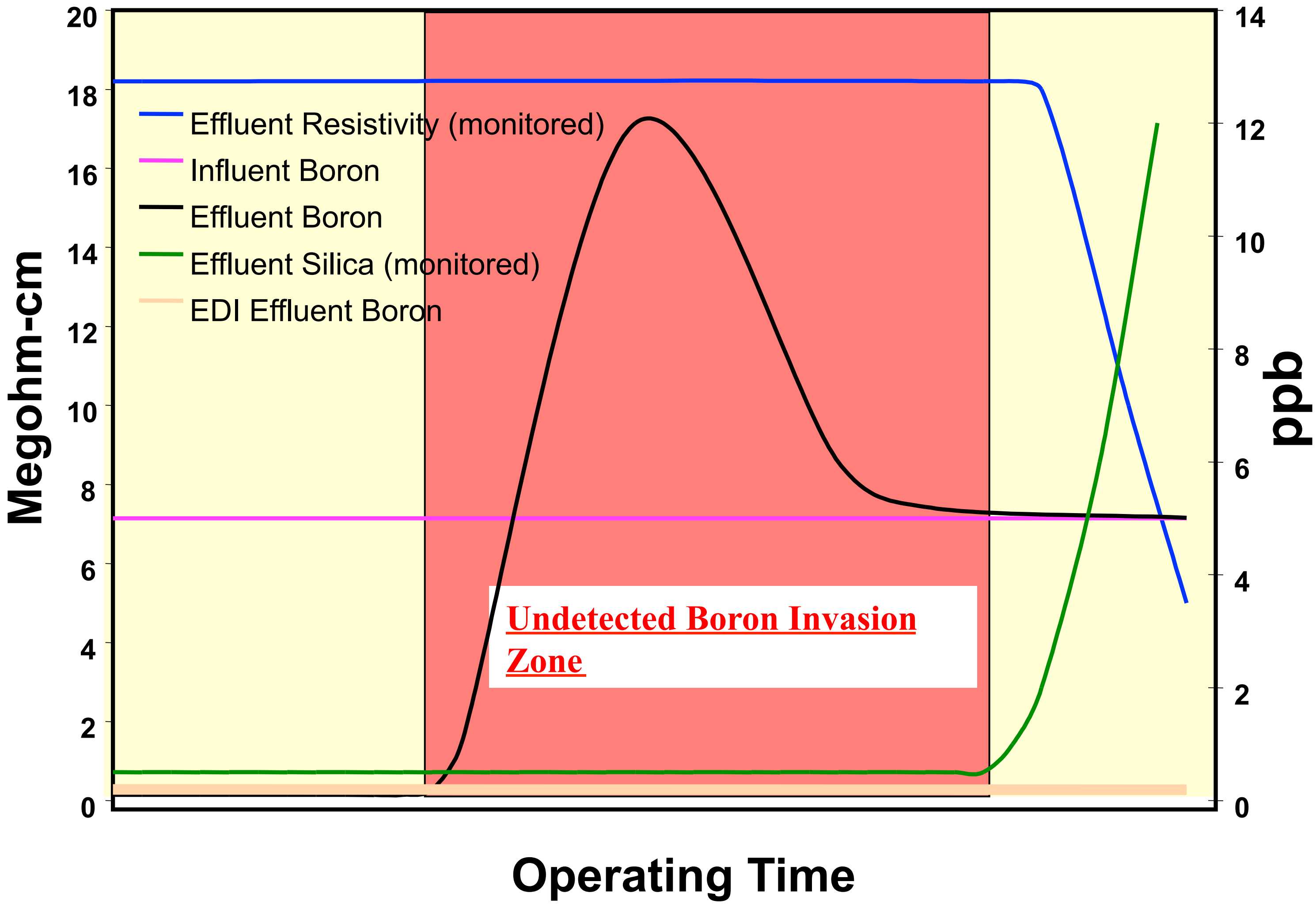
- Boron removal by RO is pH dependent
- RO does not reject Boron well at neutral pHs due to:
  - poor ionization of boric acid
  - extremely small boric acid molecule
- Typical Boron rejection by RO:
  - 50% to 80% at neutral pH
  - >90% when > pH10

Boron Removal by Ion-Exchange

- Boron is not well removed by ion-exchange due to:
  - low selectivity
  - poor ionization of boric acid
- Boron is the first to break through ion-exchange
- Studies show Boron breaks through at 20% to 50% of silica run-length
- Boron displacement produces Boron spikes in product water

Performance of Mixed-Bed Ion-Exchange

(Boron Break-through could effect wafer yield)



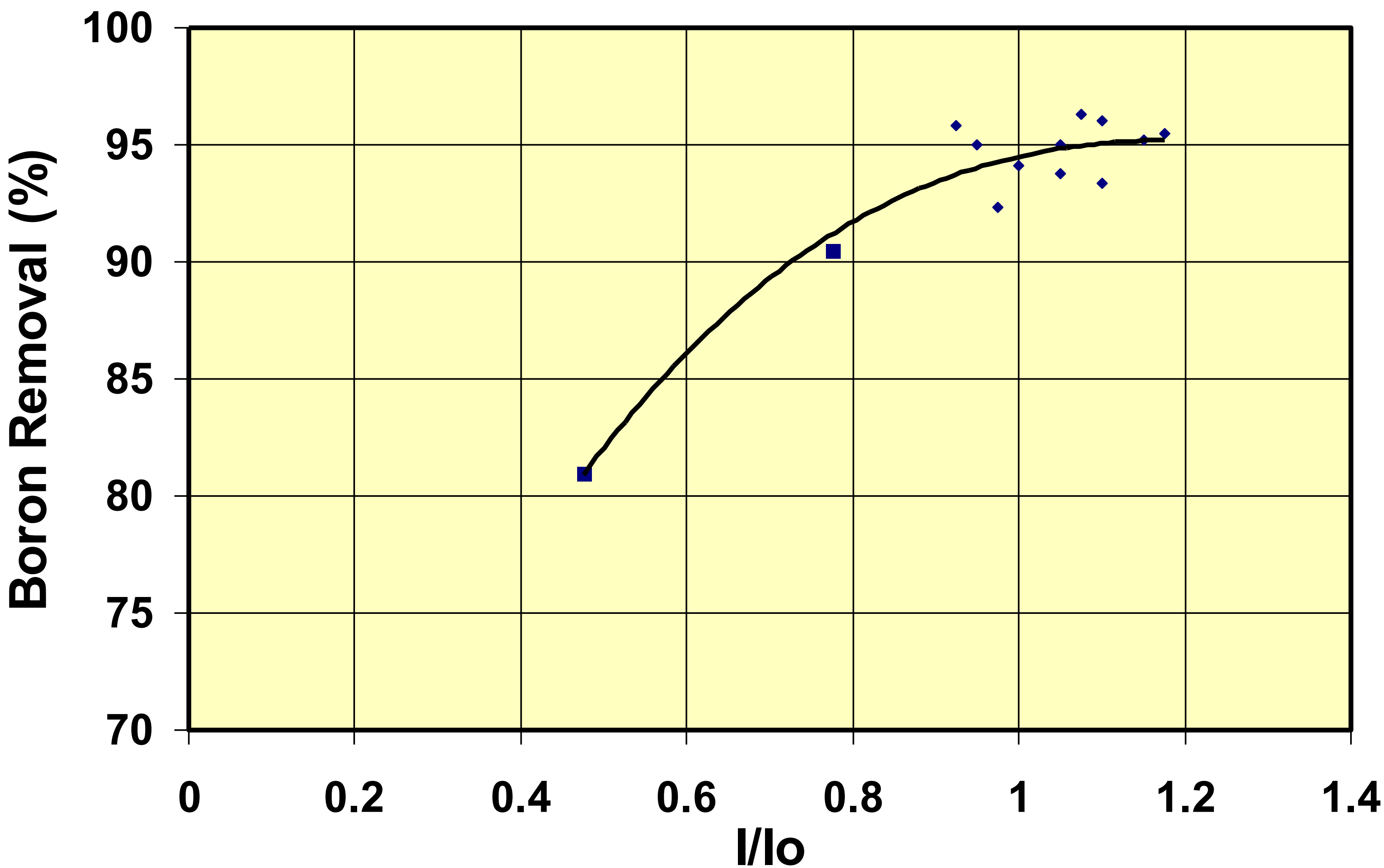
Boron Removal By EDI

- One of the most effective process to removal boron
- Well designed EDI will provide 96% to 99% boron rejection consistently

Boron Levels and Removal by RO and EDI

	Feed B (ppb)	Product B (ppb)	B Removal by EDI (%)	B Removal by RO (%)
Semiconductor Plant #2	71	2.75	96.8	39.3
Semiconductor Plant #3	83.5	2.8	96.1	24.1
Semiconductor Plant #4	64.4	0.74	96.6	24.1
Semiconductor Plant #5	2.5	<0.1	>96.0	34.2

EDI Boron Removal at Varying Current Density



Silica Removal by EDI

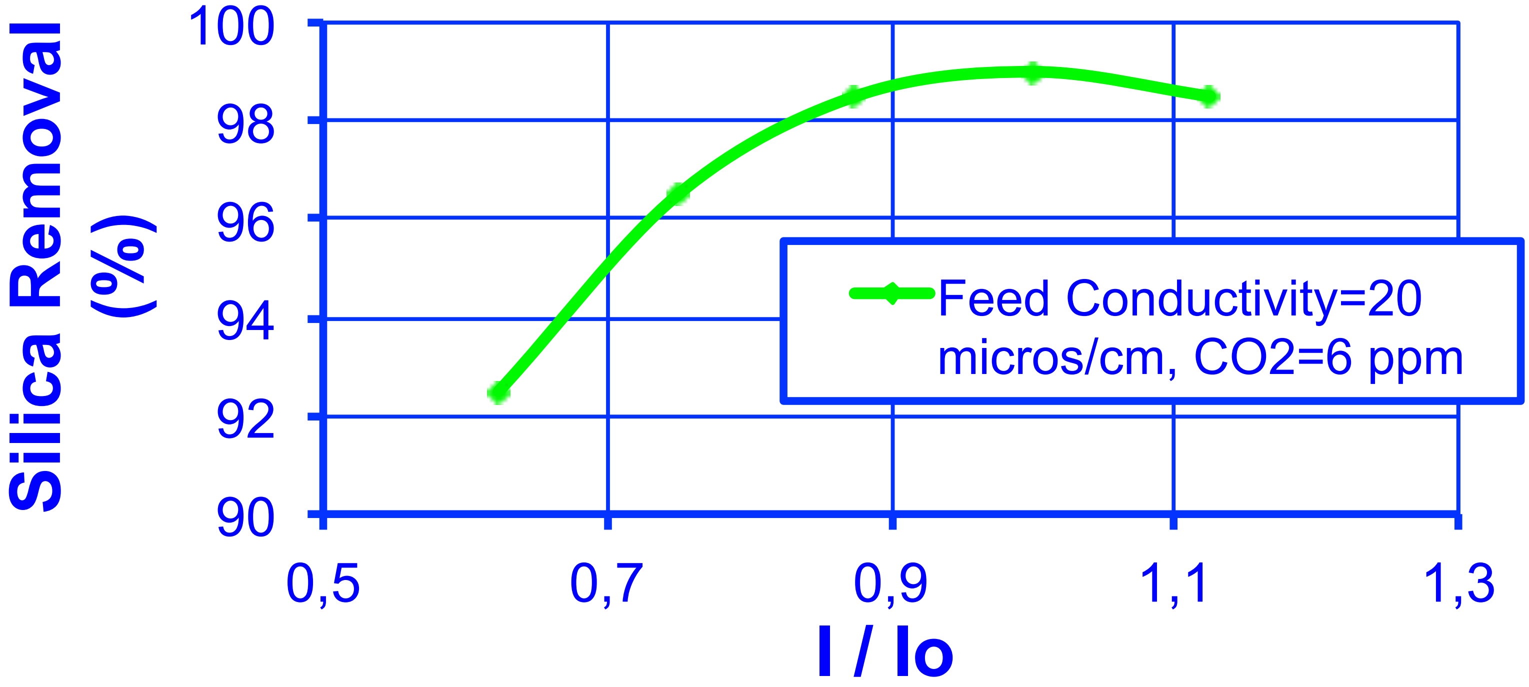
Silica removal is critical for semiconductor manufacturing

- high silica levels lead to expensive chip failures
- spec. limited by the ability of instrumentation

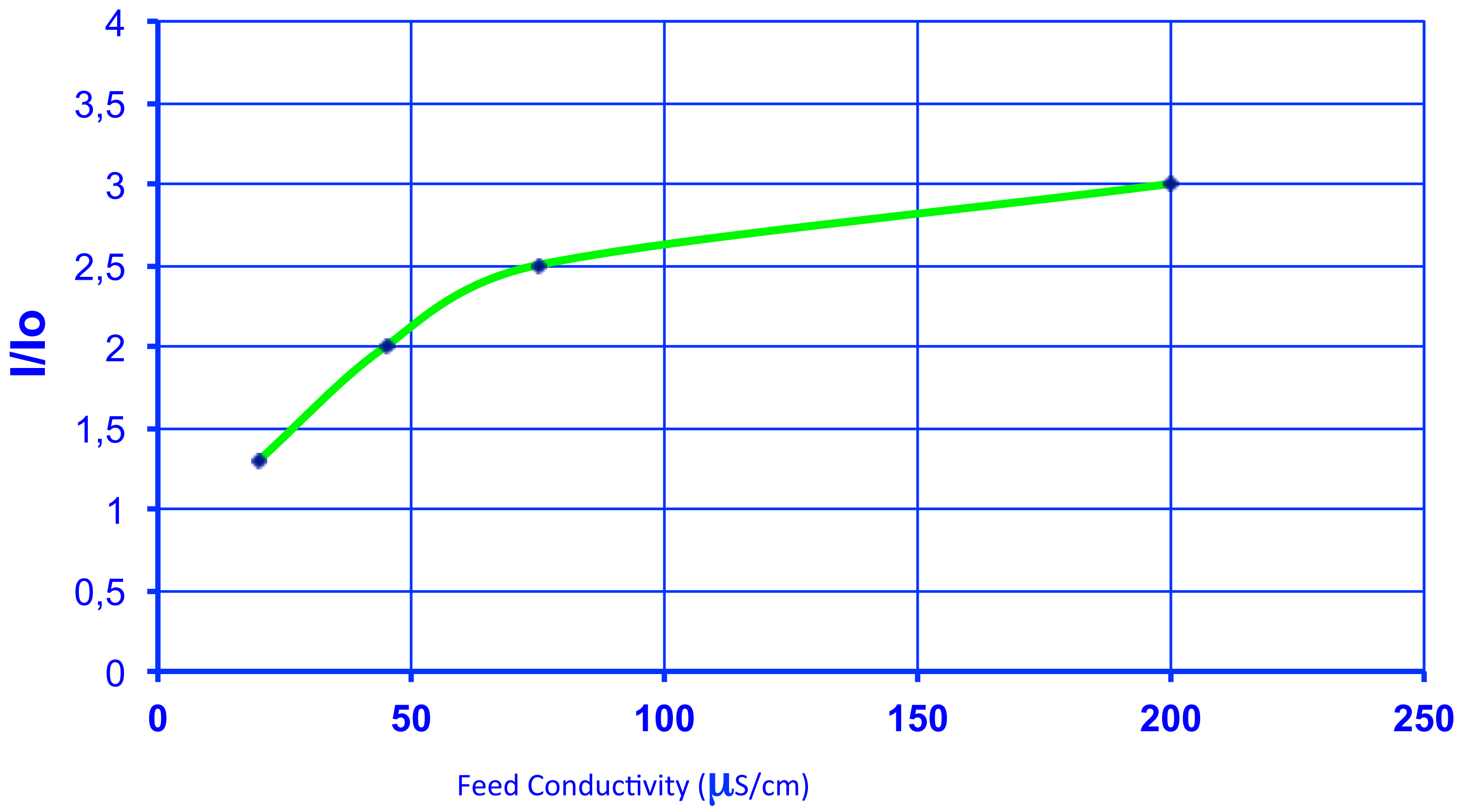
Silica Levels and Removal by EDI

	Feed SiO_2 (ppb)	Product SiO_2 (ppb)	SiO_2 Removal (%)
Semiconductor Plant #1	642	3.1	99.5
Semiconductor Plant #2	181	2.8	98.5
Semiconductor Plant #3	393	<2	>99.5
Semiconductor Plant #4	274	2.6	99.1
Semiconductor Plant #5	650	<5	>99.2

Study 2: EDI Performance at Varying Current Density



Study 3: Current Densities Required to Maintain >98.5% Silica Removal



Carbon Dioxide Removal by EDI

- Carbon dioxide is often largest load on ion-exchange beds, especially after an RO
- Not effectively removed by other membrane demineralization processes such as RO or ED unless chemical adjustments are made
- Removed >99% by EDI

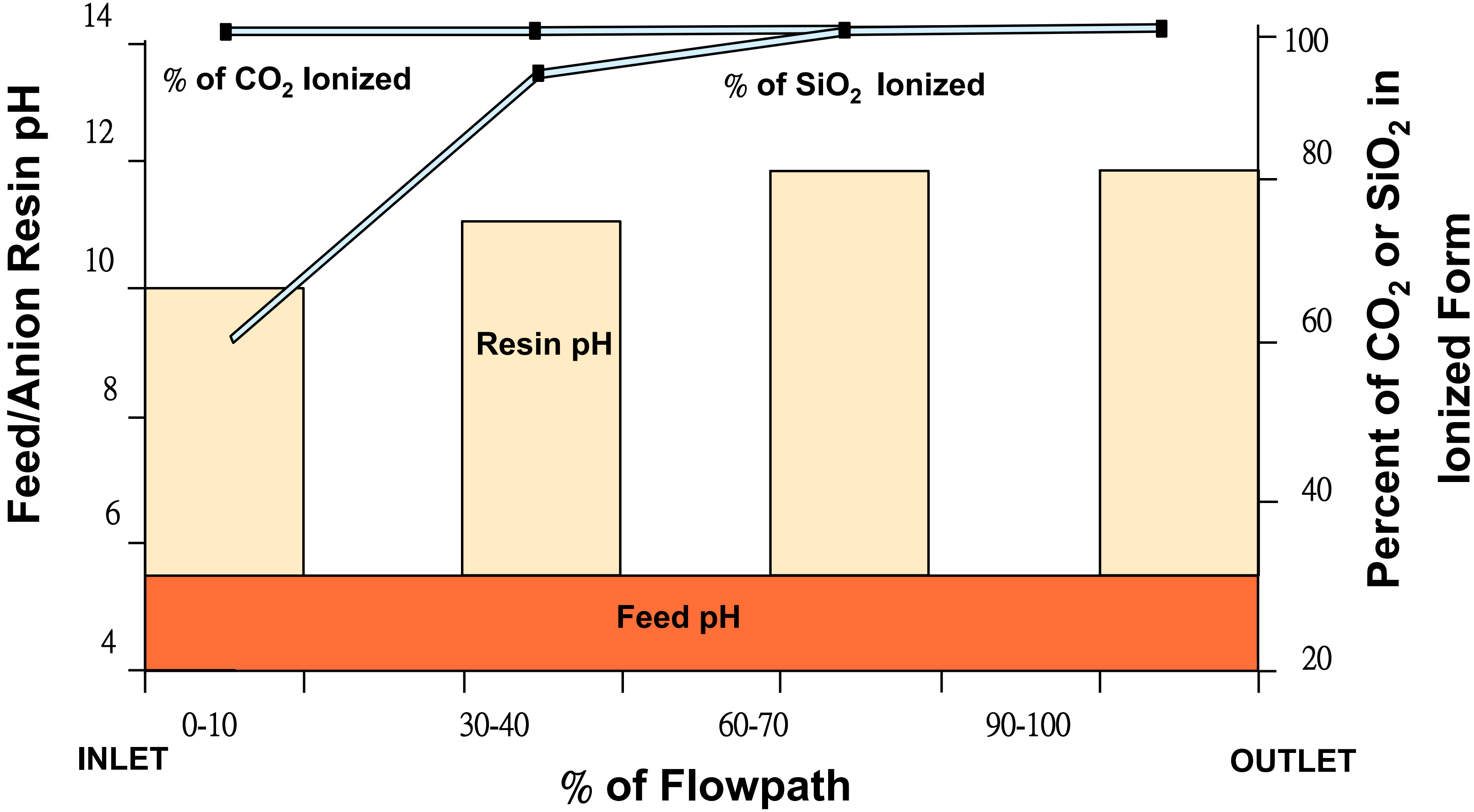
CO_2 Levels and Removal by EDI

	Feed CO_2 (ppm)	Product CO_2 (ppb)	CO_2 Removal (%)
Semiconductor Plant #1	2.80	10	99.6
Semiconductor Plant #2	4.48	29	99.4
Semiconductor Plant #3	6.52	25	99.6
Semiconductor Plant #4	6.05	10	99.8
Semiconductor Plant #5	6.50	22	99.7

Summary of Weakly Ionized Species Removal

- > 99% Silica removal
- > 99% CO_2 removal
- > 96% Boron removal
- > 98% Ammonia removal

Process Principles



EDI Performance

EDI Stack Design

EDI Performance and Pretreatment

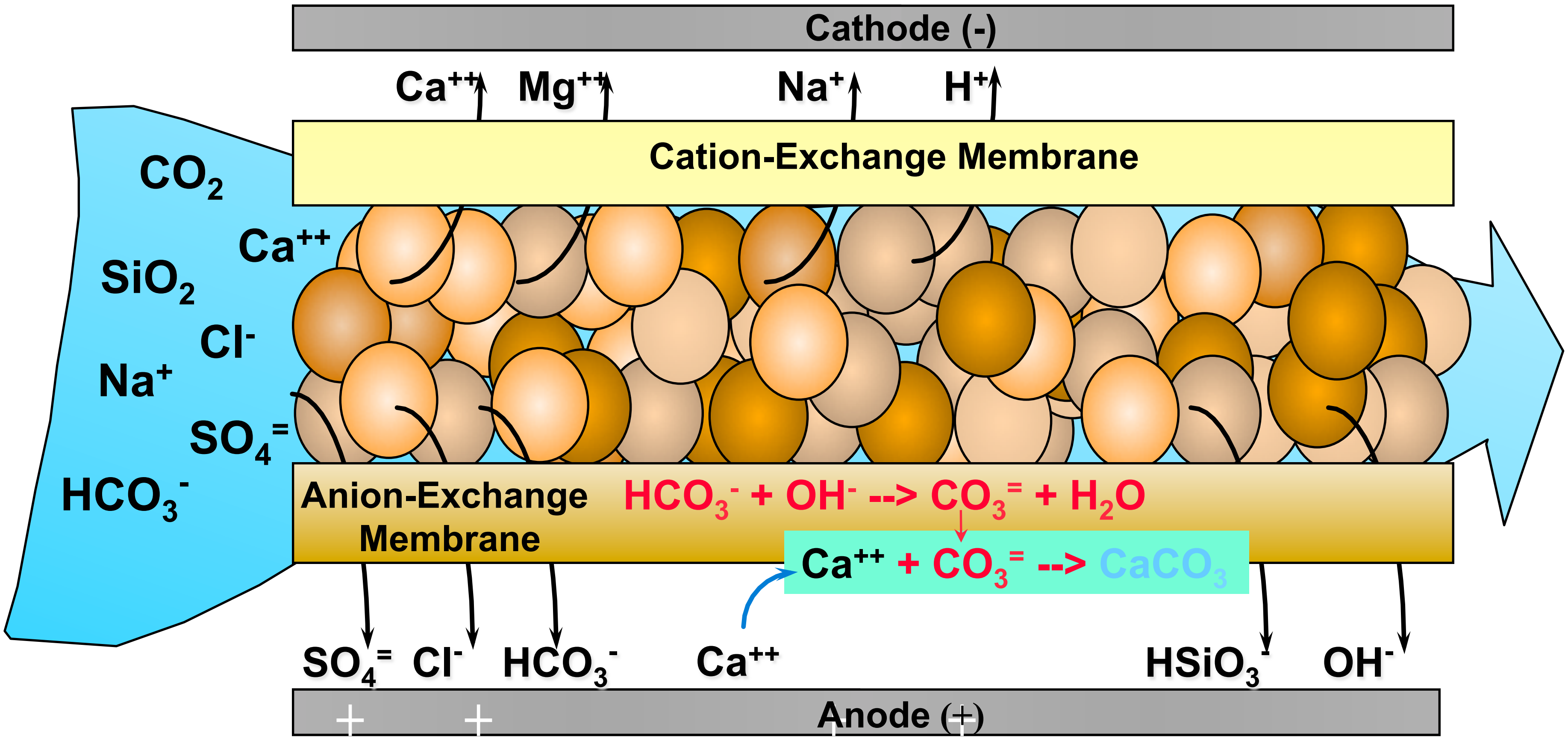
Performance

- EDI performance effected by:
  - Feed water quality
  - Stack current
  - Water recovery
  - Flow rate
  - Temperature

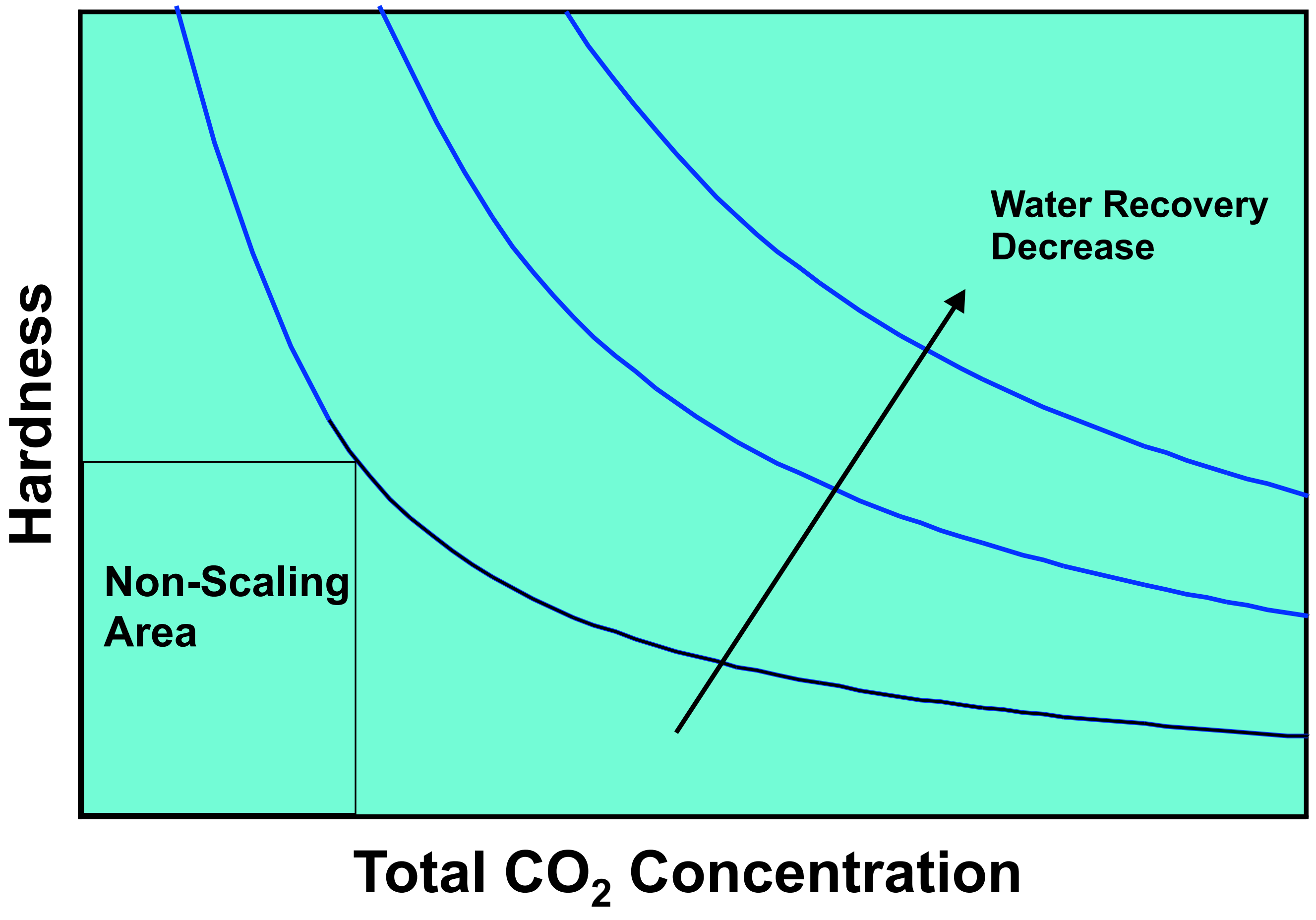
Feed Water Requirement

- Conductivity: < 40 mS/cm
- Hardness: < 0.25 ppm as $CaCO_3$
- TOC: < 0.5 ppm
- Pressure: 20 to 50 psi
- Temperature: 10 to 35oC
- pH: 4 to 10
- Chlorine: < 0.1 ppm
- Fe, Mn, Sulfide: < 0.01 ppm
- CO_2 < 8 ppm

Scaling in EDI



Feed Water Requirement



PERFORMANCE

- Stack Current
  - Controlled by
    - Stack voltage
    - Brine & electrode stream conductivity
  - Optimum current
    - Too high current
      - Higher scaling potential
      - CO_2 back diffusion
      - Higher power consumption
      - Shorter membrane life

PERFORMANCE

- Temperature
  - Better performance at higher temperature
  - Stack pressure drop is sensitive to temperature

Feedwater Requirements and Pretreatment

Pretreatment

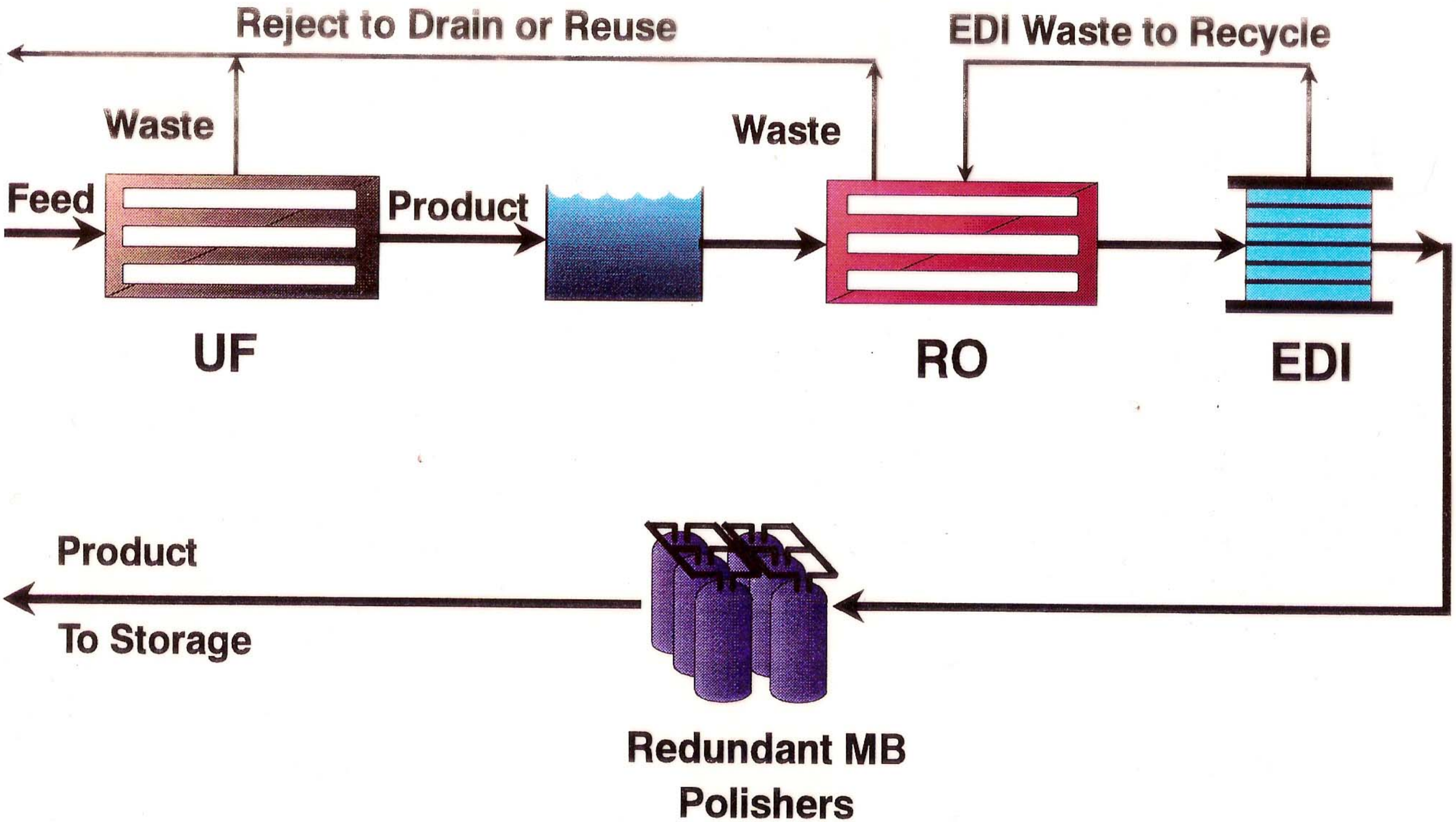
- Minimum pretreatment
  - TFC RO is required to minimize:
    - Scaling
    - Organic fouling
    - Particulate and colloidal plugging
    - Oxidative attack
    - Chemical cleaning

Pretreatment

- Optional pretreatment
  - Multimedia filter
  - AC filter
  - Degasification
  - UF
  - Softener
  - UV
  - Organic scavenger

Triple Membrane System

TMT-II



Testing - Organics

- What is removed?
  - Organic acids (acetic acid)
  - TMAH(tetramethyl ammonium hydroxide)
  - NMP(N-Methyl Pyrollidone)
- What may be removed?
  - Waco(601?) surfactant
- What isn’t removed?
  - IPA
- What may not be removed?
  - Anti-forming agent
  - Ethylene glycol

EDI Operation and Maintenance

STACK MAINTENANCE

- Routine Maintenance
- Scaling and Scaling Control
- Fouling and Fouling Control
- Bacteria Control
- Cleaning-In-Place

STACK MAINTENANCE

- Routine Maintenance
  - Daily log sheet
  - Visually inspect the stack weekly
  - Hose down any chemical buildup outside the stack
  - Check the stack torque for the first three month, and twice a year thereafter

STACK MAINTENANCE

- Stack Scaling
  - Increasing stack resistance
  - Reducing brine flow rate
  - Decreasing silica rejection
  - Product resistivity decline

STACK MAINTENANCE

- Scaling Control
  - Brine stream pH control
    - pH3 or lower
  - Softener addition ahead of EDI
  - Reduce water recovery
  - Reliable RO

STACK MAINTENANCE

- Stack Fouling
  - Increasing stack resistance
  - Decreasing silica rejection
  - Product resistivity decline
  - Stack pressure drop increase

STACK MAINTENANCE

- Fouling Control
  - AC filter
  - UV
  - Organic scavenger
  - Reliable RO

STACK MAINTENANCE

- Bacteria Grow in Brine Stream
  - Brine flow decrease
  - High bacteria count in brine stream
- Bacteria Control
  - Sanitize the brine stream periodically
    - 0.1 to 0.2 ppm level of chlorine

STACK CLEANING

- Cleaning-in-place (CIP)
  - Continuous (in-flight) brine stream acid CIP
    - pH 1.5 for hours
  - Batch brine stream acid CIP
    - pH1 or lower for more than 30 min.
  - Dilute stream salt & caustic CIP
    - 10% salt
    - pH11
    - 40 C