Improving Silica Removal By EDI and GTM

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Headquarters

Electropure™ EDI Operating in 49 Countries

The Electropure™ EDI History

- ***1977*** *Harry O'Hare EDI Prototype*
- ***1979*** *HOH Water Technology founded*
- ***1984*** *HOH EDI Patent Issued*
- ***1988*** *EPM series EDI*
- ***1996*** *HOH becomes Electropure*
- ***1999*** *Excellion™ IX Membrane Patents*
- ***1999*** *XL™ series EDI*
- ***2004*** *XL-HTS™ High Temperature Stable*
- ***2005*** *Electropure Management Buyout--SnowPure formed*
- ***2006*** *Electropure China Sales Office Opened*
- ***2007*** *XL-R™ series EDI improvements*
- ***2008*** *SnowPure International (Hong Kong) formed*
- ***2009*** *EXL™ series EDI introduced in China*
- ***2010*** *EXL™ series EDI introduced worldwide*
- ***2012*** *EXL-HTS high volume, high temperature for sanitization*
- ***2013*** *XL-DER EDI for Hemodialysis*

Agenda

1. Importance of Silica for Power Plants
2. Old EDI Model: Working Bed - Polishing Bed
3. New EDI Model: Electropure Specific Ion Model
4. Discussion: Specific RO-EDI Cases
5. Rules to Optimize SiO_2 in EDI

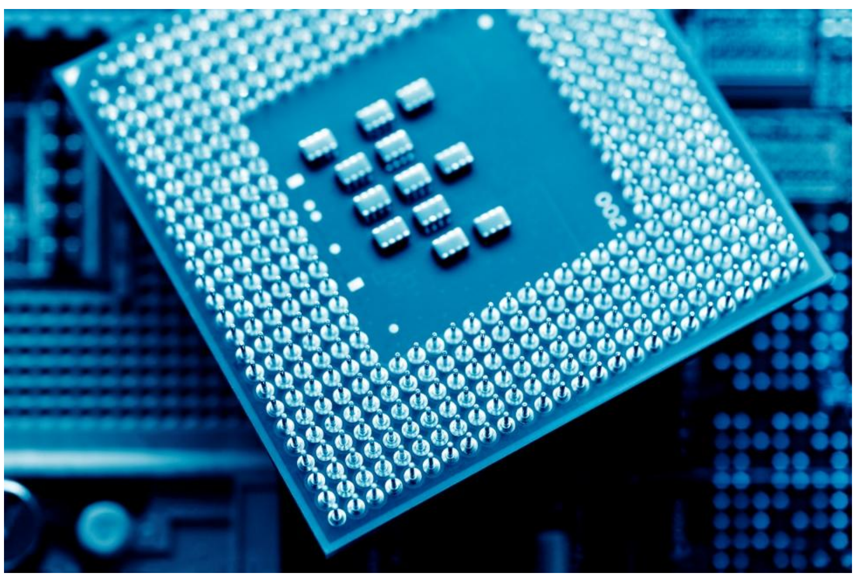
SnowPure
High Technology Water

makers of
Electropure EDI
products

Silica is Important in Power Plants and Electronics

Semiconductor Fabs

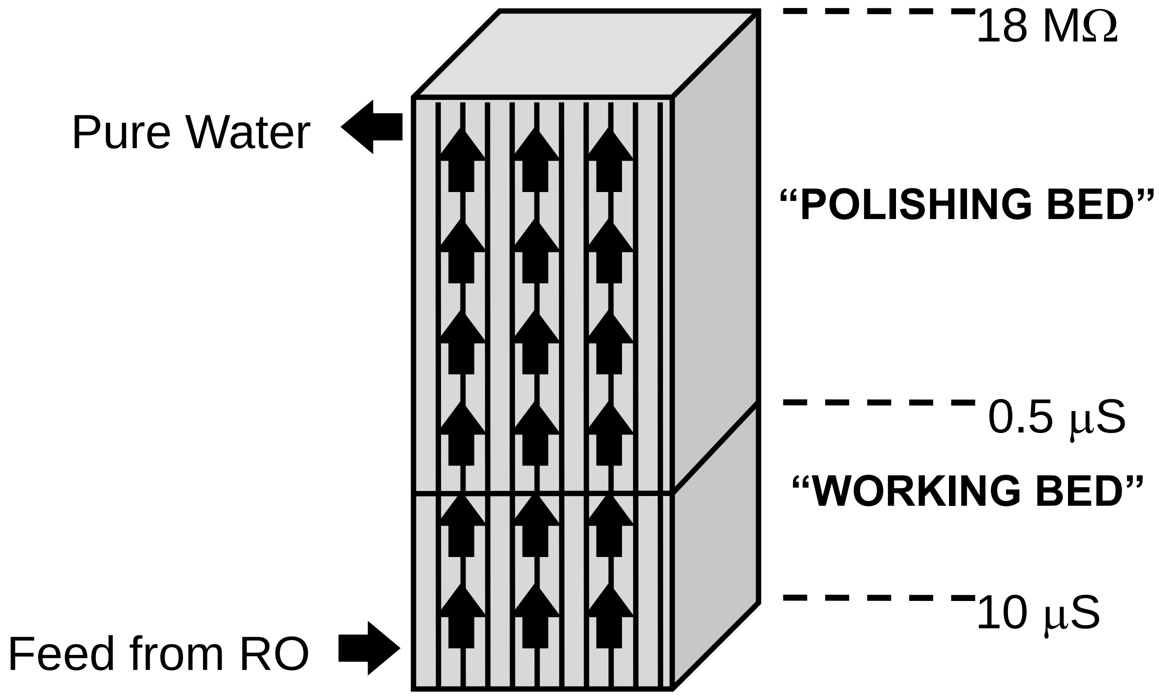
$SiO_2 < 0.1$ ppb



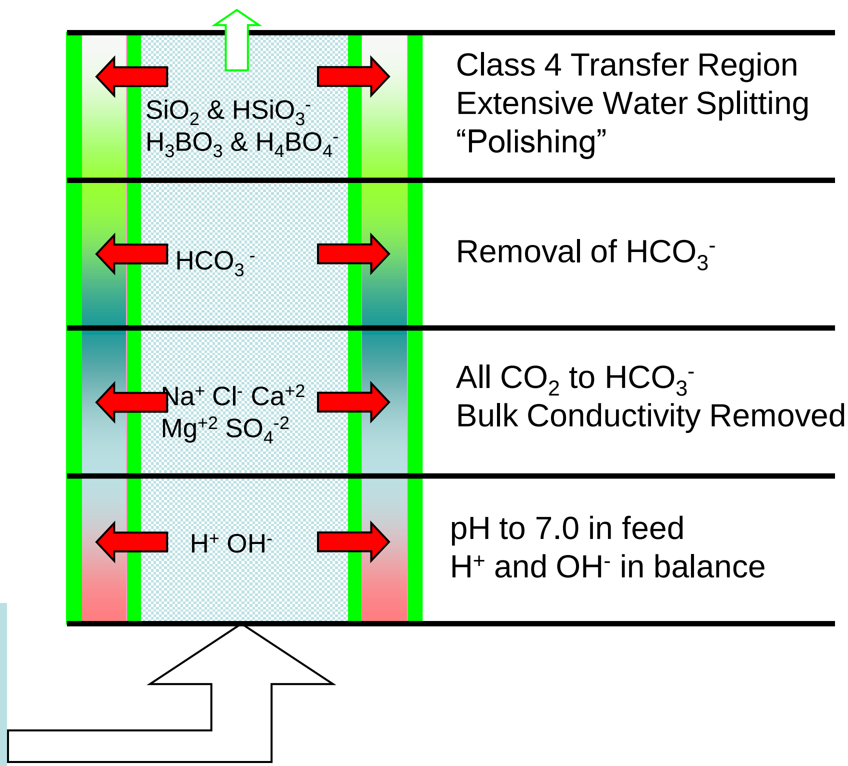
Combined Cycle High Pressure Boilers

$SiO_2 < 5$ ppb

Old EDI Model: Working Bed-Polishing Bed



Electropure's New Specific Ion Model



I: H^+ OH^-

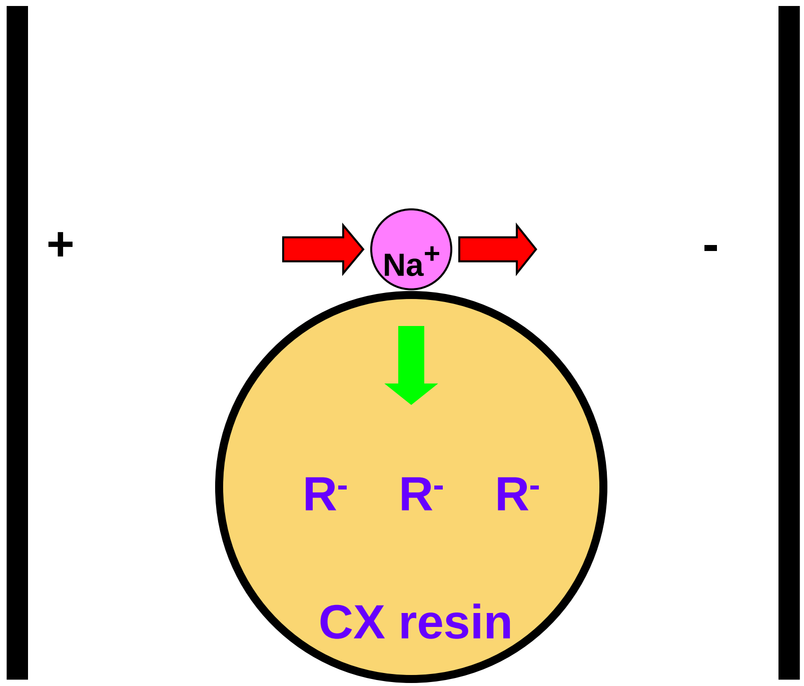
II: Na^+ Cl^- Ca^{+2} Mg^{+2} SO_4^{-2}

III: HCO_3^- $CO_2(g)$

IV: SiO_2 H_3BO_3

Forces on Cations in EDI

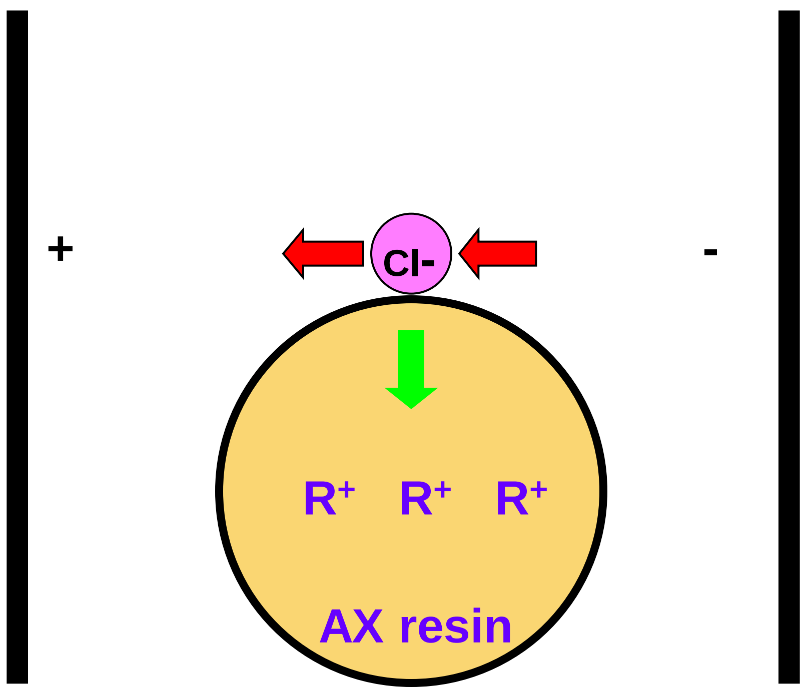
- Force 1: (green arrow)
  - Electrical Attraction to resin
  - K, Selectivity Coefficient
- Force 2: (red arrow)
  - Electrical attraction to electrodes
  - E, Charge/Mass



- K, Selectivity Coefficient
  - $Ca^{+2} > Mg^{+2} > K^+ > Na^+ > H^+$
- E, Electrical Force/Mass
  - $H^+ > Mg^{+2} > Ca^{+2} > Na^+ > K^+$

Forces on Anions in EDI

- Force 1:
  - Electrical Attraction to resin
  - K, Selectivity Coefficient
- Force 2:
  - Electrical attraction to electrodes
  - E, Charge/Mass



K, Selectivity Coefficient

$SO_4^{-2} > Cl^- > OH^- > HCO_3^- > HSiO_3^-$

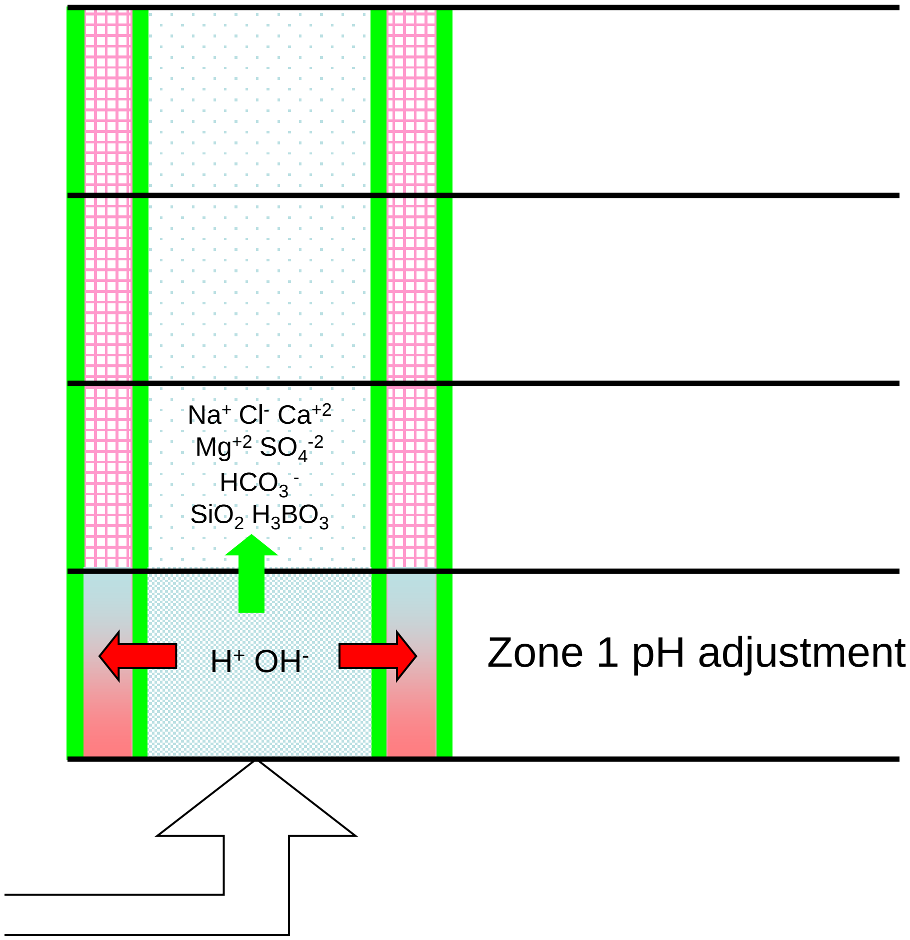
E, Electrical Force/Mass

$OH^- > Cl^- > SO_4^{-2} > HCO_3^- > HSiO_3^-$

Electropure's 4 Classes of Ions

Electropure™ Ion Class	Characteristics	Example Ions
Class 1	Low Selectivity High Mobility	H^+ OH^-
Class 2 "Conductivity"	High Selectivity Medium Mobility	Ca^{+2} Mg^{+2} Na^+ Cl^- SO_4^{-2}
Class 3 "Bicarbonate"	Low Selectivity Low Mobility Moderate Charge, Polar at pH 7	HCO_3^- pK = 6.3
Class 4 "Weakly Ionized Ions"	Very Low Selectivity Very Low Mobility Low charge at pH 7	$HSiO_3^-$ pK = 9.8 $H_4BO_4^-$ pK = 9.3

Class1: H+ and OH-



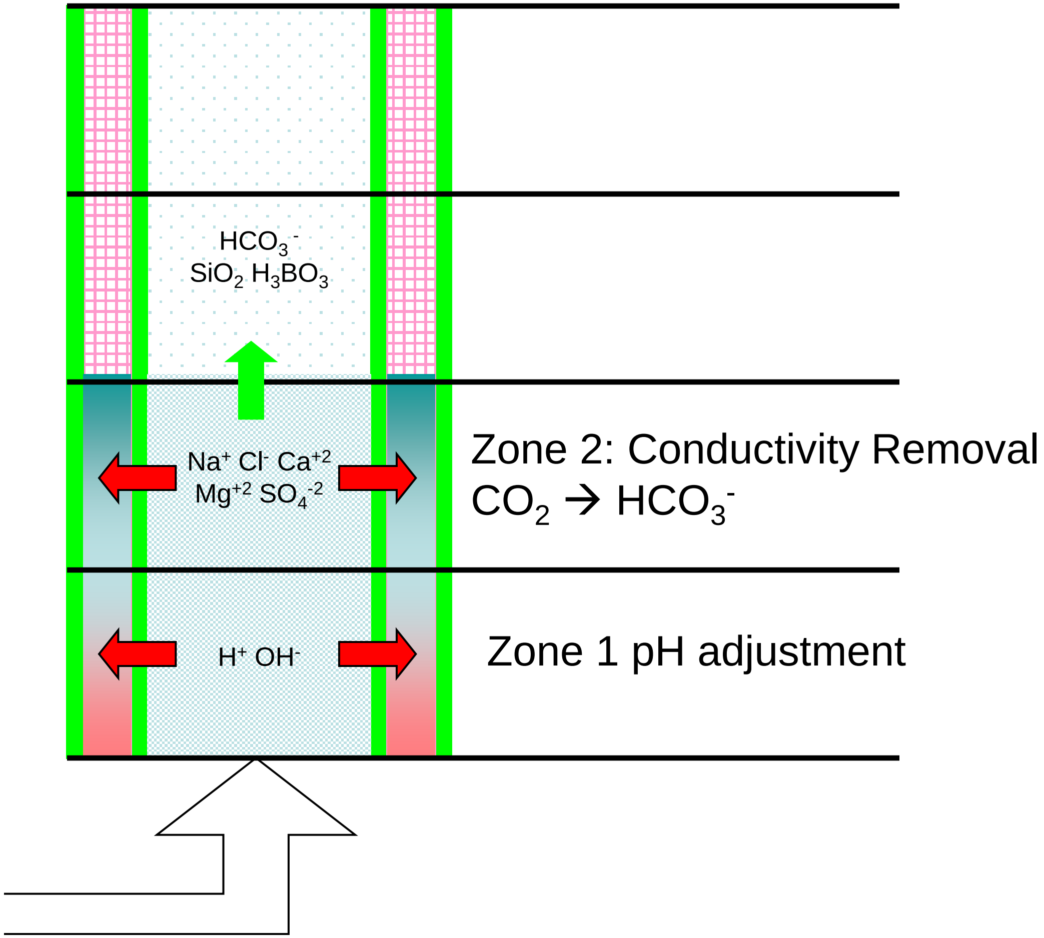
1: H^+ OH^-

2: Na^+ Cl^- Ca^{+2} Mg^{+2} SO_4^{-2}

3: HCO_3^- CO_2(g)

4: SiO_2 H_3BO_3

Class 2: Easy Ions



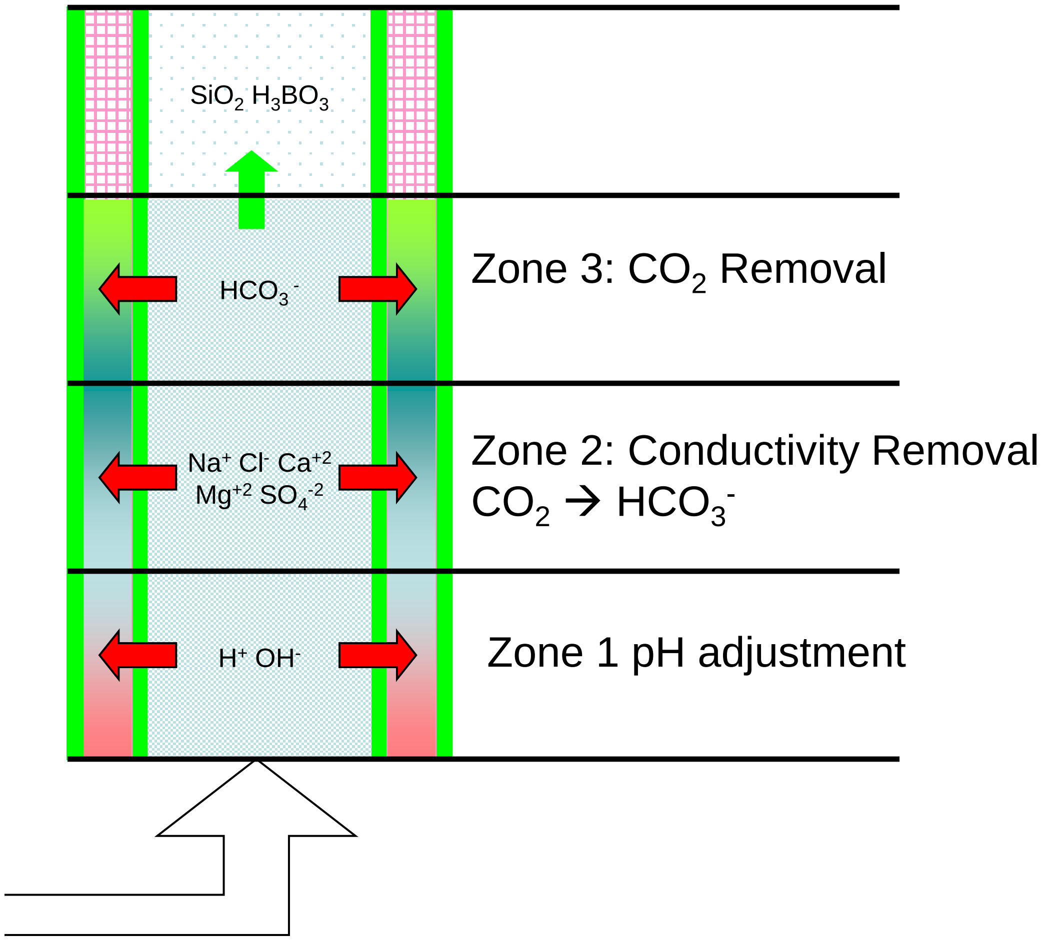
1: H^+ OH^-

2: Na^+ Cl^- Ca^{+2} Mg^{+2} SO_4^{-2}

3: HCO_3^- $CO_2(g)$

4: SiO_2 H_3BO_3

Class 3: Bicarbonate Ion HCO_3^-



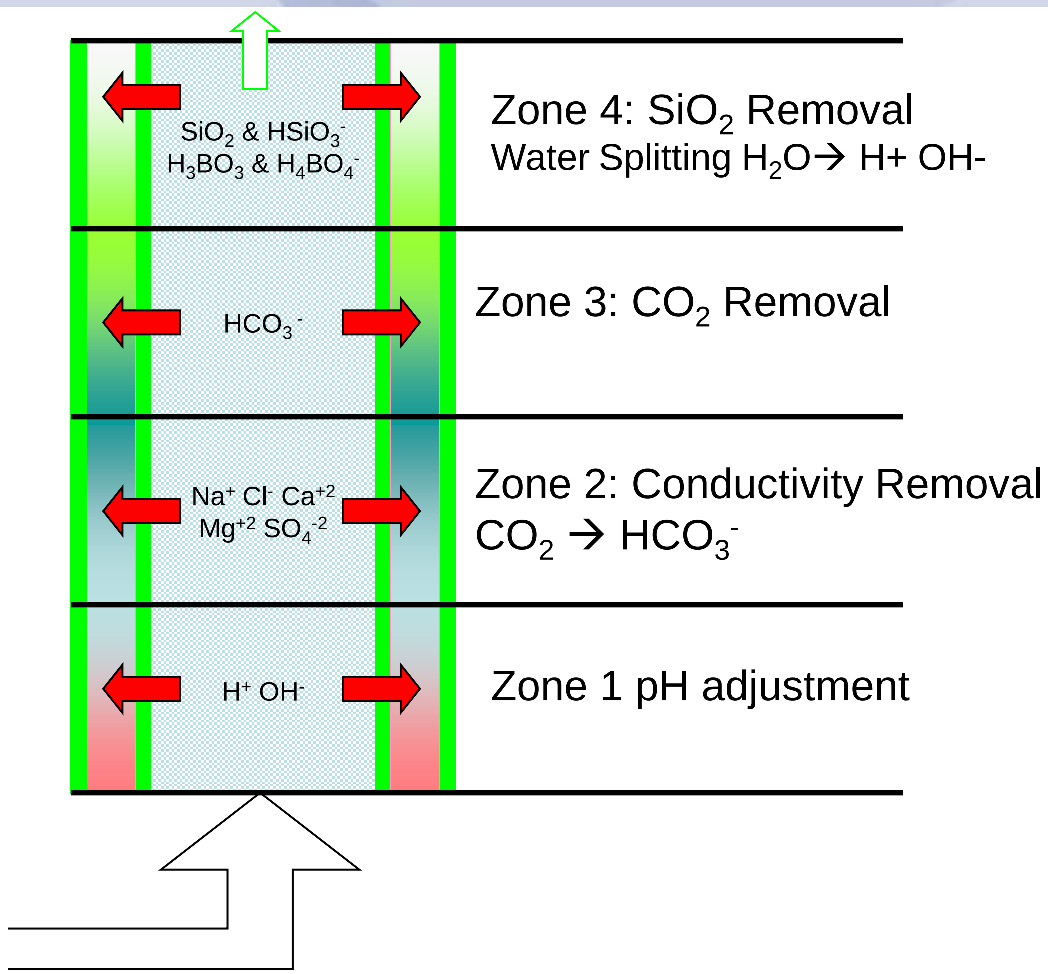
1: H^+ OH^-

2: Na^+ Cl^- Ca^{+2} Mg^{+2} SO_4^{-2}

3: HCO_3^- $CO_2(g)$

4: SiO_2 H_3BO_3

Class 4: Difficult Ions (SiO_2)



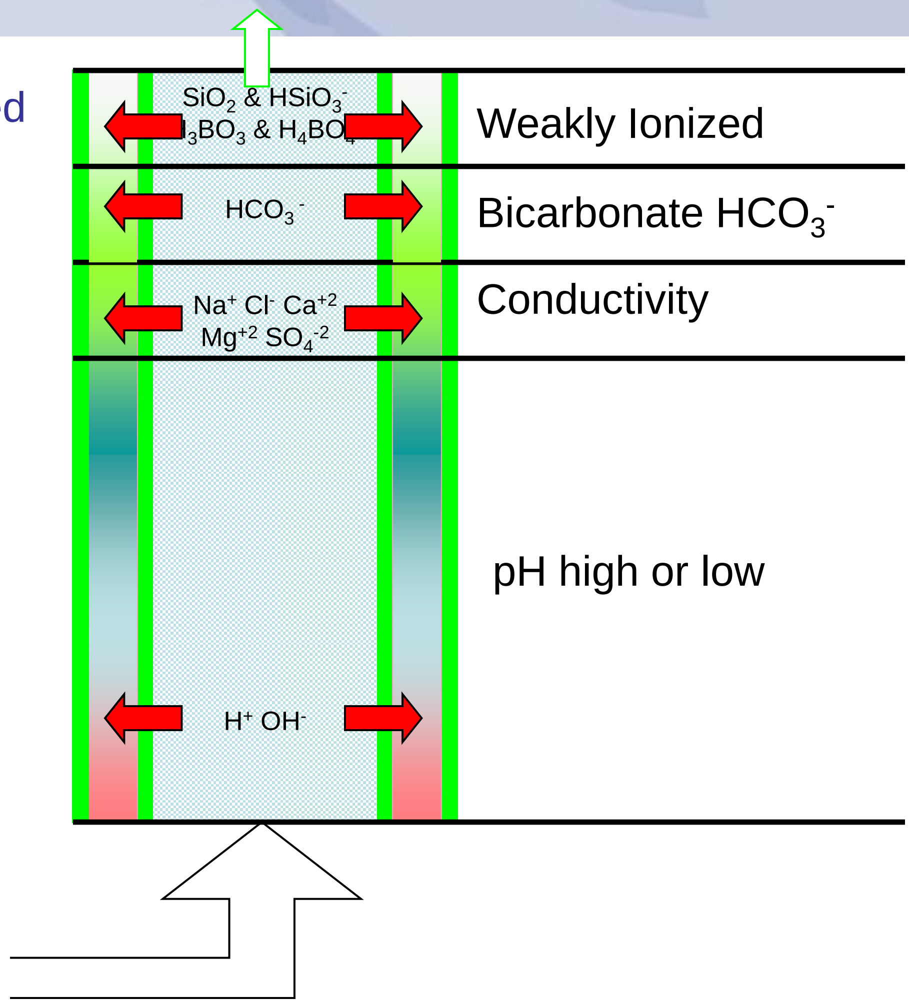
1: H^+ OH^-

2: Na^+ Cl^- Ca^{+2} Mg^{+2} SO_4^{-2}

3: HCO_3^- CO_2(g)

4: SiO_2 H_3BO_3

Case of high or low pH in EDI feed



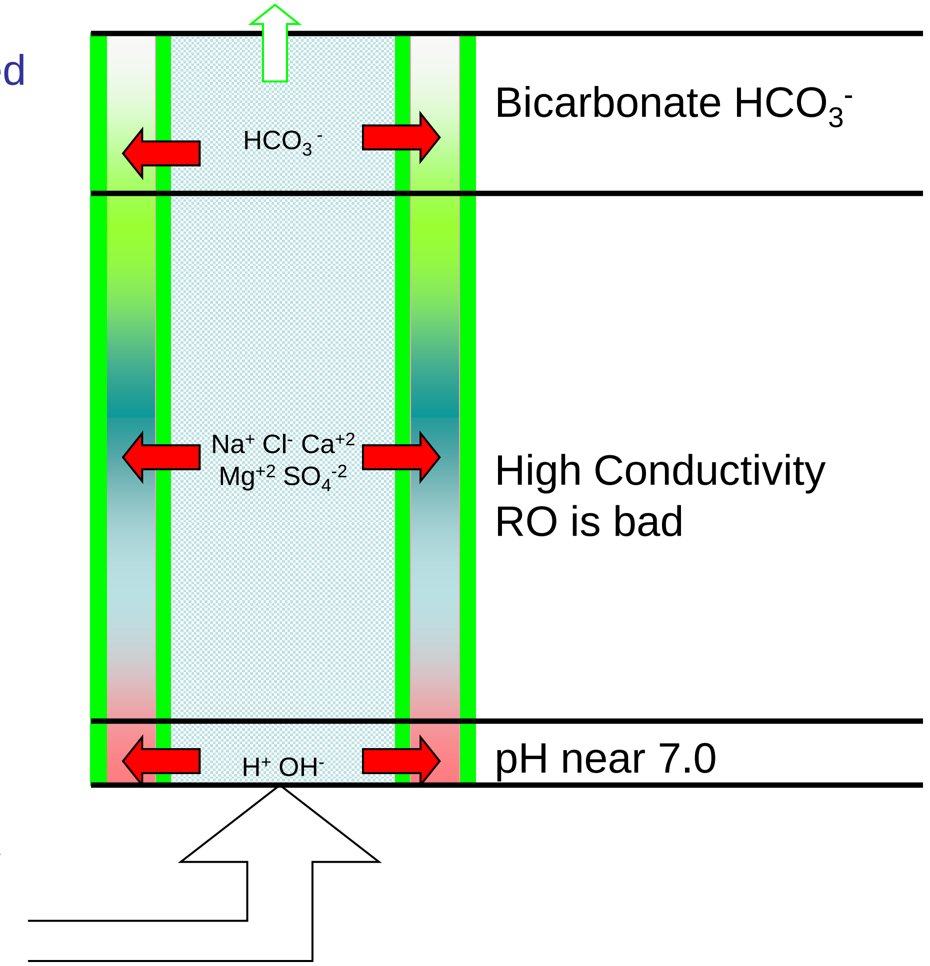
1: H^+ OH^-

2: Na^+ Cl^- Ca^{+2} Mg^{+2} SO_4^{-2}

3: HCO_3^- $CO_2(g)$

4: SiO_2 H_3BO_3

Case: High conductivity in EDI feed



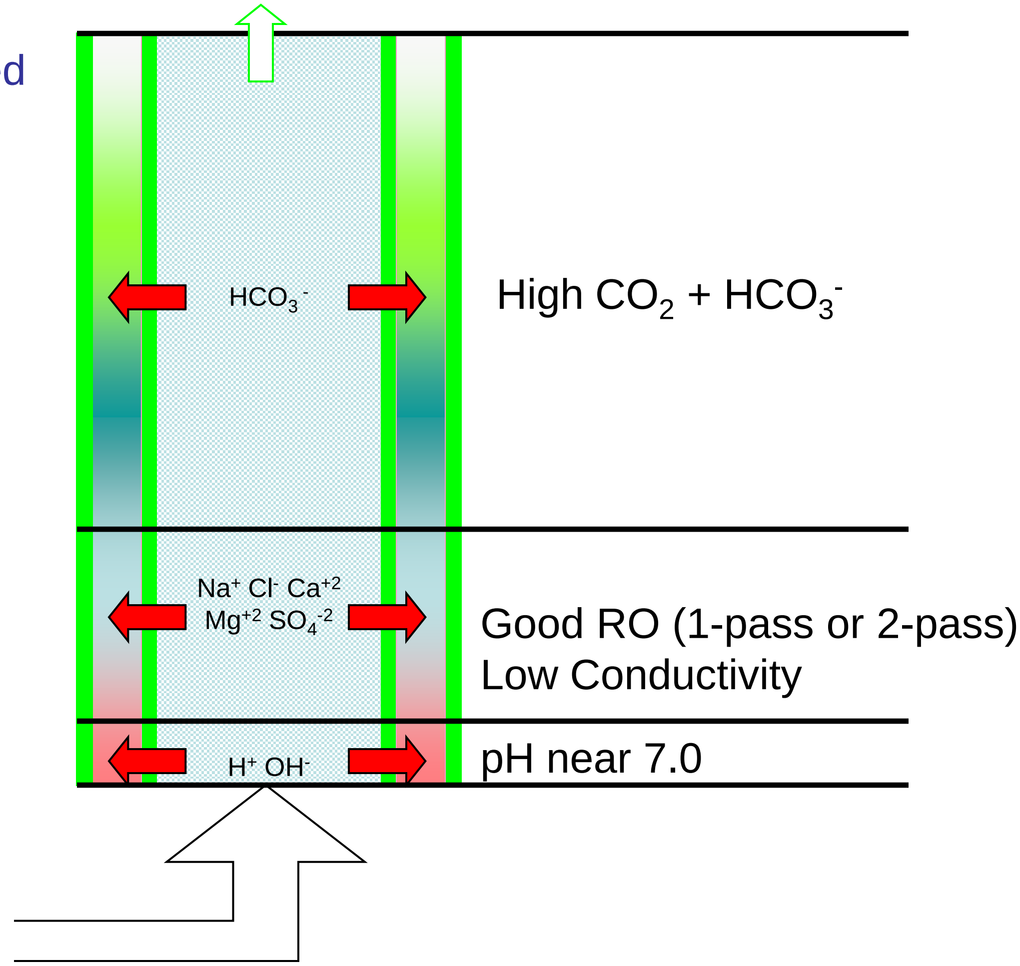
1: H^+ OH^-

2: Na^+ Cl^- Ca^{+2} Mg^{+2} SO_4^{-2}

3: HCO_3^- CO_2(g)

4: SiO_2 H_3BO_3

Case: High CO_2 +HCO_3^- in EDI feed



1: H^+ OH^-

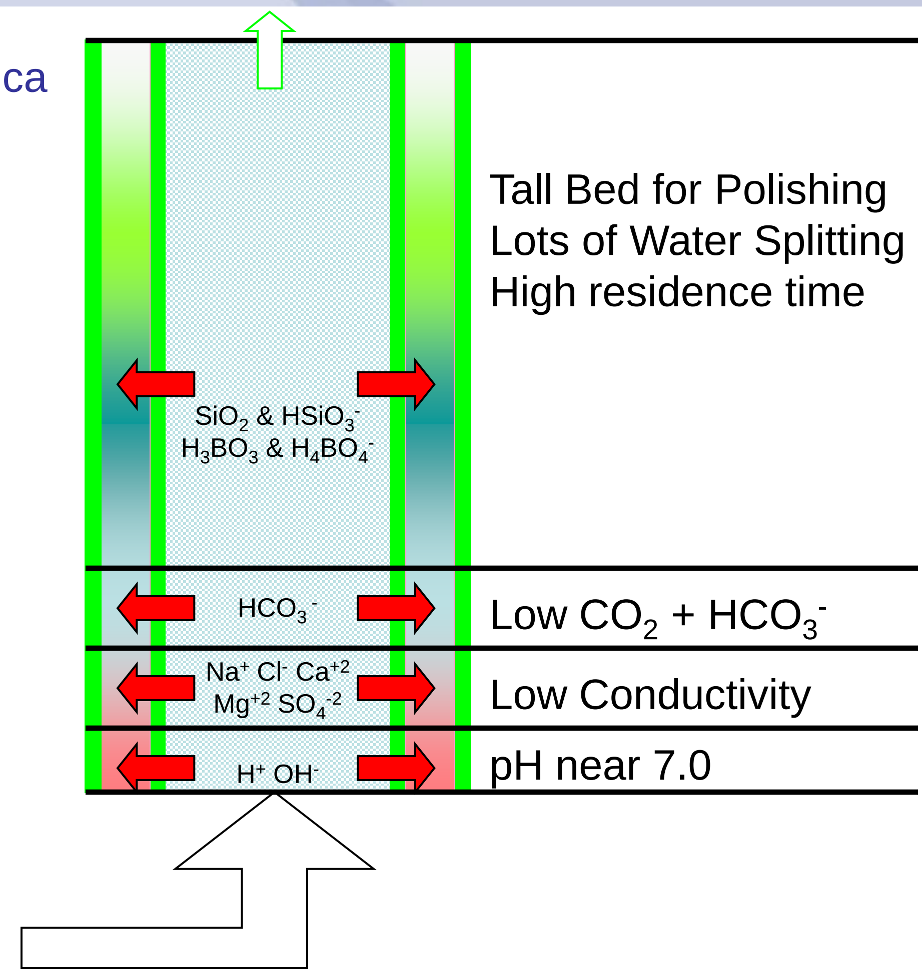
2: Na^+ Cl^- Ca^{+2} Mg^{+2} SO_4^{-2}

3: HCO_3^- $CO_2(g)$

4: SiO_2 H_3BO_3

EDI Optimized for Removal of Silica

1. pH in Control (6.5 to 7.5)
2. High Rejection RO
3. CO_2 Removal System (GTM)
4. Voltage Is Not Too Low

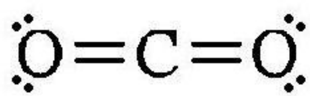


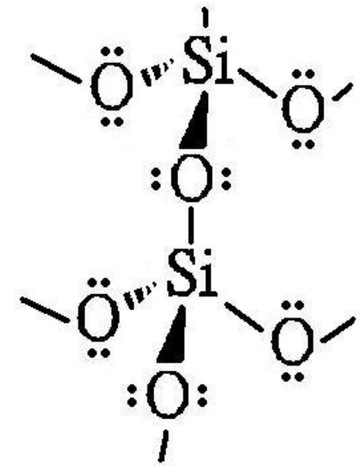
EDI “How Does It Work” Summary

- Silica < 5 ppb
- Working Bed-Polishing Bed EDI Model
- Electropure Specific Ion EDI Model
- Electropure’s 4 Classes of ions
- Optimization Rules for SiO_2
  - pH of Feed (RO permeate) near 7
  - High rejection RO System
  - Removal of CO_2
  - Voltage is High-Good Water Splitting

How does EDI remove CO_2 and SiO_2?

- EDI removes charged ions
- CO_2 and SiO_2 are not charged
- How to optimize EDI Systems to remove CO_2 and SiO_2





CO_2 Chemistry

CO_2 (gas) + H_2O ⇔ H_2CO_3 (carbonic acid)

H_2CO_3 ⇔ H^+ + HCO_3^- (bicarbonate)

HCO_3^- ⇔ H^+ + CO_3^{-2} (carbonate)

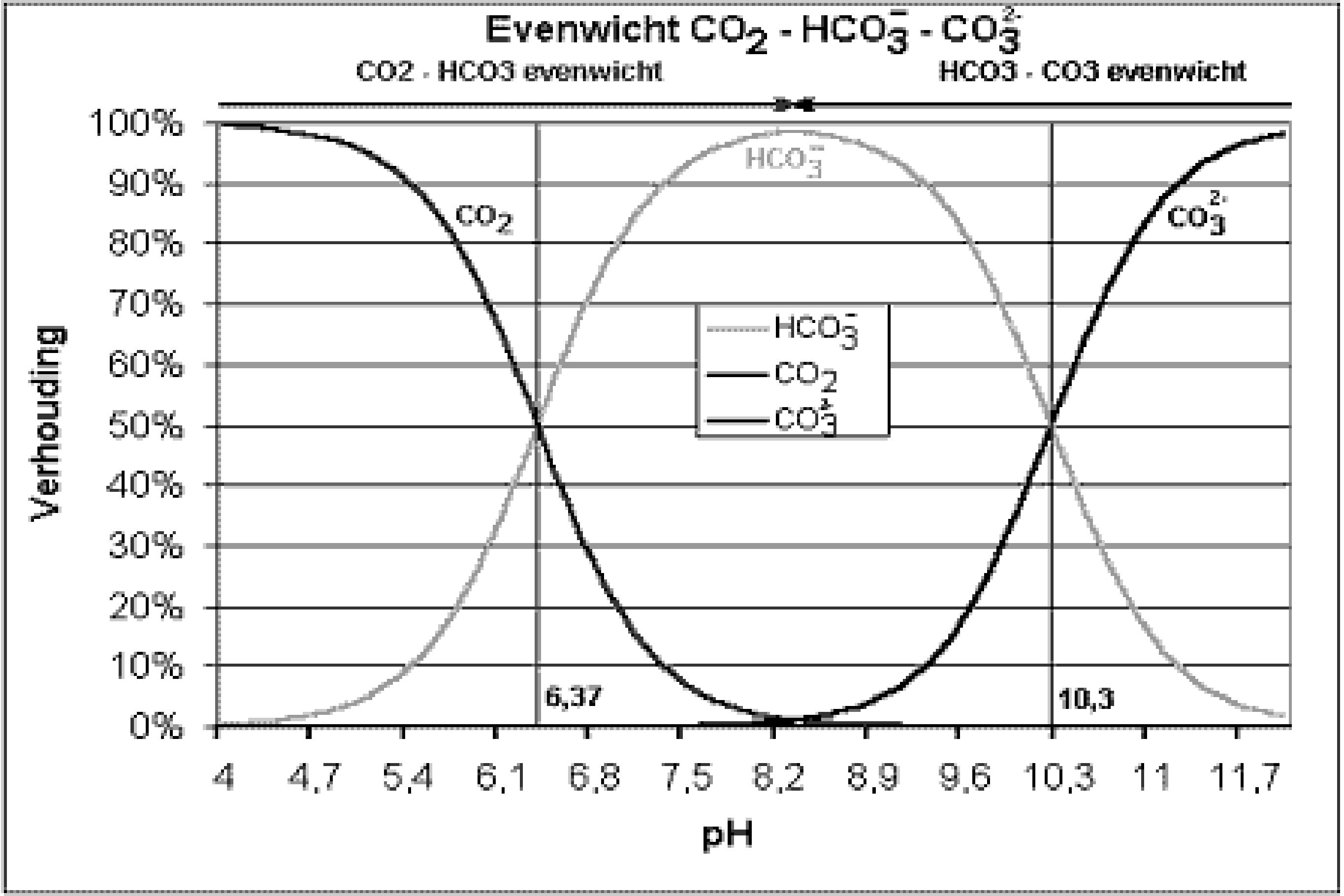
CO_2 Chemistry and pH

$CO_2 + H_2O \Leftrightarrow H_2CO_3$

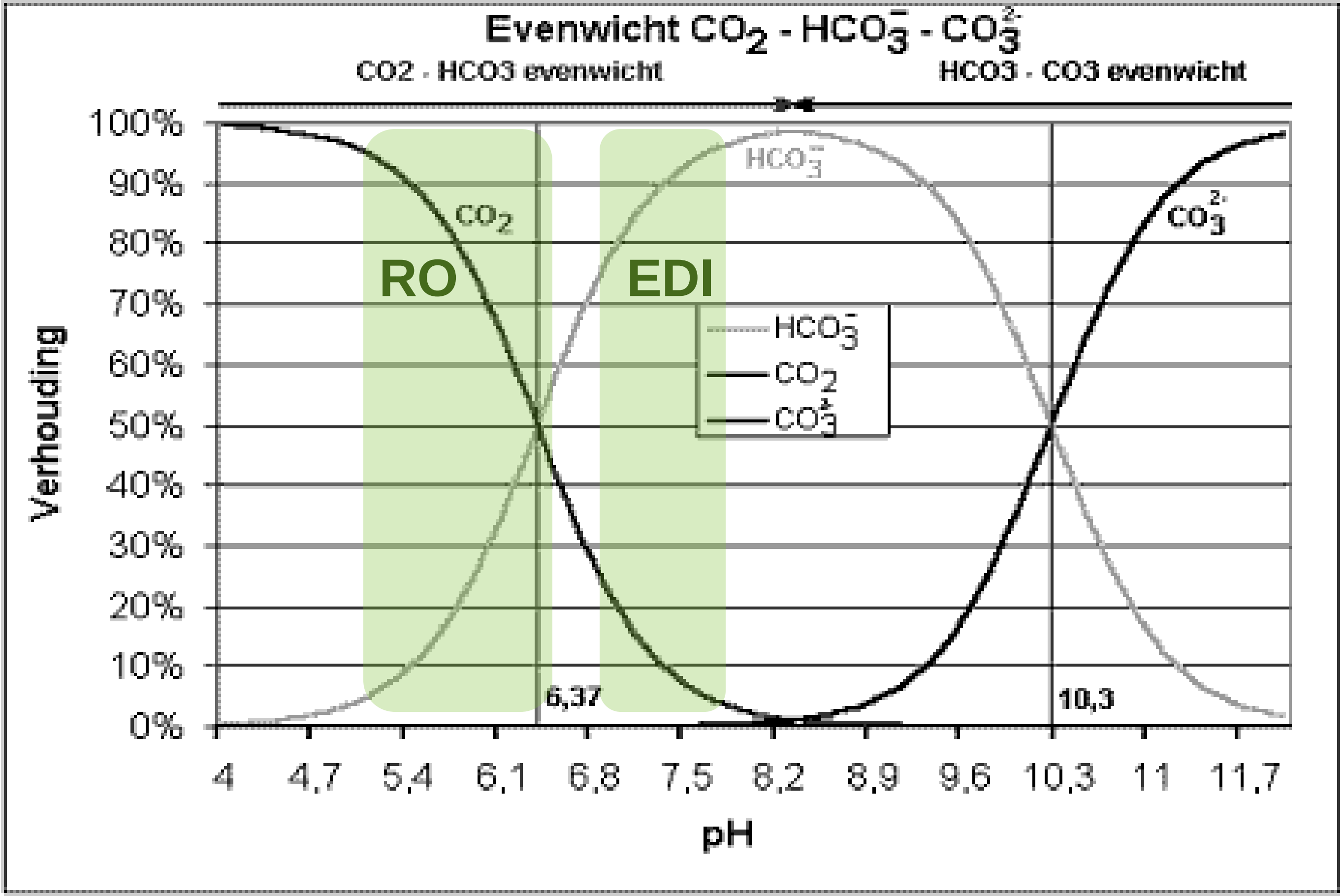
$H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$ pH = 6.4

$HCO_3^- \Leftrightarrow H^+ + CO_3^{-2}$ pH = 10.3

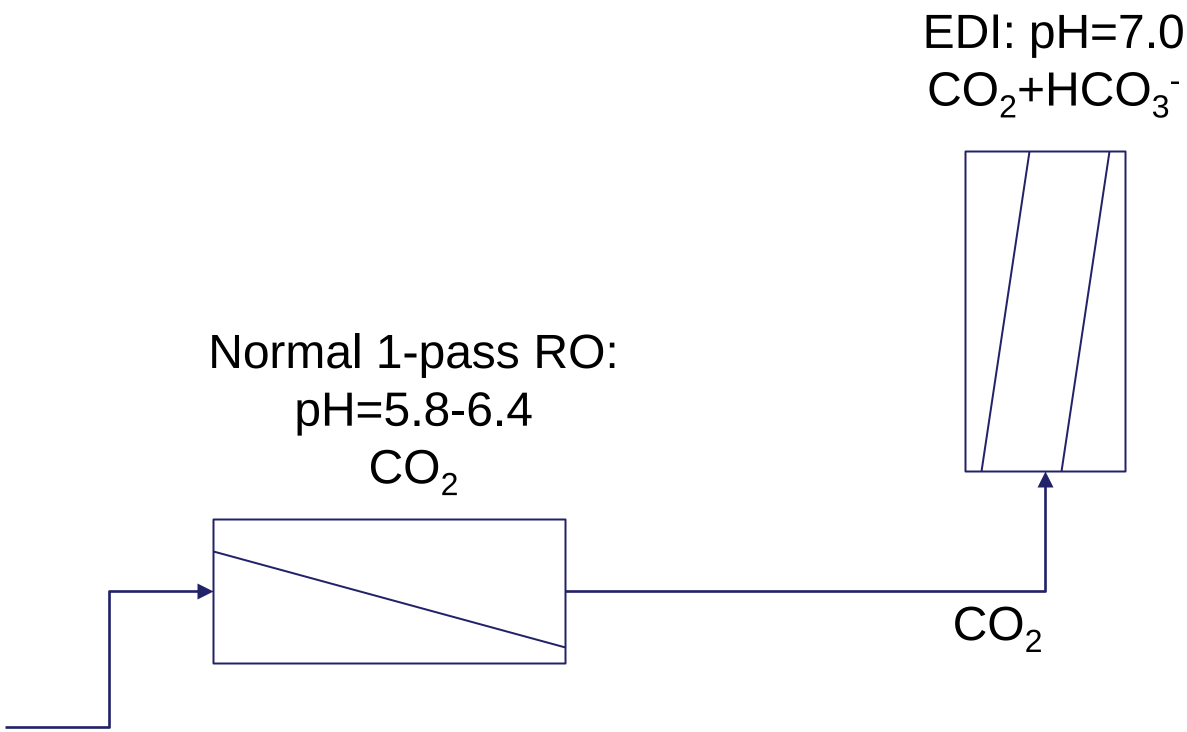
CO_2 Chemistry and pH



CO_2 Chemistry and pH



CO_2 in RO-EDI Systems



SiO_2 Chemistry and pH

$SiO_2 + 2*H_2O \Leftrightarrow H_4SiO_4$

$H_4SiO_4 \Leftrightarrow H^+ + H_3SiO_4^-$ pH = 9.8

Silica is charged only above pH 9.8

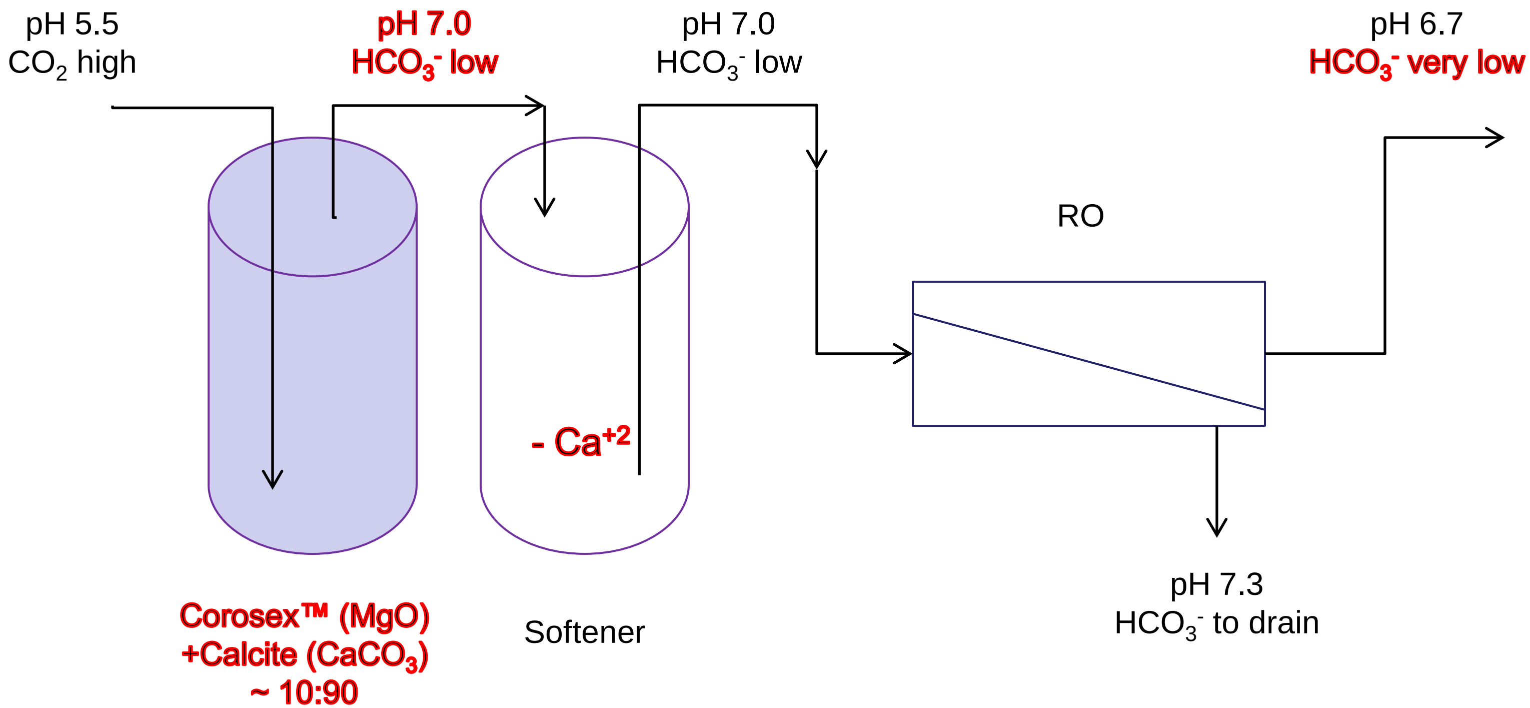
CO_2 and SiO_2 Conclusions

- RO: at pH < 6.4 CO_2 is difficult to reject
- RO: at pH < 9.8 SiO_2 is difficult to reject
- EDI: at pH = 7.0 HCO_3^- is weak
- EDI: at pH = 7.0 H_4SiO_4 is weak
- GTM: at pH < 6.0 GTM is very good for CO_2

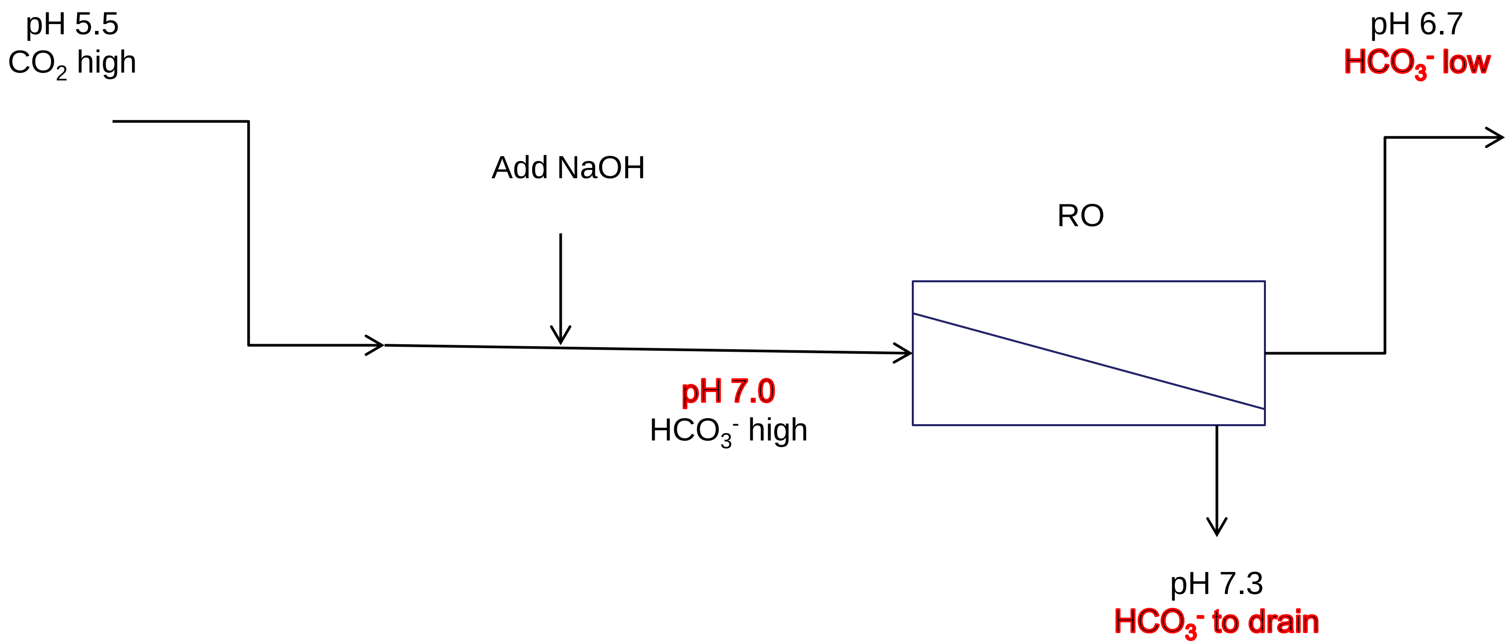
RO and CO_2

1. Use Corosex to remove CO_2 before the RO
2. pH in 1-pass RO above 6.8
3. Raise pH in 2-pass RO to above 8.3

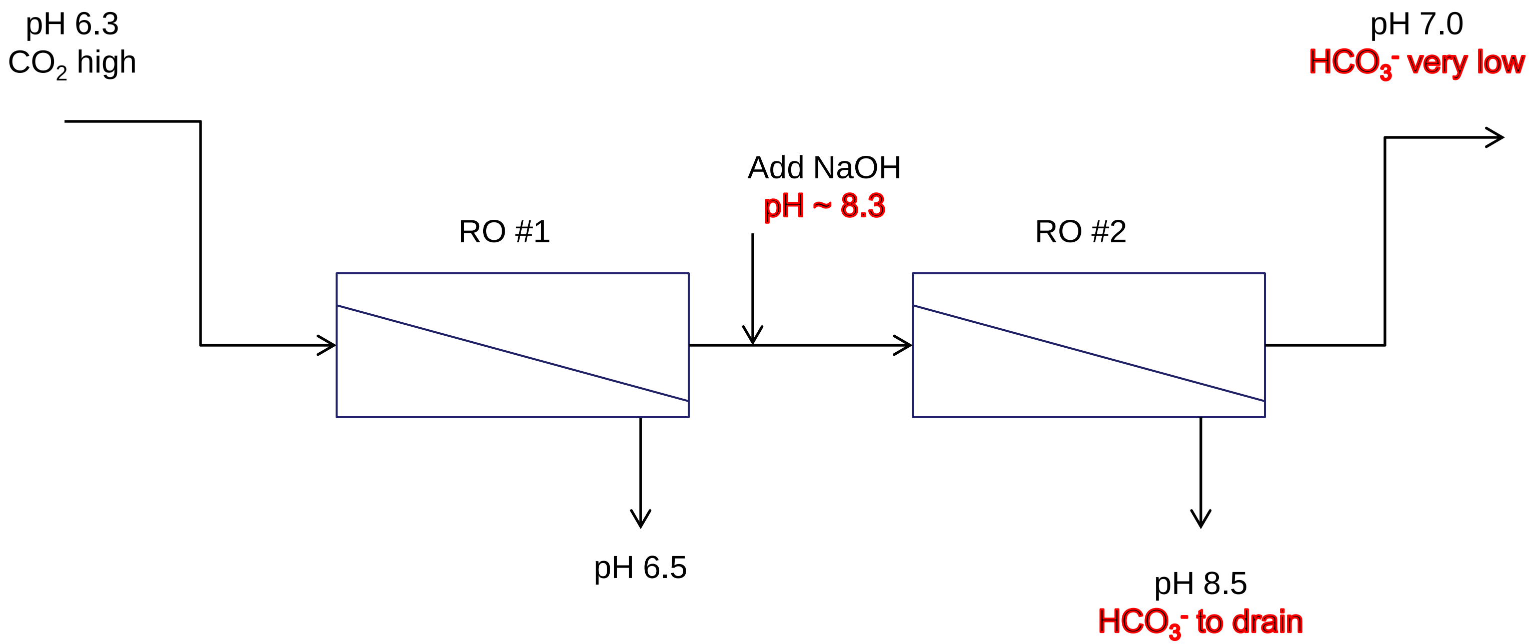
RO Option #1 (Corosex™)



RO Option #2 (pH >6.8)



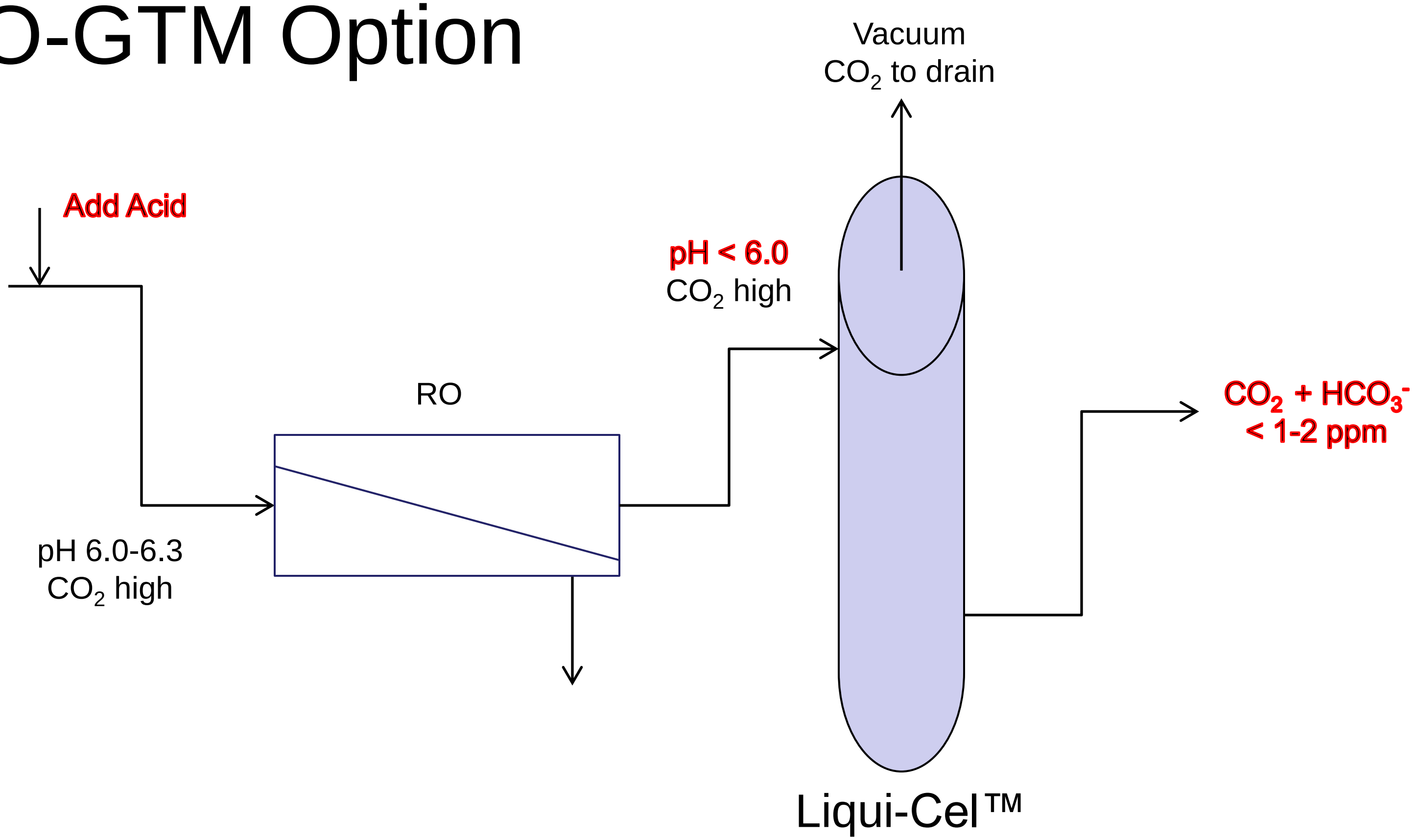
RO Option #3 (2-pass RO high pH)



GTM (Gas Transfer Membrane) and CO_2

- Use GTM (Liqui-Cel™) to remove CO_2 after the RO
- pH must be right for GTM
  - GTM removes CO_2 (gas) not HCO_3^-
  - pH should be < 6.0

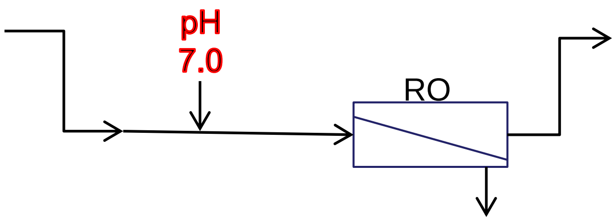
RO-GTM Option

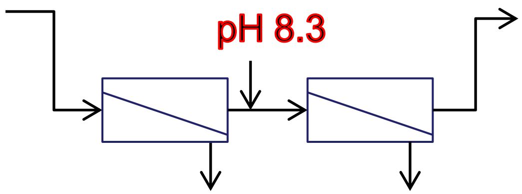


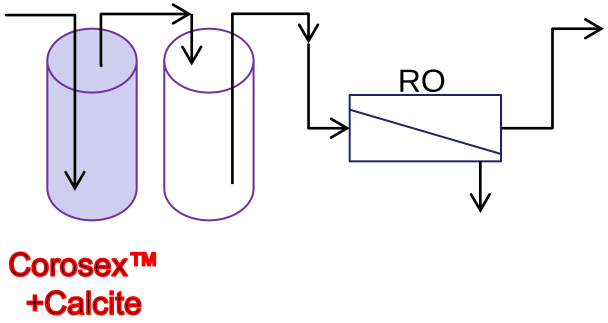
EDI Pretreatment Options

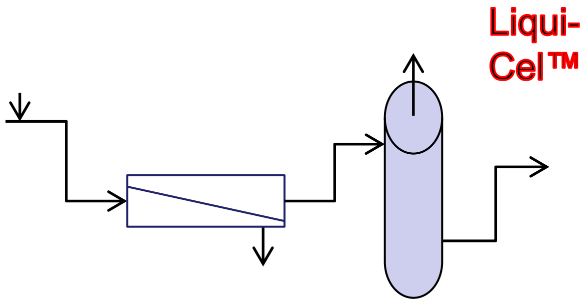
- Corosex™ removal of CO_2
- RO removal of CO_2 pH > 6.6
- 2-pass RO pH > 8.3
- RO-GTM pH < 6.0

EDI Pretreatment Options









Conclusion for CO_2

- pH is important
  - pH < 6.4 (for GTM) CO_2
  - pH > 6.4 (for RO) HCO_3^-
- Remove CO_2 before EDI
- Remove CO_2 in EDI (pH = 7.0)

Conclusion for SiO_2

- pH is important
  - $H_3SiO_4^-$ above pH = 9.8
- SiO_2 competes with HCO_3^- and Cl^-

  SiO_2 HCO_3^- Cl^-
  - HCO_3^- and Cl^- are stronger
- Use EDI pretreatment
  - CO_2 and conductivity removal
- EDI will remove up to 99% of SiO_2
  - 0.200 ppm → 2 ppb SiO_2