



# Electrochemical Antifouling Technology for Replacement of Heavy Metal and Organic Biocides in Marine Hydrokinetic Energy Generation

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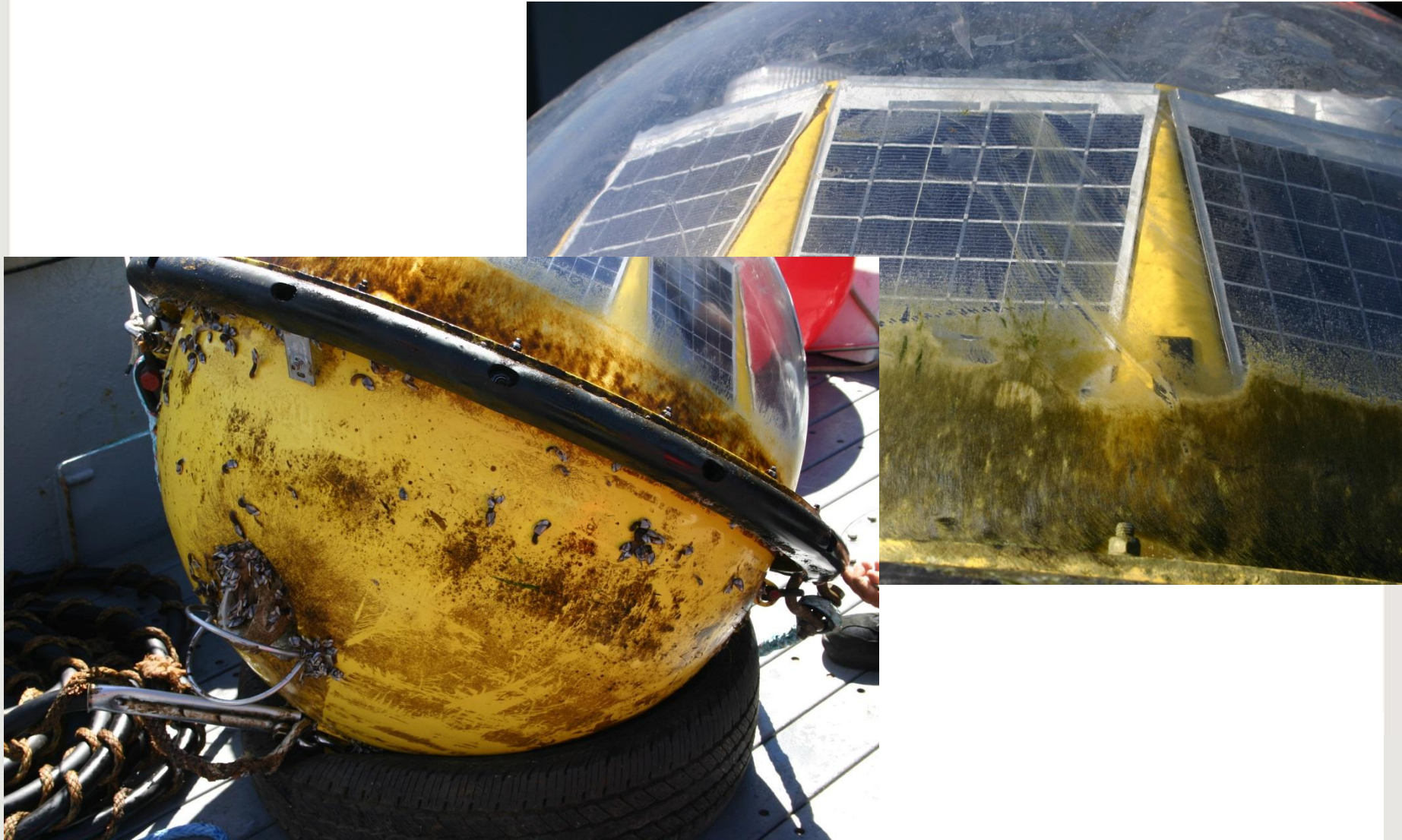
# Wave Energy Converters (WECs)



# Ocean Sentinel Instrumentation Buoy



# Triaxis Wave Monitoring Buoy



# In Practice



# Commercial Technologies

## ~~Tributyl tin self polishing~~

### Copper paints

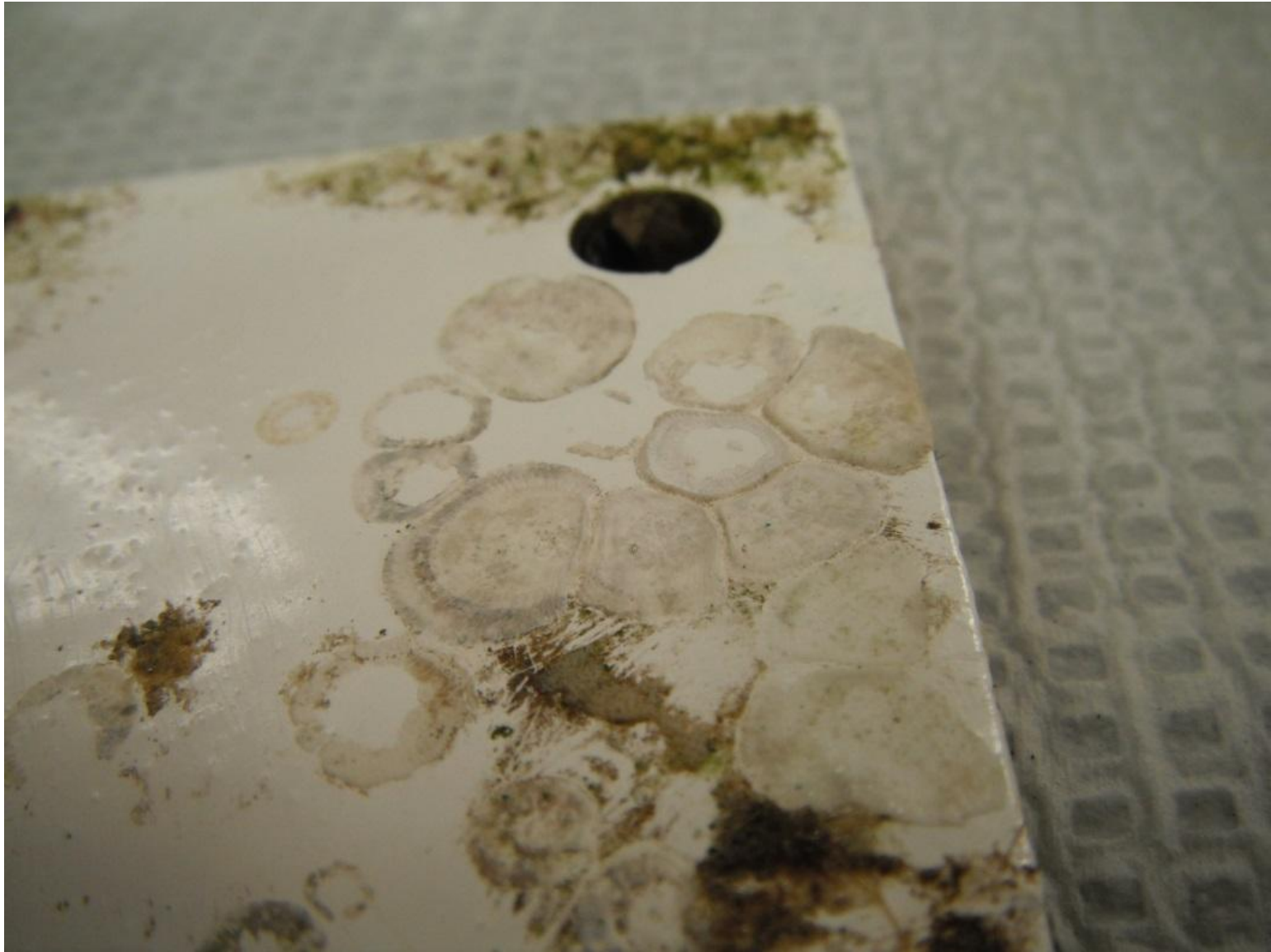
- Work fairly well
- Hard epoxies or self polishing
- Sometimes booster biocides
- Environmental concerns
- ~4-5 years max

### Foul release/slick paints

- No biocide release
- Longer life (~7 years)
- Soft/vulnerable coatings
- Need significant water velocity



# Problems



# Longer Term Solution Needed

Dry docking works fine for ships

## WECs

- Mooring lines
- Live power lines
- Neighboring devices
- Shape



We need better than what's on the market!

# Design Requirements

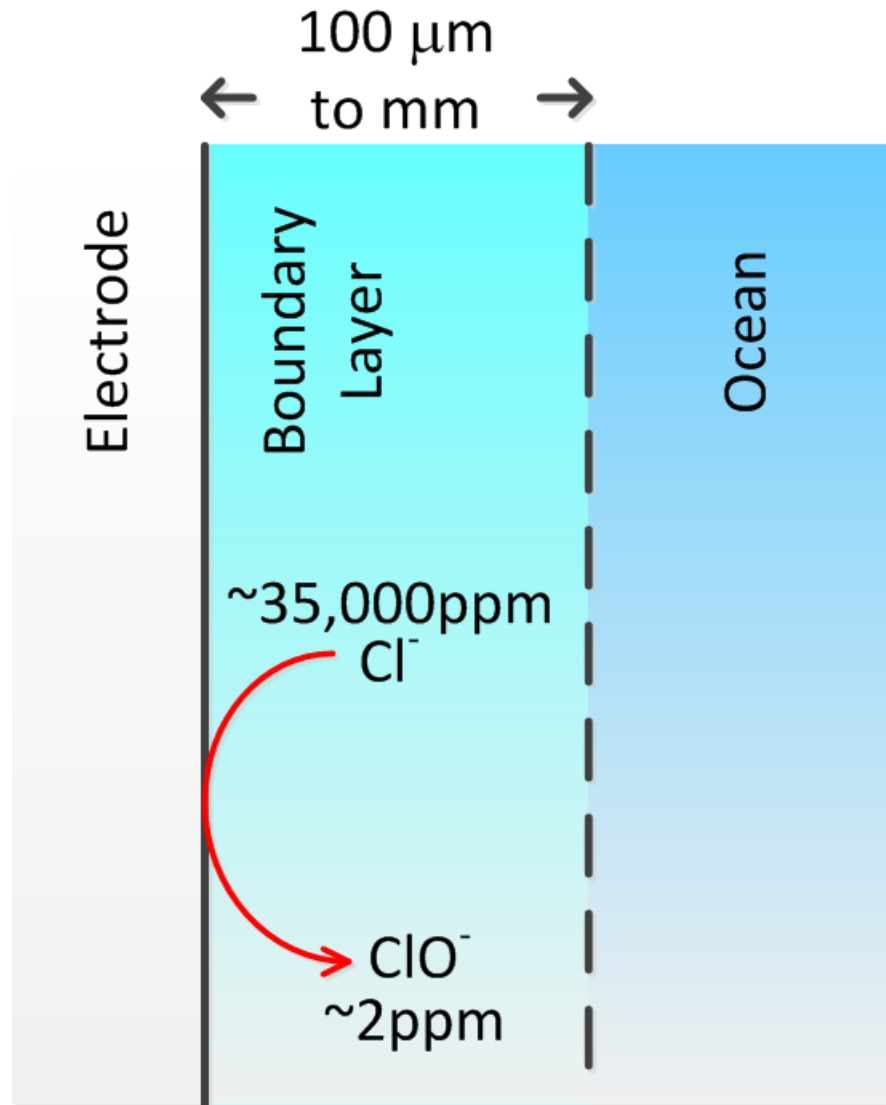
Long lasting (~20 years)

Applicable to large/complex surfaces

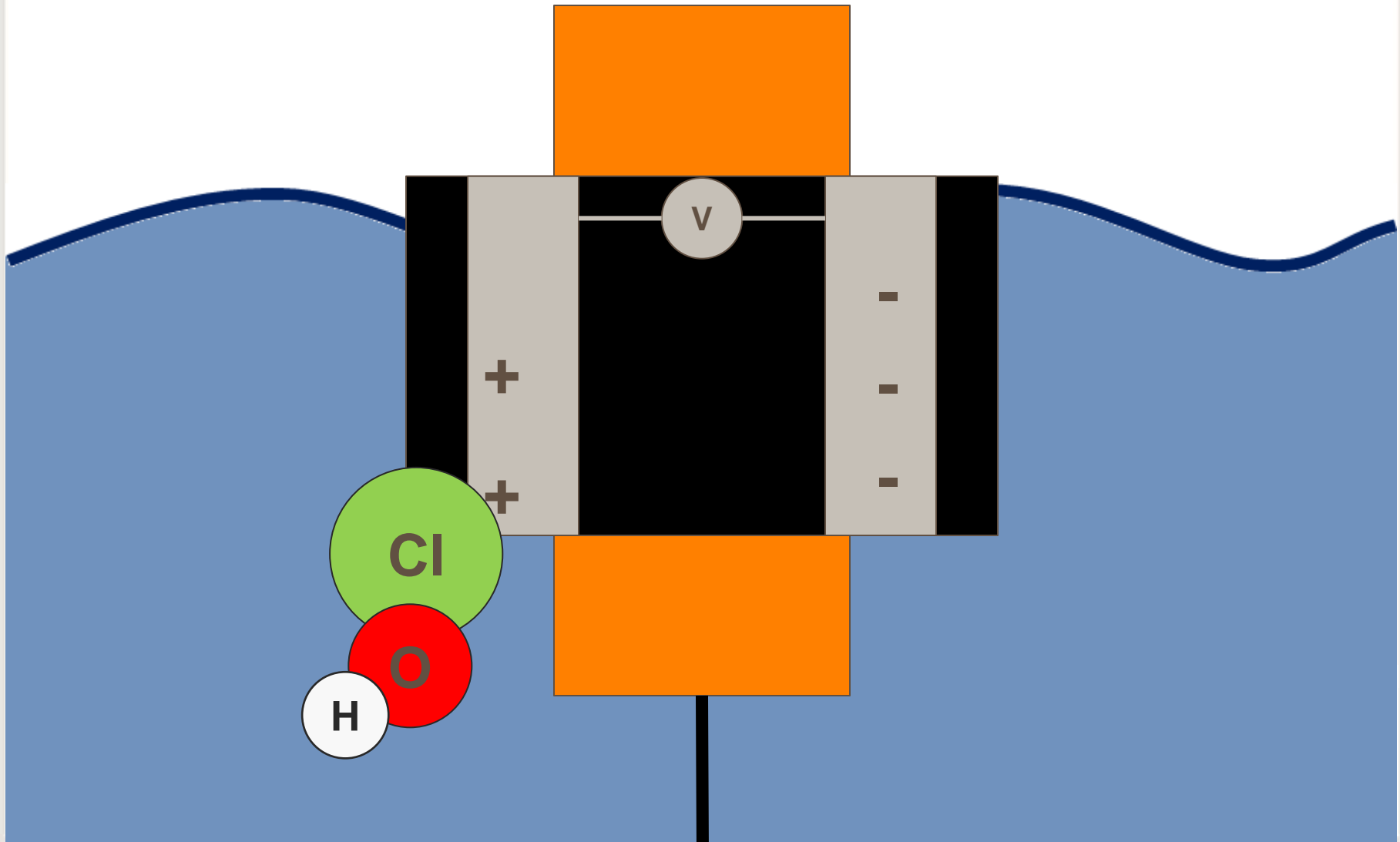
Inexpensive

Environmentally friendly

# Electrochemical Antifouling



# Electrochemical Antifouling



# Electrochemical Antifouling Advantages

Utilizes chloride ubiquitous in seawater

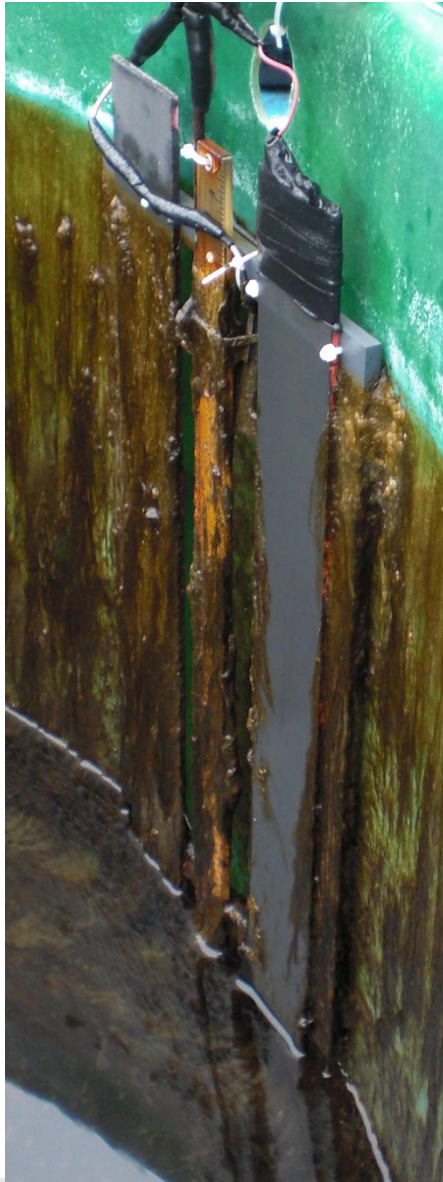
- Generate as much or as little hypochlorite as desired : adaptable
- **Does not deplete!**

Power consumption  $< 1\text{W/m}^2$

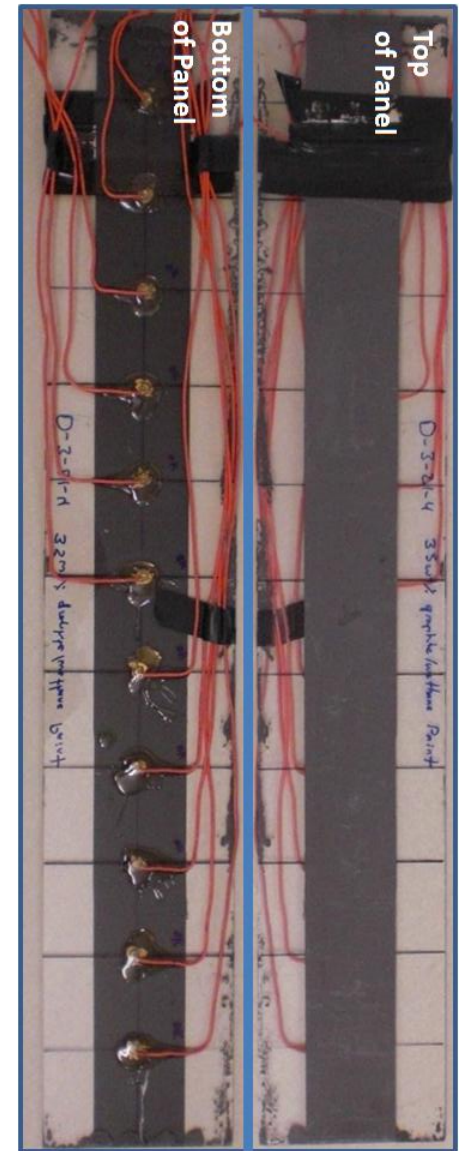
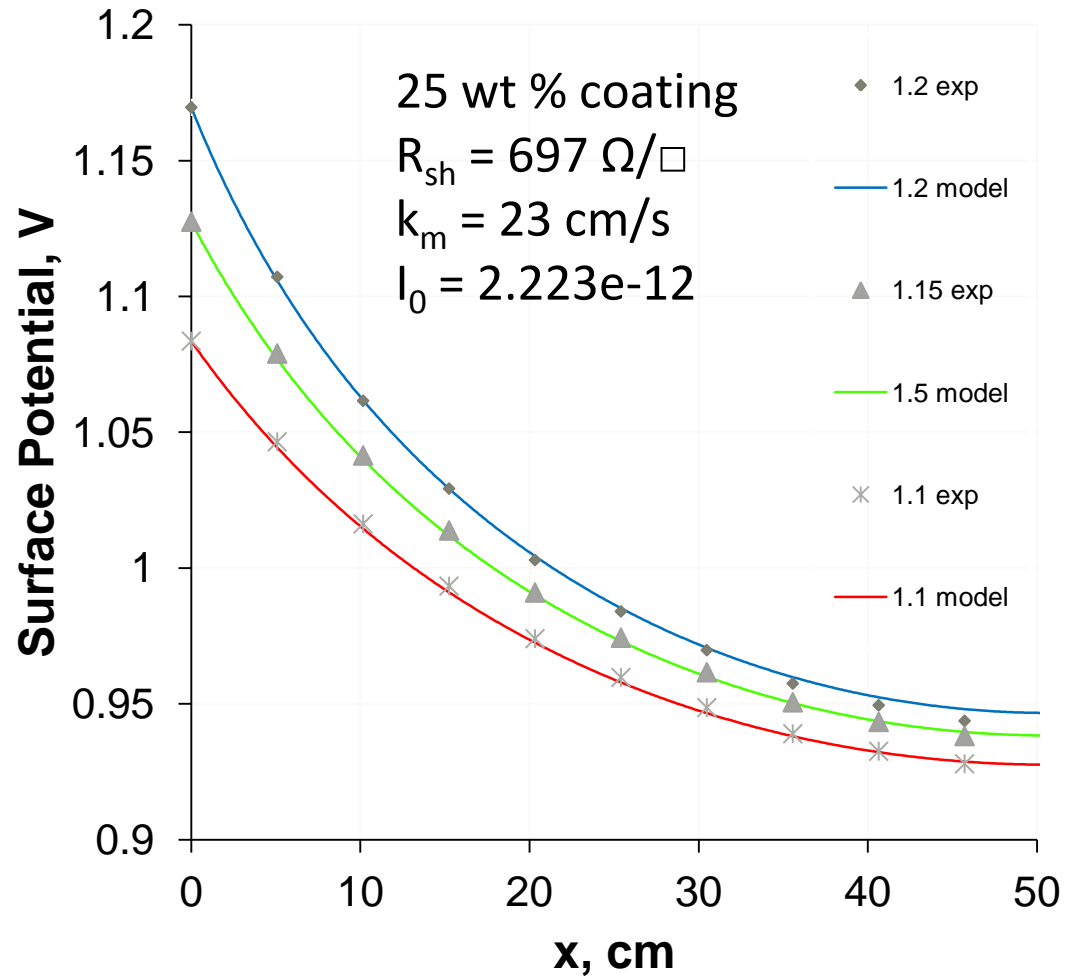
Cheap materials

Easily applied (liquid system)

# They Work!



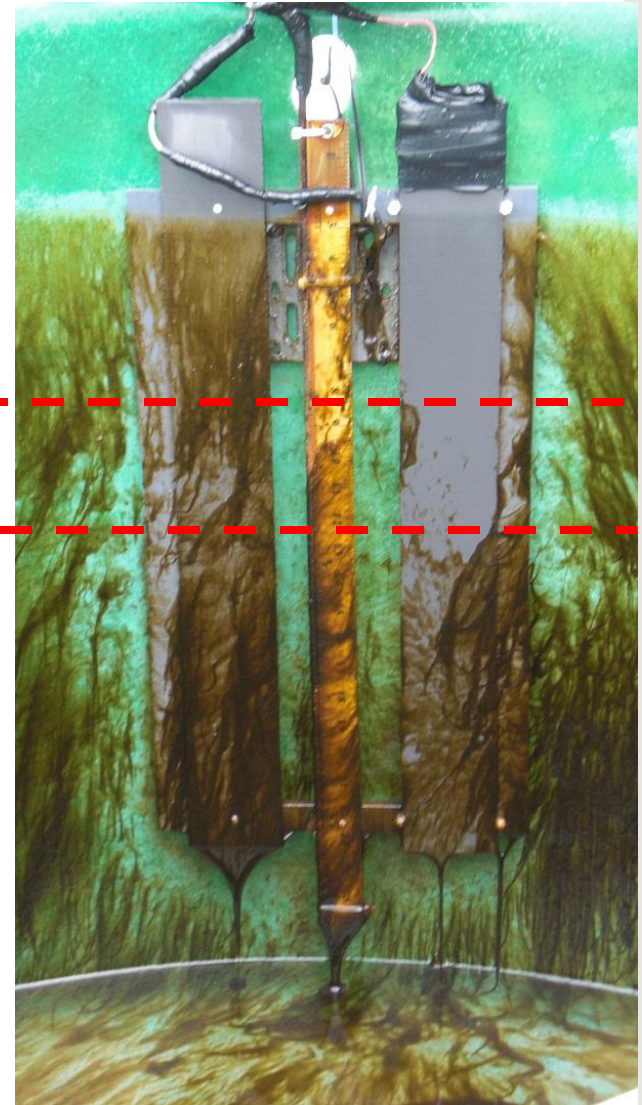
# Validating Model



# Required Potential

Maybe  
less?

$\sim 1.32\text{V}$   
v NHE



# Application of Nernst Equation

$$E = E^0 - \frac{RT}{nF} \ln \frac{[Products]}{[Reactants]}$$



pH	[Cl-]	[HClO]	T	E vs NHE
0	1M	1M	25° C	-1.49V
8	3.5 wt% NaCl	5ppm	4.4° C 40° F	-1.17V

# Minimum Potential



# Governing Equations

Momentum conservation:

$$\frac{\Delta P}{\mu L} = \frac{\partial^2 u}{\partial y^2}$$

Mass conservation

$$u \frac{\partial C}{\partial x} = D \left( \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} \right)$$

# Boundary Conditions

$$u = 0 @ y = \pm \frac{h}{2}$$

$$C_{red} = C_{red,in} \text{ for all } x, y$$

$$C_{ox} = C_{ox,in} @ x = 0$$

$$C_{ox} = C_{ox,in} @ y = +\frac{h}{2}$$

$$\frac{dC_{ox}}{dy} = j_{rx} @ y = -\frac{h}{2}$$

# Reaction Current



$$i = i_0 e^{\frac{\alpha F}{RT} \Delta V}$$

$$\Delta V = E - E_{eq}$$

$$E_{eq} = E^{\circ} - \frac{RT}{nF} \ln Q$$

$$Q = \frac{\prod C_{\text{oxidized}}^{\nu}}{\prod C_{\text{reduced}}^{\nu}}$$

$$j_{rx} = \frac{i}{nF} i = i_0 e^{\frac{\alpha F}{RT} \Delta V}$$

$$j_{rx} = \frac{i_0}{nF} e^{\frac{\alpha F}{RT} \left( E - \left[ E^{\circ} - \frac{RT}{nF} \ln \frac{\prod C_{\text{oxidized}}^{\nu}}{\prod C_{\text{reduced}}^{\nu}} \right] \right)}$$





# Electrochemical Reaction Rates

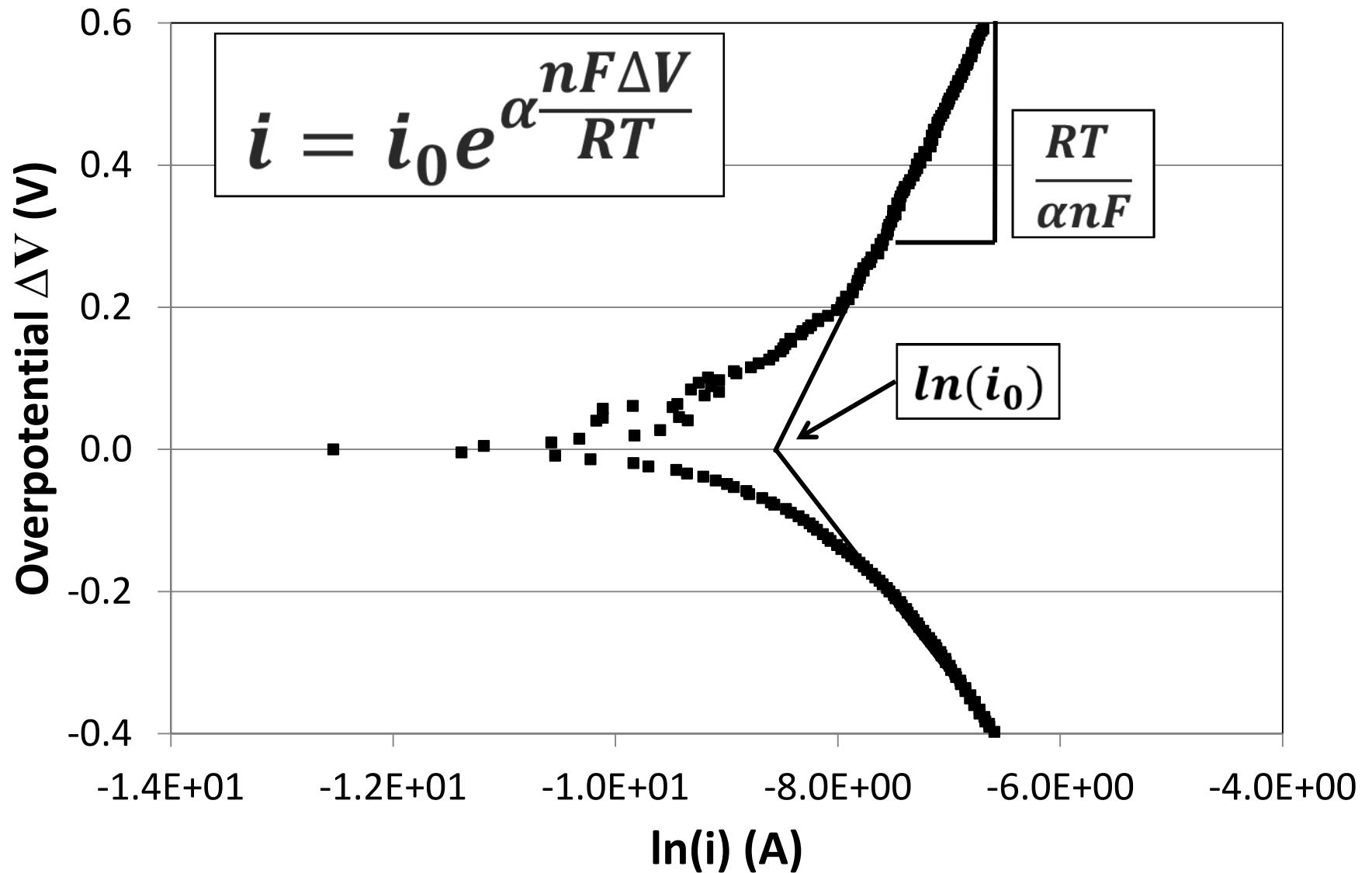
Electrochemical reaction kinetics governed by Tafel equation

$$i_{Rx} = i_0 e^{\alpha \frac{nF\Delta V}{RT}}$$

$i_0$  = exchange current density

$\alpha$  = charge transfer coefficient

# Measuring Kinetic Parameters



# Accelerated Aging

Hypotheses:

Reactions at graphite surface may cause loss of activity

Reactions are driven by current, so degradation will be proportional to current passed

# Accelerated Aging

Strategy:

Operate 2 electrode system at high current density

Field operating condition is  $\sim 20 \frac{\mu A}{cm^2}$

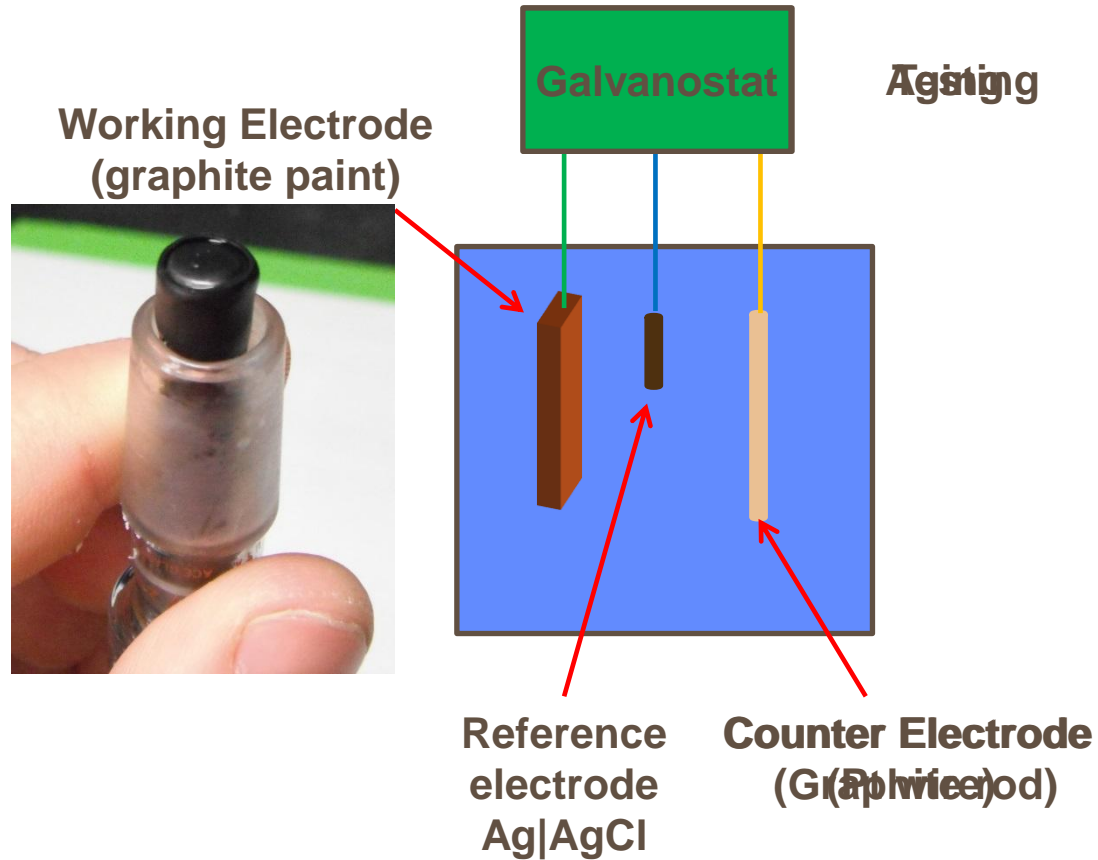
Acceleration factor = 158x

46 days simulates 20 years operation

Measure kinetic parameters

Plot parameters and fit an appropriate reaction mechanism

# Experimental Setup



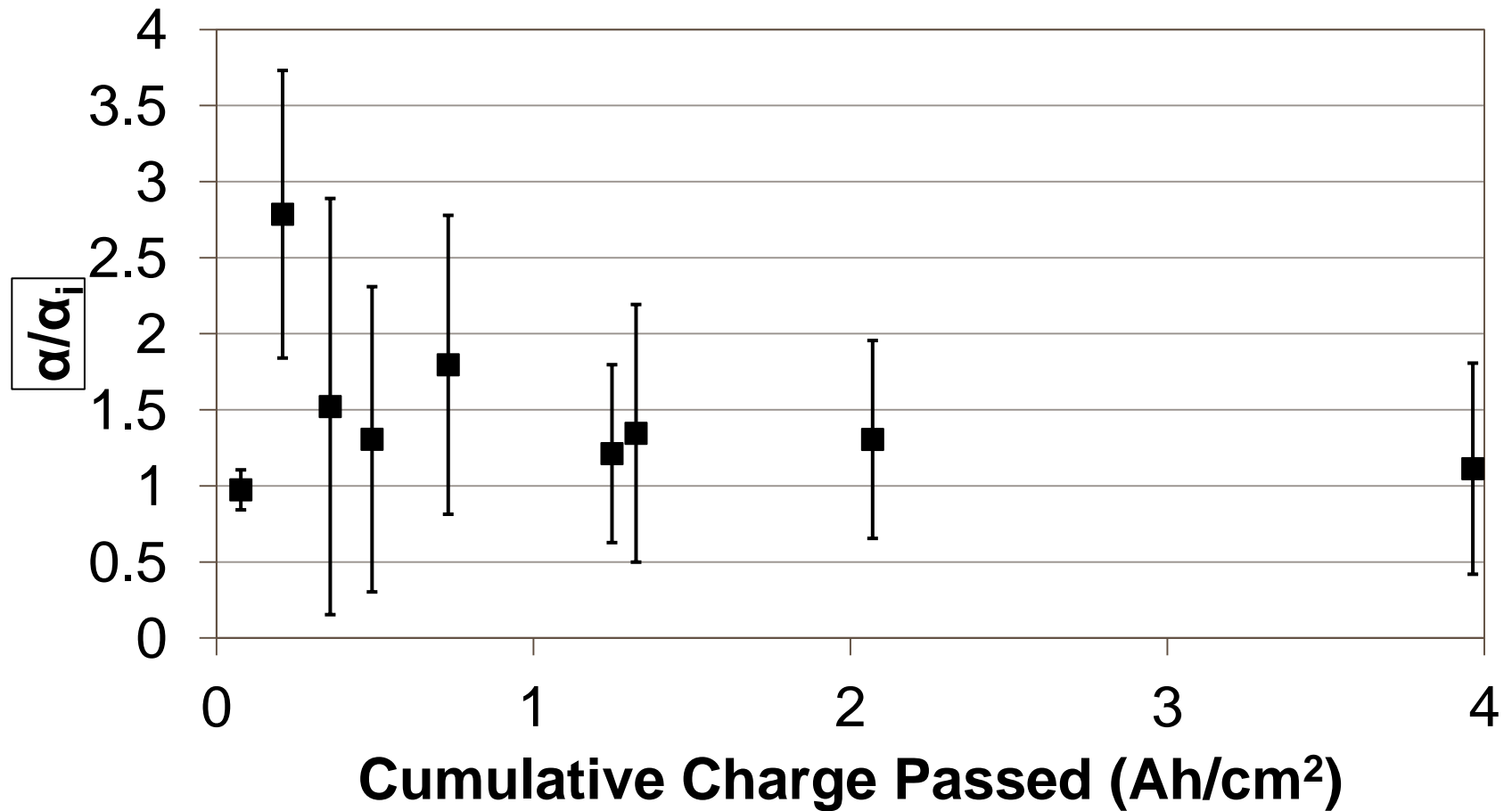


# Results: Exchange Current Density

Significant correlation for all three trials (95% CI)

Positive trend indicates better performance developing over time

# Results: Charge Transfer Coefficient



# Results: Charge Transfer Coefficient

Appears to be a negative correlation

Indicative of degradation

Linear regression shows only 1 of 3 is statistically significant at 95% confidence interval

Worst case scenarios is ~50% reduction over 20 years

Over-potential would have to double ( $0.16\text{V} \rightarrow 0.32\text{V}$ )

$1.32\text{V} \rightarrow 1.48\text{V}$  **NOT**  ~~$1.32\text{V} \rightarrow 2.64\text{V}$~~

# Conclusions

Electrochemical methods have been shown to be effective at preventing biofouling in marine environment

Degradation is probably nothing to worry about in chloride oxidation at prescribed conditions

Model simulating flow channel electrochemical reactor has been developed

Once validated model can be extended to design applications

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**Thank you for your attention!**