



Research & Technology

IMPROVING THE GALVANIC SERIES FOR DESIGN

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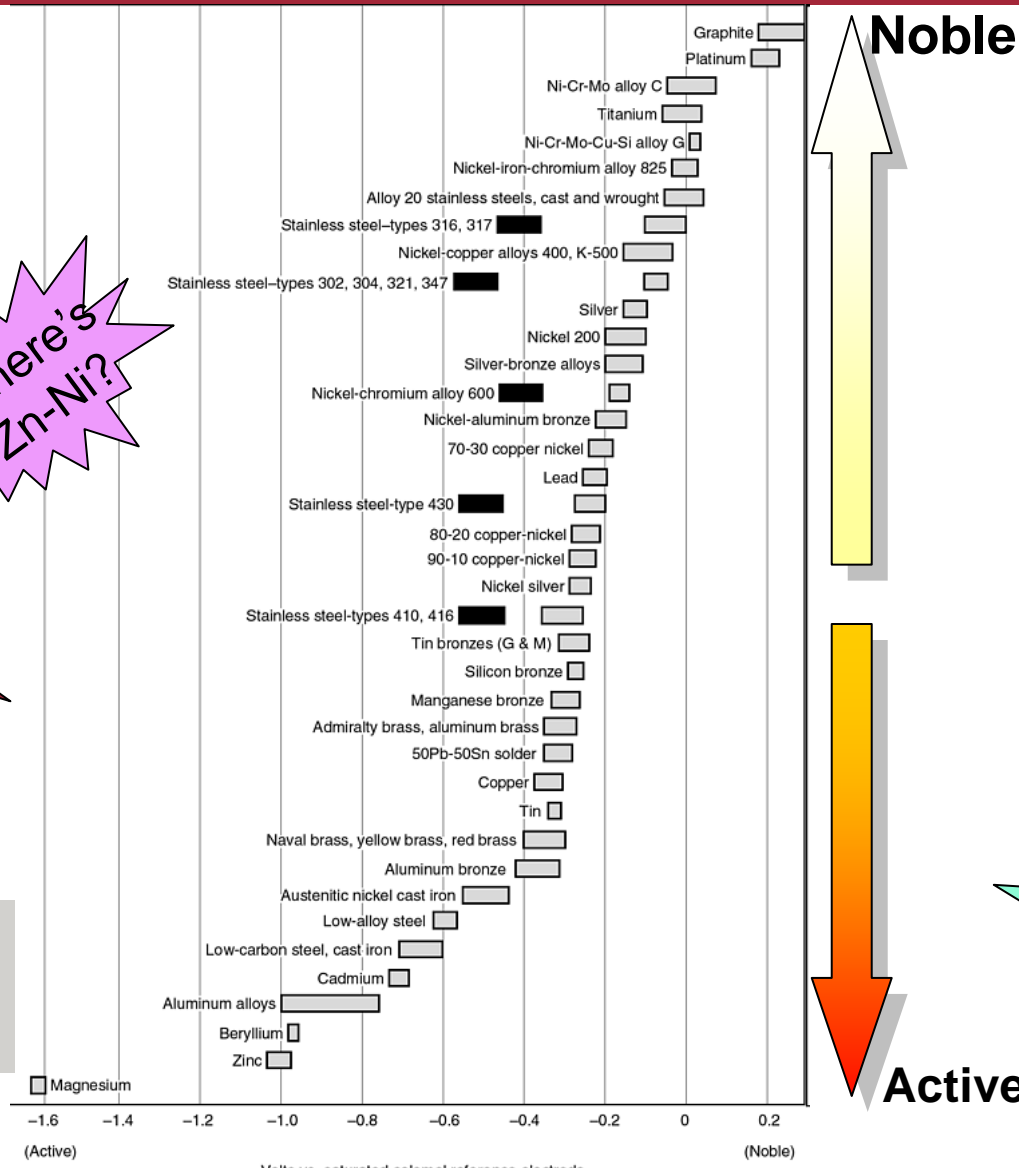
One of Many Galvanic Series Available

What's the corrosion rate?

Where's Zn-Ni?

Why is this different from the EMF series?

Metals in flowing seawater



This isn't my environment

Where's my HVOF?

Which is the cathode?

Isn't this upside down?

What's Our Concern?

- **Designer Concerns**
 - Metal compatibility with environment
 - Galvanic coupling of dissimilar metals
 - Adding an inorganic coating
 - Adding an organic coating
 - Minimizing service failures
- **Production and Maintenance Concerns**
 - Scheduling Inspections
 - Replacing Designs that don't work
 - Material and Design Trades
 - Reduce costs
 - Reduce maintenance
 - Allowing Substitutions

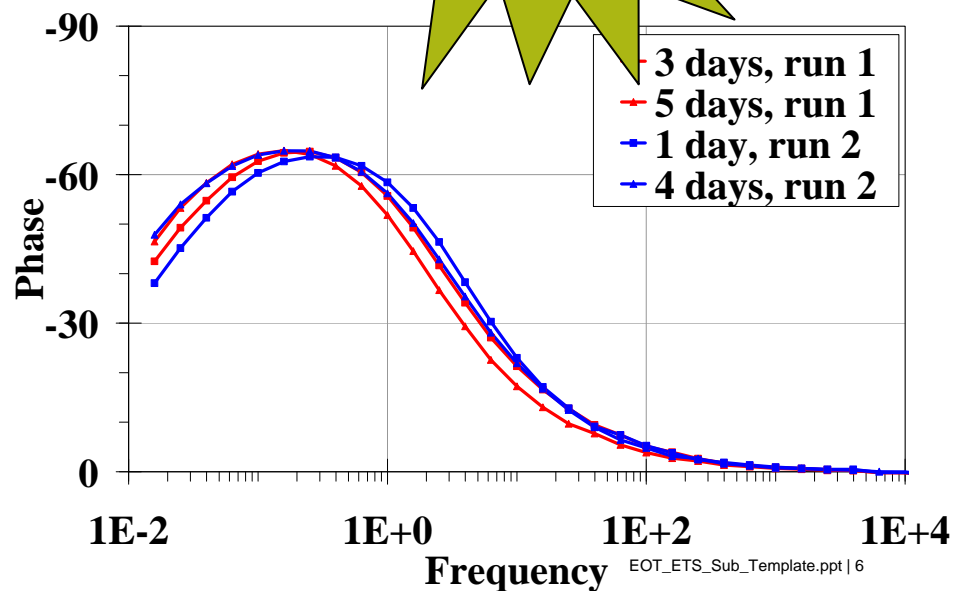
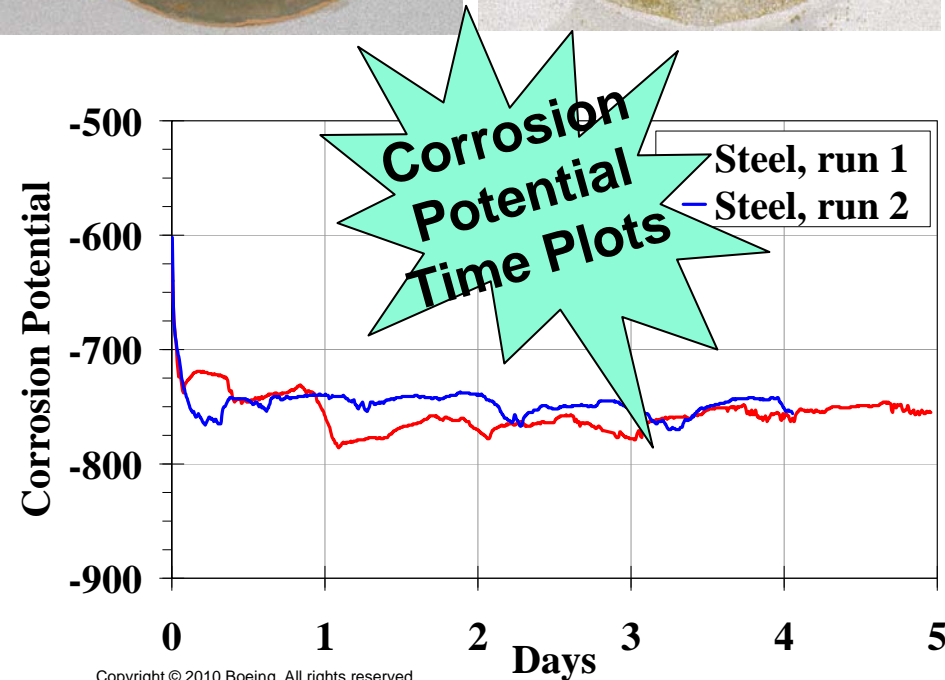
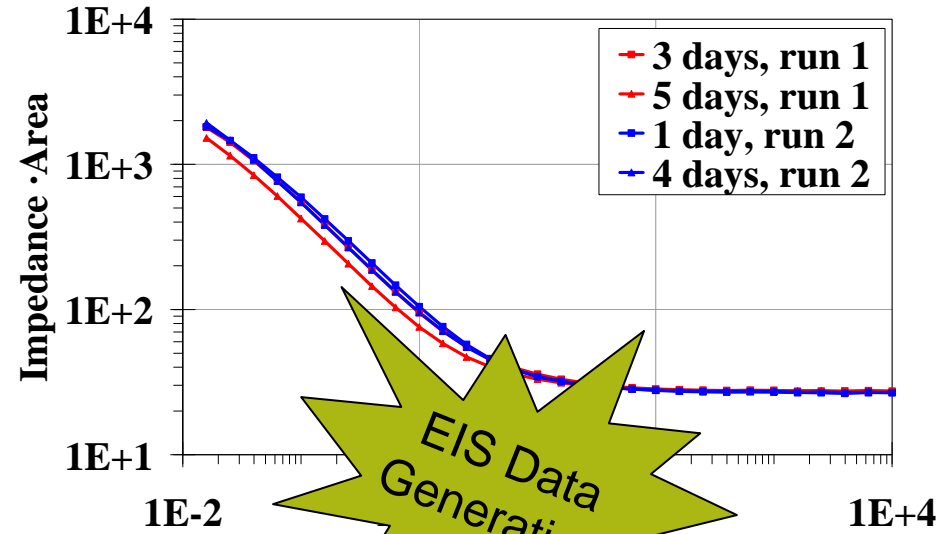
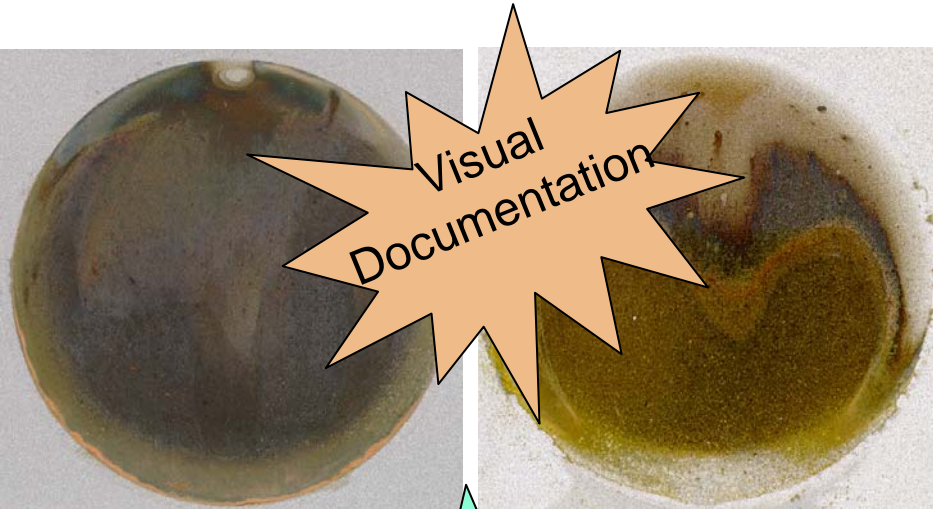
Technical Needs

- **What we do already—**
 - **Use “Galvanic Series”**
 - **Qualitatively rely on “tribal knowledge” & handbooks**
 - **Conduct Laboratory Tests**
- **What we want to do—**
 - **Use Engineering Tools to Propose Engineering Solutions**
 - **Design tools require quantitative data**
 - **Quantify severity of corrosion on all geometries**
 - **Coupled finish on substrate of detail part**
 - **Coupling of detailed parts of different materials**
 - **Reduce/Eliminate Laboratory Tests**

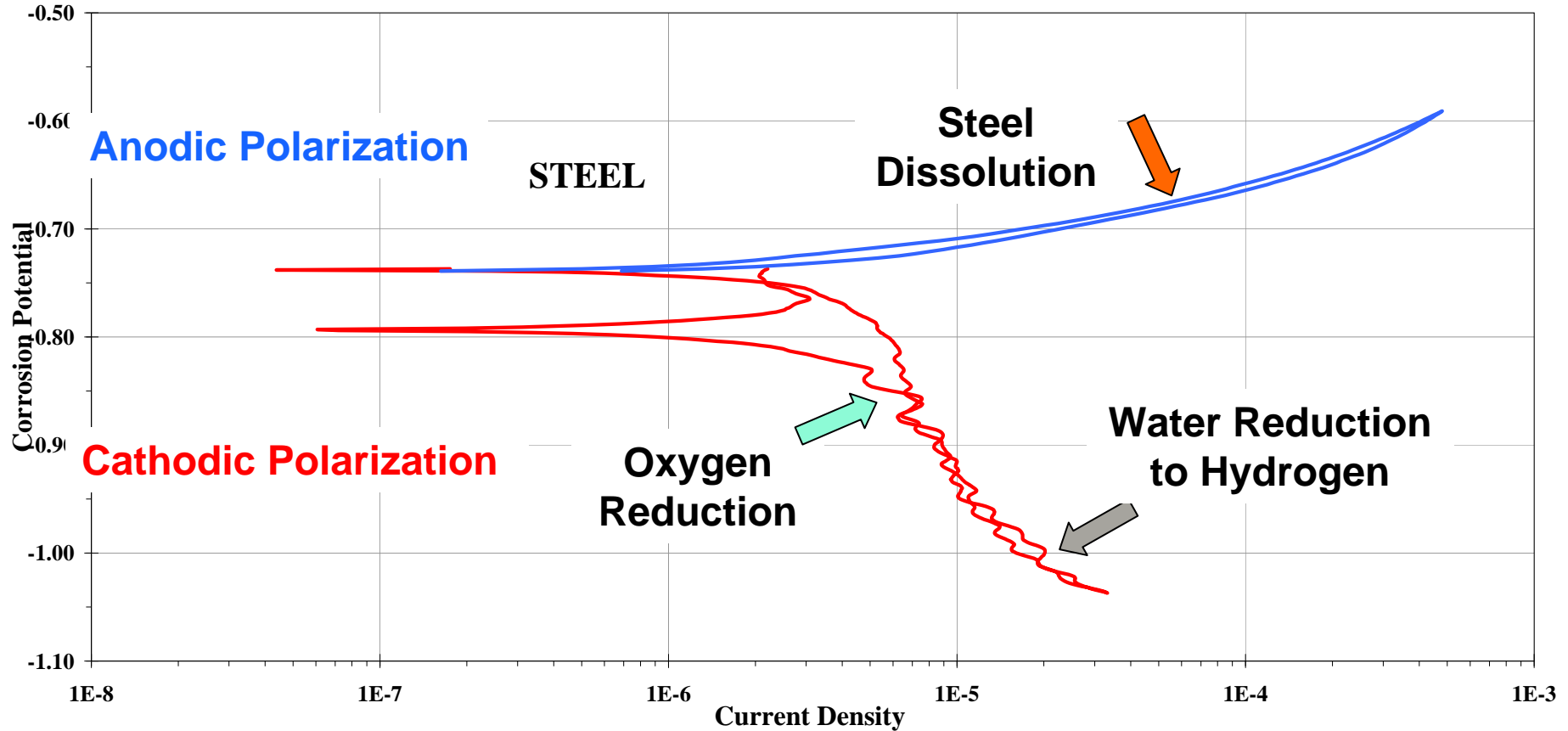
Approach Methods

- **Galvanic Series Chart for Designers**
 - Establish Steady State Corrosion Potential
 - Measure Corrosion Rate
 - Generate anodic and cathodic polarization curves
- **Predict Galvanic Coupling Effects on Geometries**
 - For 1-D(imensional) Quick-Look
 - Superimpose polarization curves
 - For 2-D & 3-D mapping
 - Work with industrial partners for computer application solutions
 - Utilize polarization curves
 - Solve potential and current distribution equations for geometry

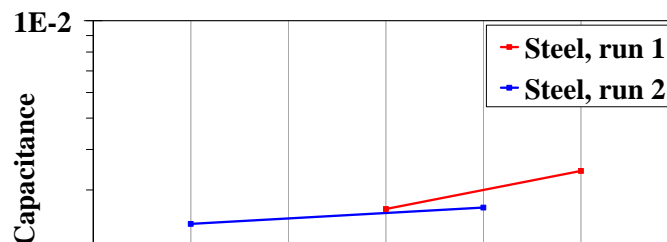
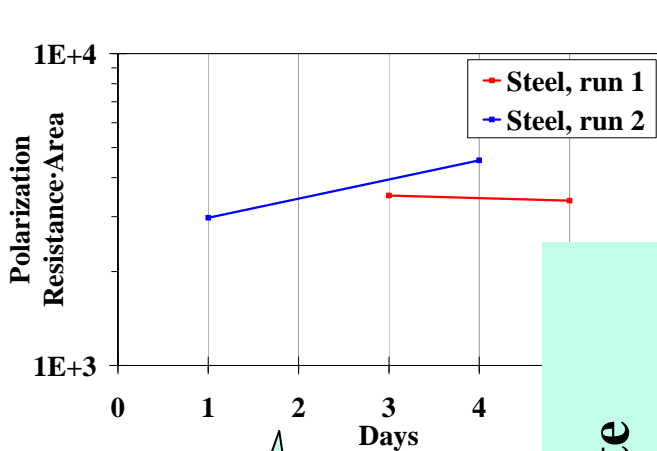
Initial Data Acquisition – Steel Example



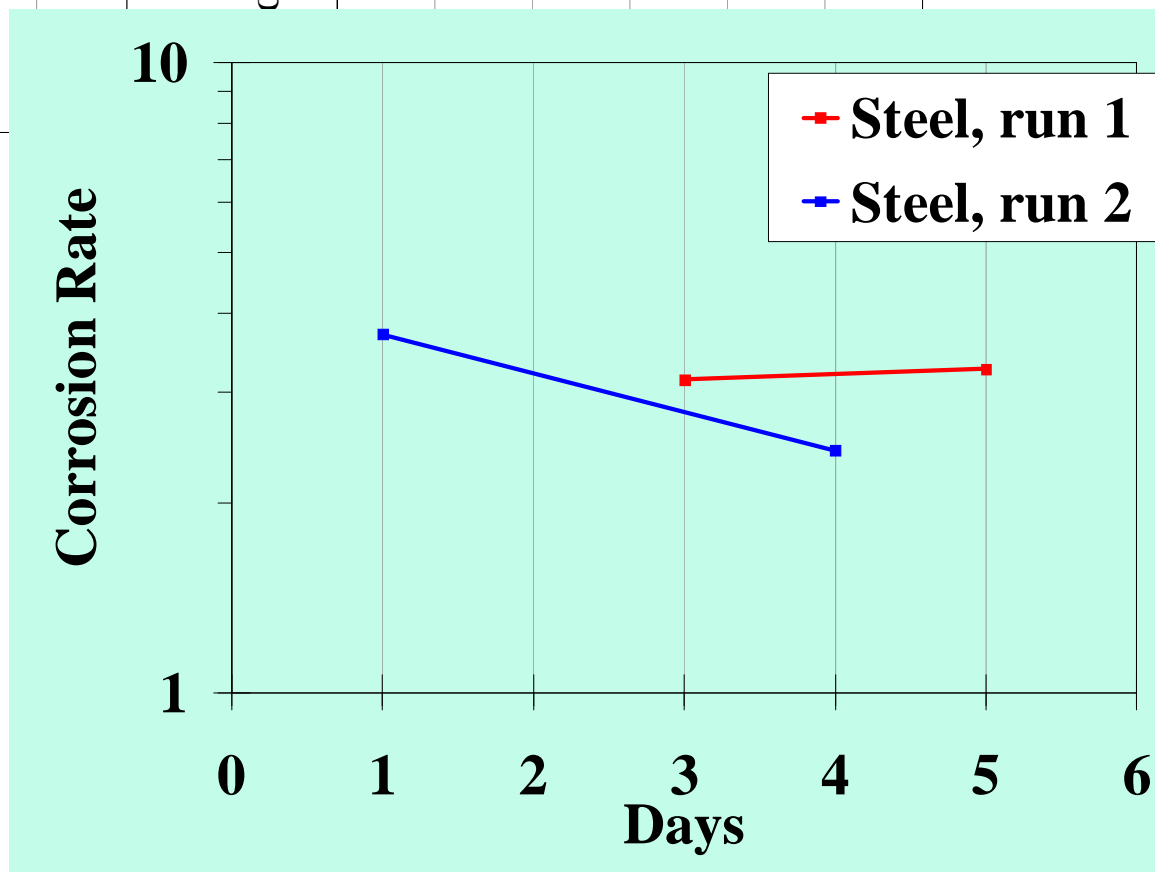
Polarization Curves of Steel in Salt Water



Data Analysis and Results

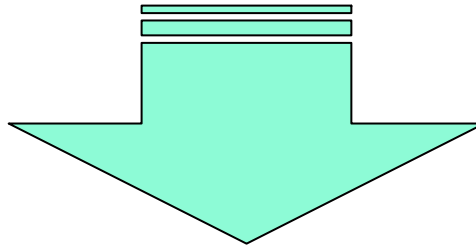


**Corrosion Rate
Time Plots**



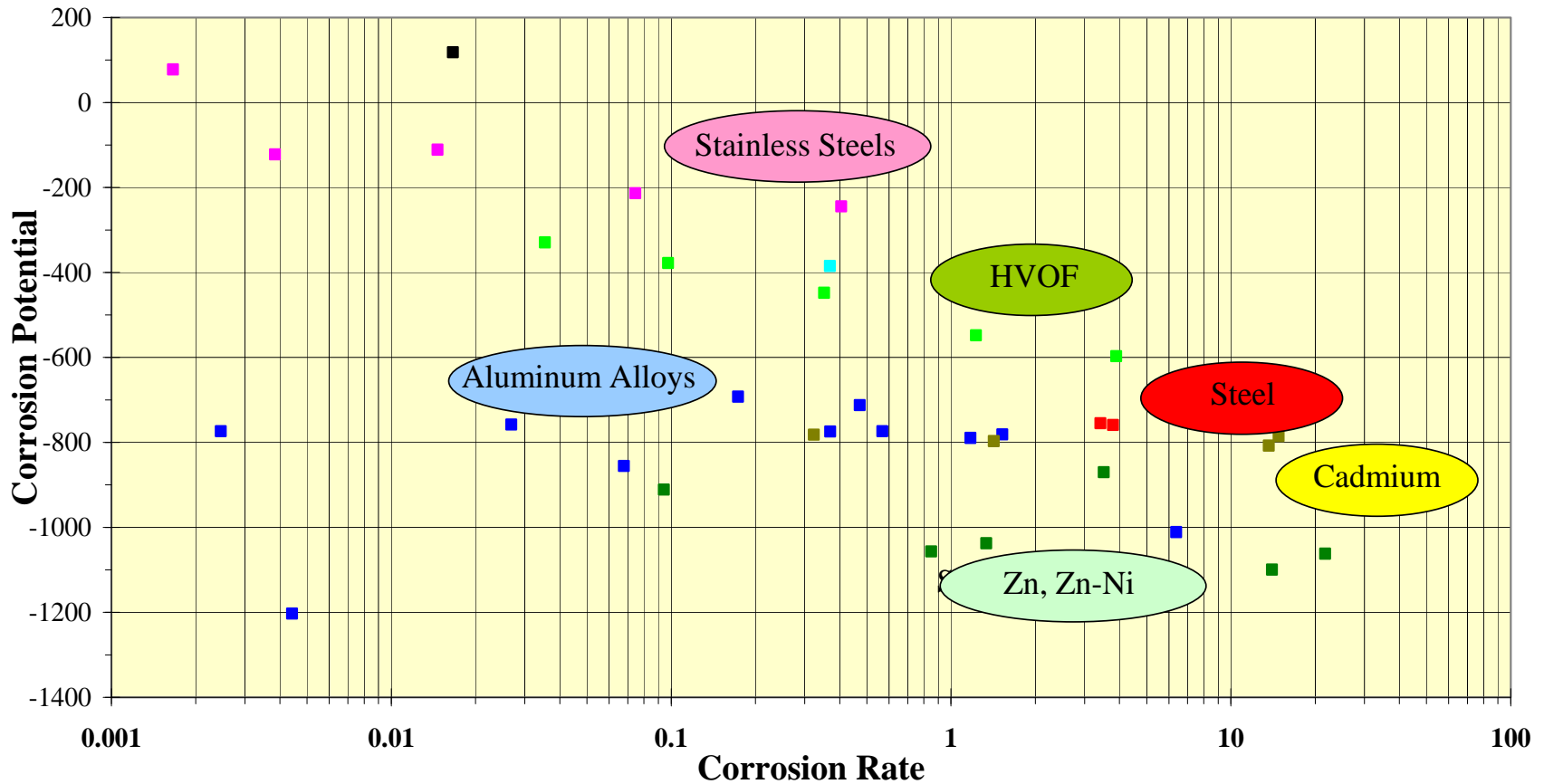
Boeing's Work to Date

- **Generated steady-state Corrosion Potentials**
- **Generated steady-state Corrosion Rates**
- **Generated some Polarization Curves**

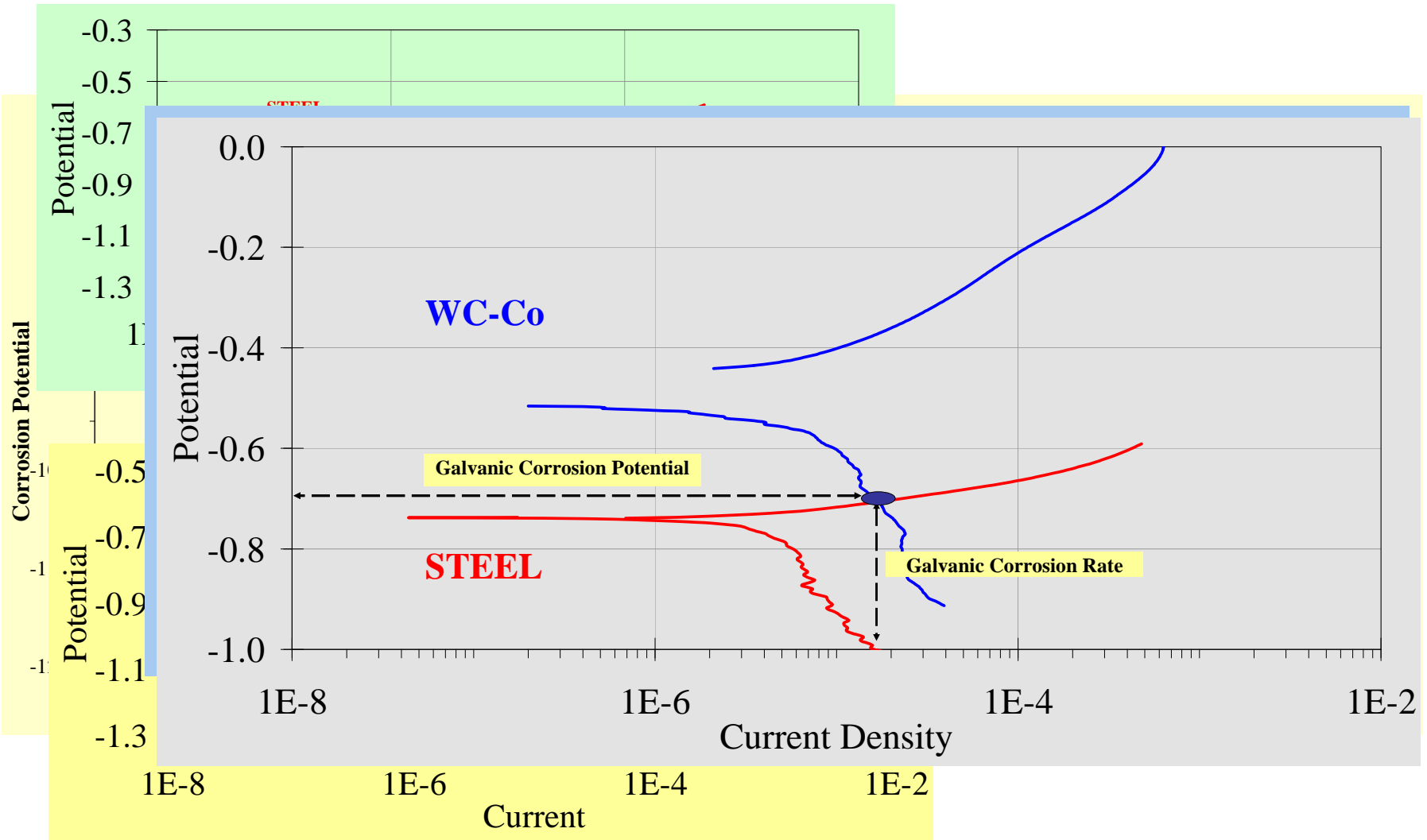


- **Initiated Next Generation Galvanic Series with 1-D Quick-Look**

Next Generation Galvanic Series



Next Generation Galvanic Series of Steel and Finishes with 1-D Quick-Look



So Far

- **Established an initial protocol**
 - **Materials and finishes placed on NG Galvanic Series**
 - **Some polarization curves utilized for 1-D Quick-Look**
- **Need an industry wide protocol to address materials, finishes, and geometries**
 - **Complete NG Galvanic Series with 1-D Quick-Look**
 - **Implement polarization curves into 2-D and 3-D design**
 - **Verify experimentally corrosion severity mapping**
 - **Funding to extend DoD relevant coating systems**
- **Into the future**
 - **Investigate crevice corrosion environments**
 - **Include organic coatings**

BACKUP

Road Forward – Phase I Methodology

- **Establish industry working group**
 - **Identify objectives**
 - **Down select test variables and procedures**
 - Environments of interest
 - Extent of variations of metals, alloys, and finishes
 - Electrochemical tests
 - Specimen geometries
 - Test Procedure criteria
 - Data Analysis
- **Conduct Electrochemical Testing on Bare Alloys**
- **Conduct Galvanic Corrosion Analysis**
 - **Generate NG Galvanic Series with 1-D Quick-Look**
 - Validate 1-D Quick-Look galvanic corrosion predictions
 - **Initiate 2-D and 3-D galvanic corrosion prediction mapping**

Road Forward – Phase II Execution

- **Establish a NG Galvanic Series with 1-D Quick-Look capabilities for Design**
 - **Complete electrochemical testing for remaining alloy families and finishes**
- **Develop and execute a test plan to validate predictions for 2-D and 3-D geometries**

Next Generation Galvanic Series

