Corrosion Engineering
Part I: Introduction

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Presentation Outline

- Background
- Design decisions
- Why costs are high
- What is corrosion?
- Risk of corrosion
- Risk reduction
- Topics covered in Parts II and III

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Background

- Corrosion is an insidious problem with wide ranging impact
  - Consumes a tremendous amount of natural resources/energy/money
- A 2001 study by the Federal Highway Administration (FHWA) estimated that (direct) corrosion costs the US $276B annually (3.1% of GDP)
  - The FHWA Study examined corrosion costs over twenty-six sectors of US economy
    - Congress directed DOD to take action... but that's only one sector!
      - The twenty-five remaining sectors of economy are decentralized with no single controlling authority
  - Results from FHWA study not a surprise...many other corrosion cost studies since the 1940's have had similar conclusions
    - What should be a surprise... 'business as usual' attitude, even with such enduring knowledge of the magnitude of the problem

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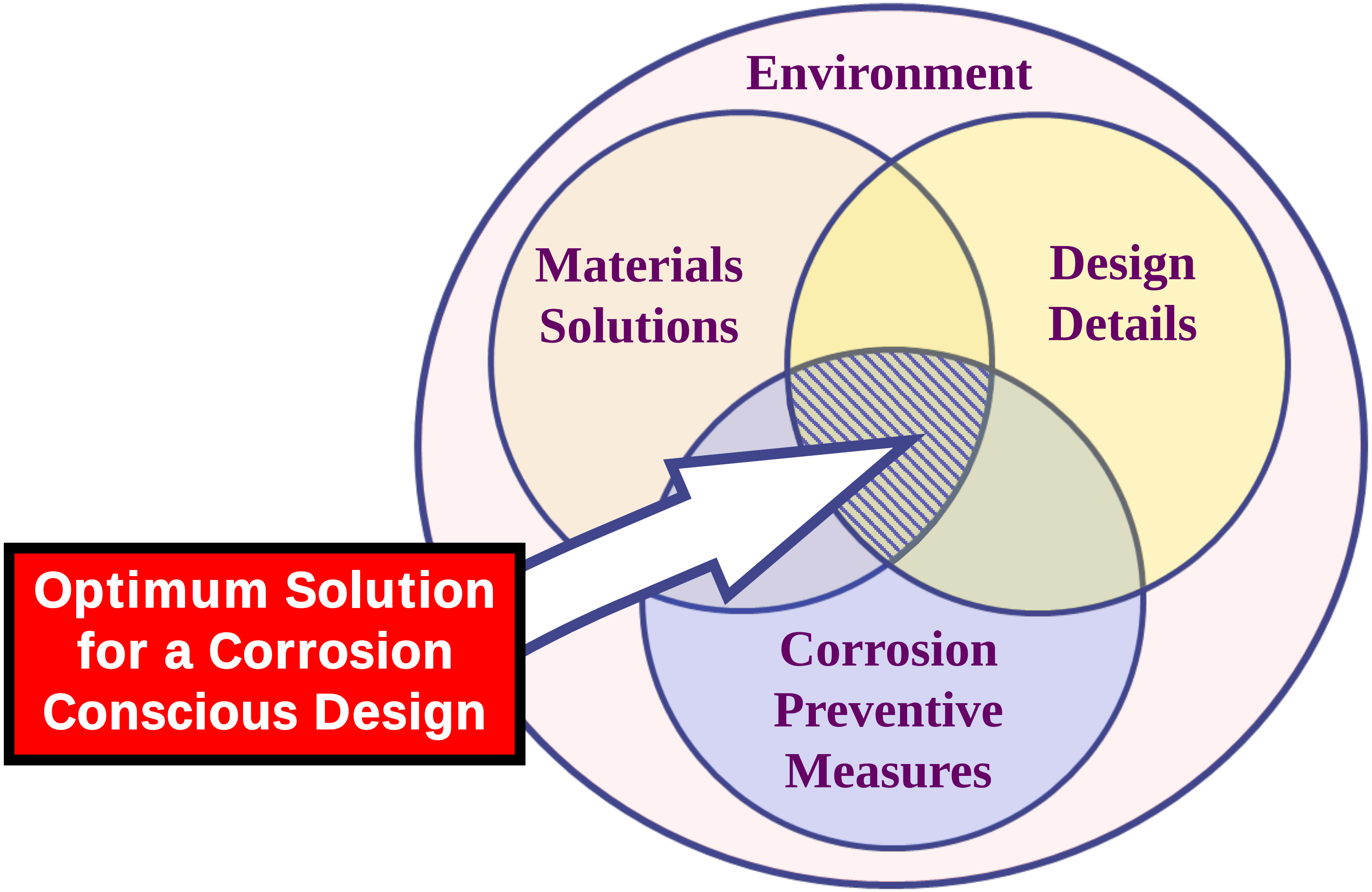
Design Decisions



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Design Decisions

- Some industries use 'lessons learned'... implemented through a required list of materials/processes/details
  - e.g.   The automotive industry learned from the past and now produces far better products than 15-20 years ago
    - Reduces need for highly trained corrosion specialists
    - But... strategy only works when the industry designs and produces the same products over and over again
- Others employ a wide array of custom selected materials, processes, and design details
  - But since materials/process selection is a design decision... it's not usually done by materials engineers
    - Result: Untrained personnel make critical decisions
      - Excessive/unplanned corrosion often results
- Other design decisions/features contribute to the problem...
- **The challenge**: affordably consider mitigation measures

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So Why Are Costs So High?

1. Design engineers aren't (usually) trained in corrosion
    - Designers receive little/no support in corrosion analysis
        - Industry practice... materials engineers only help with materials selection for critical industries/applications...
            - But even if involved... but they typically are untrained too!
    - Undergraduate engineering curricula is being reviewed
        - National Research Council committee is investigating approaches to improving corrosion skills of all graduating engineers
            - If the initiative succeeds, the problem will be reduced in the future
            - But... current engineers still require training to build skills
2. Practical design-based approaches are unavailable

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So Why Are Costs So High?

- The Question: Why is it difficult to train engineers and develop simple tools to consider corrosion during design?
- The answer! Because there are multiple, competing factors that dictate the severity of corrosion
  - Numerous forms (mechanisms) of corrosion to consider
  - Rates of corrosion are dependent on the severity of the environment and material performance
  - Structural details of the design impact corrosion rates, severity, and location
  - Corrosion resistance is often dependent on protective measures
  - System maintenance actions (or lack thereof) often influence the severity of the problem

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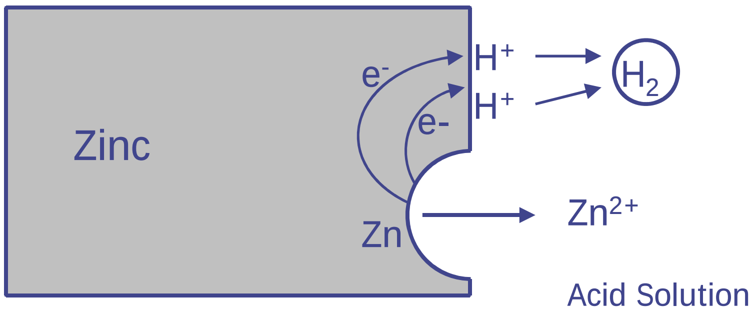
What is Corrosion?

- Corrosion is a chemical reaction
  - A metallic surface is consumed when it reacts with the environment through oxidation-reduction (redox) reactions

An Example...

$Zn \longrightarrow Zn^{2+} + 2e^{-}$ (oxidation)

$2H^{+} + 2e^{-} \longrightarrow H_2$ (reduction)



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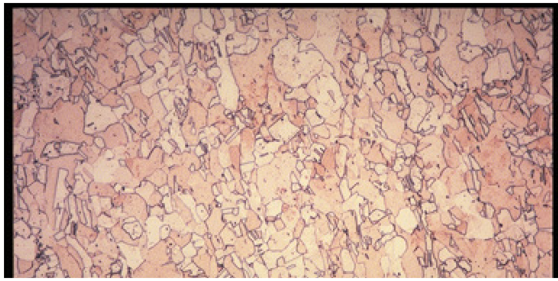
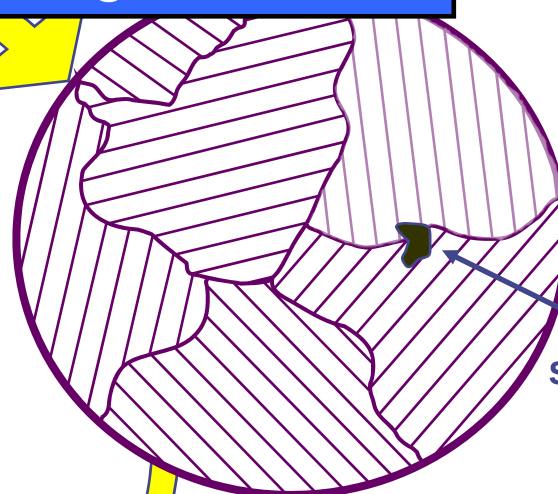
What is Corrosion?

Metallurgical Factors



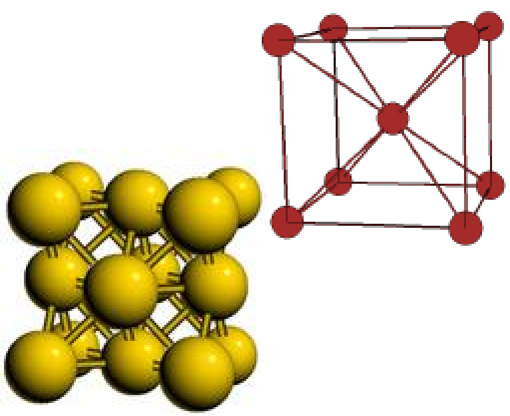
Metals are typically polycrystalline i.e. they are made from many crystalline grains



Crystallographic orientation of grains is often but not always random

Sometimes 2nd phases can be present

Crystal
<u>Structures</u>
SC
BCC
FCC
HCP
Others



Grain size and orientation, chemical composition, crystal structure, presence of second phases, and thermal processing together dictate both the mechanical properties and the susceptibility to corrosion

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What is Corrosion?

- Materials can display two different environmentally dependent reactive states
  - Passive materials... have a ‘natural’ resistance to corrosion
    - Examples of passive materials...
      - Aluminum in air
      - Stainless steel in air
      - Iron in nitric acid
  - Active materials... susceptible to corrosion
    - Examples of active materials
      - Aluminum in stagnant water
      - Iron in atmospheric conditions, marine environments

The challenge: to know the environment sufficiently well so that a selected passive material always remains in the desired state and doesn’t become active

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What is Corrosion?

- Passivity is the loss of chemical reactivity
  - A protective surface layer ~30 angstroms (or less) thick easily forms on the material's surface and protects it
    - e.g. an oxide or nitride film naturally forms due to exposure
      - 'Rust' is not a passive layer
- Iron, chromium, nickel, titanium, and alloys containing significant quantities of these elements exhibit passive behavior in *specific* environments
  - e.g. stainless steel in oxygen containing environments or iron in 70% nitric acid possess intrinsic corrosion resistance
    - The same materials in different conditions may corrode rapidly because the passive film cannot be replenished if consumed
- Passive materials are routinely used without protective measures... but not always

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Risk of Corrosion

- In principal, corrosion seems like a simple phenomenon... so why is it such a problem?
  - Because corrosion results from multiple, competing factors that vary significantly with application
    - Geometry, environment, metallurgy, and design concerns dictate the actual location, rate, and severity of in-service corrosion
      - Because of the competing factors, corrosion rates can rarely be calculated and applied
- The **Risk** of whether corrosion may result in unacceptable costs should be considered early
  - Early consideration makes better solutions possible!

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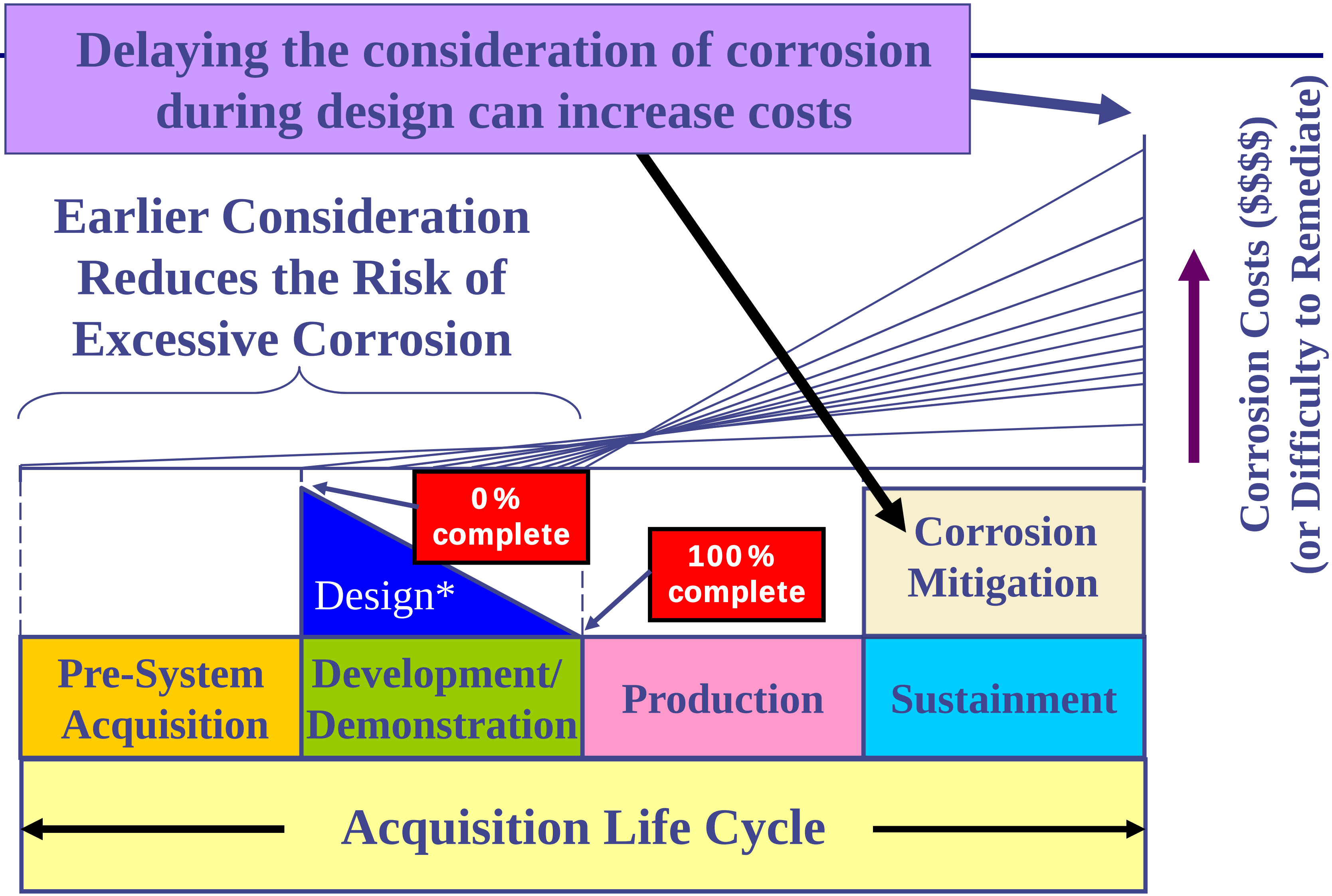
Risk of Corrosion



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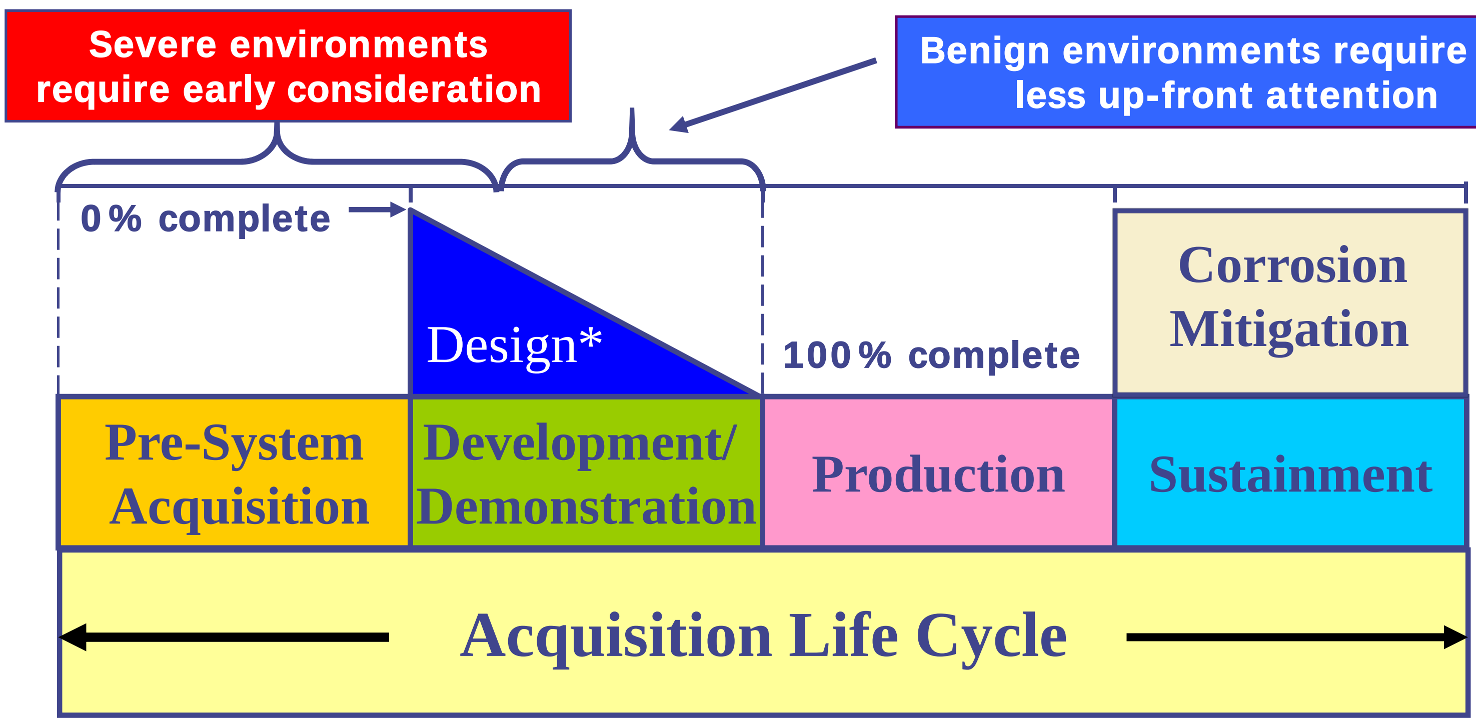
Risk of Corrosion

- Two factors determine the risk of unexpected corrosion
  - Severity of the usage environment
  - Point in acquisition cycle where it's first considered



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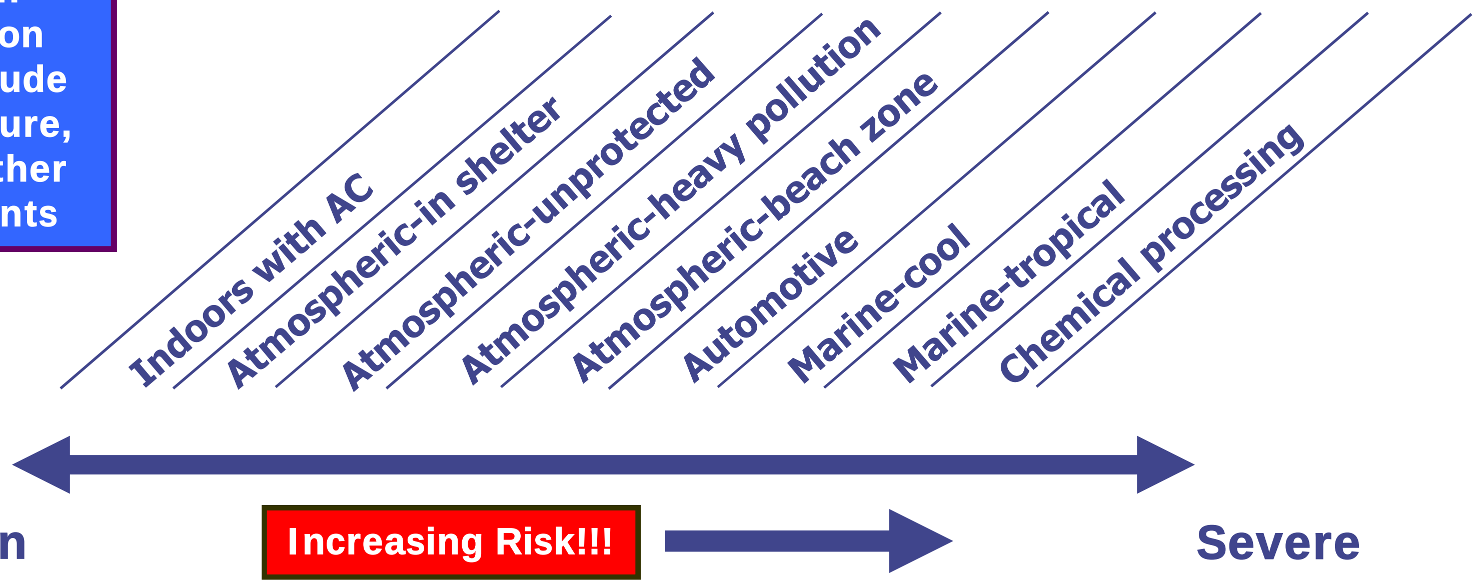
Risk Reduction

Consider the usage environment up-front

Corrosion acceleration factors include heat, moisture, chlorine, other contaminants



$	Design Investments Required	$$$$$$

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Risk Reduction

- Sometimes it's easy to anticipate the usage environment

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Risk Reduction

- Sometimes its not!!!

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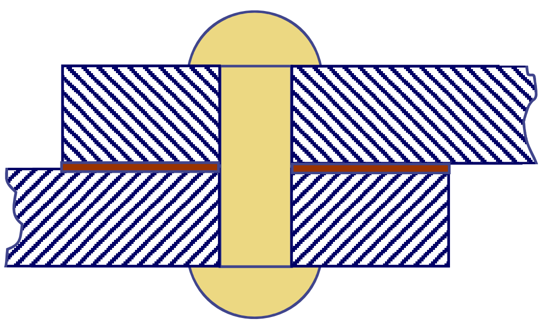
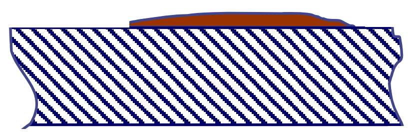
Risk Reduction

‘Environments’ can be tricky… there can be design-related microenvironments that are very corrosive

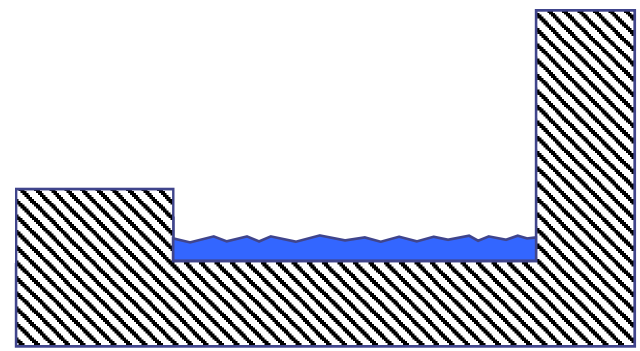
<u>EXAMPLES</u>…



Crevices



Deposits



Poor Drainage

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Risk Reduction

- Environmentally induced acceleration factors:
  - Temperature
  - Humidity
  - Ionic contamination
  - Presence or absence of oxygen
  - Dirt and debris

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Risk Reduction

- Goal: Design product to intrinsically resist corrosion
  - Select corrosion resistant materials if possible
    - Often economically infeasible
  - If forced to use other materials… pick one with the best performance
    - All materials corrode at different rates
  - Understand and consider all forms of corrosion… there are many
- Protect the material if necessary
  - Surface pretreatments, primers, topcoats, metallic platings, ceramic coatings, corrosion preventive compounds (CPCs)
    - Quality materials and application processes are critical
- Carefully consider design details
  - Joining, gaps, adjacent materials, drainage, welding, etc
- Plan for maintenance
    - Design in access for cleaning, coating reapplication, CPC reapplication

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Risk Reduction

- Get out of the stovepipe!!!
  - Corrosion is an interdisciplinary problem... use an interdisciplinary team
    - Designers
    - Reliability specialists
    - Materials specialists
    - Maintenance professionals

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Future Topics

- **Part II:**
  - Eight major forms of corrosion

    -Uniform
    -Intergranular
    -Crevice
    -Pitting
    -Galvanic
    -Stress Corrosion
    -Erosion
    -Selective Leaching

  - Several other less-common forms
- **Part III:**
  - Corrosion prevention and control

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