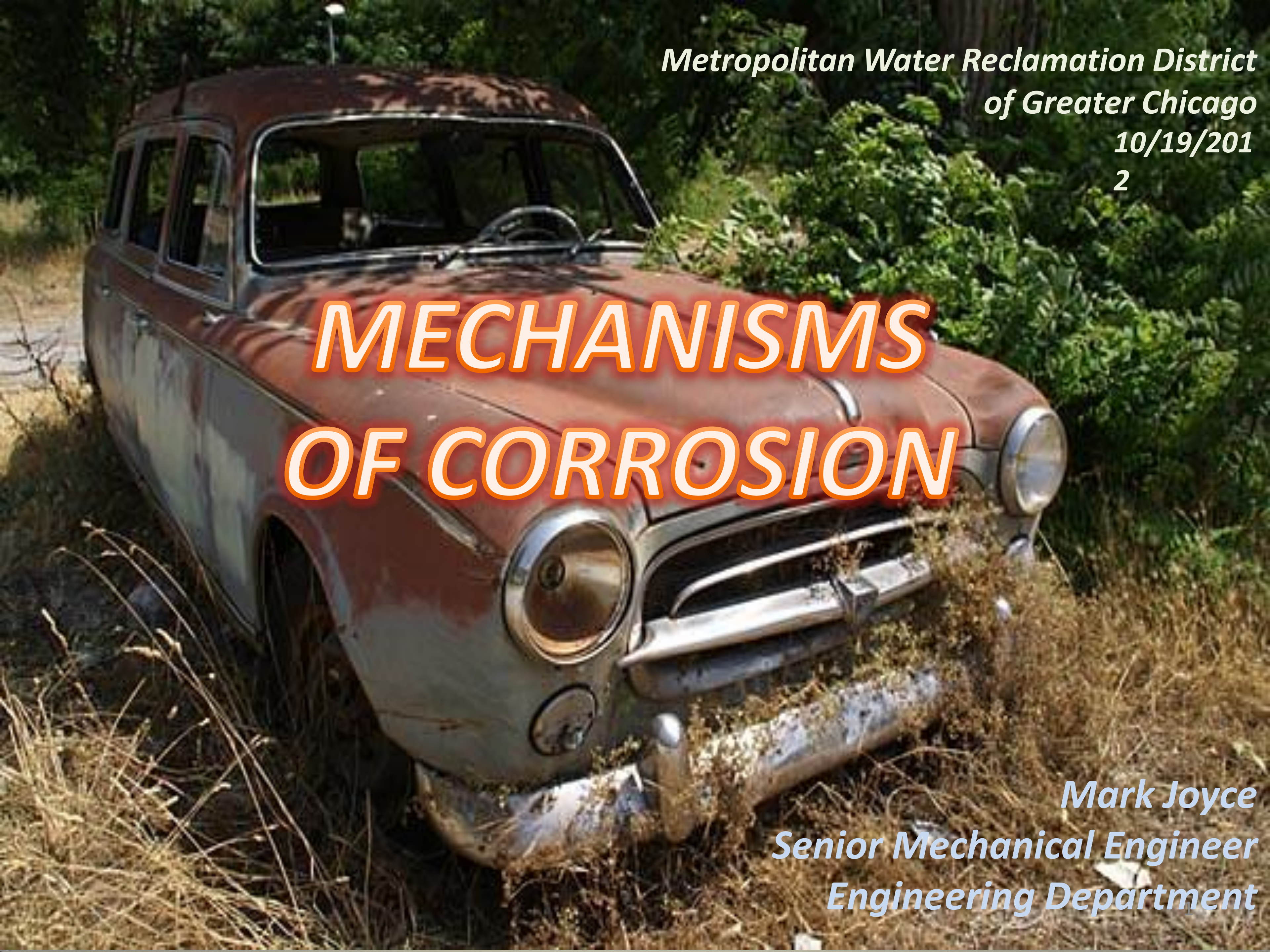

Metropolitan Water Reclamation District
of Greater Chicago
10/19/201
2

MECHANISMS OF CORROSION

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Definition of Corrosion

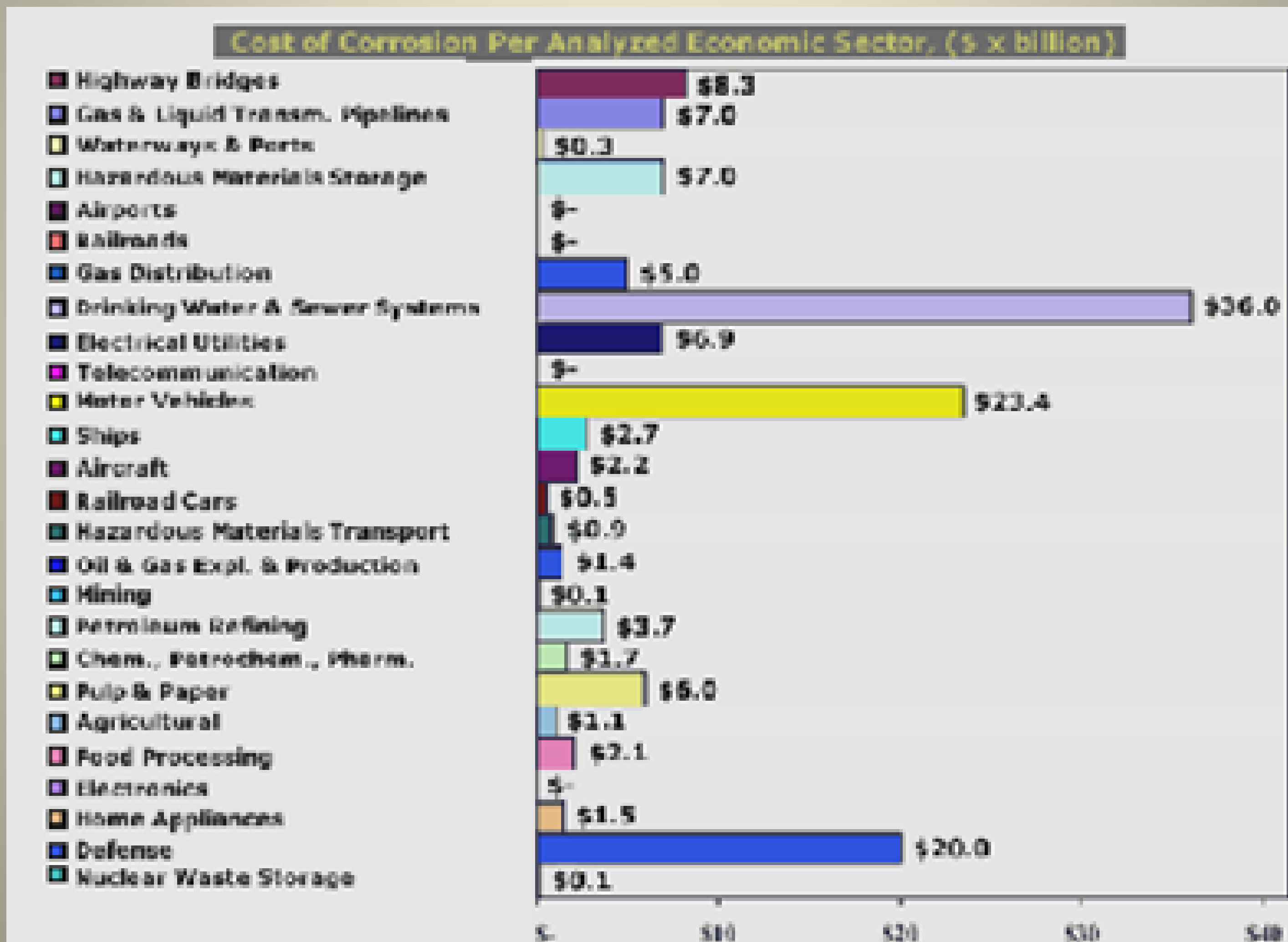
Corrosion is the deterioration of a substance (usually a metal) or its properties because of a reaction with its environment

Significance of Corrosion

- A 2002 study by the Federal Highway Authority (FHWA) showed direct losses due to corrosion at $276 billion annually in the United States, or 3% of the GDP
- The US could save about $100 billion a year through corrosion control
- It is usually more economical to control corrosion rather than eliminate it

Annual U.S. Corrosion Cost

www.corrosiondirectassessment.com



Drinking Water and Sewer System

- Cost of replacing aging infrastructure
- Cost of unaccounted-for water lost through leaks
- Cleanup of spills
- Cost of accidents
- Cost of external coatings
- Cost of cathodic protection

Most Common Forms of Corrosion

- Uniform Corrosion
- Galvanic Corrosion (Dissimilar Metals)
- Localized Corrosion
  - Pitting Corrosion
  - Crevice Corrosion
- Microbiologically Induced Corrosion (MIC)

Uniform Corrosion

- Corrosion is uniformly distributed across the surface
- Is unsightly but typically takes a long time to progress to failure due to its non-localized nature
- Because of its high visibility and slow progress, it is the easiest to mitigate

Uniform Corrosion

Galvanic Corrosion

Dissimilar Metals

- Occurs when two materials of different electrical potential are coupled together (e.g. bronze valve with a steel pipe fitting)
- One material will experience accelerated corrosion while the other experiences reduced, or zero, corrosion
- The majority of corrosion occurs at the interface of the two materials
- Can be very destructive due to its localized nature

Galvanic Corrosion

Dissimilar Metals

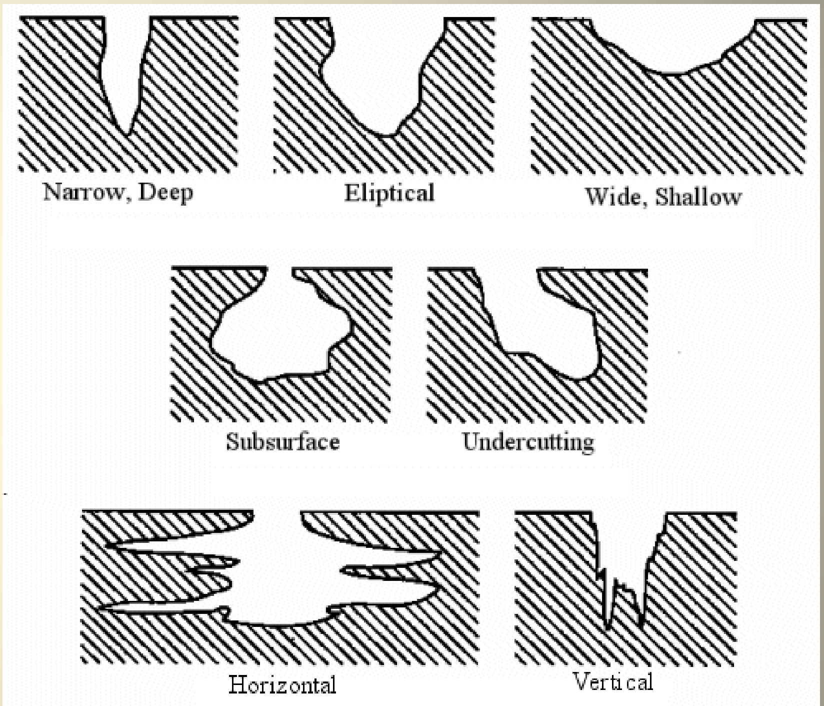
Pitting Corrosion

Localized Corrosion

- Pitting corrosion is characterized by rapid deterioration of a small area of material
- Very destructive due to the depth of corrosion and its tendency to go unnoticed
- Thru-wall penetration of piping is common
- Can be caused by:
  - Flaws in a protective coating
  - Microbiologically Induced Corrosion
  - Wet thermal insulation
  - Stray current from a cathodic protection system

Pitting Corrosion

Localized Corrosion



Crevice Corrosion

Localized Corrosion

- Like pitting corrosion, it is a localized corrosion that affects a small area
- Also like pitting corrosion, it is destructive due to its ability to quietly cause damage deep inside a material, usually out of sight
- Can be caused by gaskets, bolt heads, riveted lap joints, weld splatter, tape or paint
- More likely to be seen on metals that use a passive oxide film for protection, like stainless steel or aluminum

Crevice Corrosion

Localized Corrosion

Microbiologically Induced Corrosion

MIC

- Is caused by bacteria colonies (biofilm) parking themselves on a metal surface, like the inside of a pipe
- As part of their natural life process some of these bacteria produce sulfuric acid, others oxidize iron, leading to pitting corrosion
- Some bacteria do not damage the pipe directly but the biofilm can lead to crevice corrosion
- Bacteria love warm slow moving or stagnant water, like inside an out of service pipe leg

Microbiologically Induced Corrosion
MIC

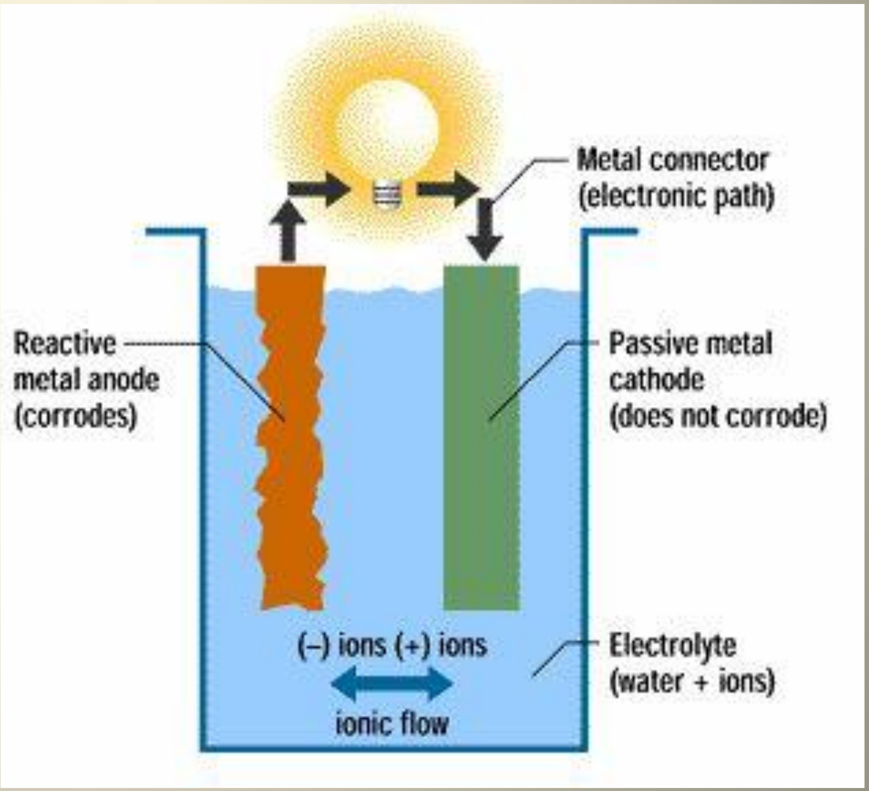
Biofilm inside pipe

After cleaning of biofilm

The Corrosion Cell

The electrochemical process leading to corrosion requires four elements. When these four elements are connected, a circuit is formed and corrosion proceeds. *Removing any of these elements breaks the circuit and stops the process.*

1. Anode
2. Cathode
3. Metallic Path
4. Electrolyte



Corrosion Cell Elements

- **Anode** – *the site from where electrons are removed and corrosion takes place*. It is an area or material that is more electronegative than the cathode
- **Cathode** – the site where electrons removed from the anode are consumed. It is an area or material that is more electropositive than the anode
- **Metallic Path** – the metallic path carries electrons from the anode to the cathode
- **Electrolyte** – the electrolyte allows ions to flow between the anode to the cathode

The Corrosion Cell

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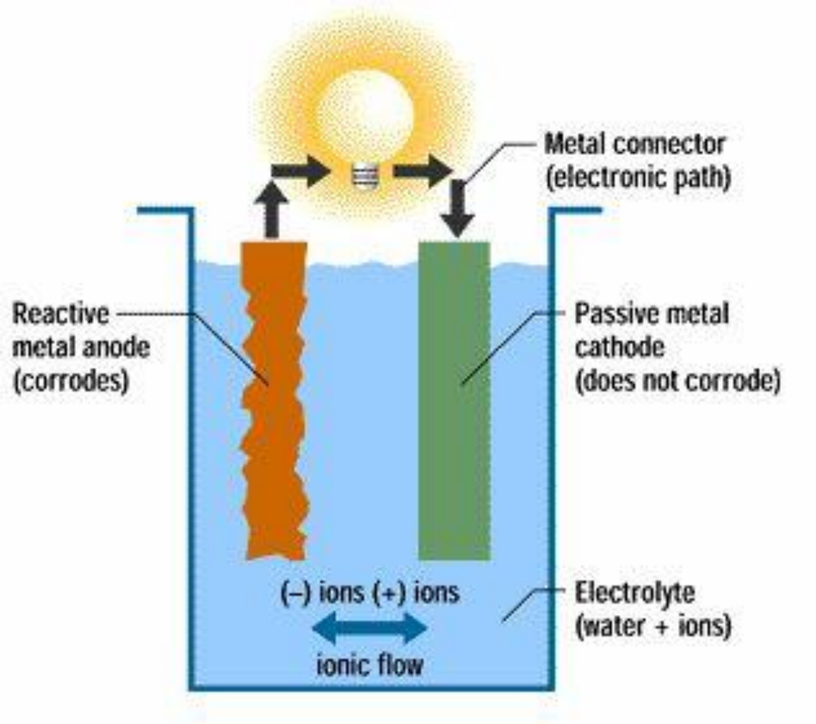
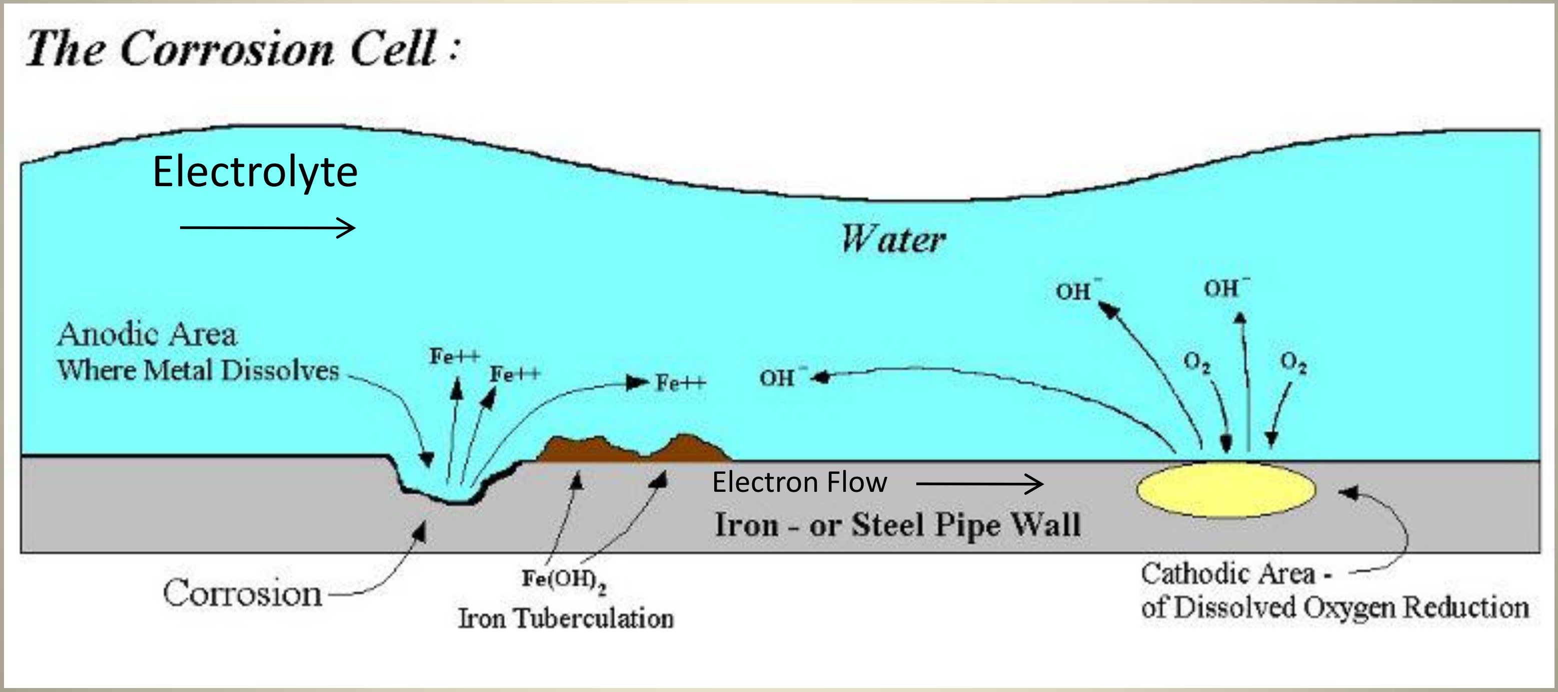


Uniform Corrosion

Uniform Corrosion at a Microscopic Level



Galvanic Corrosion

Dissimilar Metals

Galvanic Series

Gold ***More Cathodic***

Graphite

304 Stainless Steel (passive)

Nickel

Copper

Bronze

304 Stainless Steel (active)

Tin

Lead

Steel

Aluminum

Zinc

Magnesium ***More Anodic***

The galvanic series is a relative ranking of metals and semi-metals based on their electropotential, which is a natural property like density

The further apart two materials are on the series, the greater the difference in electric potential will be if they are coupled

Anodic Index

Dissimilar metal coupling should be kept under 0.15V

Metallurgy	Index (V)	
Gold, solid and plated, Gold-platinum alloy, Graphite	0.00	***Cathodic***
300 Series Stainless Steel (passive)	-0.10	
Silver, solid or plated; High nickel-copper alloys	-0.15	
Nickel, solid or plated, titanium alloys, Monel	-0.30	
Copper, solid or plated; low brasses or bronzes; silver solder	-0.35	
Brass and bronzes	-0.40	
High brasses and bronzes	-0.45	
300 Series Stainless Steel (active)	-0.50	
Tin-plate; tin-lead solder	-0.65	
Lead, solid or plated; high lead alloys	-0.70	
Aluminum, wrought alloys of the 2000 Series	-0.75	
Iron, wrought, gray or malleable, carbon and low alloy steels	-0.85	
Aluminum, wrought alloys other than 2000 Series aluminum	-0.90	
Aluminum, cast alloys	-0.95	
Zinc; galvanized steel	-1.20	
Magnesium & magnesium-base alloys, cast or wrought	-1.75	***Anodic***

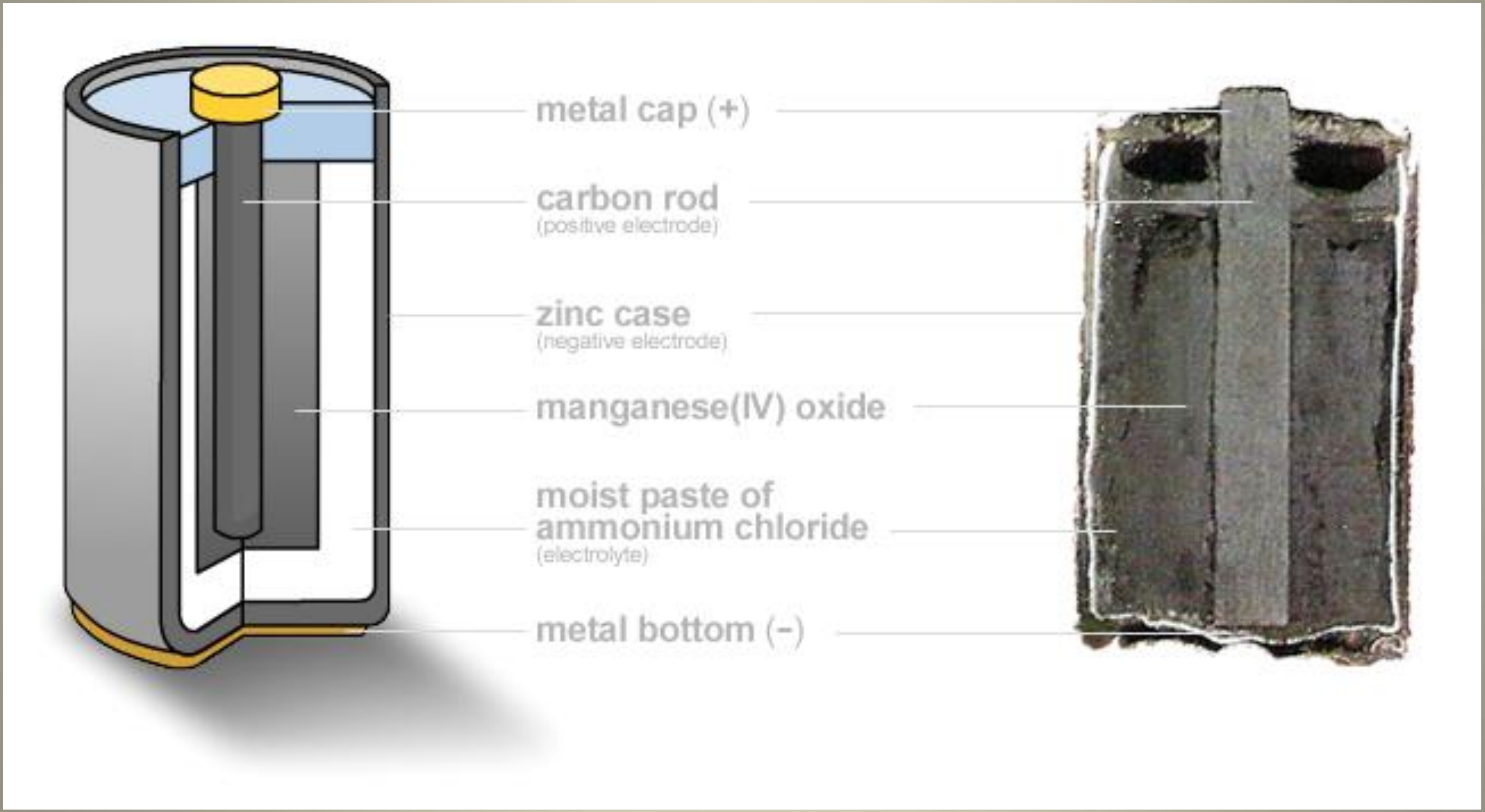
Anode/Cathode Area Ratio

- Corrosion always takes place at the anode
- The amount of corrosion current (electron flow from anode to cathode) is determined by relative positions on the galvanic series
- Current density is the amount of corrosion current per unit area of anode
- For a given current, the smaller the anode the higher the current density
- The higher the current density, the faster the anode corrodes

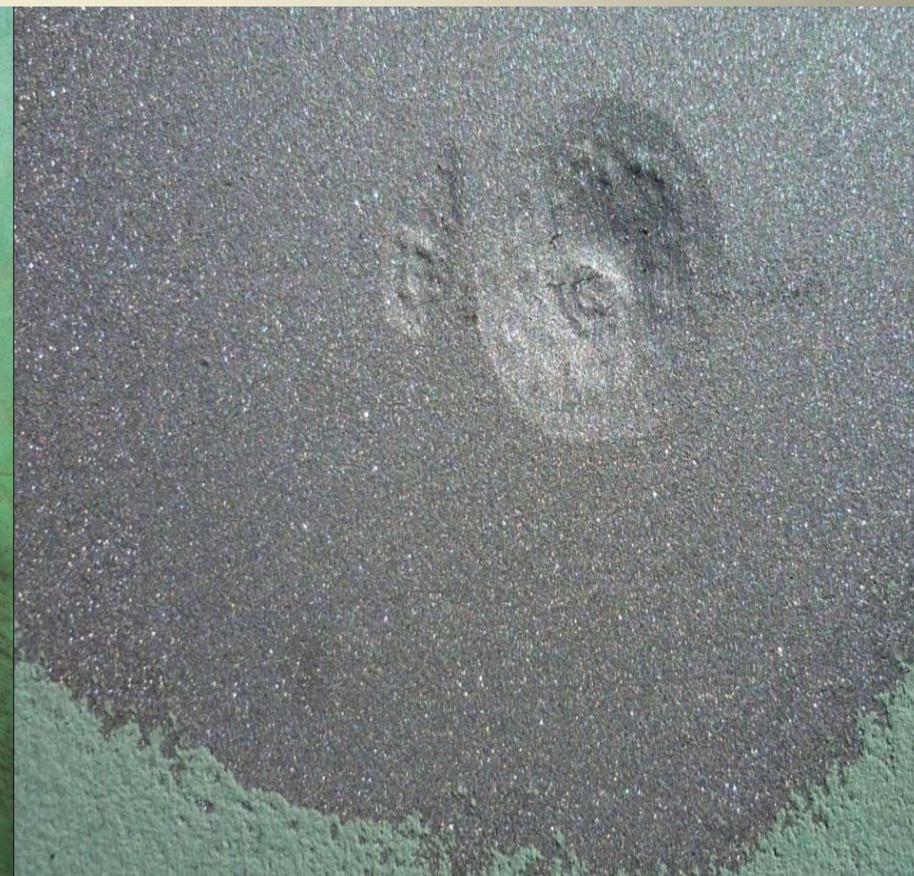
Translation….

- Big anode + small cathode = OK
- Small anode + big cathode = AVOID

Carbon Zinc Battery



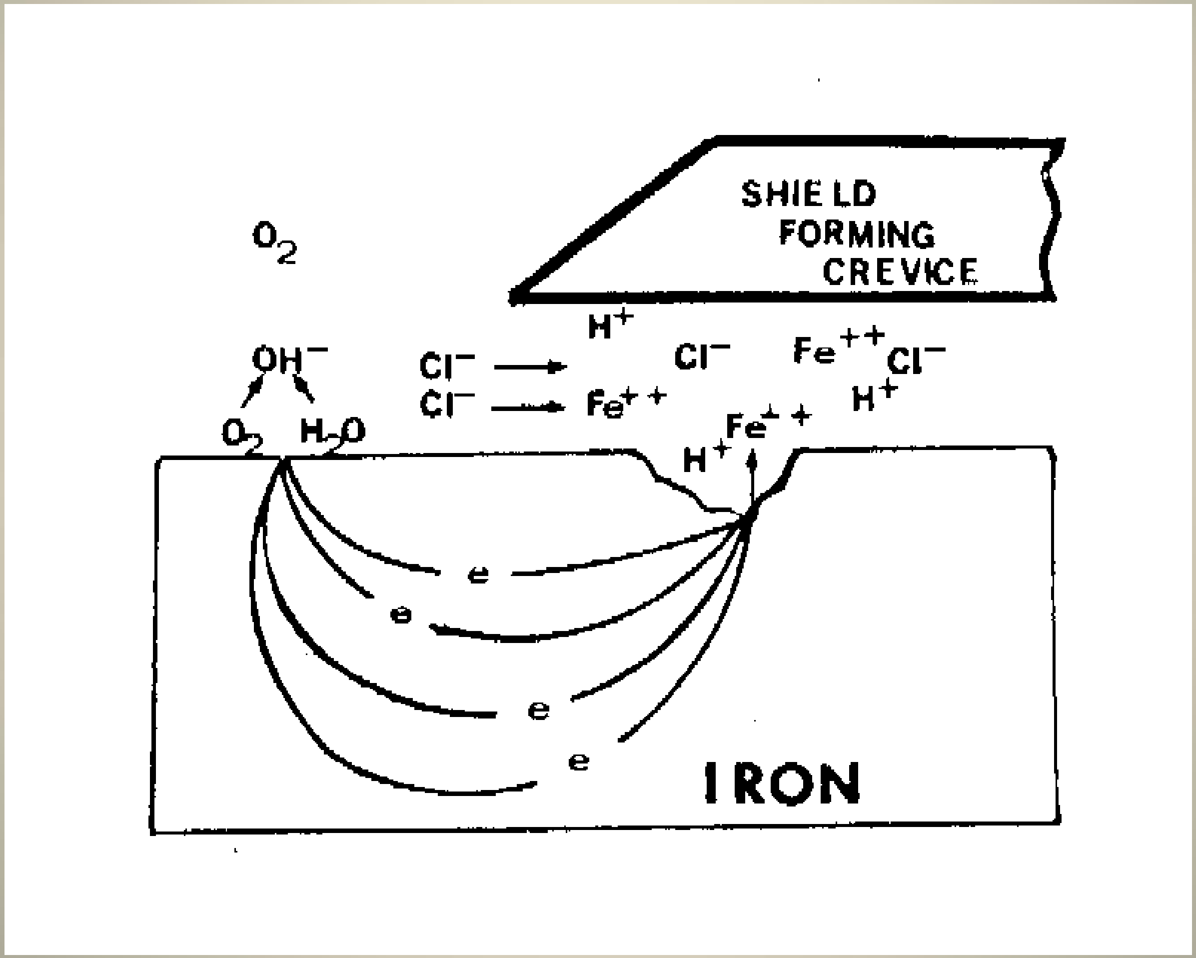
Pitting Corrosion Due to Coating Flaw



Crevice Corrosion

Localized Corrosion

Crevice Corrosion Cell



Lockport Powerhouse Wicket Gates

Methods of Corrosion Control

- **Uniform Corrosion**
  - Protective coatings
  - Use materials that are resistant to corrosion in that environment (e.g., stainless steel, aluminum)
  - If possible, modify the environment to make it less corrosive
- **Galvanic Corrosion**
  - Break the metallic path by isolating the two materials using rubber, plastic, or dielectric fittings
  - Choose materials close to each other on the galvanic series
  - Design for favorable anode/cathode area ratios

Methods of Corrosion Control

- **Pitting Corrosion**
  - Use protective coatings and maintain them
  - Proper selection of materials for the environment
  - Modification of the environment
  - Avoid materials that can hold moisture in contact with the substrate

Methods of Corrosion Control

- **Crevice Corrosion**
  - Minimize crevices wherever possible
  - Use butt-welded joints instead of lap-welded or bolted joints
  - Sealing of lap joints where they cannot be avoided
  - Use materials with higher pitting resistance
  - Provide surfaces that can easily be kept clean and free of debris

Methods of Corrosion Control

- **Microbiologically Induced Corrosion (MIC)**
  - Protective coatings
  - Avoid low to zero flow velocities
  - Mechanical cleaning
  - Chemical cleaning, if possible

Sources

- National Association of Corrosion Engineers (NACE) – www.nace.org
- www.corrosion-doctors.org
- Society for Protective Coatings (SSPC) – www.sspc.org
- Nickel Institute – www.nickelinstitute.org
- American Galvanizers Association (AGA) – www.galvanizeit.org
- American Concrete Institute (ACI) – www.concrete.org