Online Help Centre
for BC Small Water Systems

Corrosion and Corrosion Control for Small Water Systems.

Anthony S. Greville.

Corrosion Control for Small Water Systems.

Define corrosion, erosion and scaling,

Identify problems and concerns associated with corrosion,

Factors affecting the rate of corrosion,

Corrosion parameters an operator can control,

Corrosion mitigation & treatment strategies.

Corrosion Control for Small Water Systems.

Corrosion is still the most common contributor to failures in water distribution system networks, causing detrimental techno and socio-economic impacts.

A 2020 study reported it cost US $400 million to replace 11% of a concrete pipe in Los Angeles, which had been damaged by microbial corrosion alone. Estimates for sewage main corrosion restoration in the U.S. are predicted to be greater than US $1.6 trillion.

Water main breaks can flood streets, damage roadways and property, affect traffic and commutes, create downtime for businesses and increase the risk of accidents. Main breaks can also impact the distribution system, affecting flow, pressure and water quality – not to mention the cost.

Corrosion Control for Small Water Systems.

A break in a major feeder water main that supplies approximately 60 per cent of the city, approximately 1.2 mm residents, plunged Calgary's water supply into a critical state on Wednesday 05 June (so less than 2 weeks ago!).

The Bearspaw south water main, which is 11 kilometers long, and as wide as two metres in parts, suffered a break that left hundreds of homes and businesses in the city's northwest section without water and forced the closure of several roads and intersections, including parts of 6 Avenue, (also the Trans-Canada Highway in that part of the City) in both directions.

The City said that crews reached the damaged section of the critical water main on Friday 07 and had cleared water, dirt and debris to assess the site of the leak.

Corrosion Control for Small Water Systems.

The process of repairing the feeder main began on the morning of Sunday 09 June, when a section of steel pipe was fitted into the water main, replacing the damaged concrete section. The new pipe will be both welded and epoxied into place, and the repaired area will be tented to keep the heat in, allowing the new seal to become tight.

Once the repair has properly sealed, the pipe will be flushed to remove debris and to allow the Public Works crews to determine if the water flowing through the pipe is safe to drink. The Mayor said a minimum of five to seven days will be required to complete this process and at this time, it remains too early to say when the boil water advisory or the restrictions will need to be lifted.

Corrosion Control for Small Water Systems.

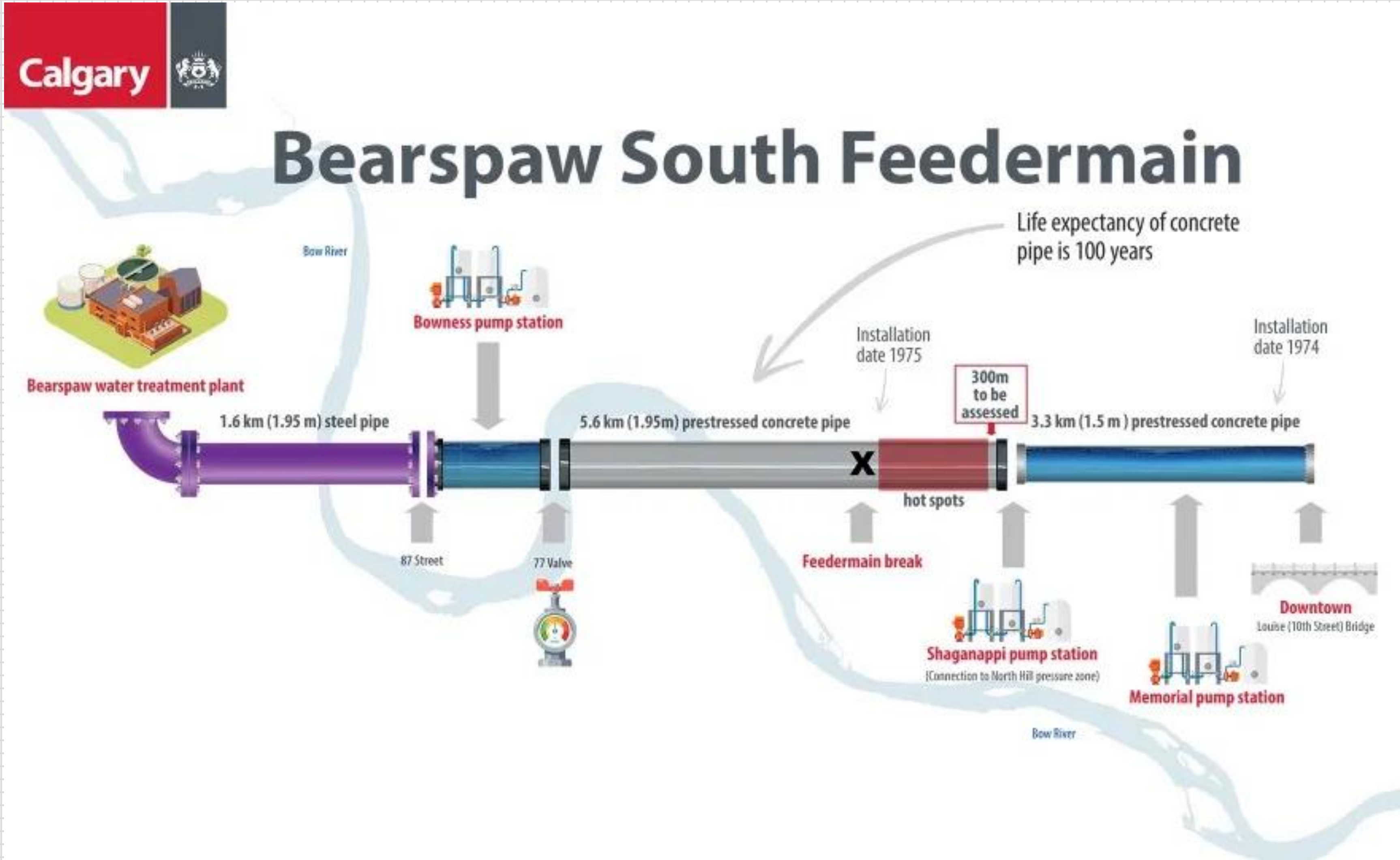
Saturday 15 June;

“We have identified potential issues that could have led to another unexpected break,” said Mayor Jyoti Gondek in a 5 pm update.

“Data gathered from robotic probes on the feeder line break in Montgomery indicate more segments will need to be dug up and replaced before water can be fed through from the Bearspaw plant,” said Gondek.

Five more segments will need to be repaired on the crucial feeder main in northwest Calgary, requiring the city to keep water restrictions in place for another three to five weeks.

Corrosion Control for Small Water Systems.



INSIDE THE BROKEN WATER MAIN

A cross-section of the Bearspaw South feeder main, which ruptured on June 5.

The excavated water main, with prestressing wires exposed.

Corrosion Control for Small Water Systems.

Corrosion Control for Small Water Systems.

A study completed by Utah State University in December 2023 surveyed more than 800 utilities and analyzed about 400,000 miles of pipe data in the US and Canada.

The data covered approximately 30.1% of the population and 17.1% of the water mains of both countries combined. The proportion of small utilities surveyed for the study was 75%.

The study determined that the United States and Canada experience 260,000 water main breaks annually, representing $2.6 billion in annual repair costs, assuming that a single water main break repair costs an estimated $10,000 in both direct and indirect costs.

Corrosion Control for Small Water Systems.

One survey question asked utilities the typical age of most water mains in their system when they fail: the average age was 53 years. At the same time, 33% of all water mains reported in the survey were more than 50 years old.

This suggests that about a third, of all water mains across the United States and Canada may be at or near the age of failure.

The study also examined break rates in corrosive soils. One finding was that ductile iron piping in highly corrosive soils (corrosion index of 3.0) will have a break rate about six times greater than one in low corrosive soils (corrosion index of 1.0).

A total of 530 utilities provided an estimate of their water loss due to leakage and the average reported value was 11%.

Corrosion Control for Small Water Systems.

Define Corrosion, Erosion and Scaling.

Water Stability.

Water stability is an important water quality parameter that needs to be fully understood. A raw, or finished, water can be corrosive, stable, or scaling in nature; this characteristic will determine how the water has to be managed by the utility operator.

Corrosion Definition.

Corrosion is the gradual deterioration of any material (usually a metal or A/C piping) as a result of a chemical and/or electrochemical reaction with its environment. Corrosion is a natural process in which a refined metal, in the presence of oxygen and moisture, is converted to a more chemically stable form, such as its oxide, hydroxide, or sulphide (original ore in the ground!).

Define Corrosion, Erosion and Scaling.

Corrosion Definition.

The corrosion of metallic materials is electrochemical in nature and is defined as the "destruction of a metal by electron transfer reactions". For this type of corrosion to occur, all four components of an electrochemical cell must be present; an anode, a cathode, a connection between the anode and the cathode to allow for the transport of electrons and an electrolytic solution that will conduct metallic ions between the anode and the cathode.

For internal corrosion of drinking water distribution systems to exist, the anode and the cathodes are sites of different electrochemical potential on the metal surface, the electrical connection is the metal and the electrolyte is the water.

The basic electrochemical reaction can be written as; $M \rightarrow M^{n+} + ne^-$

Define Corrosion, Erosion and Scaling.

Erosion Definition.

Pipe erosion, also known as erosion corrosion, refers to the gradual degradation and loss of material from the internal surfaces of pipes caused by physical erosion. Water can cause the gradual thinning of the pipe wall due to its mass, high velocity of impact, local turbulence or its abrasive quality (wastewater).

Scaling Definition.

Scaling is defined as the deposition of mineral solids on the interior surfaces of water lines, heating elements and other containers. When a water sample becomes over saturated with divalent metal ions (Ca & Mg), they precipitate as a carbonate, bicarbonate, chloride, or sulphate scale which can coat the interior walls of the distribution system mains and household piping.

Aqueous Stability.

A key characteristic of water is its stability, both its chemical stability and biological stability.

Chemical Stability.

There are several methods and indices that measure the calcium carbonate stability of water. This is an important parameter as an unstable water, with respect to calcium carbonate, can present as being either scaling or corrosive.

The Langelier Stability Index is a widely accepted method to estimate a water's calcium carbonate chemical stability. This calculation will help determine if the water is aggressive, in-balance, or scale forming.

Aqueous Stability.

The Langelier Index is an approximate indicator of the degree of saturation of calcium carbonate in water and is calculated using the pH, alkalinity, calcium concentration, total dissolved solids, and water temperature of a water sample.

The Langelier Stability Index is defined as; LSI = pH – pHs.

Where: LSI = The Langelier Stability Index,

pH = The measured pH,

pHs = The pH at which the water is saturated with $CaCO_3$ i.e. the water cannot hold any more $CaCO_3$ in solution.

Aqueous Stability.

A water is saturated with respect to calcium carbonate when there is just enough $CaCO_3$ in the water that no more can be dissolved but not enough that it will precipitate out; should any more calcium carbonate be added to the water, it will begin to form precipitate that will fall out of solution and scale.

A water sample is considered to be supersaturated with respect to calcium carbonate, when there is an overabundance of $CaCO_3$ in the water sample, and it is/will precipitating out. When this occurs, a layer of calcium carbonate film, or scale, can form along the internal walls of the pipe. This scale can be a positive, acting as a protective coating against corrosion, or a negative, reducing heat transfer efficiency in a boiler or domestic water heater.

Aqueous Stability.

If the Langelier Index is positive, then the water is over saturated with calcium carbonate, which will tend to deposit, forming scales in the distribution system.

If Langelier Index is close to zero, then the water is close to saturation with calcium carbonate, and will be neither strongly corrosive nor scale forming.

If the Langelier Index negative, then the water is under saturated with calcium carbonate and will tend to be corrosive to the distribution system.

Field experience has shown that an LSI between - 0.5 and + 0.5 has a relatively low corrosion impact on metallic components within the distribution system, and any scale deposited will form a beneficial protective layer.

Aqueous Stability.

Location	Water Source	LSI
Fort Nelson	Muskwa River	+ 0.95
Port Hardy	Tsulquate River	- 0.44
Lions Bay	Harvey Creek	- 3.9
Salmon Arm	Shuswap Lake	- 0.8
	East Canoe Creek	+ 0.7
Black Mountain/Kelowna	Mission Creek	- 2.5
	Well #5	+ 0.4
Penticton	Penticton Creek	- 2.6
	Okanagan Lake	+ 0.3

Corrosion Classifications and Descriptions.

Corrosion can take many forms and appear in just about any environment. We will not be discussing phenomena such as fatigue corrosion or stress cracking corrosion, although they may be present in some facilities.

In the water and wastewater treatment industry, the most common types of corrosion experienced are;

Concentration cell corrosion,

Galvanic corrosion,

Under deposit corrosion.

Corrosion Classifications and Descriptions.

Corrosion can also be differentiated by the location where it is occurring and the effect it has on the plant operations and the consumer. It is the responsibility of the water purveyor to produce water that is non-corrosive not only at the treatment plant, but also at the consumer curb stop valve.

As a generality, corrosion in the distribution system will lead to the degradation of the water mains, and cause an increase in iron loading, or the products of A/C mains failure (calcium silicate, aluminum and asbestos etc.).

Corrosion that occurs in the household environment will more likely cause an increase in lead and copper in the finished water.

Corrosion Classifications and Descriptions.

Other ways to properly describe corrosion are to consider the size of the anode relative to the size of the cathode in the corrosion cell.

Is the observed corrosion,

Widespread and uniform (often a pH/alkalinity issue),

Localized and pitting (often a metal imperfection issue),

Internal to the transmission lines (corrosive water),

External to the transmission lines (corrosive soils)?

Concentration Cell Corrosion.

Corrosion is a series of electrochemical reactions in which an electric current (electrons) flows through the metal that is the subject of corrosion.

Concentration cell corrosion occurs when both the anode and the cathode are within the same section of metal, and when water, the electrolyte, and oxygen are also present. In most instances concentration cell corrosion is associated with iron piping.

Metal loss (corrosion) will occur at the anode.

Metal accumulations (tubercules) will occur close to the cathode.

Concentration Cell Corrosion.

Corrosion Classifications and Descriptions.

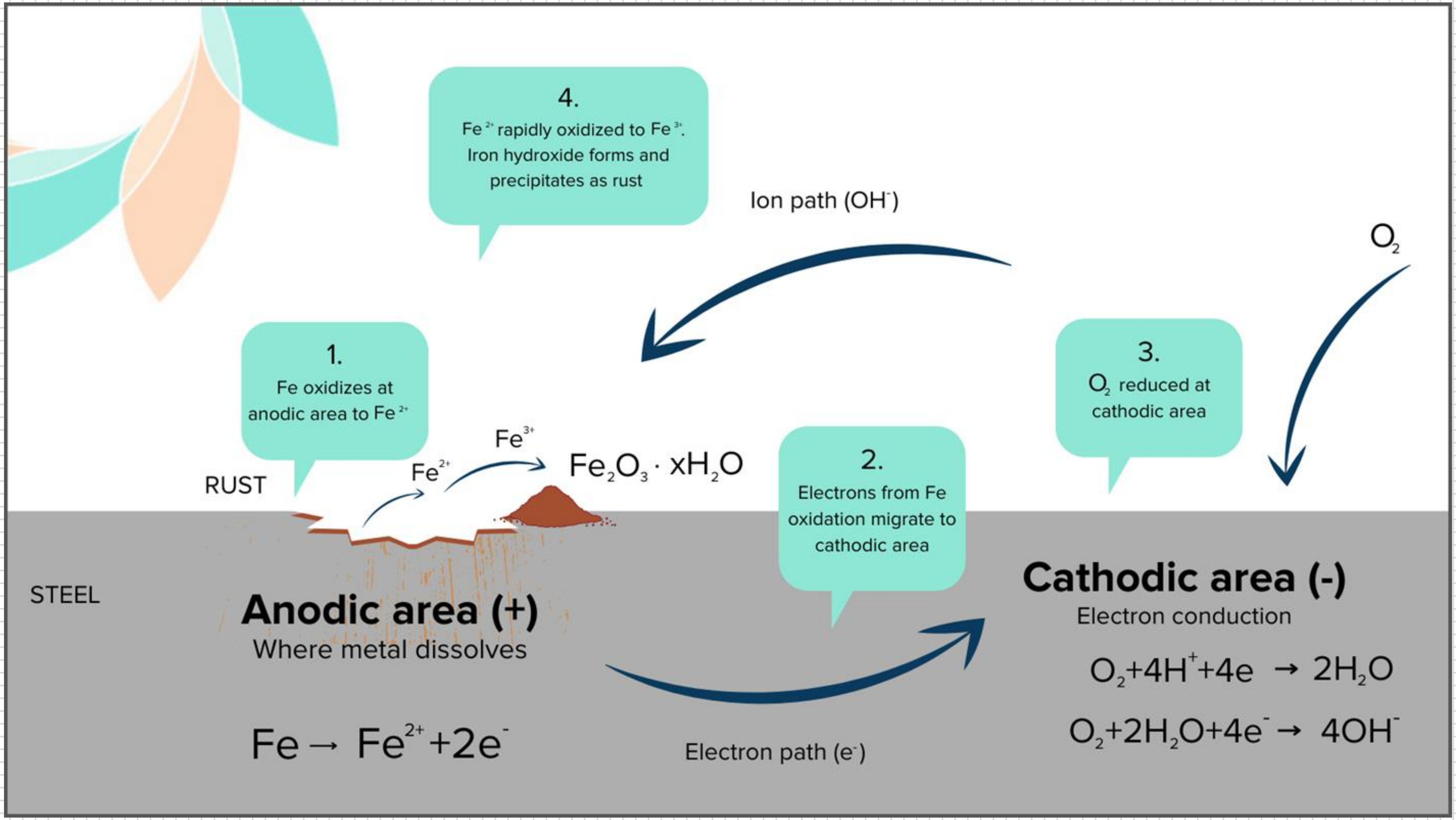
Concentration Cell Corrosion.

In a concentration corrosion cell, minor imperfections and impurities, cracks, crevices, weld points other stress points etc., in the metal pipe surface cause one location to become the anode, resulting localized oxidation (loss of electrons) and the generation of M^{n+} (often Fe^{2+}) ions, which, subsequently, go into solution in the electrolyte; so metal loss - corrosion.

This oxidation reaction results in the loss of 2 electrons, which will travel through the metallic pipe to the cathode, found at a different location.

At the cathode, water molecules, which react with any oxygen present, are reduced (gain electrons) and dissociate into hydrogen ions, H^+ and the hydroxide radical ion, ^{-}OH.

Concentration Cell Corrosion.



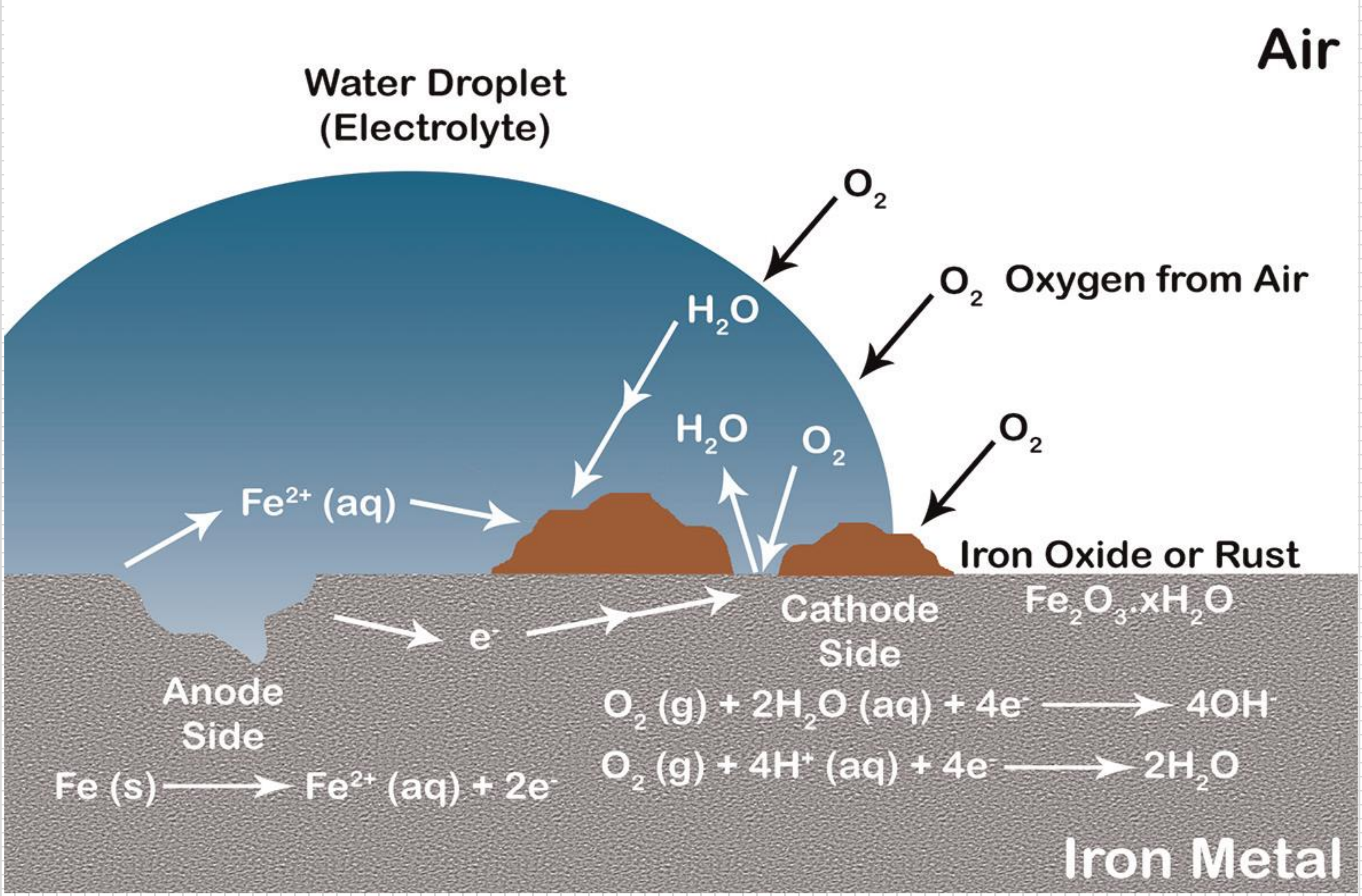
Concentration Cell Corrosion.

If there is excess oxygen present (which there almost always is!), the Fe^{2+} undergoes further oxidation, and becomes Fe^{3+}.

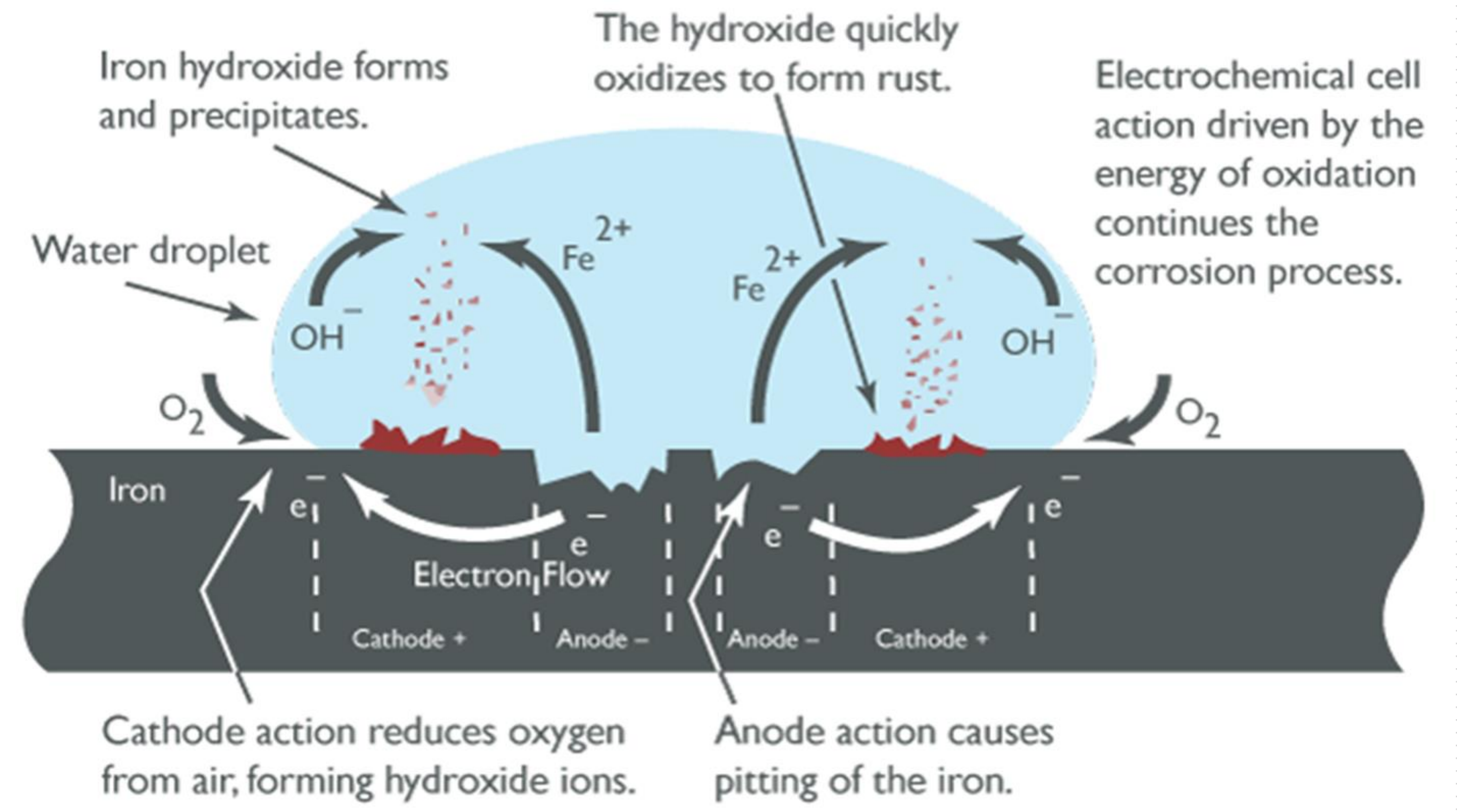
Next, in the electrolyte, the Fe^{2+} ions combine with two ^{-}OH radical ions to form ferrous hydroxide, $Fe(OH)_2$, and/or the Fe^{3+} becomes ferric hydroxide, $Fe(OH)_3$, otherwise known as rust, with the general formula $Fe_2O_3 \cdot xH_20$.

The H^+ ions gain the electrons lost by the iron and become H_2 gas.

Concentration Cell Corrosion.



Concentration Cell Corrosion.



Galvanic (Dissimilar Metal) Corrosion.

Galvanic corrosion, also called 'dissimilar metal corrosion' or bimetallic corrosion (also, incorrectly, called electrolysis), refers to corrosion damage induced when two dissimilar materials are coupled in a corrosive electrolyte. It occurs when two (or more) dissimilar metals are brought into electrical contact under water, or when there is water/moisture in the soil (external corrosion). In this type of corrosion the anode and cathode are found in the different metals.

When a galvanic couple forms, one of the metals in the couple becomes the anode and corrodes faster than it would by itself, while the other metal becomes the cathode, and corrodes slower than it would alone. If managed properly, corrosion rates can be halted at the cathode (cathodic protection).

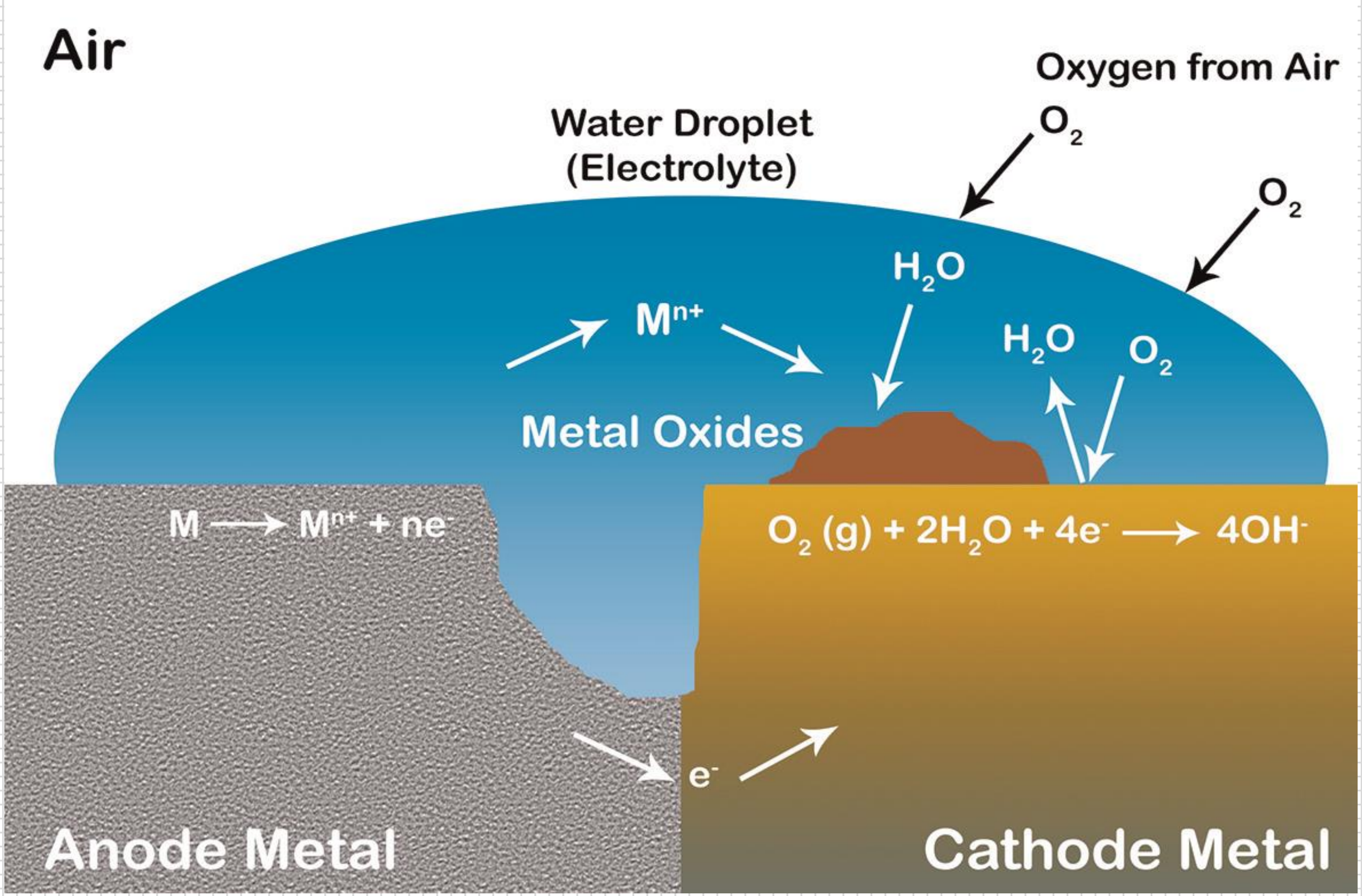
Galvanic (Dissimilar Metal) Corrosion.

The driving force for galvanic corrosion is a potential difference between the two different metals/materials.

Galvanic corrosion can be one of the most common forms of corrosion as well as one of the most destructive; especially when there is a small anode and large cathode, which can result in extensive and deep pitting.

This phenomena was given a practical application by Alessandro Volta who built, in 1800, the first electrical cell, or battery; a series of metal disks of two kinds, separated by cardboard disks soaked with acid or salt solutions.

Galvanic (Dissimilar Metal) Corrosion.



Galvanic (Dissimilar Metal) Corrosion.

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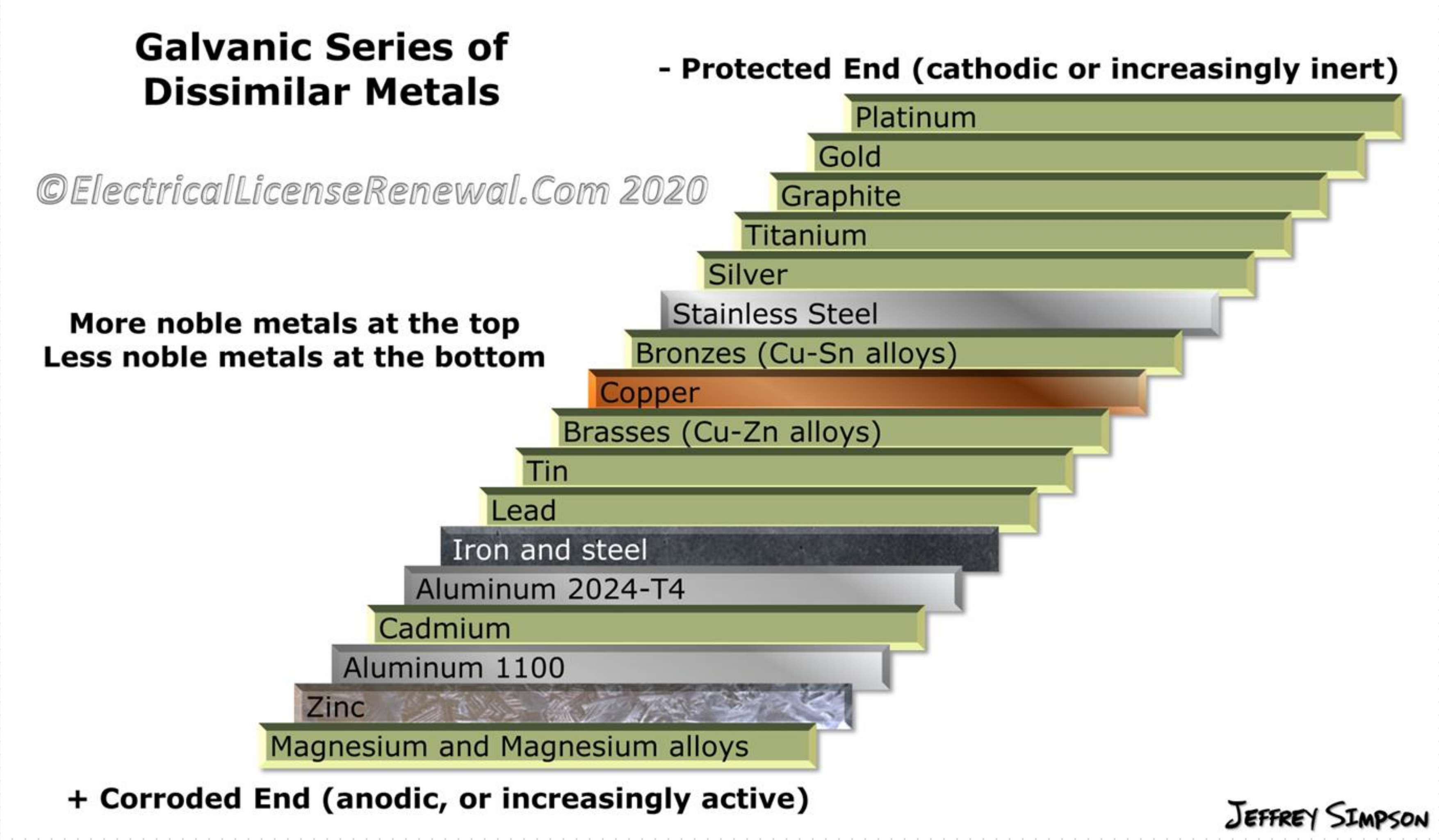
Galvanic (Dissimilar Metal) Corrosion.

In a bimetallic couple, the less noble material will become the anode in the corrosion cell and tend to corrode at an accelerated rate, compared with the uncoupled condition. The more noble material will act as the cathode in the corrosion cell.

A small anode/cathode area ratio is highly undesirable. In this case, the galvanic current is concentrated onto a small anodic area. Rapid thickness loss (pitting) of the dissolving anode tends to occur under these conditions.

Galvanic corrosion problems should be solved by designing the system to avoid these problems in the first place.

Galvanic (Dissimilar Metal) Corrosion.



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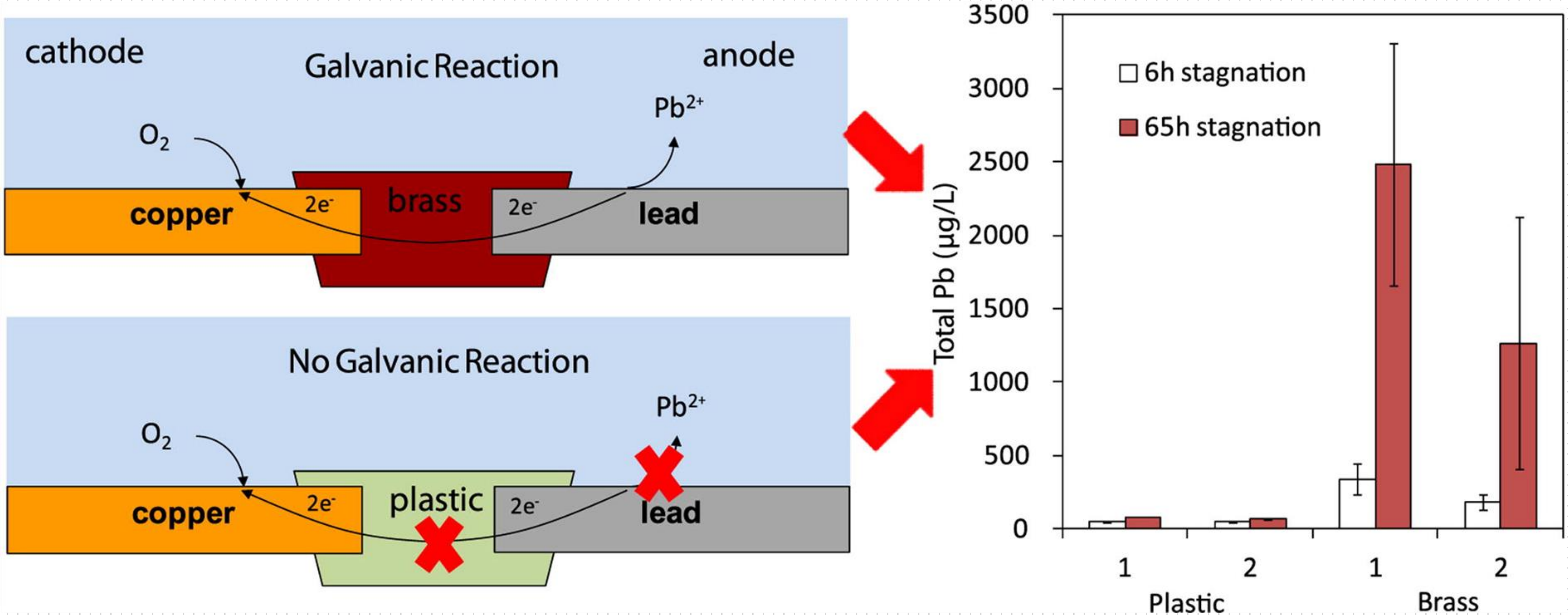


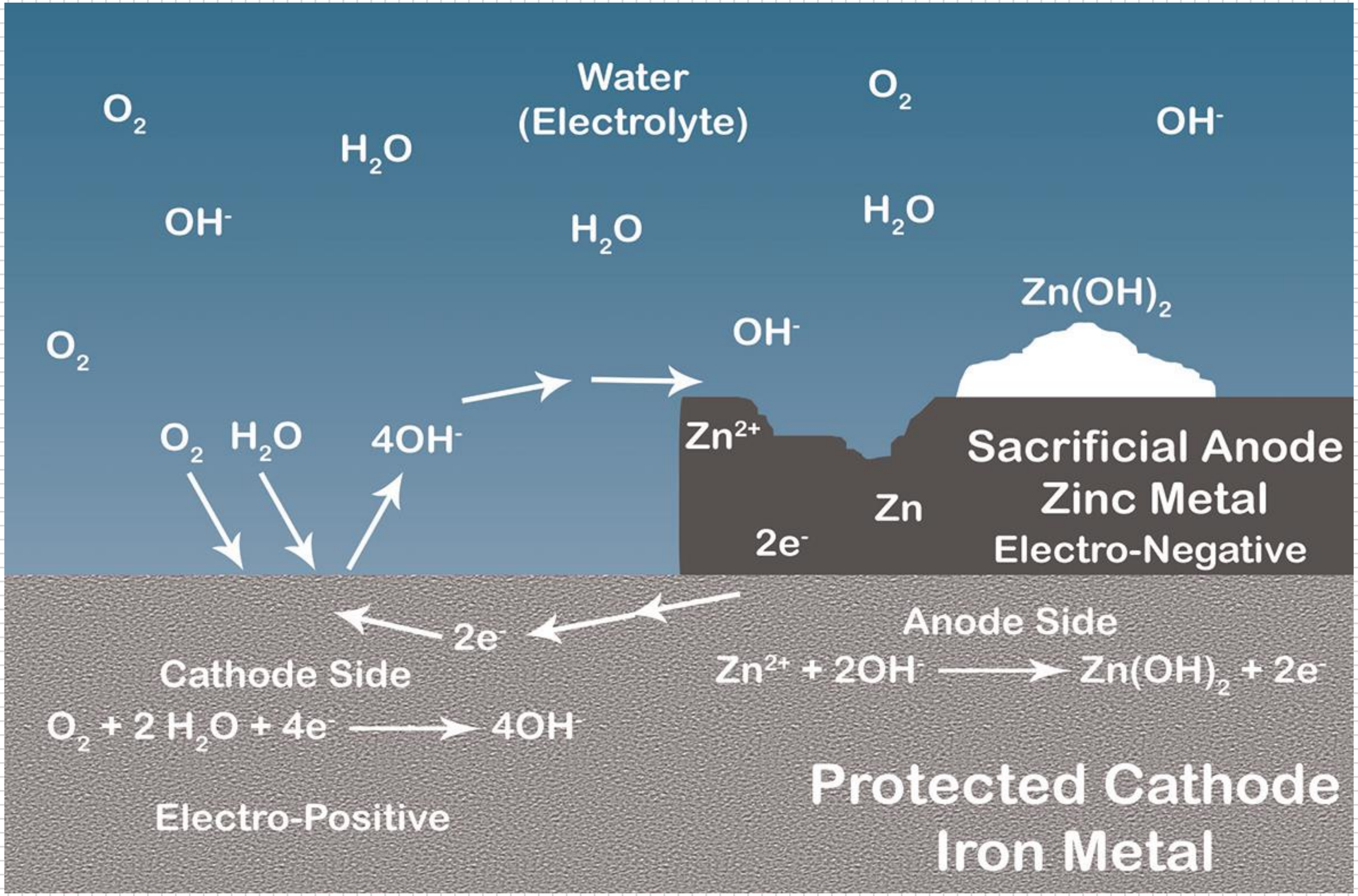
Galvanic (Dissimilar Metal) Corrosion.

The governing principles behind galvanic corrosion can also be applied to prevent galvanic corrosion becoming a problem; utilizing proper design and management techniques – including employing “galvanized iron”!

Sir Humphry Davy and Michael Faraday, in the early part of the nineteenth century, first engineered cathodic protection into their designs. The sacrificial corrosion of one metal such as zinc, magnesium or aluminum is a widespread method of cathodically protecting iron and steel metallic structures.

This protocol is still in widespread use today, especially for protecting underground water and utility piping (especially oil pipelines).

Galvanic (Dissimilar Metal) Corrosion.



Under Deposit Corrosion.

Under deposit corrosion is most commonly linked to biofilms, which frequently constitute iron bacteria and sulphate reducing bacteria. Under deposit corrosion can be found in water distribution lines, and especially in sewer collection mains.

Under deposit corrosion can also be termed Differential Aeration Corrosion. The deposit restricts the free access of air, and oxygen, under the deposit and creates the differential aeration corrosion cells. The difference in oxygen concentration generates an electrochemical potential difference that creates small but stable anodes opposite large cathodic areas, causing the metal in these smaller anodic areas to dissolve more quickly.

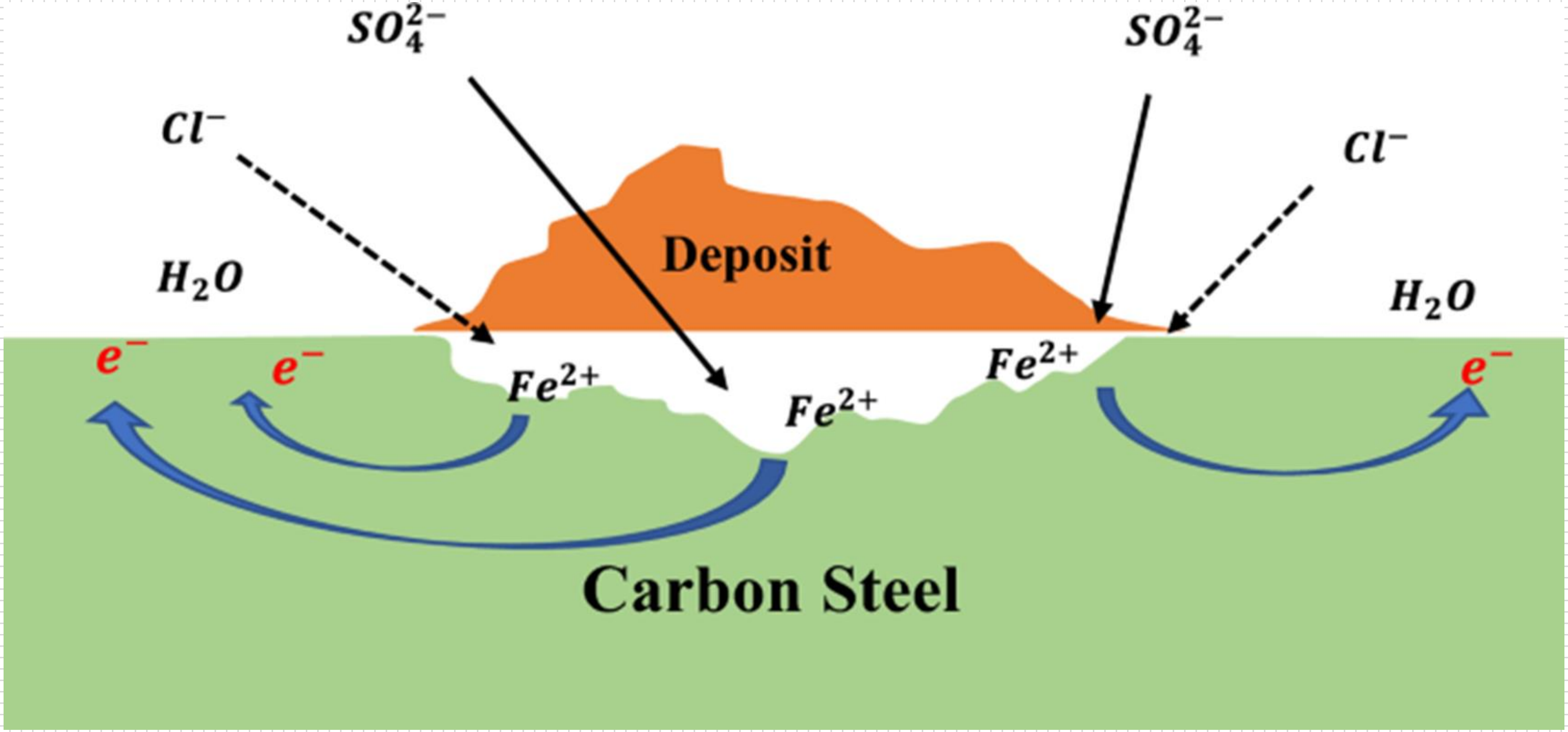
Under Deposit Corrosion.

When there is difference in dissolved oxygen concentrations between two points on the same metal surface, the two points try to reach equilibrium. The only way equilibrium can be reached is to reduce the oxygen concentration where it is highest; which is where there is no deposit. The high oxygen location becomes the cathode where oxygen is consumed and electrons are required for the reduction reaction.

The oxidation sites (anodes – metal loss) are the unprotected bare metal spots under the deposit. These unstable spots supply the electrons to the cathode by speeding up the iron corrosion reaction, $Fe \longrightarrow Fe^{2+} + 2e^{-}$.

The rate of corrosion multiplies depending on the concentration difference of dissolved oxygen between cathode and anode.

Under Deposit Corrosion.



Under Deposit Corrosion.

Many bacterial species contribute to biofilms. The biofilms are mainly formed by water bonded to extracellular polymers. These biofilms can grow rapidly by trapping other material such as iron colloids and other debris. Corrosion develops beneath these biofilms by three mechanisms;

By a differential aeration corrosion cell,

By combining with other corrosive anaerobic bacteria,

The stainless steel potential can increase until it reaches the transpassivity zone.

Under Deposit Corrosion.

Iron and Manganese Bacteria.

This type of bacteria includes *Gallionella*, *Sphaerotilus*, *Crenothrix* and *Leptothrix*. They are frequently found in water system biofilms where there has already been some degree of concentration cell corrosion. These bacteria oxidize endogenous dissolved ferrous ions (Fe^{2+}) to the ferric state (Fe^{3+}).

These bacteria contribute to corrosion by forming biofilms with the previous corrosion product and their extracellular polymers, and accelerate corrosion beneath deposits. Nevertheless, it is important to remember that many other factors, such as chlorination and dissolved oxygen, can cause or promote the oxidation of reduced metal ions.

Under Deposit Corrosion.

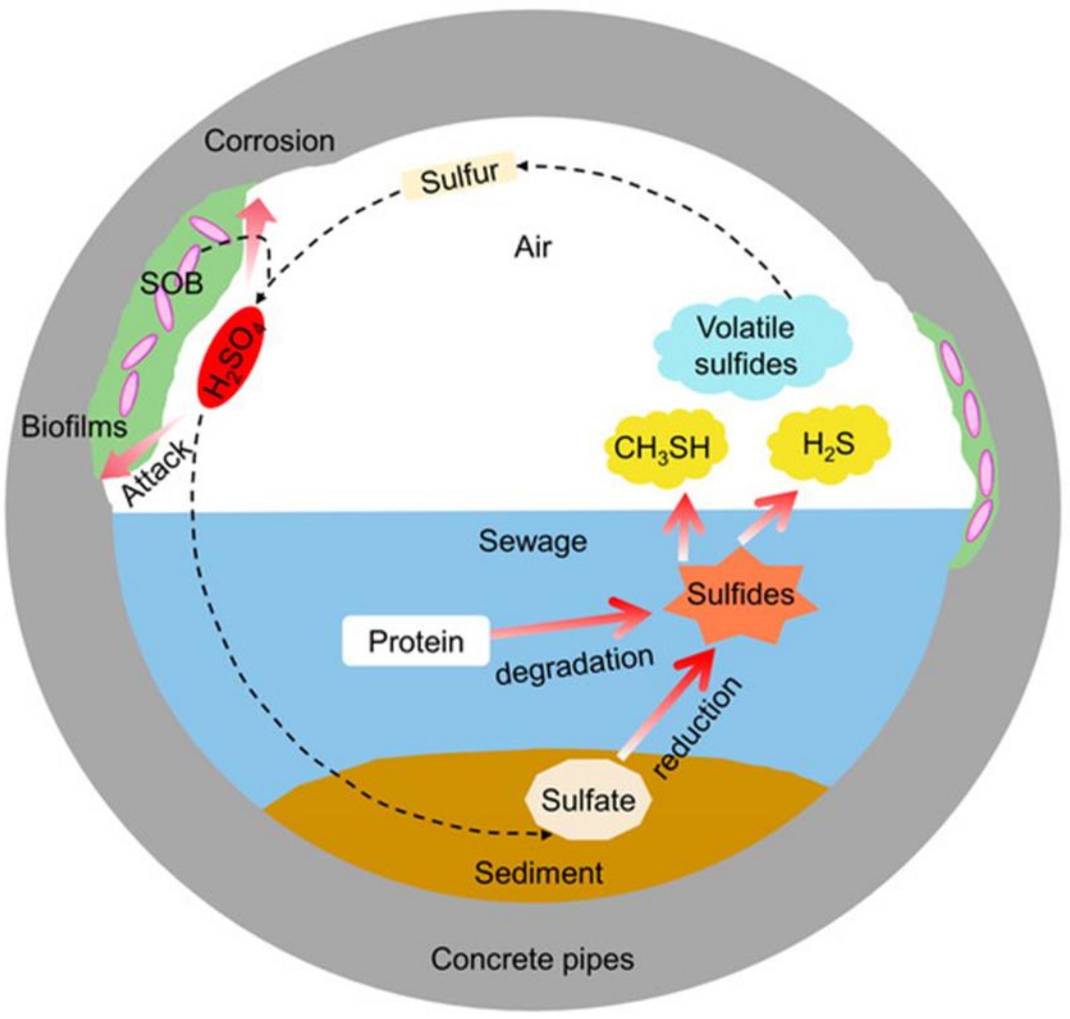
Under Deposit Corrosion.

Sulphur Reducing Bacteria.

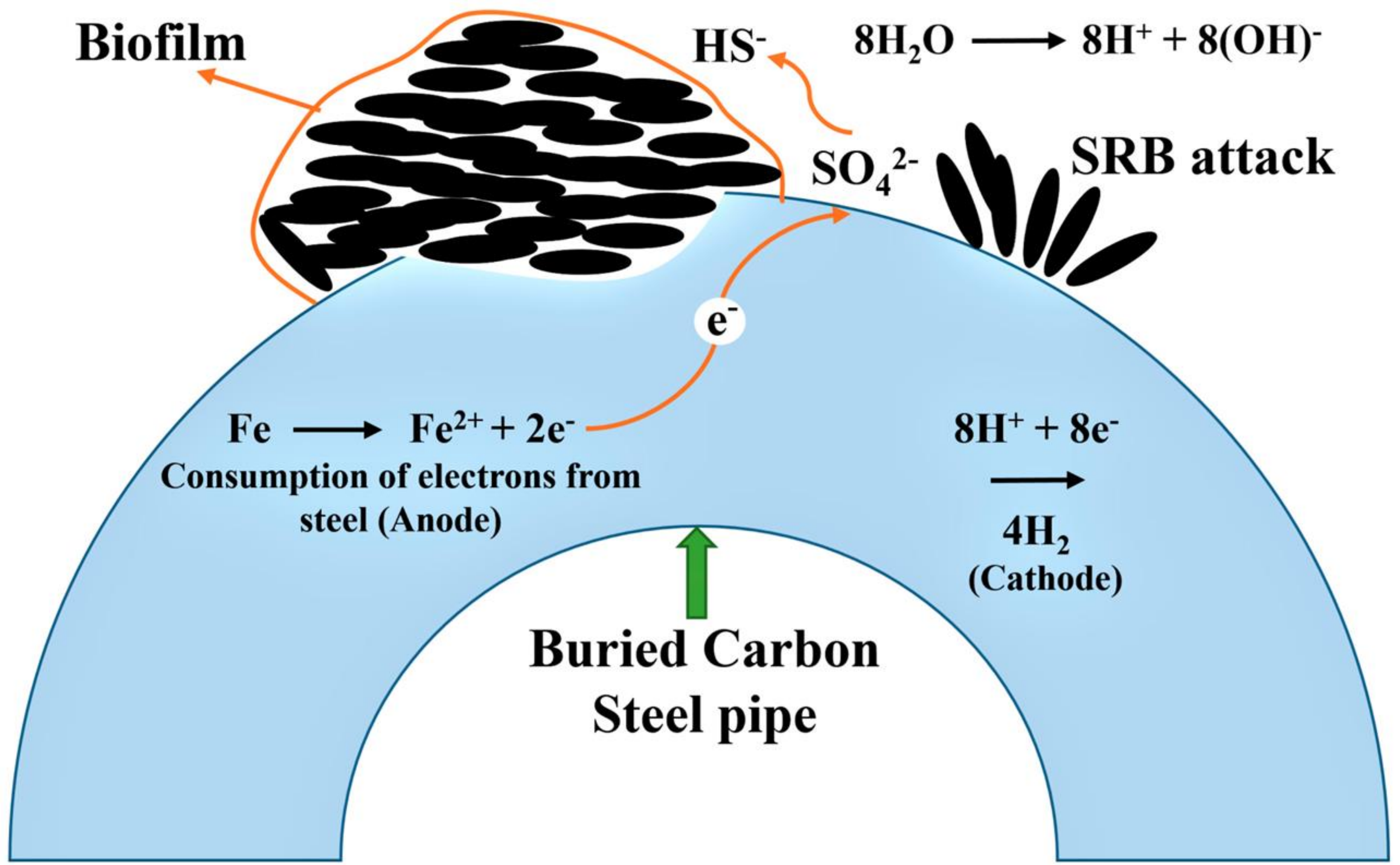
Corrosion by sulphur reducing bacteria constitutes one of the best known forms of microbiological corrosion found in wastewater transport networks. The class of bacteria responsible for this corrosion includes *Desulfovibrio*, *Desulfomonas* and *Desulfomaculum*. The special feature of anaerobic bacteria is that they metabolize sulphates and sulphites to form sulphides.

There is disagreement on the precise mechanism behind the action exercised by this corrosion. However, it is thought that it involves depolarization (acceleration) by eliminating hydrogen from cathodic sites. The presence of sulphide ions at a corrosion site is revealed by their distinctive “rotten eggs” odour (acidification).

Under Deposit Corrosion.



Under Deposit Corrosion.



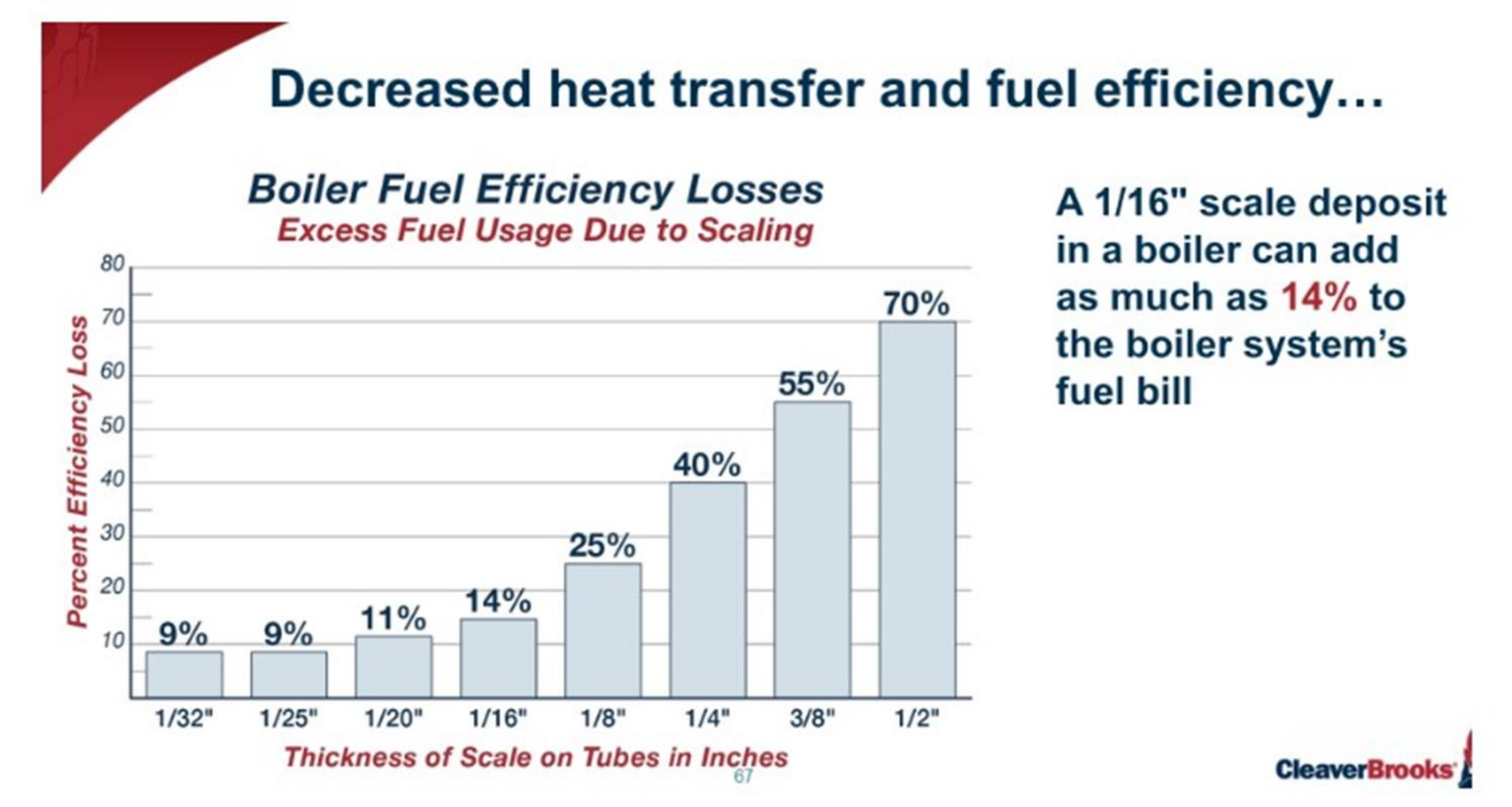
Problems and Concerns due to Corrosion.

Corrosion is a world-wide problem that results in tremendous economic consequences to various industries and all municipalities.

It is estimated the cost of corrosion is equivalent to about 1% – 4% of the gross national product (GNP) of the developed nations. A study released in 2020 reported that it would cost US $400 million to replace 11% of the concrete sewer pipe in Los Angeles, which had been damaged by microbial corrosion.

Scale too, can have a significant economic and environmental impact; the extra fuel that has to be burned due to the thermal insulation properties of calcium carbonate deposits on water heaters and industrial boilers cannot be measured.

Problems and Concerns due to Corrosion.



Problems and Concerns due to Corrosion.

Problems and Concerns due to Corrosion.

Corrosion prevention and management can also have significant public health benefits, with the corollary being, poor corrosion control can have significant public health consequences.

The benefits of a proper corrosion control management programme include;

Protection of public heath,

Improved finished water quality,

Extended life expectancy of water mains and plumbing equipment,

Compliance with an Operating Permit and the GCDWQ requirements.

Problems and Concerns due to Corrosion.

Enhanced Public Health Protection.

Poor corrosion control can result in the leaching of toxic metals into the potable water supply. Iron, aluminum, calcium silicates and asbestos fibres can be leached from the distribution system mains, while lead, copper, cadmium and zinc can be leached from household plumbing.

Iron corrosion product [$Fe(OH)_2$ & $Fe(OH)_3$] can form as tubercules, which can harbour bacteria, including coliforms, and protect them from the effects of chlorination, which can then combine to form a biofilm.

Harmful bacteria (E.coli.) held in the corrosion tubercules can also be released into the water supply as a function of a change in water velocity or pressure.

Problems and Concerns due to Corrosion.

Improved Finished Water Quality.

Poor corrosion control can also cause taste, odour, colour and staining concerns from released chemicals such as copper, iron and zinc.

Iron release from piping can cause “red water”, and an associated objectionable taste, staining and appearance. Dissolved iron can act as a food source for iron bacteria, also causing significant taste, odour and enhanced corrosion issues.

Copper leaching can introduce an unpleasant metallic taste to the water and cause blue-green staining to the plumbing fixtures.

Secondary disinfection demand can increase due to iron bacteria presence.

Problems and Concerns due to Corrosion.

Extended Life Expectancy for Distribution Piping and Household Plumbing.

Corrosion can result in a reduction in life span for unprotected metal and A/C distribution mains, valves, household fixtures and water heaters etc.

Corrosion tubercules reduce the effective diameter of the piping, reducing capacity and increasing the roughness of the insides of the pipe, elevating resistance to water flow.

Both factors result in a reduction of system efficiency and an increase in pumping costs due to this hydraulic friction within the water main piping.

Corrosion causes leaks in the distribution system, which in turn lead to losses in water flow rates and delivered pressure (and non-revenue water losses).

Problems and Concerns due to Corrosion.

Compliance with an Operating Permit and the GCDWQ requirements.

As discussed in the previous slides, corrosion can cause an increase in metal ion concentrations which could readily force the purveyor to be out of compliance with their operating permit and the GCDWQ mandates.

Both acidifying bacteria, [*Thiobacillus*, *Thiooxidans and Clostridium* genuses are linked to microbiological corrosion in steel] and nitrifying bacteria, often found in wastewater, and shielded in corrosion product and biofilm, can lower the pH of the finished water. This can be an issue in those facilities with low natural alkalinity and marginal pH.

Factors Affecting the Rate of Corrosion.

Corrosion factors have been classified into four main categories;

Materials of construction factors,

Operational factors,

Water quality factors,

Environmental factors.

Factors Affecting the Rate of Corrosion.

Materials of Construction Factors.

Metal alloy type (metallurgy), surface conditions and roughness,

Position of the metal(s) on the Galvanic Series,

Manufacturing defects – cracks, cervices, welds, stress points etc.,

Age of pipe – greater corrosion during first year and towards extended age. Scale accumulations over time can mitigate the effects of age,

Stagnant Water at dead ends.

Factors Affecting the Rate of Corrosion.

Operational Factors.

- Water flow,
- Water pressure,
- Water hammer,
- Type of water,
  - Treated potable water – stable vs. unstable,
  - Abrasive, raw industrial wastewater and municipal sewage,

Factors Affecting the Rate of Corrosion.

Water Quality Factors - Chemical.

Dissolved oxygen concentration (mgL^{-1}),

Total dissolved solids (TDS)

Conductivity, M^{n+} (μScm^{-1}),

Calcium and total hardness,

Alkalinity (HCO_3^- & CO_3^{2-}) and pH,

Chloride (Cl^-), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}) & silicate.

Factors Affecting the Rate of Corrosion.

Water Quality Factors – Biological.

Certain bacteria can generate CO_2 and H_2S, which will accelerate corrosion.

Iron bacteria can form a biofilm slime, underneath which CO_2 generation will lower pH and increase the rate of corrosion. Slime can also release iron particulate, resulting in taste, odour and red water concerns.

Sulphur reducing bacteria, under anaerobic conditions reduce SO_4^{2-} to form iron sulphide (FeS), CO_2, and hydrogen sulphide (H_2S), which will also lower the pH of the water. “Rotten egg” smell and black water often result.

Factors Affecting the Rate of Corrosion.

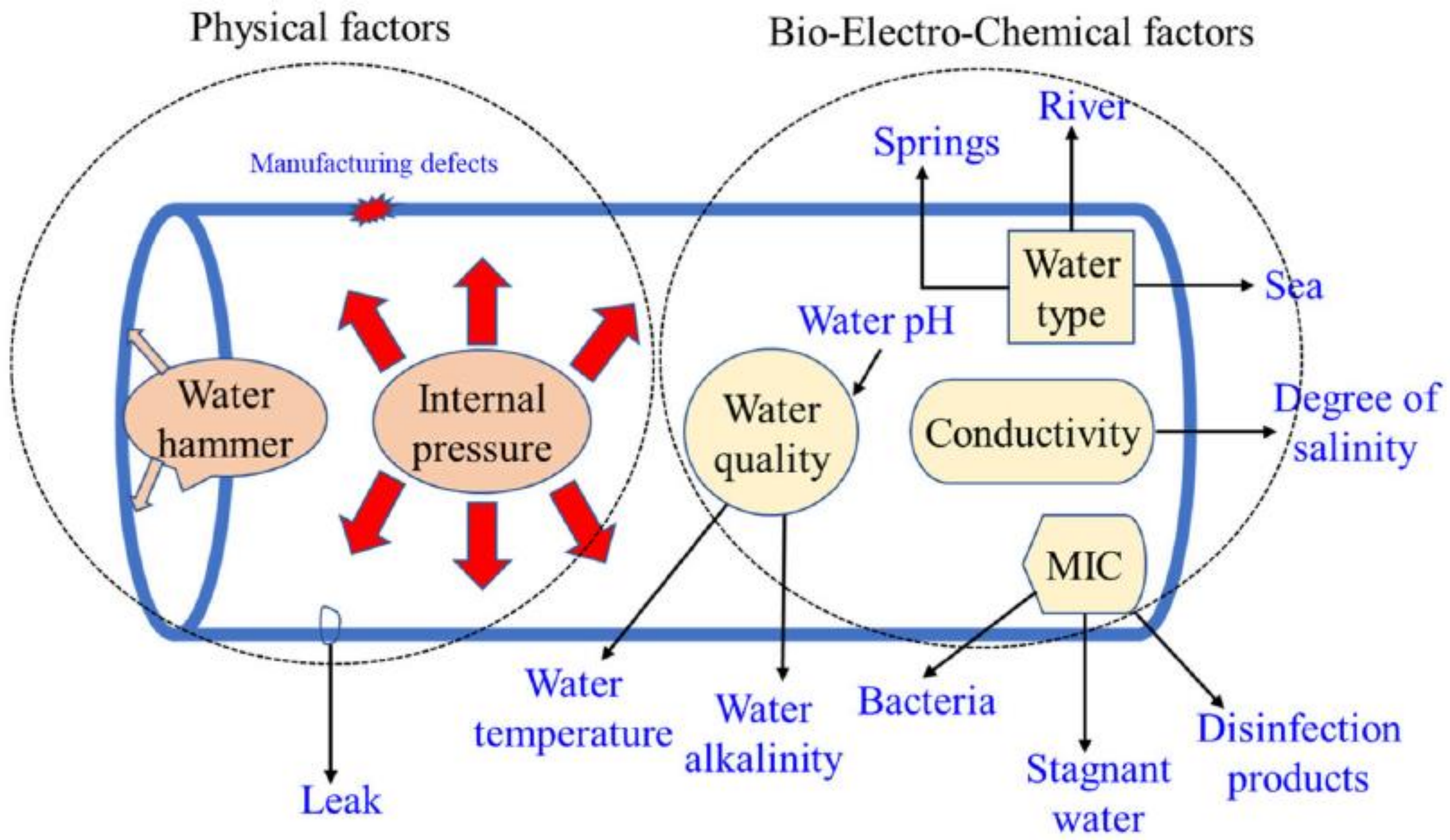


Fig. 4 Schematic representation of operational factors influencing water pipeline corrosion. The operational factors that induce corrosion in water pipes are split into two categories: physical factors and bio-electro-chemical factors.

Factors Affecting the Rate of Corrosion.

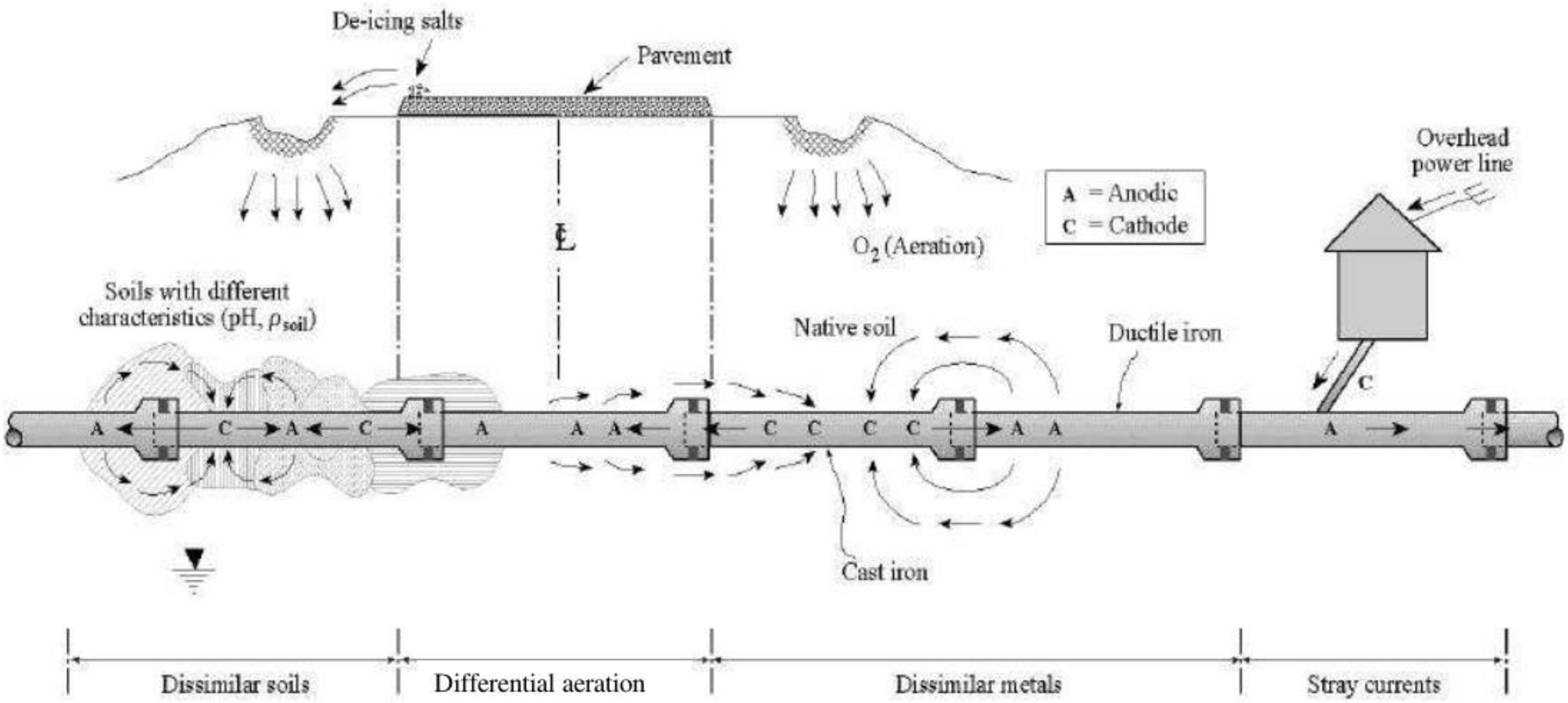
Factors Affecting the Rate of Corrosion.

Environmental Factors.

Most often environmental factors are associated with external corrosion to the distribution or collection mains.

- Soil composition and characteristics,
- Stray electrical currents – power lines and railway lines etc.,
- Presence of corrosive gases,
- Temperature.

Factors Affecting the Rate of Corrosion.



Factors Affecting the Rate of Corrosion.

Soil composition and characteristics.

Moisture content,

pH,

Acidity,

Differential aeration potential,

Electrical resistivity,

Chemical components – Cl^{-}, SO_4^{2-},

Microbial activity.

Factors Affecting the Rate of Corrosion.

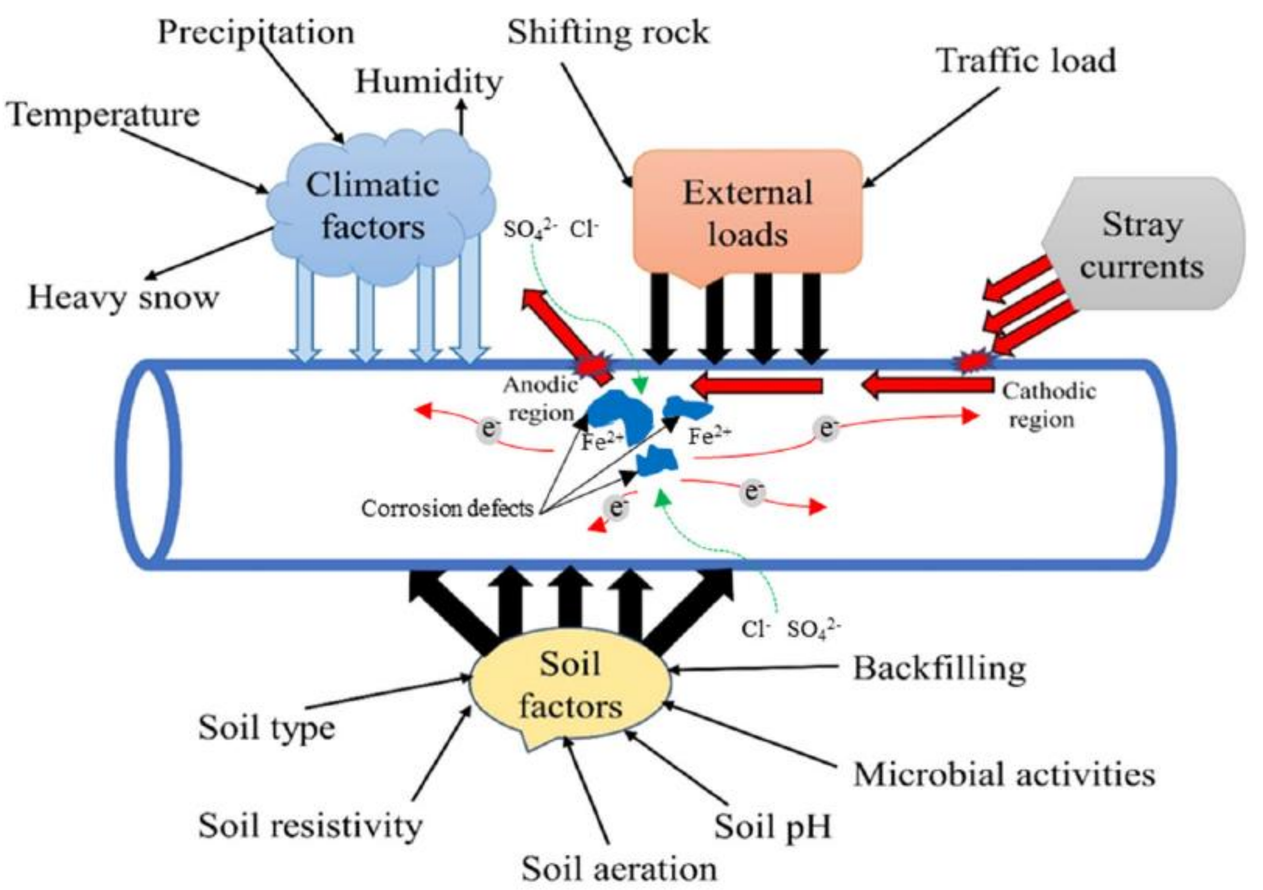


Fig. 2 Schematic representation of environmental factors influencing water pipeline corrosion. The factors impacting the corrosion level in water pipelines, including climatic factors, external loads, stray current and soil characteristics.

Factors Affecting the Rate of Corrosion.

Factors Affecting the Rate of Corrosion.

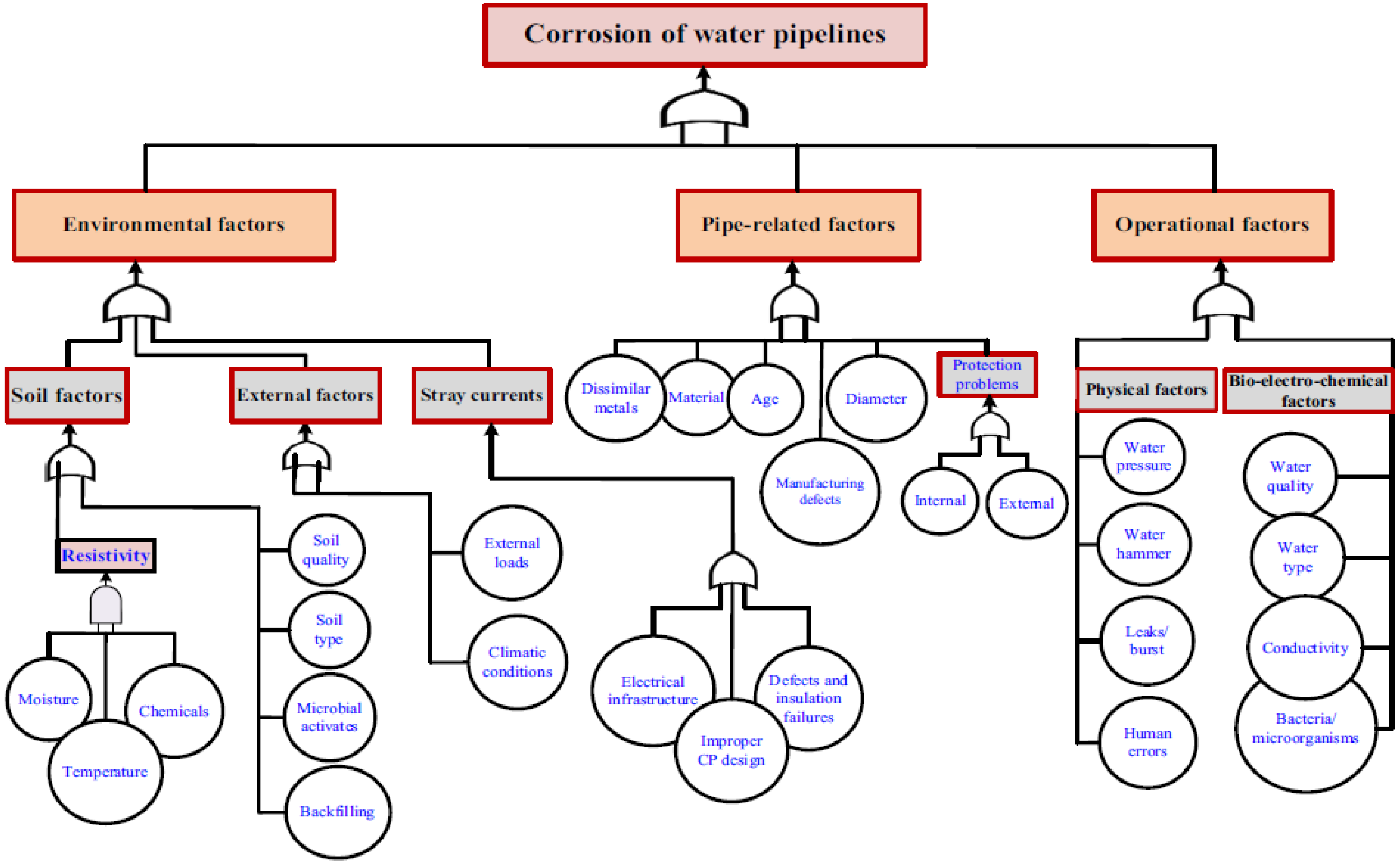


Fig. 5 Fault tree diagram of the corrosion causes for water pipelines. A comprehensive summary of the corrosion causes in water pipes based on bibliometric and systematic analysis.

Factors Affecting the Rate of Corrosion.

As a general statement, the following conditions will promote internal corrosion within a water distribution or wastewater collection system.

High flow velocities and pressures,

High dissolved oxygen,

Low pH and alkalinity,

Low calcium hardness,

High total dissolved solids,

High temperature,

Presence of bacteria.

Corrosion Parameters an operator can control.

Typically the Federal Government is responsible for the science and research, including the development of guidelines for drinking water quality and associated corrosion protocols.

The Provincial and territorial governments are generally in charge of regulating drinking water systems, including setting local quality standards.

Municipalities are usually responsible for the actual treatment and distribution of drinking water to the public. Operators work for municipalities and are required to implement a multi-barrier approach that includes monitoring of the water quality in the distribution system, at the consumer's tap and, when necessary, implementing an effective corrosion control program.

Corrosion Parameters an operator can control.

As a very simplistic comment, the operator can only control four factors that contribute to corrosion potential in the distribution system;

Finished water pH – uniform metal loss,

Finished water alkalinity,

Finished water bacteriological content – localized metal loss,

High water flow velocity & pressure – physical erosion.

Corrosion Mitigation & Treatment Strategies.

A municipality has several option available to either eliminate corrosion, or else mitigate the effects of corrosion.

Design the system to lower the potential for corrosion,

Adjust pH and alkalinity to manage the water supply,

Create a $CaCO_3$ passive layer to protect the lines from corrosive water,

Use corrosion inhibitors to create a passive layer barrier,

Use cathodic protection to protect against large scale external corrosion,

Introduce a sacrificial anode to protect against internal corrosion.

Corrosion Mitigation & Treatment Strategies.

Active corrosion protection techniques focus on halting or neutralizing the corrosion causing electrochemical reactions. Active corrosion protection techniques inhibit corrosion to the material being protected. They can be considered to be the application of a defined protocol that actively disrupts the normal formation of anodes on the materials.

Passive corrosion protection techniques focus on the isolation of the material from corrosion causing elements, to mitigate the effects of corrosion. With passive protection, a protective coating may act as a barrier that prevents air and moisture from coming into contact with the underlying iron substrate. When these two elements are removed from the electrochemical cell, corrosion cannot occur on the surface of the material/metal.

Corrosion Mitigation & Treatment Strategies.

Corrosion Mitigation & Treatment Strategies.

Design the system to lower the potential for corrosion.

Correct materials/metallurgy; alloys, reinforced concrete, plastics etc.,

Use of galvanizing, non-metallic coatings and Pb free fittings/solder,

Only use NSF/ANSI Standard 61 materials,

Reduce the number of 90^0 right angles, use 30^0 and 45^0 connections,

Install insulating pipe supports,

Design out all environmental, soil, stray electrical currents factors etc.,

Proper and enhanced disinfection protocols.

Corrosion Mitigation & Treatment Strategies.

Design the system to lower the potential for corrosion.

Corrosion resistant materials are used where protective coatings and passive layers provide insufficient protection or are not economically feasible. These materials include stainless steels, titanium, plastics, polypropylene, polytetrafluoroethylene (PFAS – Teflon!), fiberglass, and special alloys.

Stainless steel is a corrosion resistant ferrous alloy that fights rust with the addition of Cr (17 - 20%), Ni, (8 – 13%) Mo, and Ti. Different chromium percentages are added to make iron harder, and resistant to corrosion (304 SS); 2% Mo for use in saline environments (316 SS).

Corrosion Mitigation & Treatment Strategies.

Corrosion Mitigation & Treatment Strategies.

Adjust pH and alkalinity to manage the water supply.

Adjust water pH and alkalinity to ensure water is less corrosive, but not scaling. High alkalinity water can also be corrosive to some metals,

Adjust alkalinity to ensure LSI (or other indices) stability,

Adjust pH to be within the 7.0 – 10.5 range (GCDWQ – 2015),

If lead and copper are present, adjust pH to within 7.5 – 9.5 range,

For iron stability, total bicarbonate alkalinity should be > 60 mgL^{-1},

For Cu and Pb stability, bicarbonate alkalinity should be 30 – 70 mgL^{-1}.

Corrosion Mitigation & Treatment Strategies.

Treatment Strategy	Objective	Effectiveness
Lime additions only	Increases pH and hardness	Used in low hardness but moderate alkalinity.
Lime additions enhanced with sodium carbonate	Increases pH, hardness and alkalinity	Best overall option, good for galvanized iron and AC pipes
Sodium carbonate additions	Increases pH and alkalinity	Low alkalinity water
Sodium hydroxide additions	Increases pH	Used for pH adjustment in moderate hardness waters
Sodium hydroxide additions, enhances with sodium carbonate (soda ash)	Increases pH and allows for alkalinity adjustment	Excellent option for Pb in soft waters at pH 8.3 or above
Carbon dioxide or sulphuric acid additions	Decreases pH and alkalinity	Used after lime softening

Corrosion Mitigation & Treatment Strategies.

Create a $CaCO_3$ passive layer to protect the lines from corrosive water.

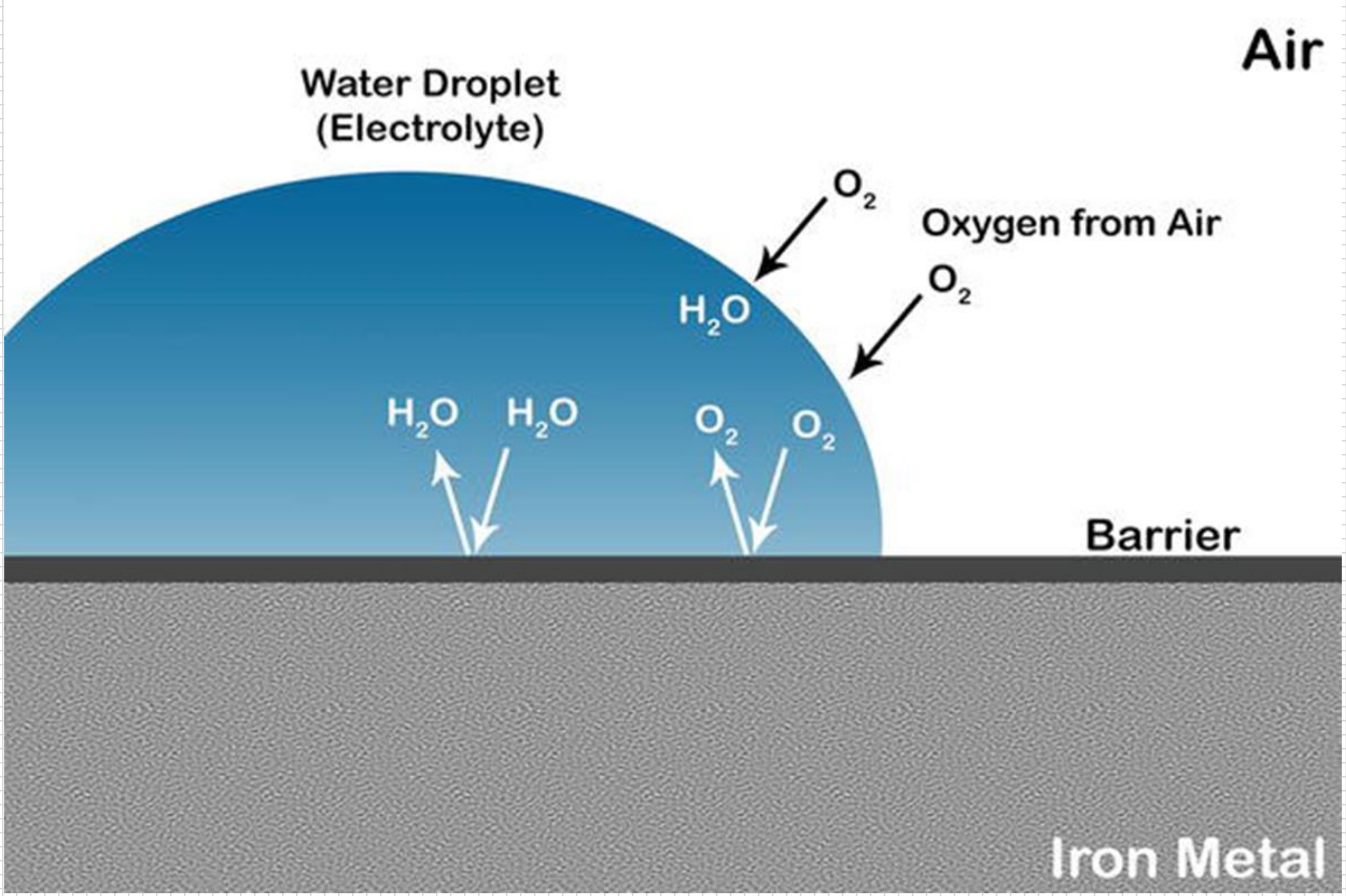
Associated with controlling pH and alkalinity.

Some protecting coatings can erode, any breaks can cause severe corrosion in small locations – worst outcome.

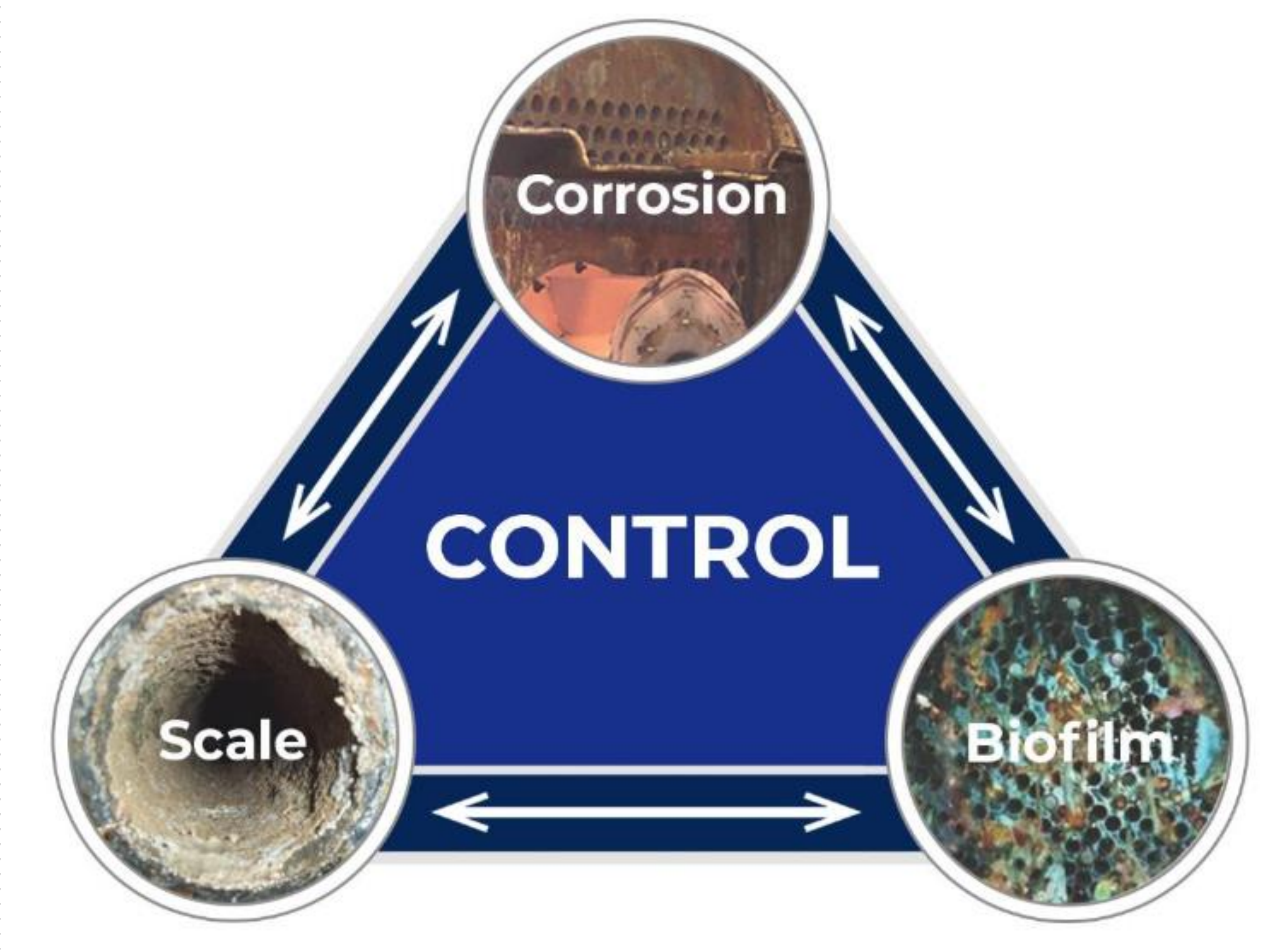
Maintaining the water chemistry at a slightly scaling stability index, so at a pH just above the saturation point for $CaCO_3$ will allow for a protective layer of calcium carbonate to form on the internal surfaces of the distribution system pipe, protecting against a corrosion cell forming.

Closely controlled lime additions are the best option for this strategy.

Corrosion Mitigation & Treatment Strategies.



Corrosion Mitigation & Treatment Strategies.



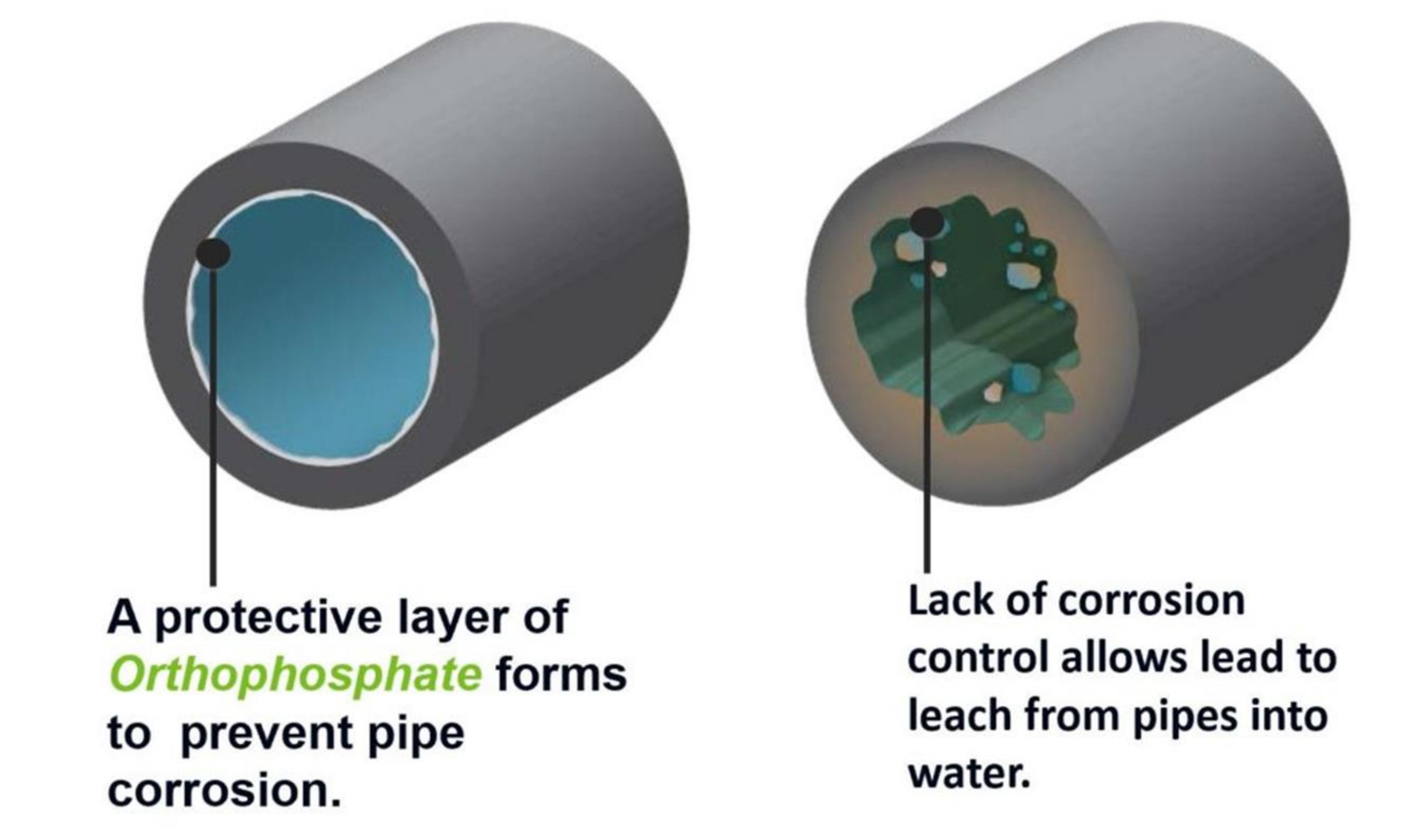
Corrosion Mitigation & Treatment Strategies.

Use corrosion inhibitors to create a passive layer barrier.

Similar to developing a $CaCO_3$ passive layer, chemical corrosion inhibitors create a passive layer when the raw water chemistry has very low pH, alkalinity and hardness (local snow melt water sources) such that adjustment would be expensive and often impractical.

Some silicates and the chloride, sulphate and orthophosphate salts of zinc have been found to provide substantial protection towards A/C pipe when proper concentrations, and recommended pH ranges, are maintained throughout the distribution system. Zinc coats the pipe and protects it against fibre release and water attack.

Corrosion Mitigation & Treatment Strategies.



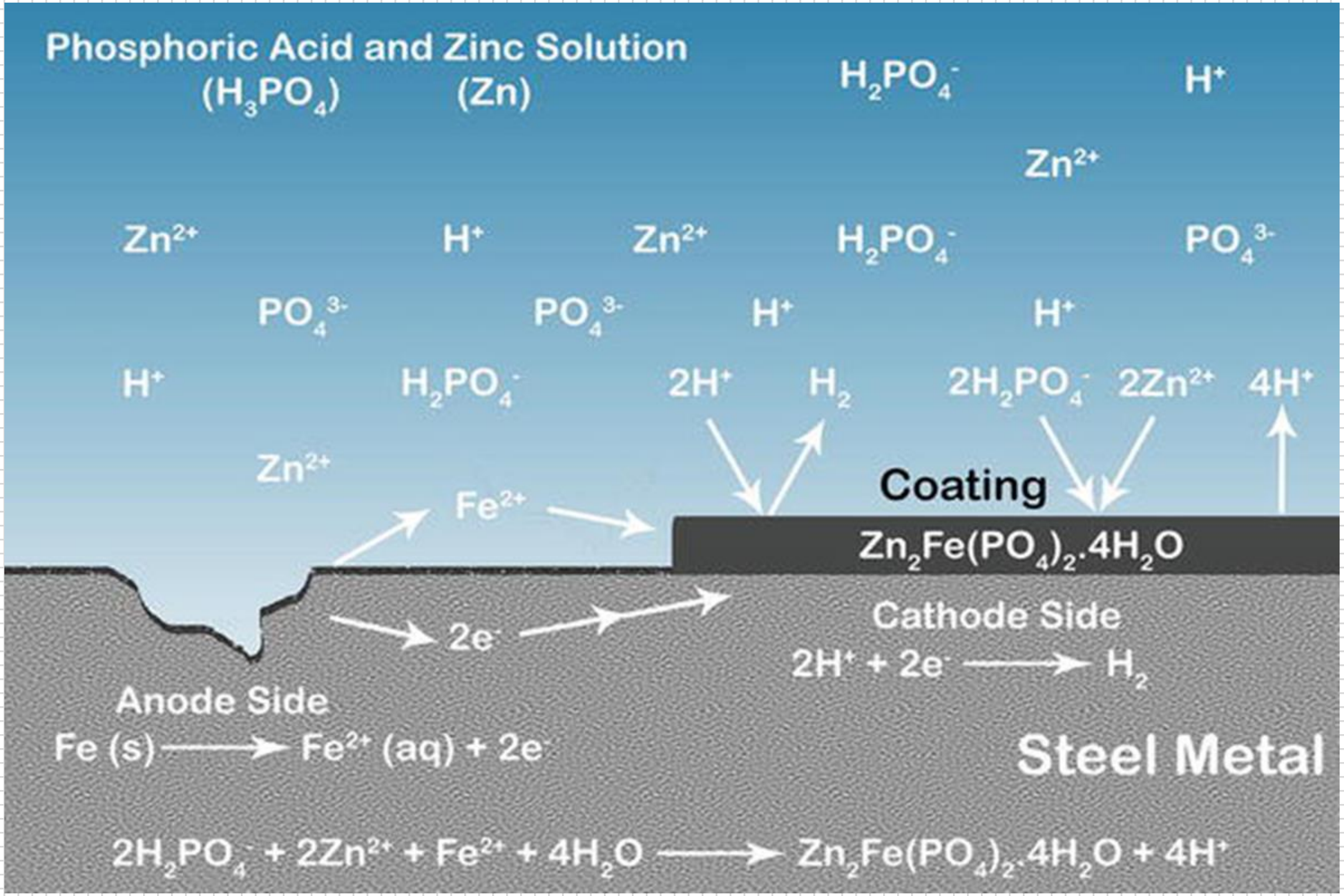
Corrosion Mitigation & Treatment Strategies.

Use corrosion inhibitors to create a passive layer barrier.

The addition of inorganic zinc corrosion inhibitors, such as zinc orthophosphate ($Zn_3(PO_4)_2$) to steel provides an active corrosive protection strategy towards the steel substrate. Hydrolyses in water generates zinc (Zn^{2+}) and phosphate (PO_4^{3-}) ions. These ions then act as cathodic and anodic inhibitors, respectively.

Polyphosphates can also sequester both dissolved and colloidal iron, preventing precipitation causing both red water and iron based biofilm. This effect does not prevent corrosion, but does offer relief against some of the negative consequences of corrosion.

Corrosion Mitigation & Treatment Strategies.



Corrosion Mitigation & Treatment Strategies.

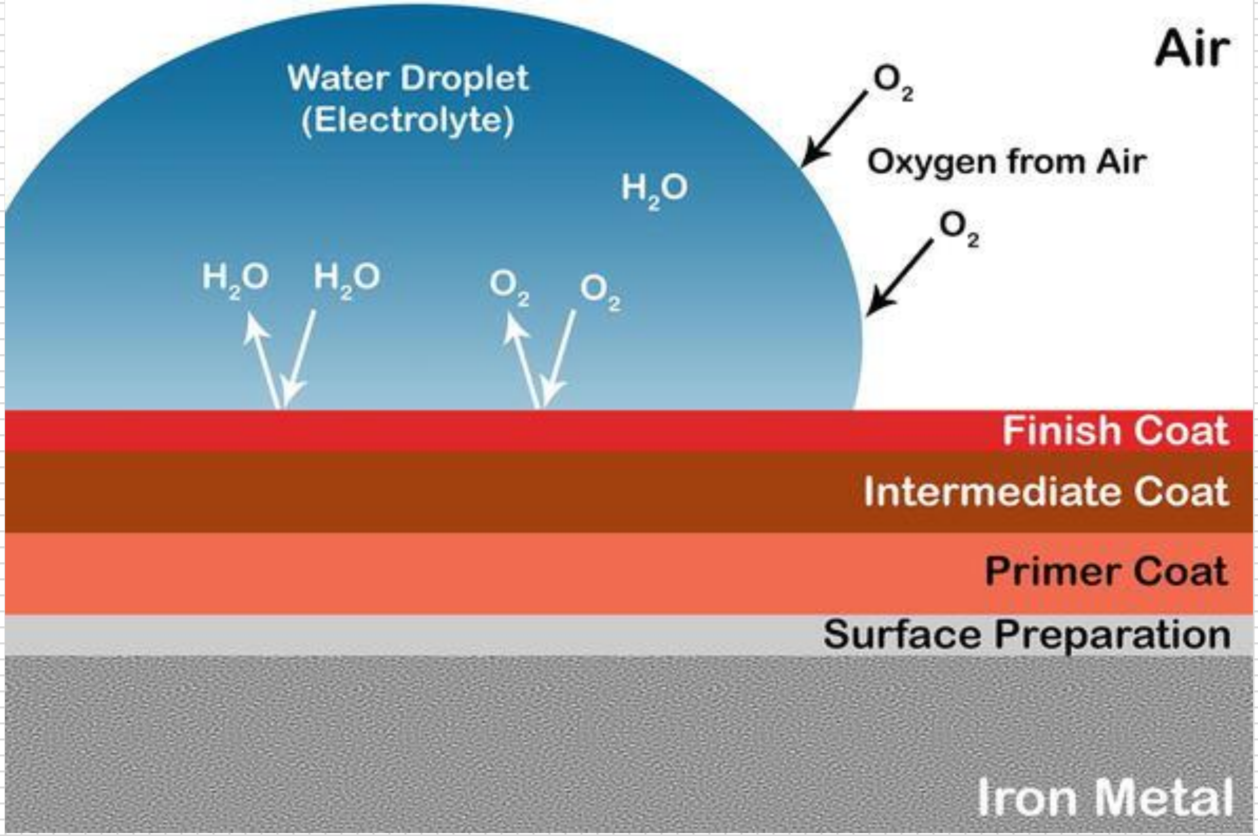
Use corrosion inhibitors to create a passive layer barrier.

As a generality, zinc orthophosphates can be used as a corrosion resistant coating on iron and steel, and are the better selection to prevent copper and lead distribution system corrosion, while polyphosphates are more effective in preventing distribution system iron corrosion.

It must be noted that the effectiveness of all corrosion inhibitors, be they orthophosphates, polyphosphates, or silicates is largely dependent on maintaining an effective chemical residual of the inhibitor throughout the distribution system as well as maintaining the recommended pH and alkalinity of the water.

Corrosion Mitigation & Treatment Strategies.

Use paint as the simplest option to create a protective corrosion barrier!



Corrosion Mitigation & Treatment Strategies.

Use cathodic protection to protect against large scale external corrosion.

Cathodic protection involves a direct or indirect electrical connection between a more reactive material and the material to be protected. Cathodic protection is a simple method of diverting the corrosion towards the sacrificial material and away from the preferred metal, which remains protected.

Cathodic protection is also a means of corrosion control which diverts the normal flow of current that is corroding the inside walls of the storage tank to a sacrificial piece of metal (anode) which is attached to the tank or the distribution line

Corrosion Mitigation & Treatment Strategies.

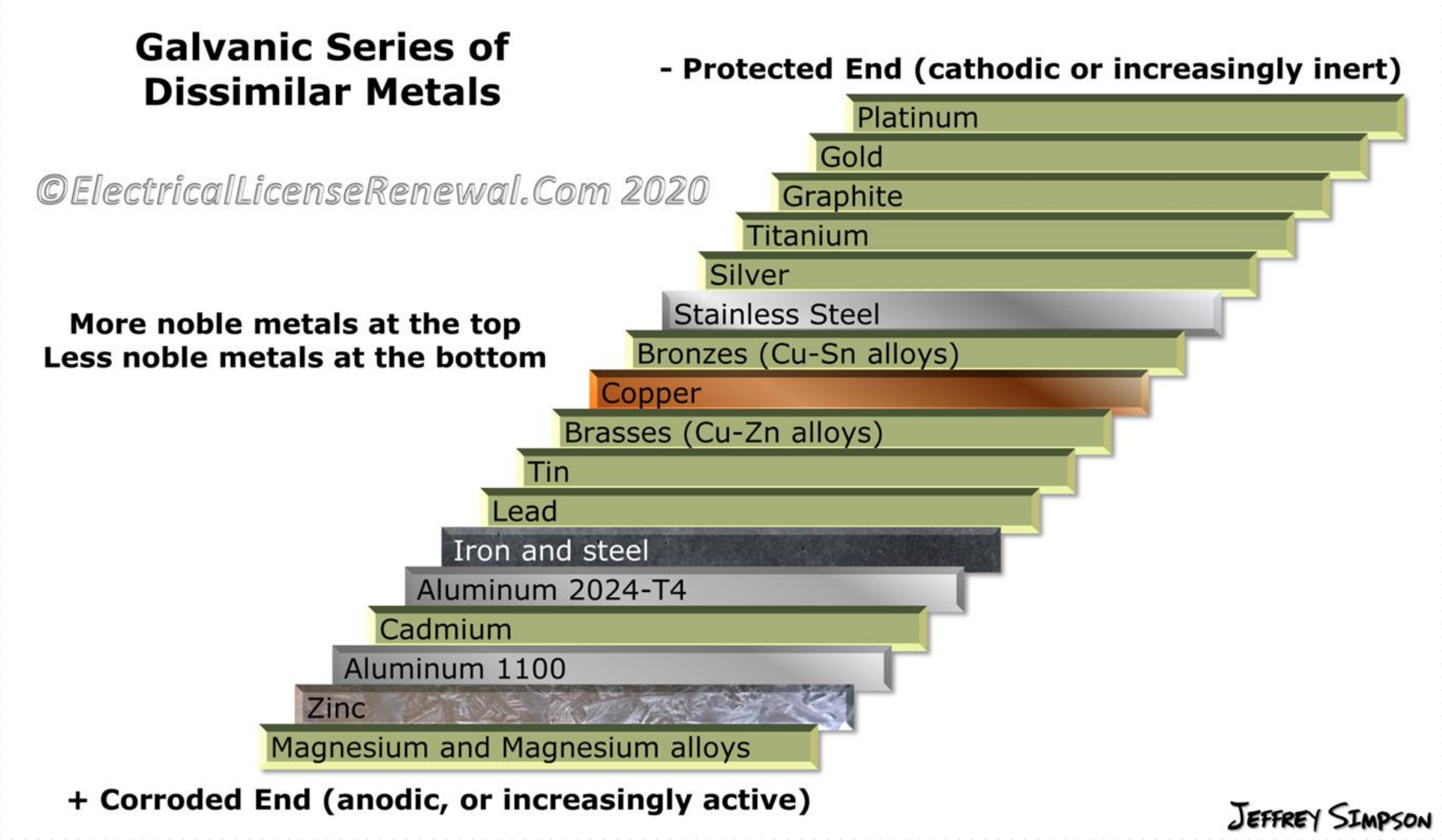
Use cathodic protection to protect against large scale external corrosion.

Cathodic protection involves using a sacrificial galvanic anode consisting of a less noble, so more reactive, metal further down the electromotive series table than iron, brass, copper, bronze and steel.

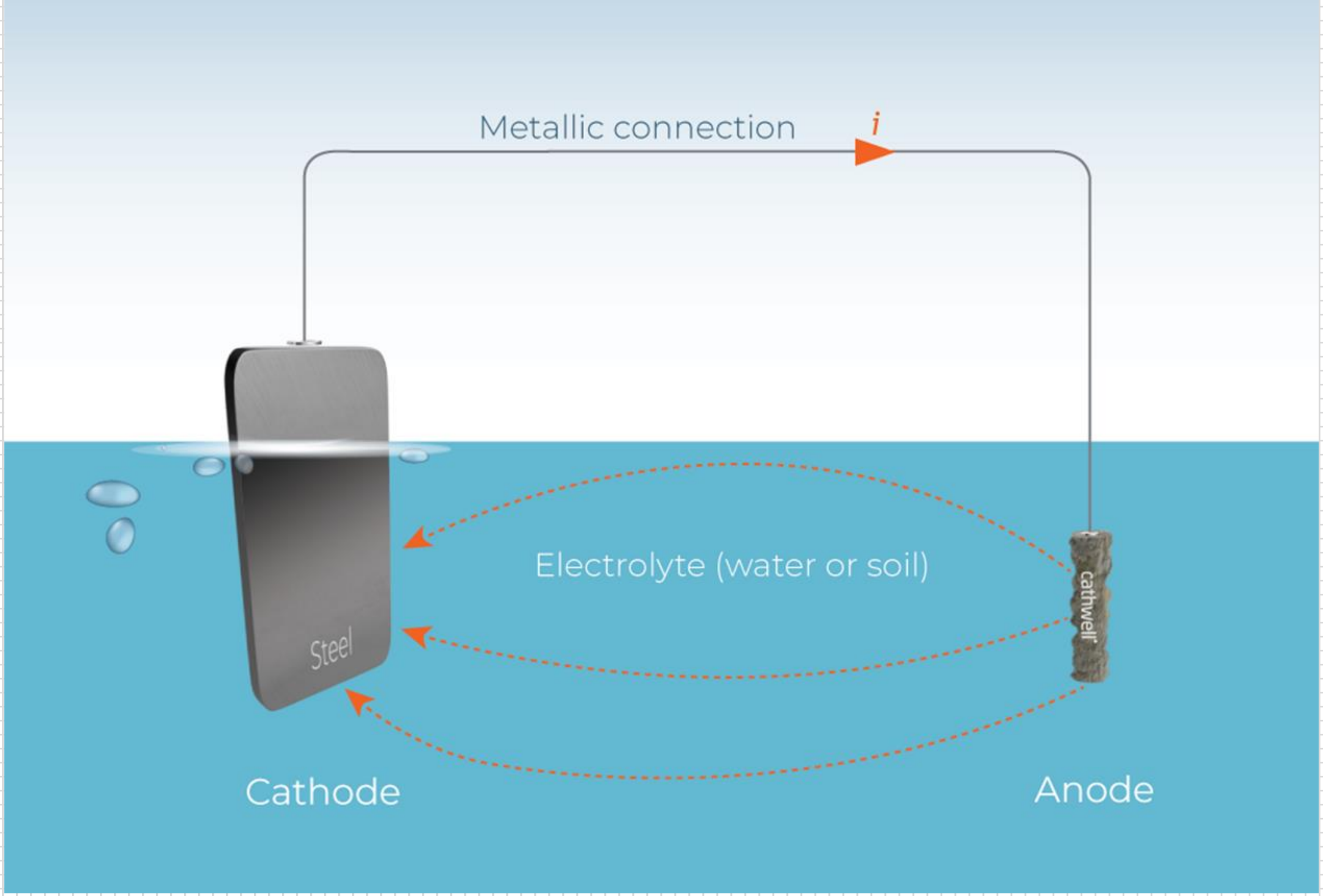
Or by an anode energized by a power source utilizing a direct current.

Cathodic protection for larger structures, and the sacrificial anode strategy for smaller bodies, are essentially the same process, with different delivery techniques. Both strategies are a galvanic corrosion phenomenon, relying on maintaining a high rate of corrosion at the anode, and reducing the reaction at the cathode to a negligible rate.

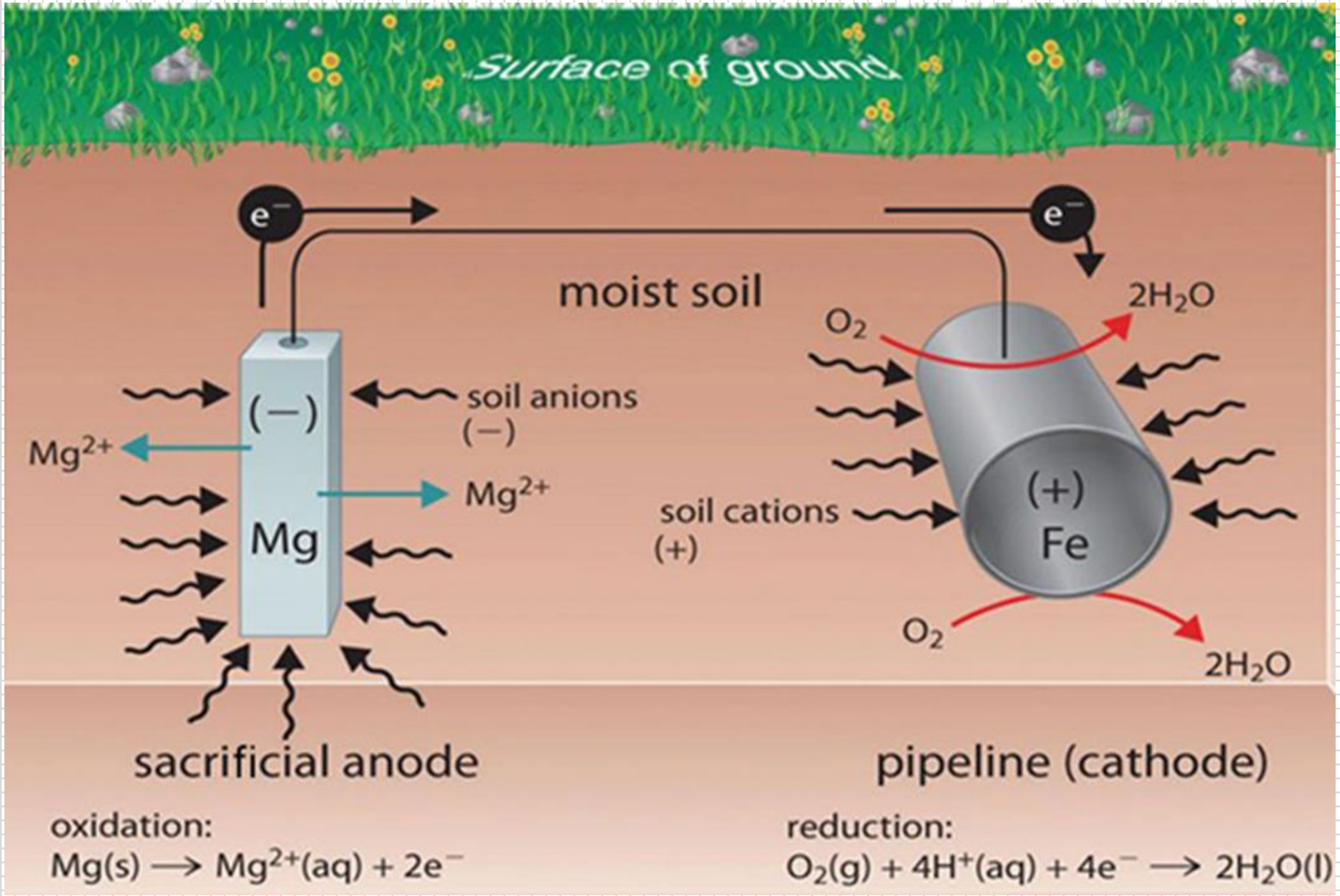
Corrosion Mitigation & Treatment Strategies.



Corrosion Mitigation & Treatment Strategies.



Corrosion Mitigation & Treatment Strategies.



Corrosion Mitigation & Treatment Strategies.

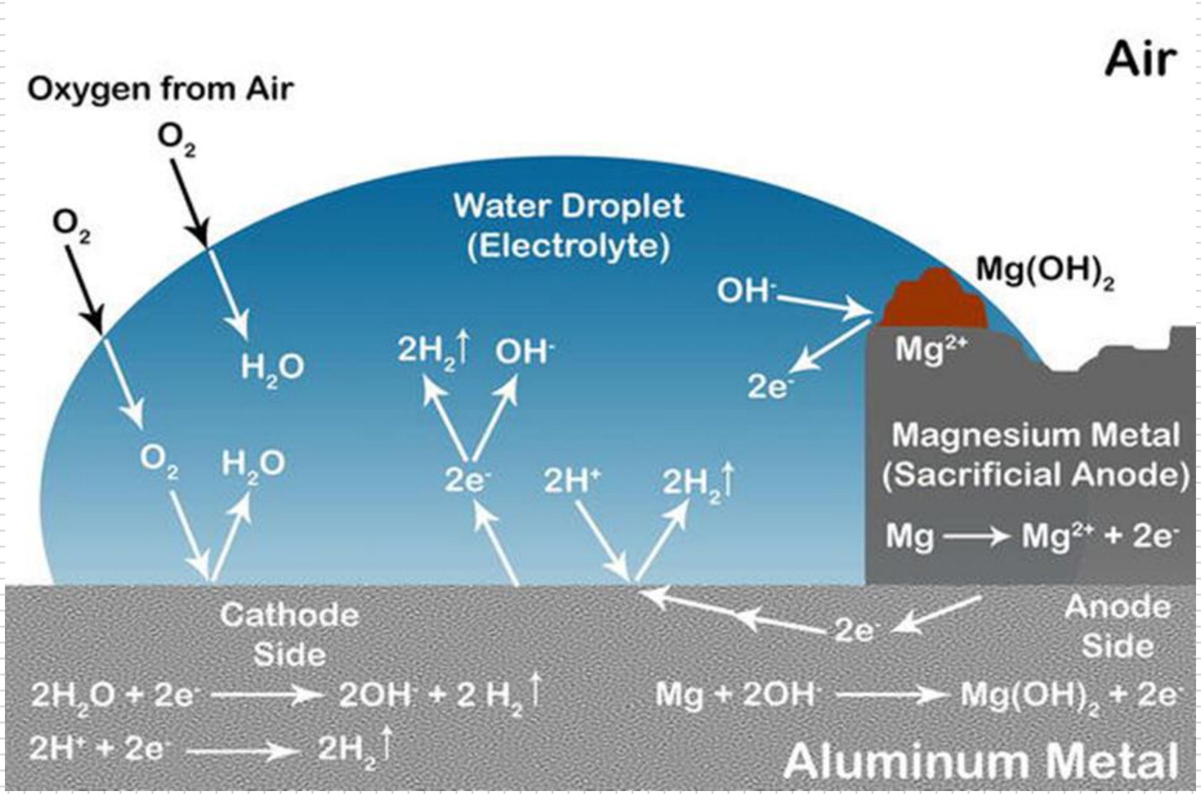
Introduce a sacrificial anode to protect against internal corrosion.

Sacrificial anodes are typically manufactured from the high reactivity metals, such as magnesium, aluminum, or zinc. These metals will readily give up their electrons, and suffer metal loss accordingly (corrode) as the anode in a galvanic cell configuration.

Zinc or magnesium anodes are commonly used for small structures in the water treatment industry as they will oxidize before the iron metal they are protecting, while larger structures can use cathodic protection as described previously.

Corrosion Mitigation & Treatment Strategies.

As shown previously, zinc is frequently used to protect steel, while magnesium is often employed as a sacrificial anode to protect aluminum.



Corrosion Mitigation & Treatment Strategies.

Introduce a sacrificial anode to protect against internal corrosion.

Sacrificial anodic protection does not require the addition of chemicals,

Cathodic protection systems can be manual or automatic,

Automatically controlled systems are preferred since they will adjust to changing conductivity of the soil or water,

Cathodic protection can be very costly.

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