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# Corrosion Protection on Submarines

**Pablo Garcia Gonzalez**

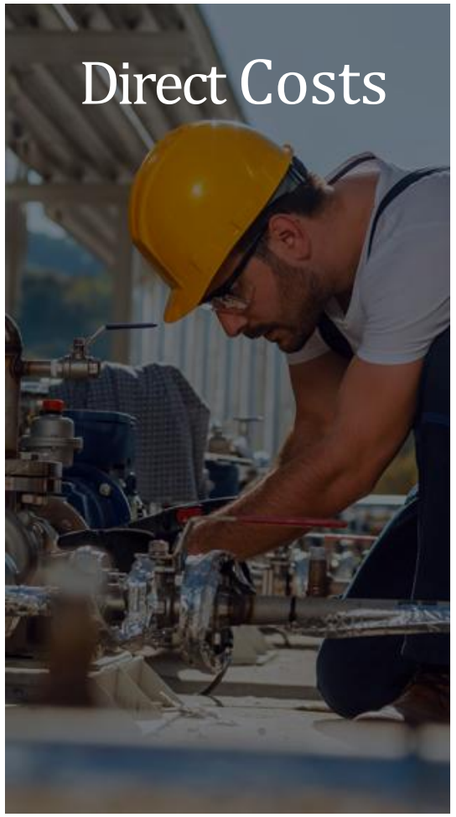
# Need to protect submarines from corrosion.

Corrosion has a huge global economic impact and poses a complex problem for submarines, directly impacting the safety of these vessels. This risk is exacerbated by the extreme marine environment in which they operate, and can compromise their structural integrity and the safety of their crew.

# Costs associated with corrosion

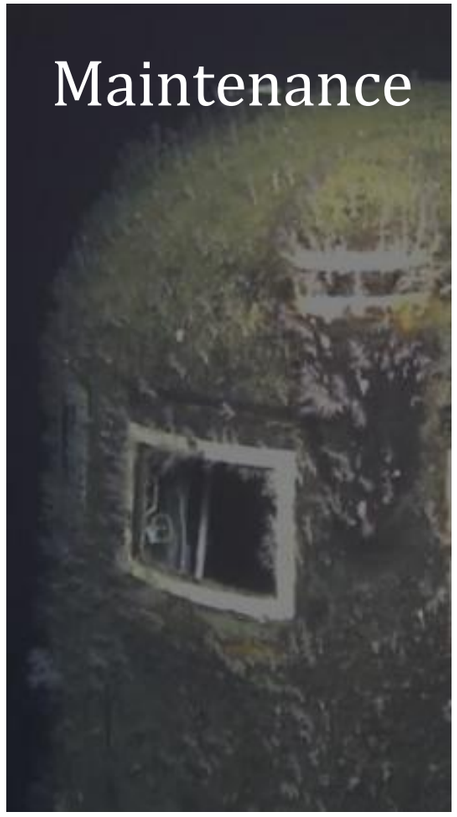
Financial and operational impact of corrosion


Corrosion generates annual costs of billions of dollars globally.




Includes direct expenses for repairs both equipment and vessels.


Indirect costs are a result of the inactivity of submarines.




Lack of proper maintenance increases costs exponentially.


Affects strategic operational response capability

# IMPORTANCE OF CORROSION RESISTANCE

## DEGRADATION

Corrosion is a chemical or electrochemical process where one material degrades when interacting with another in a common environment.

## CRITICALITY

The safety of the crew could be compromised by structural failures caused by corrosion, making the fight against this phenomenon an essential requirement.

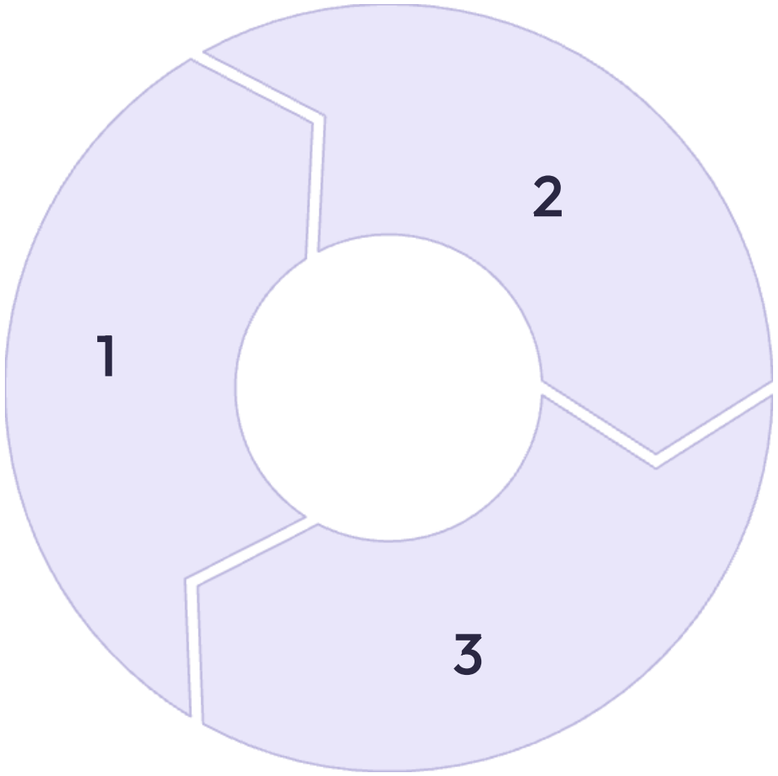
## VULNERABILITY

Submarines mainly use steel and metal alloys, materials that are highly vulnerable to corrosion.

# Corrosion Mechanisms

## Anodic Reaction

The less noble metal loses electrons and dissolves in the electrolyte in the form of ions.




## Electron Transfer

The released electrons are directed towards a cathode where another chemical element gains them.

## Cathodic Reaction

Another chemical element such as oxygen gains the electrons released at the anode

# Seawater as an Electrolyte

## Salinity

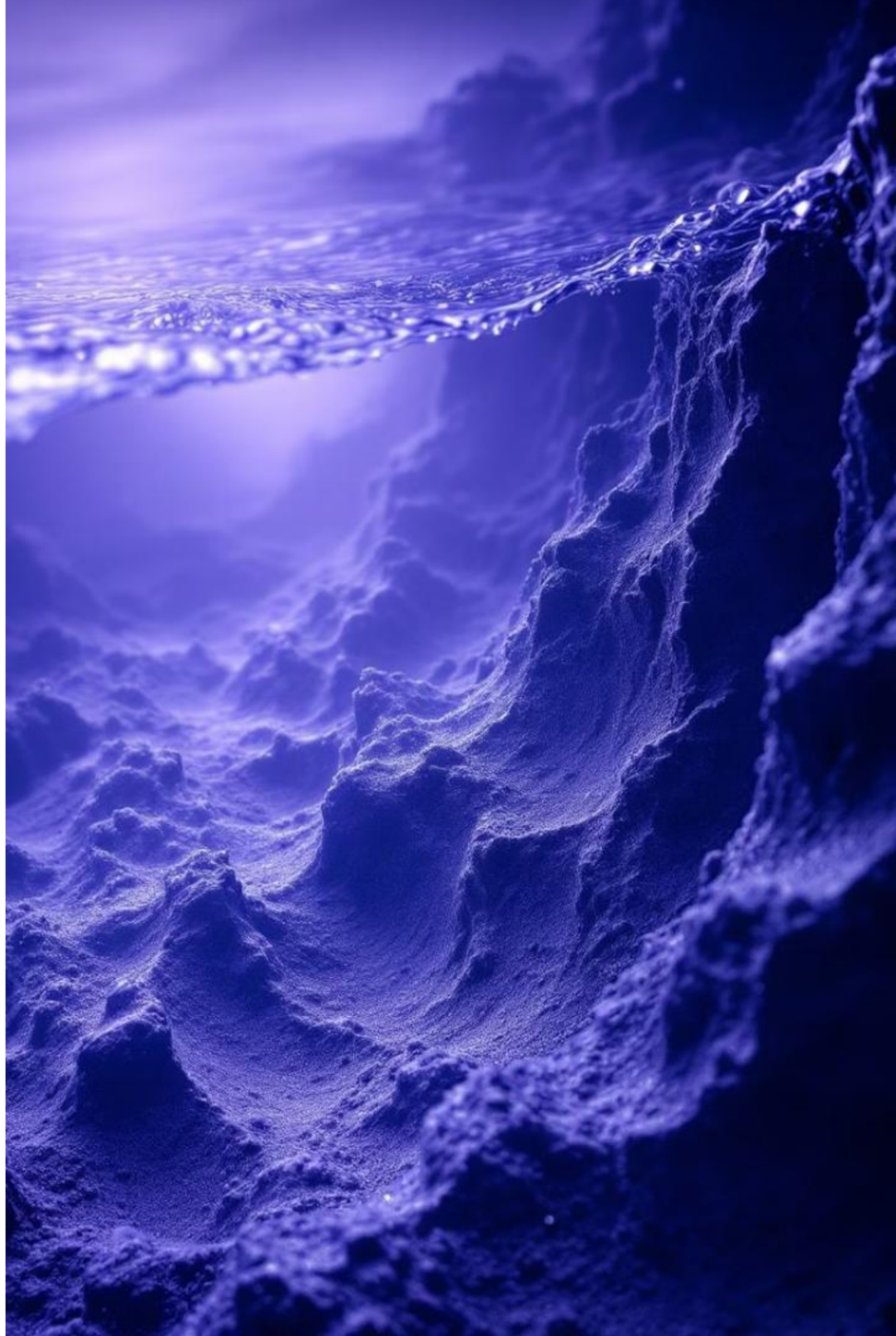
The high concentration of sodium chloride and other compounds increases the conductivity of water, facilitating electron transfer and accelerating oxidation reactions.

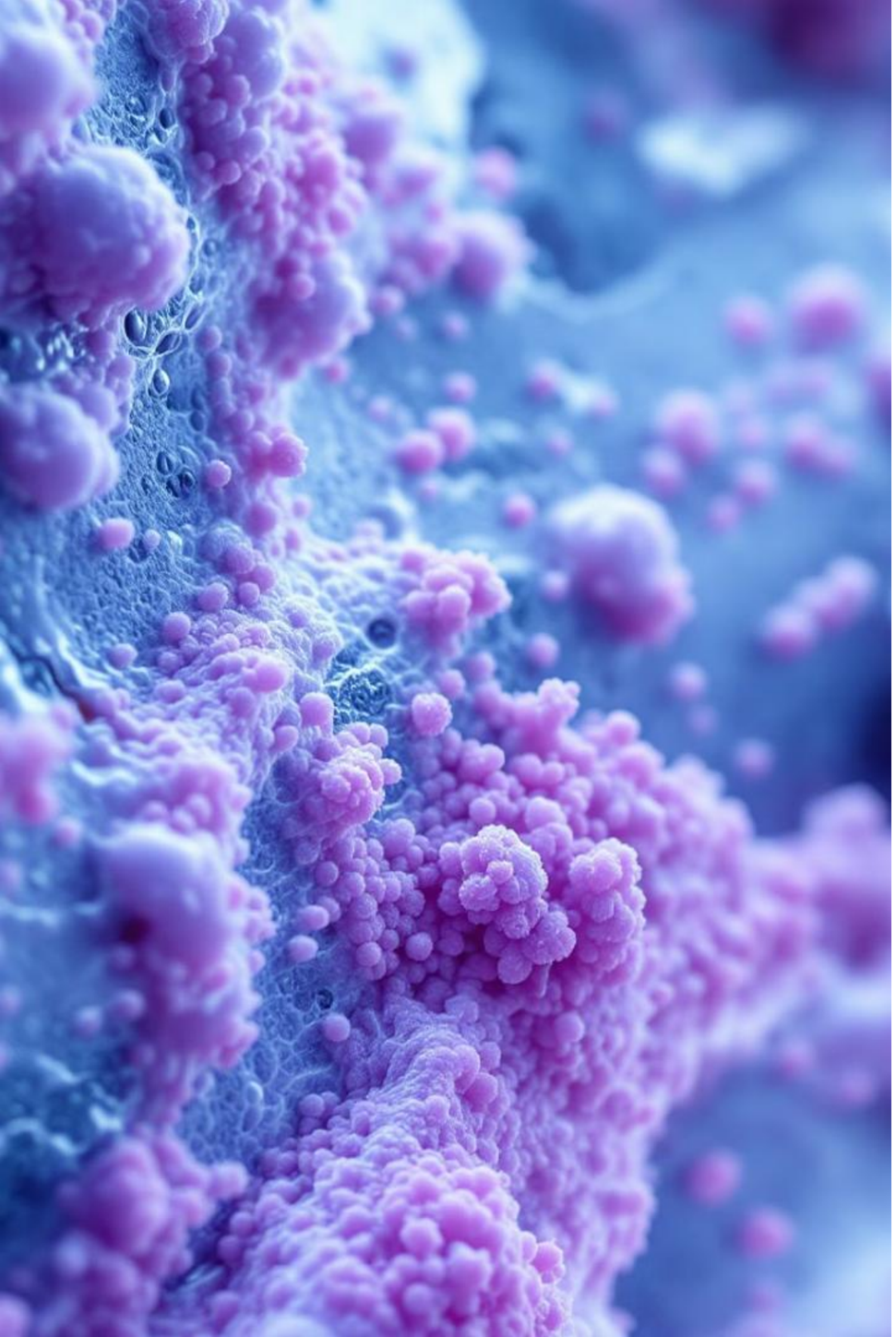
## Hydrostatic Pressure

It affects the solubility of gases in water, oxygen concentrations and the salinity of the electrolyte, altering the rate of oxidation reactions.

## Temperature

An increase in temperature also increases the speed of chemical reactions, accelerating corrosion processes over time.





# Sulphate Reducing Bacteria

### Anaerobic Metabolism

They thrive in oxygen-free environments and metabolize sulfates in seawater, generating hydrogen sulfide, which is highly corrosive.

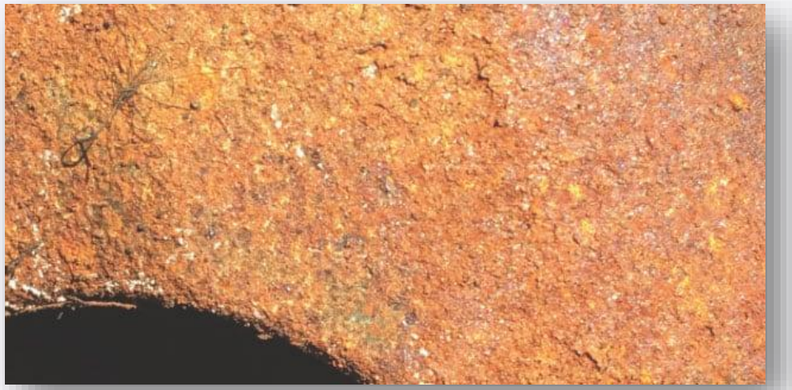
### Biofilm Formation

They adhere to metallic material, forming biofilms that create an environment that favors corrosion reactions.

### Cathodic Depolarization

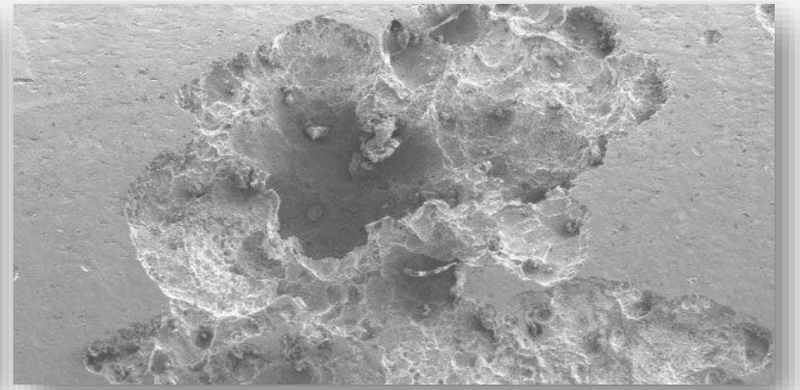
They consume hydrogen from the metallic material, accelerating cathodic reactions and forming metal sulfides with the released ions.

# UNIFORM AND LOCALIZED CORROSION



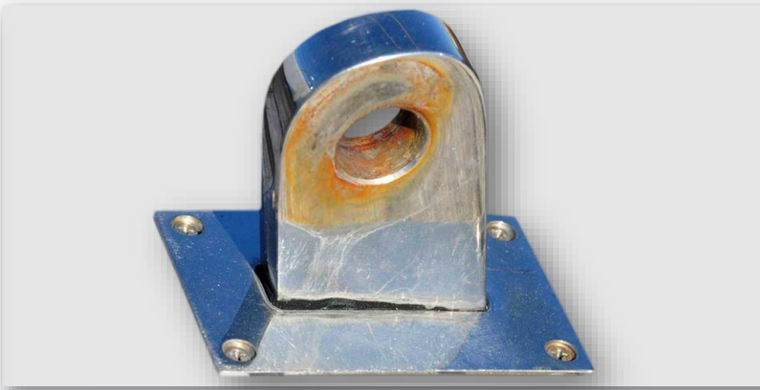
## Uniform Corrosion

It occurs when the entire exposed metal surface corrodes equally, resulting in a long-term reduction in metal thickness and reduced strength compared to the original design. In submarines, this problem is exacerbated by high hydrostatic pressures and the constant changes to both the hull and equipment.



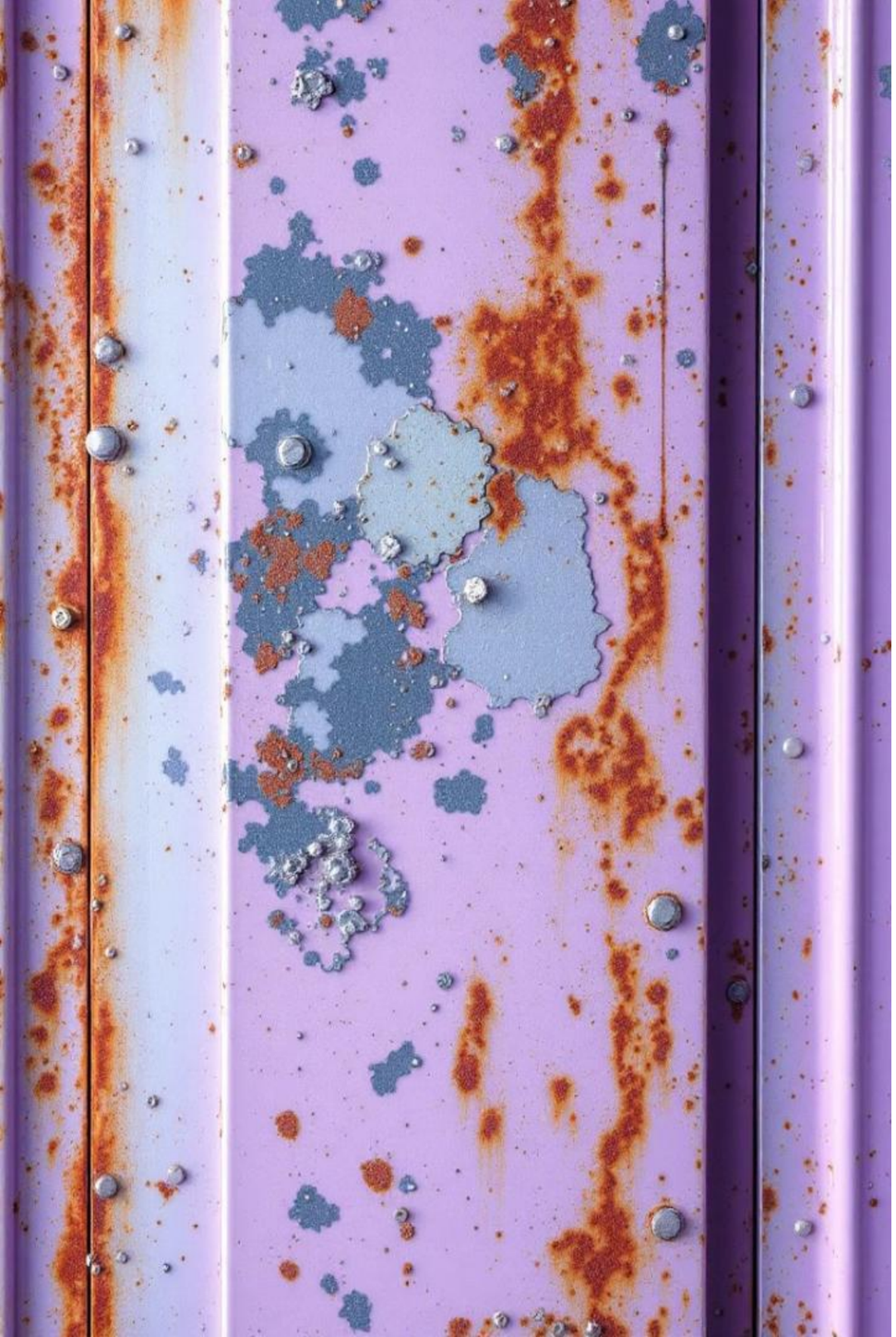
## Pitting corrosion

It is characterized by the formation of small cavities on the metal surface. It is usually caused by the presence of chloride ions that damage the protective passive layers, or by physical damage to those layers. The greatest danger is that these concentrated attacks are deep and rapid, and can create pores that allow water to pass through.



## Crevice corrosion

It originates in confined spaces where corrosive products become trapped, retaining ions and generating variations in oxygen concentration. Bolted joints, gaskets, and flanges are common sources of this type of corrosion.



# Other types of corrosion in naval environments

## Intergranular corrosion

In metals and alloys, grain boundaries at the microscopic level often have a less perfect atomic structure and may contain impurities, making them more vulnerable to corrosion.

## Stress corrosion cracking

Stress corrosion cracking occurs when a material is simultaneously subjected to mechanical stress and exposure to a corrosive environment, generating cracks that propagate through the metal and promote corrosion.

## Galvanic corrosion

It occurs when two metals of different electrical potential are in contact through an electrolyte. It is a common problem in shipbuilding due to the use of different metal alloys in contact, such as in bolted joints.

## Fatigue corrosion

In the case of fatigue corrosion, the stresses are cyclical and repetitive, such as vibrations or bending, and can cause significant damage with not very high loads.

# Materials Used in Submarines

1

## High Strength Steels

Used in critical structural elements such as the heavy-duty hull. Although they have some corrosion resistance, they generally require additional protection.

2

## Stainless Steels

They are used on elements in continuous contact with corrosive environments. Their protection comes from a passive layer of chromium oxide that separates the steel from the electrolyte.

3

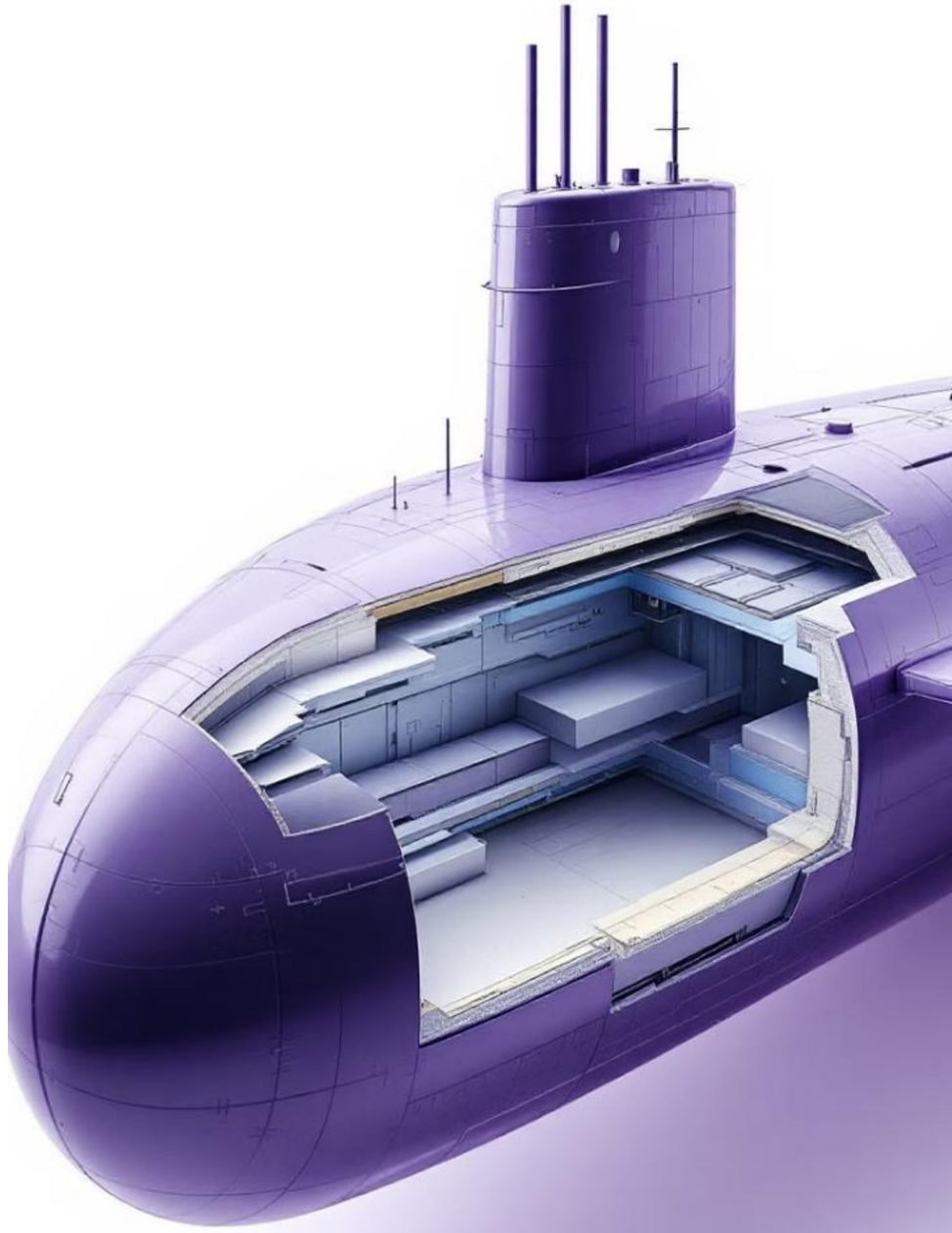
## Aluminum Alloys

Used for their high strength, corrosion protection, and low weight. They form a natural external passive layer, but are vulnerable to chlorides.

4

## Titanium and its Alloys

They offer high performance with great resistance and corrosion protection. Their use is limited by their high cost, and they are used only for critical components.



# Current Protection Methods

## Sacrificial Anodes

Materials such as zinc absorb the effects of corrosion, protecting the main structure. They should be placed according to the materials to be protected.

## Coatings and Paints

They establish a barrier between the metal and the corrosive environment, preventing contact with seawater, oxygen or other corrosive substances.

## Corrosion Inhibitors

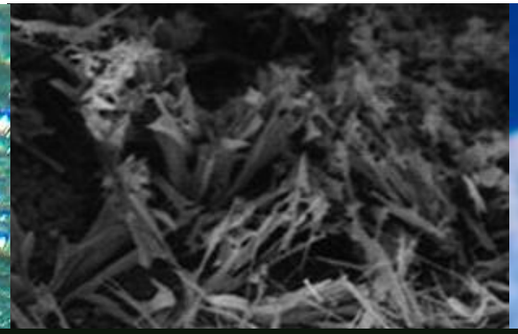
Chemical substances that reduce the rate of corrosion through different mechanisms: cathodic, anodic, barrier or organic inhibition.

# Requirements for coatings

Key features for effective protection

## Impermeability

The coatings must be impermeable to water and oxygen.



## Adhesion to metal

Adhesion between the coating and the metal is vital to prevent damage.

## Coating thickness

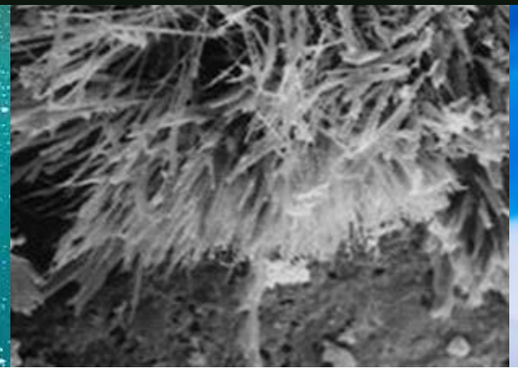
Necessary to prevent degradation and corrosion.

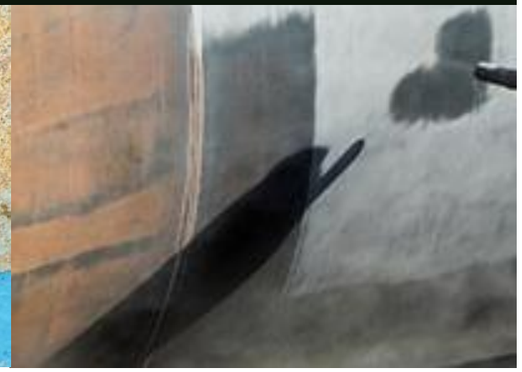
## Resistance to degradation

Prevents corrosion from spreading between the coating and the metal.

## Corrosion prevention

Prevents significant damage to the metal.





# Corrosion Inhibitors

## Mechanisms of Action

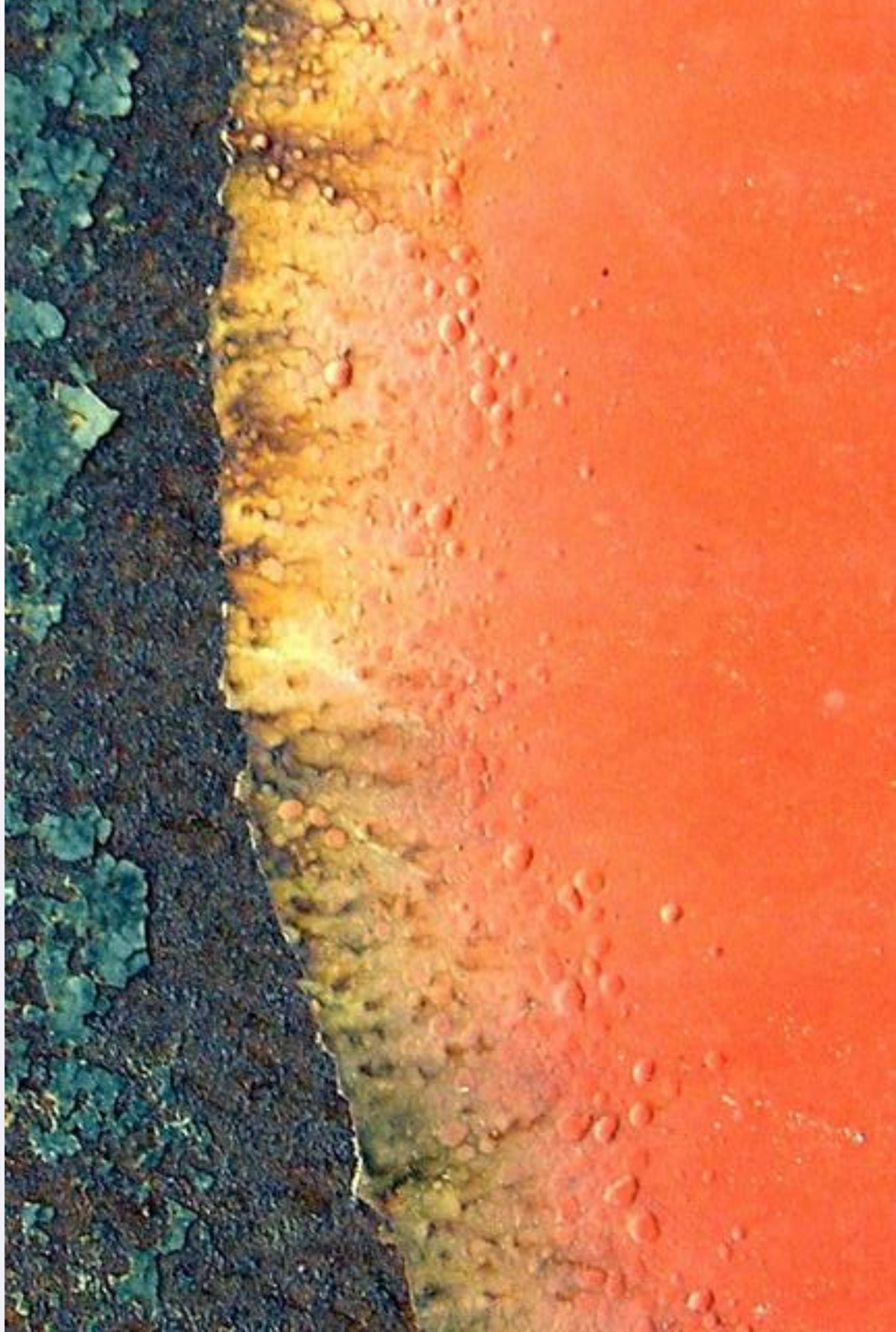
Corrosion inhibitors are chemical substances that reduce the rate of corrosion through different mechanisms: cathodic or anodic inhibition, or by forming protective barriers that prevent the access of corrosive ions.

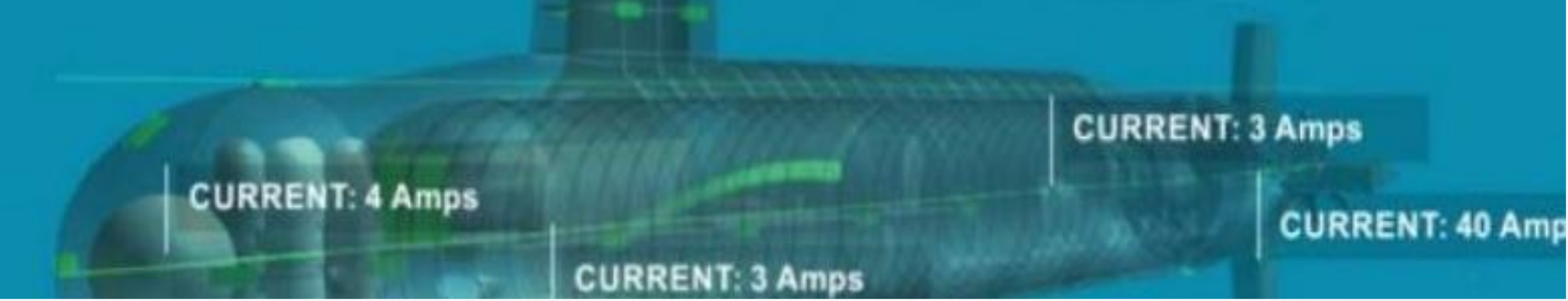
## Types of Inhibitors

Phosphates and chromates are examples of anodic inhibitors that form passive layers on metals. Organic compounds such as amines and imidazolines also exist.

## Current Research

The industry continues to research to improve the characteristics of existing inhibitors and develop more environmentally friendly alternatives, such as non-toxic inhibitor pigments, that can replace environmentally harmful substances..






# Cathodic Protection for Submarines

## Basic Principle

Cathodic protection transforms the metal structure into a cathode, preventing oxidation. It can be applied using impressed electric current or sacrificial anodes.

## Application in Submarines

Historically, submarines have used sacrificial anodes. Impressed current protection, although more efficient, presents challenges on subsea platforms due to its complex installation and maintenance.

## Challenges and Advances

The goal is to improve current management through more precise control systems, remote monitoring, and materials with reduced corrosion requirements, while maintaining the submarine's stealth capabilities.

# Graphene: The Material of the Futur

## Structure and Properties

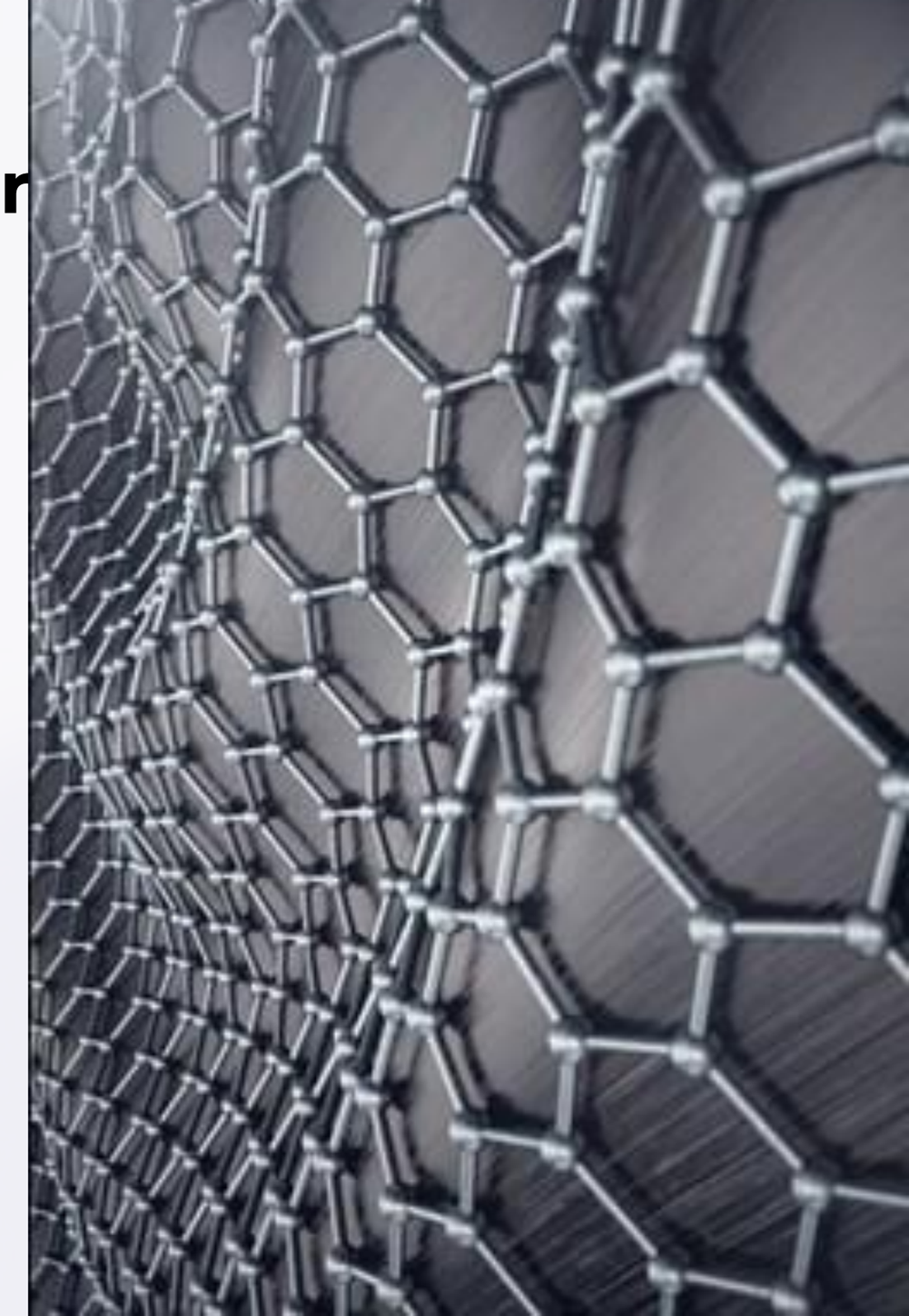
Material made up of carbon atoms in extremely thin two-dimensional layers, with extraordinary physical and electrical characteristics and corrosion resistance.

## Application

It can be applied by chemical vapor deposition or spraying, the main challenge being adhesion to metal surfaces.

## Current Challenges

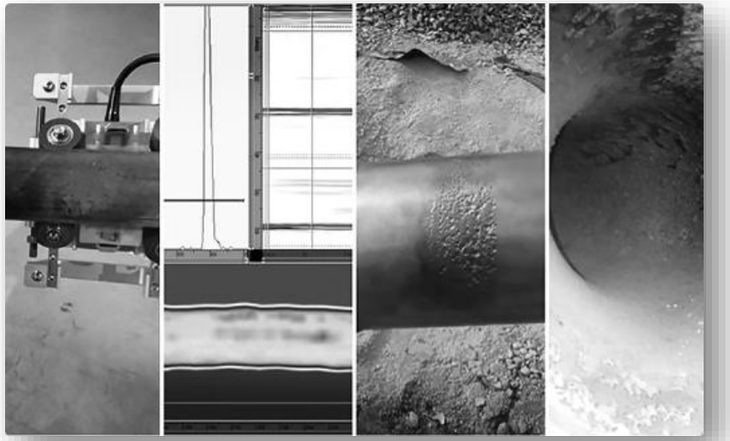
Limitations in production capacity, high costs, and lack of experience in extreme real-life environments such as submarines.



# New Inspection Methods

## Wireless Sensors

Sensors are being integrated along submerged structures to continuously monitor cathodic protection and detect corrosion development at critical points, even in hard-to-reach areas.



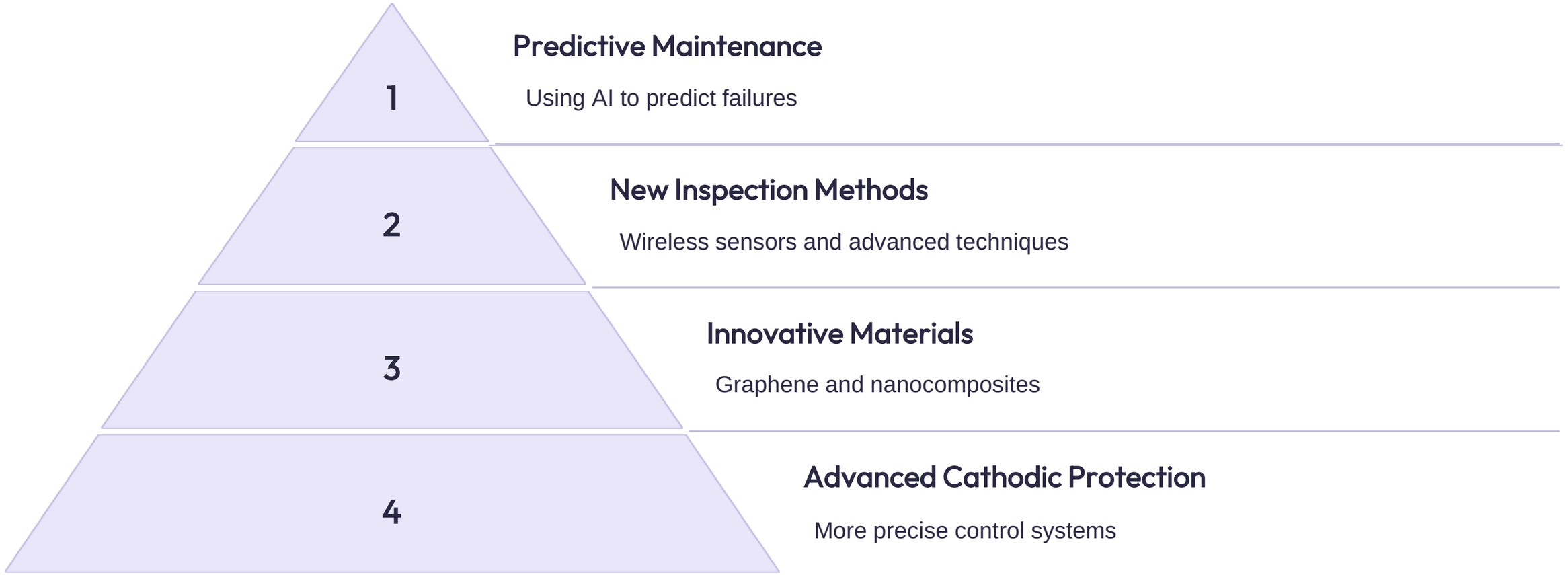
## Advanced Techniques

Methods such as computed tomography, magnetic resonance imaging, and scanning probe microscopy allow corrosion processes to be observed at microscopic scales or in internal structures, detecting corrosion at very early stages.


## Artificial intelligence

The information obtained by these new methods can be used in predictive maintenance techniques that, thanks to machine learning and artificial intelligence, predict the start and development of corrosion processes.

# Future Perspectives in Corrosion Protection



# Thank you!