Corrosion Threats

Internal nad External corrosion

Controlling corrosion

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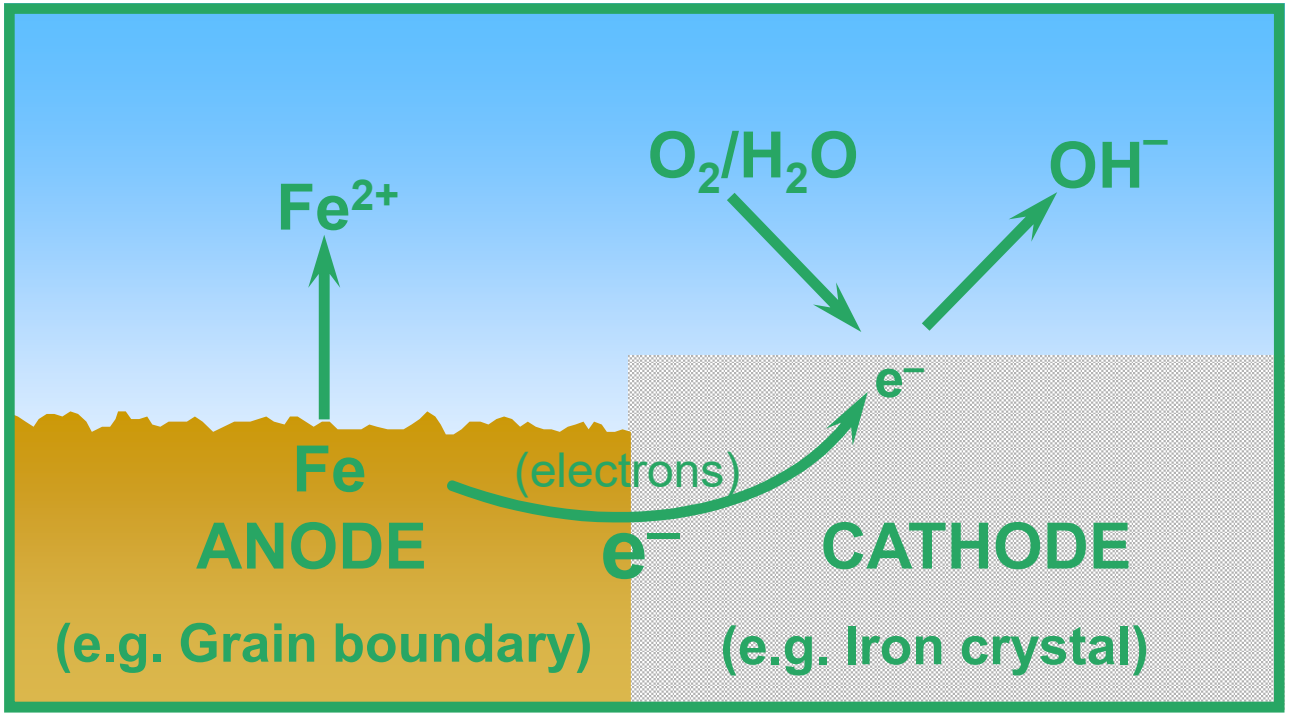
Sarajevo 2024

WHAT IS CORROSION?



Corrosion is TWO Reactions (at least!)

TYPES OF CORROSION

GENERAL

PITTING

MICROBIAL

EROSION

FATIGUE

GALVANIC

CRACKING

General (Uniform) Corrosion

Corrosion uniformly distributed over a metal surface. It is the most common form of external corrosion of carbon steel

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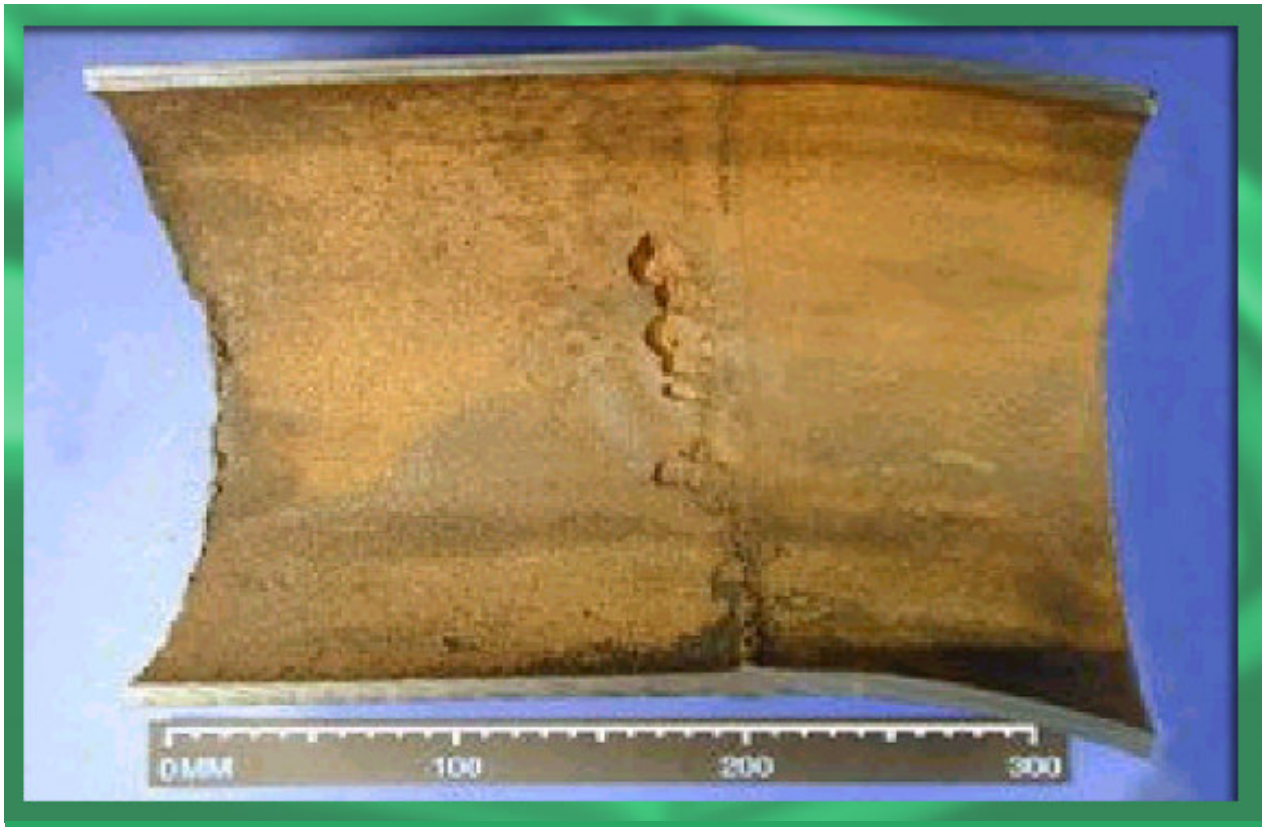

Pitting Corrosion

Highly localised corrosion resulting in deep penetrations in only a few locations

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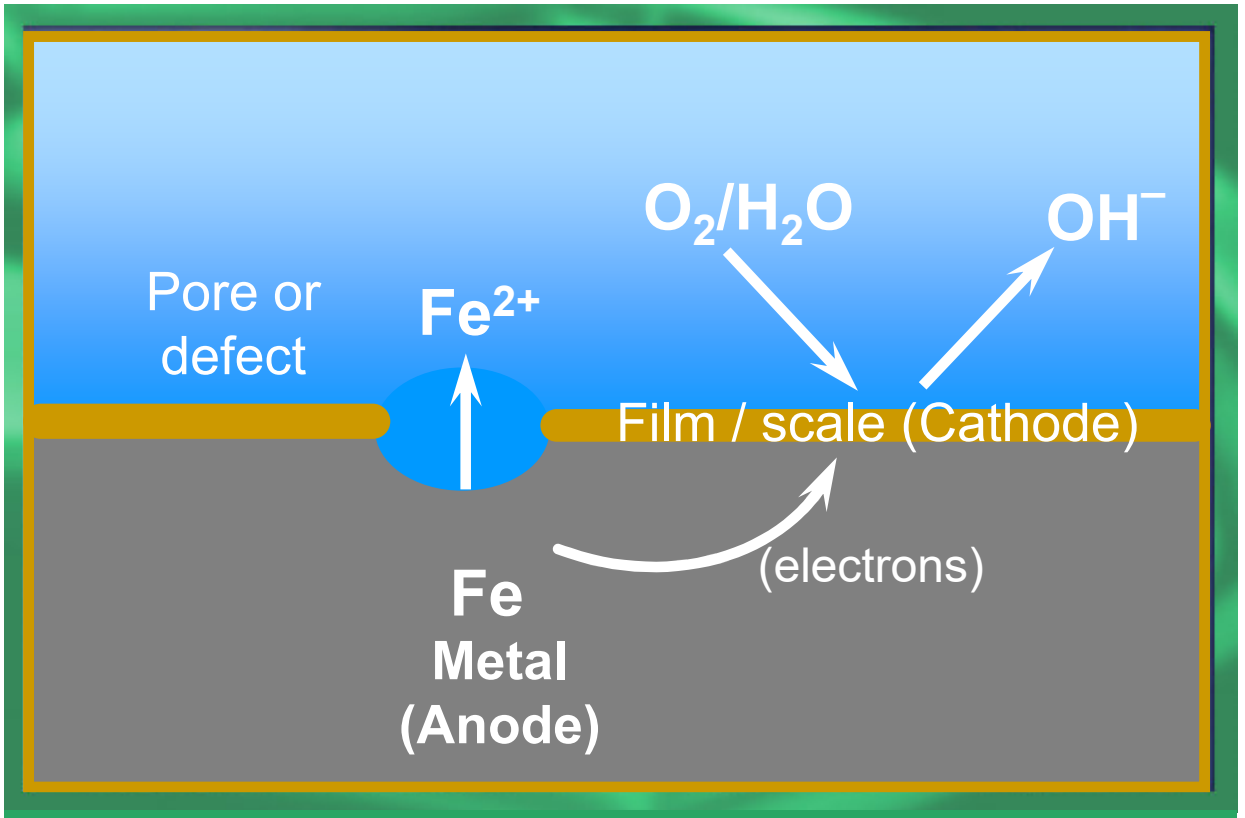

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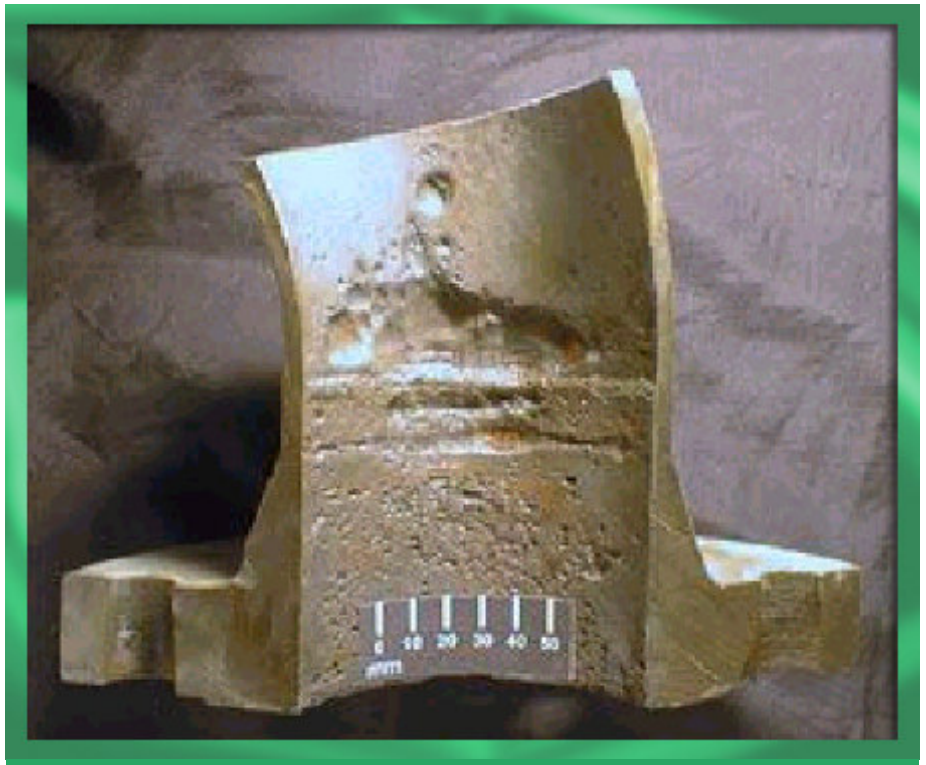


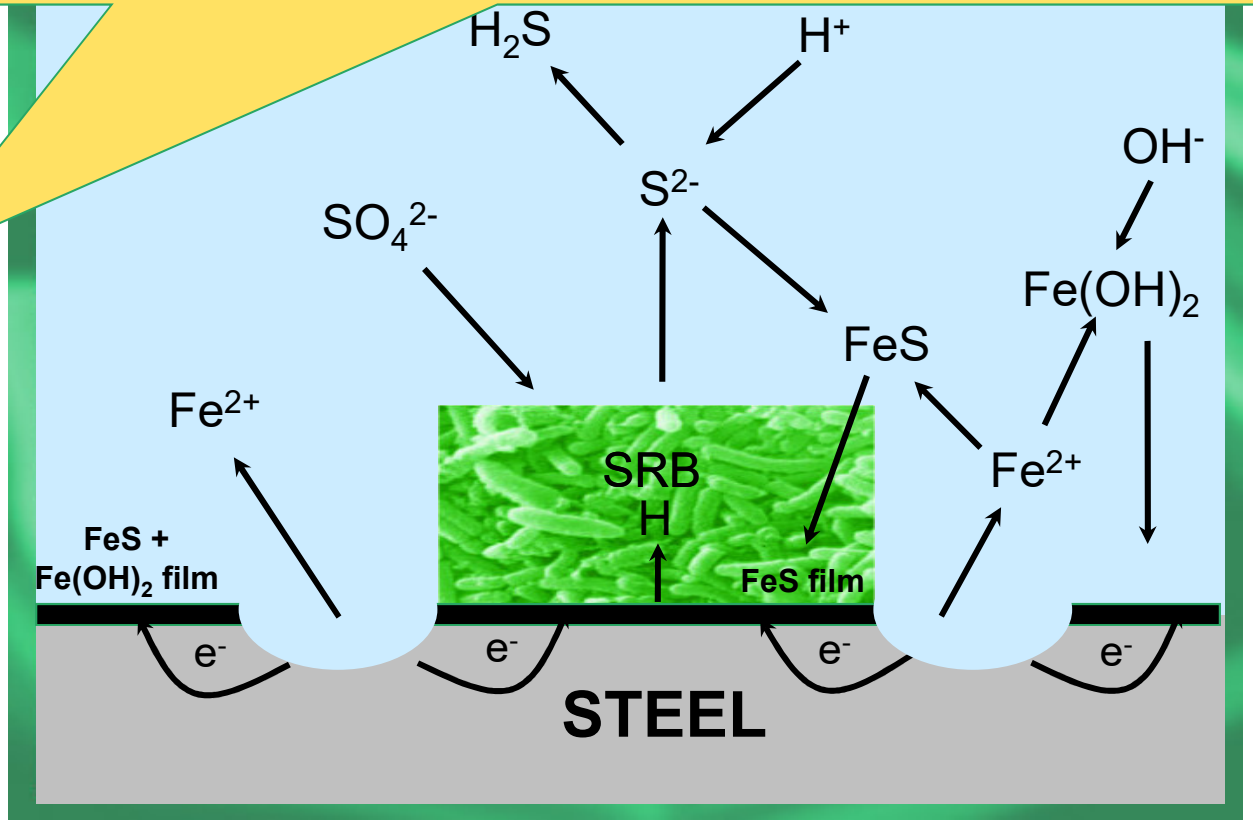
Microbial Corrosion

Corrosion (usually pitting) caused by bacteria. The most destructive in the industry are Sulphate Reducing Bacteria (SRB)

TYPES OF CORROSION

"How do SRB corrode steel?"

"Sulphate Reducing Bacteria produce sulphide as a metabolic by-product. The sulphide generates hydrogen sulphide, which is the main cause of microbial corrosion"



TYPES OF CORROSION

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CRACKING

Erosion Corrosion

The action of corrosion and erosion together in a moving corrosive fluid producing accelerated corrosion

TYPES OF CORROSION

GENERAL

PITTING

MICROBIAL

EROSION

FATIGUE

GALVANIC

CRACKING

Fatigue

Fatigue failures are progressive and grow under the action of the fluctuating stress

TYPES OF CORROSION

GENERAL

PITTING

MICROBIAL

EROSION

FATIGUE

GALVANIC

CRACKING

Galvanic Corrosion

Accelerated corrosion of a metal due to electrical contact with a more noble metal or non-metallic conductor in a corrosive environment

TYPES OF CORROSION

GENERAL

PITTING

MICROBIAL

EROSION

FATIGUE

GALVANIC

CRACKING

Cracking - E.g. Stress Corrosion Cracking or Hydrogen Induced Cracking

Fracture in a brittle manner because of exposure to specific substances such as chlorides or hydrogen sulphide

Process Plant & Structures

External Corrosion

Atmospheric Corrosion / Coating Failure
Corrosion under Insulation

Pipework & Vessels

Internal Corrosion

CO_2, Organic acids, H_2S & Erosion Corrosion

Export Pipelines

Internal Corrosion

CO_2, Organic acid & Microbial Corrosion

Drains & Deadlegs

Internal Corrosion

Oxygen, Bacteria & Carbon Dioxide

Water Systems

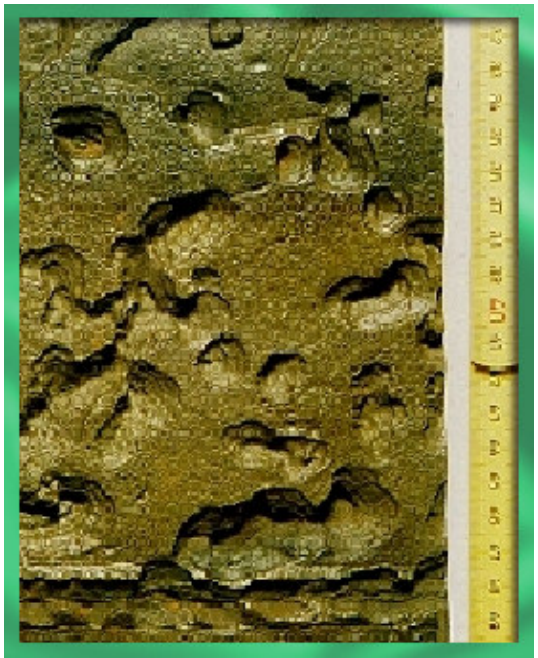
Internal Corrosion

Oxygen & Bacteria

INTERNAL CORROSION

INTERNAL CORROSION

"What are the key INTERNAL corrosion threats and how are they controlled?"



Carbon Dioxide Corrosion

Erosion Caused by Sand

Microbial Corrosion

THE THREATS

"What are the main **INTERNAL** corrosion threats?"

CARBON DIOXIDE corrosion of our process plant and pipelines

Co-produced **ORGANIC ACIDS** (e.g. Acetic Acid)

Corrosion by **BACTERIA** (primarily Sulphate Reducing Bacteria, SRB) - especially in our main oil pipelines and topsides stagnant areas

Corrosion and cracking caused by **HYDROGEN SULPHIDE (H_2S)**

OXYGEN in service water and water flood systems

EROSION and **EROSION CORROSION** caused by solids production and / or excessive flow rates

SCALE formation in pipelines and vessels leading to underdeposit or localised corrosion

Misuse / misapplication of the **CHEMICALS** used to control corrosion and scale

SOME FACTS

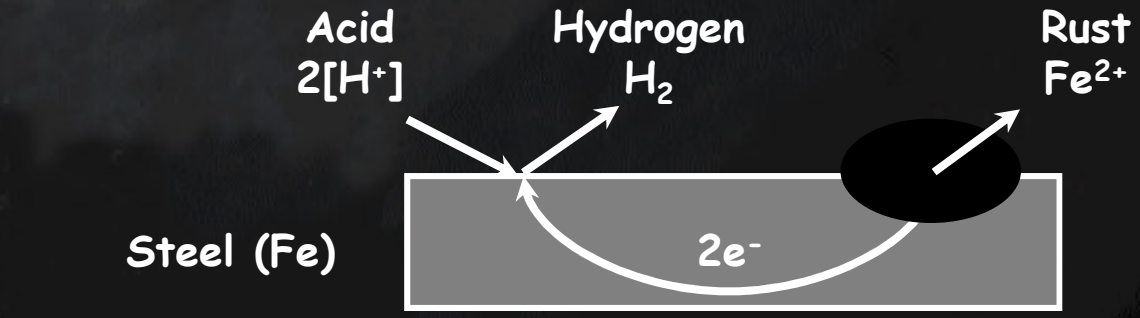
"Some background"

How does carbon dioxide corrode steel..?

Carbon Dioxide + Water = Carbonic ACID = Corrosion

$$CO_2 + H_2O \longrightarrow H_2CO_3 \rightleftharpoons \underset{\text{Acid}}{H^+ + HCO_3^-}$$

Corrosion



CO_2 corrosion of carbon steel

SOME FACTS

"Some background"

Factors which impact corrosion rates……..

Pressure: The solubility of CO_2 is dependant on the partial pressure of CO_2. **i.e. higher pressures mean higher corrosion rates**

Temperature: Generally, the higher the temperature the faster the corrosion (kinetics)

Solution Chemistry: Specific ions in formation water can change the acidity. e.g.The higher the bicarbonate [HCO_3^-] the lower the corrosion rates. Organic acids will increase the corrosivity

CO_2 corrosion of carbon steel

SOME FACTS

"How fast will it corrode?.."

CO_2 Corrosion Rates - De Waard and Milliams

Corrosion Rate (Gas) = $V \times F_s \times F_G$ mm/y

Corrosion Rate (Oil) = $V \times F_{pH}$ mm/y

Basic Equation:	$Log_{10}(V) = 5.8 - \frac{1710}{} + (0.67 \times Log_{10}(Pco_2))$
Scale Factor:	$Log_{10}(F_s) = \frac{2500}{} - 7.5$
Glycol Factor:	$Log(F_G) = 1.2 \times Log_{10}(W_G) - 2.4$
pH Factor:	$Log_{10}(F_{pH}) = -0.13 \times (pH_{meas} - pH_{calc})$
	$pH_{calc} = 3.71 - 0.5 \times Log_{10}(Pco_2) + 0.00417 \times T$

V = Corrosion rate (mm/y)

T = Temperature (°C)

Pco_2 = CO_2 partial pressure (Bar)

W_G = % water in glycol

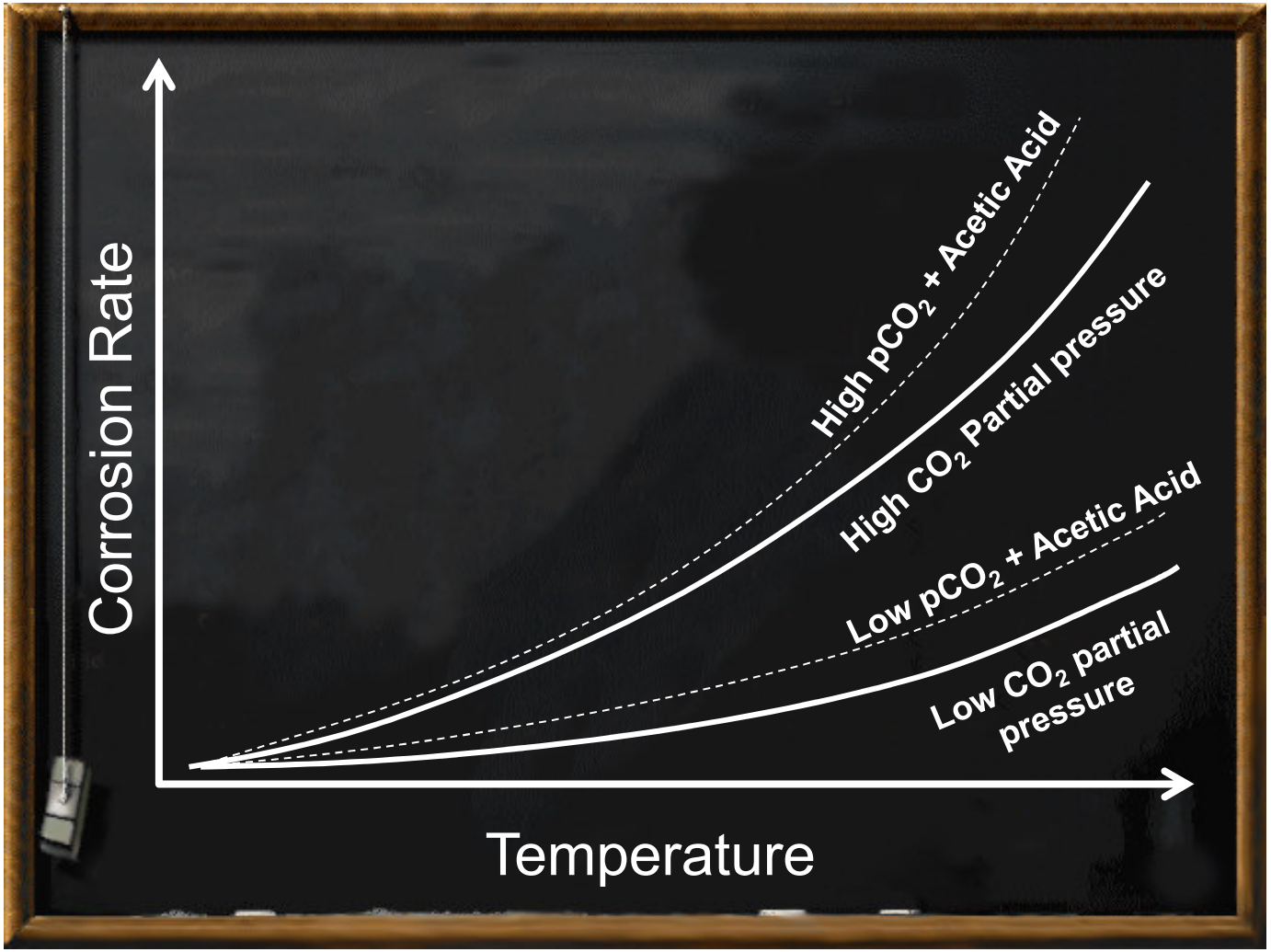
The BP CO_2 prediction model is **"Cassandra"**

(named after the Greek goddess - fated never to be believed..!!)

CO_2 corrosion of carbon steel

SOME FACTS

"…which means"



CO_2 corrosion of carbon steel

SOME FACTS

"What about H_2S?"

Similarly….

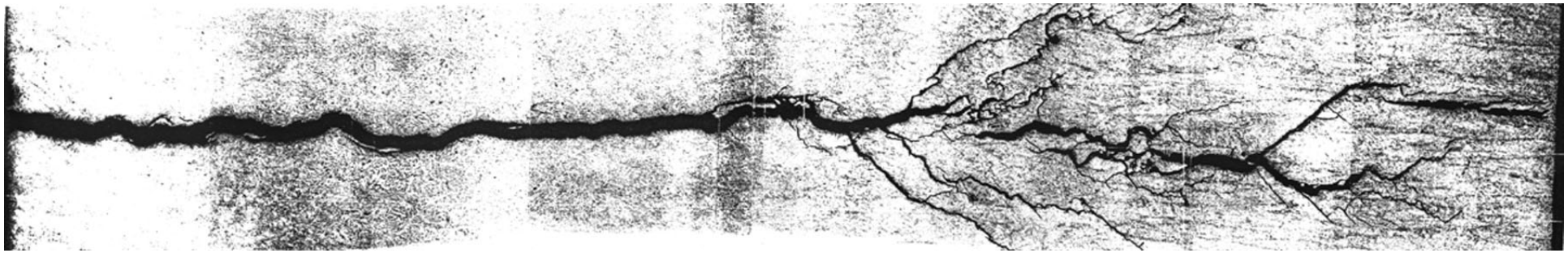
Hydrogen Sulphide + Water = **ACID**

$$\mathbf{H_2S + H_2O \longrightarrow \underbrace{H^+ + HS^-}_{\text{Acid}} \longrightarrow CORROSION}$$

However…. **H_2S** prevents

$$H^\circ + H^\circ \longrightarrow H_2$$

…and causes localised attack. Our main concern is cracking….



SOME FACTS

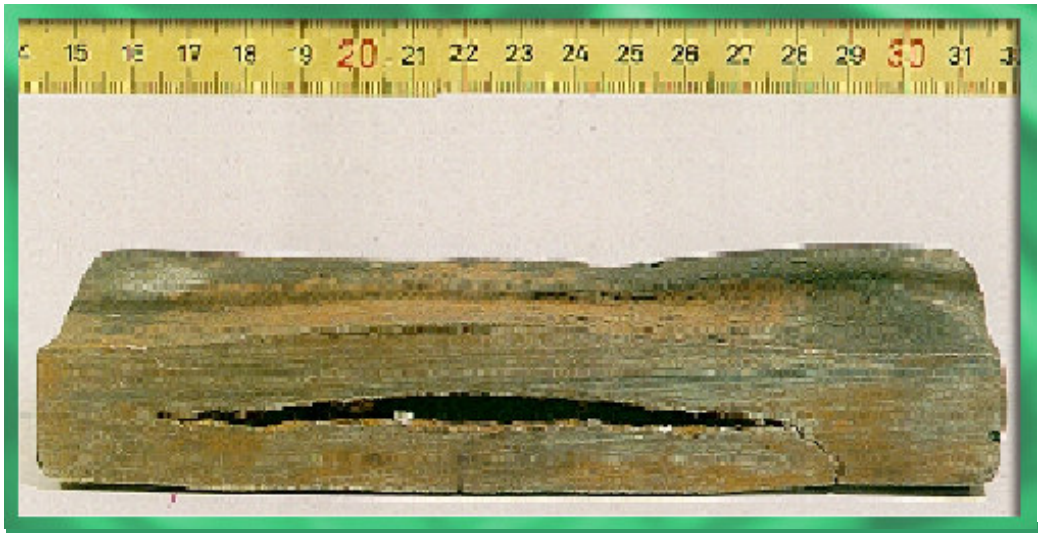
"What about H_2S?"

H_2S causes

Sulphide Stress Cracking (SSC)

and..

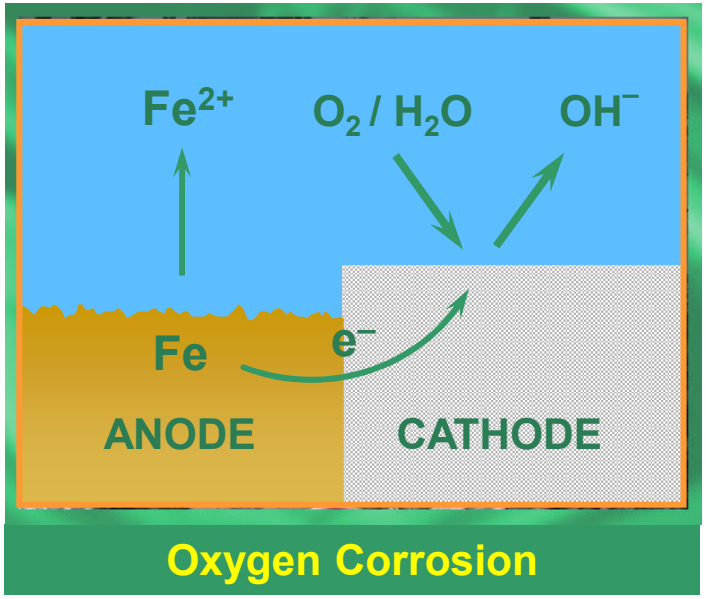
Hydrogen Induced Cracking (HIC)

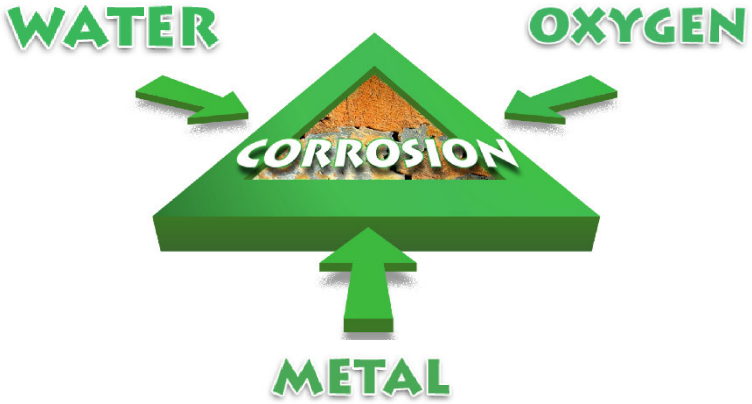


Hydrogen Induced Cracking of Carbon Steel

SOME FACTS

OXYGEN in water **will** corrode steel and other metals





$2Fe + O_2 + 4H^+ = 2Fe^{2+} + 2H_2O$

Iron + Oxygen = Rust

OXYGEN is a strong oxidising agent. It will oxidise iron, producing iron oxides and hydroxides (i.e. rust)

OXYGEN causes **pitting**, **weld** and **general** corrosion

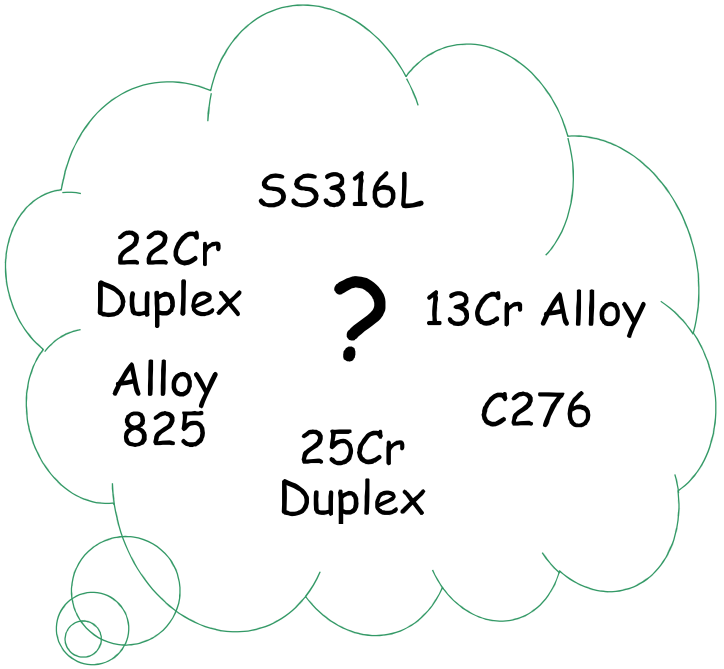
CONTROLLING INTERNAL CORROSION

Materials Selection

Coatings & Linings

Process Management

Chemical Management



CONTROLLING INTERNAL CORROSION

Materials Selection

Coatings & Linings

Process Management

Chemical Management

CONTROLLING INTERNAL CORROSION

" How do we control these threats?"

Materials Selection

Coatings & Linings

Process Management

Chemical Management

PROCESS MANAGEMENT

"How does process control affect corrosion?"

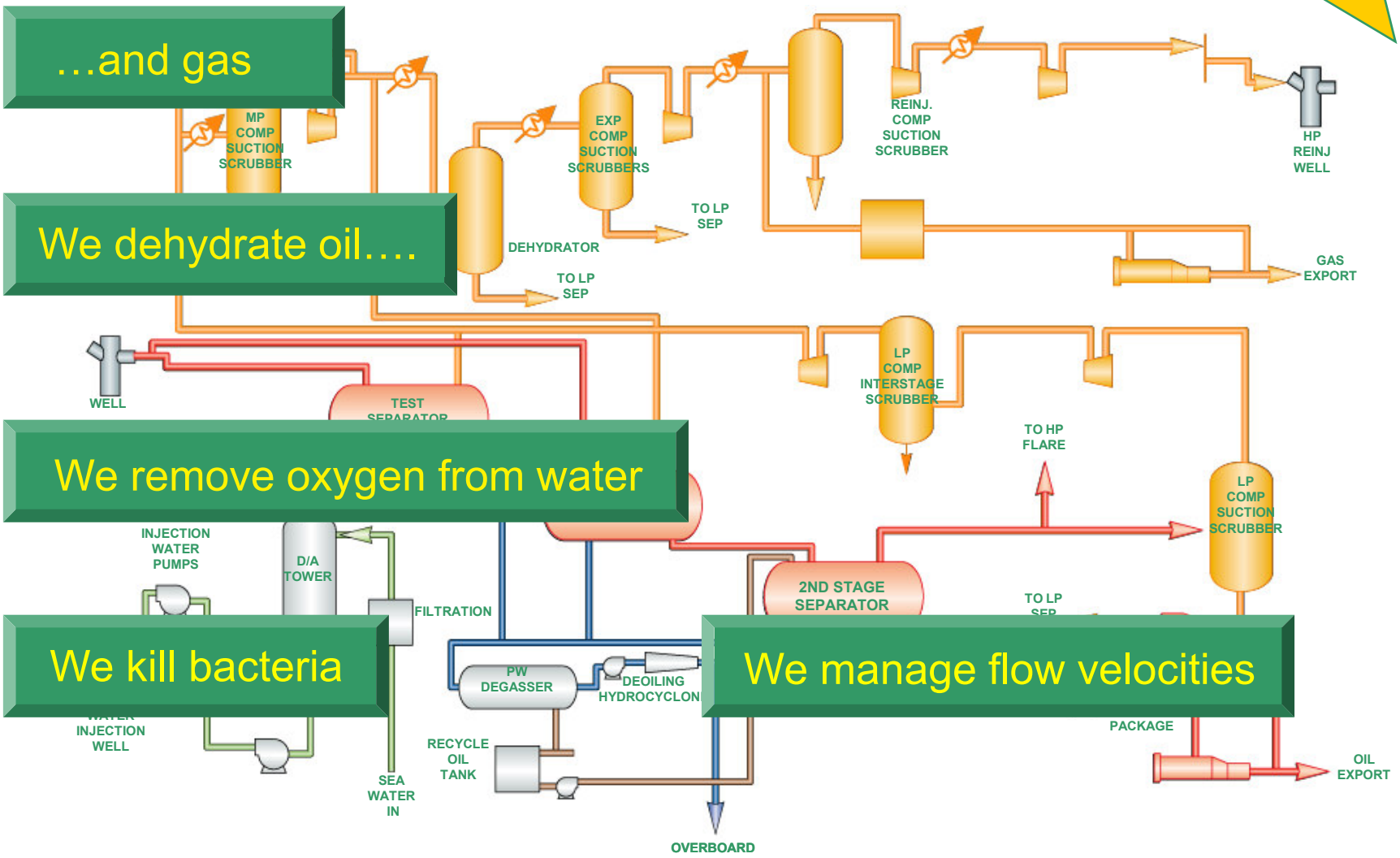
…and gas

We dehydrate oil….

We remove oxygen from water

We kill bacteria

We manage flow velocities



CONTROLLING INTERNAL CORROSION

Materials Selection

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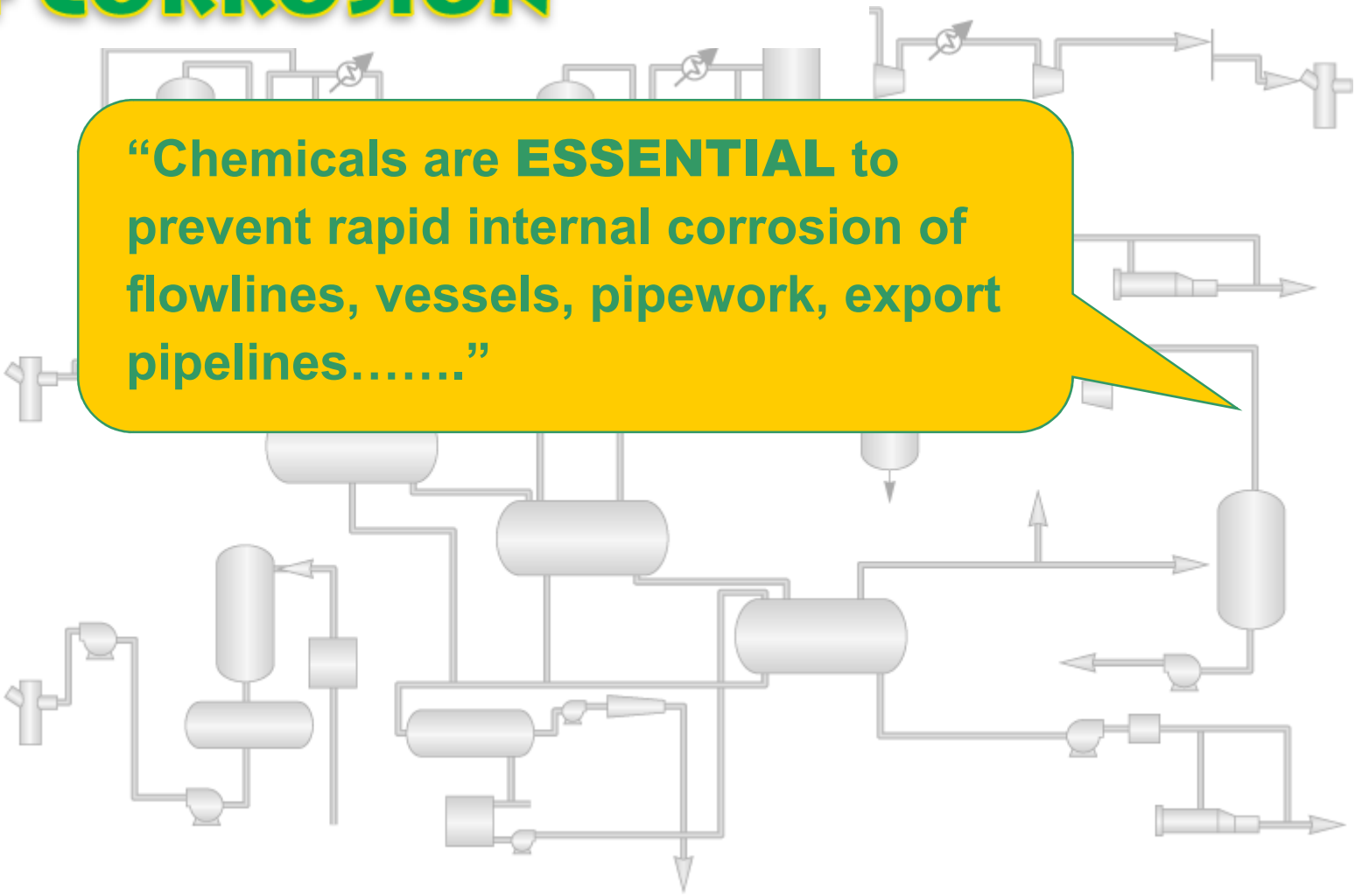
Process Management

Chemical Management

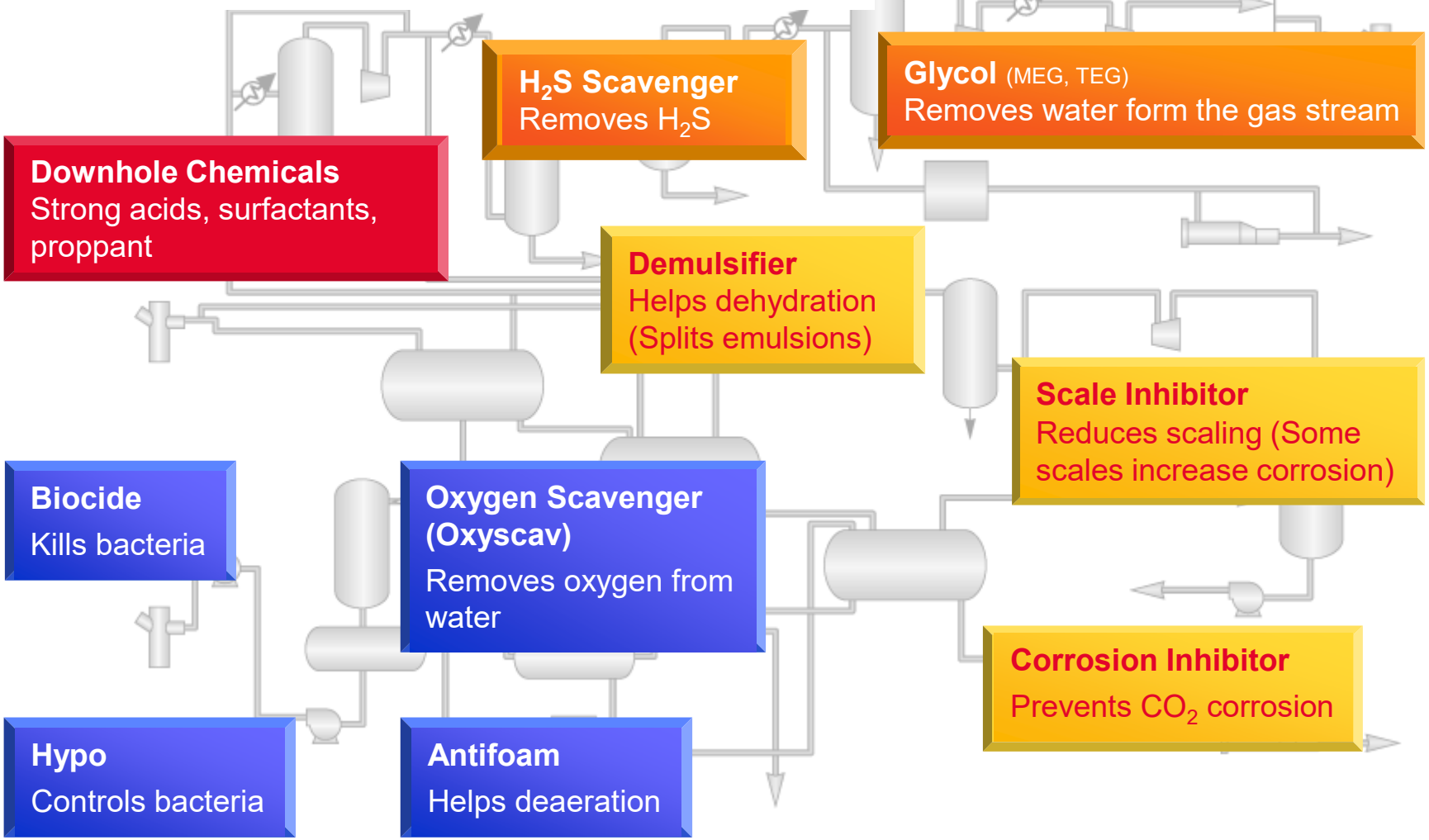
CHEMICAL CONTROL OF CORROSION



"Chemicals are **ESSENTIAL** to prevent rapid internal corrosion of flowlines, vessels, pipework, export pipelines……."

CHEMICAL CONTROL OF CORROSION

"What are the main chemicals we use to control corrosion?"



Downhole Chemicals
Strong acids, surfactants, proppant

H_2S Scavenger
Removes H_2S

Glycol (MEG, TEG)
Removes water form the gas stream

Demulsifier
Helps dehydration (Splits emulsions)

Scale Inhibitor
Reduces scaling (Some scales increase corrosion)

Biocide
Kills bacteria

Oxygen Scavenger (Oxyscav)
Removes oxygen from water

Corrosion Inhibitor
Prevents CO_2 corrosion

Hypo
Controls bacteria

Antifoam
Helps deaeration

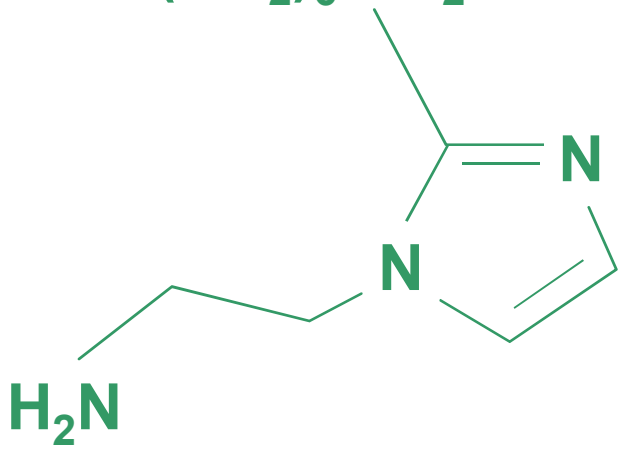
SOME FACTS

"What are corrosion inhibitors and how do they work?"

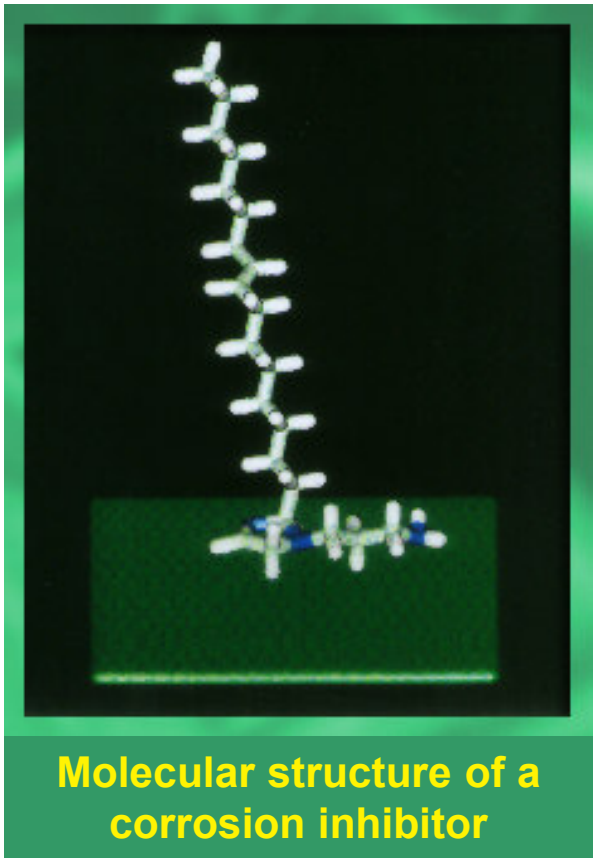
A typical inhibitor molecule..

This end repels water

$$CH_3(CH_2)_7CH = CH(CH_2)_6\,CH_2$$



This end is attracted to metallic surfaces

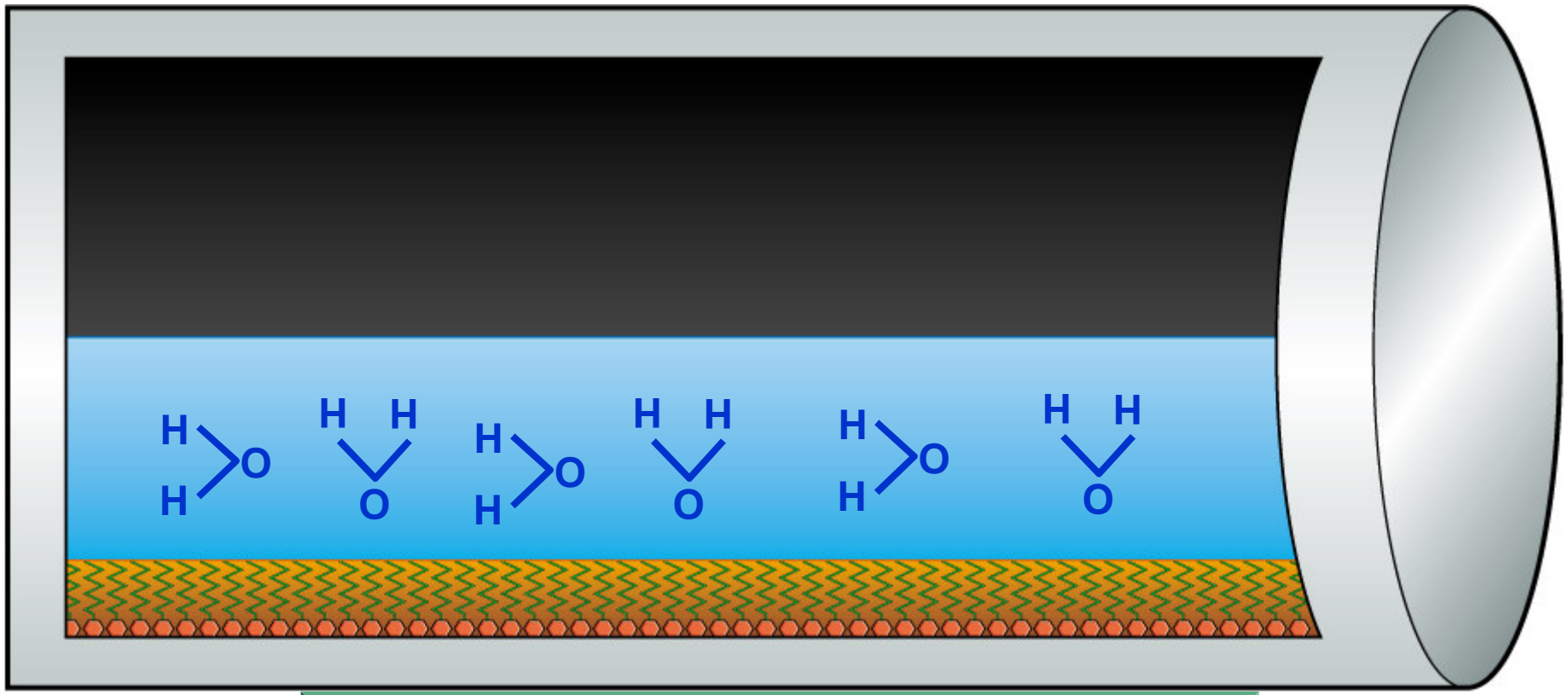


Molecular structure of a corrosion inhibitor

Oleic Imidazoline

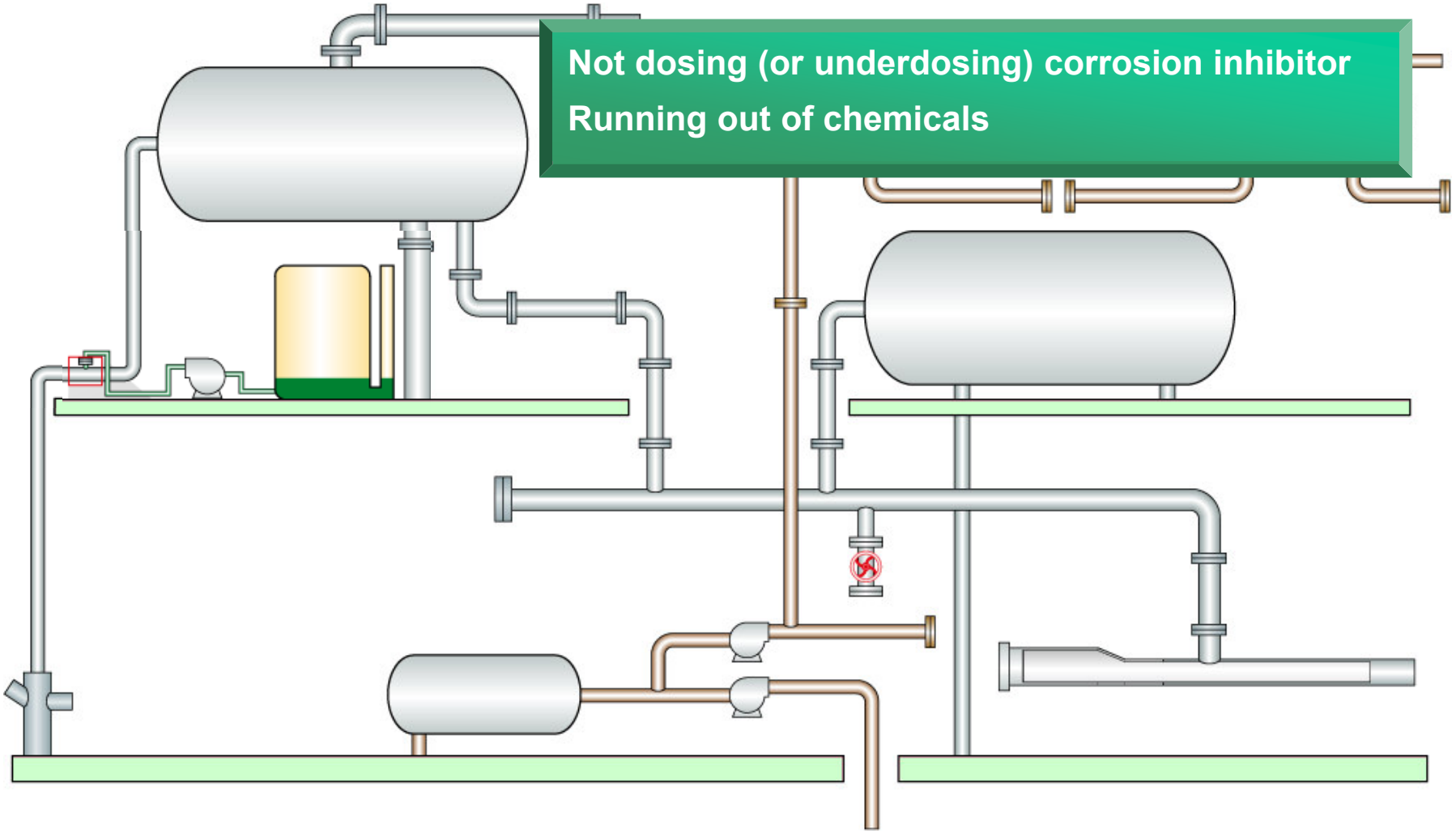
SOME THREATS

"How do they work?"



Like a paint film…. but DYNAMIC

WHAT CAN GO WRONG?



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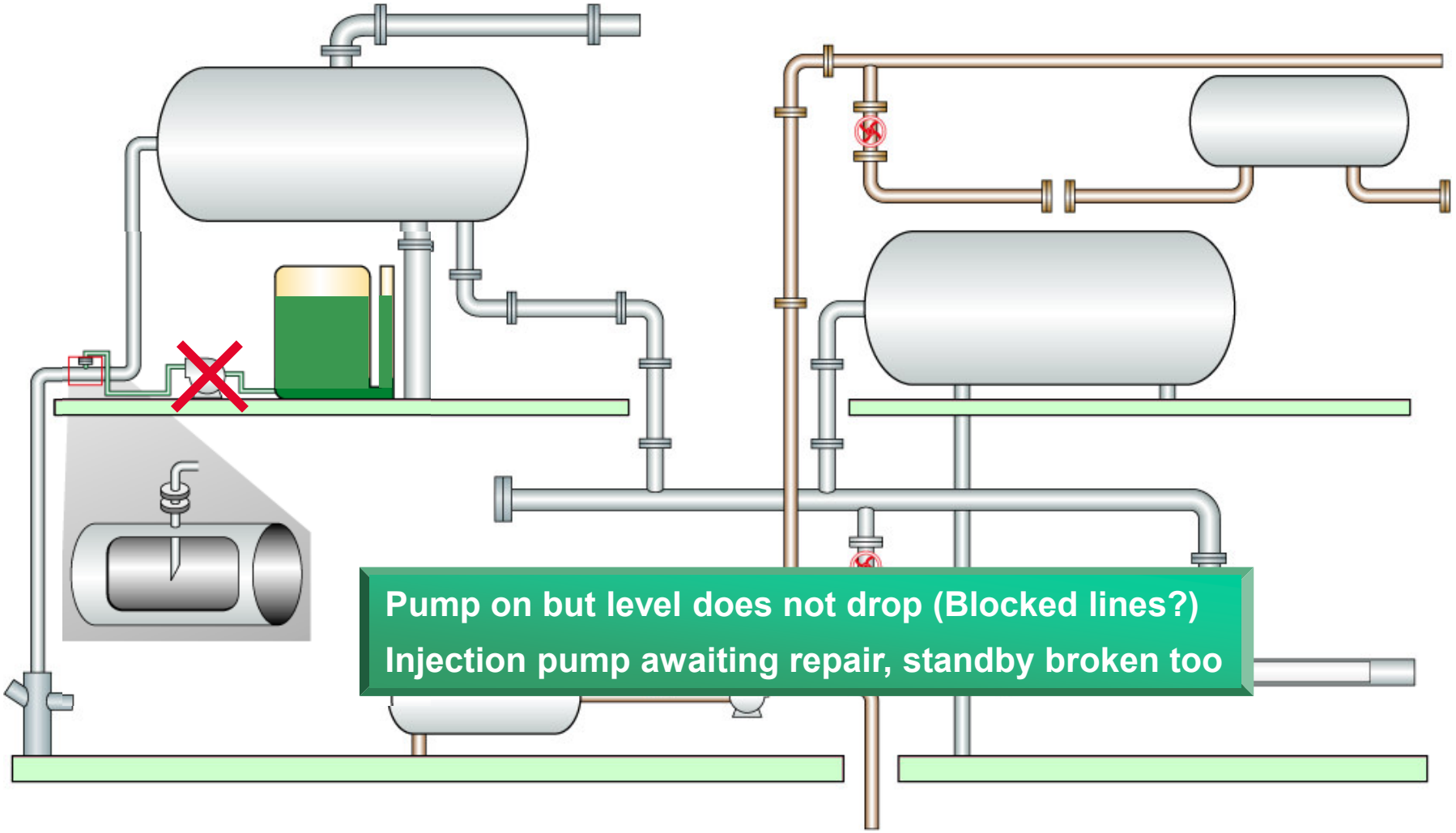

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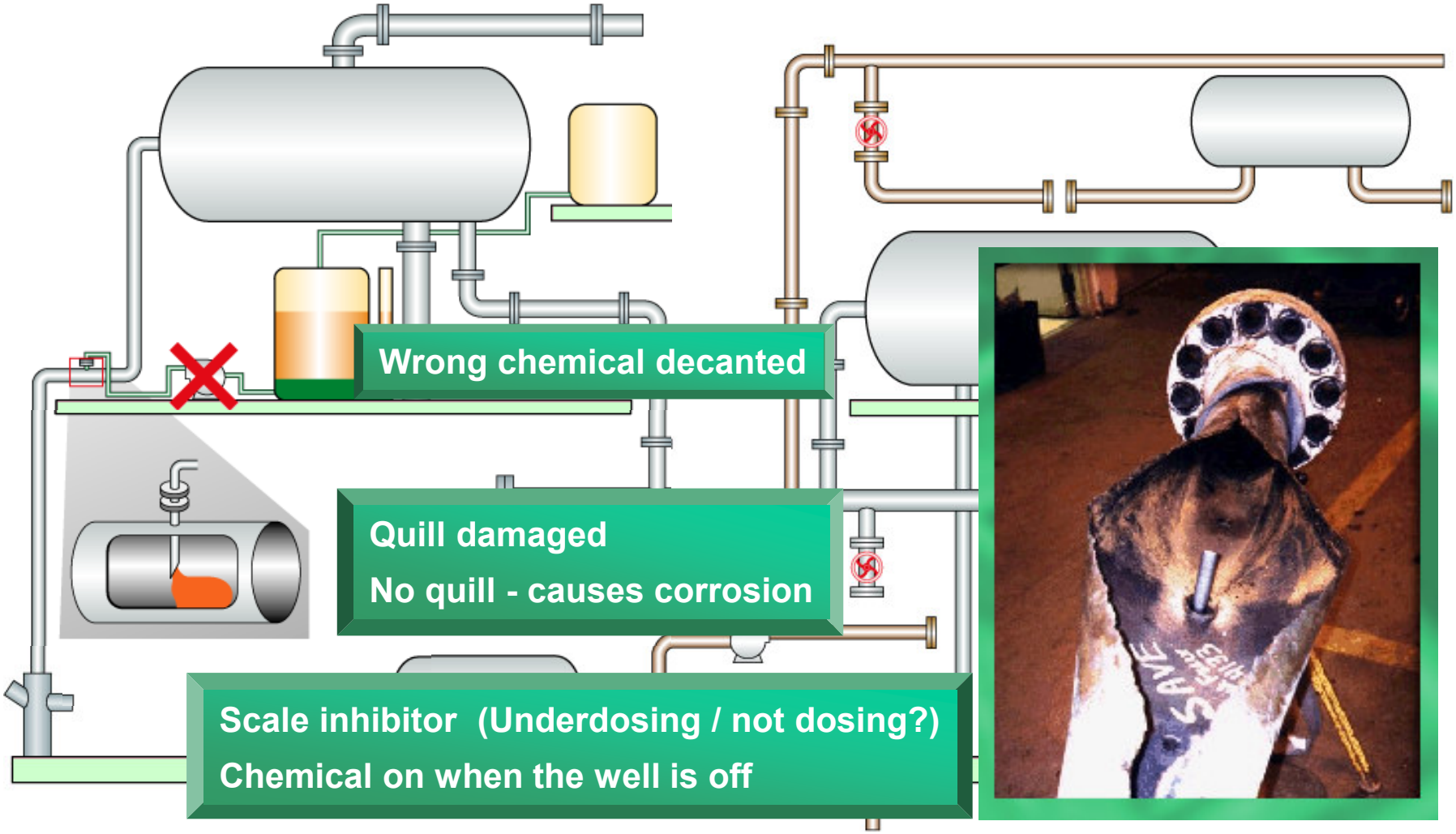
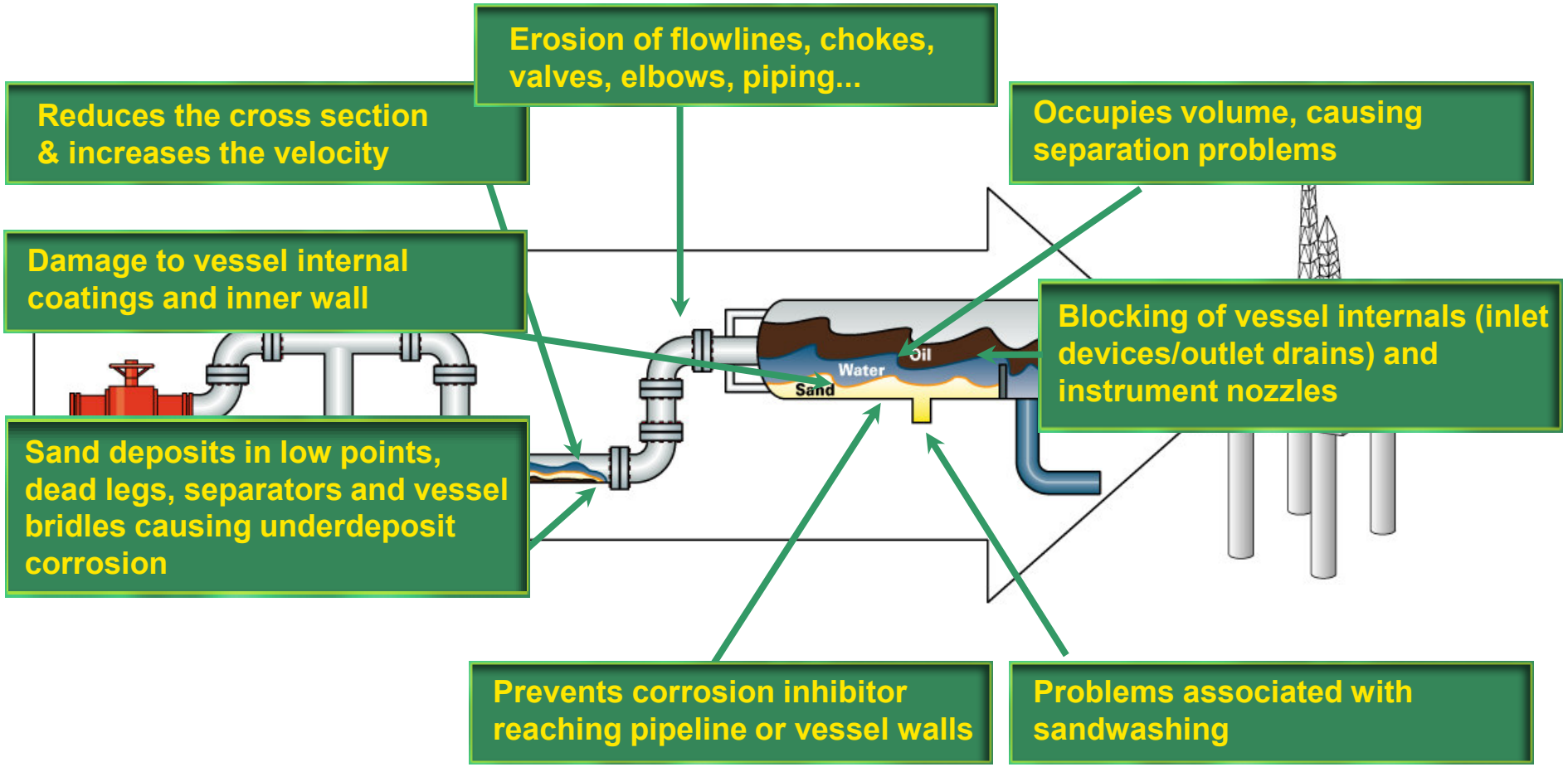


WHAT CAN GO WRONG?

"What problems do solids cause?"



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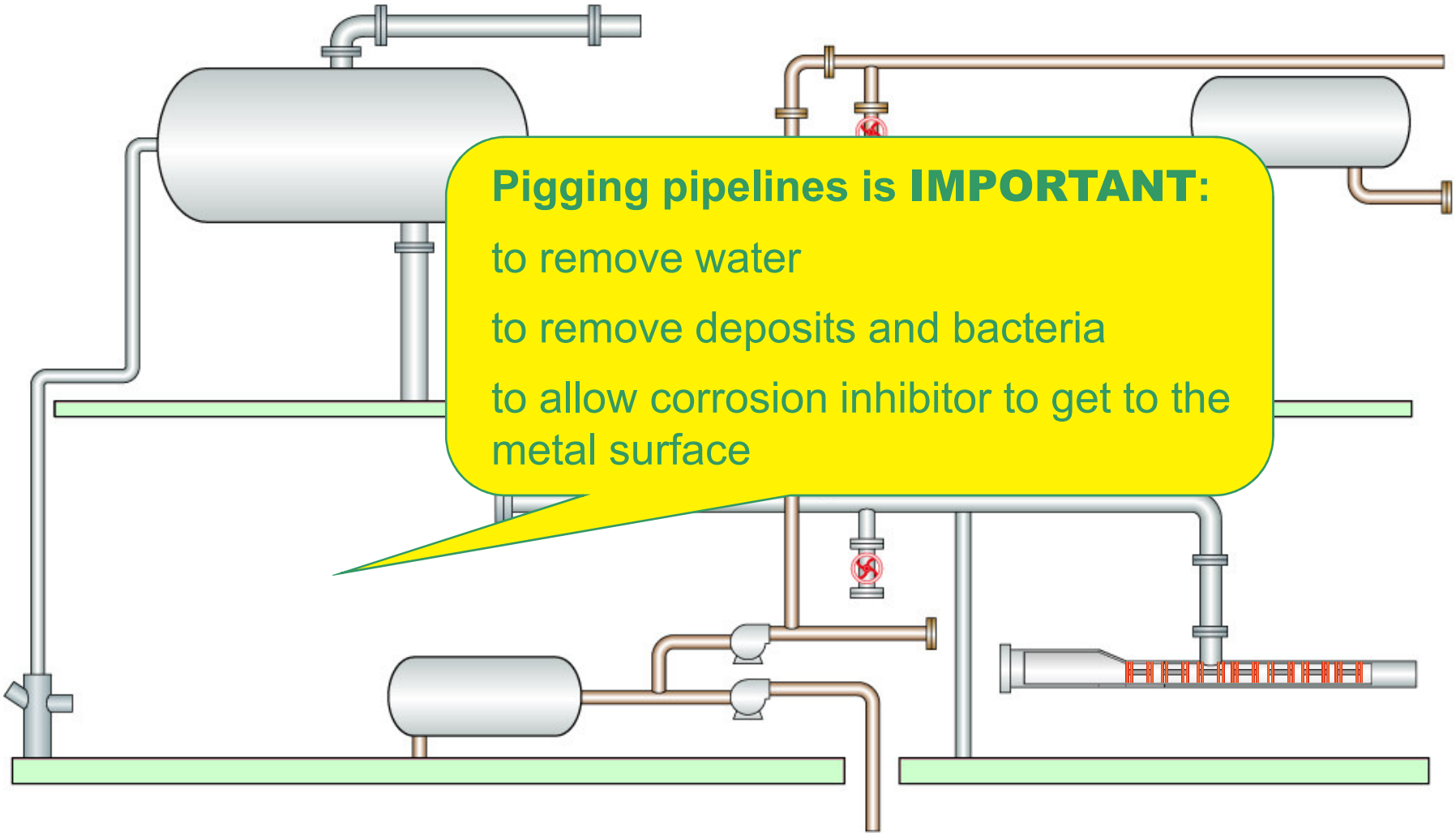


TACKLING THE RISK

"What can we do to reduce the threat"

Good Chemical Management is Vital

We depend on chemicals for corrosion control in our hydrocarbon process plant, export pipelines and water processing equipment

We could not operate our plant for long without chemicals

TACKLING THE RISK

"What can we all do?"

- Know your chemicals and how they impact corrosion and each other
- Think once, think twice, is the right chemical going to the right place?
- Is the back-up equipment working should the chemical pumps fail
- Monitor fluid parameters regularly
- Make it known if process conditions change (e.g. flow rates) Adjust chemical rates accordingly
- Keep chemical stocks up, especially in winter
- Ensure that sampling is carried out per procedures
- Support CIC corrosion management activities, e.g. scaffolding to aid coupon retrieval

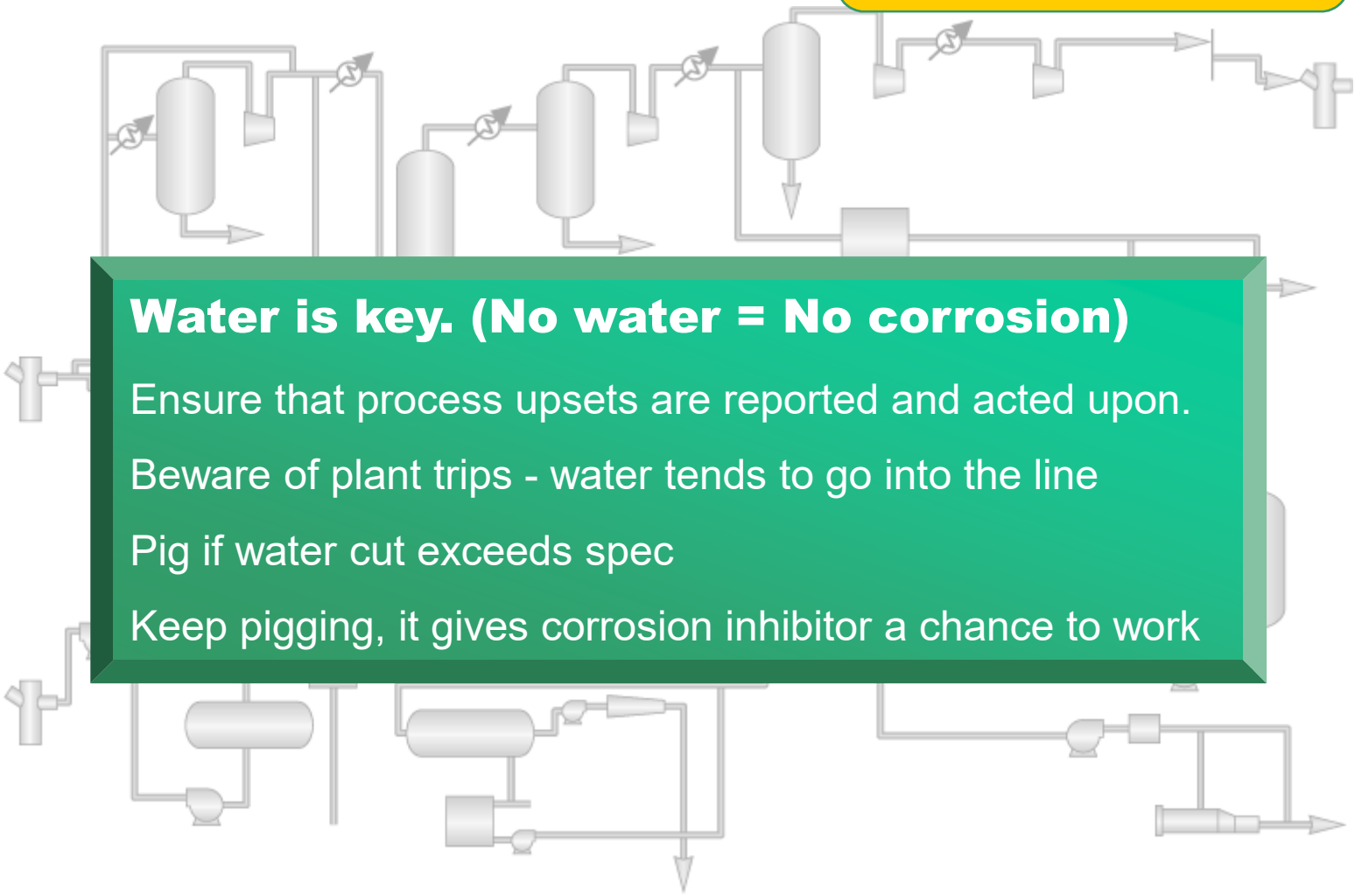
TACKLING THE RISK

"Some of the things we can do to reduce the threat"

Maintenance work - When opening up pipework, look inside and report concerns

TACKLING THE RISK

"Some of the things we can do to reduce the threat"



Water is key. (No water = No corrosion)

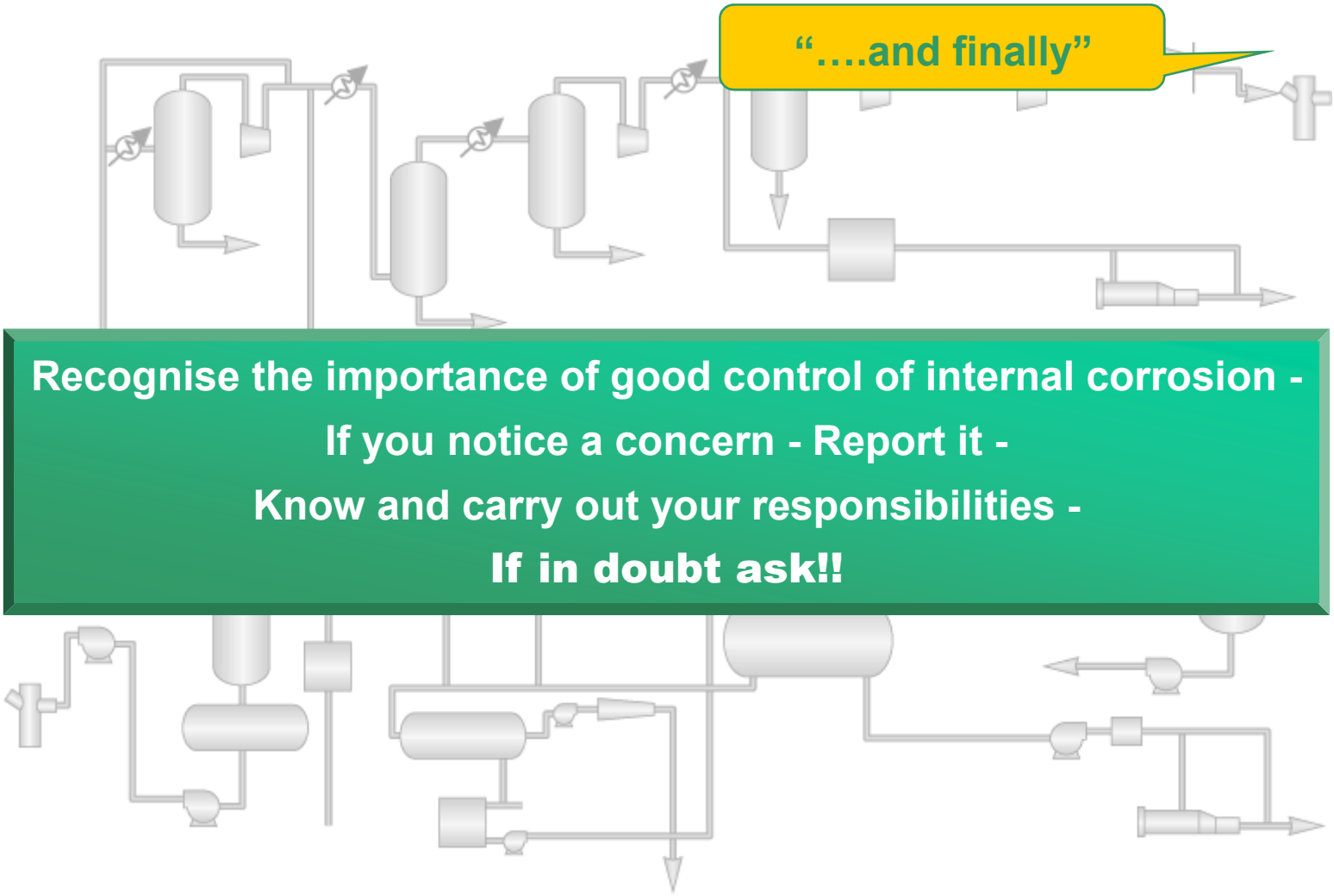
Ensure that process upsets are reported and acted upon.

Beware of plant trips - water tends to go into the line

Pig if water cut exceeds spec

Keep pigging, it gives corrosion inhibitor a chance to work

TACKLING THE RISK



Recognise the importance of good control of internal corrosion -

If you notice a concern - Report it -

Know and carry out your responsibilities -

If in doubt ask!!

EXTERNAL CORROSION

EXTERNAL CORROSION

What are our **external corrosion** threats?
How can we control them?

External corrosion of structural steel work

INTRODUCTION

External Corrosion Threats

Some Background

- External Corrosion
- Cathodic Protection

What Goes Wrong

What Can We Do?

THE THREATS

"What are the main **EXTERNAL** corrosion threats?"

Atmospheric Corrosion

- External corrosion caused by oxygen and water
- The example above nearly caused serious injury - or worse

Atmospheric Corrosion

Coatings Degradation of Topsides Structures & Plant

Corrosion under Insulation

Vibration / Fatigue Failures

Corrosion of Fastenings and Fittings

Corrosion of Stainless Steel / Duplex

Corrosion of Subsea Structures….

…. and Pipelines

THE THREATS

Coating Breakdown & Damage

- Natural degradation of coatings with time
- Accidental damage

Atmospheric Corrosion

Coatings Degradation of Topsides Structures & Plant

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THE THREATS

Corrosion Under Insulation (CUI)

- Caused by water ingress into insulation
- Affects not only carbon steel but also corrosion resistant alloys
- Insulated pipes, vessels and valves are all at risk

Atmospheric Corrosion

Coatings Degradation of Topsides Structures & Plant

Corrosion under Insulation

Vibration / Fatigue Failures

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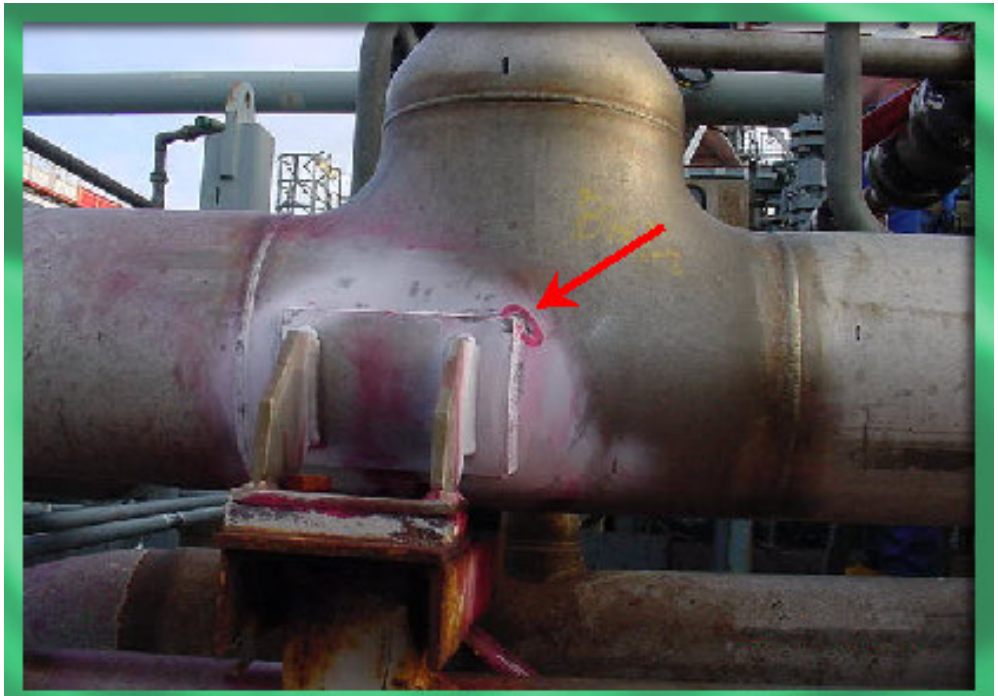
THE THREATS



Vibration Failures

- Especially small bore pipework
- Loose supports wearing away paint leading to fretting and corrosion

Atmospheric Corrosion

Coatings Degradation of Topsides Structures & Plant

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THE THREATS

Fastenings and Fittings

- Poor preservation of bolting
- Mixing materials

Atmospheric Corrosion

Coatings Degradation of Topsides Structures & Plant

Corrosion under Insulation

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Corrosion of Subsea Structures….

…. and Pipelines

THE THREATS

Corrosion Resistant Alloys

– **Duplex steels and stainless steels are at risk of pitting, crevice and cracking**

Atmospheric Corrosion

Coatings Degradation of Topsides Structures & Plant

Corrosion under Insulation

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Corrosion of Subsea Structures….

…. and Pipelines

THE THREATS

Subsea Structures & Pipelines

- **Poorly maintained or monitored CP systems**

Atmospheric Corrosion

Coatings Degradation of Topsides Structures & Plant

Corrosion under Insulation

Vibration / Fatigue Failures

Corrosion of Fastenings and Fittings

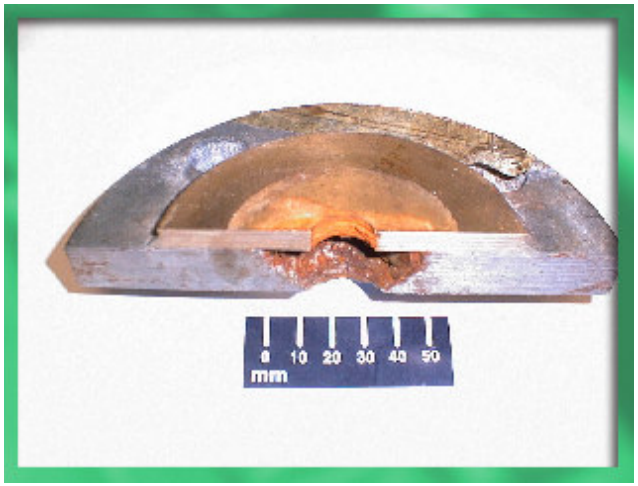
Pitting and Cracking of Stainless Steel / Duplex

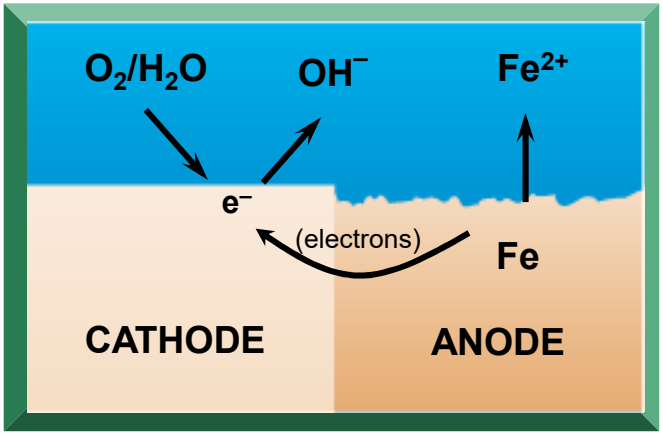
Corrosion of Subsea Structures….

…. and Pipelines

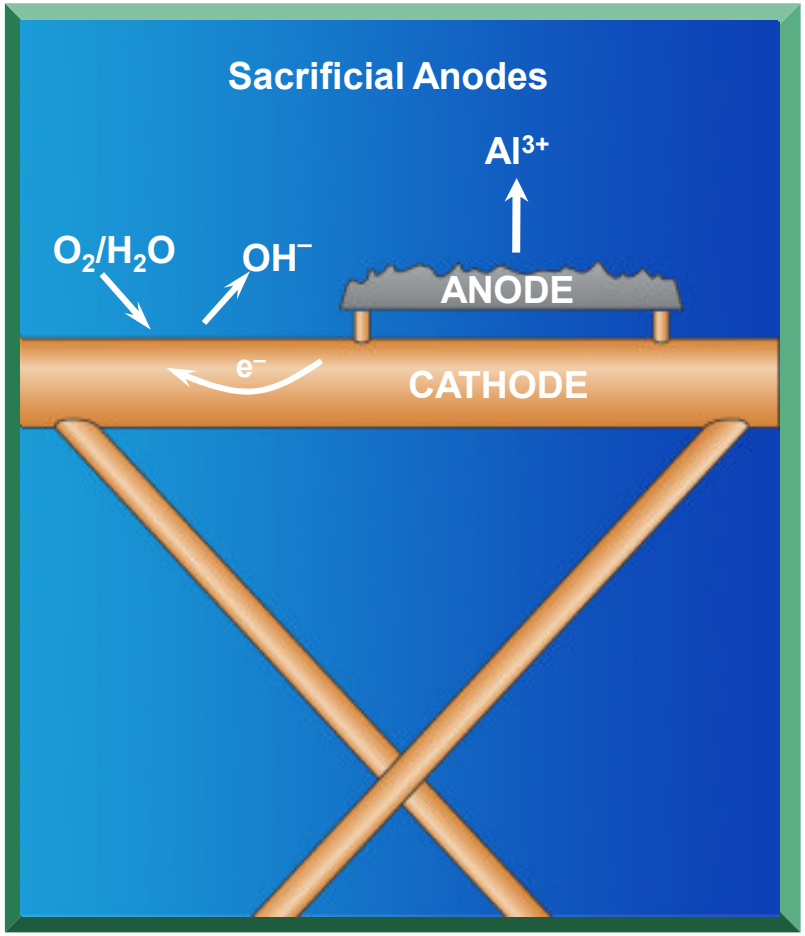
SOME FACTS

Remember…. Galvanic Corrosion?





"How does cathodic protection work?"



SOME FACTS

The marine environment around Trinidad is one of the most corrosive in the world. Steel corrodes at ~1-2mm/year (c.f. North Sea ~0.2 mm/year)

Why..? Temperature (+ moisture + salt)

Corrosion resistant alloys are subject to corrosion at elevated temperatures

- Duplex stainless steel is at risk of cracking if hot (>80°C) and permanently damp (e.g. under deposits)
- 316 stainless steels are subject to pitting and stress corrosion cracking if hot (>50°C)

Fastenings and fittings fail because wrong materials are used e.g. carbon steel plugs in cunifer or stainless steel pipework *(Galvanic corrosion)*

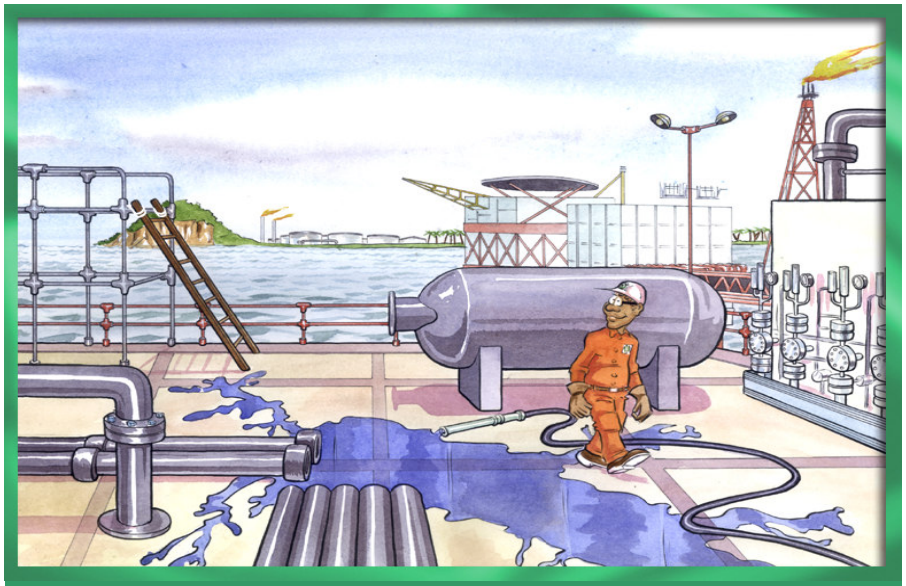
Surface corrosion often looks worse than it is - but inspection is required to assess the severity

Beware of corrosion under pipe supports

WHAT CAN GO WRONG?

External Corrosion

– Minimise time of wetness, e.g. don't allow hoses to run unnecessarily



Metal + Water + Corrodent = Corrosion

WHAT CAN GO WRONG?

External Corrosion

- Minimise time of wetness, e.g. don't allow hoses to run unnecessarily
- Even corrosion resistant alloys can corrode
- For example - stainless steel impulse lines

Corrosion of Stainless Steel Impulse Lines

WHAT CAN GO WRONG?

External Corrosion

- Minimise time of wetness, e.g. don't allow hoses to run unnecessarily
- Even corrosion resistant alloys can corrode
- For example - stainless steel impulse lines
- ..and stainless steel / duplex vessels & pipework
- Remove deposits

Corrosion of Stainless Steel Separator

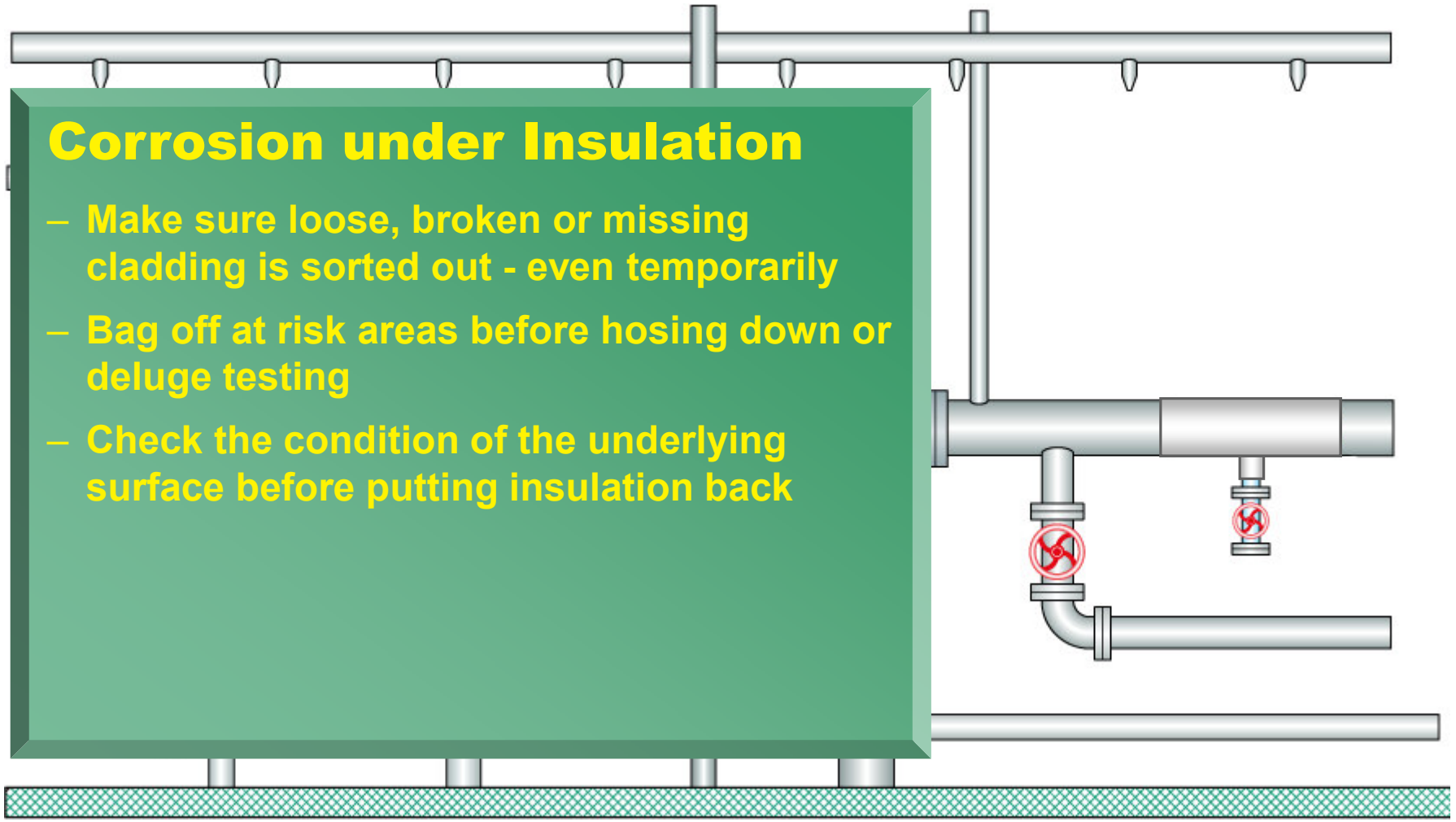
WHAT CAN GO WRONG?

Coatings

- Not finishing painting after construction or mods
- Not reporting concerns or damage
- Make the most of any opportunity to inspect inaccessible places, they often get neglected
- Report ANY concerns or damage

Damage to New Coating

WHAT CAN GO WRONG?



Corrosion under Insulation

- Make sure loose, broken or missing cladding is sorted out - even temporarily
- Bag off at risk areas before hosing down or deluge testing
- Check the condition of the underlying surface before putting insulation back

WHAT CAN GO WRONG?

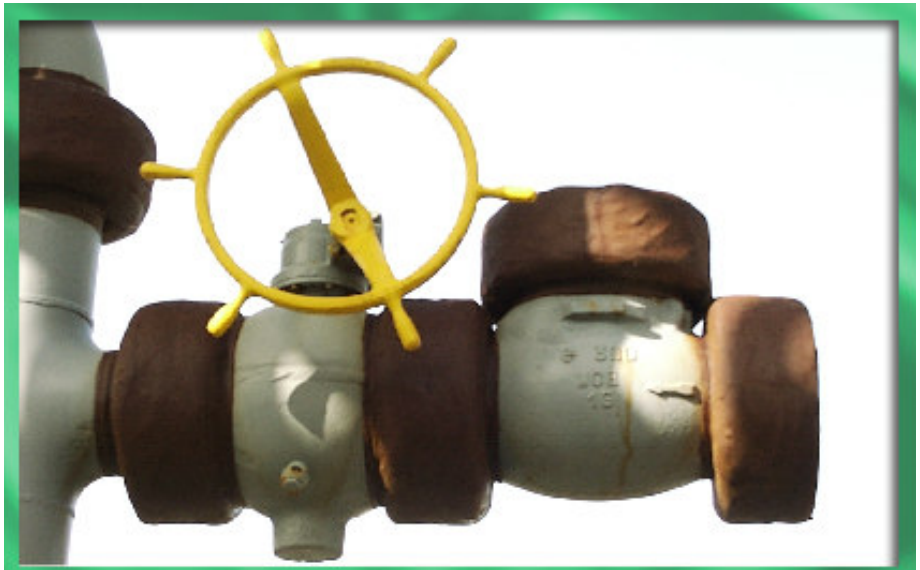
Corrosion under Insulation

- Make sure loose, broken or missing cladding is sorted out - even temporarily
- Bag off at risk areas before hosing down or deluge testing
- Check the condition of the underlying surface before putting insulation back
- Get something done about places where you have to step on insulation to access equipment
- Report any concerns

WHAT CAN GO WRONG?

Fastenings and Fittings

- Use the correct material
- e.g. consider hot dipped spun galvanised steel bolting
- Tape flanges
- Consider preservation coatings and caps

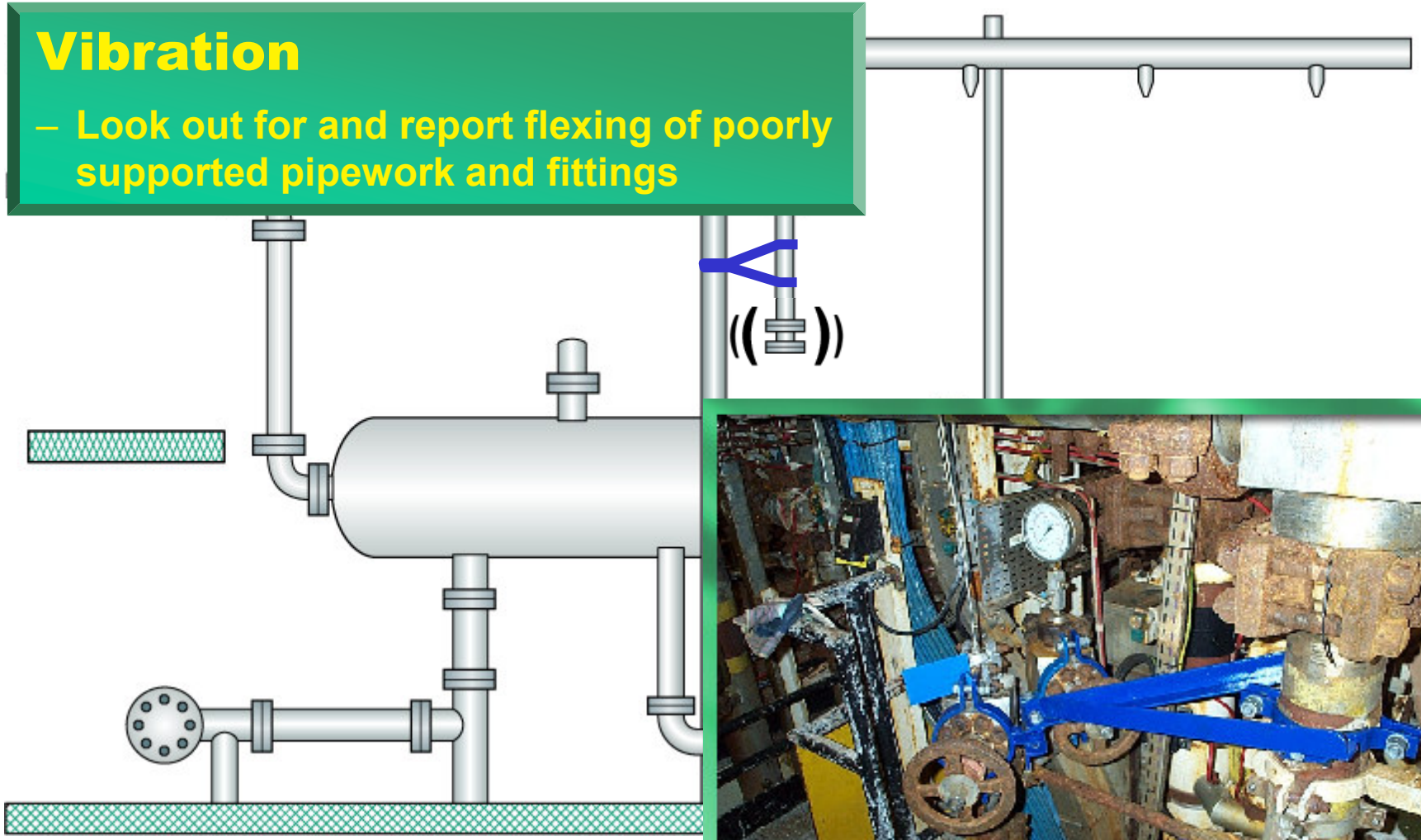


Taped Flanges

WHAT CAN GO WRONG?

Vibration

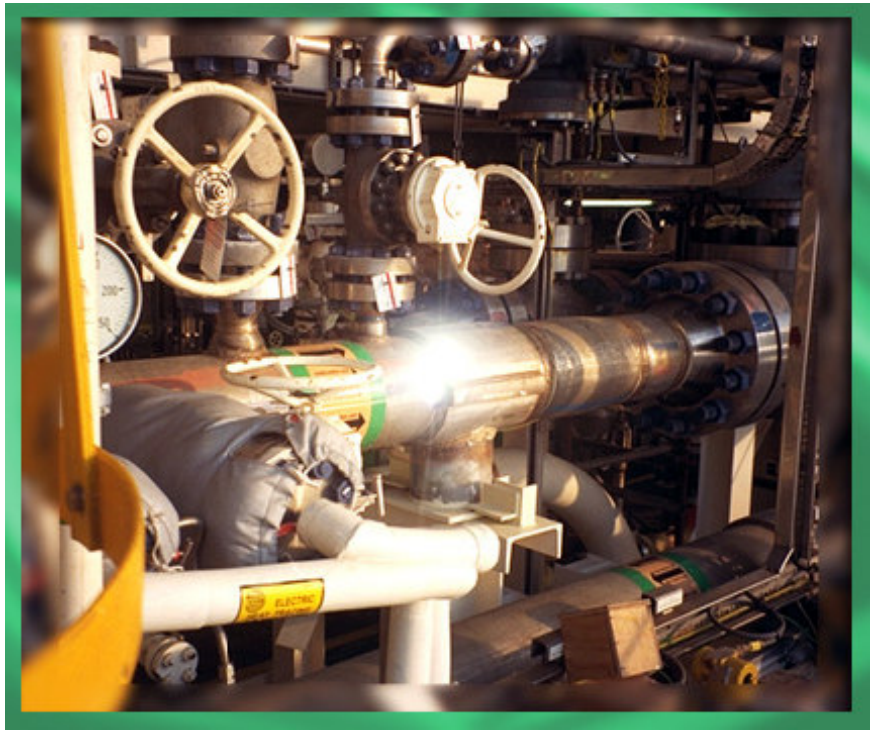
– Look out for and report flexing of poorly supported pipework and fittings



CORROSION CONTROL

CORROSION CONTROL

How do we **control corrosion** in BPTT?



How can we prevent this…..

….becoming this..?

INTRODUCTION

Threats – A Reminder

Corrosion Control Process

How do we Control Corrosion:

- Externally
- In Process Systems
- In Water Systems
- In Dead Legs

Corrosion Monitoring

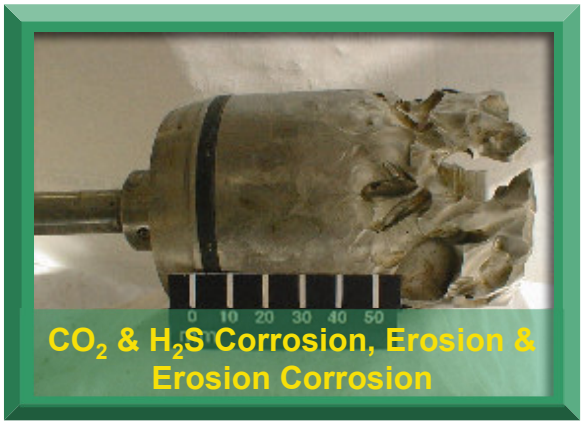
THE THREATS

"Where are the main corrosion threats?"

Atmospheric Corrosion, Coating Degradation & CUI

O_2 , Microbial & Erosion Corrosion

"What are the corrosion mechanisms?"



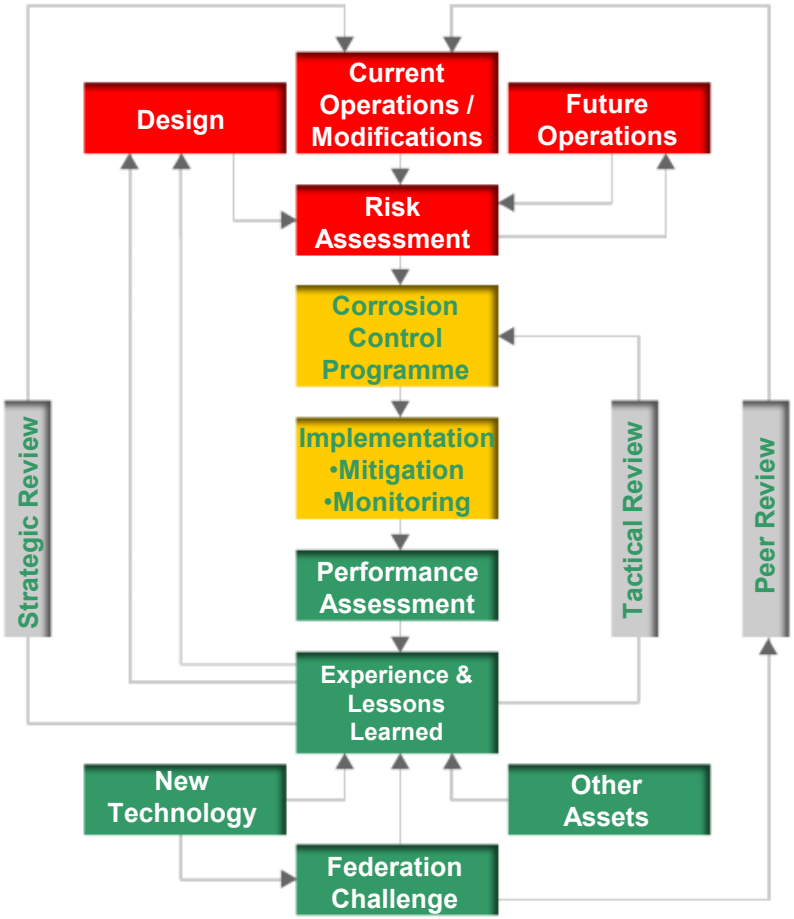
CO_2 & H_2S Corrosion, Erosion & Erosion Corrosion

O_2 , CO_2 & Microbial Corrosion

CO_2 Corrosion

OUR CORROSION CONTROL PROCESS

BP Corrosion Control System



Assess Risks

▼

Corrosion Control Programme

▼

Implementation

▼

Review

ASSESSING THE RISKS

"How do we assess the corrosion risks?"

Identify the deterioration mechanisms

e.g. carbon dioxide, bacteria, oxygen

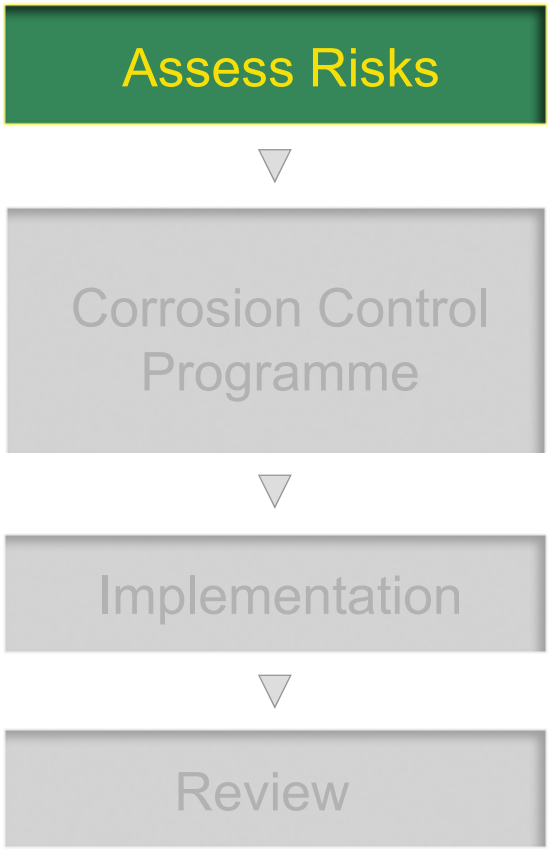
Assess likelihood & rate of deterioration

Estimate the risk

(Risk = Consequences (Safety & Operability) x Likelihood)

Rank the priorities

Outcome drives the Corrosion Control Programme / Monitoring / Inspection



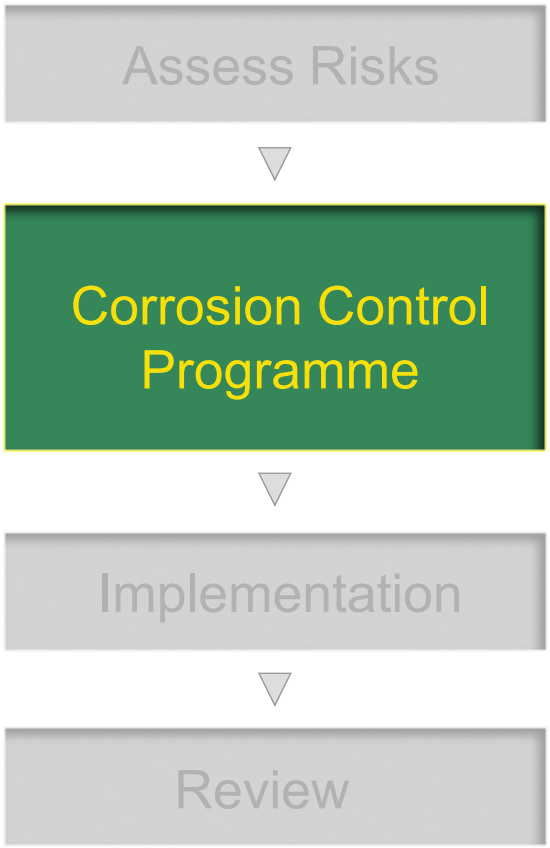
CONTROLLING CORROSION

"What is a corrosion control programme?"

Modify production process in line with conditions - e.g. throughput management, dehydration, gas dehydration

Implement corrosion mitigation - chemical deployment (e.g. corrosion inhibitor, oxygen scavenger, biocide), materials selection

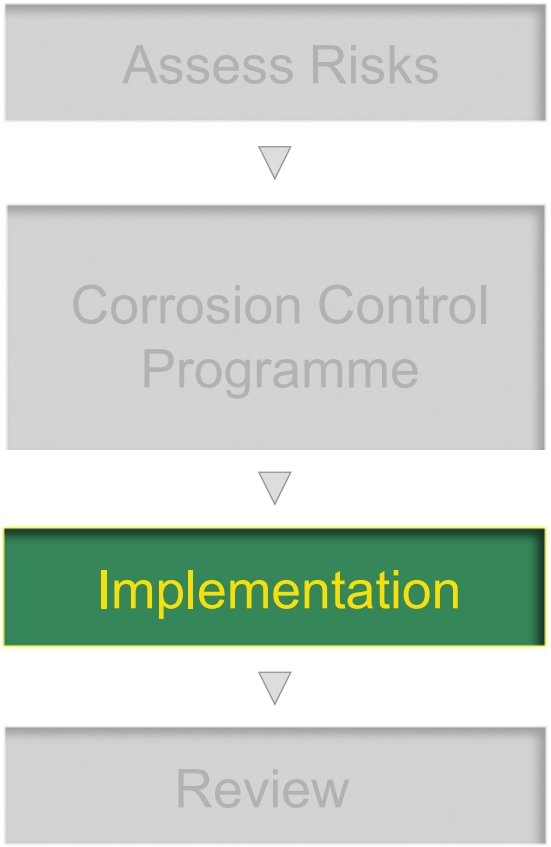
Undertake engineering changes / modifications - e.g. replacement plant or minor process changes



OUR CORROSION CONTROL PROCESS

... put the Corrosion Control Programme into action

….more on this in a moment



INSPECTION & MONITORING

We Monitor & Inspect

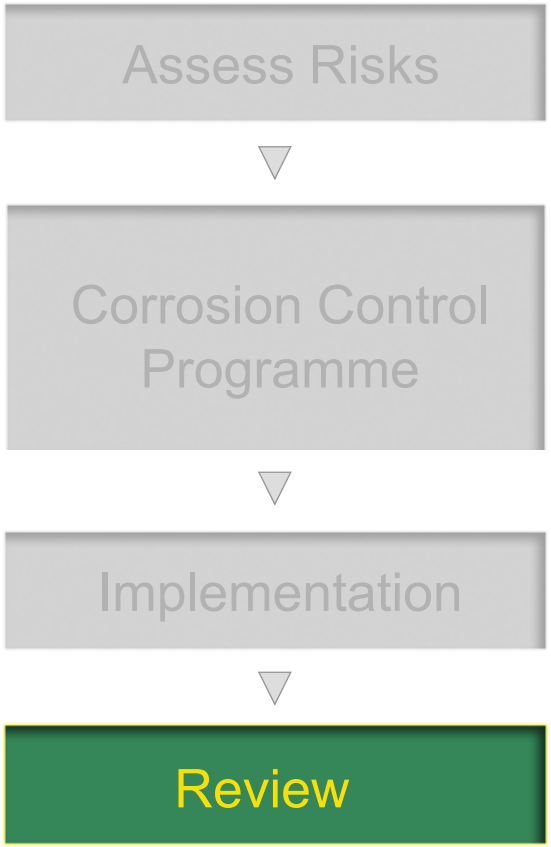
To check that our plant integrity is OK and that our corrosion control activities are working

Risk Based Inspection

We can't inspect everything - so we use RBI to prioritise where and how often we should inspect

i.e. We assess the probability and consequence of corrosion and concentrate on areas of high risk.

Priority goes to the high risk areas

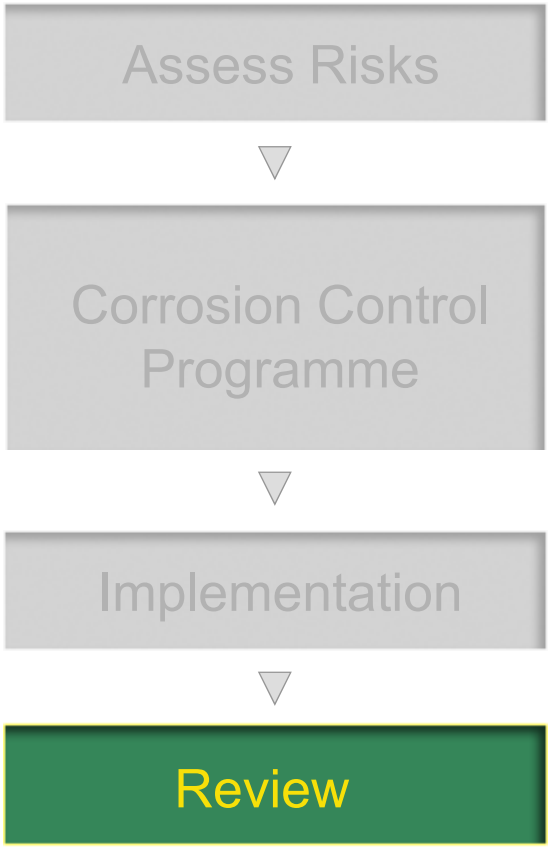


REVIEW

We review the outcomes of the corrosion control programme to optimise its effectiveness

Our *key performance indicators* tell us where we stand

- Anomalies
- Remedial orders
- Leaks
- Cost



CONTROLLING CORROSION IN ACTION

Externally

In Process Fluids

In Water Systems

In Dead Legs

EXTERNAL CORROSION

Vessels - Pipework - Structures

How do we avoid this?

"**Paint to isolate** them from water and corrodents"

EXTERNAL CORROSION

Corrosion Under Insulation

How do we avoid **CUI**?"

"We try to keep insulation **dry**"

EXTERNAL CORROSION

Bolting & Fastenings

Select materials to avoid galvanic corrosion and/or **protect bolting**, e.g. caps or preservative

How do we avoid corroded bolting?

EXTERNAL CORROSION

Corrosion Resistant Alloys

How do we avoid damaging CRA's?

Avoid the build-up of "salt" deposits or coat where necessary

EXTERNAL CORROSION

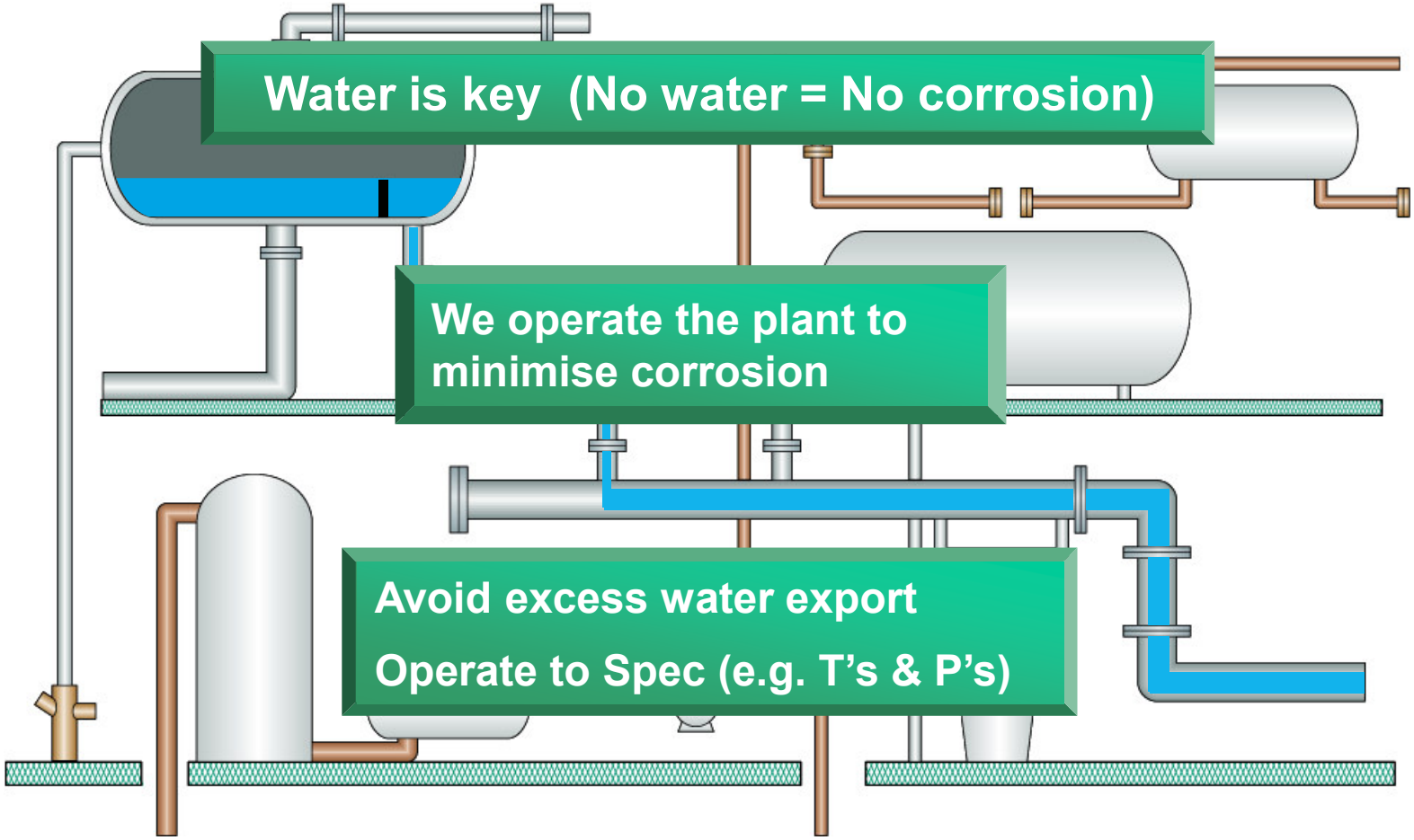
Subsea

How do we avoid corrosion subsea?

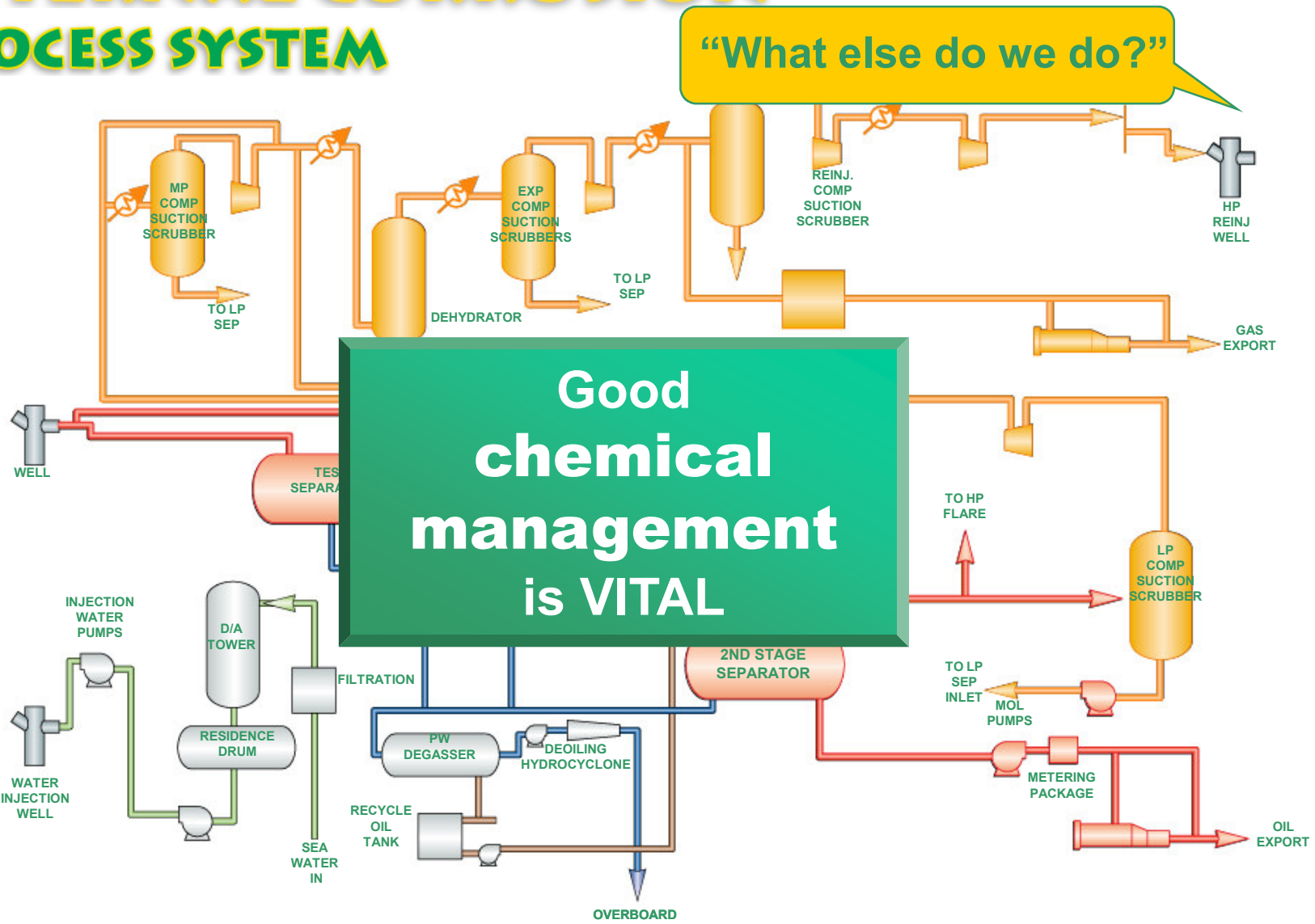
We use **coatings** and **cathodic protection** by sacrificial and impressed current anodes to prevent corrosion

INTERNAL CORROSION
PROCESS SYSTEM

"How do we avoid corrosion in our process systems?"



INTERNAL CORROSION
PROCESS SYSTEM



INTERNAL CORROSION
PROCESS SYSTEM

This equipment protects infrastructure worth $$Millions

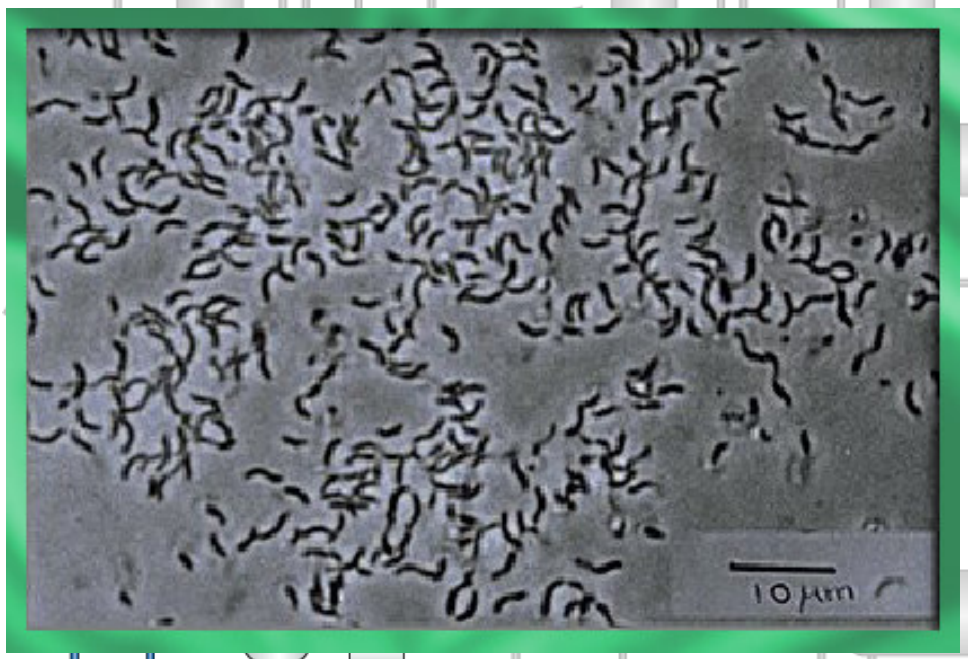
INTERNAL CORROSION
WATER SYSTEM

"How do we avoid corrosion in our water systems?"

Remove Oxygen
(Deaerators - Oxyscav - Avoid Leaks)

INTERNAL CORROSION

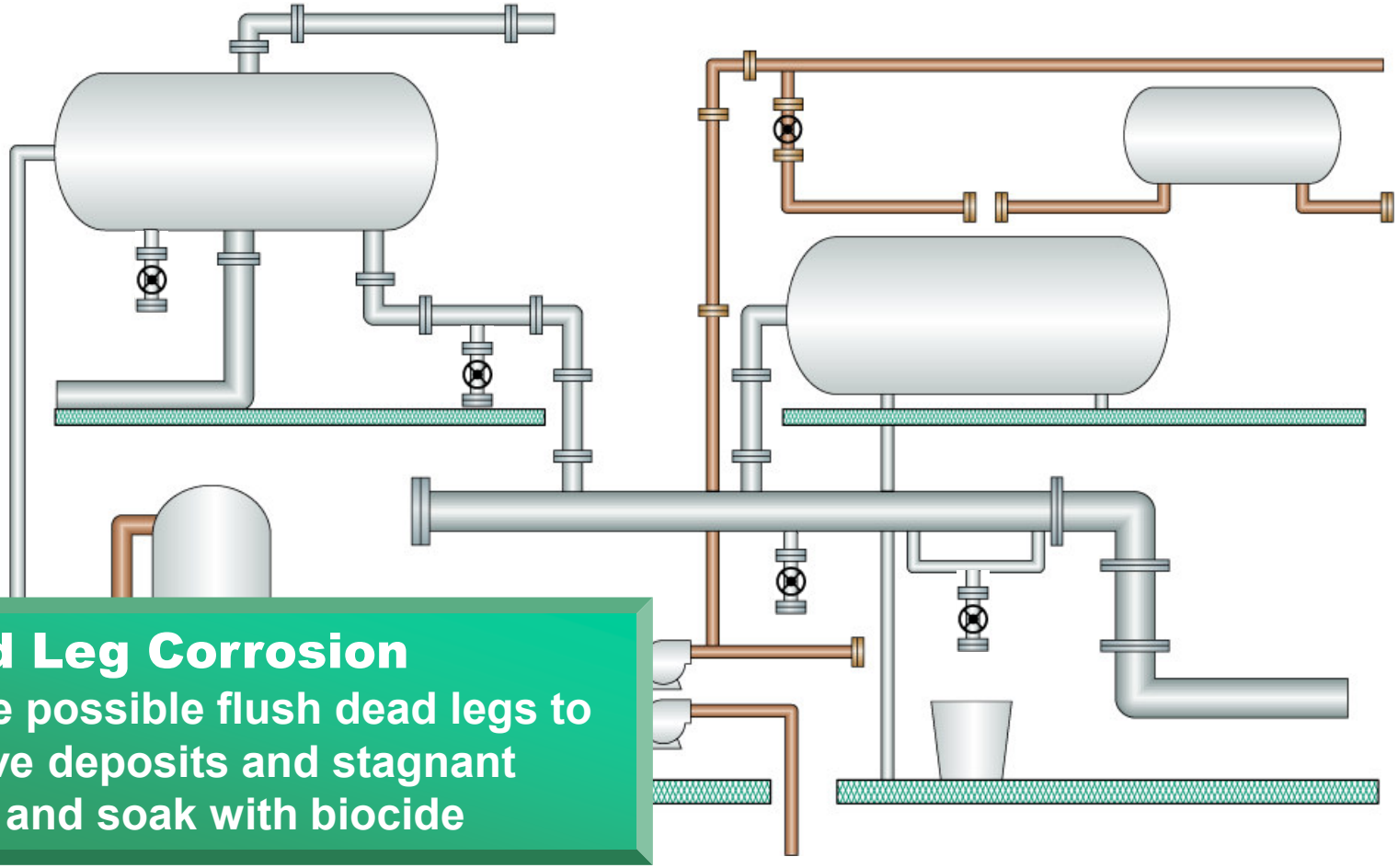
WATER SYSTEM



Control bacteria (Chlorination)
Kill bacteria (Biociding)

DEAD LEG CORROSION

"How do we avoid **dead leg** corrosion?"

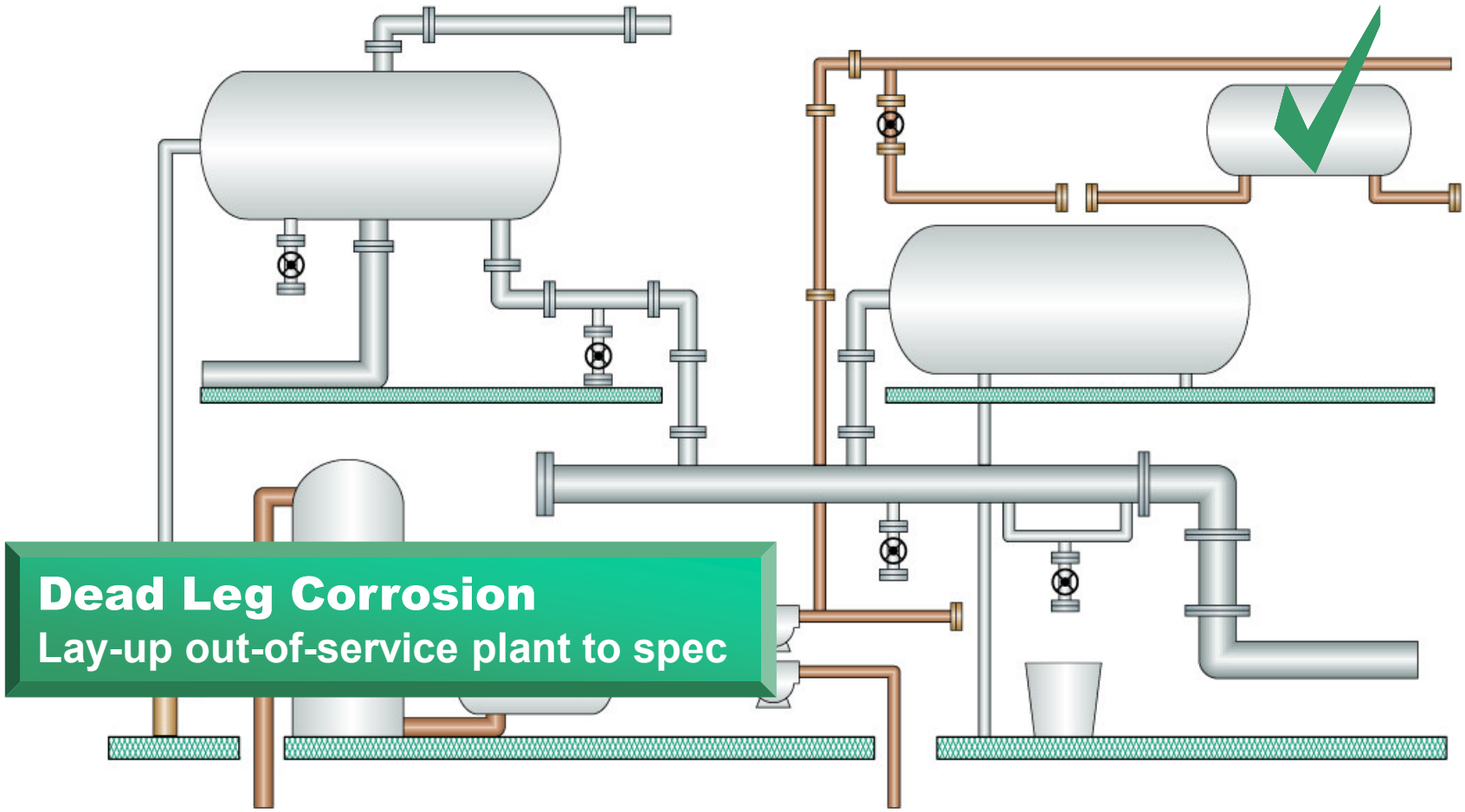


Dead Leg Corrosion

Where possible flush dead legs to remove deposits and stagnant water and soak with biocide

DEAD LEG CORROSION

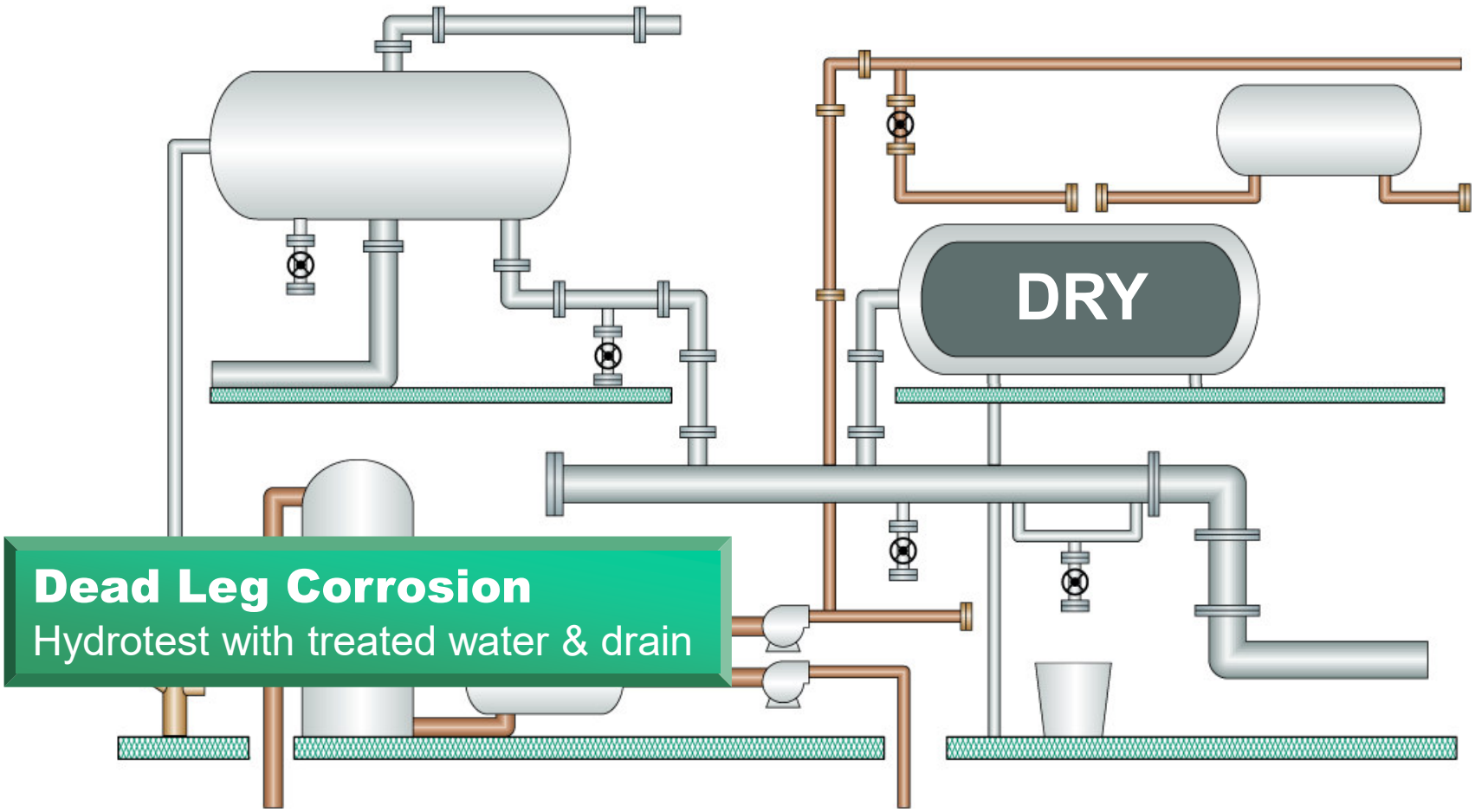
"How do we avoid **dead leg** corrosion?"



Dead Leg Corrosion
Lay-up out-of-service plant to spec

DEAD LEG CORROSION

"How do we avoid **dead leg corrosion?**"



Dead Leg Corrosion
Hydrotest with treated water & drain

CORROSION MONITORING

How does it help to control corrosion?

Corrosion monitoring allows us to respond to corrosion before too much damage is done

Internal corrosion monitoring helps us to optimise corrosion control activities, e.g. inhibitor injection rates - whilst minimising operational costs

It can be used as an alarm for operational excursions, e.g. excess water export

On-line techniques help us to understand what operational activities increase corrosion so that we can consider change

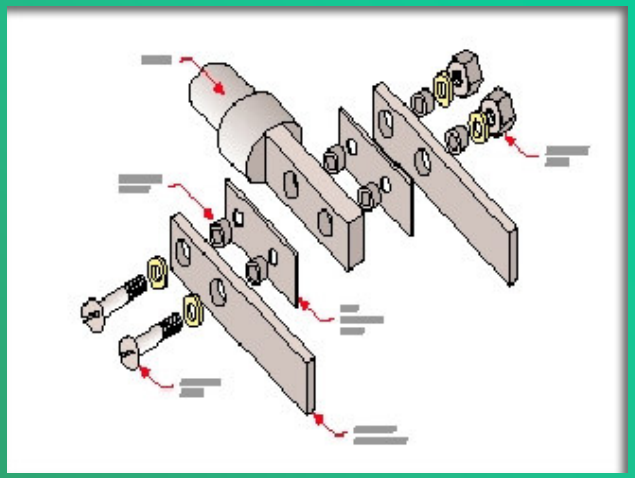
Corrosion Probes

CORROSION MONITORING

Probes or coupons are put into or onto pipework or vessels at locations which may be at risk

The main methods of corrosion & erosion monitoring are:

Weight-loss coupons



Weight-Loss Coupons

Weight loss coupons give corrosion rates averaged over time, i.e. coupons are removed and weighed every few months

CORROSION MONITORING

Probes or coupons are put into or onto pipework or vessels at locations which may be at risk

The main methods of corrosion & erosion monitoring are:

Weight-loss coupons

Electrical Resistance (ER) probes

Electrical Resistance

A metal element is exposed to the fluid

As the element corrodes, it gets thinner, as it thins, its resistance increases

The resistance is recorded at regular intervals

The corrosion rate is calculated from the change in resistance

CORROSION MONITORING

Probes or coupons are put into or onto pipework or vessels at locations which may be at risk

The main methods of corrosion & erosion monitoring are:

Weight-loss coupons

Electrical Resistance (ER) probes

Linear Polarisation Resistance (LPR) probes

Linear Polarisation Resistance (LPR)

A corrosion probe containing identical metal elements is exposed to the fluid

A small voltage is applied between them (~10mV)

The current that flows is measured

The current approximates to the corrosion rate - It's not an exact science..!!

CORROSION MONITORING

Probes or coupons are put into or onto pipework or vessels at locations which may be at risk

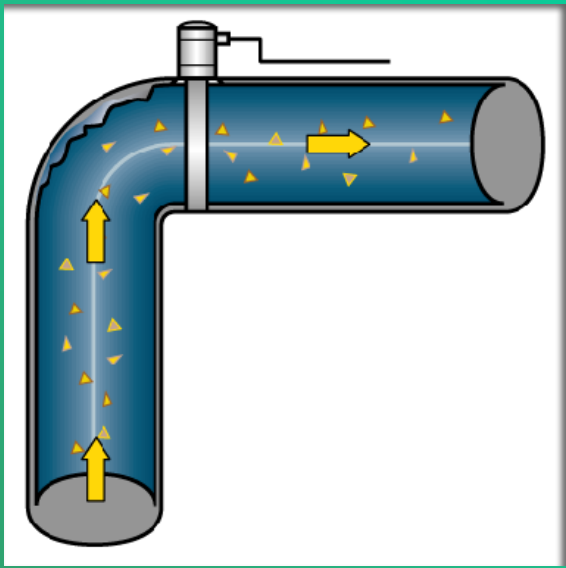
The main methods of corrosion & erosion monitoring are:

Weight-loss coupons

Electrical Resistance (ER) probes

Linear Polarisation Resistance (LPR) probes

Acoustic sand monitoring probes



Acoustic sand monitoring

A sensor is clamped on to the outside of a bend, where it monitors the ultrasonic pulses caused by particles hitting the pipe wall

WHAT CAN I DO?

- Understand what and where are the main *corrosion threats*
- Play your part in preventing corrosion
  - Externally
    - Avoid water getting into insulation
    - Avoid damaging paint-work
  - Internally
    - Help to maintain chemical injection
    - Look out for corrosion damage when opening up plant
- Report any corrosion damage or concerns

"Corrosion is everyone's concern"