Corrosion in Offshore Energy

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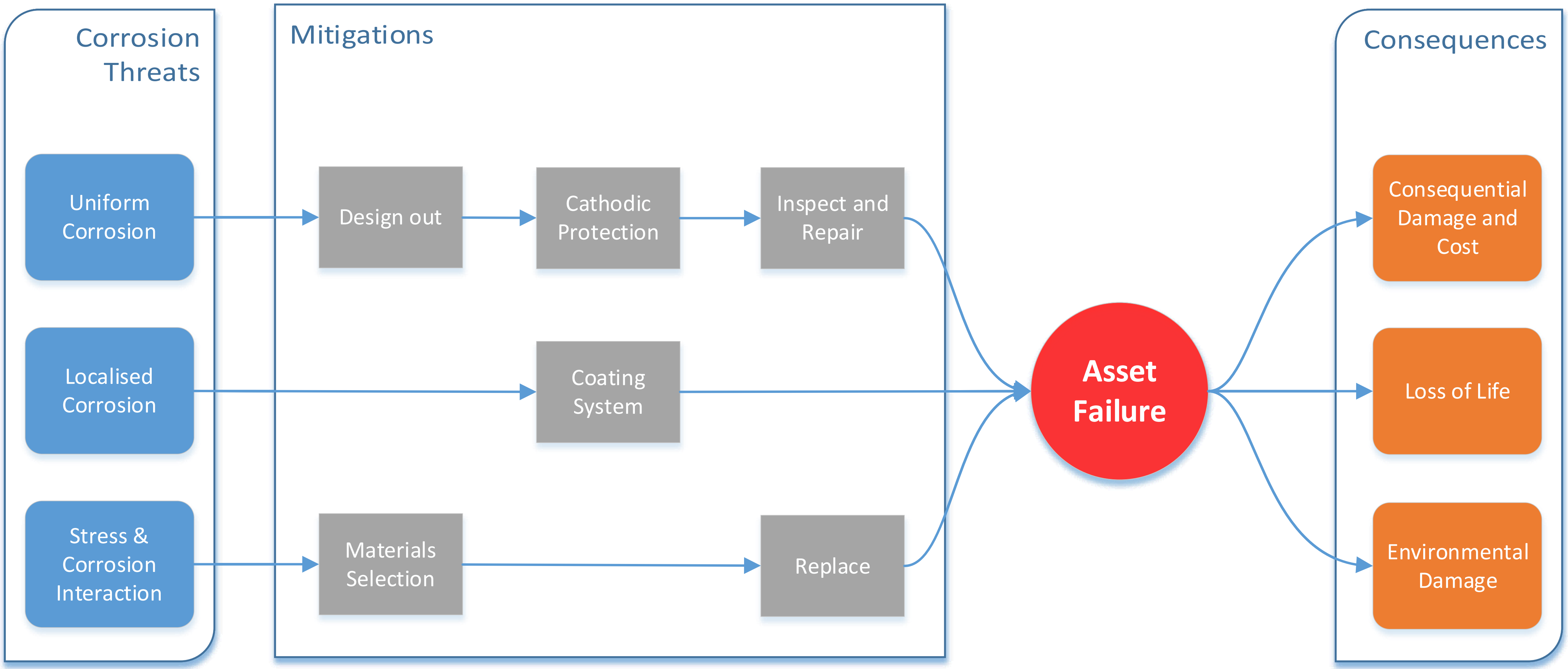
SYSTEMS AND ENGINEERING TECHNOLOGY

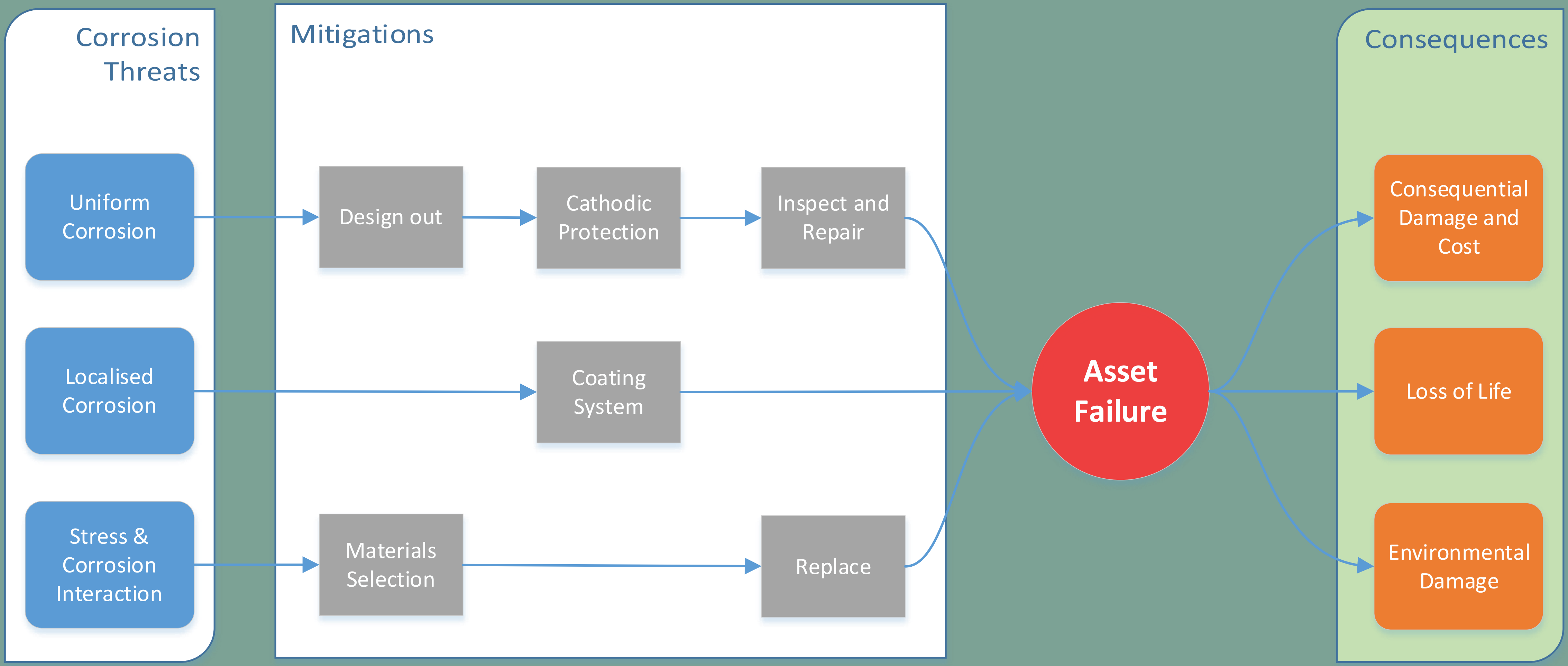
FRAZER-NASH CONSULTANCY

Example Corrosion Failure Pathways



1. The Cost and Consequences of Corrosion

Why should we care about it?



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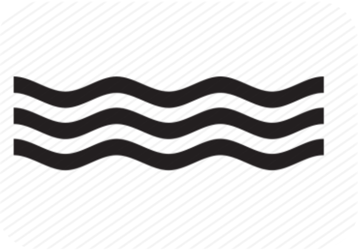
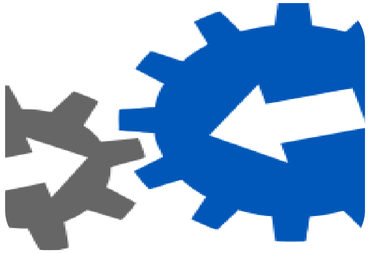
Corrosion as a Hazard

“**Corrosion** is a natural process which **converts a refined metal** to a more stable form such as its oxide, hydroxide or sulphide state, leading to deterioration of the material.”

Metal



Water



Contact

Time

“corrosion costs equivalent to about 3%–4% of each nation's GDP”[1]

“estimates the global cost of corrosion to be US $2.5 trillion”[1]

High Severity + High Likelihood = High Cost

1. *IMPACT study (International Measures of Prevention, Application and Economics of Corrosion Technology) released 2016.*

The Erika Disaster 1999

- 12th Dec 1999 the vessel split in two spilling 20,000 tonnes of oil
- Damaged over 400 km of coastline
  - 40,000+ sea birds and mammals killed
  - Clean up took 12+ months
  - Generated 200,000 tonnes of oily waste
- Huge reputational damage for the industry
- Estimated costs: €192,800,000

The Cause and Aftermath

- Root cause concluded to be excessive corrosion and poor management of repairs
- Parts of the ship were 30-50% corroded, severely inhibiting structural strength
- “Catalogue of errors” surrounding inspection and maintenance
- EU legislation reform passed in 2003

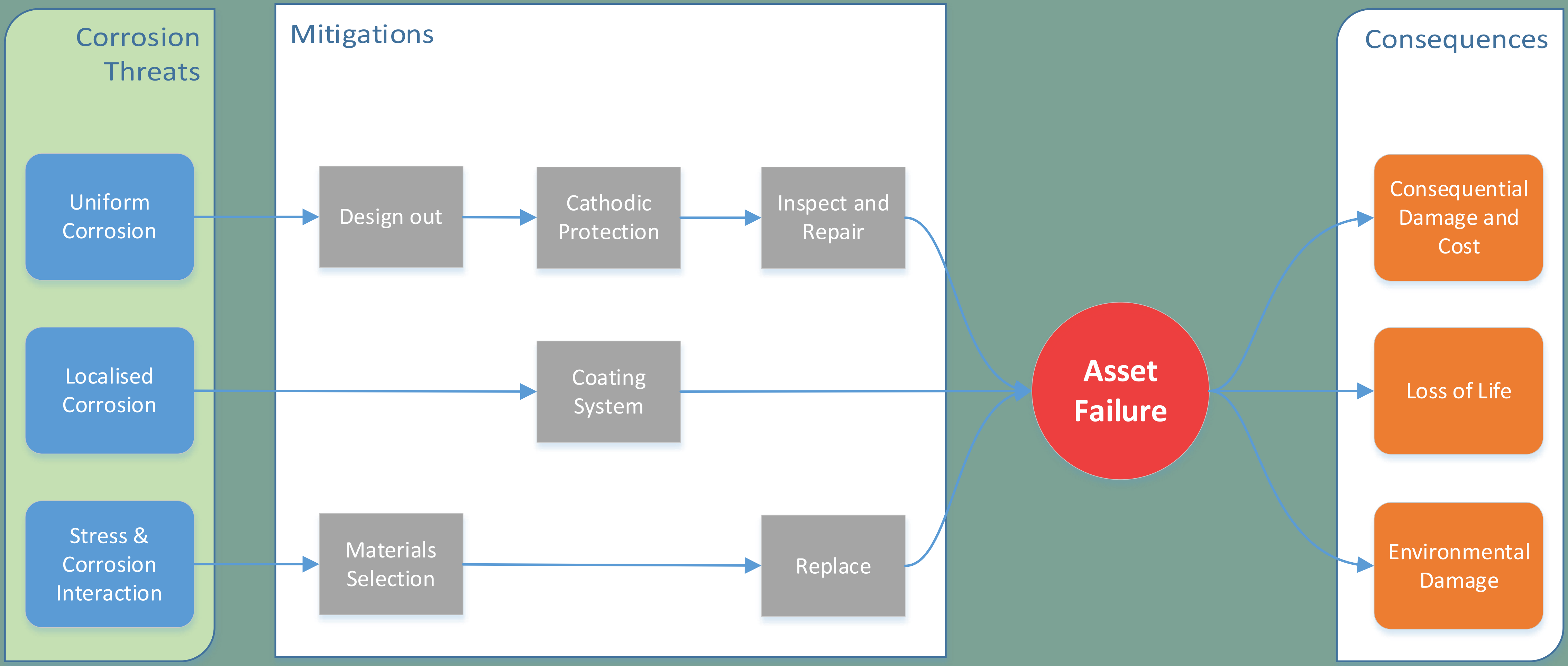
Corrosion in Offshore Energy

- Long-term problem in a relatively nascent industry
- Addressing corrosion has the potential to:
  - Prevent outage
  - Reduce environmental damage
  - Reduce risk to life during maintenance
  - Save money
- Cost of remedying coating failures is 50-100 times higher for offshore compared to onshore[1]
  - Coating failure on a wind farm offshore Ireland cost over £2m to fix
  - 20 x cost of original installation

1. https://www.twi-global.com/media-and-events/insights/better-coatings-can-substantially-reduce-the-cost-of-offshore-wind-energy

2. Corrosion Threats

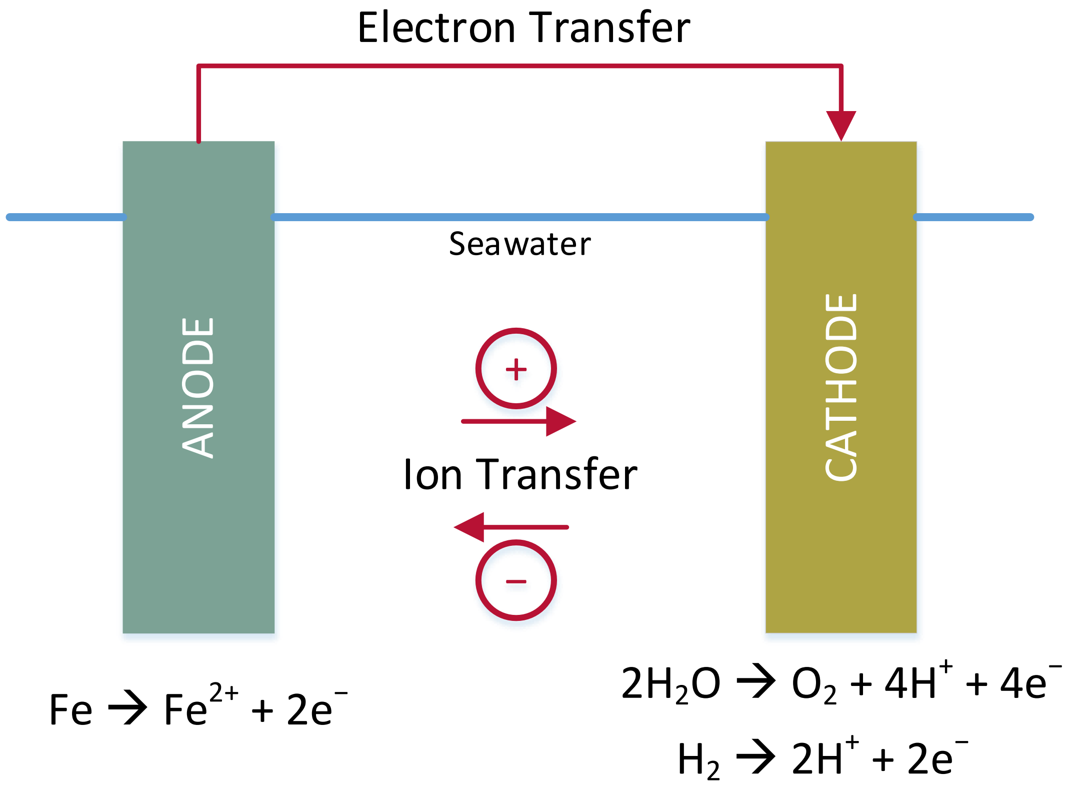
How do assets corrode?



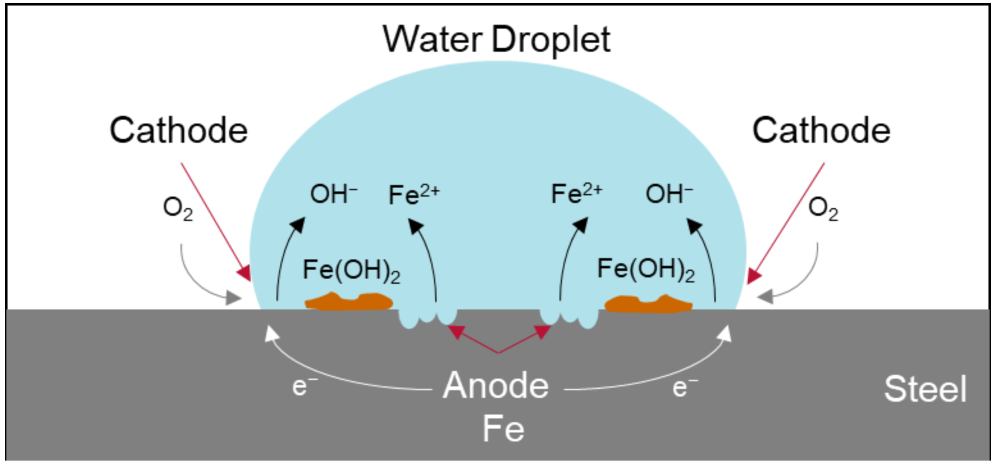
Why does Corrosion Happen?

- Brief reminder of aqueous electrochemistry
- 4 Key Components:
  - Anode – metal oxidation
  - Cathode – oxygen/water reduction
  - Electrical Connection for e^- transfer
  - Water for ion transfer

- Require a favourable environment that provides:
  - A Driving Force (thermodynamics)
  - Enables Charge Transfer (kinetics)



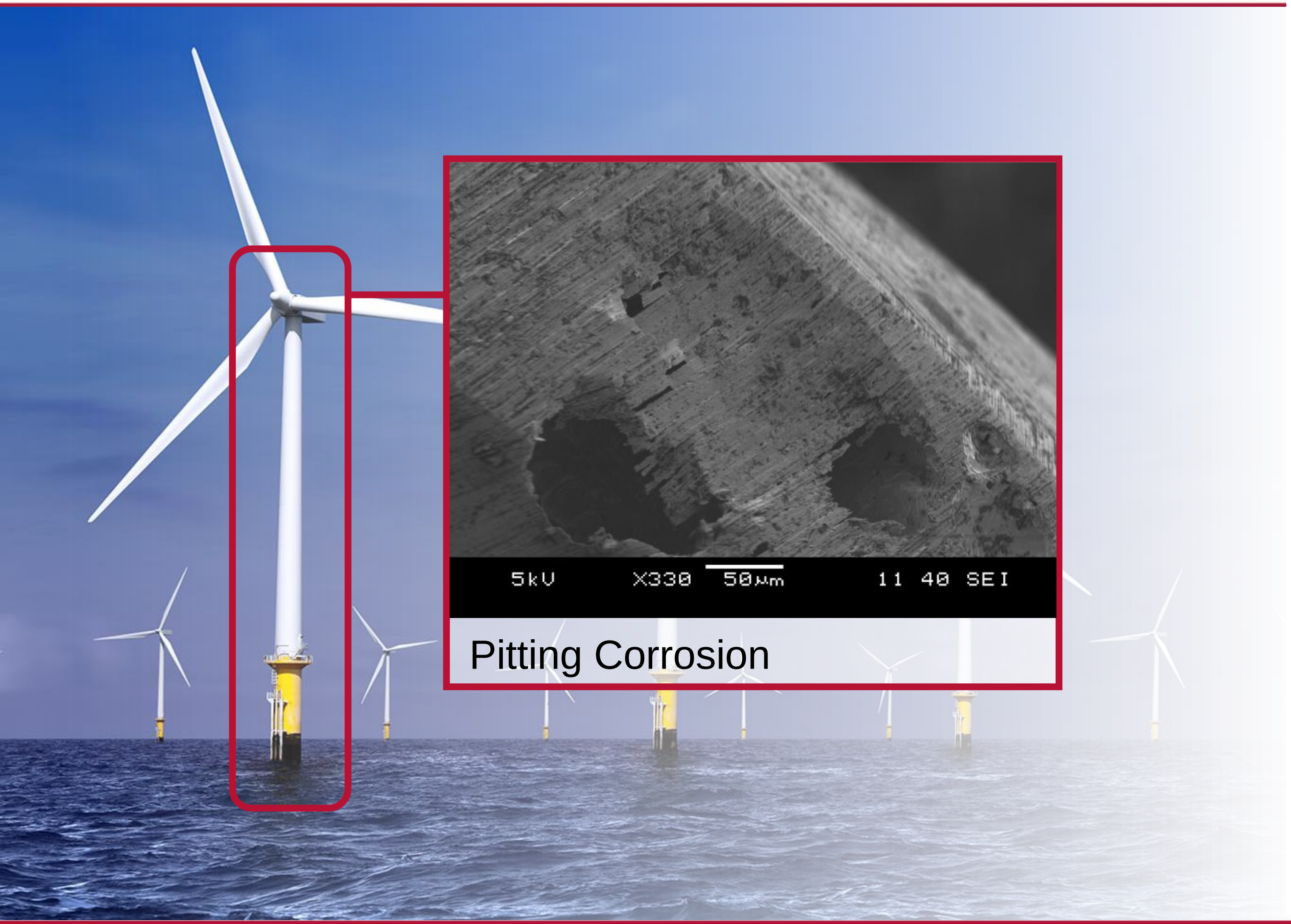
Uniform Corrosion (e.g. Rust)



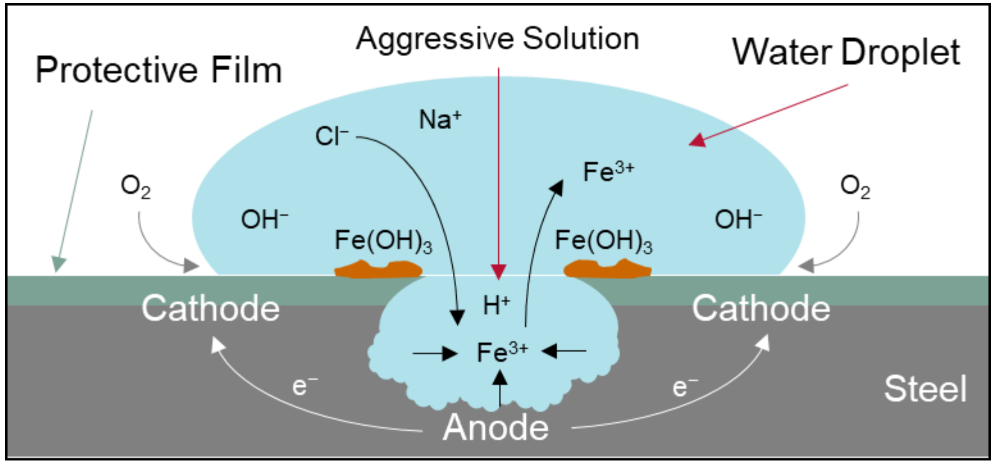
- Key Material Factors:
  - Material stability to water/seawater
  - Surface homogeneity
  - Microstructure homogeneity
  - Inherent ability to form protective film
- Key Environment Factors:
  - Temperature
  - Dissolved O_2
  - pH
  - Salinity / Salt Deposition
  - Water Velocity
  - Time of Wetness

Image: Rust_and_dirt by Roger McLassus

Pitting Corrosion



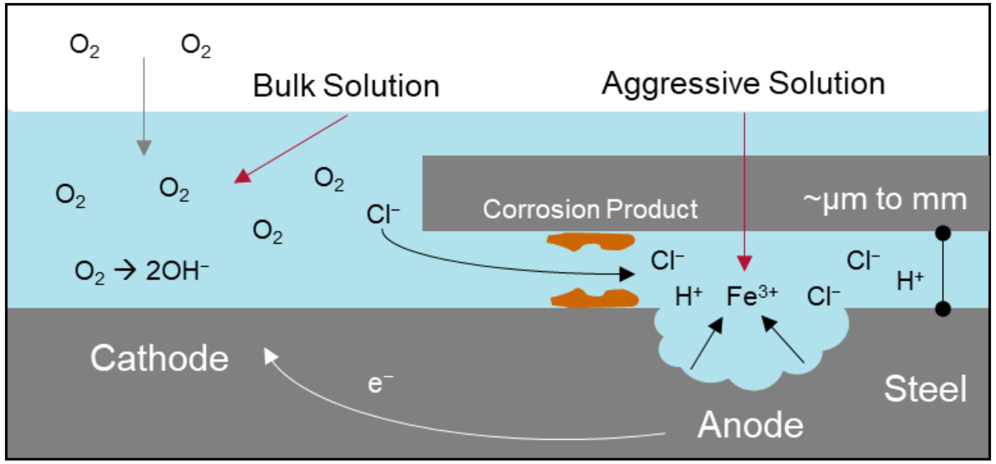
Pitting Corrosion

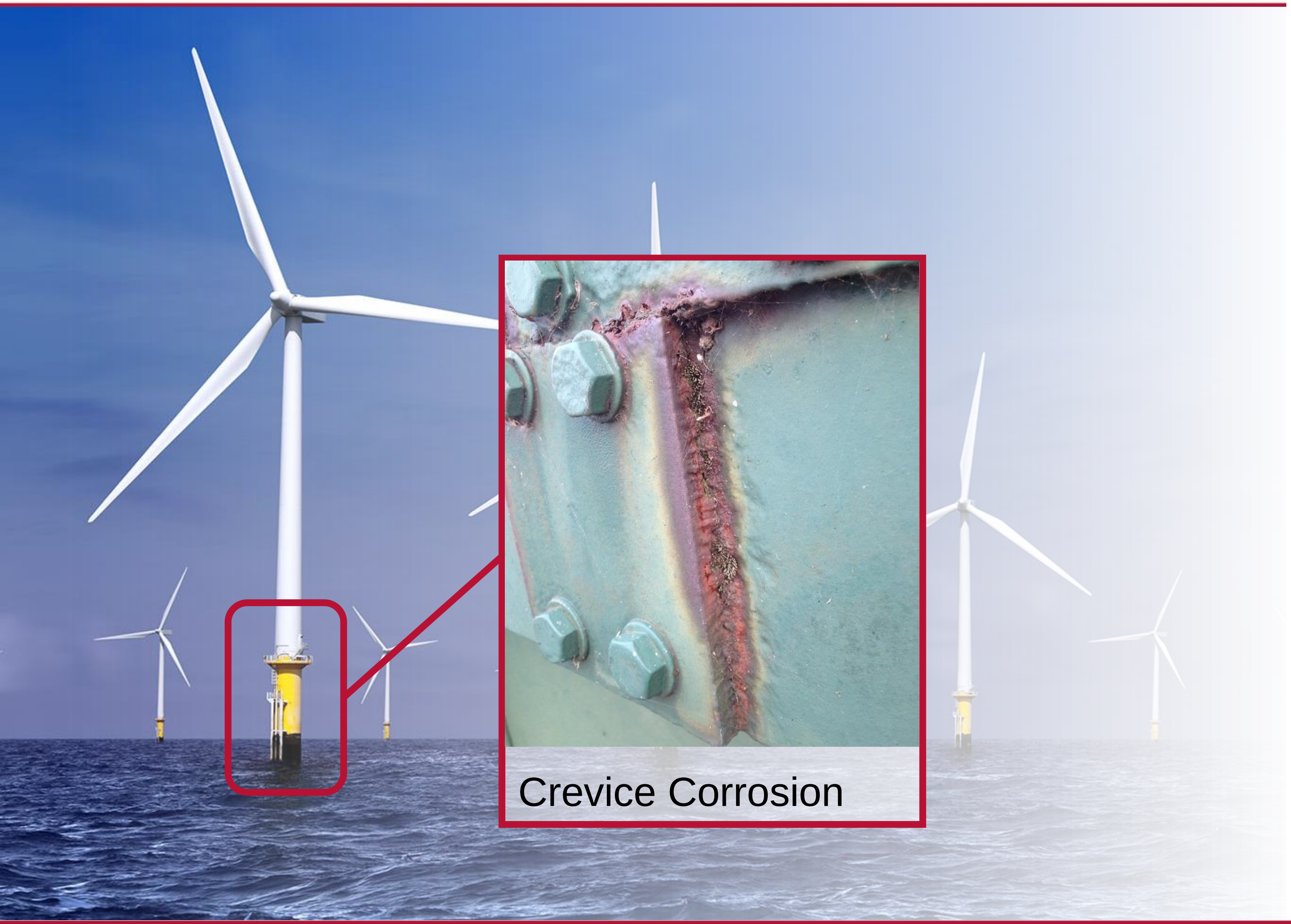


- Key Material Factors:
  - Material (PREN number)
  - Surface roughness
  - Presence of inclusions
  - Protective film quality

- Key Environment Factors:
  - Chloride concentration
  - Temperature
  - Synergy with other anions
  - Water velocity

Crevice Corrosion





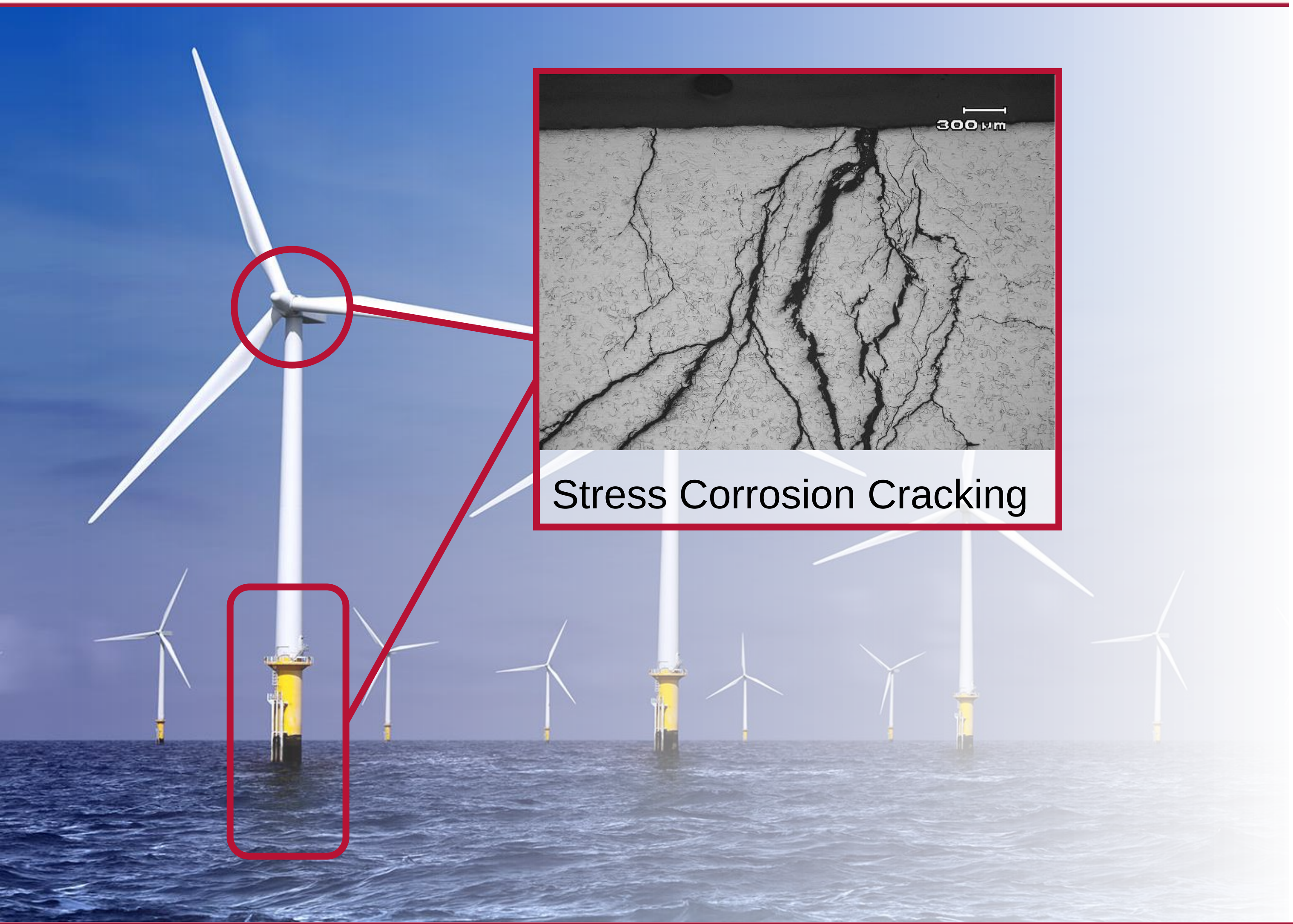
Crevice Corrosion

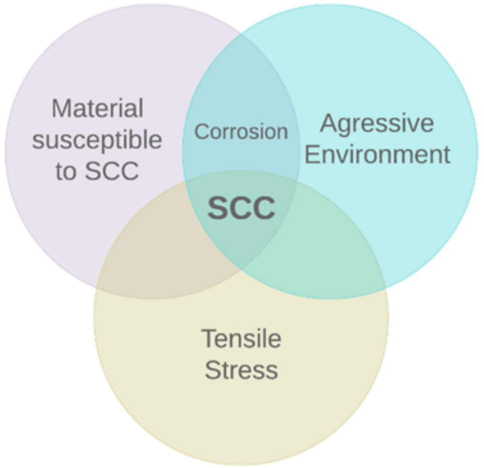
- Key Material Factors:
  - Geometry / Design
  - Material

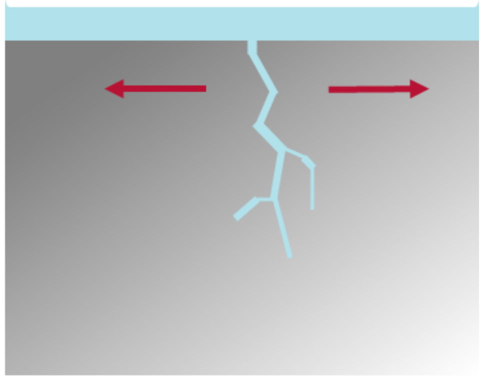
- Key Environment Factors:
  - Chloride concentration
  - Temperature
  - Synergy with other anions
  - Water velocity

Image: by GRALISTAIR, 2013/07/10, CC BY-SA 4.0

Stress Corrosion Cracking

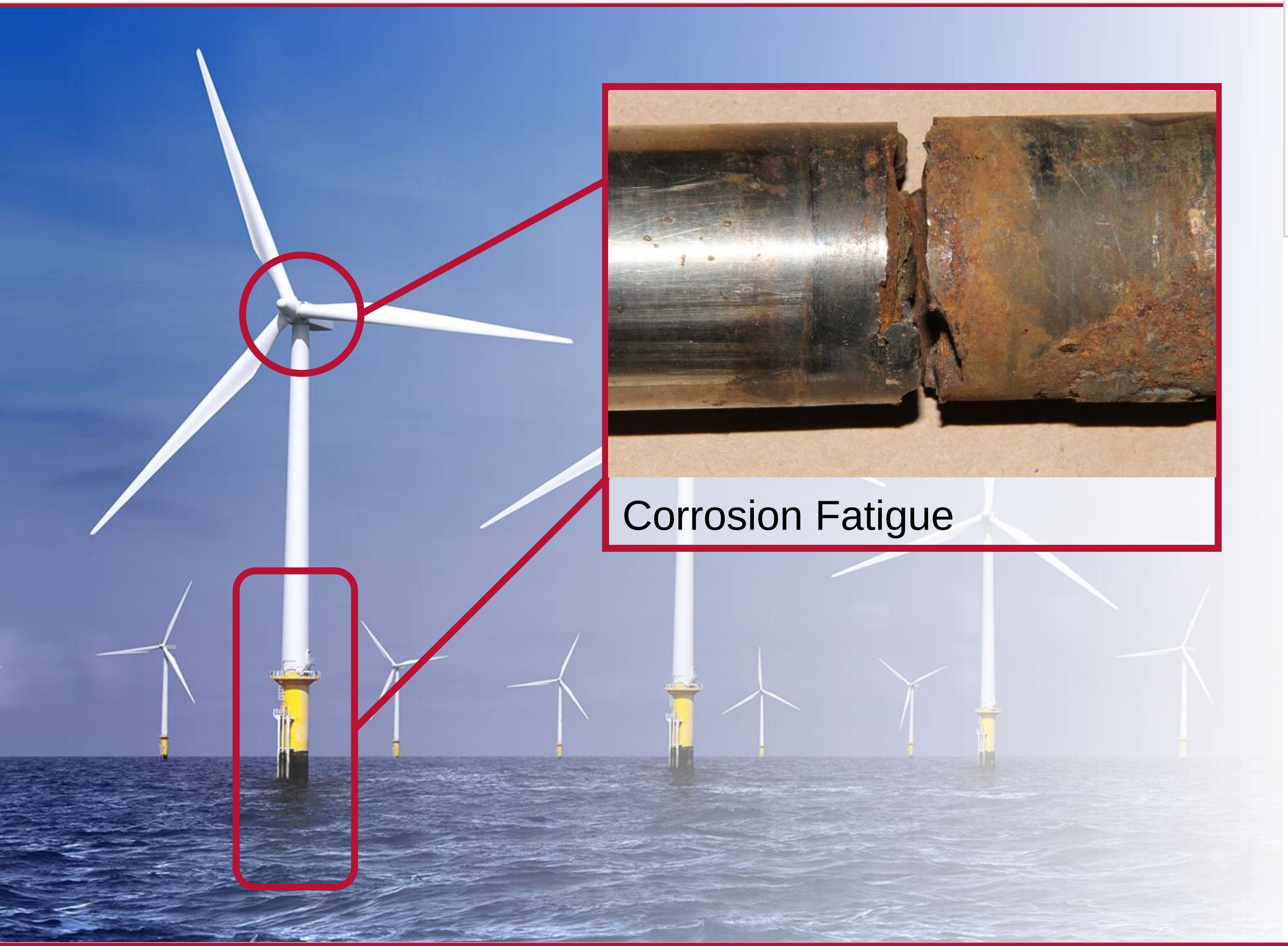


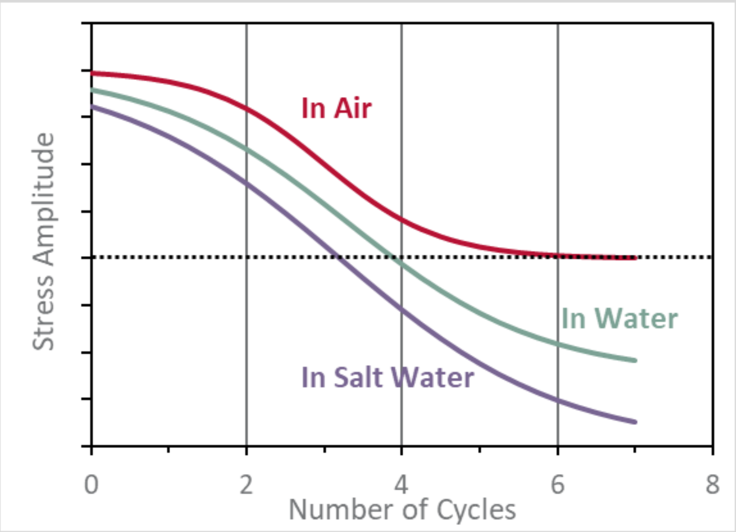


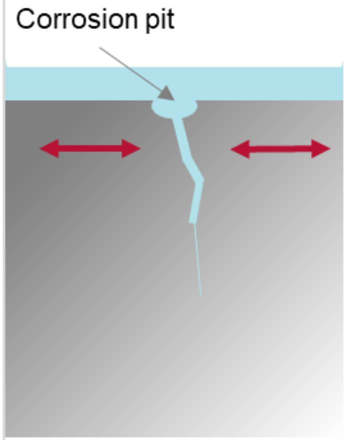


- Key Material Factors:
  - Operational & residual stresses
  - Surface finish
  - Microstructure e.g. sensitisation
  - Presence of defects/pits
- Key Environment Factors:
  - Aggressive anion concentration
  - Temperature
  - Lower pH
  - Cathodic protection

Corrosion Fatigue

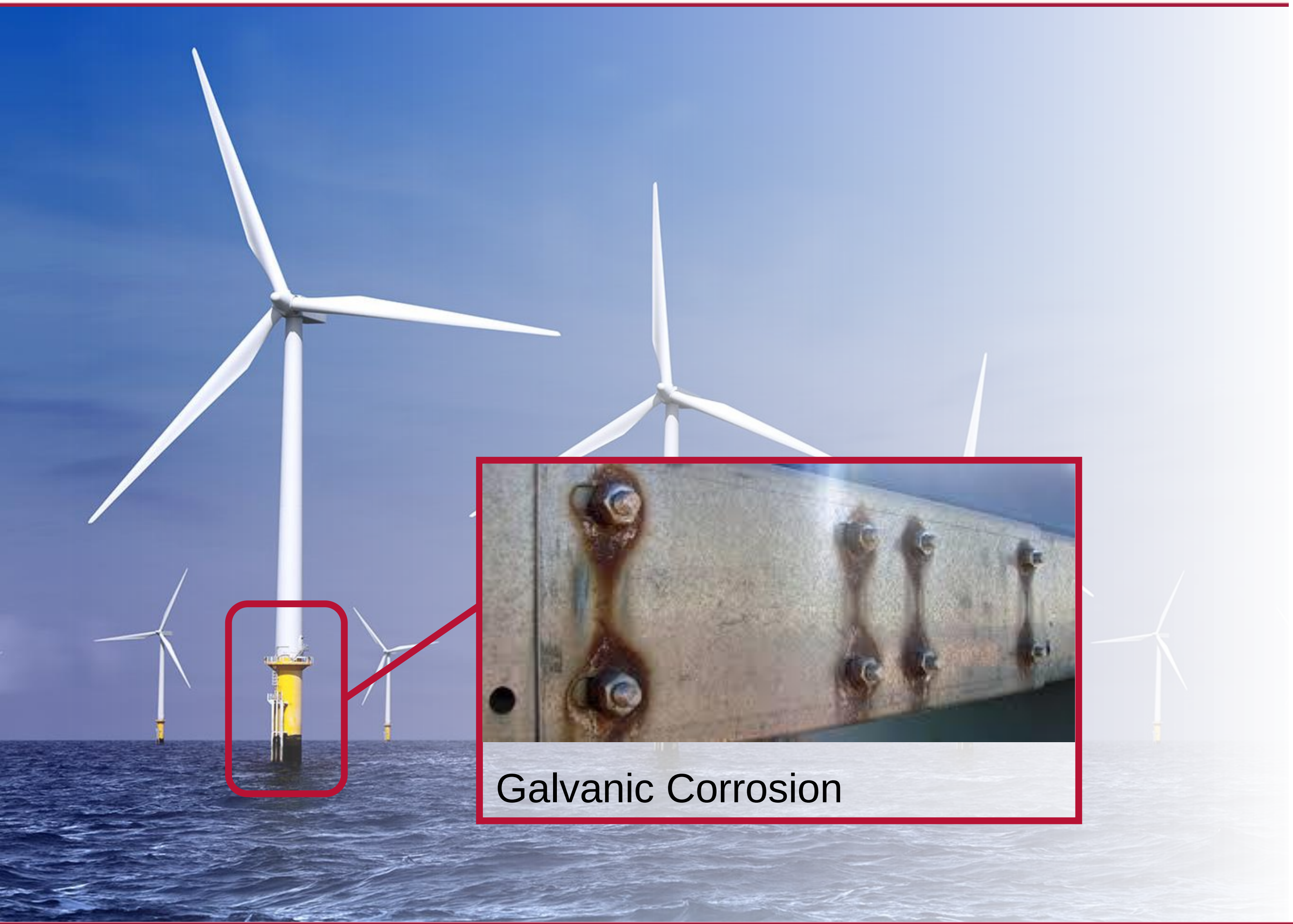


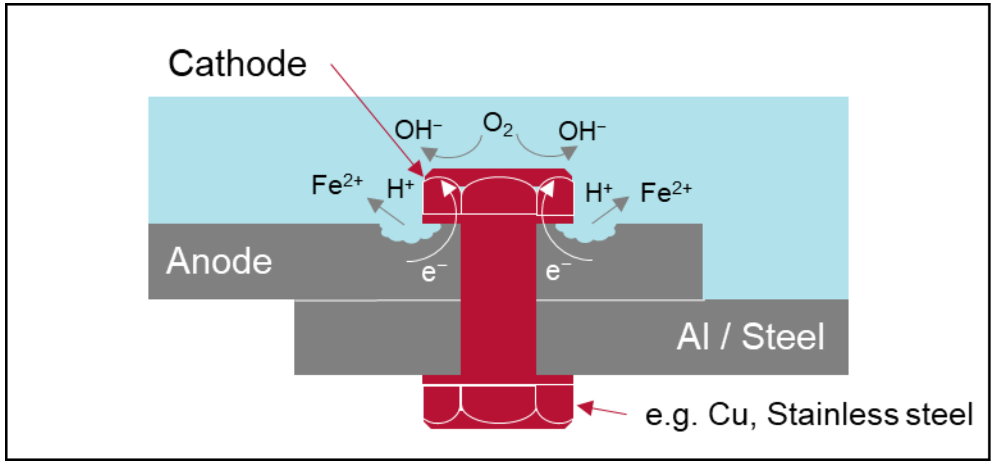




- Key Material Factors:
  - Cyclic stress-strain curve
  - Material
  - Microstructure (defect size/type)
- Key Environment Factors:
  - Aggressive anion concentration
  - Temperature

Galvanic Corrosion





- Key Material Factors:
  - Electrical and electrolyte contact
  - Potential difference
  - Surface area ratio
  - Passivation
  - (Selective phase corrosion)
- Key Environment Factors:
  - Aggressive anion concentration
  - Temperature

Image: D3j4vu at English Wikipedia

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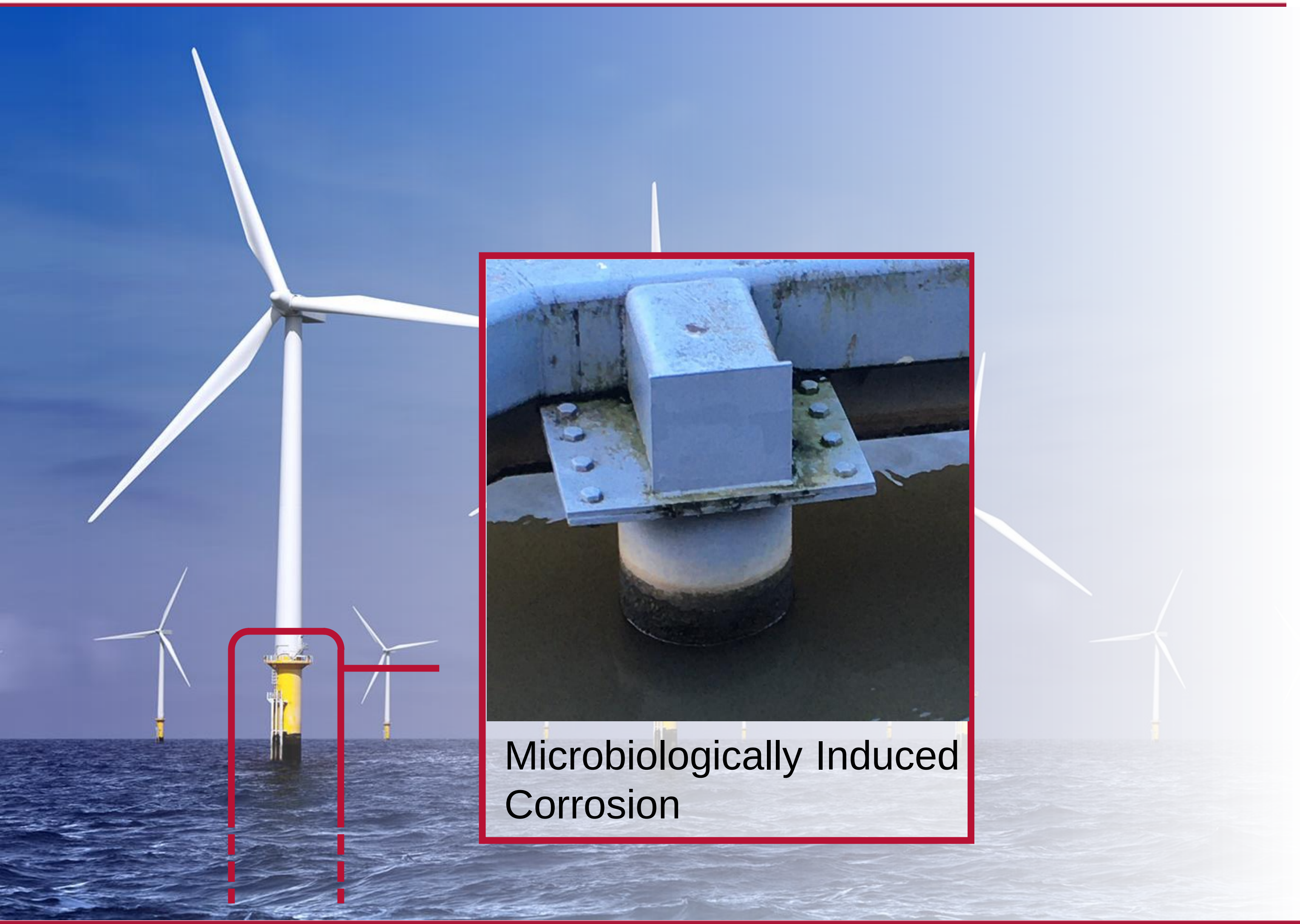
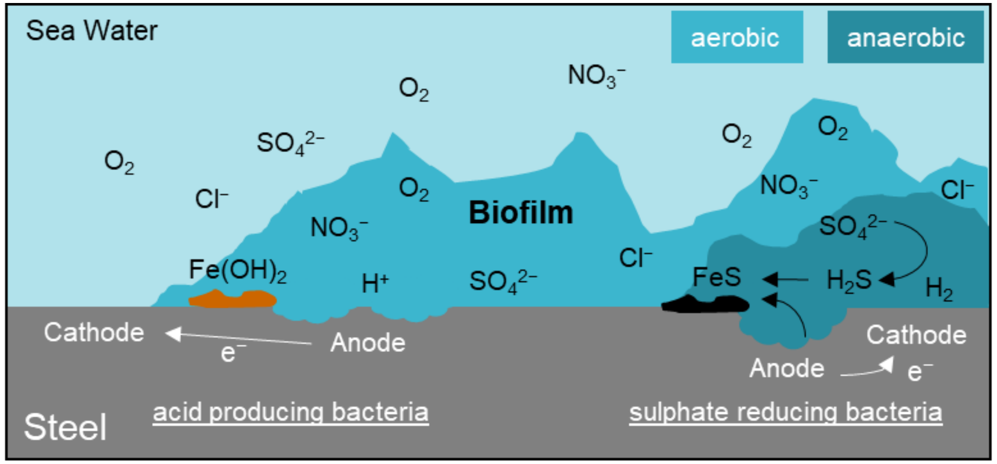
Microbiologically Induced Corrosion



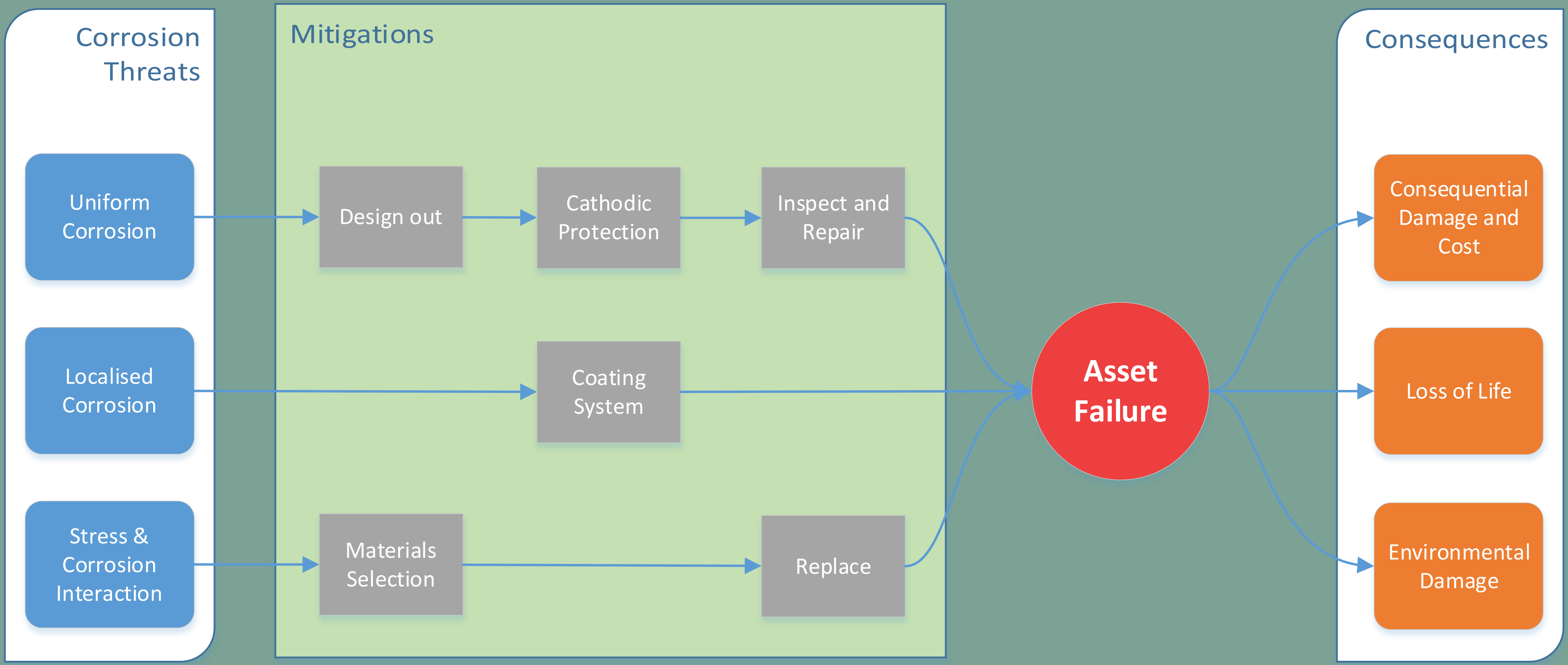
Microbiologically Induced Corrosion



- Key Material Factors:
  - Microfouling species
  - Macrofouling species
  - Water depth
  - Water velocity
- Key Environment Factors:
  - Temperature
  - Salinity
  - O_2 concentration
  - Water velocity

3. Mitigation Strategies

How can you manage the threats associated with corrosion?

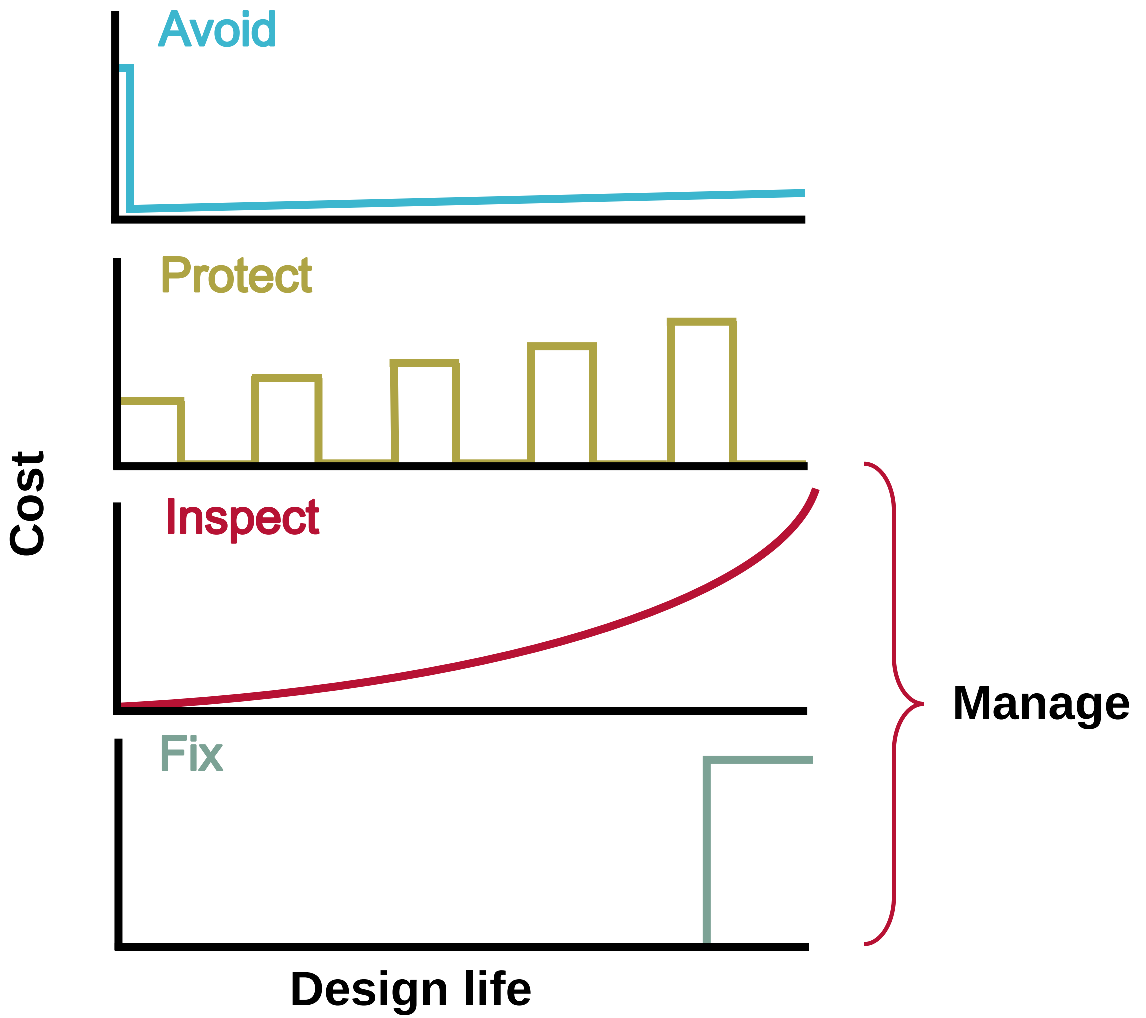


Mitigation Strategies

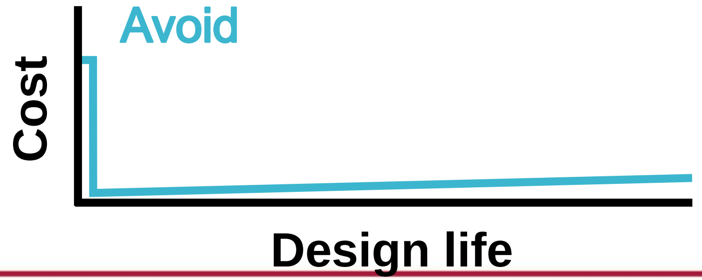
Avoid
- Materials selection
- Design out

Protect
- Coating system
- Cathodic protection

Manage
- Inspect and repair
- Fix/replace – free (until it's not)



Avoid – By Design



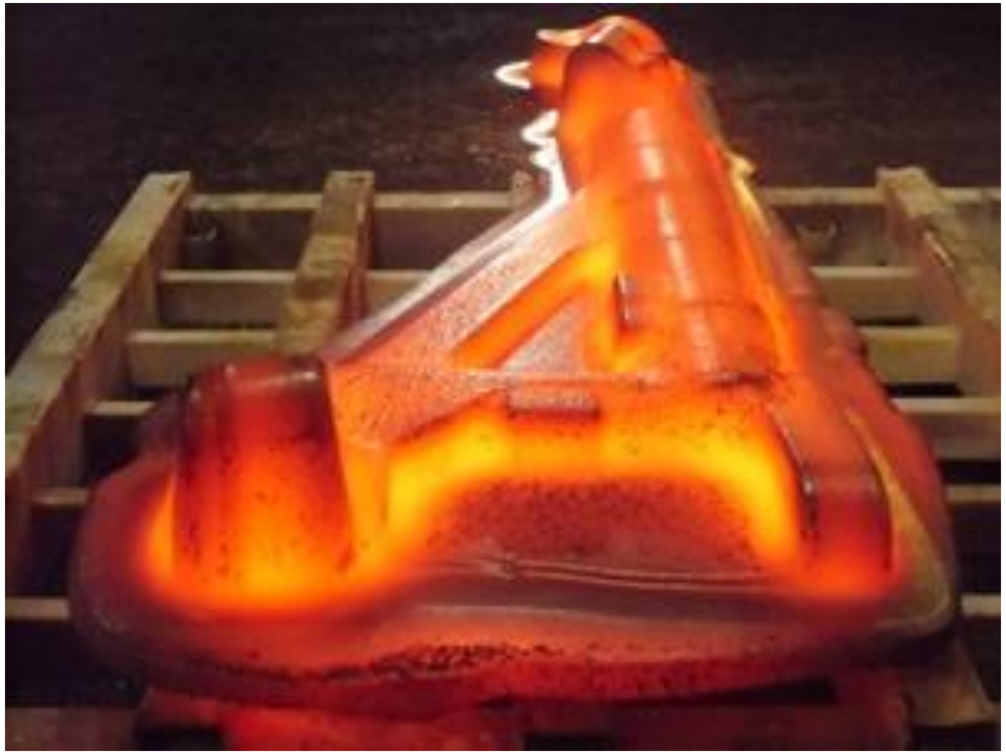
Design with corrosion in mind!

Metrics to aid materials selection:

- Pitting Resistance Equivalent Number (PREn)
- Critical Pitting Temperature (CPT)

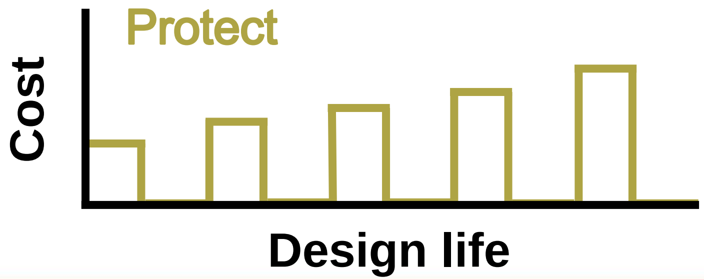
Important considerations:

- Pooling of water
- Sharp edges
- Incompatible materials next to each other
- Accounting for stresses
- Environmental conditions
- Seal enclosed spaces and dehumidify if feasible (eg. Humber Bridge)



Forged CRES main fitting after closed die operation. (Courtesy of Aubert & Duval)

Protect – Coatings



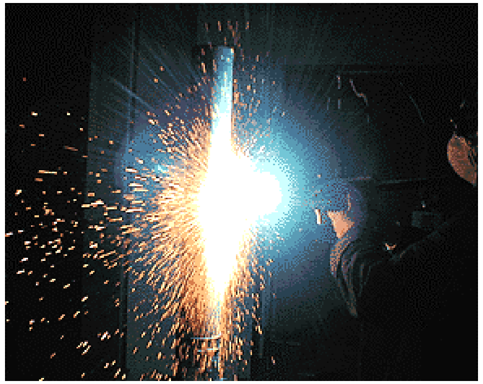
Three categories:

1. **Barrier**: Inhibits environmental interaction with the substrate
2. **Sacrificial**: Preferential corrosion protects substrate
3. **Adaptive**: Detects damage and releases chemicals to detect, inhibit or repair

- Cost: ~£1 - £10,000 per square metre
  - Need to fit the coating to the requirement

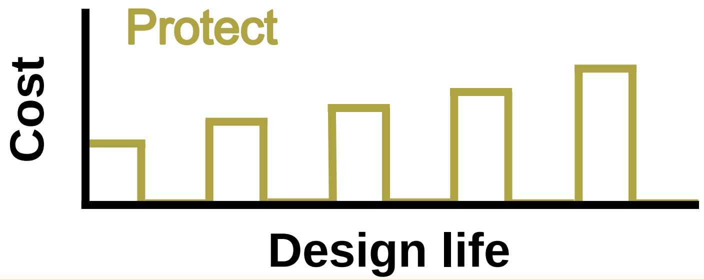
- Coating application is important and complex

Preparation, Preparation, Preparation



Courtesy of TRL9 Limited

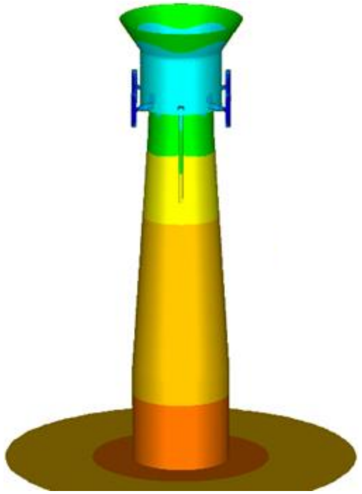
Protect – Cathodic Protection

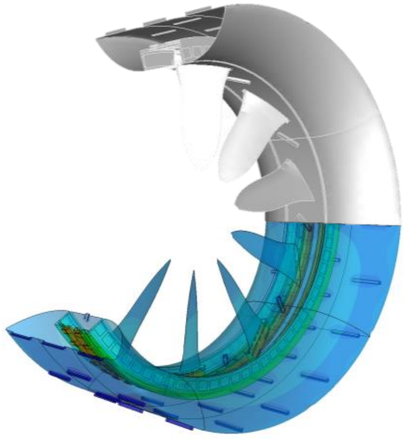


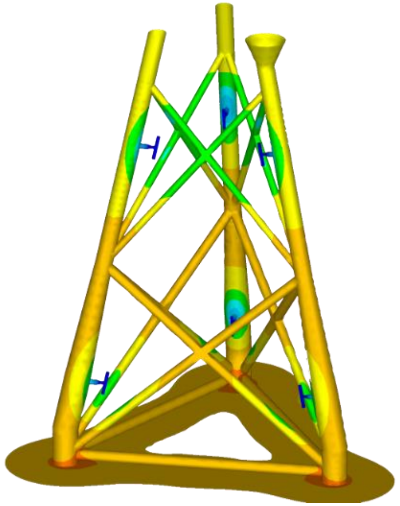
Two types:

1. **Sacrificial Anode:**
   - use of a more reactive metal to protect a less active material from corroding
2. **Impressed Current Cathodic Protection (ICCP):**
   - use of a controlled external electrical power source to polarise the metal anode

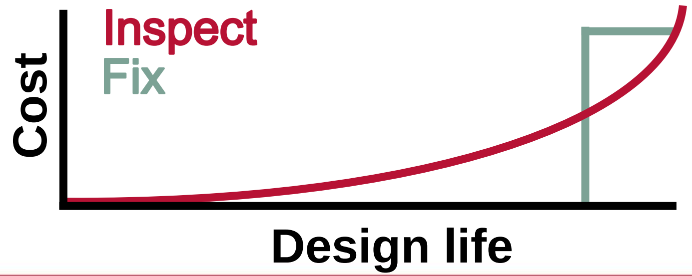
- Other types of protection:
  - Inhibitors
  - Lubricants
  - Cladding

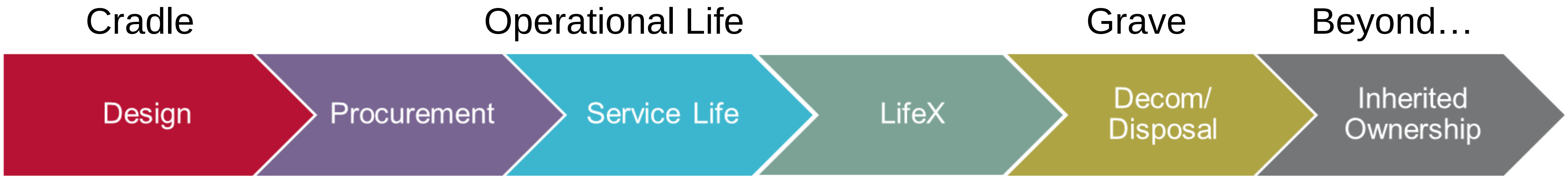






Manage





Inspect – visual/advanced NDT techniques coupled with management of the data collected

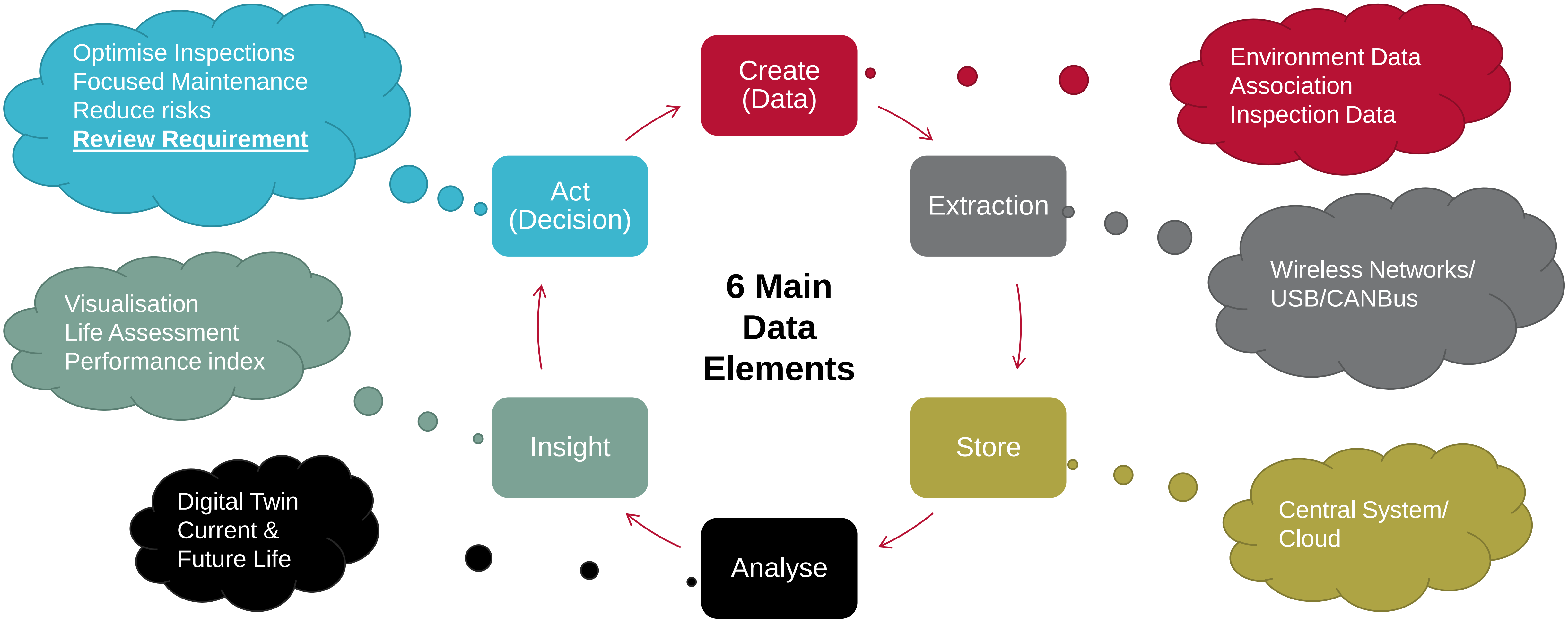
Maintain – periodic and timely planned overhaul

Repair – infrequent repair work

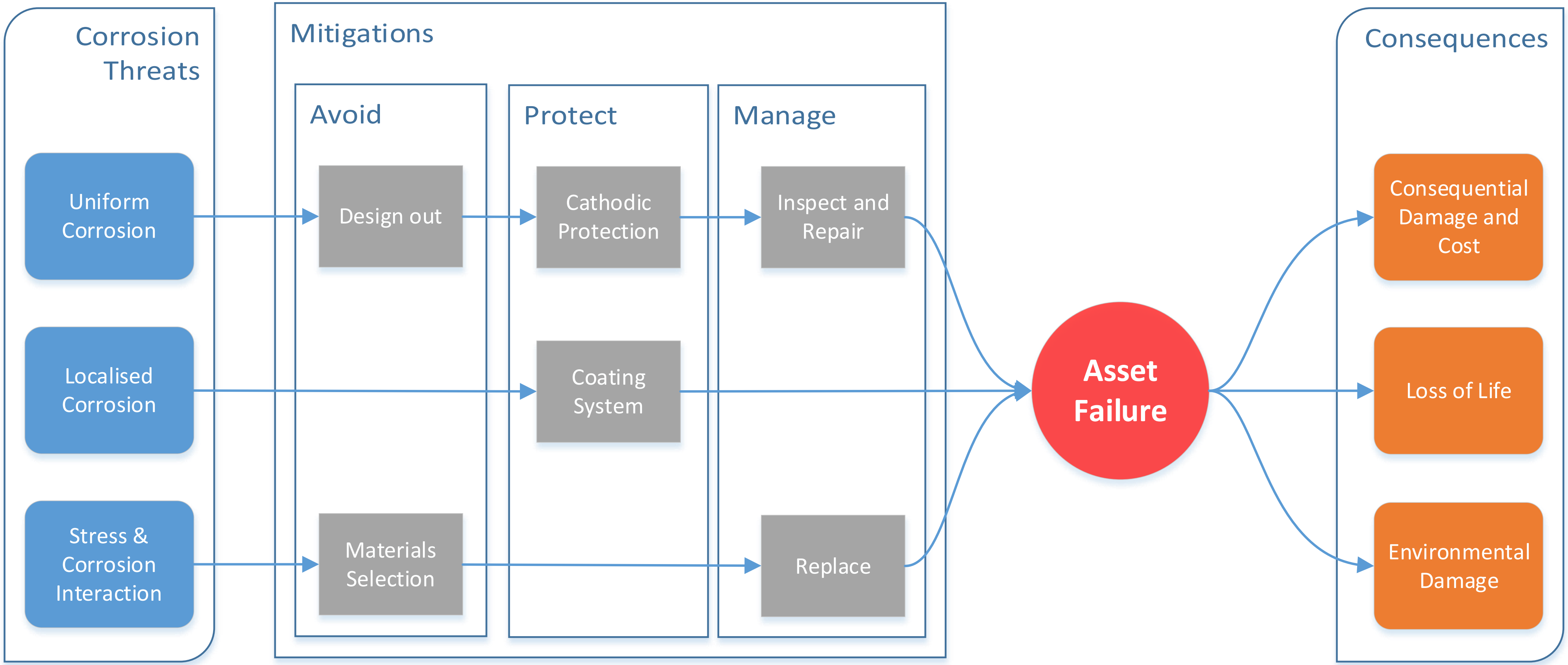
"Ensuring safety, improving availability and optimising investment"

Asset Management: The art and science of making the right decisions, at the right time, to maximise value

Managing Asset Degradation in the Environment (MADE)



Summary - Corrosion in Offshore Energy



Doing nothing is free, until it's not