CORROSION RISKS IN MINING

For: **Canadian Diamond Drilling Association**

Zoe Coull / Brycklin Wilson

Date: 3rd Mar 2021

Agenda

- What is corrosion?
- How corrosion affects the mining industry:
  - H&S risks
  - Costs
  - Environmental risks
- Corrosion mechanisms – an intro!
- Exploring Environmentally Assisted Cracking
- Questions and discussion

ICE DRAGON CORROSION INC

WHY DO THINGS CORRODE / RUST?

1. Our built world is largely thermodynamically unstable!
2. Oxidation of materials due to interaction with their environment.
3. Corrosion is also what happens when engineers don’t think about corrosion…

ICE DRAGON CORROSION INC

ICE DRAGON
CORROSION INC

WHY DO WE CARE ABOUT CORROSION?

1. HUMAN SAFETY
2. COST
3. ENVIRONMENT

1. HUMAN SAFETY

Safety: Shiploader Collapse (Chile)

Jorge Chilcumpa

ICE DRAGON
CORROSION INC

Safety: Conveyor Collapse (Canada)

ICE DRAGON CORROSION INC

2. COST

Direct Cost of Corrosion to global industry:

i.e. for materials, chemicals, personnel hours

~$80,000 spent per second

($2.5 TR per year)

ICE DRAGON CORROSION INC

Indirect Cost of Corrosion to global industry?

i.e. loss of production, safety incidents, environmental impacts?

…not tracked

Likely to be more substantial than direct costs

ICE DRAGON CORROSION INC

Corrosion costs in Mining?

- **Direct costs** are hidden inside maintenance budgets and depends on operation size, ore type, location, geography, water source, design, plant age etc. – no 'formula':

$3-10M / yr

- **Examples of indirect costs**:
  - One tank failure = $5M
  - Single pipe failure in Autoclave = $50M
  - Production losses from corrosion failures est. $15-20 M/yr
  - CIL tank circuit failure = $5M

Direct + indirect = $100's M over LOM?

ICE DRAGON CORROSION INC

3. ENVIRONMENT

Environment: Tailing dam collapse

E.g. Aging tailing dam infrastructure, Duke Energy, 2014

39,000 tons of coal ash spilled into the Dan River

Drainage pipe corrosion / concrete damage was a contributing factor

Promise to Society:

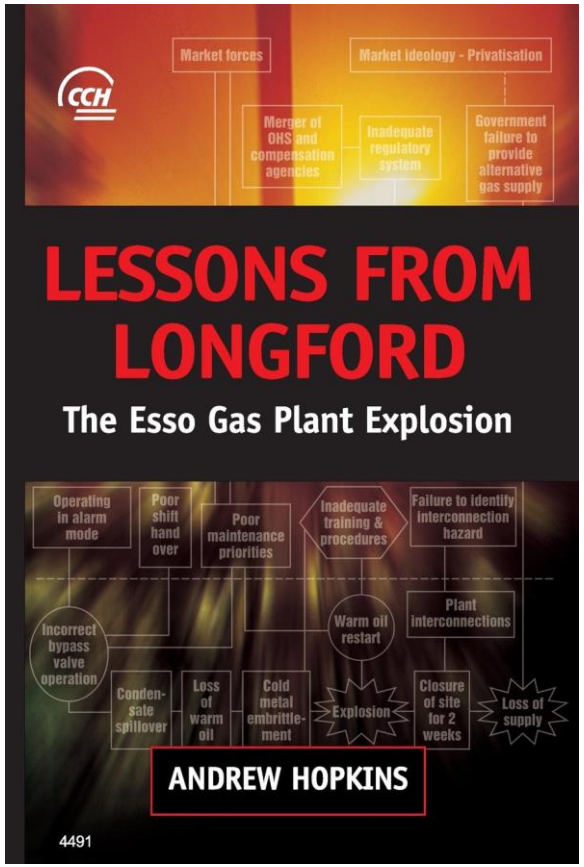
These will last forever….

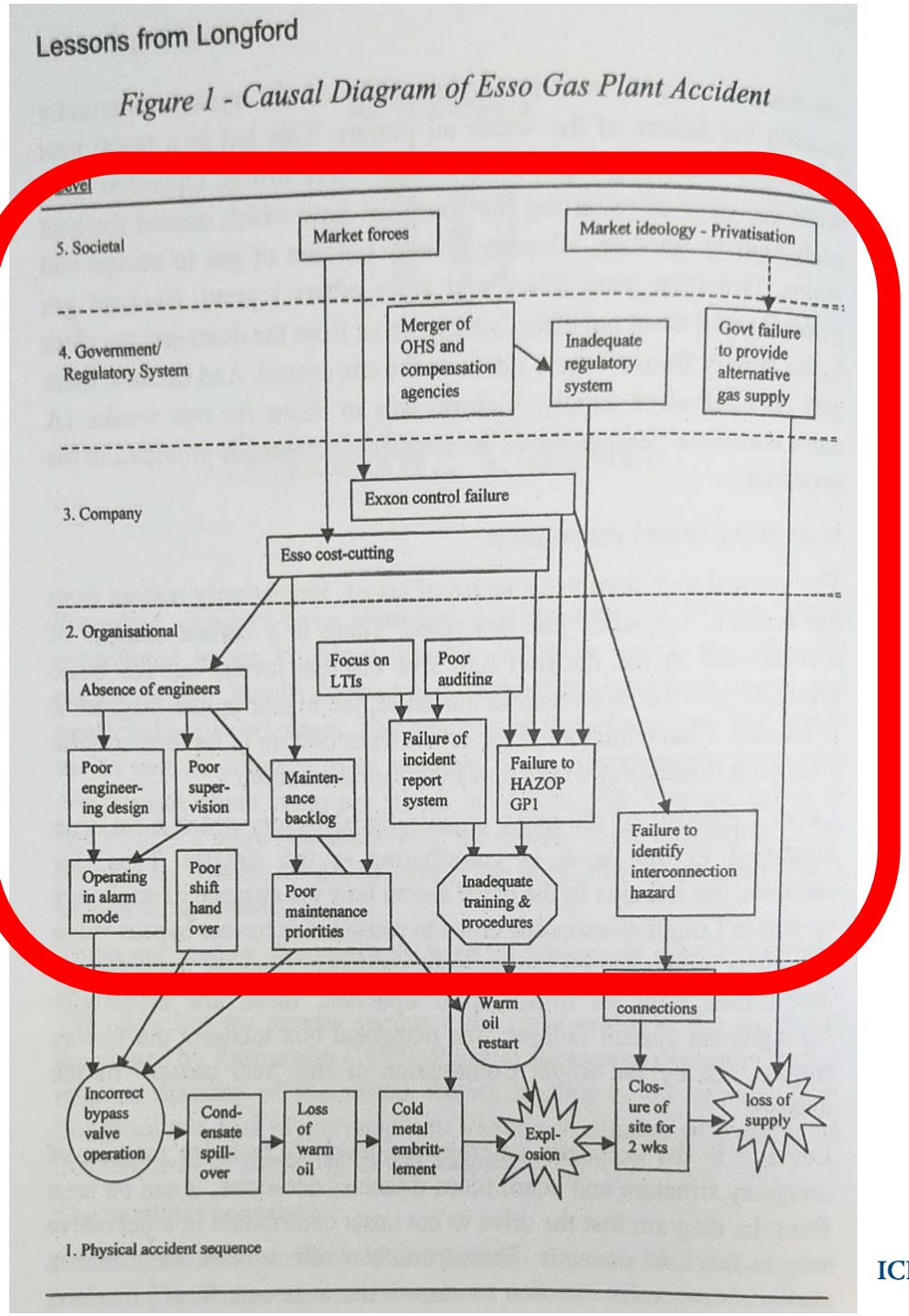
ICE DRAGON CORROSION INC

CAUSAL FACTORS FOR THESE RISKS IN MINING?

TECHNICAL **AND MANAGEMENT**…

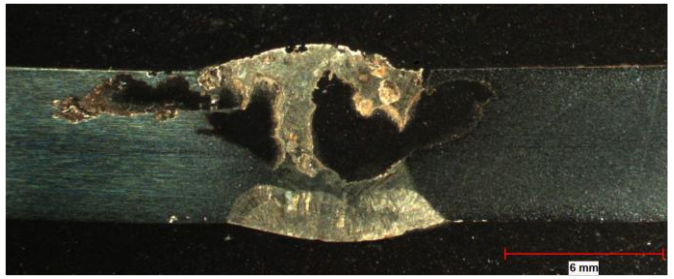
Catastrophic failures: many factors beyond simply technical…





ICE DRAGON CORROSION

CORROSION MECHANISMS


6 mm

DRAGON
CORROSION

Need to know the mechanism and the cause – to know what we are fixing!

The mechanism is an input into selecting:

- Materials
- Coatings
- Environmental controls (Corrosion Inhibitors, biocides etc)
- Cathodic / anodic protection
- Monitoring / inspection

ICE DRAGON CORROSION INC

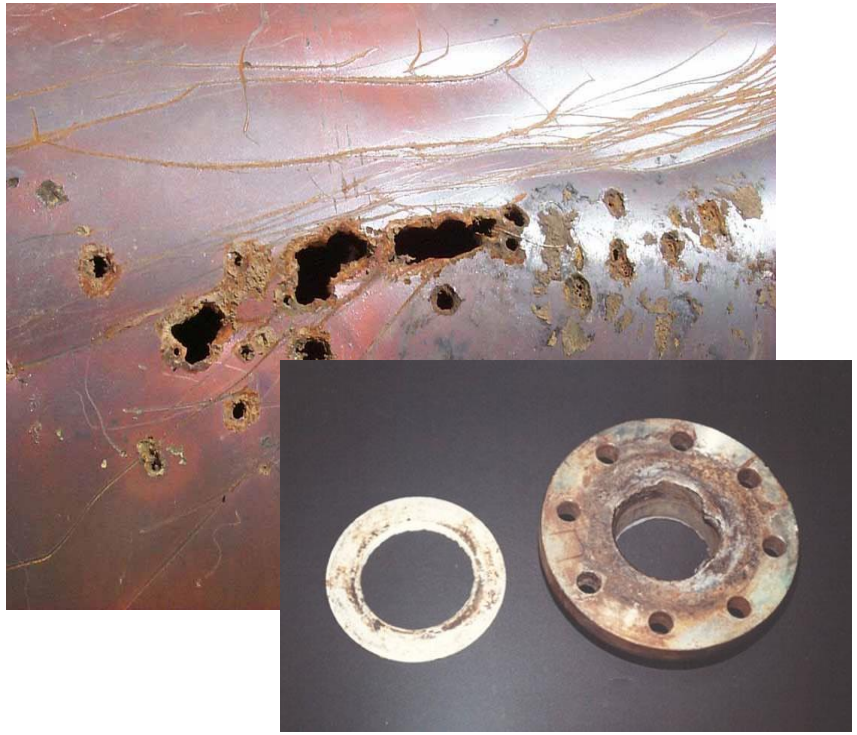
Types of corrosion

Uniform corrosion

Occurs evenly over entire surface area of element or large fraction of total area

Pitting and crevice corrosion

Localized corrosion, leads to holes in metal. Difficult to predict and monitor.



ICE DRAGON CORROSION INC

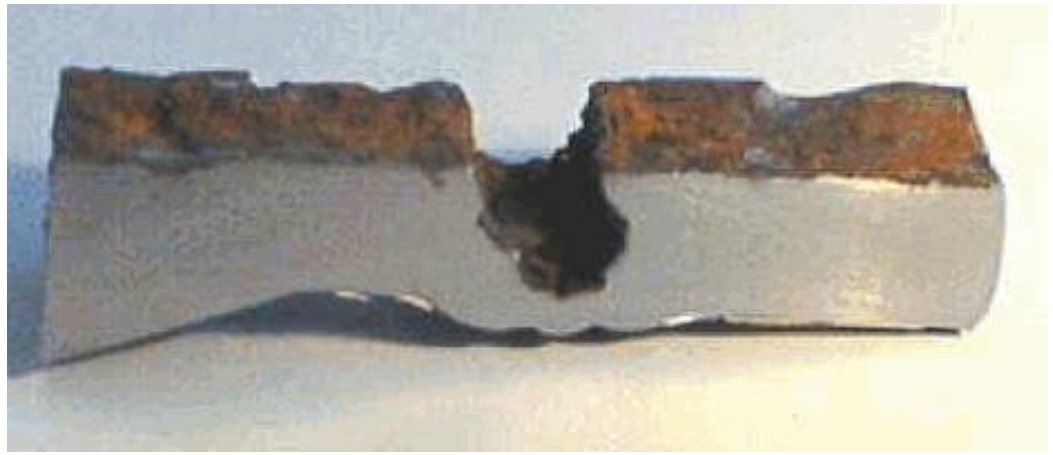
Types of corrosion

Microbial Corrosion

Microorganisms adhere to the surface and change the interfacial chemistry e.g. sulphate reducing bacteria (SRB).

Galvanic corrosion

Electrochemical process involving preferential corrosion of one metal relative to another or preferential weld attack.



ICE DRAGON CORROSION INC

Corrosion and wear

Erosion-corrosion

Caused by combination of corrosive fluid and wear; rate of corrosion is accelerated.

ICE DRAGON CORROSION INC

Corrosion and mechanical stress
(Environmentally Assisted Cracking)

Stress corrosion cracking (SCC)

Can be fast and catastrophic or slow – requires susceptible material, corrosive environment and stress (residual or applied). Often specific combinations.

Corrosion Fatigue cracking (CF)

Caused by combination of corrosive environment and fatigue loading. Any corrosion, not specific environment.

Hydrogen Embrittlement (HE)

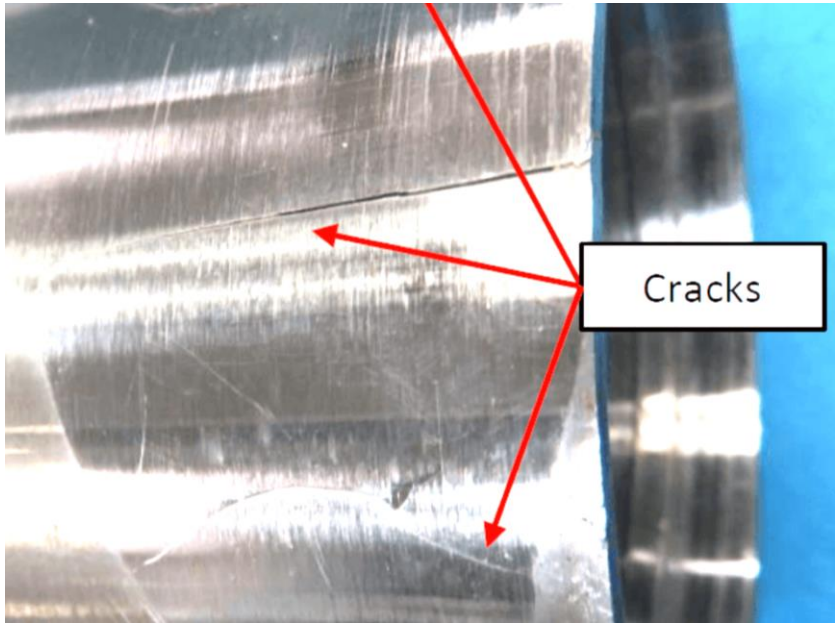
Multiple mechanisms – atomic hydrogen is absorbed into the metal matrix and causes brittle fracture.

ICE DRAGON CORROSION INC

Borehole Deviation Guidelines

Wear, twisting, heat cracking, fatigue…

"Warning! All of the fractures and cracking mentioned above may be worsened by environmentally assisted corrosion (EAC) or "stress-corrosion". It is recommended that drilling fluids are treated to neutralize acidity and corrosive hydrogen bearing agents."



But not fully understood how this mechanism might affect service life of drill rods – EAC is complicated!

ICE DRAGON CORROSION INC

Stress Corrosion Cracking

- Static stress – residual (from forming/welding) or applied
- Environment – corrosive due to the presence of aggressive species, pH, temperature
- Material – must be susceptible to corrosion in the environment in question

Usually seen in specific systems… but there is a wide spectrum of mechanisms / environments / materials that are susceptible.

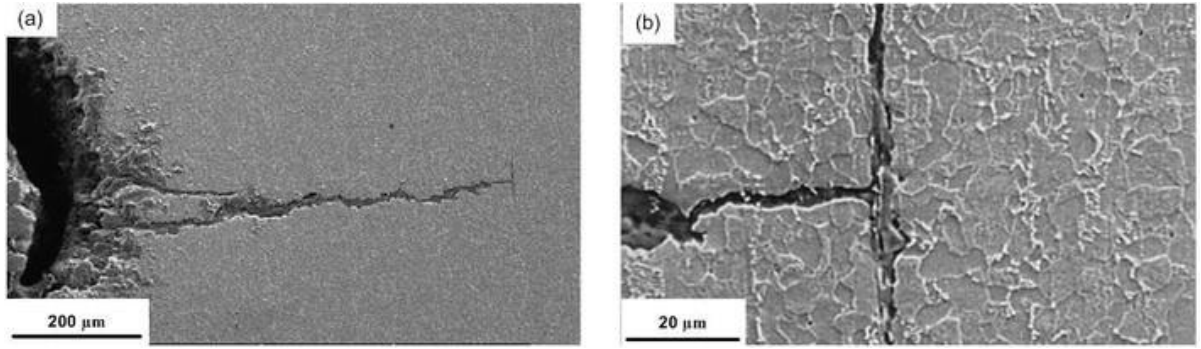
Cracking can be intergranular or transgranular.

Intergranular SCC of an Inconel heat exchanger tube

Chloride stress corrosion cracking in 316SS with multi-branched "lightning bolt" transgranular crack pattern.

ICE DRAGON CORROSION INC

Example SCC systems



High-pH SCC of CS oil transportation pipeline

Carbon Steel:

- Caustic: pulp and paper pressure vessels
- Nitrates: nuclear waste containers
- Carbonate-bicarbonate:
  - high pH (9 -13)/ T>40C / CP / intergranular cracking – high pressure natural gas lines
  - near neutral pH (5-7) / transgranular cracking / cyclic loads – buried pipe
- Neutral water / steam: power generation environments

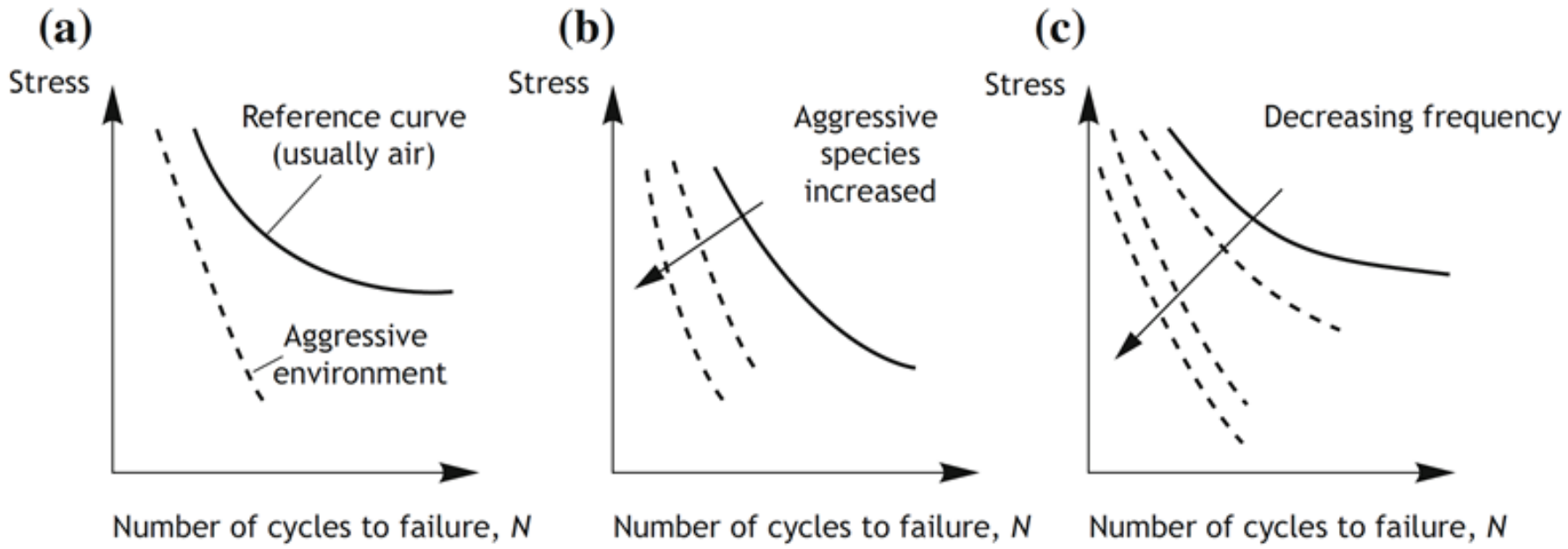
Other:

- Stainless steel - Chloride SCC
- Ti in liquid dinitrogen tetroxide and methanol in a US space program!

ICE DRAGON CORROSION INC

Corrosion Fatigue

- Where stress encountered is cyclic
- Any corrosion can reduce fatigue resistance – not system specific
- Can eliminate the fatigue endurance limit in steels
- Cracking is not usually branched, although can see branching if cycle frequency is low



ICE DRAGON
CORROSION INC

Hydrogen Embrittlement

- Hydrogen can enter metals from forming processes, welding, electroplating etc
- Corrosion can also be a source of hydrogen through cathodic reaction in acidic environments
- The presence of hydrogen sulphide can increase hydrogen entry (sulphide stress corrosion SSC) (S poisons hydrogen recombination)

Examples of HE:

- High-strength steels with their lower fracture toughness can be susceptible to HE, chlorides and S increase severity
- Al alloys, Ti, copper – all undergo HE in specific environments

ICE DRAGON CORROSION INC

Summary

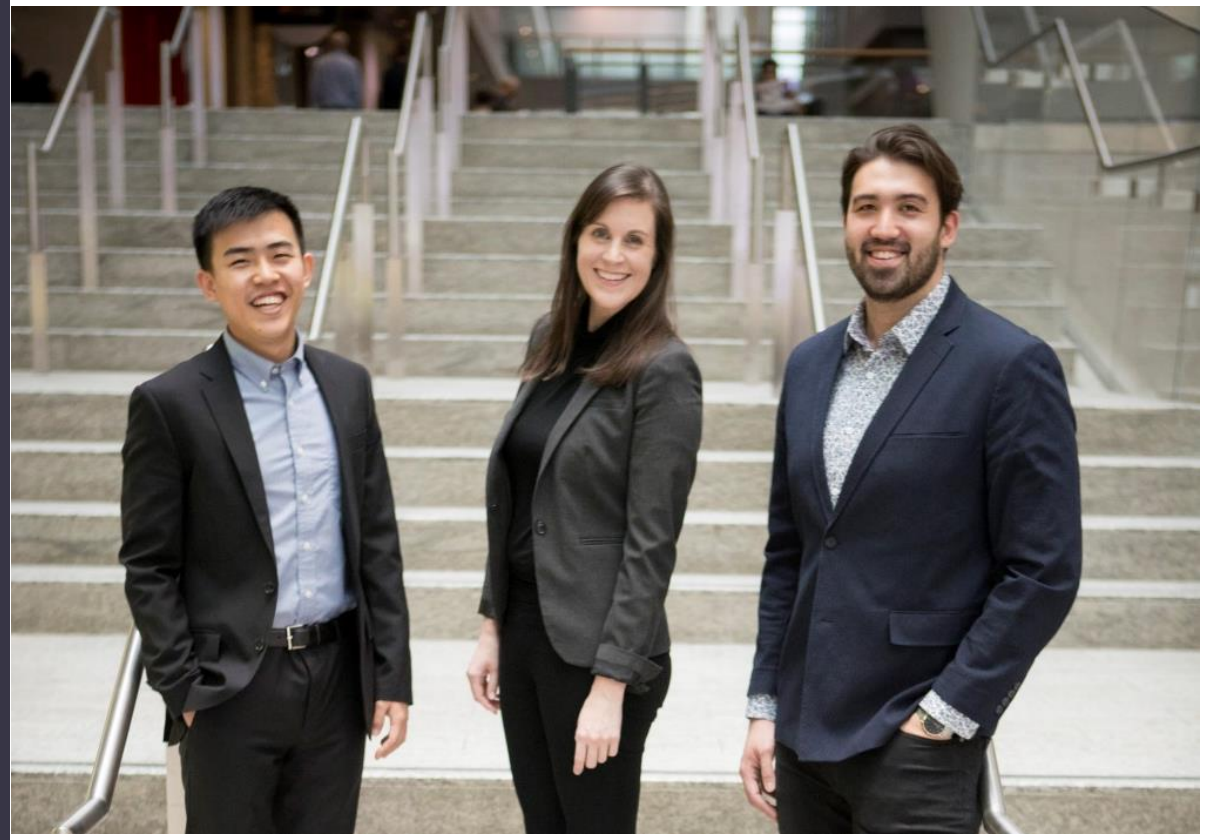
Corrosion of mining assets has been linked to:

- Fatalities
- Near misses
- Environmental discharge events
- Loss of asset availability
- Maintenance costs of $100’s M
- Production losses of $100’s M

Need to know what mechanism is occurring so that we can choose suitable control methods!

ICE DRAGON CORROSION INC

Thank You



Please connect!

zoe@icedragoncorrosion.com | 647-525-1602

linkedin.com/Zoe Coull

ICE DRAGON CORROSION INC