Boiler Tube Life Management

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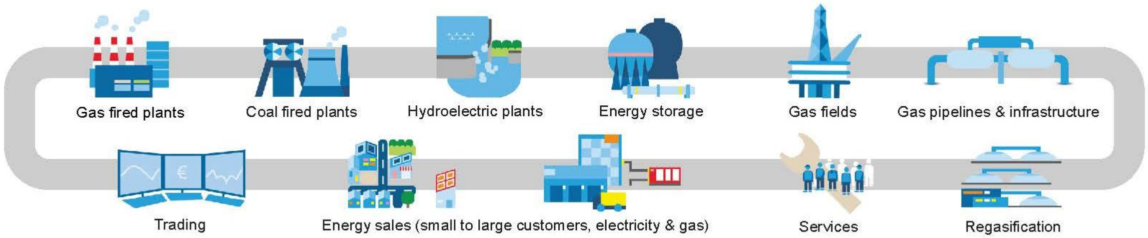
Fuel & Energy Research Forum – Sheffield – 11th April 2018

We are Uniper

Main activities:



Generation

Net capacity by fuel type (GW)

Electricity production (TWh)

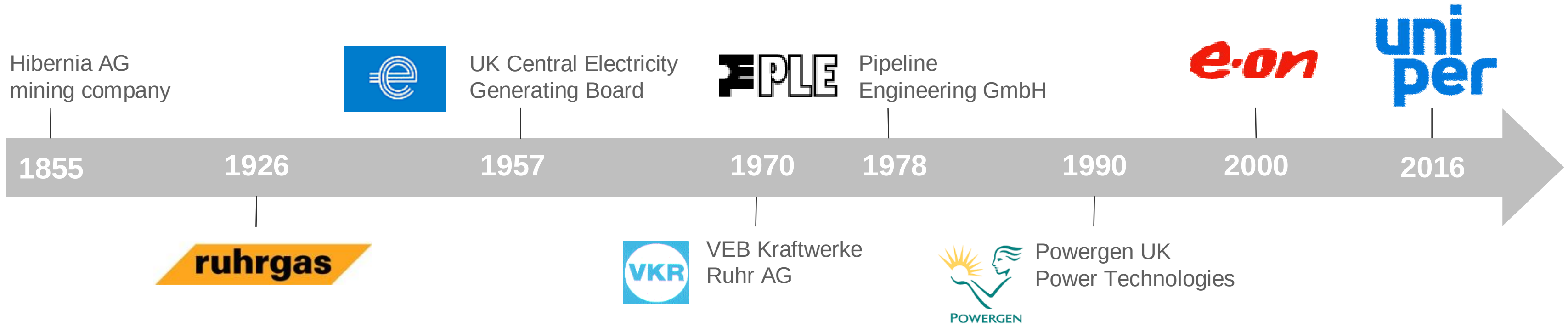
Expertise built on engineering excellence and owner operator asset experience

We are a **one-stop shop** offering a broad range of services that work closely together, reducing complexity and risk for customers

Our **background as an asset owner/operator** gives us deep understanding of the energy industry and our customers' needs

We are **independent** of equipment and component suppliers, giving us freedom to choose the best solution for customers

Expertise based on experience



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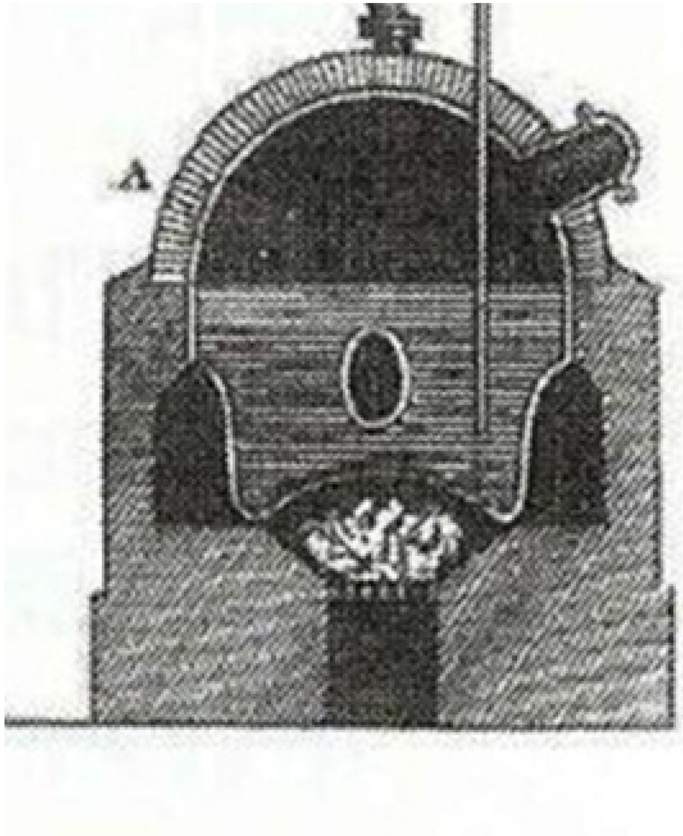
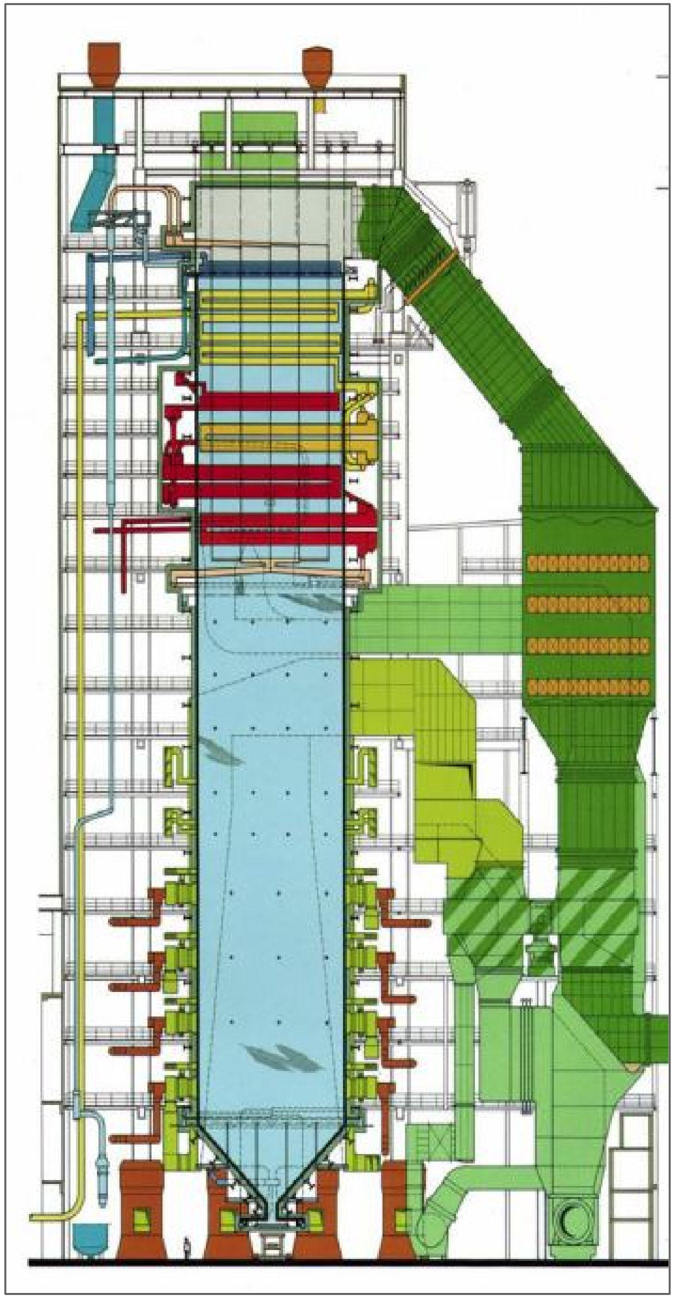
Boiler Evolution



250 years



Modern Boiler Diversity

Boiler Designs	Fuel	Materials
Single Pass (Tower) Two Pass Multiple Pass 'D-Boiler' HRSG	Coal (black & brown)	Carbon Steel 13CrMo 10CrMo T23/T24 T91 X20
Pulverised Fuel CFB Bubbling Bed Grate	Oil Orimulsion	T304/316/321/347 T310/HR3C
Drum & Once Through (Benson)	Gas (natural & blast furnace)	Alloy625
	Waste Biomass (wood, straw, peat, MBM, poultry litter)	Misc Coatings
	Co-firing all of above	

80°C Temperature 650°C

<1MPa Pressure 35MPa

Stand-by → Cyclic → Seasonal → Base-load

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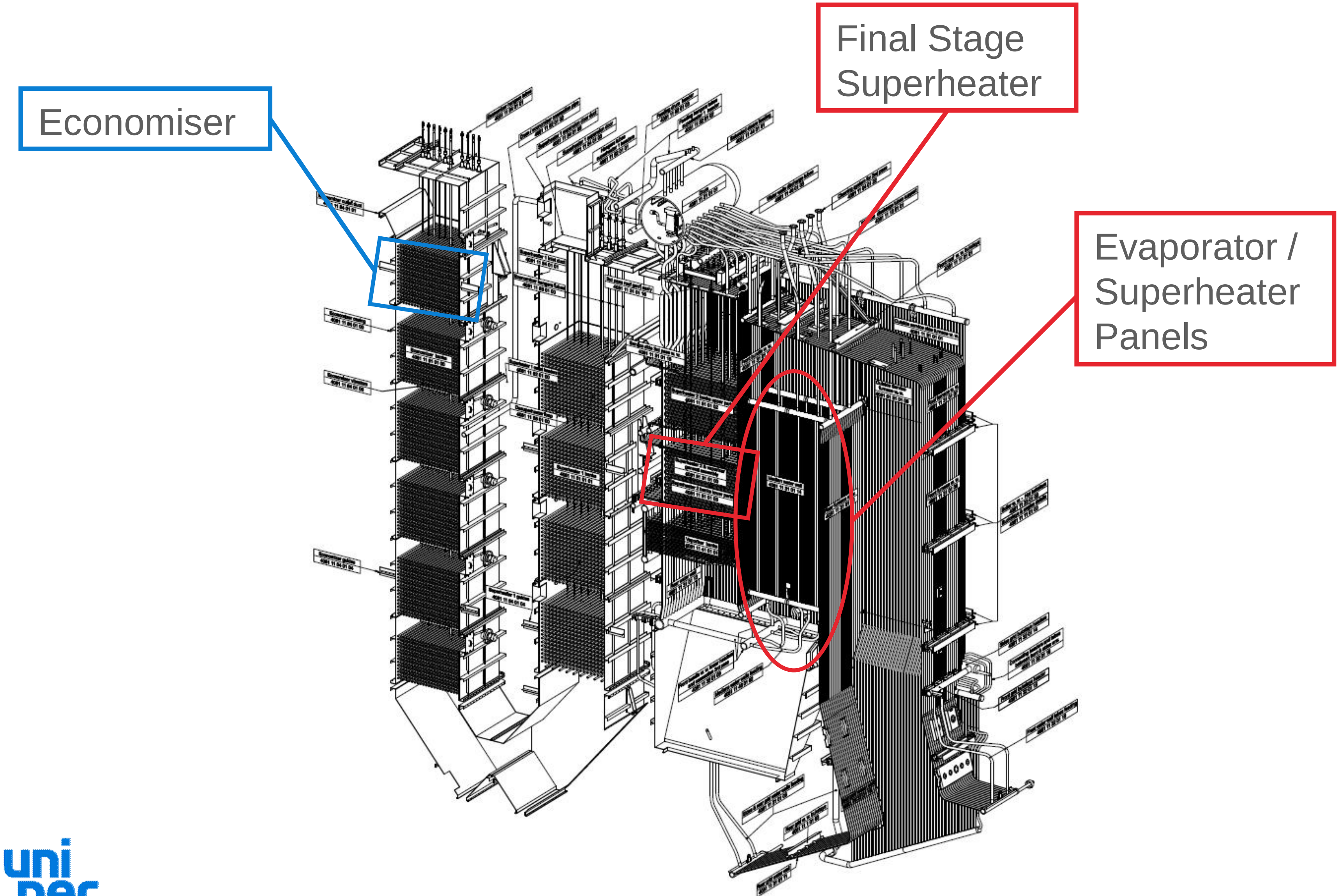
Influence of Boiler Design on Failure Location



Boiler Tube Failures

- Boiler tube failures responsible for 2% – 5% loss of plant availability worldwide
  - This represents the majority of forced outages on plant
- Thermal boiler plant offers a wide range of tube damage mechanisms (at least 15 different failure modes)
- Plant design and operation can strongly influence the potential for tube failure

- Conventional fossil plant (Coal, Gas, and to some extent Biomass)
  - Many of these failures are influenced by commercial requirement for power generation
  - 2-shifting and low load operation of plant in response to market demands
  - High final steam temperatures to maximise efficiency

- Waste to Energy plant (and some Biomass plant) driven by alternative commercial model
  - Economic disposal of waste is primary concern
  - Failures due to aggressive nature of fuel represents primary issue
  - Reliable plant operation between planned outages is critical
  - Final steam temperatures limited (typically to ~400°C) due to corrosion concerns

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Cost of Boiler Tube Failures

- Boiler Tube Failures are not generally a safety issue (although there are notable exceptions to this)
- Any preventative measures will be justified on commercial basis
- Major costs of tube failure are typically associated with lack of asset availability i.e. No Power Generation (e.g. Conventional Fossil) or No Fuel Consumption (e.g. Waste to Energy)
- The actual costs of tube repair are typically relatively minor
    - Scaffolding for access (where required)
    - Boiler Engineer to identify failure location and mechanism – Essential to plan appropriate repair strategy
    - Non-Destructive Testing – Damage to local tubes (thickness loss, crack detection, post-repair quality assurance)
    - Replacement tubing
    - Welding

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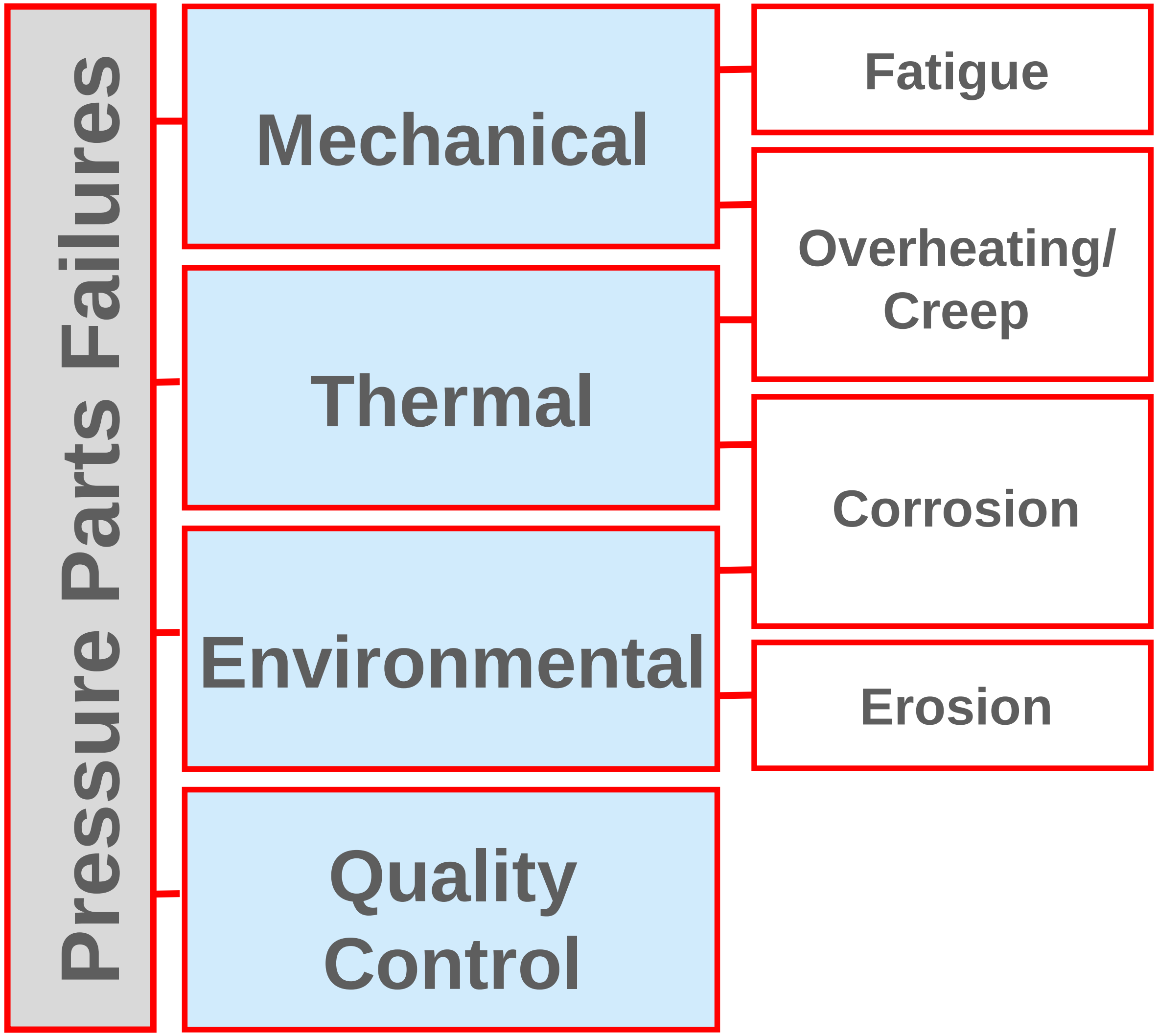
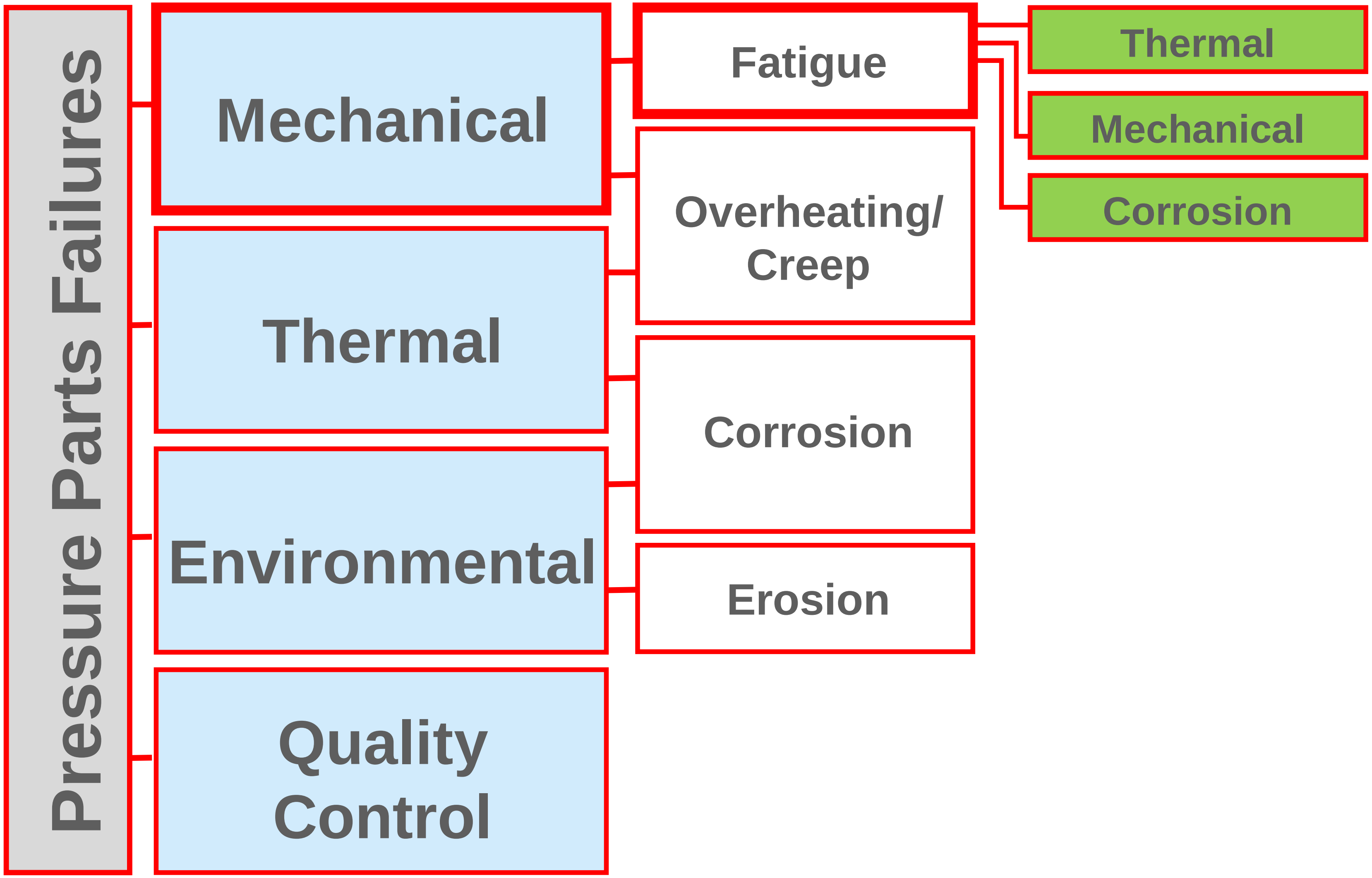
Tube Refurbishment Strategies

- Extent of tube repair / refurbishment during planned outages will be dependent on market drivers
  - Conventional Plant
    - Refurbishment will be undertaken when stages become life expired. However, downward pressure on costs means prioritisation of replacement – unlikely all work will be undertaken.
    - During operational campaigns, repairs may be undertaken on an opportune basis, dependent on the prevailing operational practice (driven by the Electricity Market needs). Balance between investment and operational income.
  - Waste to Energy plant (and some biomass plant)
    - Aim to achieve uninterrupted operation (no tube failures) between planned outages – More regular replacement, and deployment of high grade materials to prevent failures

Pressure Parts Failure; Mechanistic Causes

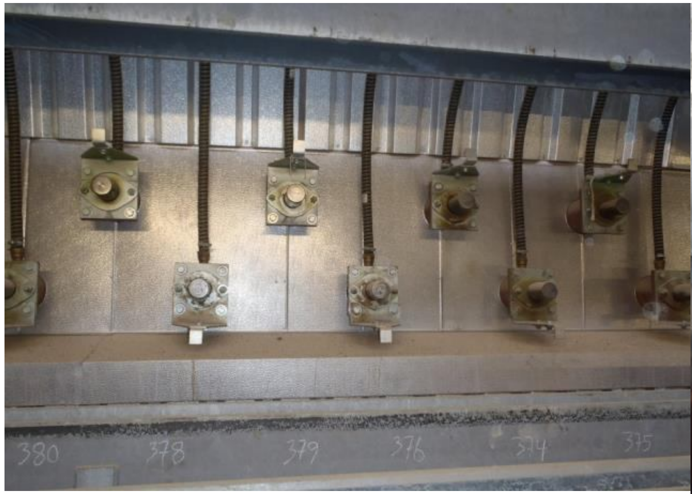


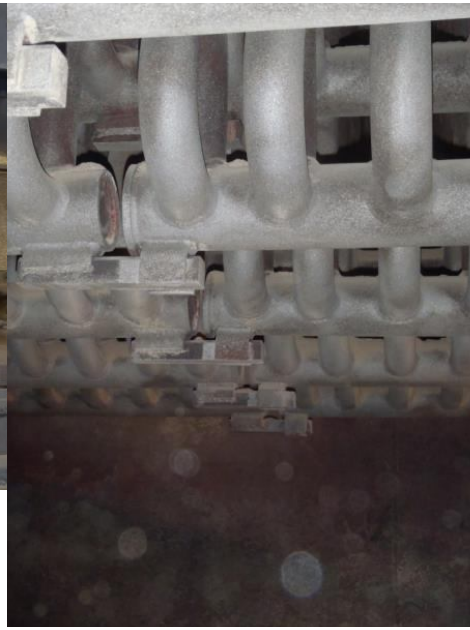
Pressure Parts Failure; Mechanistic Causes



Fatigue

- Typically a start related damage mechanism, however:
- Fuel based issues can have an impact primarily due to propensity for fouling, and strategies utilised to removed fouling. Particularly significant for Waste to Energy and Biomass plants.
- Fatigue typically restricted to issues with:
    - Gas flow resulting in tube vibrations
    - Soot management strategies - Potentially long term issues associated with tube cleaning (rapping systems etc.)

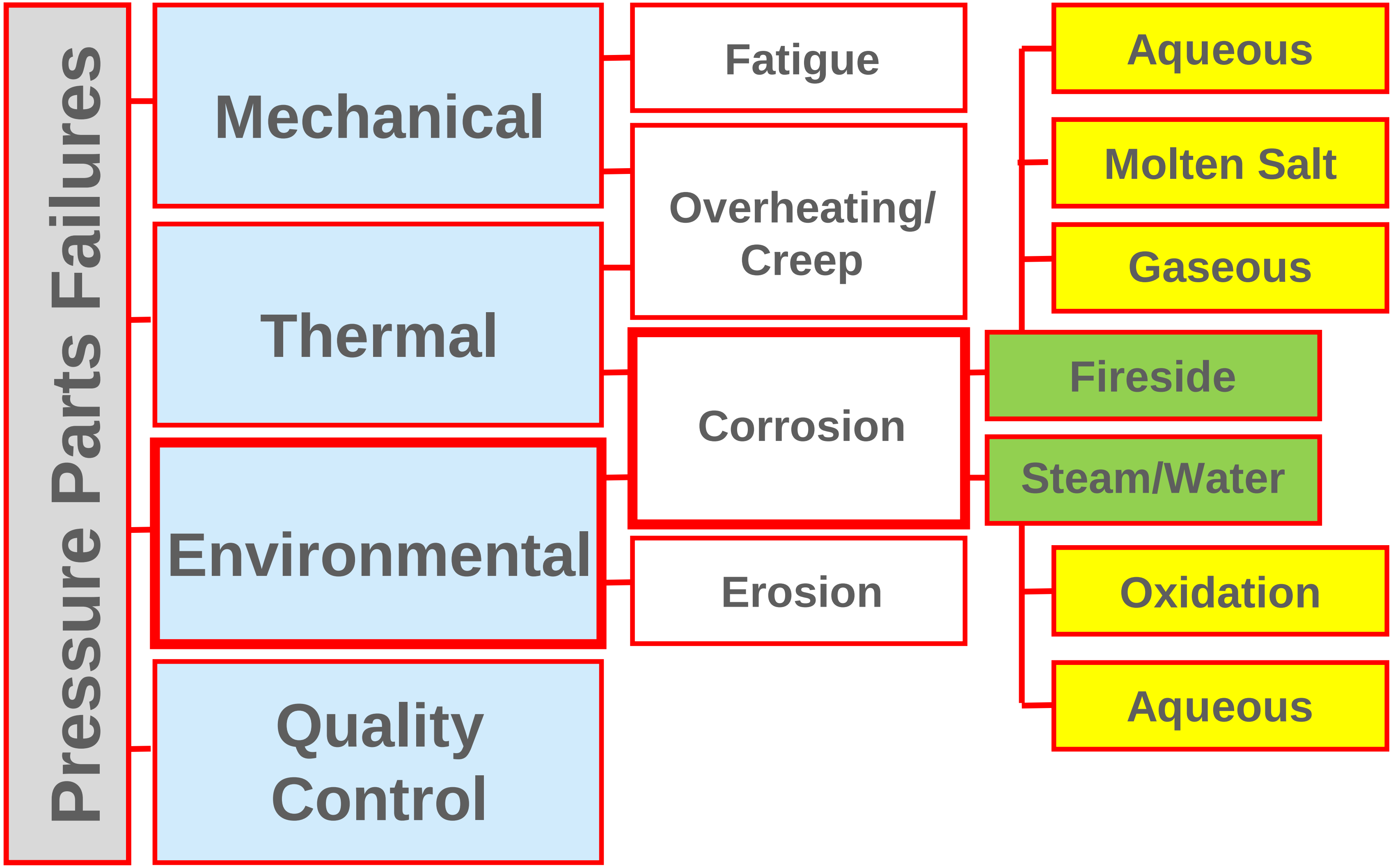




Fatigue

- Gas pass tube vibrations can result in both fretting damage, and fatigue to tubes if the support structure is not optimised for the gas flow.
- Can be influenced through fouling and gas laning within the stage.

Pressure Parts Failure; Mechanistic Causes

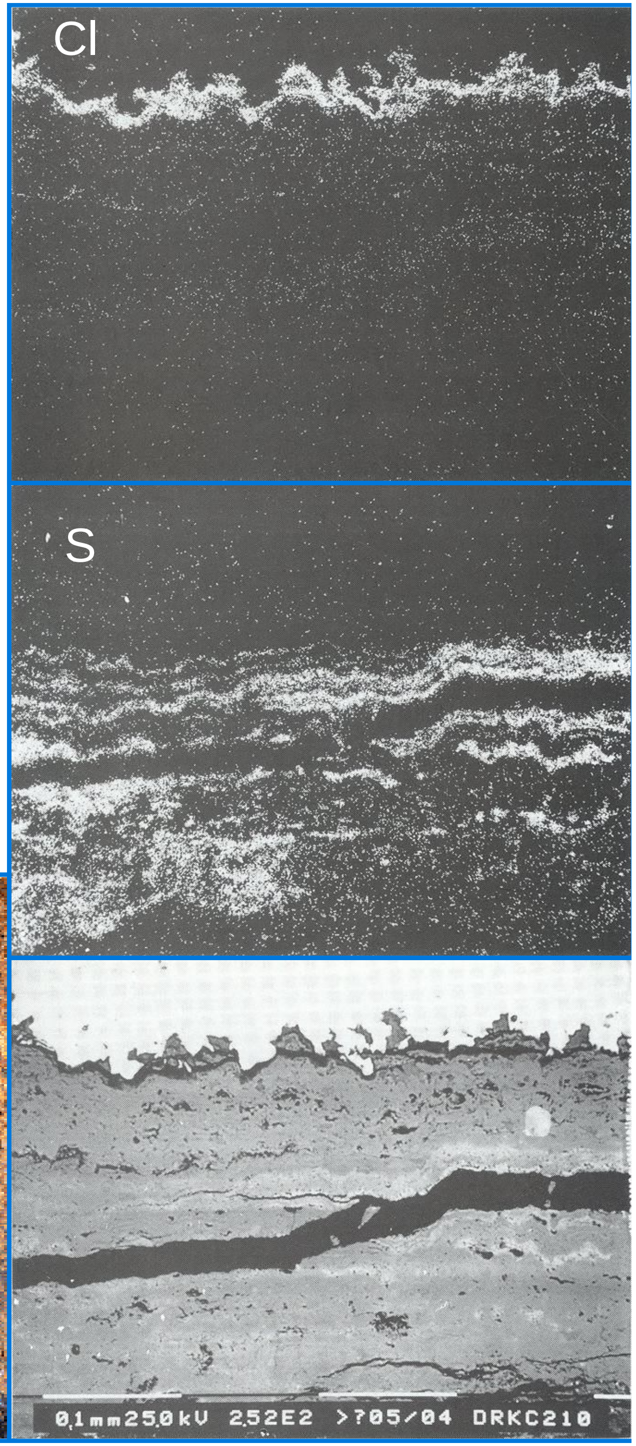


Fireside Corrosion

- Active species determined by tube metal temperature and fuel chemistry – S, Cl, Alkali Metals, Heavy Metals.
- Monitored through visual/tactile surveys and strategic tube wall thickness checks.
- Refractory also employed to protect tubing, although this can sustain unacceptably high temperatures in flue gas at later stages

Fireside Corrosion (Coal)

- Furnace wall (combustion zone)
- Gaseous mechanism
- Reducing (low O_2) environment a necessary pre-requisite (often associated with flame impingement)
- Fuel sulphur and chlorine worsen wastage rate where low O_2 persists
- Temperature and heat flux important parameters



Fireside Corrosion

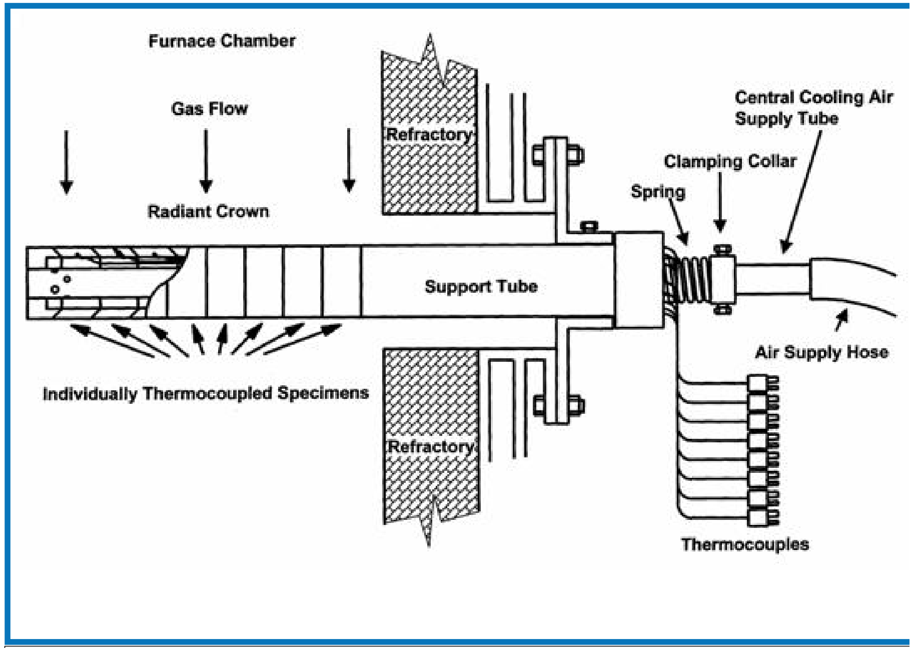
- High temperature (steam tubing)
  - Associated with molten sulphatic phases (K/Na) from ash deposit
    - Scale fluxing
    - Enhanced sulphidation
  - Influence of fuel chemistry recognised (ie sulphur & chlorine)
    - Alkali metals (when tied into clays in coal) are relatively inert
    - However, Chlorine promotes release of Alkali Metals
  - Influence of temperature (>570°C) and incident heat flux
  - Mathematical relationship for austenitic tubing:

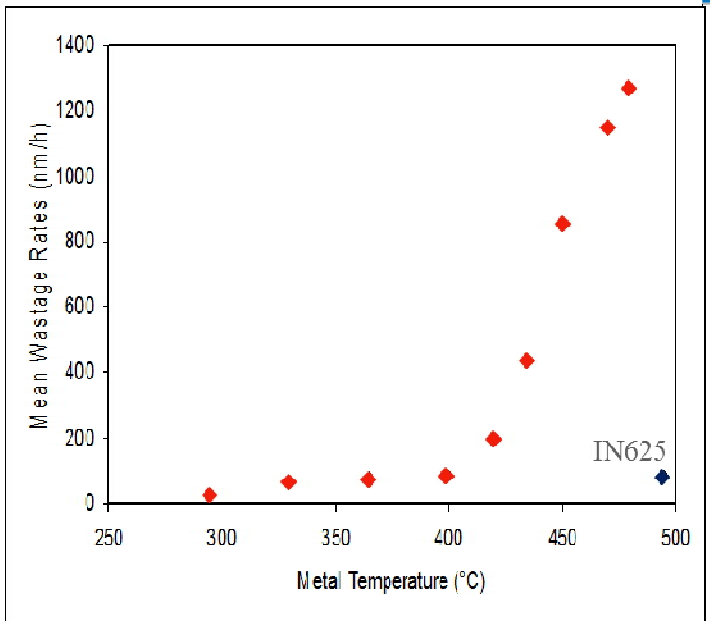
$$r = A \times B\left(\frac{T_g}{G}\right)^m \left(\frac{T_m - C}{M}\right)^n (\%Cl - D)$$

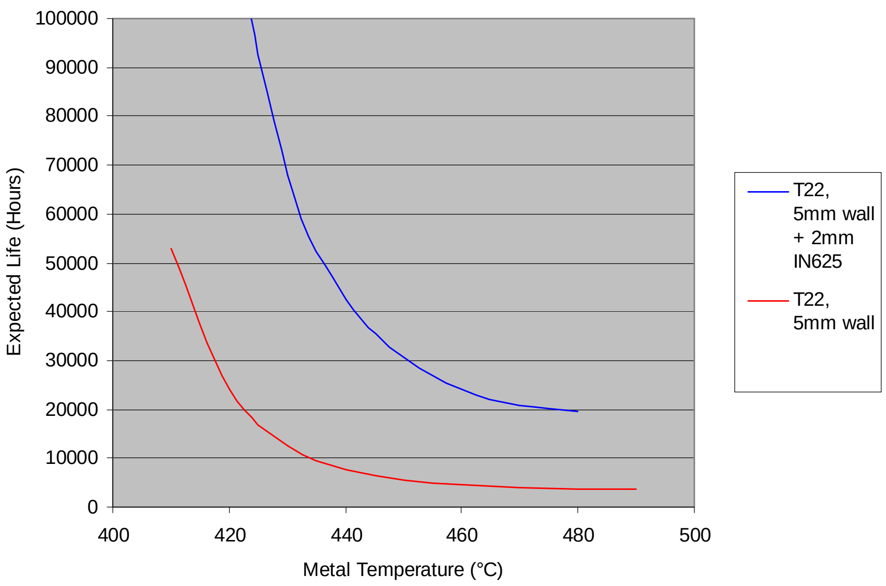
  - Biomass / Waste to Energy – potential for corrosion intensification
    - Reactive alkali metal and heavy metals, eg Zn, Pb, Sn, As and often higher Chlorine content

Fireside Corrosion

- Evaluation of candidate materials through site specific probe studies and/or installation of ‘rainbow’ tubes.
- Example; Attack by alkali chlorides when firing a biomass fuel.
- Marked effect of operating temperature.
- Benefit of IN625 weld overlay over plain T22.
- Weld overlays still not fit and forget!







Fireside Corrosion

Corrosion of IN625
weld overlay

Fireside Corrosion

Mitigation:

- Tube life extension through alternative materials – monobloc, overlay or thermally sprayed
- Quality Control applied during manufacture / installation can strongly influence the longevity of materials within the boiler. This is particularly true of products applied in-situ

Dew Point Corrosion

- Temperature control issues towards the boiler exit can lead to issues with dew point corrosion
- Boiler control systems should automatically compensate for low temperatures at economiser BUT systems are not always perfect
- If gas exit temperatures not managed properly, then rapid corrosion can occur, necessitating stage replacement

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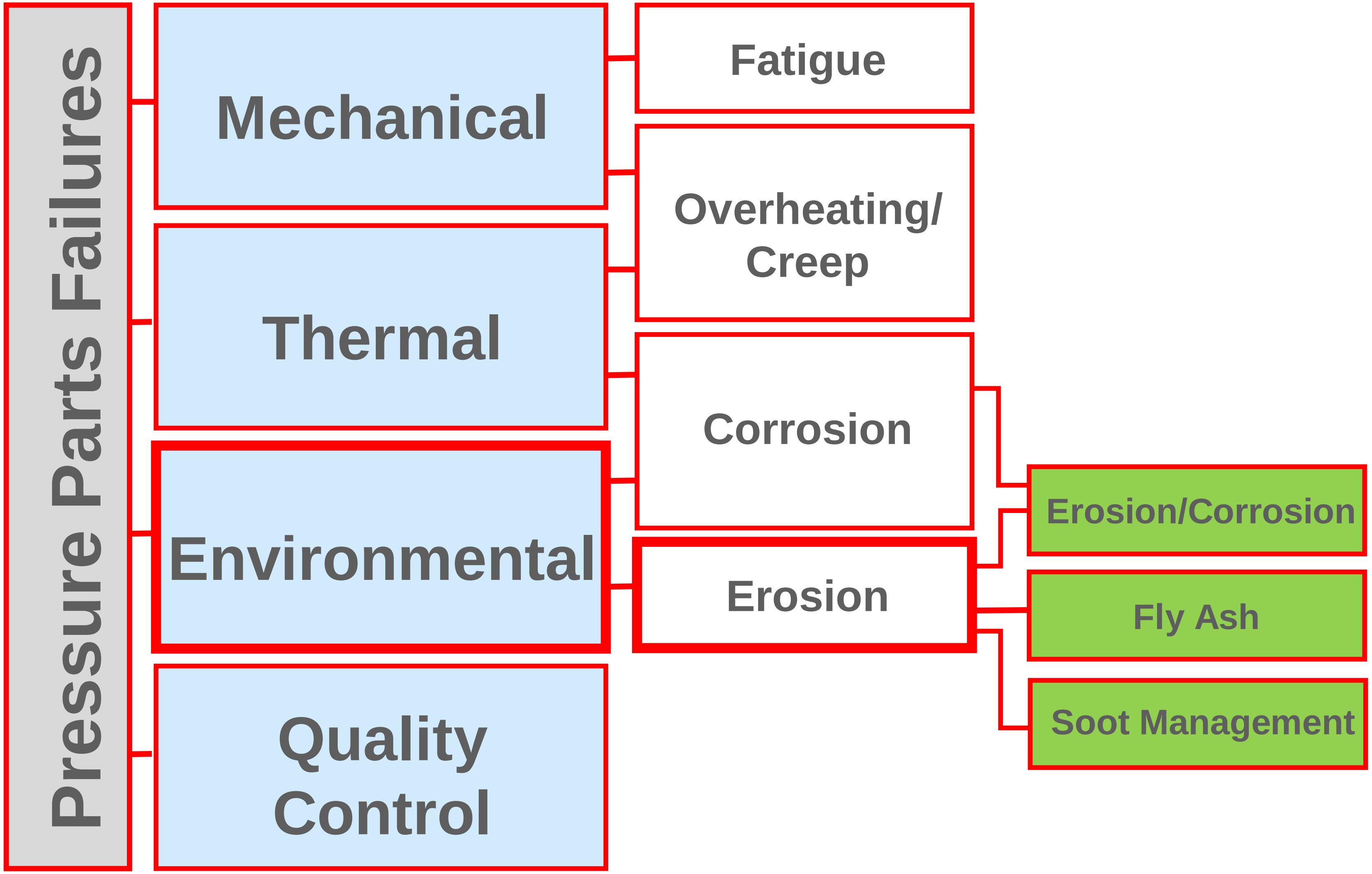
Pressure Parts Failure; Mechanistic Causes



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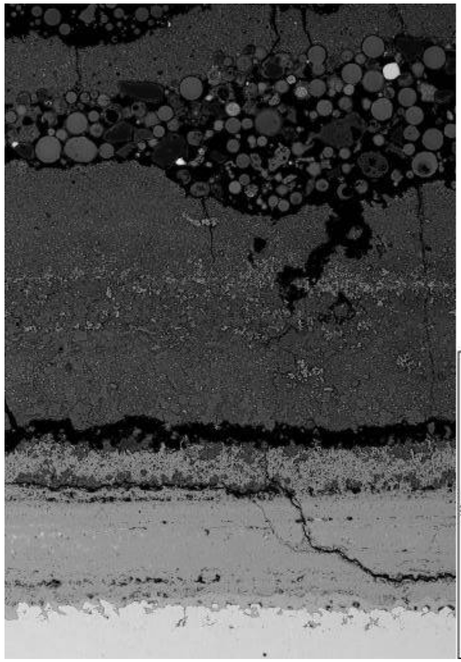
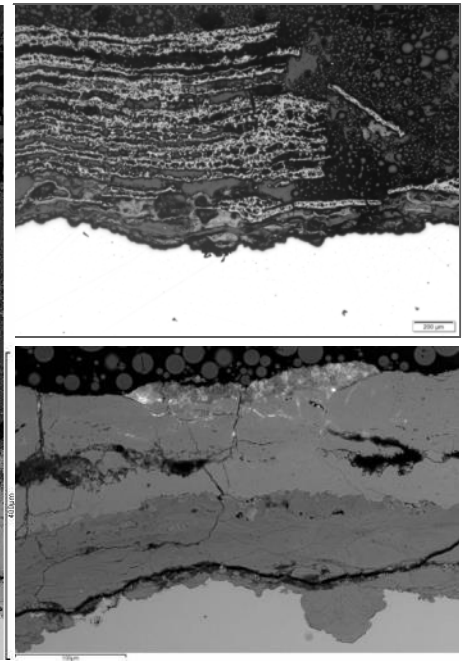
Erosion-Corrosion

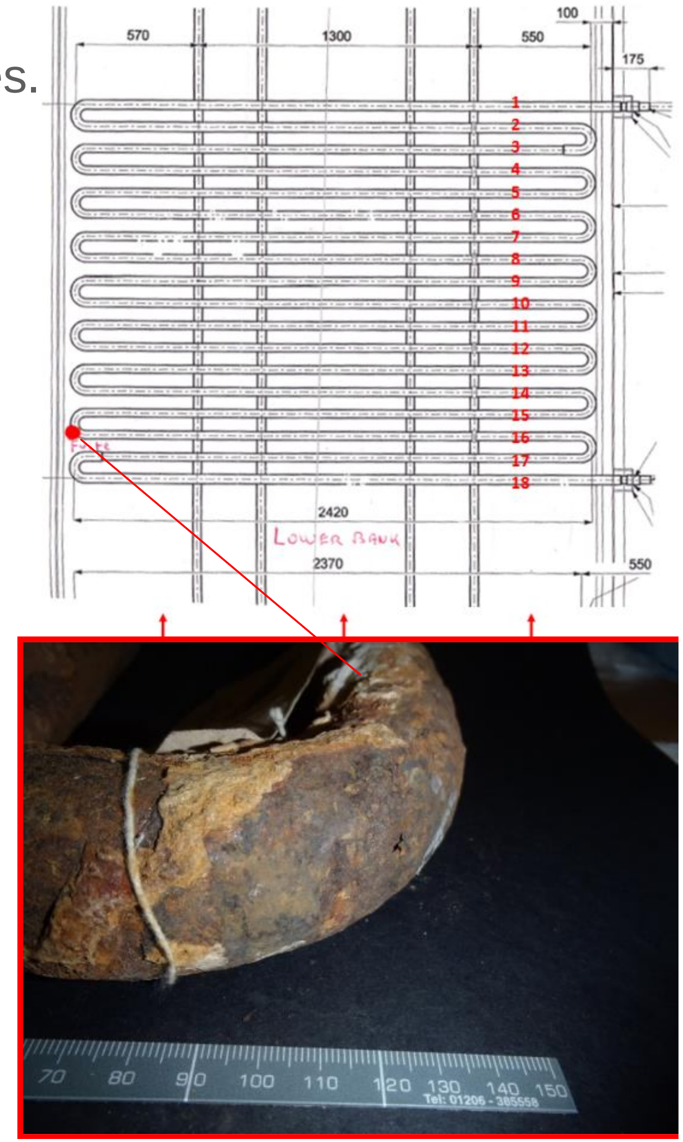
- Tubes developing mechanically weak/defective corrosion scales can experience enhanced wastage through the synergistic action of corrosion and erosion.
- Chlorine is almost invariably the active corrosion species.
- Sootblower erosion and/or local increases in flue gas velocity (fouling/blockages) can exacerbate metal loss.
- Corrective measures usually involve upgrade to more corrosion resistant material.



Good scale (protective)
13CrMo44



Poor scale (un-protective)
15Mo3



Erosion-Corrosion

- Fuel composition can significantly influence the propensity for fouling of tubing within the gas pass – Alkali metals and iron sulphide can promote fouling.
- This is typically associated with an increase in flue gas temperature later in gas pass due to fouled stages not extracting heat.
- Soot cleaning then required to remove deposits and maintain the desired temperature distribution within the boiler
- Soot cleaning strategies are important
- If system not optimised, and operators trigger a clean too regularly, can cause significant erosion damage to tubing
- Intelligent control systems available
- Mid-life changes in fuel supply can strongly influence fouling characteristics – need to re-evaluate soot cleaning strategy following such changes.

Soot Cleaning Systems

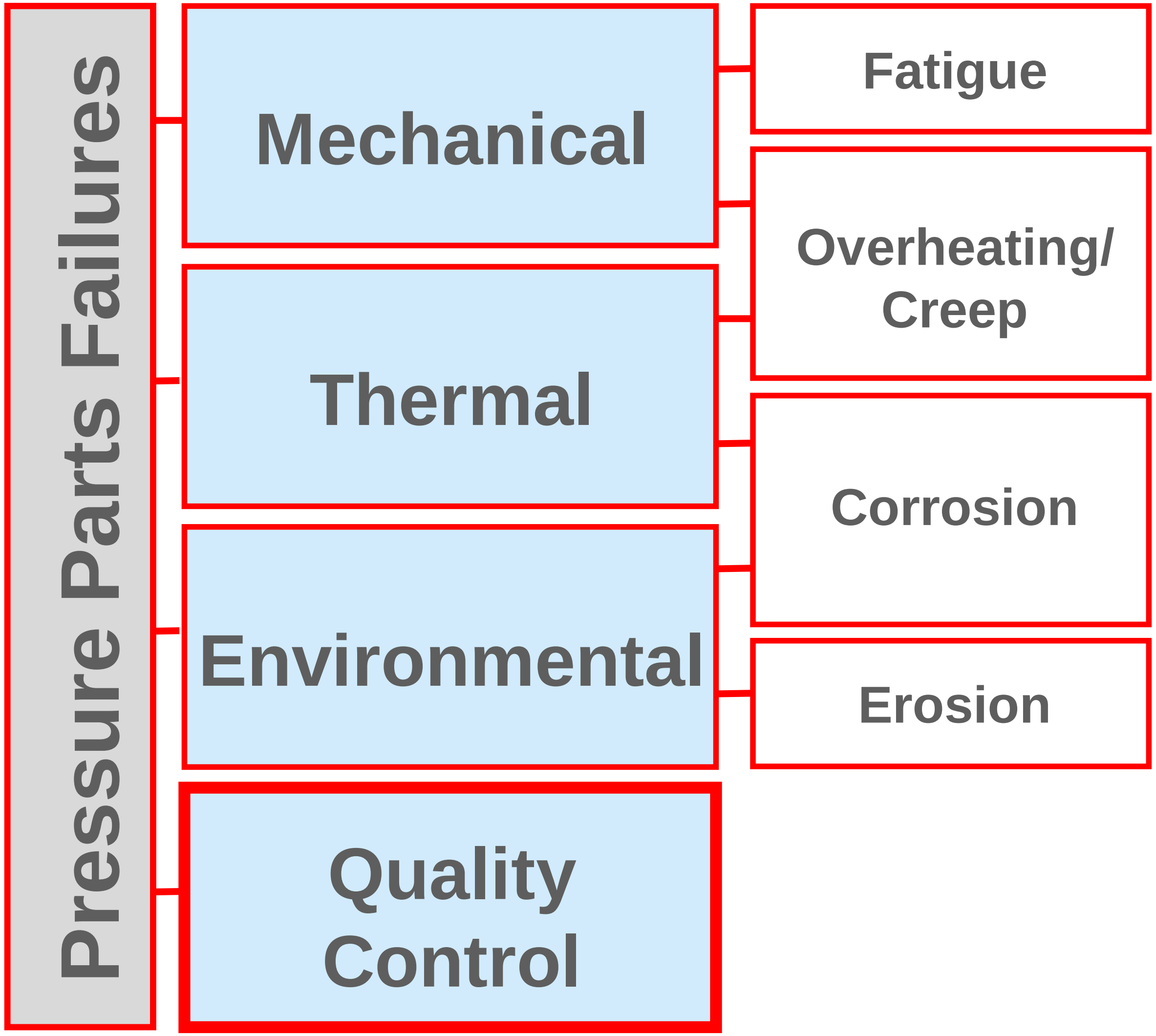






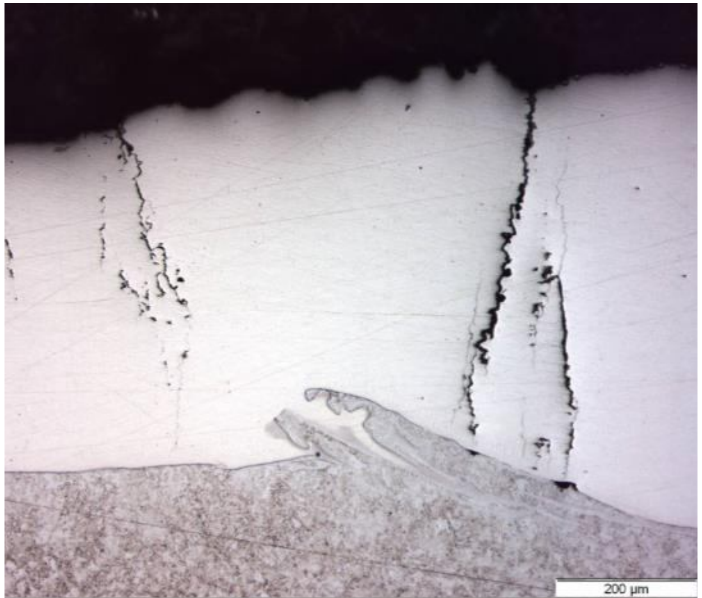


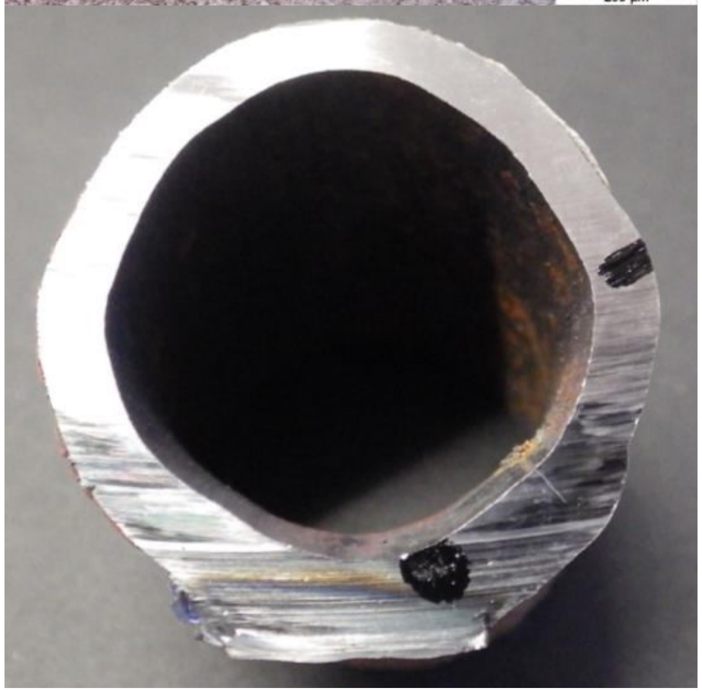
Pressure Parts Failure; Mechanistic Causes



Quality Control

- Quality control - critical to avoid premature tube failures
- Weld overlay
  - Excessive dilution – compromise corrosion performance
  - Weld defects – In worst case scenario, through thickness cracking of weld deposit will act as pathway for corrosive species to attack substrate, allowing coating to be undermined
- Tube Manipulation
  - Non-code compliant tube bending can introduce defects, such as unacceptable deformation (ovality), and increased hardness rendering the tube susceptible to premature failure (Stress Corrosion Cracking, Low temperature creep).





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Tube Failure Management

- **Renew tubes wholesale** – typically at planned outage on basis of known wastage rate to optimise maintenance strategy for reliability.
- **Improve design of tube stage** – Inevitably plant built to a cost, therefore optimisation of stage design (and materials employed) versus the original installation can potentially reduce maintenance burden.
- **Selective tube renewal** – Lead tubing inevitably encounters more severe conditions compared to more sheltered tubing within the bank, replacement of lead tubing can economically extend lifetime of stage prior to full replacement.
- **Local repair** – Typically undertaken in response to forced outages. Critical to select correct repair procedure (overlay, tube insert) for failure mechanism and tube location.
- **Improvement in repair quality** – Ensure appropriate NDT applied to avoid early life failures. Critical when undertaking stage replacement to minimise ‘bathtub’ failures.
- **Change operational procedures** – e.g. appropriate management of soot cleaning systems or gas exit temperatures.

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Thank you for your attention