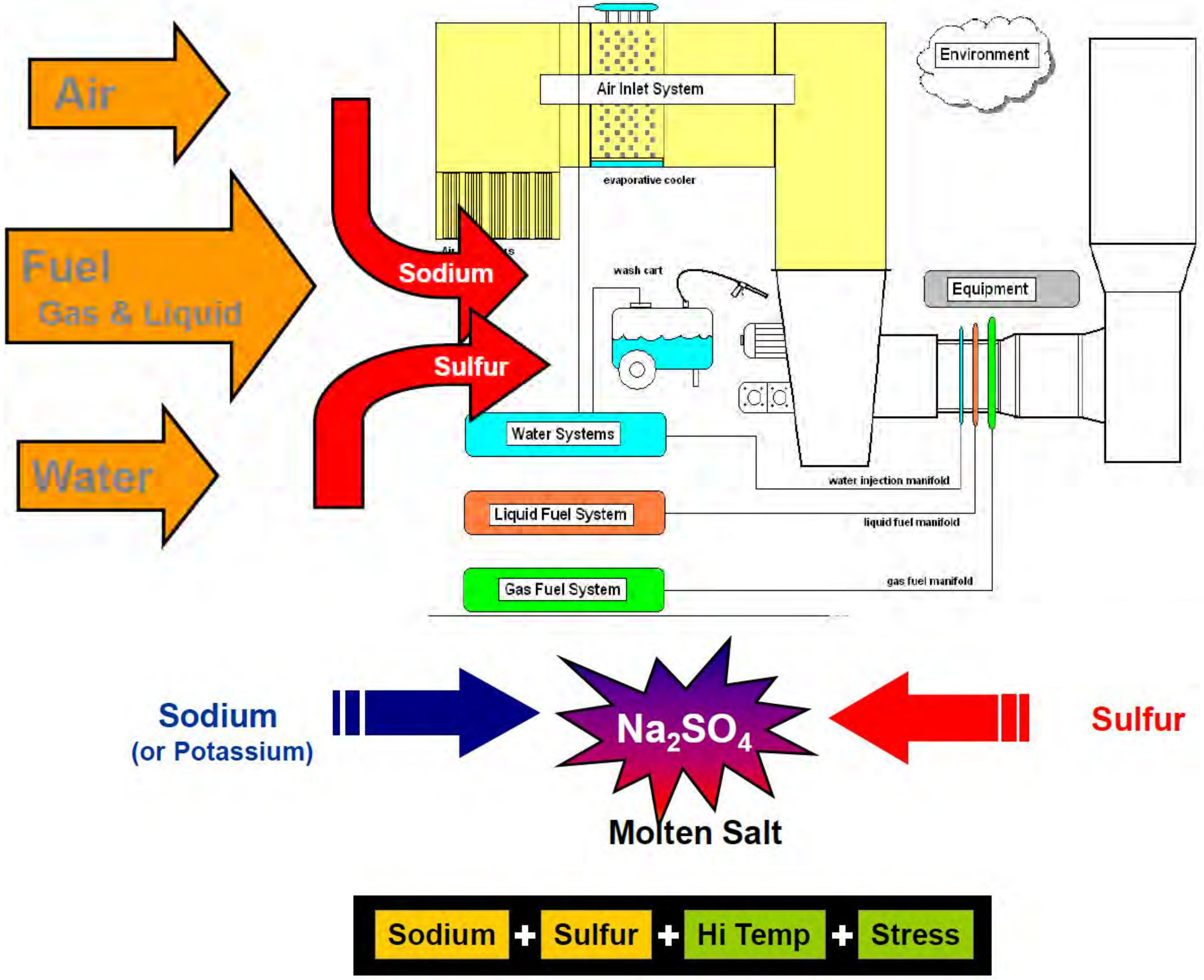
# Case Study of Harsh Environment Impact on Gas Turbines Pre-Mature Failures in Malaysia Offshore Waters and Novel Approach in Resolving the Prolong Issues

# Presenter Biography

- Ir Dr Harris Abd Rahman Sabri
- Staff Rotating, Centre of Operational Excellence (CoE) Division, PETRONAS Carigali Sdn Bhd
- 15 years in PETRONAS
- Started career in oil and gas as Rotating Engineer (Maintenance) at Downstream utilities plant
- 2 major Greenfield projects; Lead package engineer for LM2500+G4, RB211 24 GT, Taurus 60 and Taurus 70
- Undertaken role as governance under Malaysia Petroleum Management
- Present; under CoE, he provides technical leadership and solutions to specific reliability/integrity improvement, and lead the digital initiatives related to rotating equipment
- Team leader for PETRONAS Rotating Equipment Analytics (PROTEAN) solutions

# Harsh Environment - Definition

- Environment where alkaline metals are present and may combine with Sulphur to create a corrosive molten salt
  - Offshore
  - Coastal
- Contamination can come from multiple places
  - Air
  - Fuel
  - Water
- Molten salts cause accelerated oxidation or sulfidation attack on high temperature alloys



# Types of Hot Corrosion

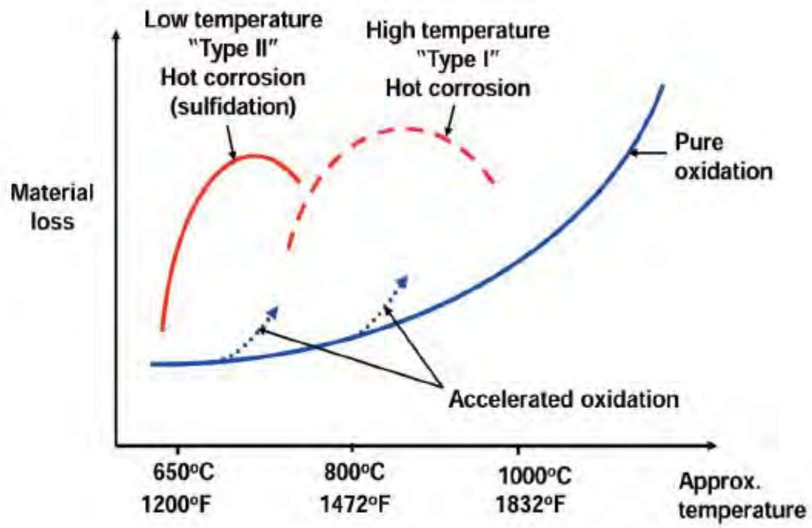
**Type I Hot Corrosion**

- High Temp (Type I)
- 800 – 950 degC
- Typically occurs at Blade Tip

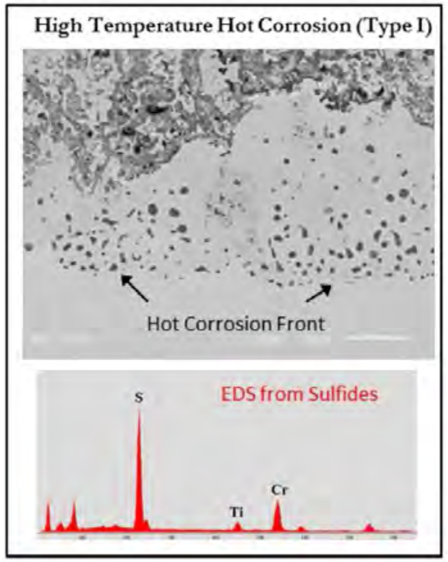
*subjected to respective concentration of S, NaCl, and other components (Ca+, K+ etc) which may also leads to hot corrosion

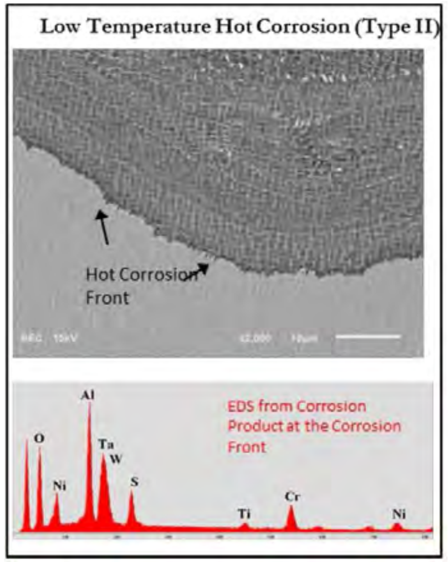
**Type II Hot Corrosion**

- Low Temp (Type II)
- 670 – 750 degC
- Pitting attack
- Typically occurs under blade platform



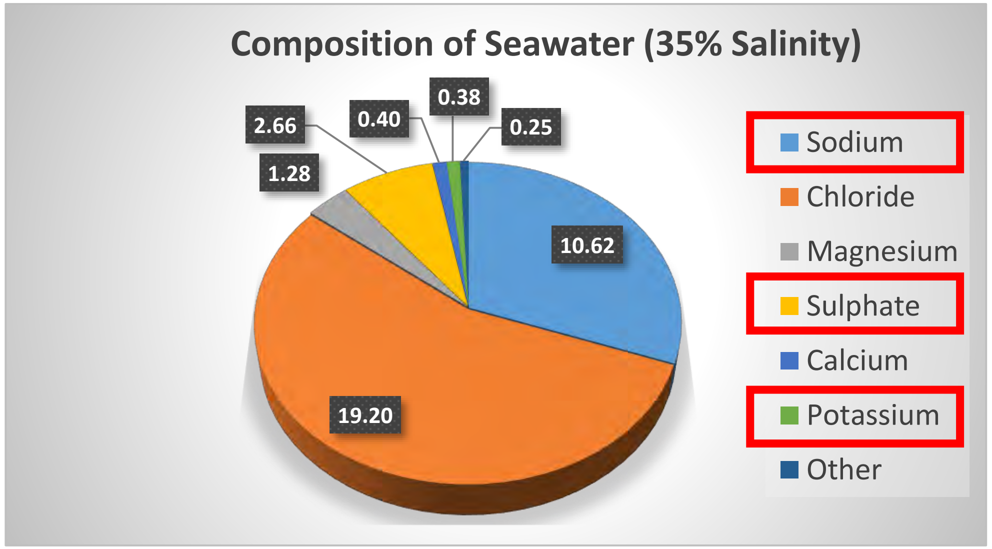

Source: E. Kosieniak *et. al.;* Component Failure in Gas Turbine Hot Corrosion, Journal of Failure Analysis and Prevention, June 2012, Volume 12, Issue 3, pp 330-337



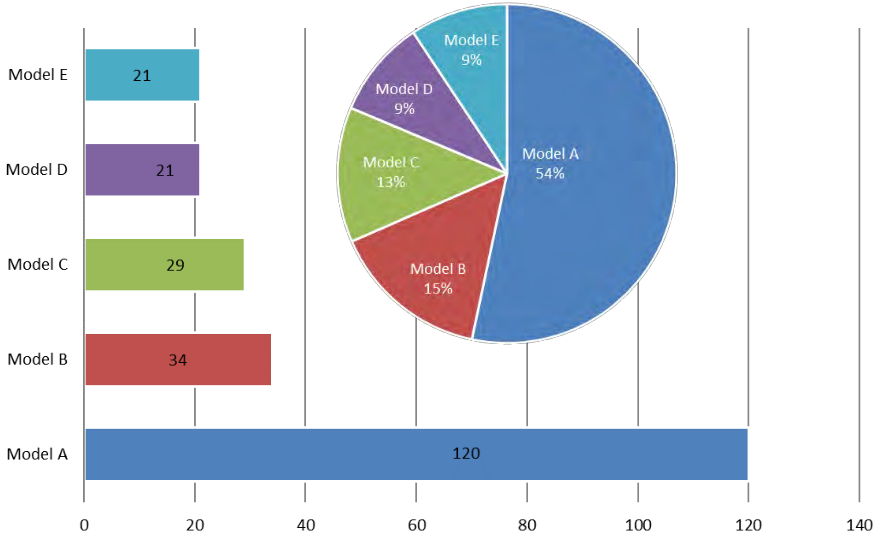



# Problem Statement - Background

- Increase in use of turbomachinery in offshore applications
  - *Increased power density*
  - *Efficient*
- Offshore environment – unforgiving on high temperature alloys
  - *Natural environment contains the presence of sulfur in various forms (SOx, H2S, S); catalyst for hot corrosion*
- Turbine durability and platform reliability severely affected by hot corrosion
  - *$$ lost due to unplanned downtime*



# Root Cause Investigation – Affected Turbines




| Model line | Total units | # Failures Over 12 yrs |
|---|---|---|
| A | 120 | 0 |
| B | 34 | 0 |
| C | 29 | 16 |
| D | 21 | 1 |
| E | 21 | 4 |

| Model C Users | #units | Failures 2006 to 2018 |
|---|---|---|
| User 1 | 2 | 0 |
| User 2 | 4 | 0 |
| User 3 | 6 | 2 |
| User 4 | 3 | 2 |
| User 5 | 3 | 3 |
| User 6 | 4 | 9 |
| User 7 | 3 | 0 |
| User 8 | 4 | 0 |

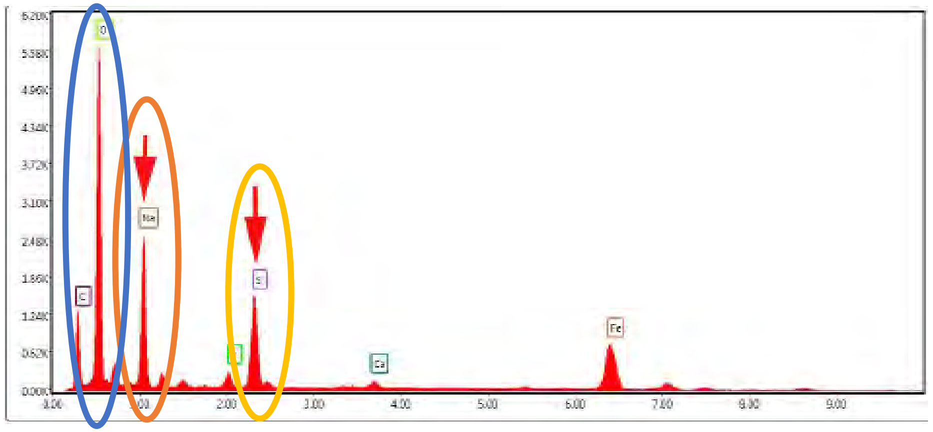
**Fleet of 225 Gas Turbines within PETRONAS under this investigation**

**Model C is most affected over 12 year span**

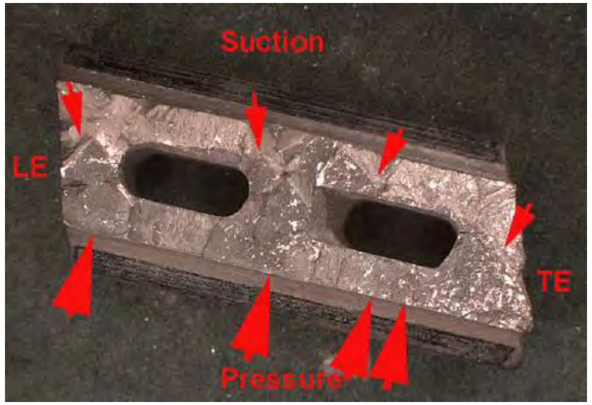
**50% of Model "C" Users have experienced hot corrosion issues**

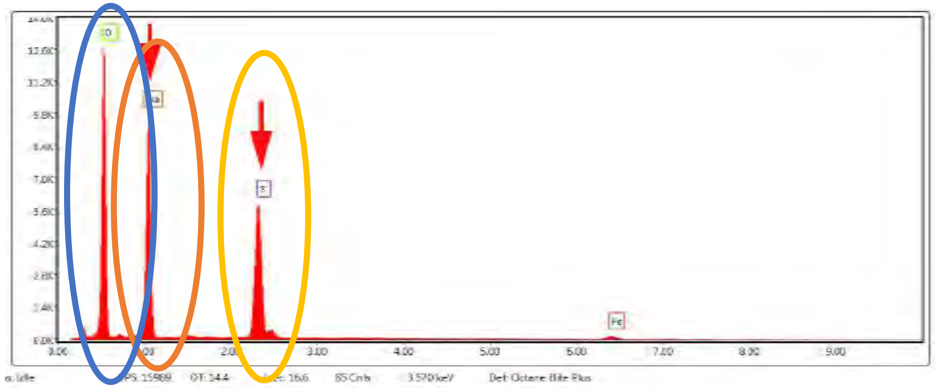
# Root Cause Investigation – Failure Analysis Reports

- **Fouling in compressor air path**
  **Corrosive species found via EDS Spectrum**
  - **Oxygen**
  - **Sodium**
  - **Sulphur**



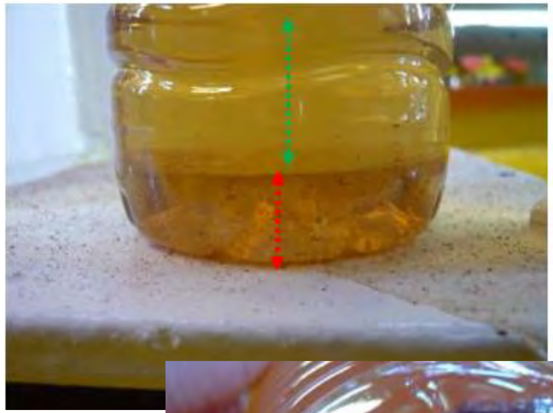
- **Failure mechanism confirmed as hot corrosion type II attack, considering the temperature range at the location**
- **Corrosive species found in turbine cooling path via EDS Spectrum**
  - **Oxygen**
  - **Sodium**
  - **Sulphur**



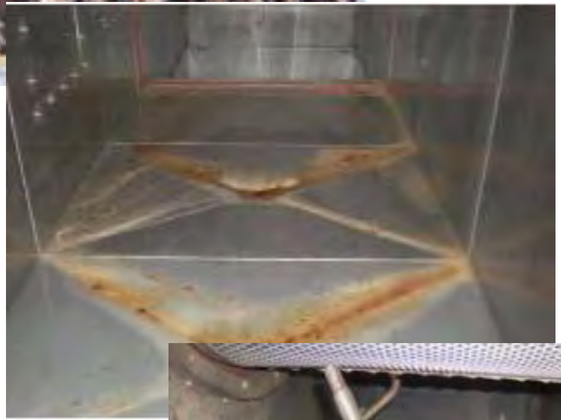



# Root Cause Investigation – Site Investigations

- **Air Filters**



- **Water in diesel**



- **Inlet duct water ingress**

- **Impurity materials**

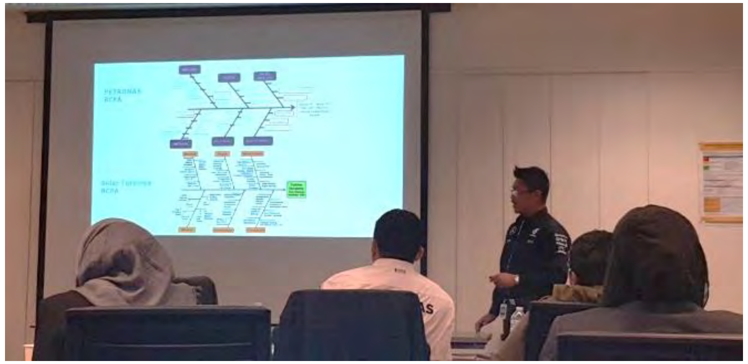
- **Inlet duct water ingress**

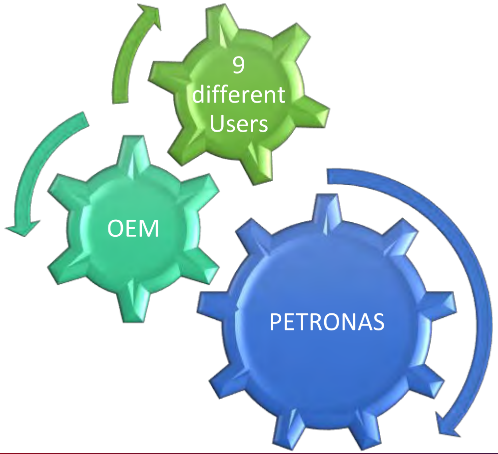
- **Liquid fuel filters**

# Root Cause Analysis – Full Team Collaboration

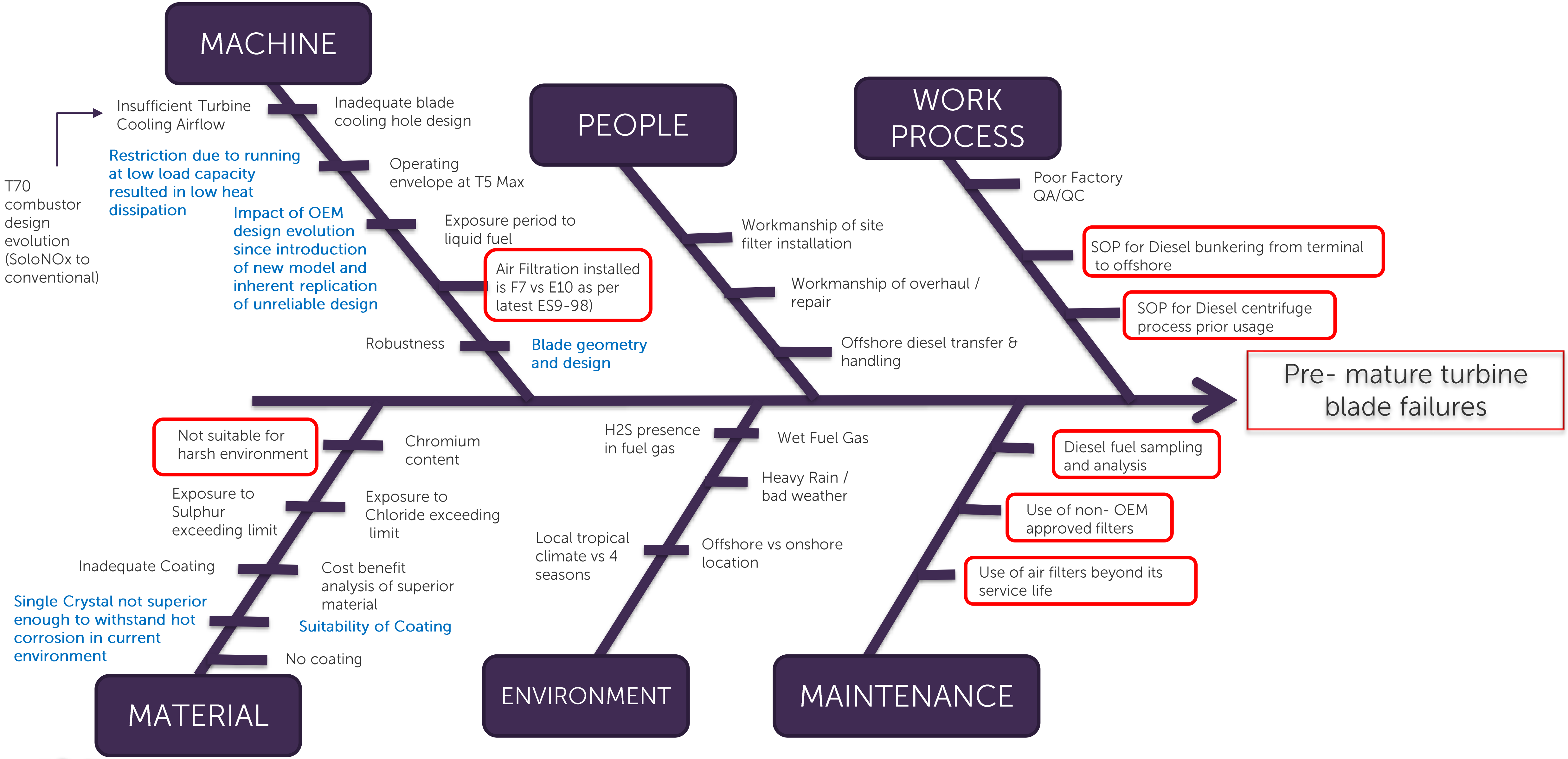
Harsh Environment Specific Session during OEM User Conference 2018

RCFA session between PETRONAS and OEM Technical Experts

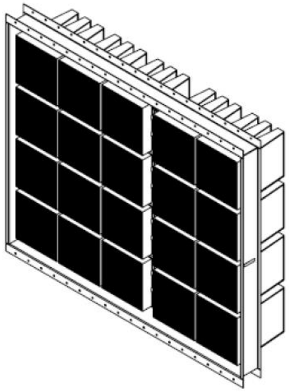





# Root Cause Failure Analysis – Fishbone Diagram



# Solution – Partnership with OEM and Users



**A**
**Air Filtration**

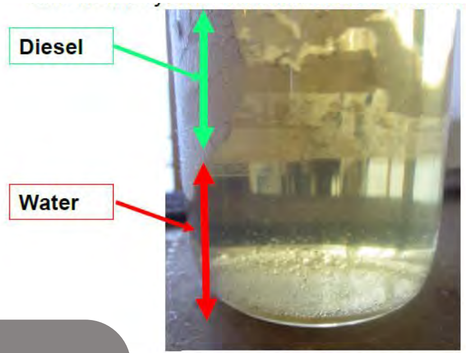
Prevent corrosive species ingestion via filtration improvement

**B**
**Blade Alloy**

Improve blade corrosion resistance via blade alloy and coating selection

**C**
**Clean Fuel**

Prevent corrosive species ingestion via monitoring and ensuring clean fuel




Liquid fuel sample from facility fuel tank

**D**
**Digital**

Monitor data to enable proactive prevention measures

# Solution – Air Filtration Efficiency

A

Air Filtration

Filtration Frame Retrofit Solution

- Improved efficiency
  - F7/F8 to E10 hydrophobic
- Lower cost
- Utilize existing housing
  - No hot work required
- Minimal Downtime to install

9,500 hours
- original filters

19,500 hours
- G4 Prefilters
- E10 final filters

# Solution – Blade Alloy and Coating Selection

**B**

Blade Alloy

Blade Alloy selection

- Double Chromium content
- Corrosion resistant coatings applied
- Stage 1 and Stage 2


**High Cr content Blade with Protective Coatings**

# Solution – Ensure Clean Fuel and Digital Connectivity

C

Clean Fuel

Clean Fuel Initiative

- Frequent sample analysis
- Develop clean up strategy with OEM and Users
  - Tank cleaning, Centrifuge Maintenance, Recirculation through Filters
- Monitoring plan

Improved results

| User 3 | Diesel Sample 1 | Diesel Sample 2 | Diesel Sample 3 | Diesel Sample 4 | Diesel Sample 5 |
|---|---|---|---|---|---|
| | **Feb-18** | **Apr-18** | **Jun-18** | **Aug-18** | **Oct-18** |
| | **Not Compliant** | **Close to compliance** | **Close to compliance** | **Compliant** | **Compliant** |

D

Digital

Remote Data Monitoring

- Detect issues early
- Proactive problem solving
- Partner with OEM to benefit from worldwide fleet statistics

# Results so far as of April 2019

## ZERO

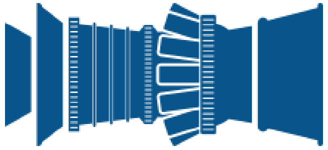
**Pre mature failures**

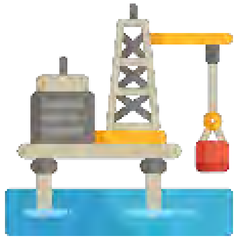
After ABCD implementation kick off in 2018

## Key Success Factors

| | | |
|---|---|---|
| INTEGRATOR | LEADERSHIP | COLLABORATION |
| TRANSPARENCY | DATA DRIVEN | BETWEEN USERS |
| PARTNERSHIP | RCA | USERS AND OEM |

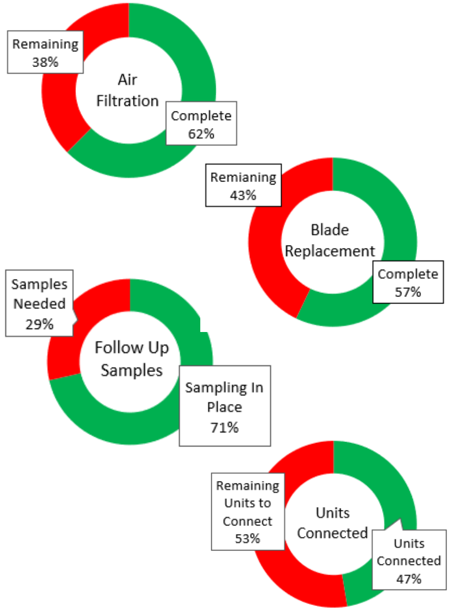
**Quality Relationship with OEM**





**OEM and User Engagement Improved**

## Progress as of April 1, 2019




## 100%

**ABCD Completion by Q1 2020**

## >USD 6 Mill

**Cost Saving for PETRONAS for ABCD**

## 2020

**Continuous Monitoring of ABCD Effectiveness**

## ~USD5Mill

**Cost Avoidance with Improved Reliability and Availability**