WORLD-CLASS OUTSTANDING INTERNATIONAL

PROGRAM | EXHIBITION | NETWORKING

DEEP OFF-SHORE COMBUSTION AIR FILTERING SYSTEM ANALYSIS

OFF-SHORE FILTER SYSTEMS ANALYSIS TO PEAK GTG AVAILABILITY AND RELIABILITY IN HARSH CONDITION

42nd Turbomachinery
29th Pump SYMPOSIA

PETROBRAS

TEXAS A&M ENGINEERING TEES TURBOMACHINERY LABORATORY

ATM

GEORGE R. BROWN CONVENTION CENTER
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ABOUT THE AUTHORS

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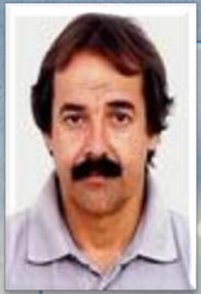

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Francisco Carlos is Senior Engineer and Turbomachinery Advisor at Petrobras Brazil. He has over 30 years of strong background in Filter Systems Design, being responsible for the GTG Filter Systems Operation at Campos Basin Off-Shore Units. He has a bachelor's of Mechanical Engineering

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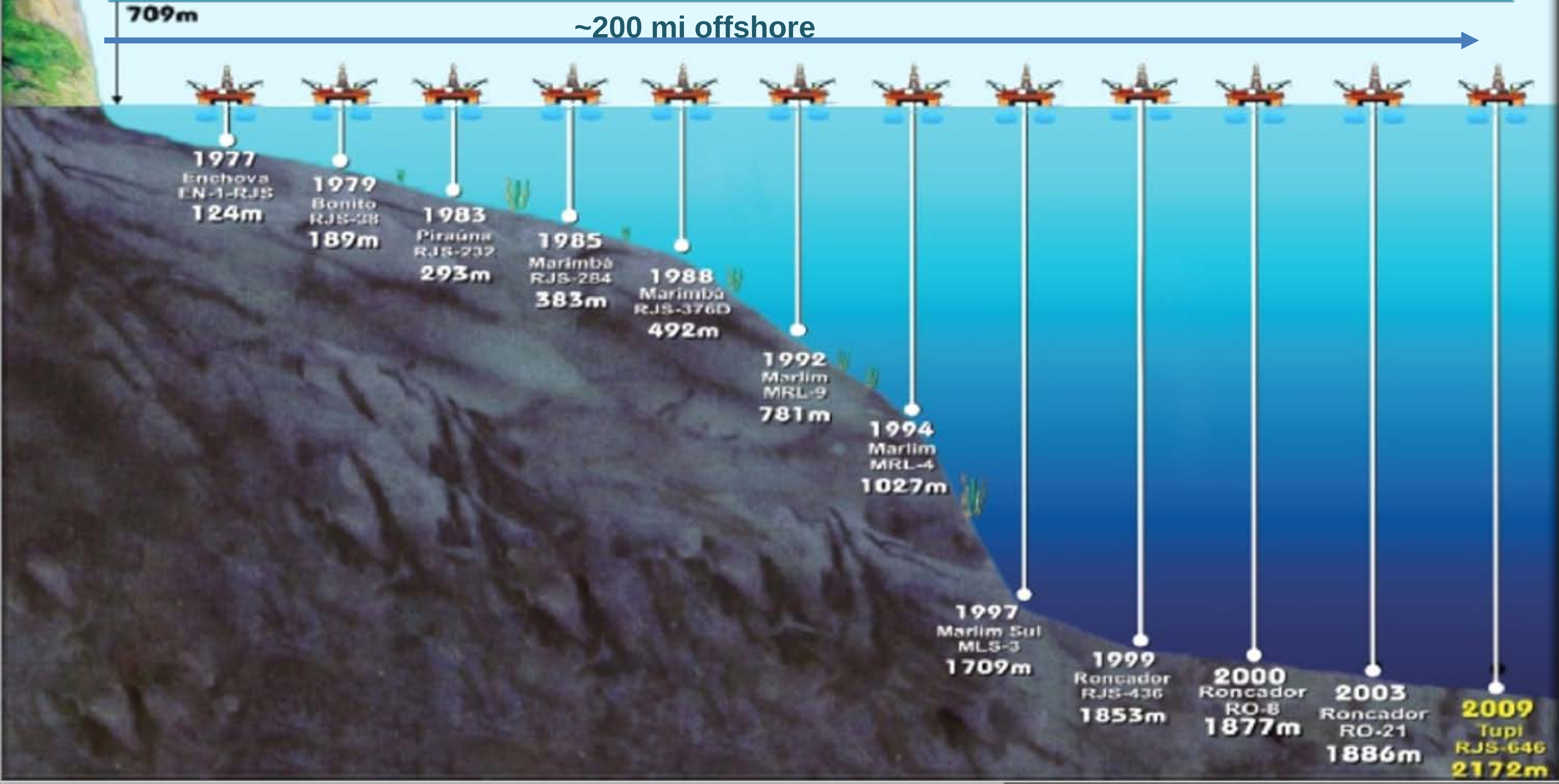
EVOLUTION OF DEEP WATER O&G PRODUCTION

Greater off shore distance

- ***Increases need for high reliabilty power systems***
- ***Logistic challenges***
  - ***Transportation Cost***
  - ***Uncertainty [weather, storage, lead time]***



PROBLEM STATEMENT

Deeper water location increases the challenges

- Power systems fundamental to off-shore facilities [Reliability & Availability]
- Filters MTTF:
  - Improve from 6k *to 12k hours Prefilter*
  - Improve from 10-12k *to 24k hours Final Filter*
- *Reduce Life Cycle Cost by 20%*

Salty environment increases risk of Thermal Corrosion

- Improve filter salt efficiency by > 50%

Inertial Separation Philosophy x Filtration Grade

- Size Really Matters?

Challenge

✓Which driver to consider to select the optimum combustion air filtration system for gas turbines installed on deep off-shore platforms??

PETROBRAS EXPERIENCE

FLEET MAKEUP

- OVER 250 GTGs
- 100+ PLATFORMS
- PRE SALT APPLICATIONS:
  - 31 MW ISO GTGs

OPERATION ISSUES

- THERMAL CORROSION
- SHORT FILTER LIFE / PRESSURE DROP
- POOR FILTER PERFORMANCE
  - DRAINAGE
  - DURABILITY
  - COMPRESSOR FOULING
  - DOMESTIC OBJECT DAMAGE

KEY PARAMETERS FOR SYSTEM SELECTION

A

Reliability Availability

- **MTTF Increase**
- **Less Downtime**

B

Long Service Life

- **Prevention of Thermal Corrosion**
- **Less Filter Stress**

C

Life Cycle Cost

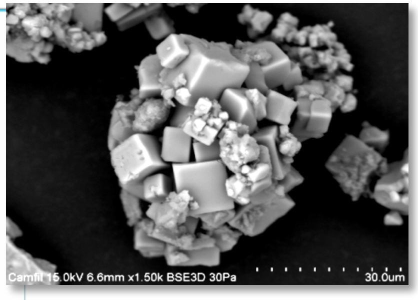
- **Balance Factors [Technic/Economic]**
- **Max. $$$$ Savings**
- **Minimize Turbine Fouling**

A

DEEP OFF-SHORE PLATFORM ENVIRONMENTAL CHALLENGES

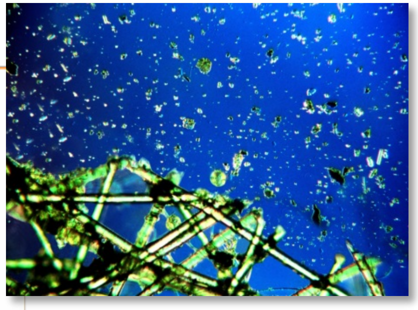
Two main sources of particles:

- Airborne salt / sea spray
- Platform generated particles such as hydrocarbons



Location – Deeper Off-Shore

- Amplifies critical importance of gas turbine performance
- Logistic challenges:
  - Availability of parts
  - Response time for repairs
  - Cost of transporting parts
  - Weather



A INLET FILTRATION OPTIONS

Medium velocity

2500 cfm

2 to 3 filters / MW

0.75 – 1 m² / MW

More Filtration Area [Less Stress]

Optimized to filter particles of all types

High Velocity

4500 cfm

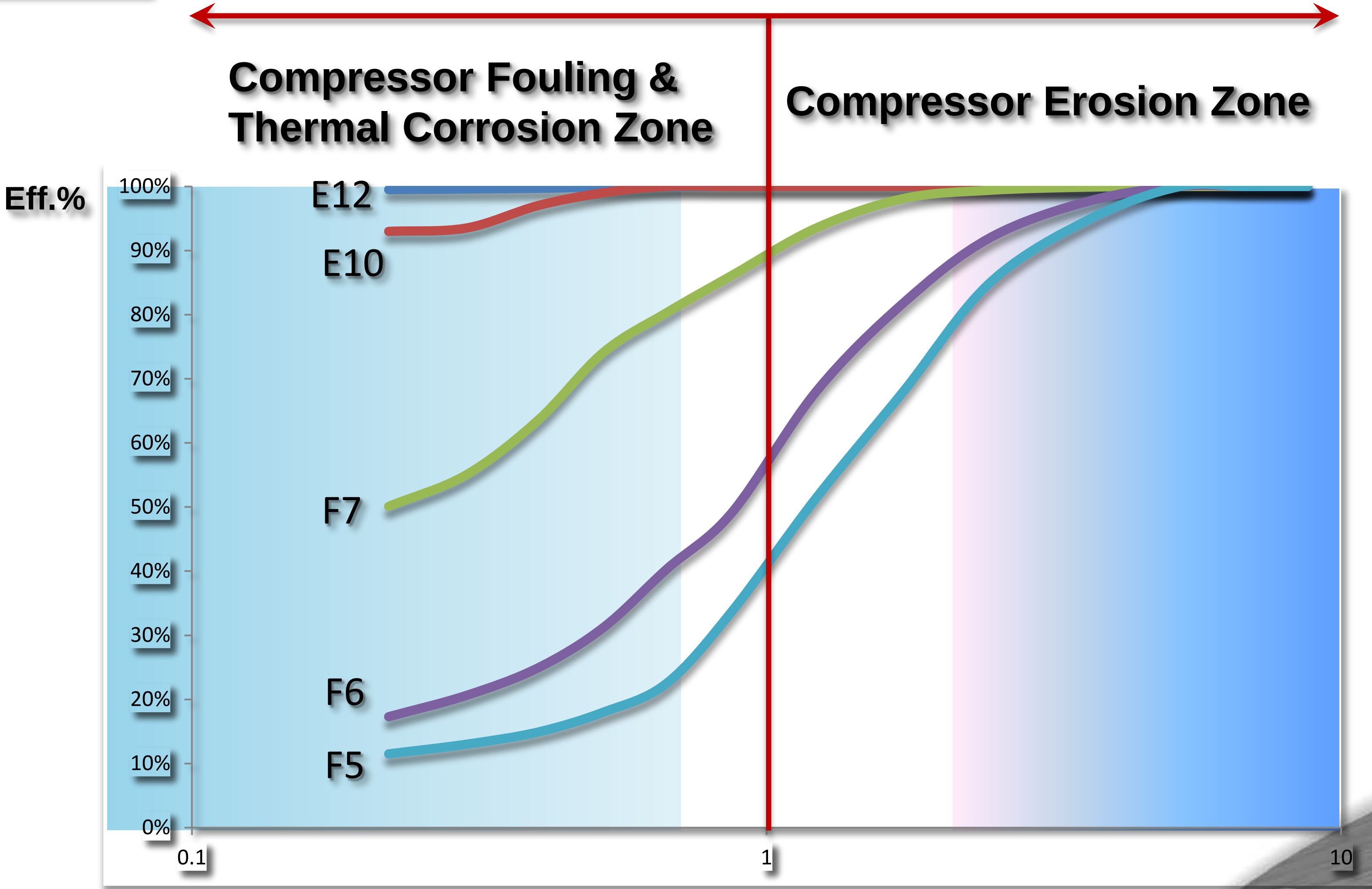
1.5 filters / MW

0.5 m² / MW

Inertial Separation Required

Optimized to filter wet salt particles

TYPICAL OFF-SHORE SYSTEM EFFICIENCY



Ref.:EN-779:2012

Particle Size [µm]

B

FILTER LIFE

Multi Stage Filtration System allows operators to Change Filters on-line

- Increase Availability

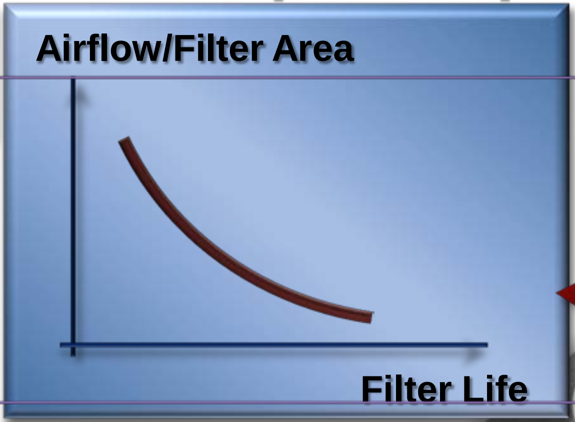
Filter Life directly related to Airflow per Filter Element and dust caught by filter

- Less Air Flow Ratio means Less Filter Stress = Long Filter Life

Filter Integrity Critical:

- High (wet) burst strength
- Water resistance / drainage
- Salt removal efficiency

Air Flow Ratio [Filter Stress]



C FACTORS IN LIFE CYCLE COST

Capital Investment: [CAPEX]

- Cost of filter housing [inc. platform m^2 value]

Direct Filter costs: [OPEX]

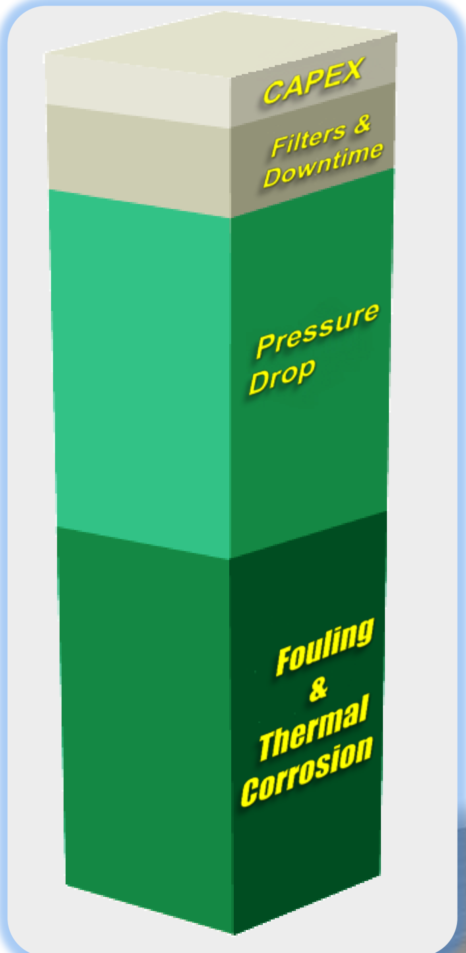
- Cost of replacement filter elements
- Transportation to site, installation and disposal
- Downtime for filter replacement

Indirect Filter costs: [OPEX]

- Output lost due to pressure drop

Fouling and thermal corrosion cost: [OPEX]

- Reduced power output
- Increased heat rate / fuel consumption
- Water wash consumable cost and downtime
- Turbine Parts replacement / Refurbishment



C

LCC PREMISSES

ASSUMPTIONS

- LOGISTIC COST [Transport, Install, Storage, Disposal]
  - $270 / Rigid Filter [Final Filter]
  - $140 / Bag Filter [Prefilter]
- Heat Rate: $7.3 / MM BTU
- MW Value: $95 / MW-hr
- 6,000 Operation Hours / Year
- Air Compressor Efficiency < 0.80 – Dirt Filter
- 100mm H20 [10mbar] inlet drop means:
  - 1.42% Power Output Loss
  - 0.45% Heat Rate Increase

$$NPV = A(1 + (i - e))^{-n}$$

Where:
A= cost of item under consideration
i=discount rate used for cost of capital decision
e = inflation rate
n= time – operational life – years

PRESSURE DROP

- <100 MM H2O [10 mbar] as per API 616 for all system calculated

CURRENT PETROBRAS EXPERIENCE

- PREFILTER: 6,000 hours [G4]
- FINAL FILTER: 12,000 hours [F7]

C

LIFE CYCLE COST ASSESSMENTS

- True value of high quality air intake: maintaining turbine in peak performance
  - More $$$ configuration means $$$$ saving along life cycle.
  - The more cost configuration the more saving along life cycle.

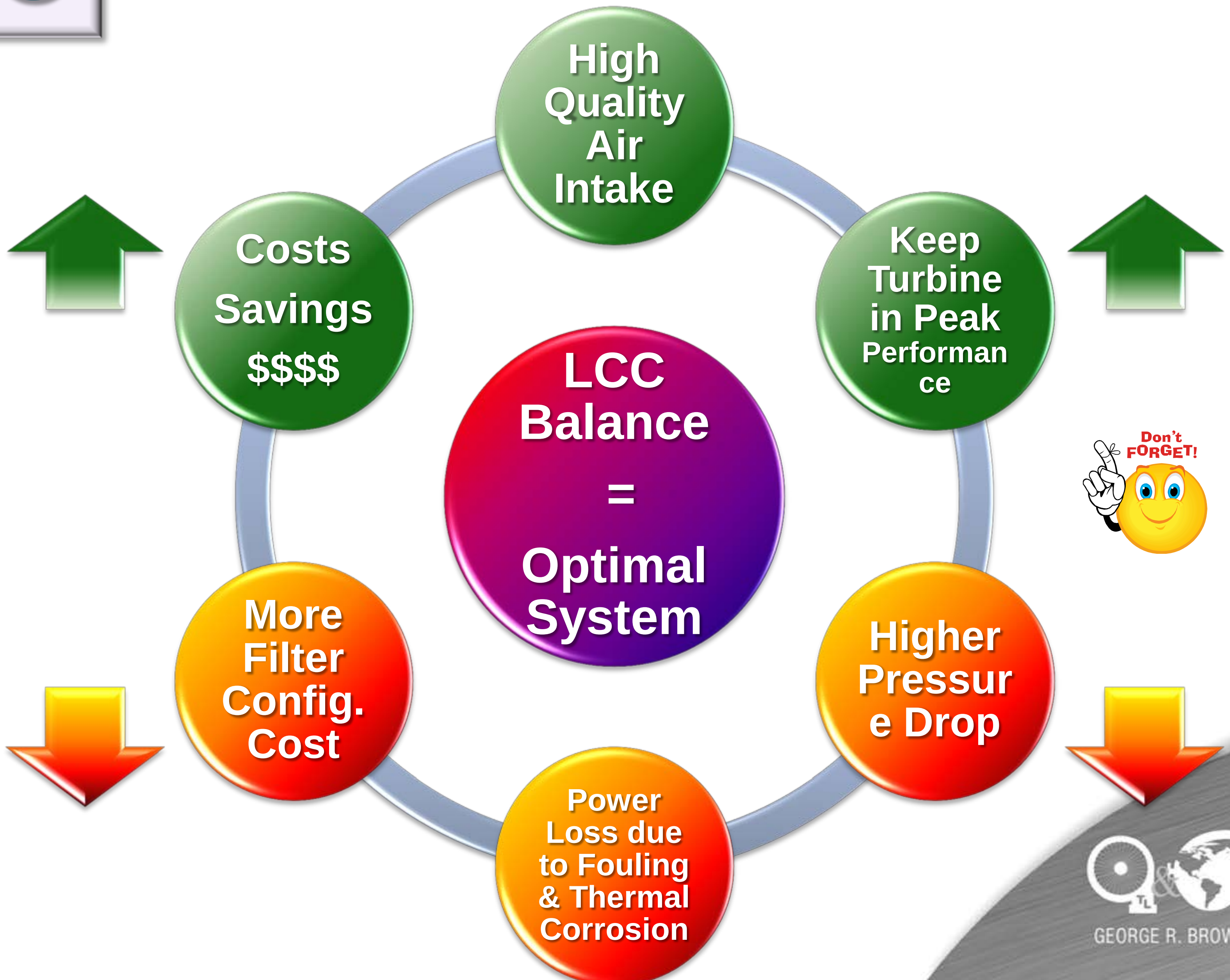
Increasing Filtration Efficiency leads to:

Minimize performance loss due to fouling and thermal corrosion [+]

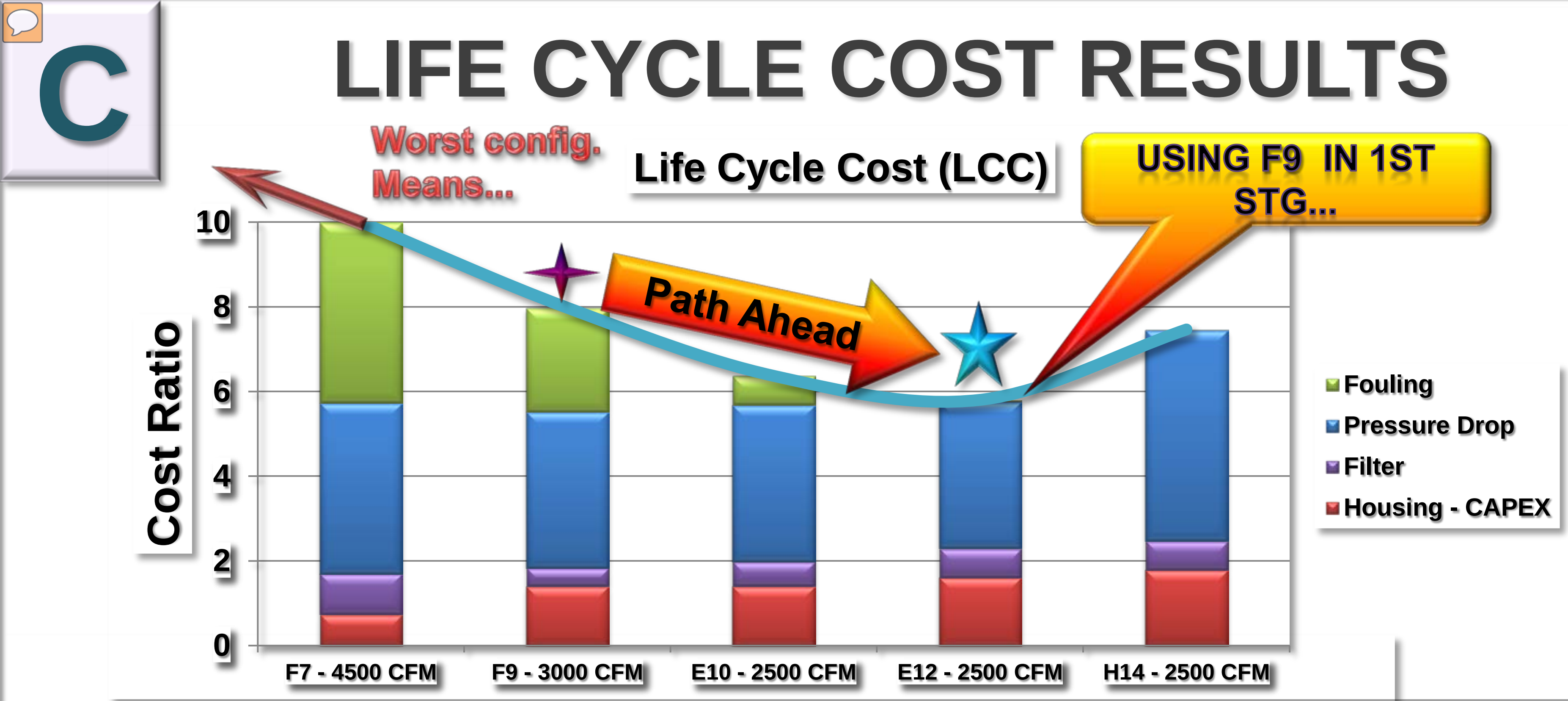
Increased intake pressure drop and direct and indirect filtration costs [$$$] [-]

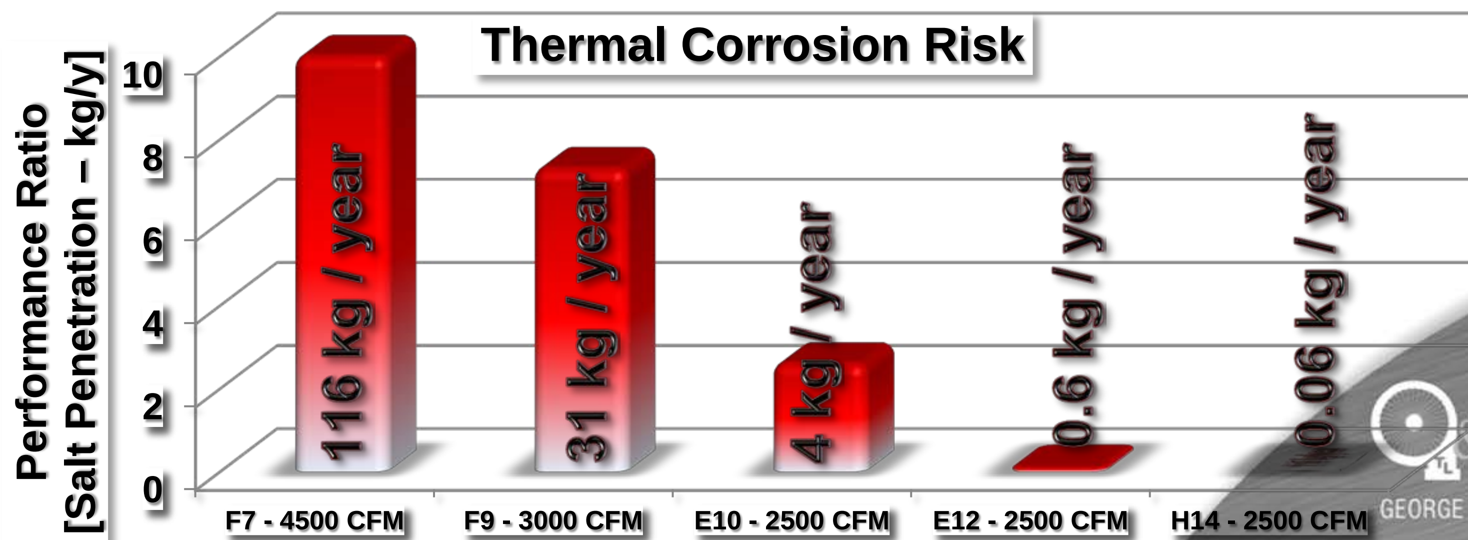
Optimal air intake will balance many factors to minimize overall Life Cycle Cost (LCC) [$$$$]

C LIFE CYCLE COST ASSESSMENTS



LIFE CYCLE COST RESULTS





C

LCC Recommendations

OPEX main cost driver

- Turbine fouling and Filter pressure drop

Main cost of Filters Systems is Filtration Grade

- Filter House Size, Purchase, Transport, Installation, Storage and disposal costs are secondary

Fouling / Thermal Corrosion costs can be dramatically reduced with good filtration;

- **E12 minimizes LCC;**
- E10 minimum recommended [Assuming some Fouling]

Multiple filter stages (different grades) increase availability and efficiency;

Increased Filter Houses (MID velocity / 2500-3000 CFM):

- Reduced pressure drop
- Increased filter life
- Minimize difference in filter class between stages [Máx 3]

Salt Removal Efficiency (coalescing effect)

- Ability to remove aerosol particles

A+B+C

CONCLUSIONS / SUMMARY

Filter Integrity Critical:

- High (wet) burst strength
- Water resistance / drainage
- **Salt removal efficiency – including aerosol particles**

Focus on Filtration Efficiency to enhance Gas Turbine Availability and Reliability

Filter House CAPEX is secondary when approaching the air intake from an LCC perspective

Best Life Cycle Cost for offshore is achieved with mid velocity, multiple stages with different grades and salt removal efficient.