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# Risk Based Inspection Data Integration for Assessing Microbiologically Influenced Corrosion in the Oil and Gas Industry

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# Agenda

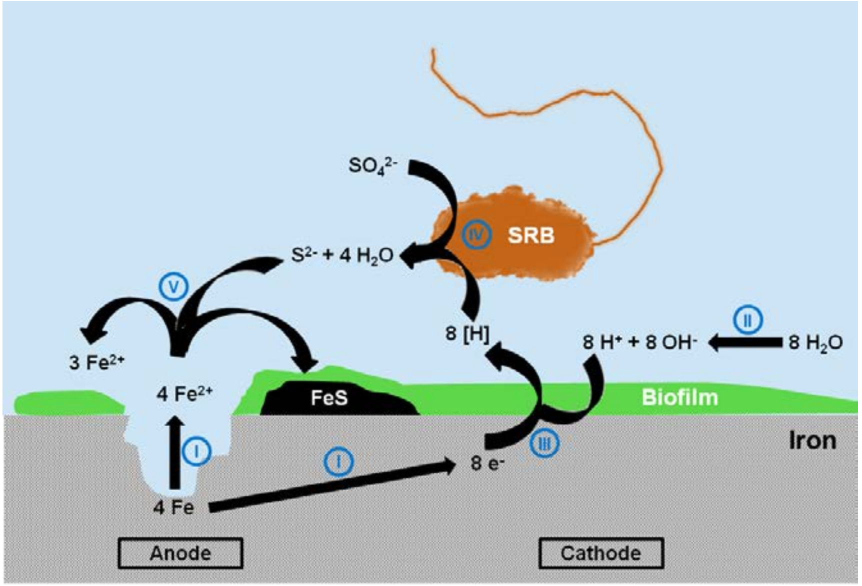
1. Background
2. Previous work
3. Current Model
    3.1. Screening Assessment
    3.2. Ranking Tool
4. Integration process
5. Dataset for implementation
6. Conclusion

# Background

# What is MIC?

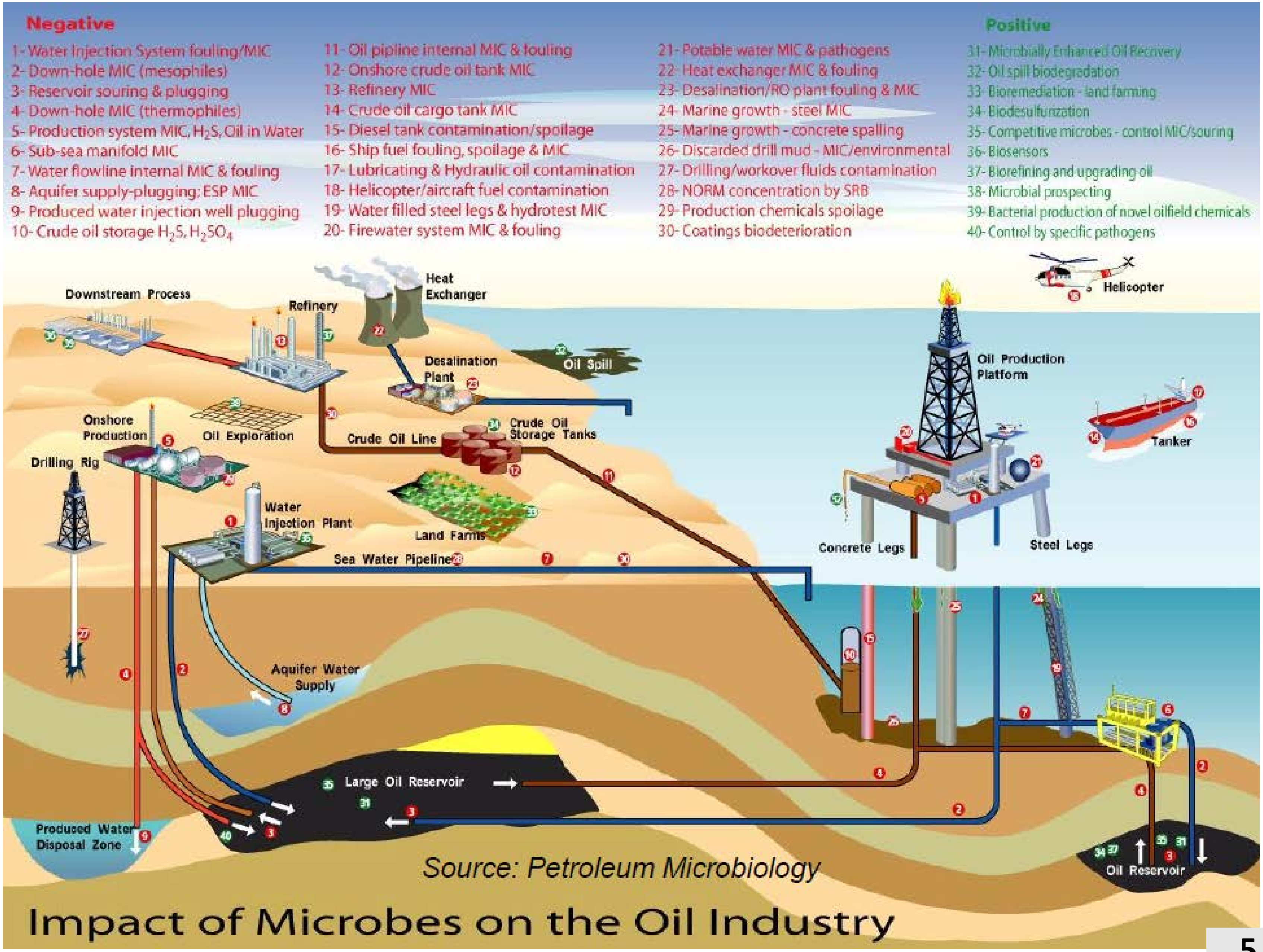
MIC: **M**icrobiologically **I**nfluenced **C**orrosion

- According to NACE, MIC is “corrosion affected by the presence and/or activity of microorganisms in biofilms on the surface of the corroding material”
- Presence of microorganisms alone does not necessarily mean MIC is a threat
- Three layers of requirement must be met:
  - Microbial ABUNDANCE
  - Microbial ACTIVITY
  - Microbial DIVERSITY




Scheme of iron corrosion by SRB based on reactions as suggested by the cathodic depolarization theory. I, iron dissolution; II, water dissociation; III, proton reduction; IV, bacterial sulfate reduction and V, sulfide precipitation.
**Source:** Mechanisms of Microbiologically Influenced Corrosion: A Review
World Applied Sciences Journal 17 (4): 524-531, 2012

# The role of microorganisms in the Oil and Gas Industry



# What is RBI?

RBI: **R**isk **B**ased **I**nspection

$$Risk = Likelihood * Consequence$$

- RBI is a decision-making technique that identifies, assesses and maps industrial risks
- Risk (of failure) = likelihood of failure (LOF) x consequence of failure (COF)
- As MIC is a degradation mechanism, the model works within the boundaries of LOF estimation
- We ‘circuitize’ in order to prioritize
- Semi-quantitative approach is taken

**WHAT** to inspect

**WHEN** to inspect

**WHERE** to inspect

**HOW** to inspect

**WHAT** to report

Inspection, Risk-Based. "API Recommended Practice 580." *American Petroleum Institute* (2018).
GL, DNV. "DNV GL-RP-G101: risk based inspection of offshore topsides static mechanical equipment." (2017).

# What is MMM?

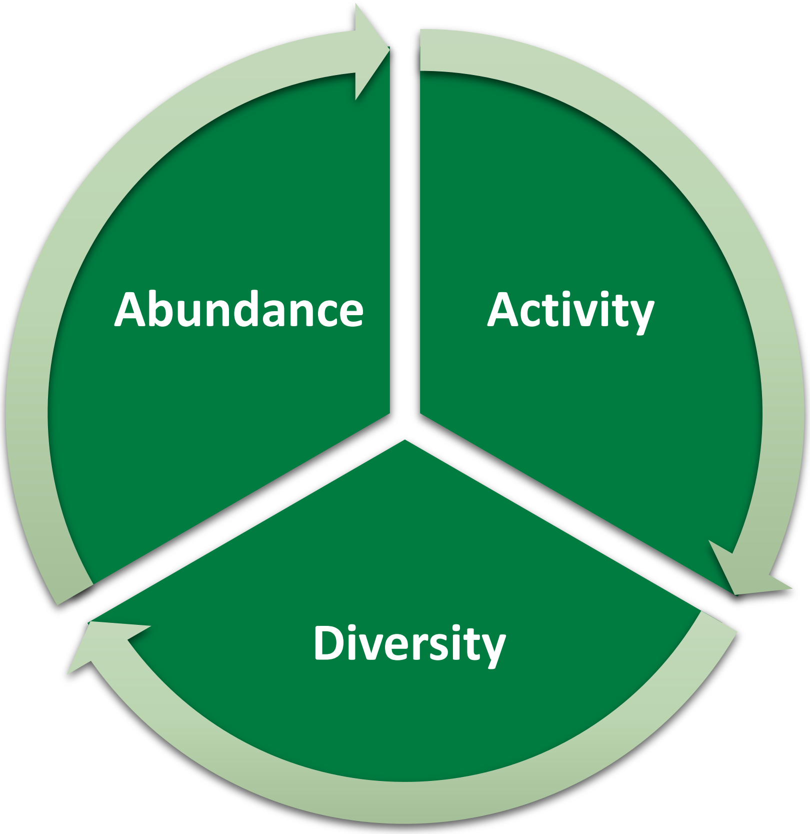
MMM: **M**olecular **M**icrobiological **M**ethods

- Abundance
  **Q**uantitative **P**olymerase **C**hain **R**eaction (qPCR)

- Activity
  **A**denosine **Trip**hosphate assay (ATP)

- Diversity
  **N**ext **G**eneration **S**equencing (NGS)

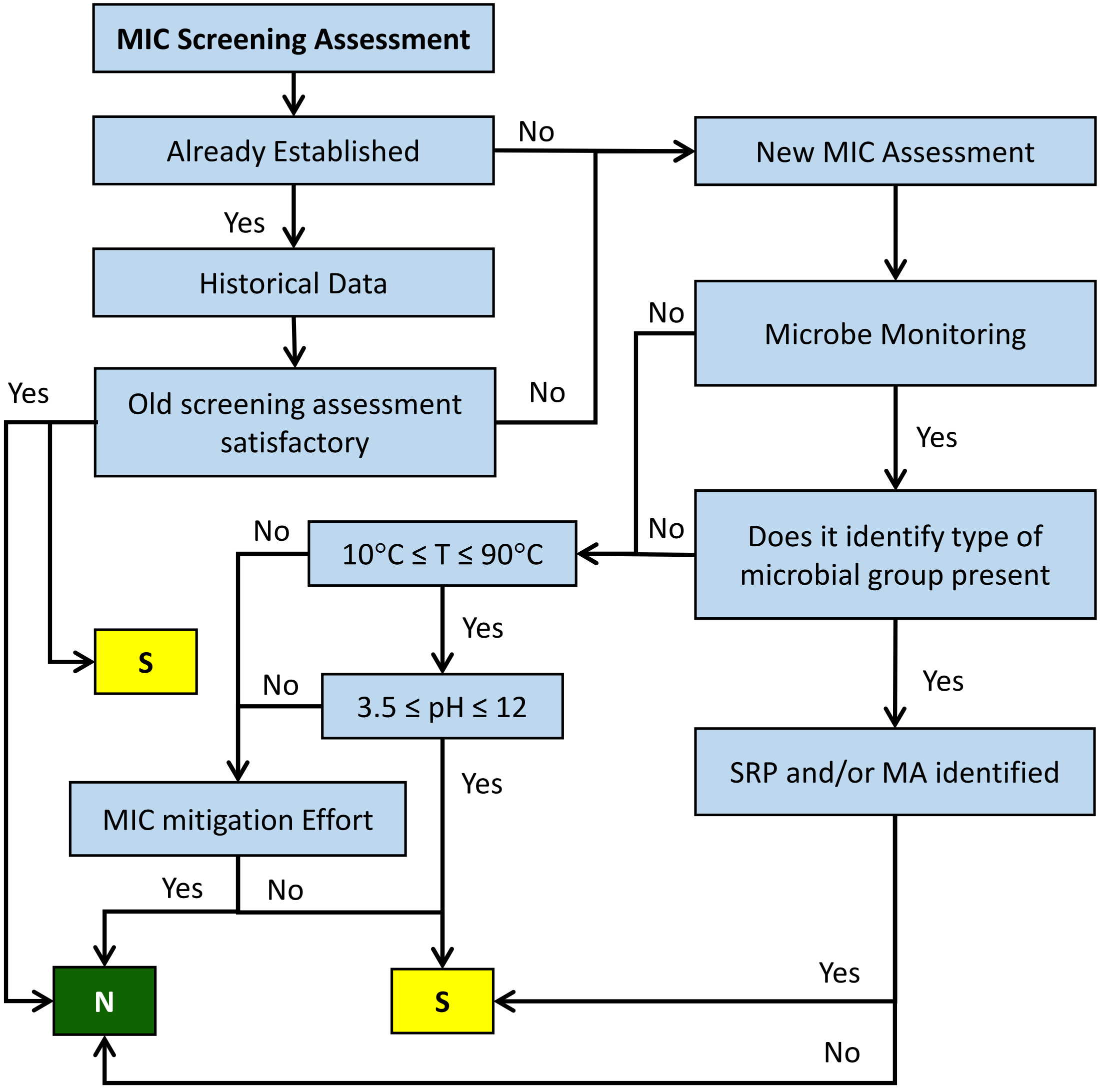
- Output reliable results as culture independent methods
  - Do not depend on selective media
  - Can account for a wider spectrum of microorganisms




Skovhus, Torben Lund, Dennis Enning, and Jason S. Lee. *Microbiologically influenced corrosion in the upstream oil and gas industry*. CRC press, 2017.

# Previous Work

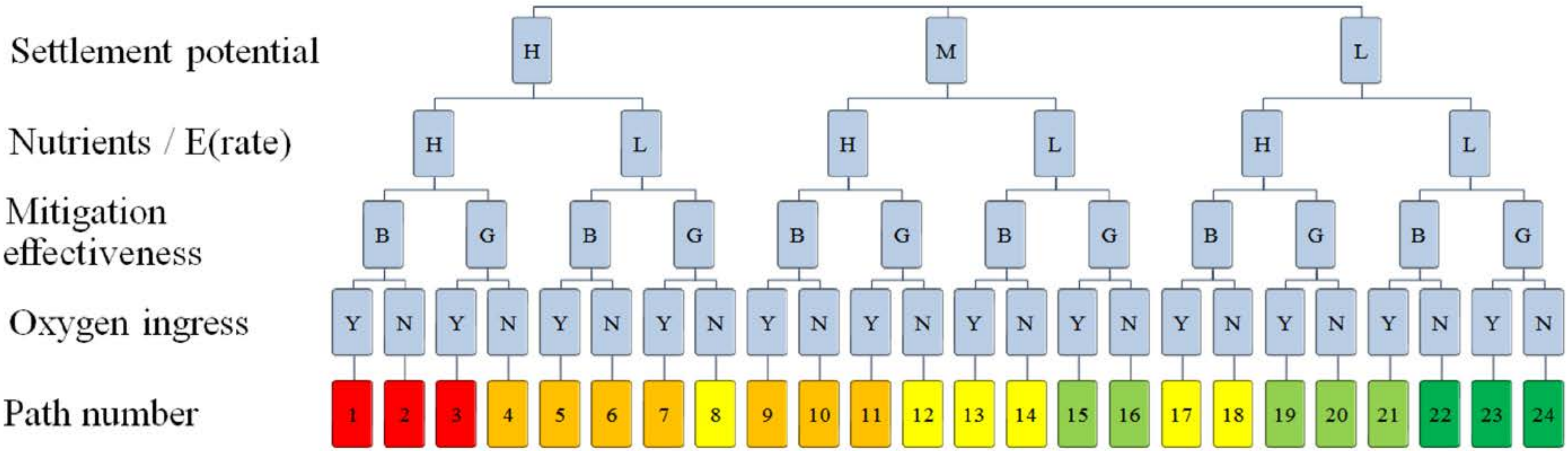
# Andersen's Model, 2014 – Screening Assessment




- Corrosion circuit is defined and assessed
- Temperature, pH, fluid chemical characteristics, fluid dynamics dependent
- Use of data already gathered
- Focus effort into components at higher threat of MIC
- N: Negligible LoF
- S: Significant LoF


Skovhus, Torben Lund, Erlend Stokstad Andersen, and Elizabeth Hillier. "Management of microbiologically influenced corrosion in risk-based inspection analysis." *SPE Production & Operations* 33.01 (2018): 121-130.

# Andersen's Model, 2014 – Ranking Tool




Captions: H: high, M: medium, L: low, B: bad, G: good, Y: yes, N: no.

- Corrosion circuit is qualitatively ranked
- Likelihood prioritization paths
- 5 MIC drivers are taken into consideration
- The asset is ranked within 5  LOF categories

| LoF |
|---|
| Very high |
| High |
| Medium |
| Low |
| Very low |

Skovhus, Torben Lund, Erlend Stokstad Andersen, and Elizabeth Hillier. "Management of microbiologically influenced corrosion in risk-based inspection analysis." *SPE Production & Operations* 33.01 (2018): 121-130.

# Current Model

# Model Rationale

What the present model aims to accomplish?

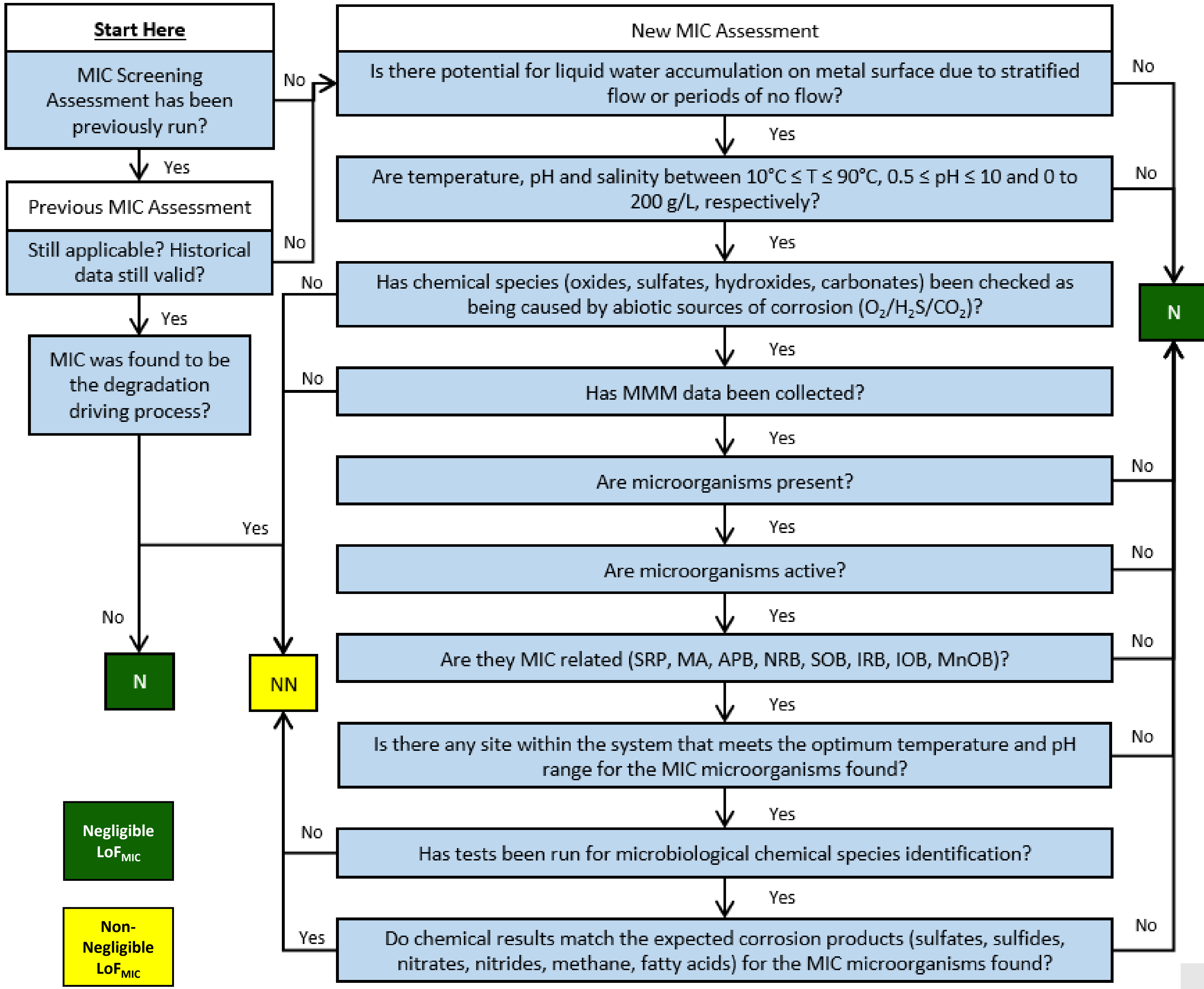
Drive where inspections will be carried out due to the threat of MIC at assessed corrosion circuits based on the absence or presence of historical and current data

The driving question:

**IF THE PARAMETER HAS A LARGER VALUE**
**IS MORE LIKELY TO BE MIC OR LESS LIKELY TO BE MIC?**

# Model Rationale

- 2 step approach
  - Screening Assessment
    - Narrows down where inspections will be conducted
    - “Do we have a problem here?”
  - Ranking Tool
    - Determines prioritization level
    - “How big of a problem is that?”
- Three levels of MIC influence:
  - Screening Assessment → Discarders
  - Ranking Tool → Indicators – ‘Red flags’
  - Ranking Tool → Enhancers


Start Here
MIC Screening Assessment has been previously run?
No
Yes
Previous MIC Assessment
Still applicable? Historical data still valid?
No
Yes
MIC was found to be the degradation driving process?
Yes
No
N
NN
New MIC Assessment
Is there potential for liquid water accumulation on metal surface due to stratified flow or periods of no flow?
Yes
No
Are temperature, pH and salinity between 10°C ≤ T ≤ 90°C, 0.5 ≤ pH ≤ 10 and 0 to 200 g/L, respectively?
Yes
No
Has chemical species (oxides, sulfates, hydroxides, carbonates) been checked as being caused by abiotic sources of corrosion ($O_2$/$H_2S$/$CO_2$)?
Yes
No
Has MMM data been collected?
Yes
No
Are microorganisms present?
Yes
No
Are microorganisms active?
Yes
No
Are they MIC related (SRP, MA, APB, NRB, SOB, IRB, IOB, MnOB)?
Yes
No
Is there any site within the system that meets the optimum temperature and pH range for the MIC microorganisms found?
Yes
No
Has tests been run for microbiological chemical species identification?
Yes
No
Do chemical results match the expected corrosion products (sulfates, sulfides, nitrates, nitrides, methane, fatty acids) for the MIC microorganisms found?
Yes
No
N
Negligible $LoF_{MIC}$
Non-Negligible $LoF_{MIC}$

# Ranking Tool

- MIC degradation drivers are divided into 6 information groups
    1. Settlement potential
    2. Operational
    3. Microbiological
    4. Chemistry
    5. Metallurgical
    6. Degradation

- Their influence over MIC is integrated by connecting interplaying parameters

- A microbiological consortia (presence of multiple microbiological functional groups, MFG) indicates a higher threat of MIC

    - SRP: Sulfate reducing prokaryotes (both bacteria and archaea)
    - SOB: Sulfate oxidizing bacteria
    - MA: Methanogens archaea
    - NRB: Sulfate reducing bacteria
    - APB: Acid producing bacteria
    - IRB: Iron reducing bacteria
    - IOB, MnOB: iron and manganese oxidizing bacteria

# Chemical and Microbiological Integration

- Presence of total iron in concert with iron reducing bacteria (IRB);
- Presence of sulfate related species and also sulfate reducing prokaryotes (SRP = sulfate reducing bacteria, SRB + sulfate reducing archaea, SRA)
- Presence of nitrogen related species and nitrate reducing bacteria (NRB)
- In concert with ATP assay results
- Indicates presence, activity and microbiological diversity
- These three levels of evidence properly integrated allows reliable assessment of the threat of MIC and may assist assessors on where focusing time and effort

# Considered Parameters

**6 Information Groups**

**Settlement Potential**
- Presence of deadlegs, bypasses
- Operating time with no flow
- Flow regime
- Water cut

**Operational**
- pH
- Temperature

**Microbiological**
- Abundance
- Activity
- Diversity
- Sample type

**Chemistry content**
- Hydrogen sulfide
- Carbon dioxide
- Oxygen
- Total iron
- Sulphate
- Nitrate
- Volatile fatty acids
- Chloride

**Degradation**
- Presence of deposits
- Corrosion morphology
- Corrosion rate

**Metallurgical**
- Material type

# Ranking Tool Integration

| | | | |
|---|---|---|---|
| **Settlement** | **SETTLEMENT POTENTIAL SCORE** | **5** | |
| **Settlement** | Presence of deadlegs, bypasses | YES / NO | |
| **Settlement** | Operating time with no flow | days / year | |
| **Settlement** | Flow regime | Stradified, Laminar, Turbulent | |
| **Settlement** | Water cut (%) | 20 | |
| **Metallurgical** | **METALLURGICAL SCORE** | **9** | |
| **Metallurgical** | Material type | Carbon steel, stainless steel, corrosion resistance alloy | |
| **Operational** | **OPERATIONAL SCORE** | **Temperature (°C)** | **pH** |
| **Operational** | Operating Conditions | 25 | 6.75 |

- Information Groups
  - Settlement potential
    - Potential for water contact on the circuit surface
  - Metallurgical
  - Operational

Final output: a semi-quantitative Total MIC Score that allows relative prioritization of assets on regards to MIC

# Ranking Tool Integration

| | | |
|---|---|---|
| Chemistry | CHEMISTRY SCORE | 8 |
| Chemistry | **Gas Composition** | **Amount** |
| Chemistry | $O_2$ (ppm) | 0.00 |
| Chemistry | $CO_2$ (ppm) | 0.39 |
| Chemistry | $H_2S$ (ppm) | 0.00 |
| Chemistry | **Liquid Composition** | **Amount** |
| Chemistry | Iron, total (ppm) | 10.50 |
| Chemistry | Chloride (ppm) | 16144.08 |
| Chemistry | Sulfate (ppm) | 17.90 |
| Chemistry | Nitrate (ppm) | 7.56 |
| Chemistry | Volatile fatty acids (ppm) | - |
| Chemistry | **Solid Composition** | **Amount** |
| Chemistry | Iron carbonate (weight %) | 3.90 |
| Chemistry | Iron oxide (weight %) | 17.80 |
| Chemistry | Iron hydroxide (weight %) | 11.50 |
| Chemistry | Iron sulfate (weight %) | 12.00 |

- Chemistry information group
- Environmental conditions to integrate with microbiological data

# Ranking Tool Integration

| | | | | |
|---|---|---|---|---|
| Biological | BIOLOGICAL SCORE | | 8 | |
| Biological | **Sample type** | | **Solid (g), surface ($cm^2$), liquid (mL)** | |
| Biological | **Abundance - qPCR** | **Number** | | **Exponent** |
| Biological | Abundance - qPCR, cell/mL | 6.7 | | 5 |
| Biological | **Activity - ATP** | **Number** | | **Exponent** |
| Biological | Activity - ATP, cell/mL | 1.44 | | 7 |
| Biological | **Diversity - NGS** | | **%** | |
| Biological | SRP (Sulfate reducing prokaryote) | | 20.90% | |
| Biological | NRB (Nitrate reducing bacteria) | | 57.60% | |
| Biological | IRB (Iron reducing bacteria) | | 6.20% | |
| Biological | General heterotrophic | | 8% | |
| Degradation | DEGRADATION SCORE | 7 | | |
| Degradation | Presence of deposits | | YES / NO | |
| Degradation | Form of Corrosion | | Pitting / Uniform | |
| Degradation | Corrosion rate (CR), mm/yr | | 0.02 | |
| MIC | TOTAL MIC SCORE | 7 | | Moderate |

- Information Groups
  - Biological → Accounts for microbiological consortia
  - Degradation

# Corrosion Circuit Implementation

- Next steps:
  - Real data testing for model calibration and validation
  - Data on regards to offshore, onshore and topsides operations
  - Tailoring for specific archetype conditions
    - Crude oil gathering systems
    - Seawater systems
    - Produced water systems
- Definition of the independent information group score weights for the overall threat of MIC

# Conclusions

- A two-step model that accounts for multiple layers of evidence and incorporates RBI to assess MIC toward onshore, offshore and topside facilities in the oil and gas industry is under development

- MIC has to meet the three layers of microbiological requirements, abundance, activity, and diversity, to pose a threat

- Different layers of evidence must be integrated in order to properly assess MIC: environmental (chemical, metallurgical, operational) and biological

- It accounts for the enhancement of the threat of MIC when there is a consortia of microorganisms

- Next steps
  - Real data testing for model calibration and validation
  - Tailoring for specific archetype conditions
    - Crude oil gathering systems, seawater systems, produced water systems

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# Thank you!


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