MONITORING TO COMBAT MICROBIOLOGICAL ISSUES IN OILFIELD PROCESS SYSTEMS

– UNDERSTAND THE OPTION FOR BETTER VISIBILITY.

Institute of Corrosion Aberdeen Branch Meeting/Technical Presentation- October 2023

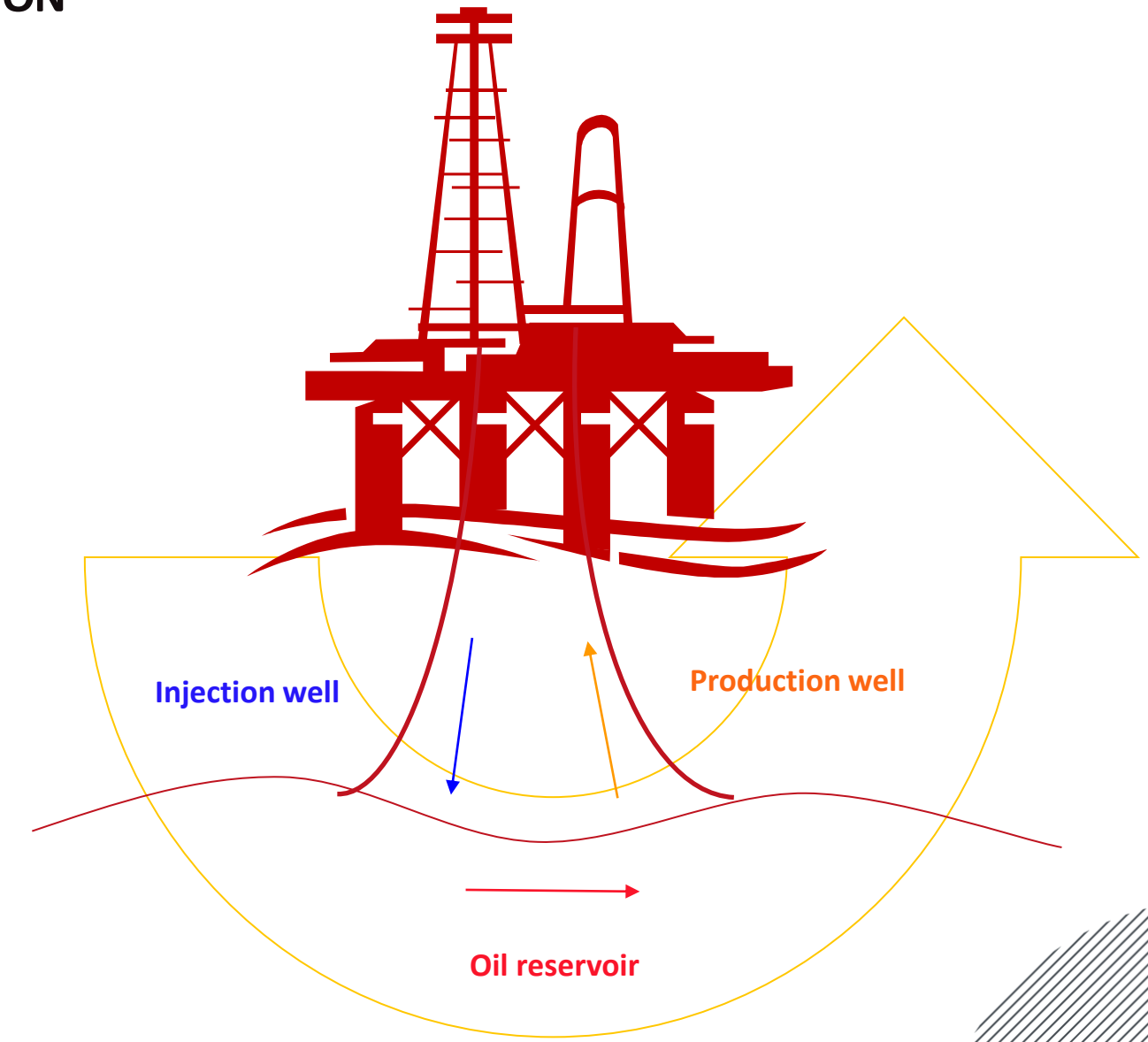
Heike Hoffmann

OVERVIEW

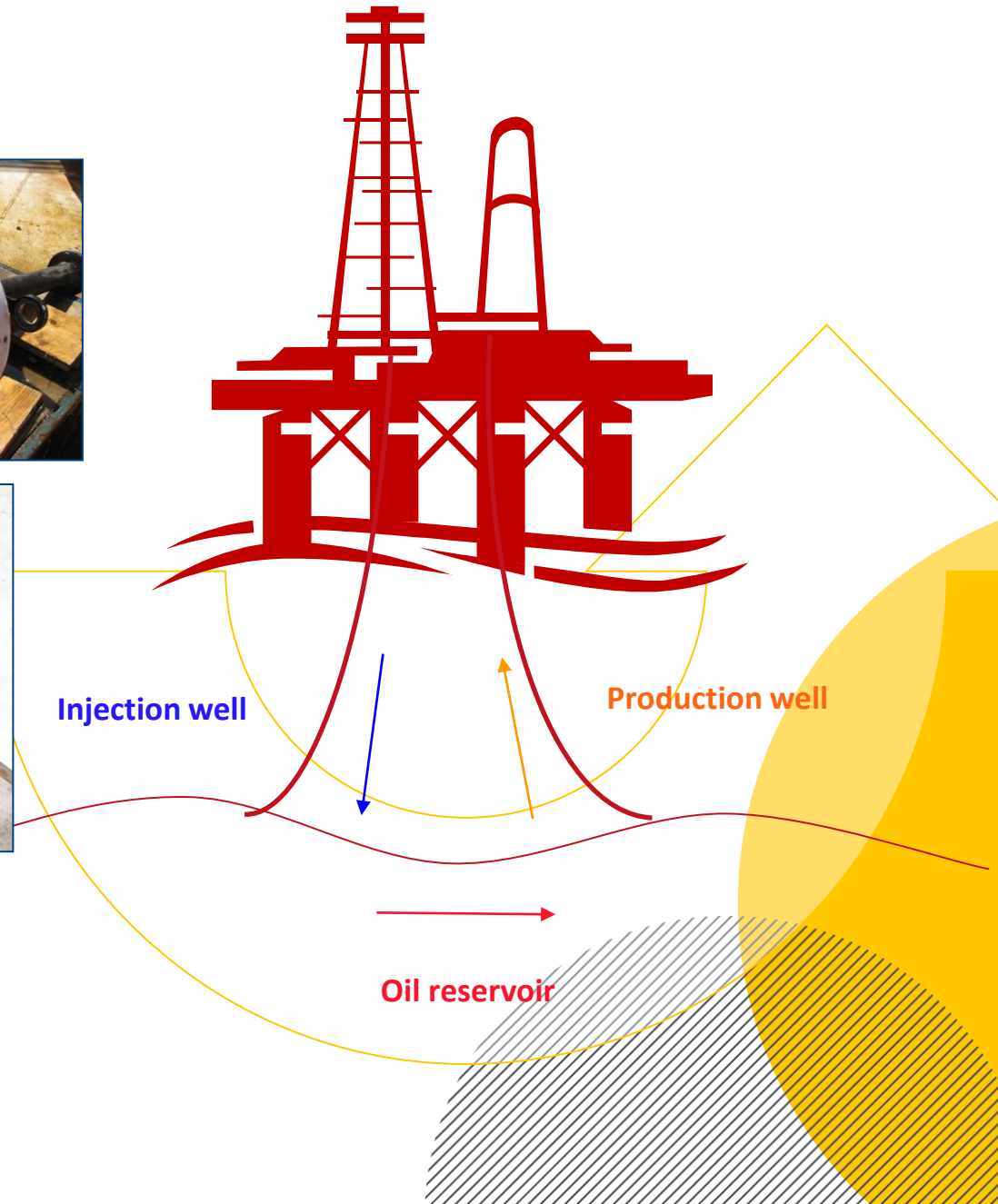
- MICROBES IN THE OIL AND GAS INDUSTRY (WHERE?)
- CONSEQUENCES (WHO & WHY?)
- SAMPLING & MONITORING (HOW?)
- CASE STUDY (HOW?)

MICROBES IN THE OIL AND GAS INDUSTRY

OIL PRODUCTION



MICROBIAL ISSUES –WHERE?



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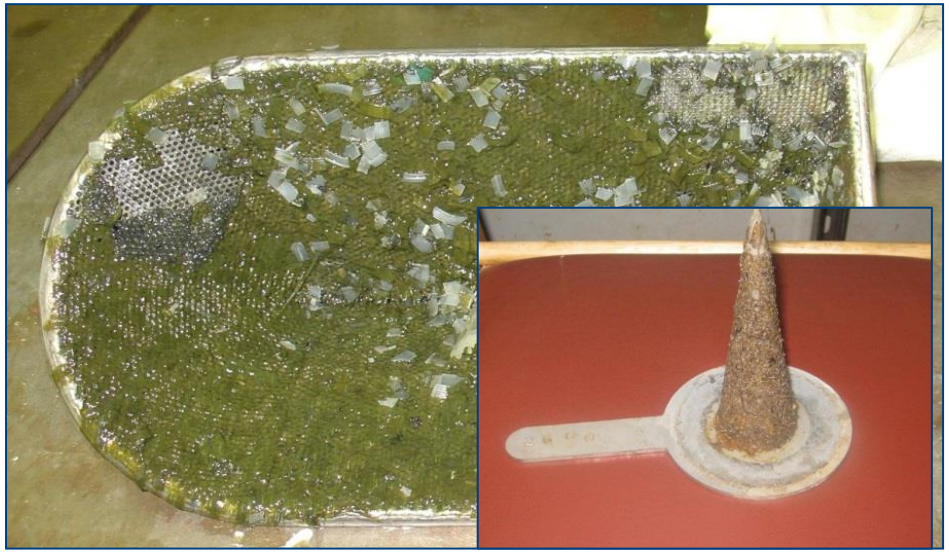

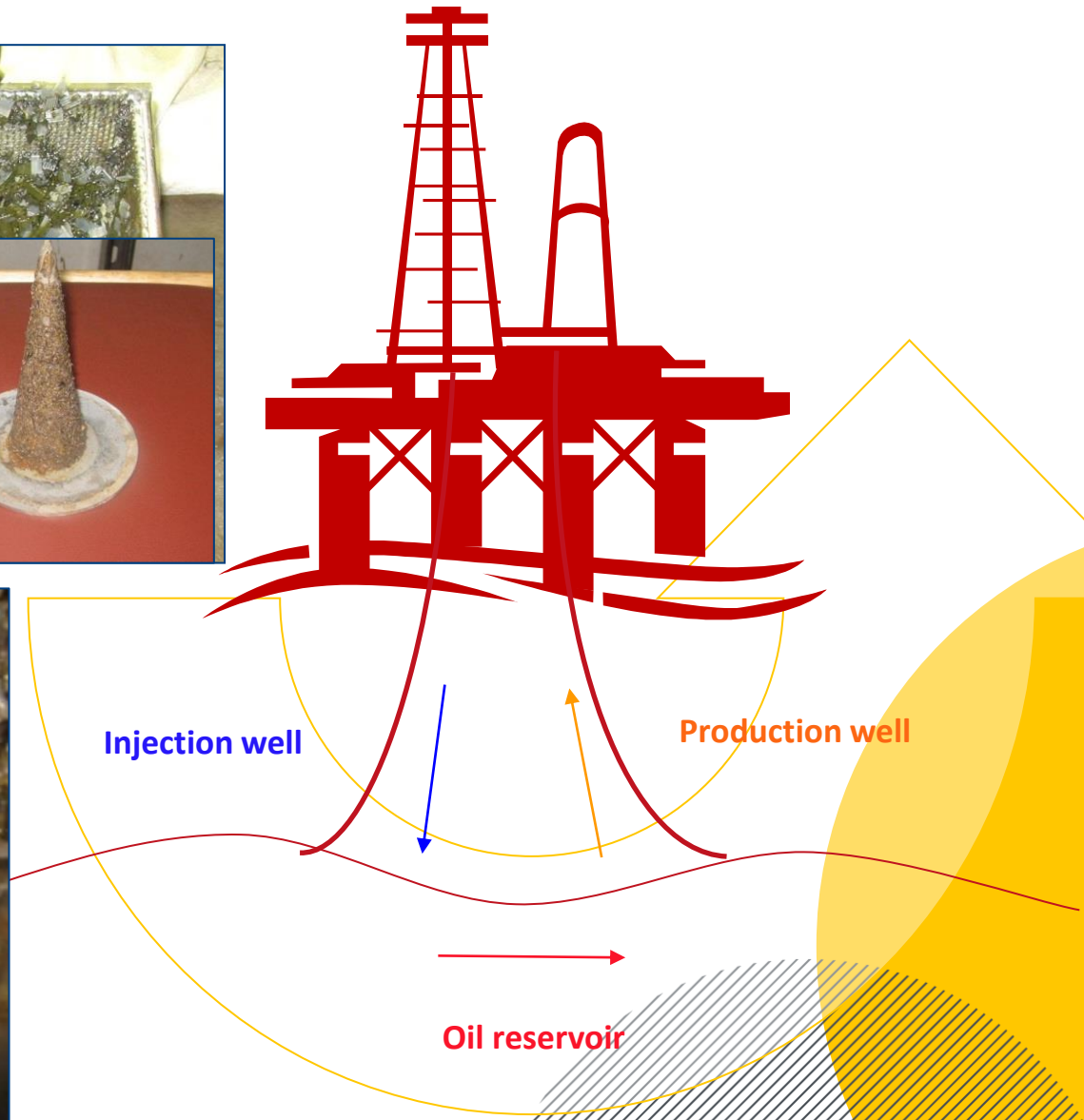

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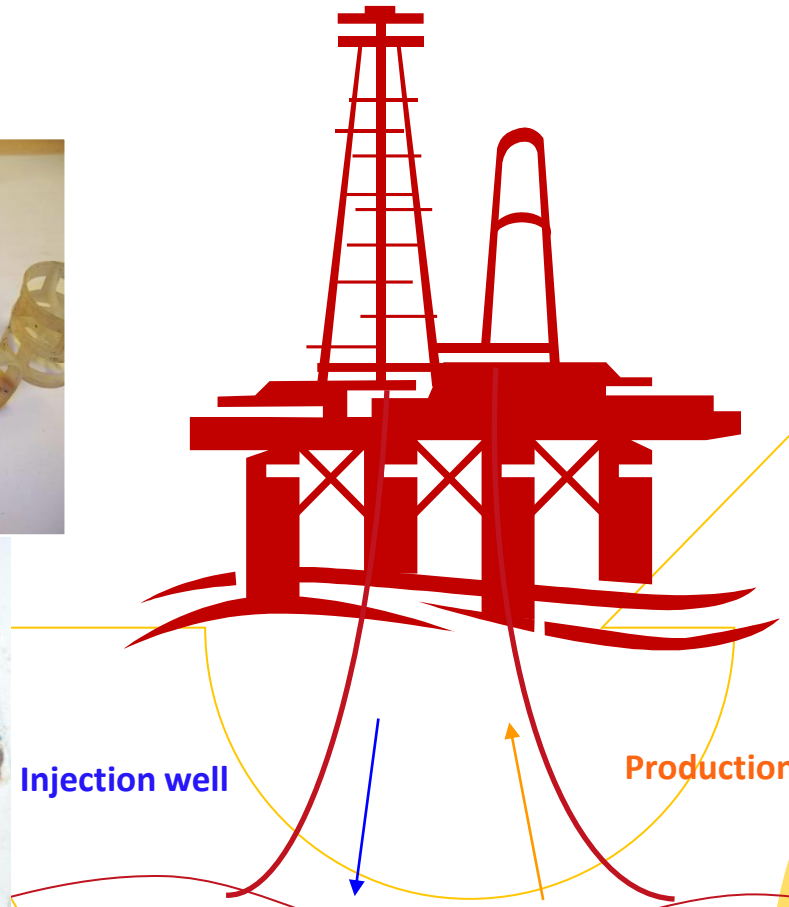

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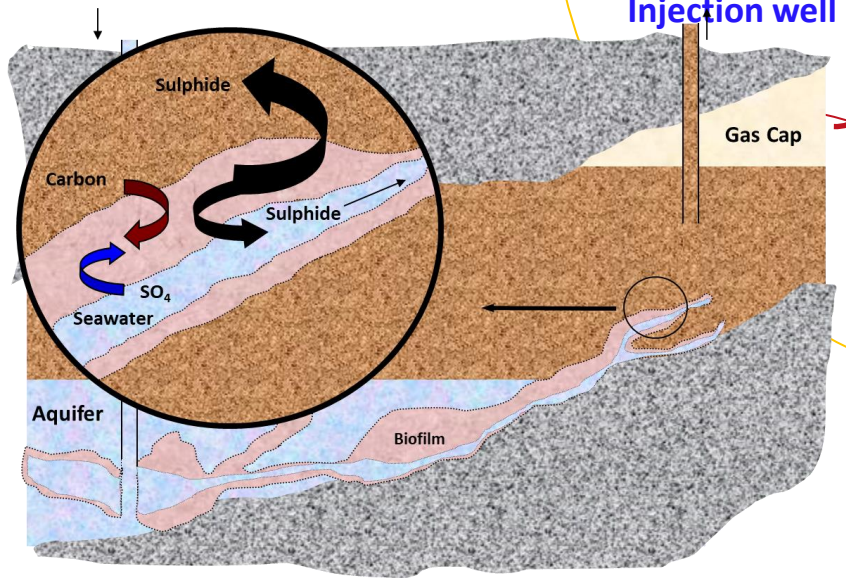

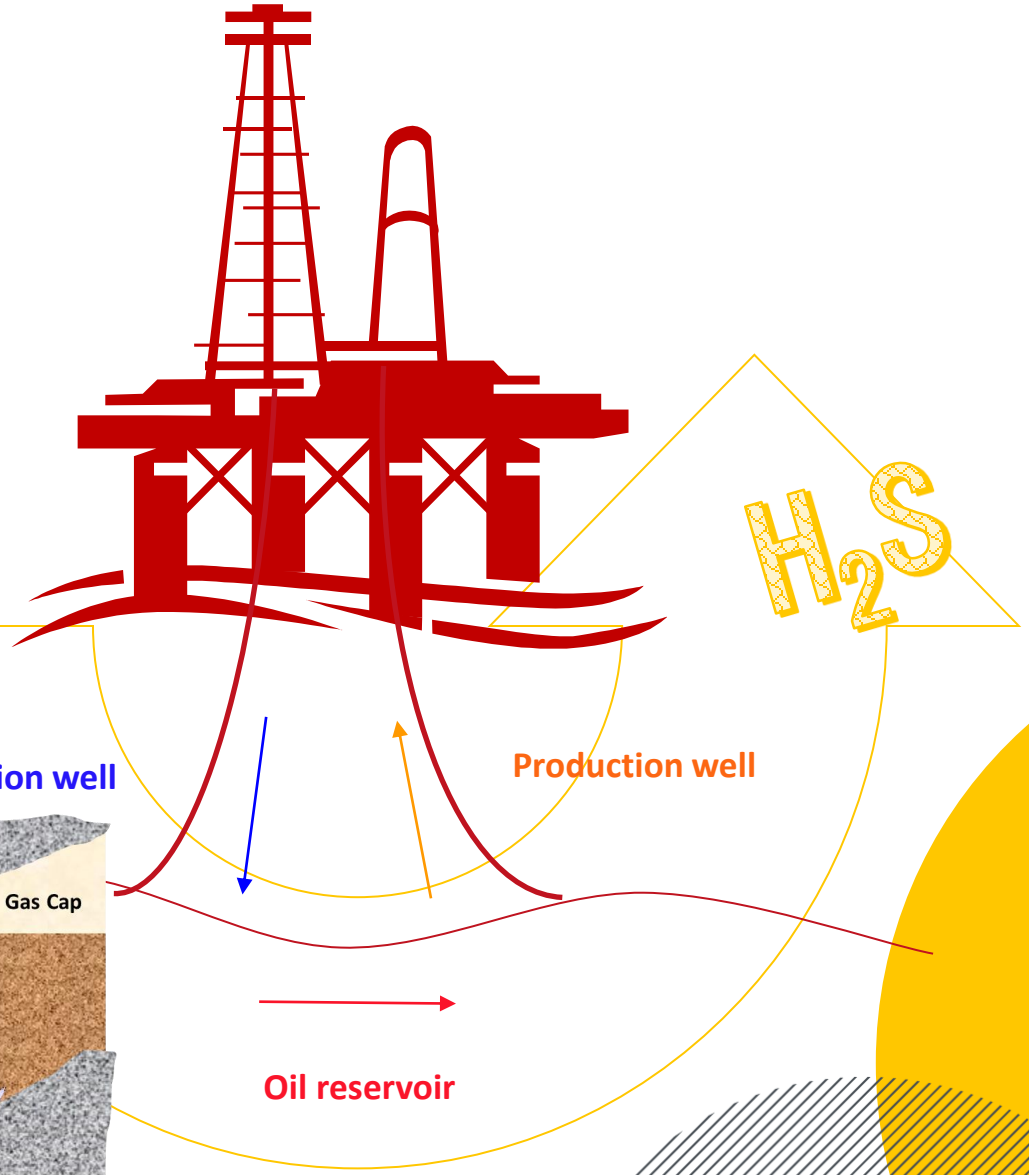

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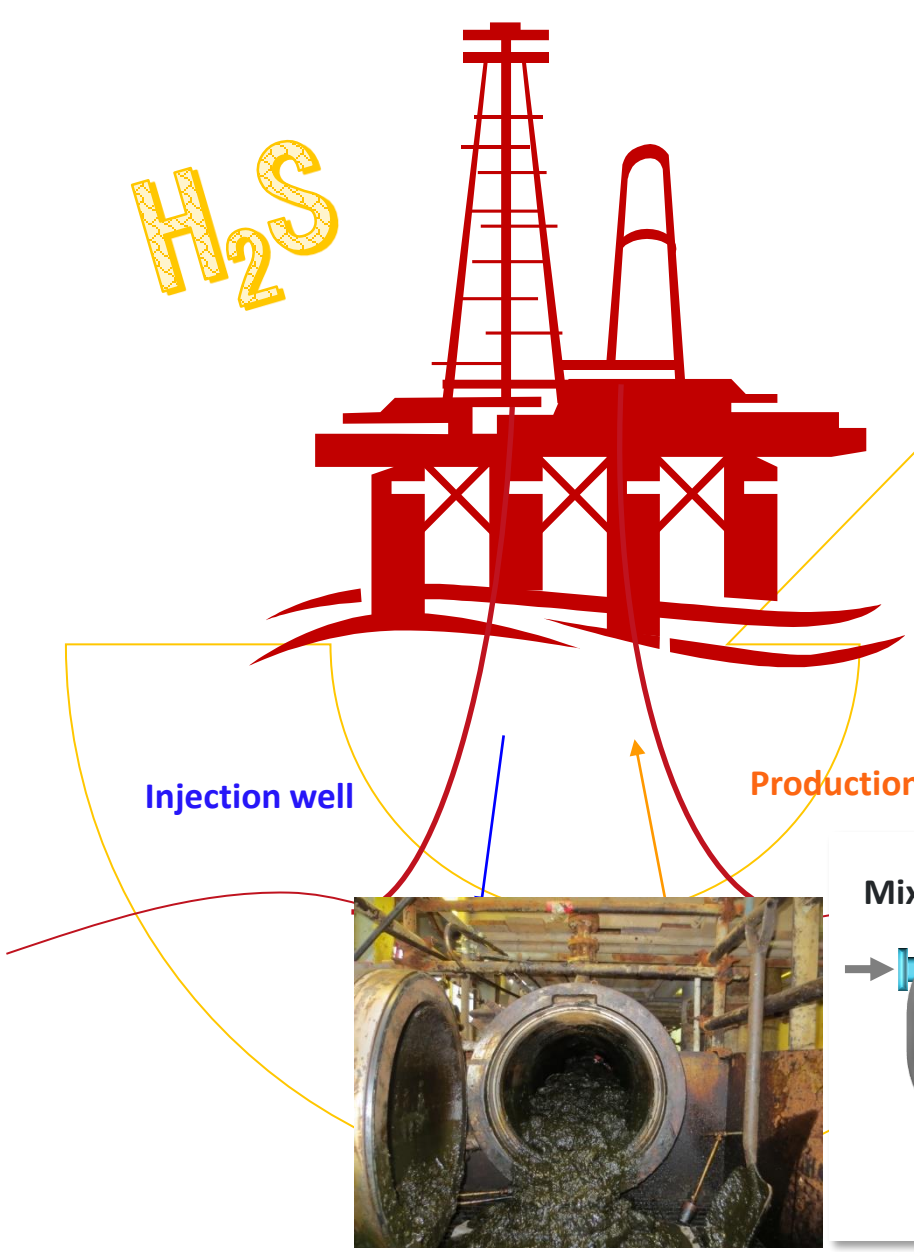
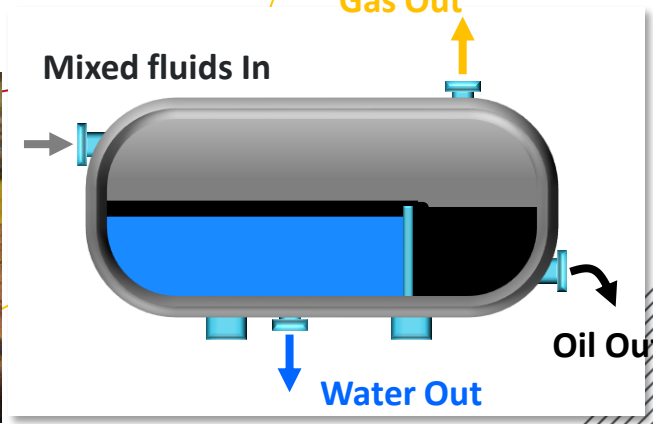




OILFIELD MICROBIOLOGY – WHO ARE WE LOOKING FOR?

- Historically the main culprits the Oil and Gas Industry is looking for:
  - Sulphate reducing Bacteria (SRB)
  - General Heterotrophic Bacteria (GHB)
  - Acid Producing Bacteria (APB)

- More recently molecular method reveals the involvement of other organisms, for example:
  - Sulphate reducing Archaea (SRA)
  - Methanogens
  - Iron Reducing Bacteria
  - And others

CONSEQUENCES

ADVERSE EFFECT OF MICRIOBIOLOGCAL CONTAMINATION

- Biofouling – Flow Assurance
- Unwanted Reservoir Plugging
- Reservoir Souring
- Oil Separation Issues
- Corrosion due to the presence & activity of microorganisms

MICROBIOLOGICALLY INFLUENCED CORROSION (MIC)

- Corrosion due to the presence & activity of microorganisms
- Recent studies show that MIC may account for up to 20% of the $2.5 trillion global cost of corrosion
- In petroleum production the major threat from MIC comes from sulphate reducing bacteria (SRB)
- SRB are a diverse group of anaerobes utilising SO_4 to produce S^{2-}
- Several mechanisms have been proposed for microbial corrosion including;
  - Cathodic depolarisation
  - Enzyme dehydrogenase
  - Anodic depolarisation
  - Generation of Iron Sulphides
  - EPS production
  - Sulphide Stress Corrosion & Hydrogen Induced Cracking
- Other microorganisms can also directly and indirectly influence corrosion

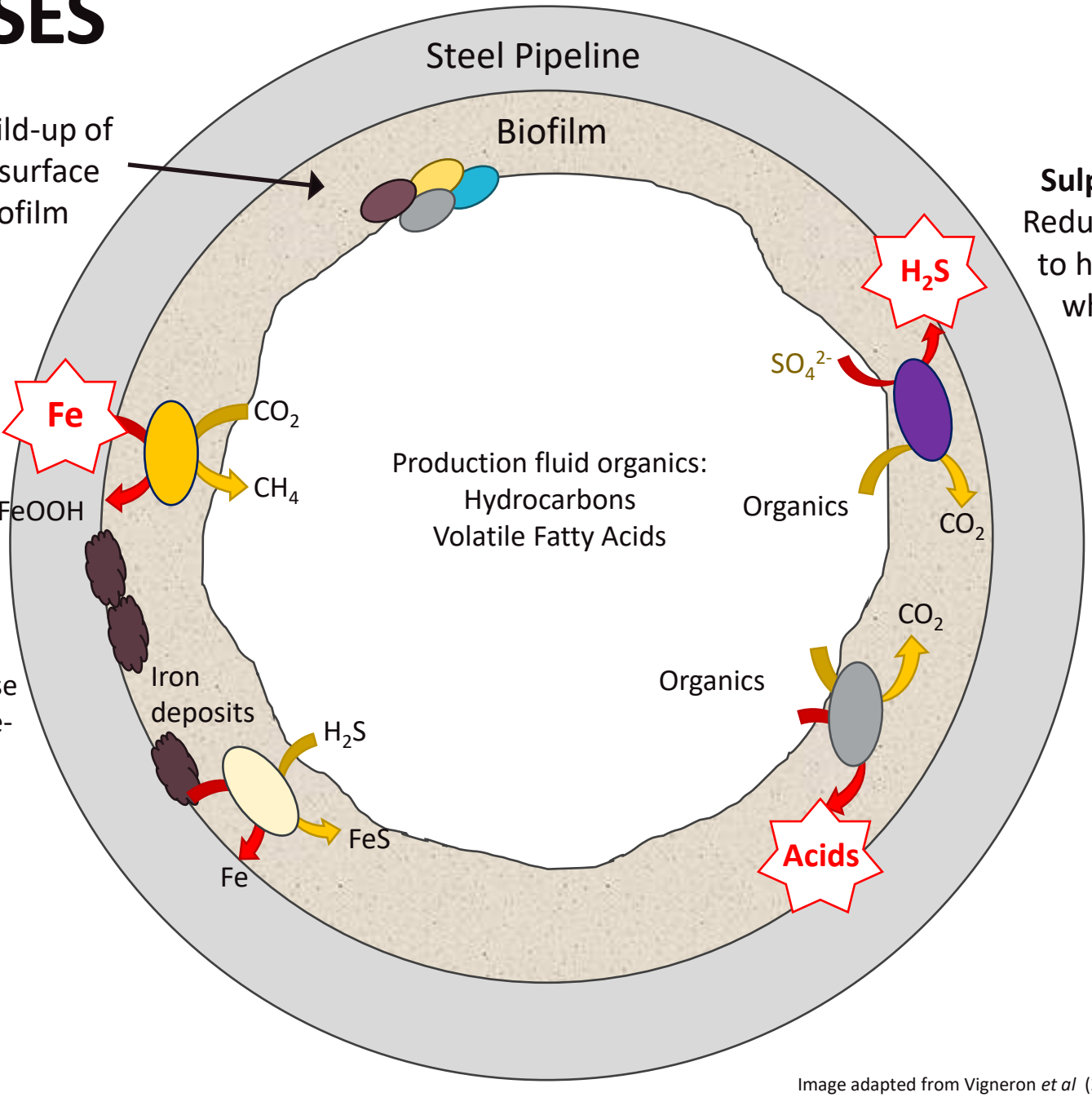
MIC PROCESSES

Biofouling – build-up of microbes on a surface leading to biofilm

Iron Oxidizers – Remove electrons from steel/iron pipelines

Iron Reducers – Oxidise iron deposits which re-exposes pipeline to further corrosion

EMIC: electrical microbiologically influenced corrosion



Sulphate Reducers – Reduce sulphur species to hydrogen sulphide which is corrosive

Acid Producers (Fermenters) – Convert organic material to acidic by-products which corrode pipework

CMIC: Chemical microbiologically influenced corrosion

Image adapted from Vigneron *et al* (2018) Damage to offshore production facilities by corrosive microbial biofilms. *Appl Microbiol Biotechnol* 102:2525.

SAMPLING & MONITORING

OILFIELD MICROBIOLOGY

- Microbiological monitoring purpose is to generate appropriate data in order to:
  - Predict areas of risks (vessels, pipework, systems) and potential source of microbiological contamination and its effects
  - Help to set-up appropriate mitigation strategies
  - Monitor effectiveness of strategies

TRADITIONAL MONITORING

Culture depending methods (triplicate MPN method)

As directed by guideline documents such as

NACE TMO 194-2014, Field Monitoring of Bacterial Growth in Oil and Gas Systems

or its predecessor's *API RP 38* & *Joint Venture 001/87*

Water samples by serial extinction dilution
Biofilm or other solid material by a dispersion procedure, followed by serial extinction dilution

MOLECULAR METHODS

Molecular methods were introduced to the oilfield to improve sensitivities and reduce analysis time

- NACE - TM0212-2018 Detection, Testing, and Evaluation of Microbiologically Influenced Corrosion on Internal Surfaces of Pipelines
- Energy Institute 2012 - A practical evaluation of 21st century microbiological techniques for the upstream oil and gas industry

- None PCR – based methods
  - Fluorescence *in situ* Hybridization (FISH)

- (PCR) based methods:
  - Quantitative Polymerase Chain Reaction (qPCR)
  - Next Generation Sequencing (NGS) – different platforms

ANALYSIS

Microbiological

- MPN Inoculations
- SRB Filter Enrichments
- SRB Qualitative
- FISH analysis
- qPCR analysis
- NGS
- Bacteria, Yeast and Mould

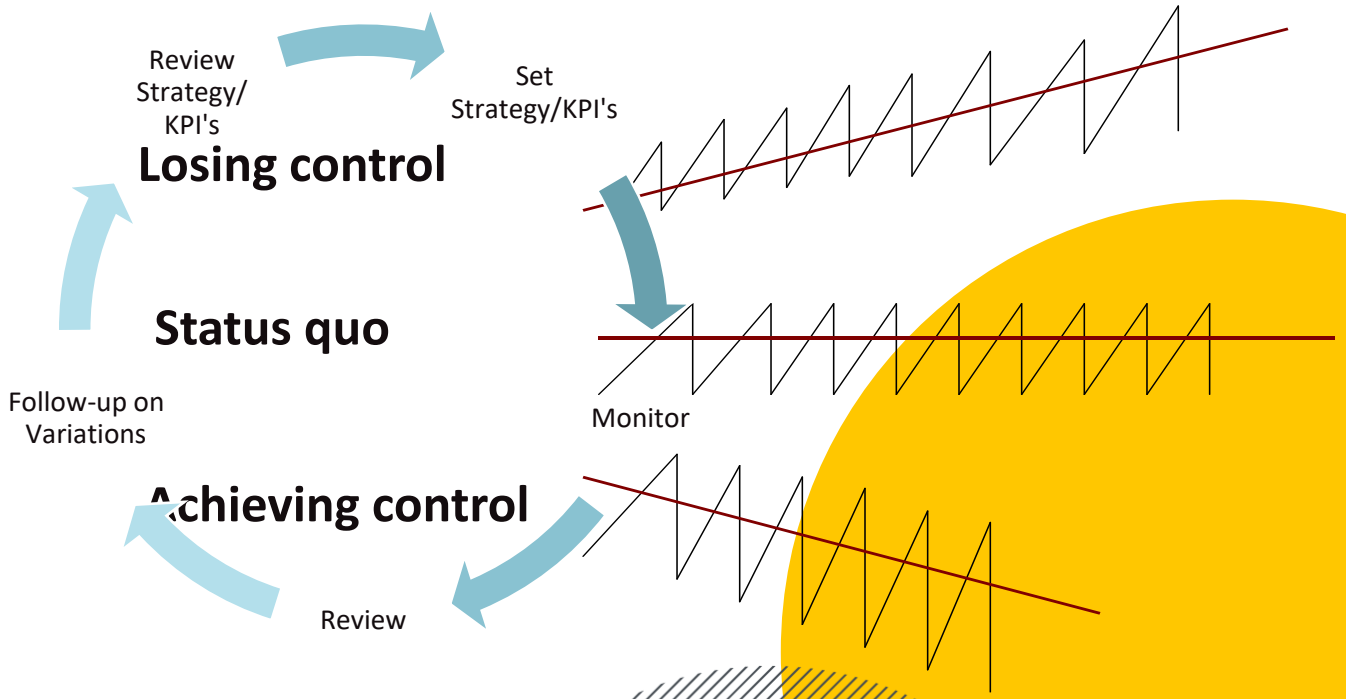
Chemical

- pH
- Temp
- Residual Chlorine
- Residual Sulphite
- Dissolved Oxygen
- Sulphide
- VFA
- Nitrate and Nitrite
- Iron

SAMPLING & MONITORING – TRENDING OF DATA

- Expect variable data
- Always consider additional information

- **Present results**
- Long term – Sessile monitoring
- Short/Long term – Planktonic monitoring



Don’t expect to see meaningful patterns unless lots of sessile/planktonic data is being produced

MOLECULAR AND CULTURE BASED METHODS

- The challenge to monitor and understand microbiological numbers in oil and gas installation remains, even with a suite of microbiological and molecular methods available to the industry

- Culture-depending methods such as triplicate MPN counts are well established in the industry for decades, although their limitations are well known

- Molecular Method are now used frequently as routine tools, for example
  - data from qPCR are used routinely as a monitoring technique aiding in understanding the status of the offshore system and guiding the action required to be taken
  - whilst next generation sequencing (NGS) remains a method used for more in depth testing, such as in failure investigations

- When comparing different methods such as the culture-dependent triplicate MPN methods and the culture-independent method qPCR, the question remains, what is the difference between the two outputs?

CASE STUDIES

MPN ANALYSIS VERSUS QPCR ANALYSIS (PLANKTONIC)

- LP Separator sample – inoculated into appropriate media and incubated for GHB/APGHB and SRB
  - DNA extracted directly for qPCR analysis (Total Bacteria, SRB and SRA)

[cells per ml]	Total Bacteria/GHB	APGHB	SRB	SRA
qPCR	3.3E+06	-	1.5E+05	8.4E+03
Triplicate MPN	2.0E+05	4.5E+00	4.5E+04	-

Sulphide <0.1 mg/L

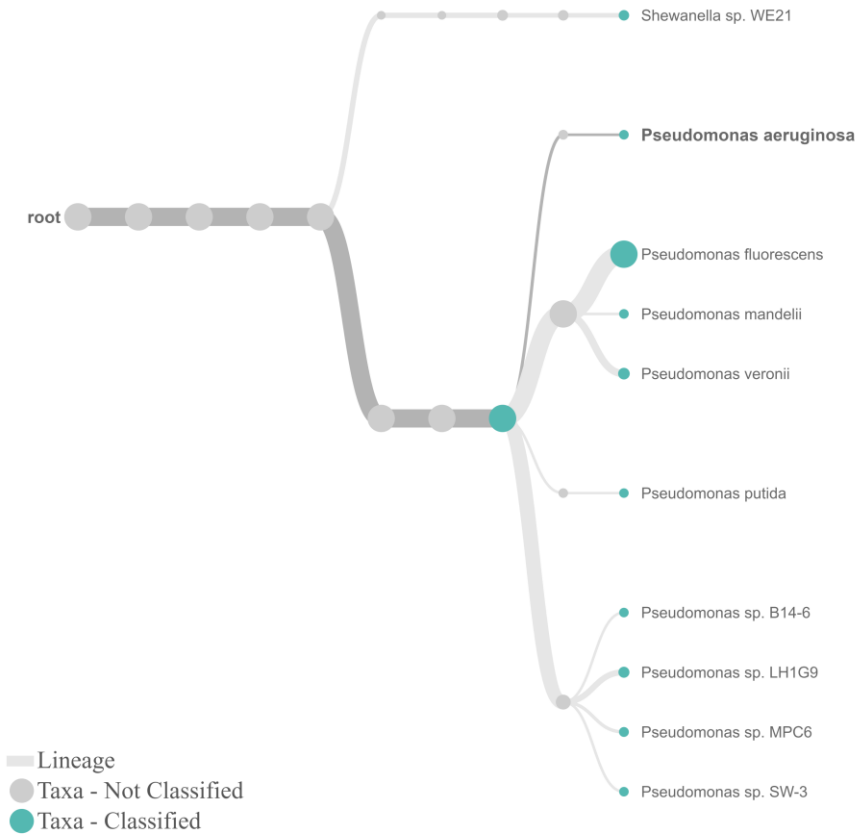
MPN ANALYSIS VERSUS QPCR ANALYSIS (SESSILE)

- Welding – 6 o'clock swab sample – inoculated into appropriate media and incubated for GHB/APGHB and SRB
  - DNA extracted directly for qPCR analysis (Total Bacteria, SRB and FeOB)

[cells per cm²]	Total Bacteria/GHB	APGHB	SRB	FeOB
qPCR	8.4E+07	-	1.2E+06	3.6E+07
Triplicate MPN	7.5E+02	1.5E+01	4.5E+04	-

Sulphide 0.164 µg/cm²

- Mainly *Pseudomonas* (81.95%) and *Shewanella* (4%)
- Some sulphate reducer detected such as *Desulfovibrio (0.02%)*



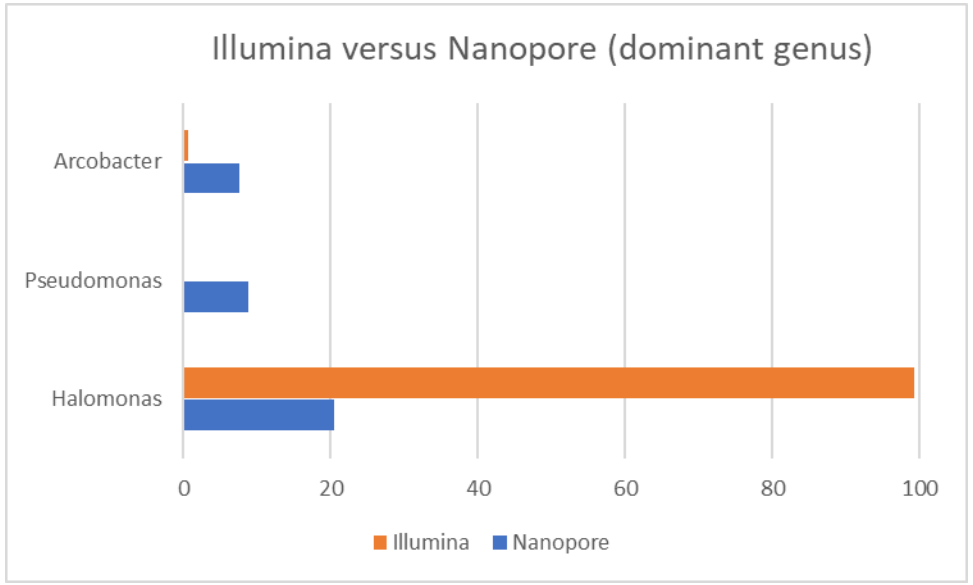
CULTURING VERSUS DIRECT IDENTIFICATION

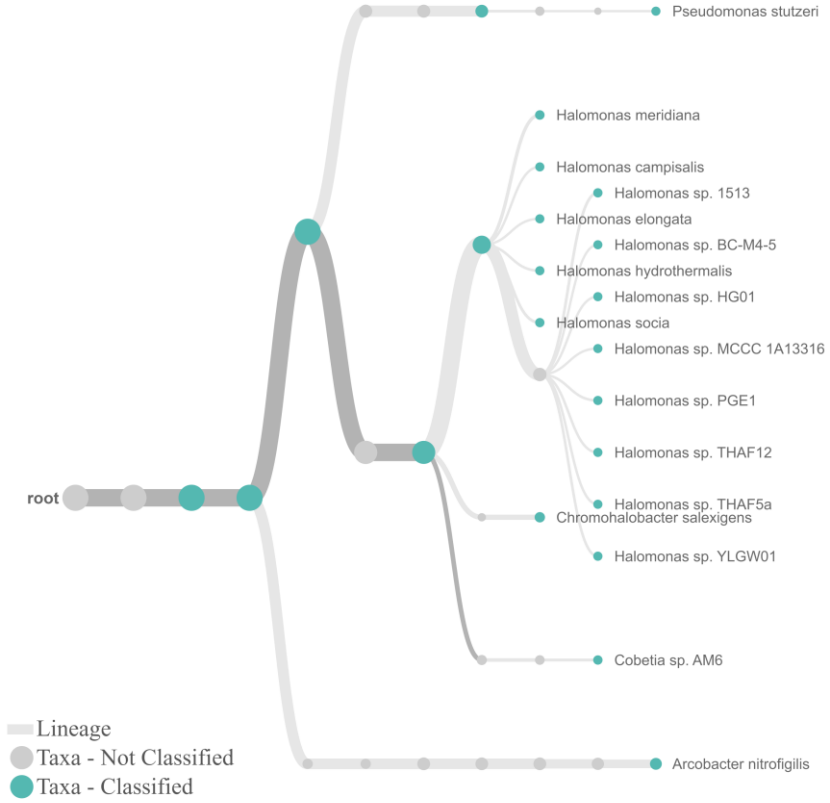
- Routine Monitoring gave comparable results – similar conclusion and actions based on results

- Failure Investigation - slight differences in results, but considering background information and other available results analysis offered good understanding and assisted in root cause identification

ILLUMINA MISEQ VERSUS OXFORD NANOPORE MINION

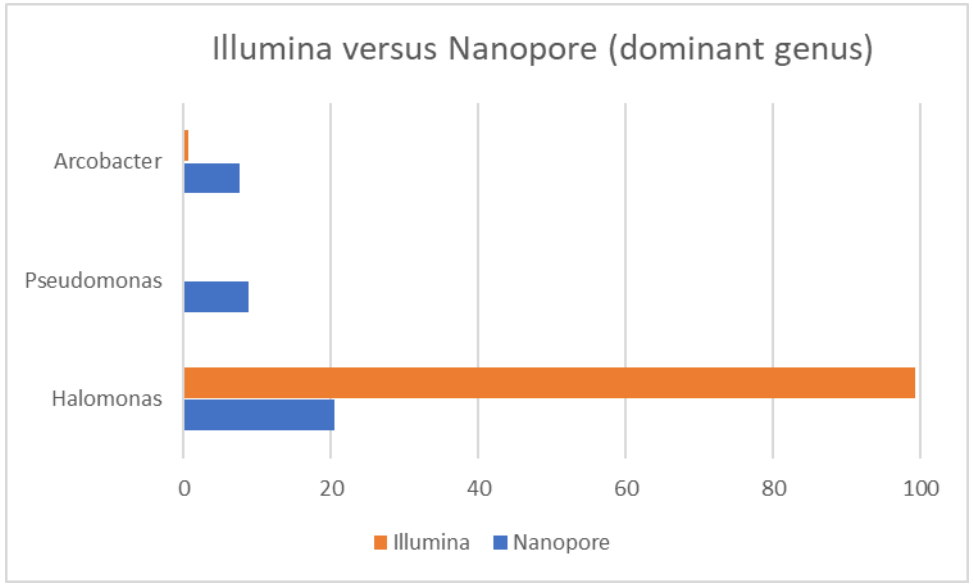
- Swab sample from removed spool (Condensate Separator) - Spool Middle section 6 ‘o’ clock
- Illumina 45,488 Total Reads versus MinION 176,000 Total Reads
- High level comparison – both identified the same most dominant microorganisms (*Halomonas*)
- More details from Nanopore MinION Run



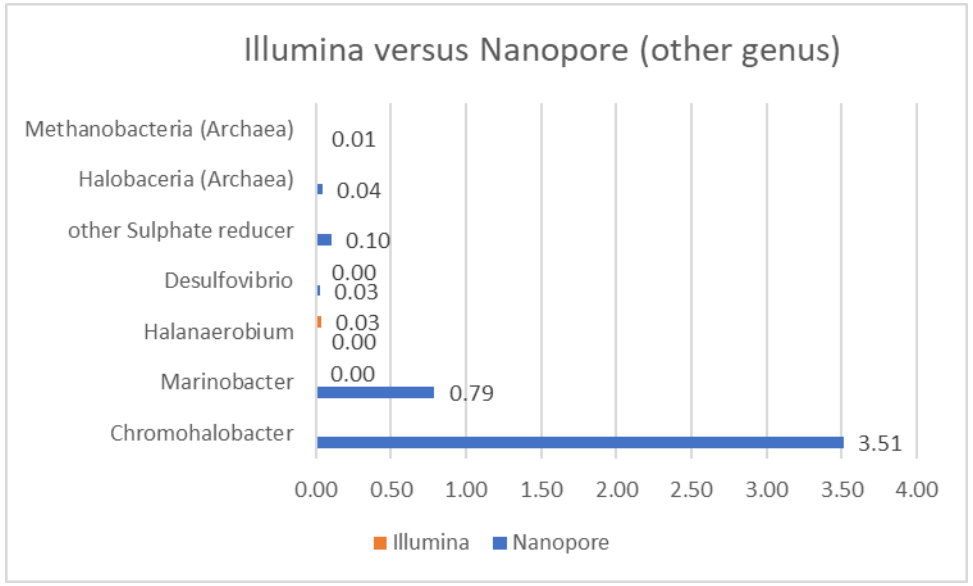


ILLUMINA MISEQ VERSUS OXFORD NANOPORE MINION (VERSUS QPCR)

45,488 Total Reads (Illumina)



176,000 Total Reads (MinION)



[cells per cm²]	Total Bacteria	SRB	IRB	SRA	Meth
qPCR	3.9E+04	1.2E+02	5.1E+03	8.6E+02	1.0E+04

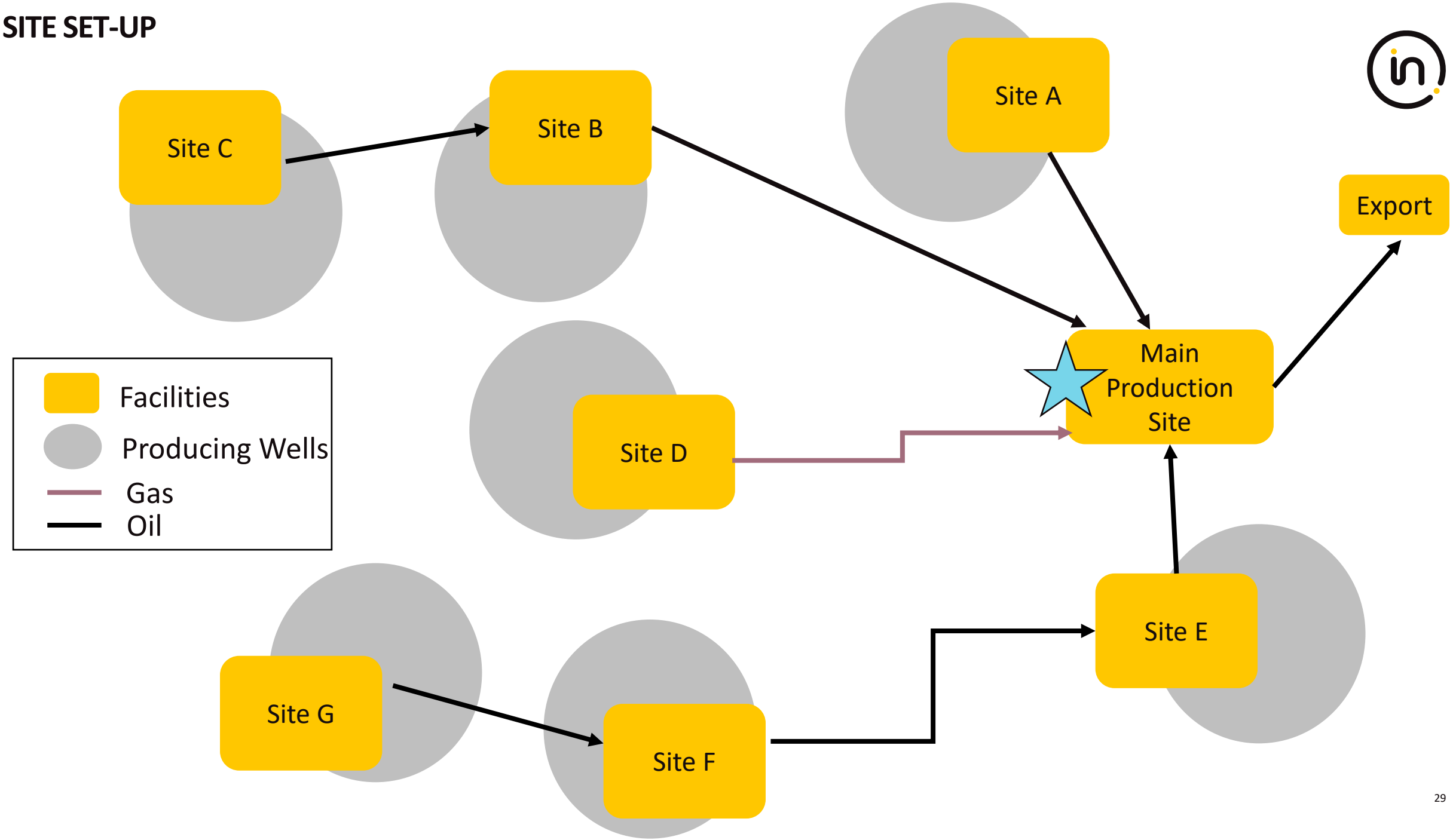
- *Archaea* underestimated by both approaches (*Methanobacteria* and *Halobacteria* by MinION)
- *Desulfovibrio* identified a very low percentages from both sets of analysis.

BACKGROUND

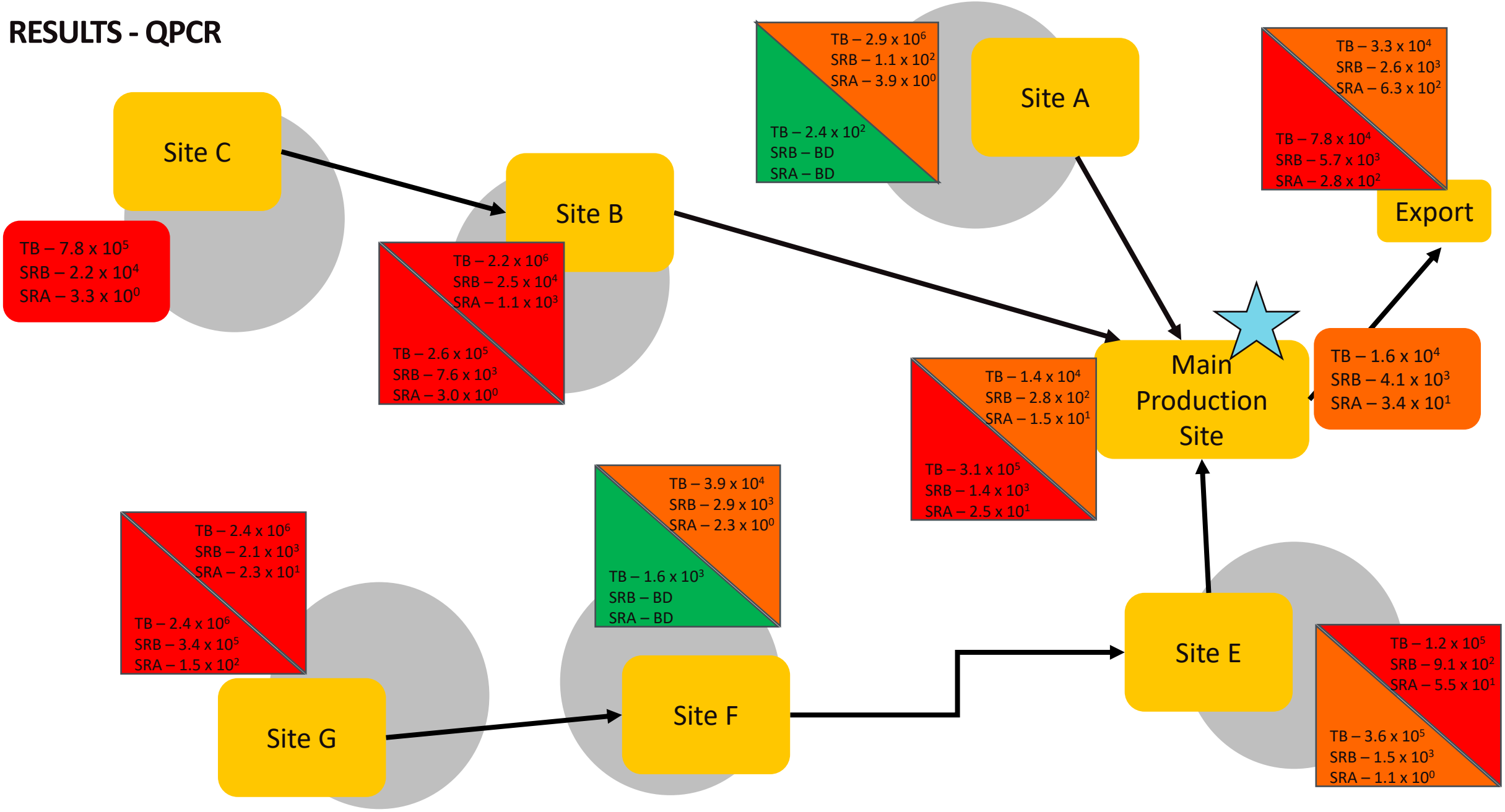
- Site contained > 100 gas fields and > 55 oil fields currently in production (onshore)
- +500 producing gas wells and more than 200 producing oil wells
- All feeding into a production site through kilometres of pipeline and flowlines, via around 10 major satellite facilities.
- Underground storage for processed gas at the main site
- Crude Oil and processed natural gas sent further through pipelines to be transported off.
- Water used from bores and a reverse osmosis treatment plant.

- **Issue**: Build-up of “biofilm” at main process site
- **Aim:** Determine source of contamination

SITE SET-UP

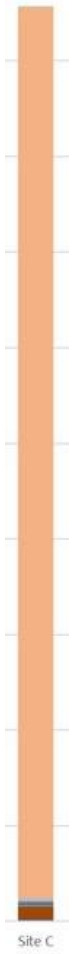

Site C
Site B
Site A
Export
Main Production Site
Site D
Site E
Site G
Site F
Facilities
Producing Wells
Gas
Oil

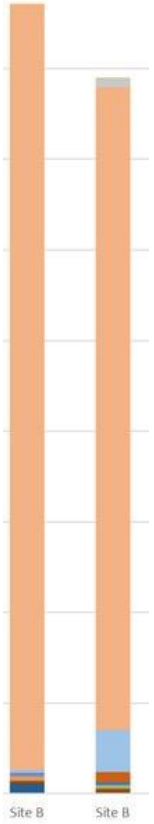
RESULTS - QPCR

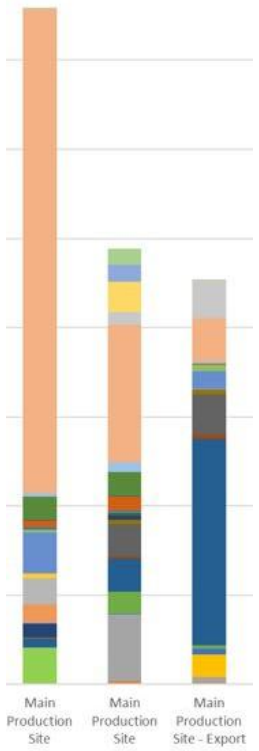


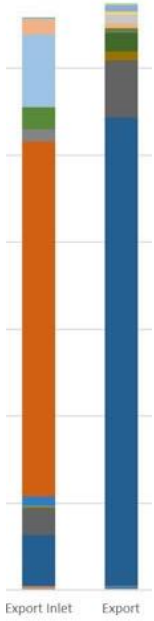
RESULTS – NGS (SITE C TO MAIN PRODUCTION)

Site C → Site B → Main Production Site → Export









SUMMARY

- All methods have some limitations
- Biased in all of these by the choices we make
- Molecular analysis, especially NGS will give a good indication what is there, helps to identify possible mechanisms which are sometimes not well understood
- MPN analysis gives indications what can grow in the system
- qPCR (DNA based) gives indication what is in the system and can grow if conditions are favourable
- Monitoring for microbial contamination gives the indication of a potential risk
- This is why regular testing is key along with collecting meta data (sulphide, VFA, operational changes etc) and trending the data
- Many of testing methods used in the O&G industry are linked back to the drinking water industry standards
- Looking for indicator microorganism = giving an indication of potential contaminations

INSTITUTE OF CORROSION

THANK YOU!

QUESTIONS?