Molecular and Risk-Based Approach to Nutrient Development for a Proposed Sub-Surface Biogasification Field Trial in a Biogenic Gas Field

Adewale J. Lambo[1], Dariusz Strapoc[1], Michelle Pittenger[1], Ladonna Wood[2], Matt Ashby[2], Bradley Huizinga[1]

[1]ConocoPhillips, [2]Taxon Biosciences

ISMOS-3 Calgary
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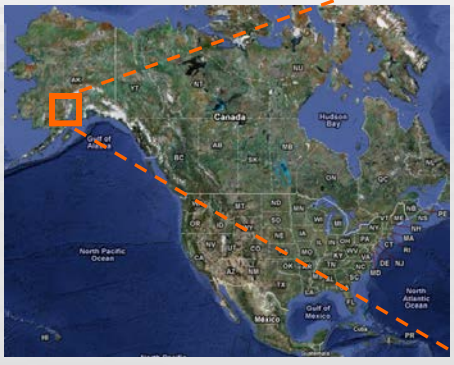
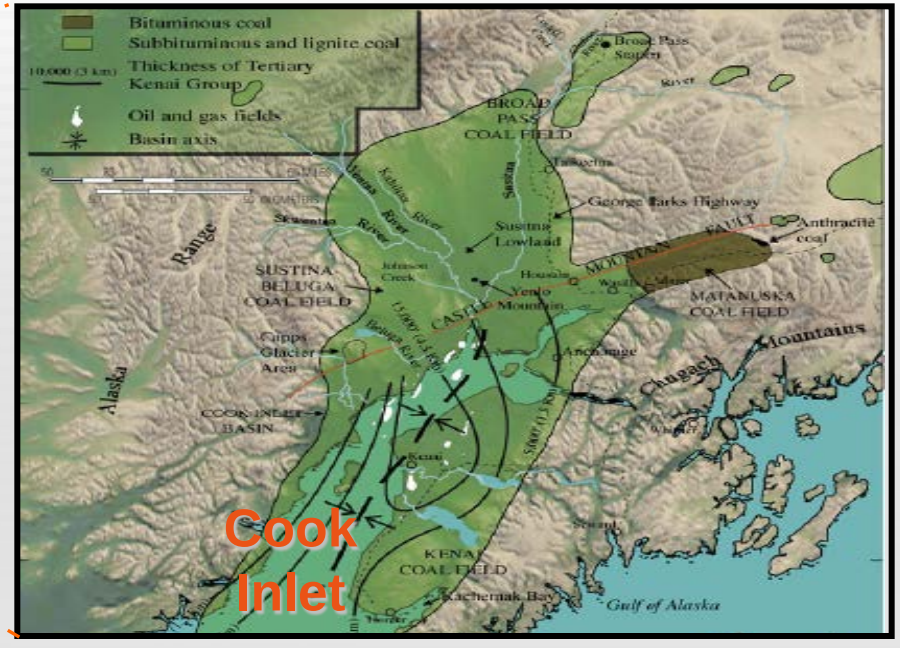
Study Area: Cook Inlet Basin





Dominated by fluvial sediments and interbedded, sub-bituminous coals

Organic matter is accessible
Thin, low maturity coals

Sandstone with organic debris
Volcanic ash as nutrient source

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Field sampling: Water chemistry and environmental parameters are variable across the field

Field Sampling

- Gas molecular/isotopic composition ($\delta^{13}CH_4$, -61 to -68‰)
- Microbial community analyses (Archael/Bacteria)
  - DNA yield (40 – 1680 µg/L)
- Water chemistry (inorganic/organic)
  - variable nutrient supply
  - Field pH 6.3 – 8.1
  - Alkalinity mg/L (275 – 2045)
  - Fe, mg/L (1 - 250); acetate (0 - 350); salinity (90 - 4900)
- Temperature (9 – 18 ^oC)
- Depth (935 – 1760 m)

Gas sampling

Coal outcrop sample collection

Water sampling

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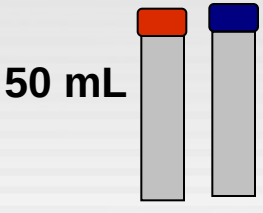
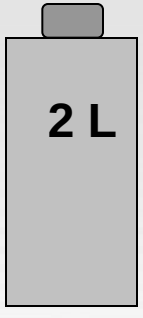
Onsite sampling of important parameters

Multi-parameter measurements using YSI Sonde

- Redox potential
- Dissolved oxygen
- Turbidity
- pH
- Temperature
- Salinity
- TDS
- Conductivity





≤ 4 °C

Detailed lab analysis

- Anions and cations
- Microbial analysis (16s RNA)
- Microbial culturing
- Gas molecular and isotopic composition

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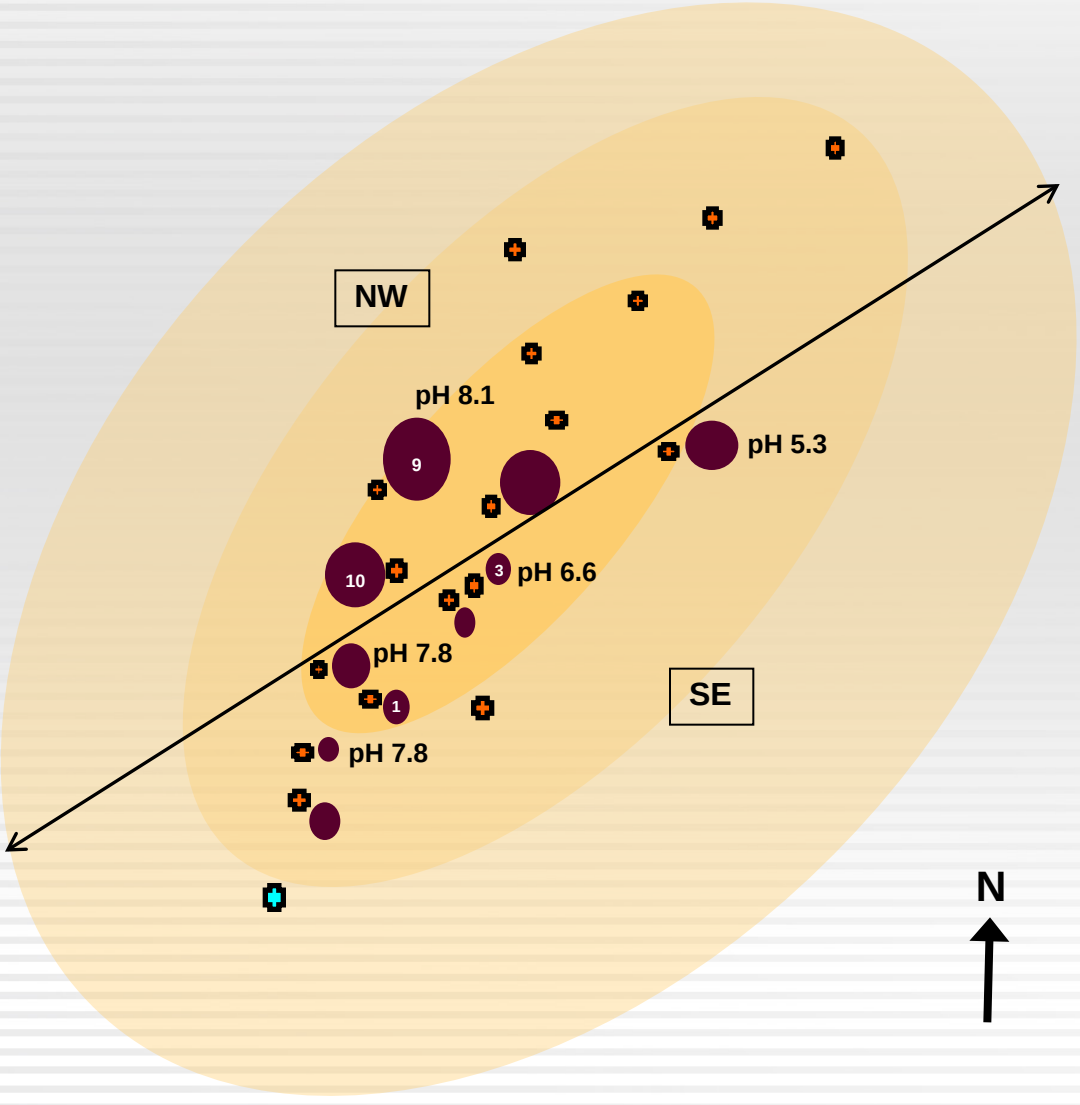
DNA yield varies across the field and shows distinct spatial variation

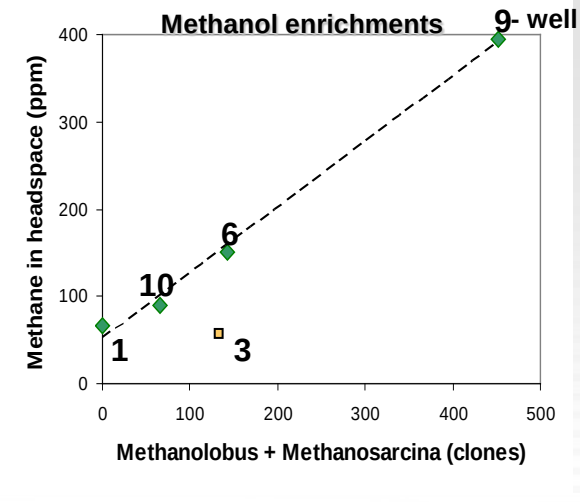
Of what effect is the microbial composition ?



DNA yield

Prod. well

Inj. well



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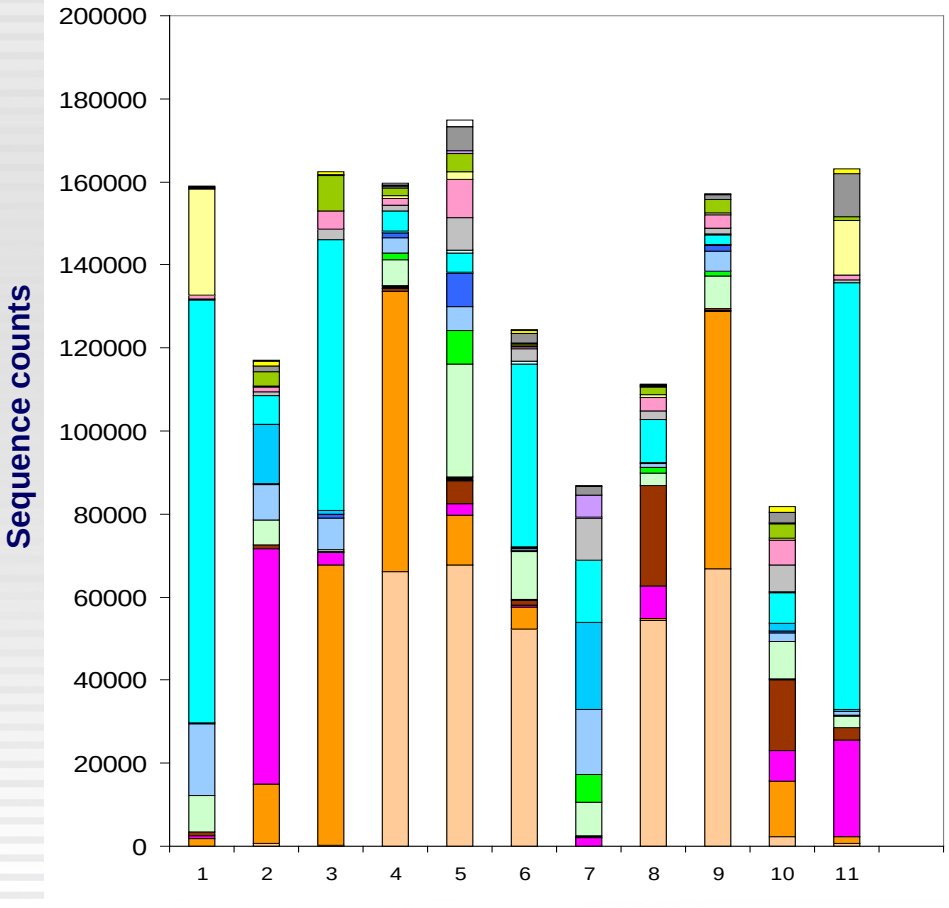
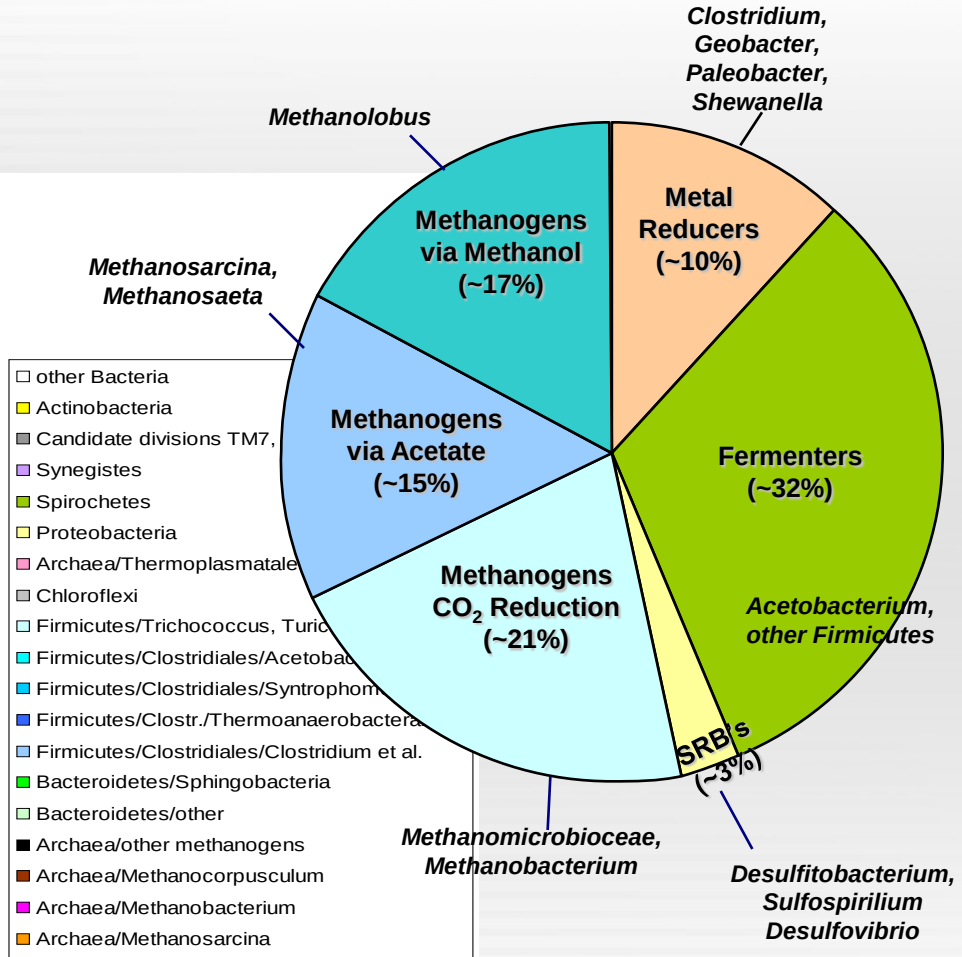
Composition of microbial population in Cook Inlet water and phylotype distribution of clones





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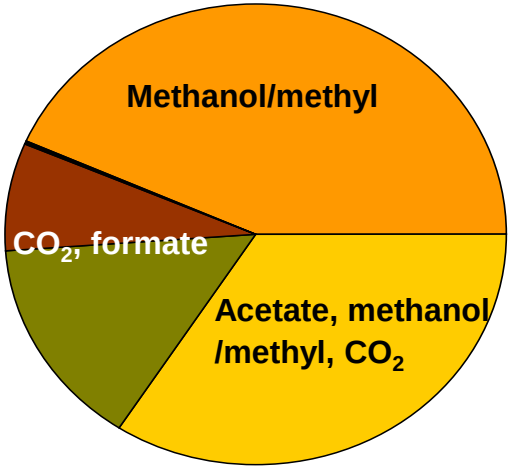
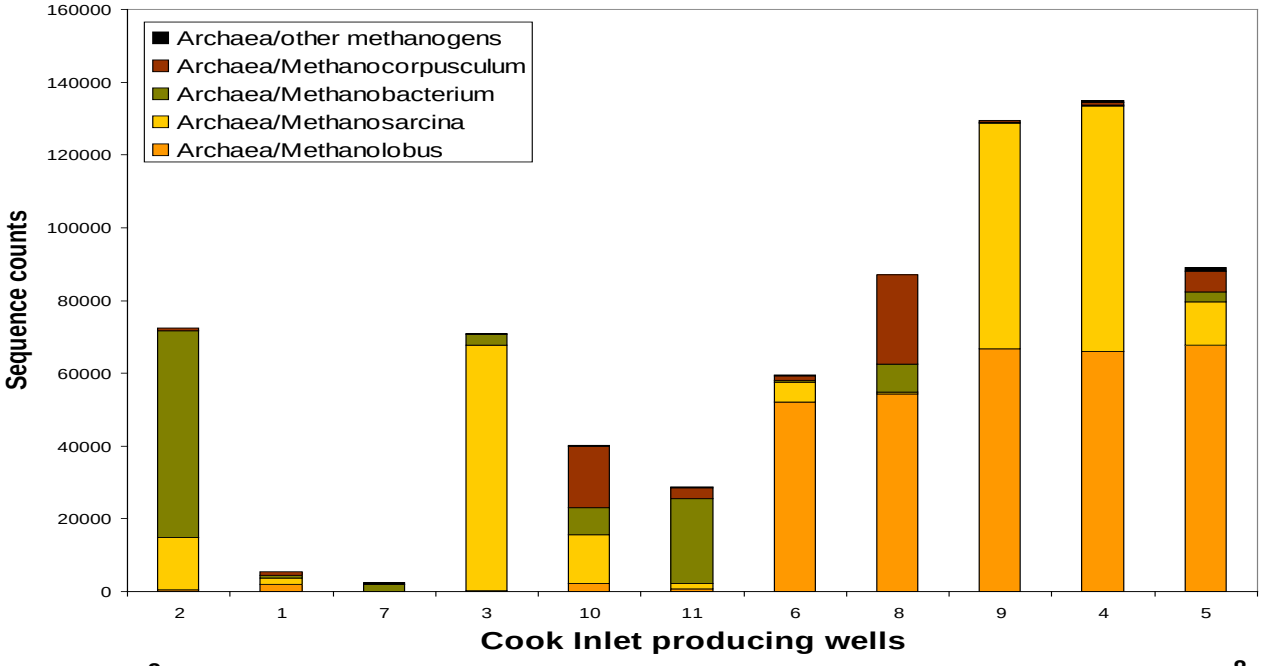
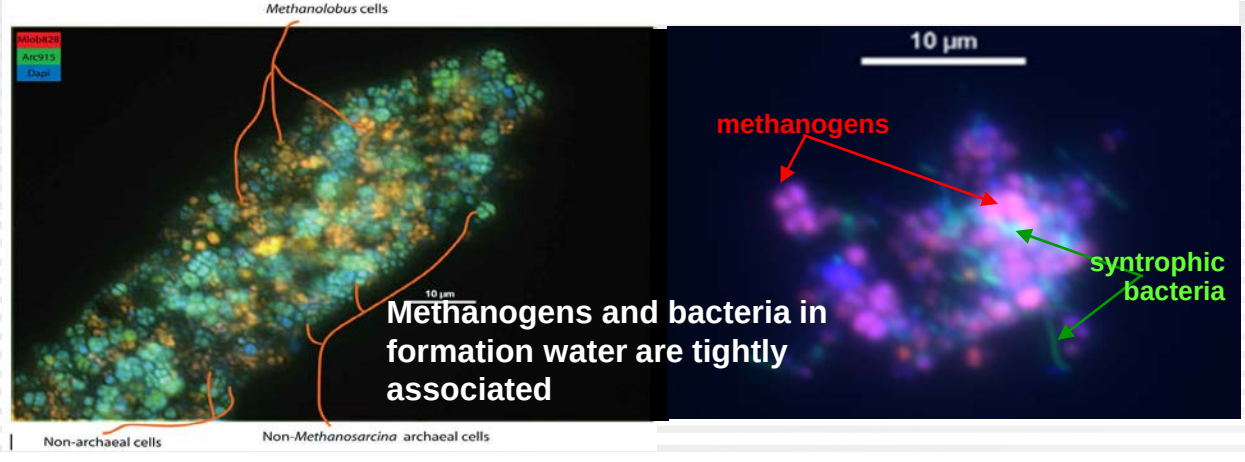
Relative distribution of Archaea population in Cook Inlet water and their methane forming pathways







Methanogens and bacteria in formation water are tightly associated

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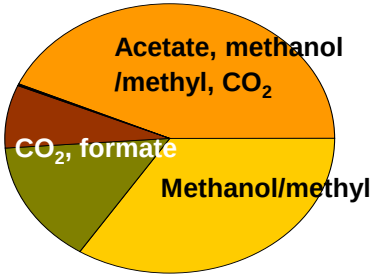
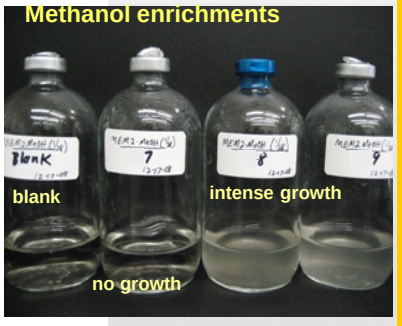
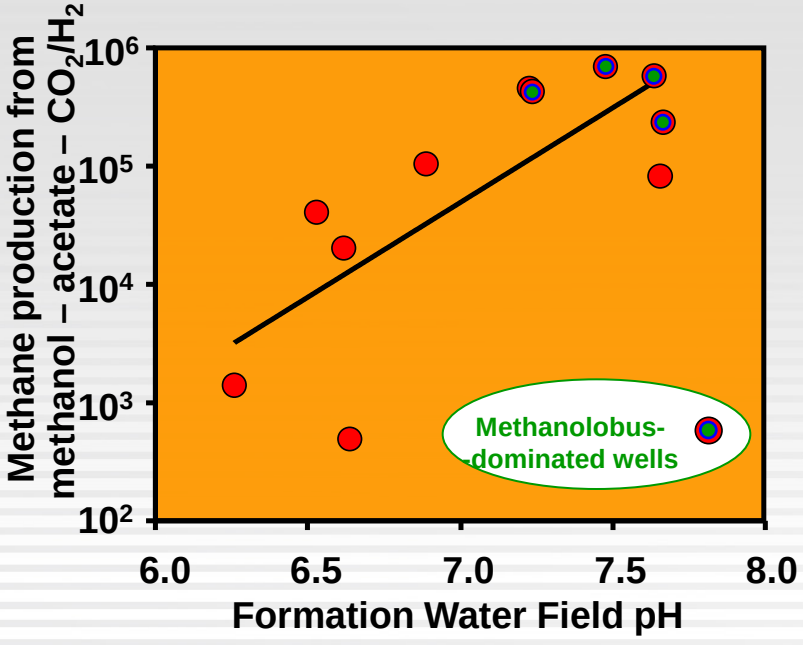
Archaea population dominated by methanogens using methanol/methyl pathway







Include diverse group of methanogens and the pathways involved already identified in lab studies

Complex Polymers

↓

Monomers

↓

Propionate
Butyrate
Succinate
Alcohols

H_2/CO_2	CO	Acetate	Methanol	CH_3-amine CH_3-sulfide	2-Propanol 2-Butanol
Methanomicrobia, Methanobacteria, Methanococci	*Methanosarcina, Methanobacteria,*	*Methanosarcina Methanomicrobia Methanobacteria*	*Methanosarcina Methanosaeta*	Methanosarcina Methanolobus	Methanosarcina Methanolobus

CH_4

	ΔG^o
$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$	-135.6
Methanol + $H_2 \rightarrow CH_4 + H_2O$	-112.5
4 Methanol + $H_2 \rightarrow 3CH_4 + CO_2 + 2H_2O$	-104.9
4 Methylamine + $2H_2O \rightarrow 3CH_4 + CO_2 + 2H_2O$	-75.0
Acetate $\rightarrow CH_4 + CO_2$	-31.0

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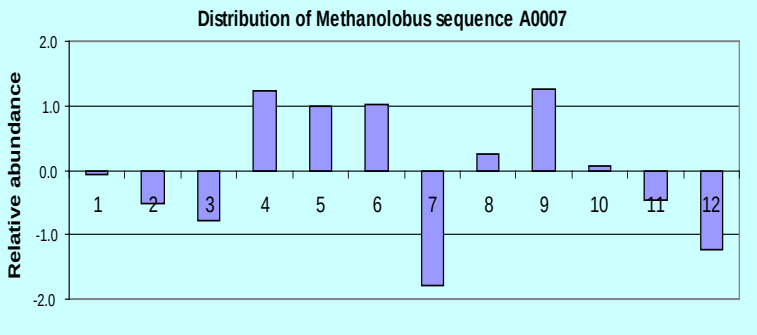
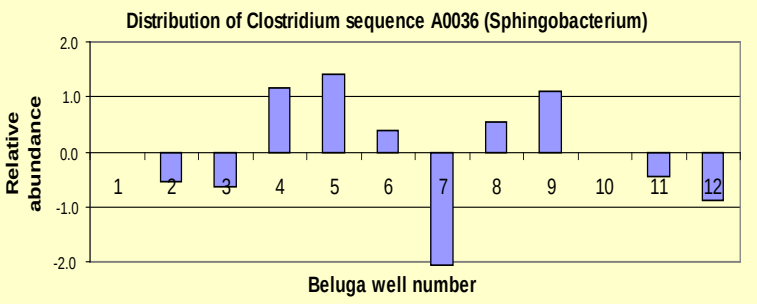
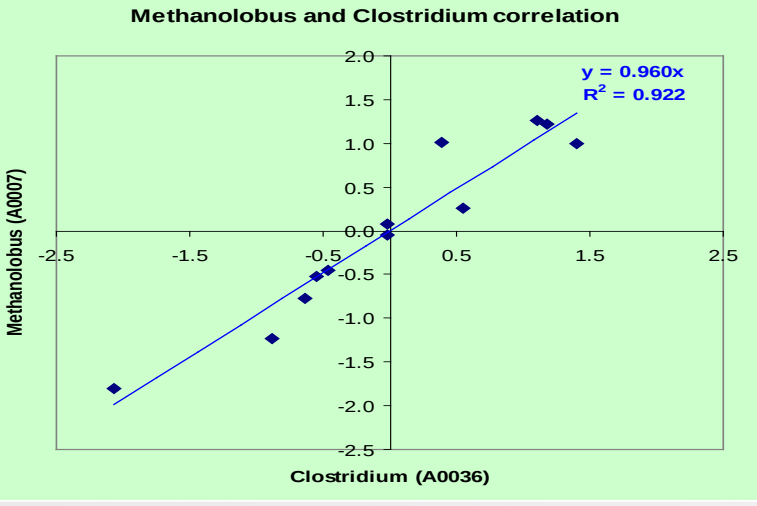
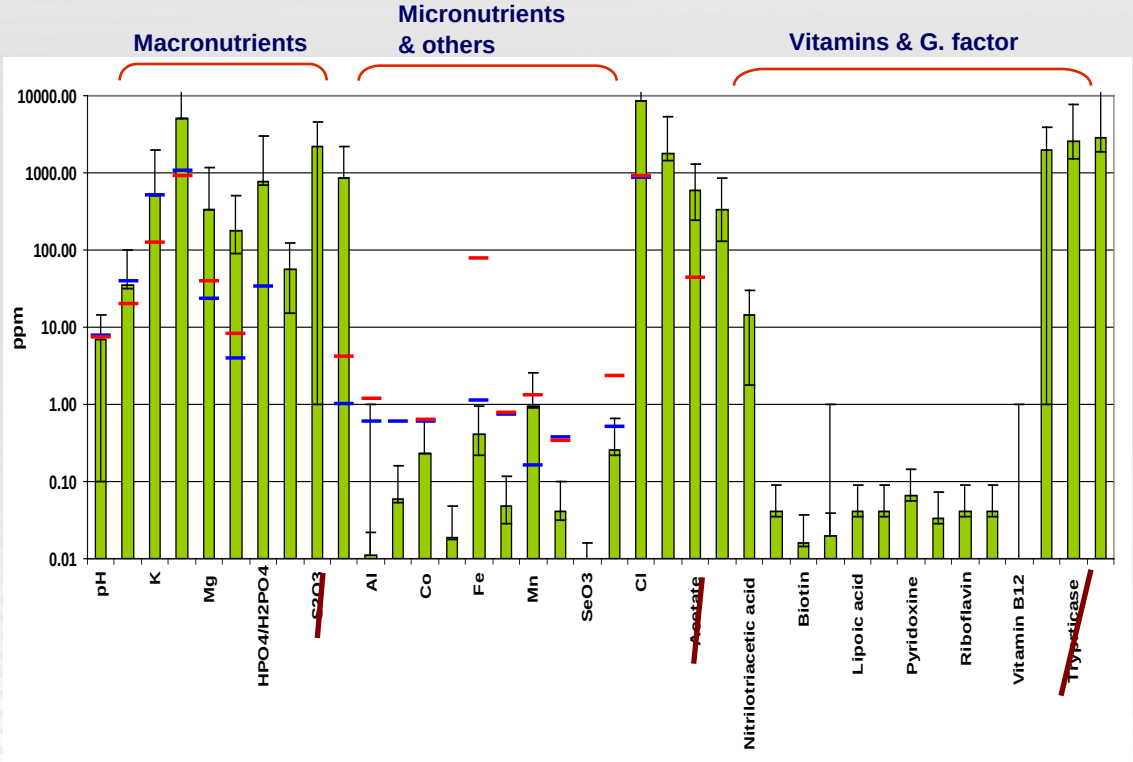
Nutrient recipe: developed using known information on nutrient requirements of mathematically-correlated microbial associations







Nutrient recipe development not a stand-alone process!!



Comparison of nutrient recipe composition with formation water from two different wells

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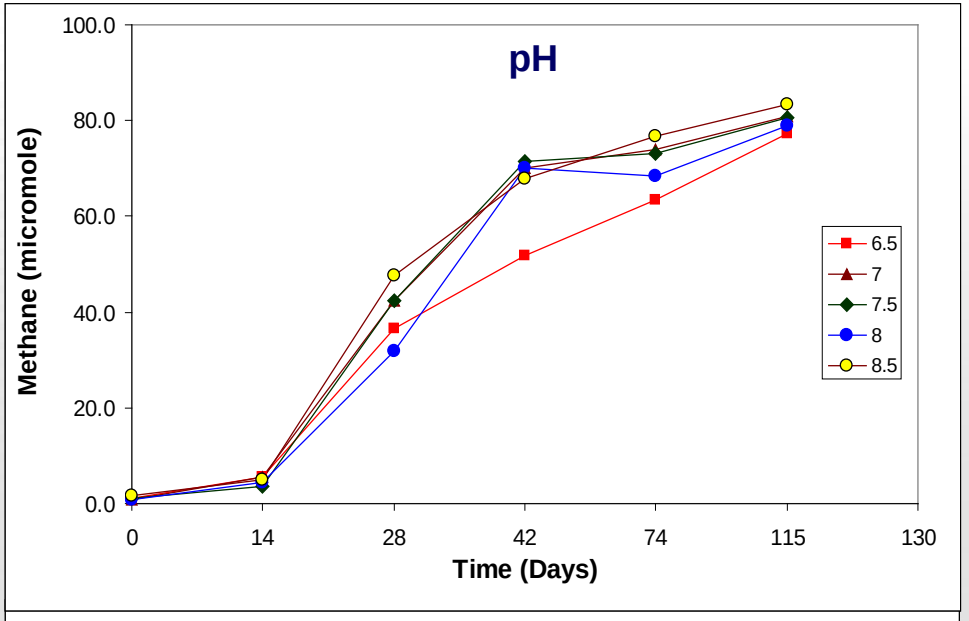
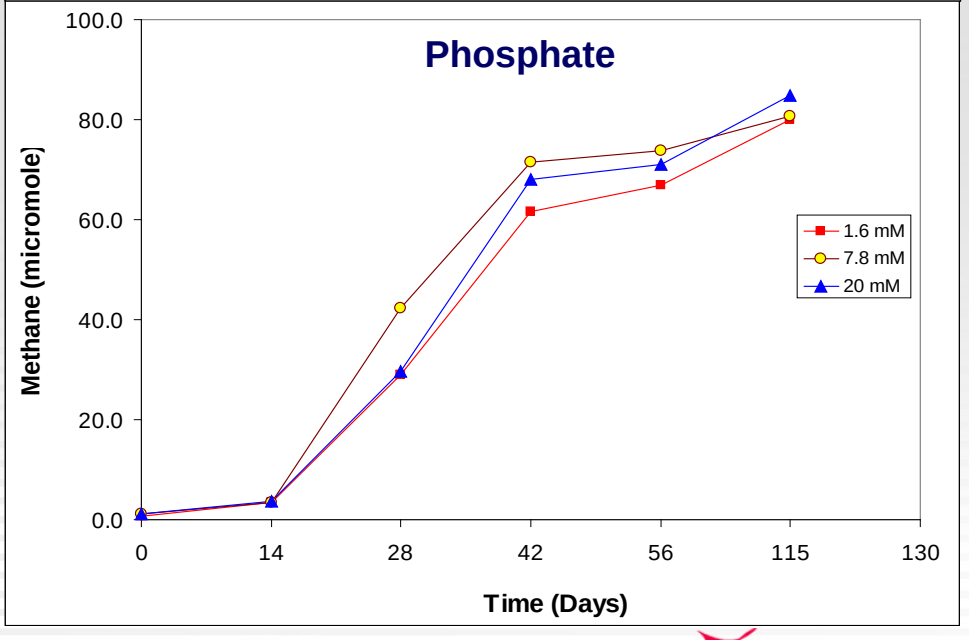
Optimization of methane production in sand-pack cultures with formation material





- Sand-pack tubes with formation water without nutrient additions (Baseline)
- Sand-pack tubes with formation water and varying or optimized concentration of nutrients
- Sand-pack tubes with addition of optimized nutrients and extra formation water consortium

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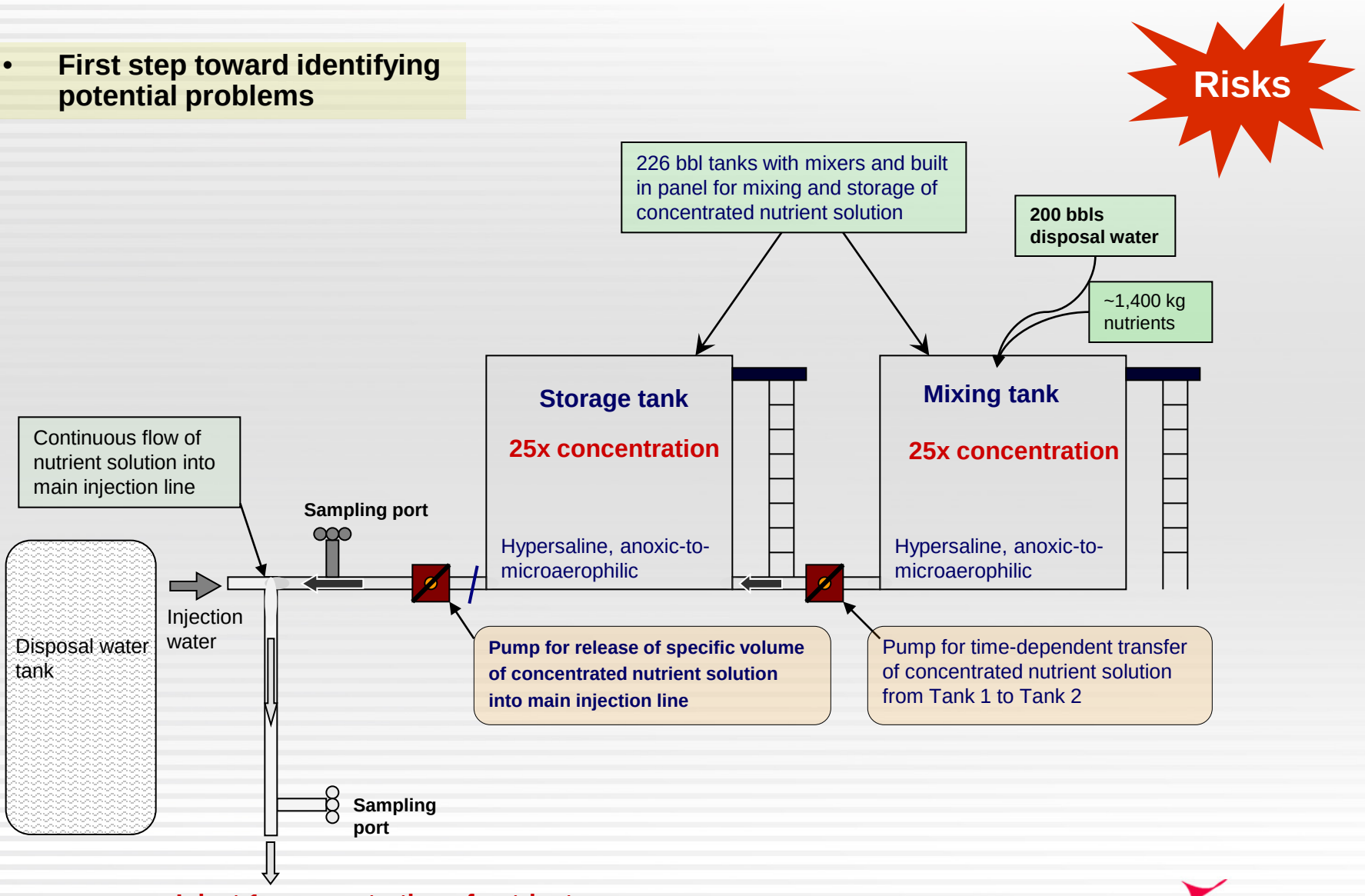
Schematic of on-site nutrient injection

- **First step toward identifying potential problems**



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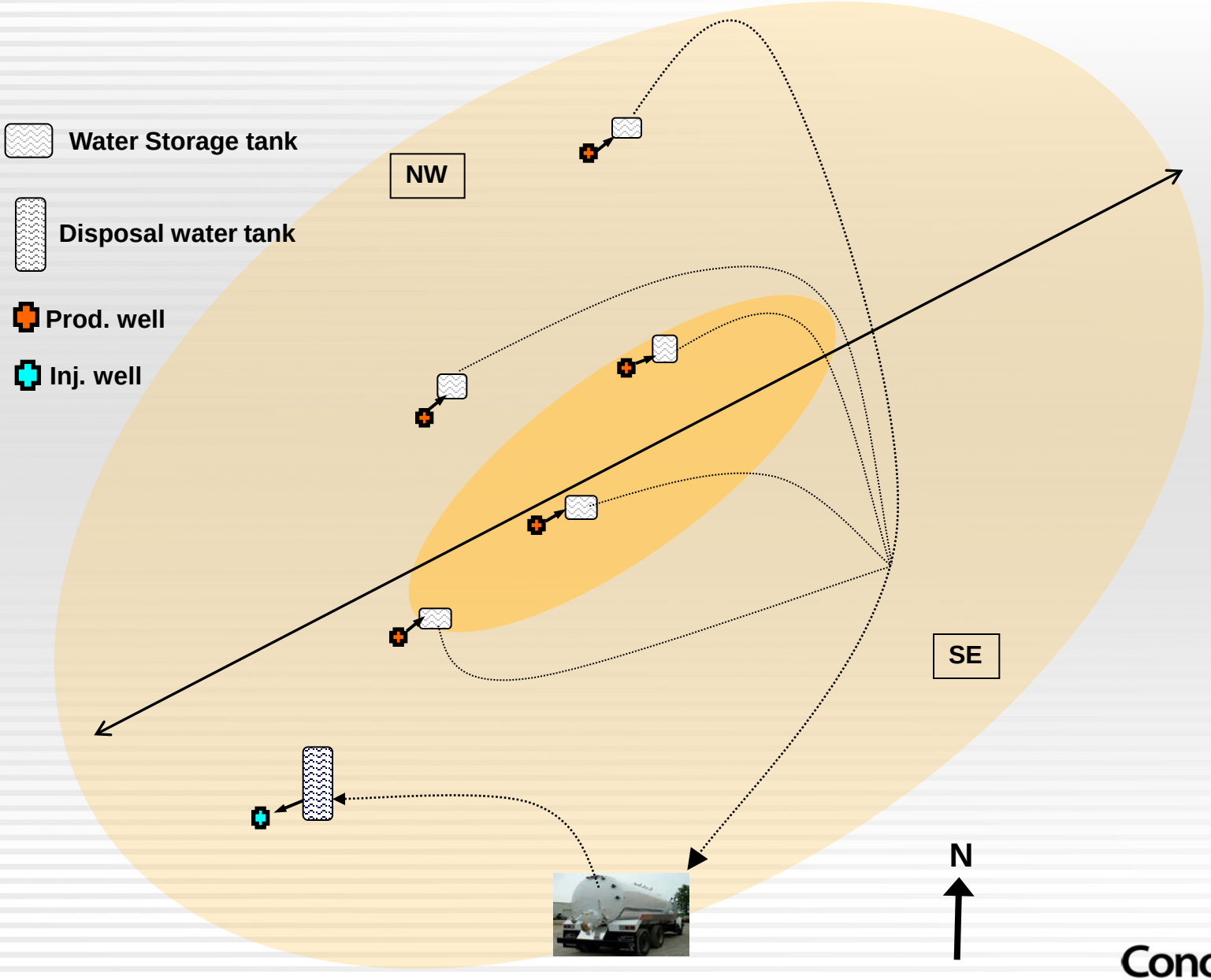
Water collection and distribution across the field



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Issues: risk analysis and mitigation plans

Over-riding principles during field trial: Do no harm to reservoir

- No HSE issues (and no H_2S production)
- No injectivity issues
- Limit biofilm prevalence
- Avoid biofouling, bioplugging, and bio-corrosion
- Avoid bio-sludge or inorganic sludge formation in tanks
- Avoid inorganic scale formation in nutrient-produced water mixture

List potential problems → Evaluate probability/severity → Identify likely cause → Propose preventive action/contingency plan → Test problem/preventive action or contingency plan → Identify appropriate action

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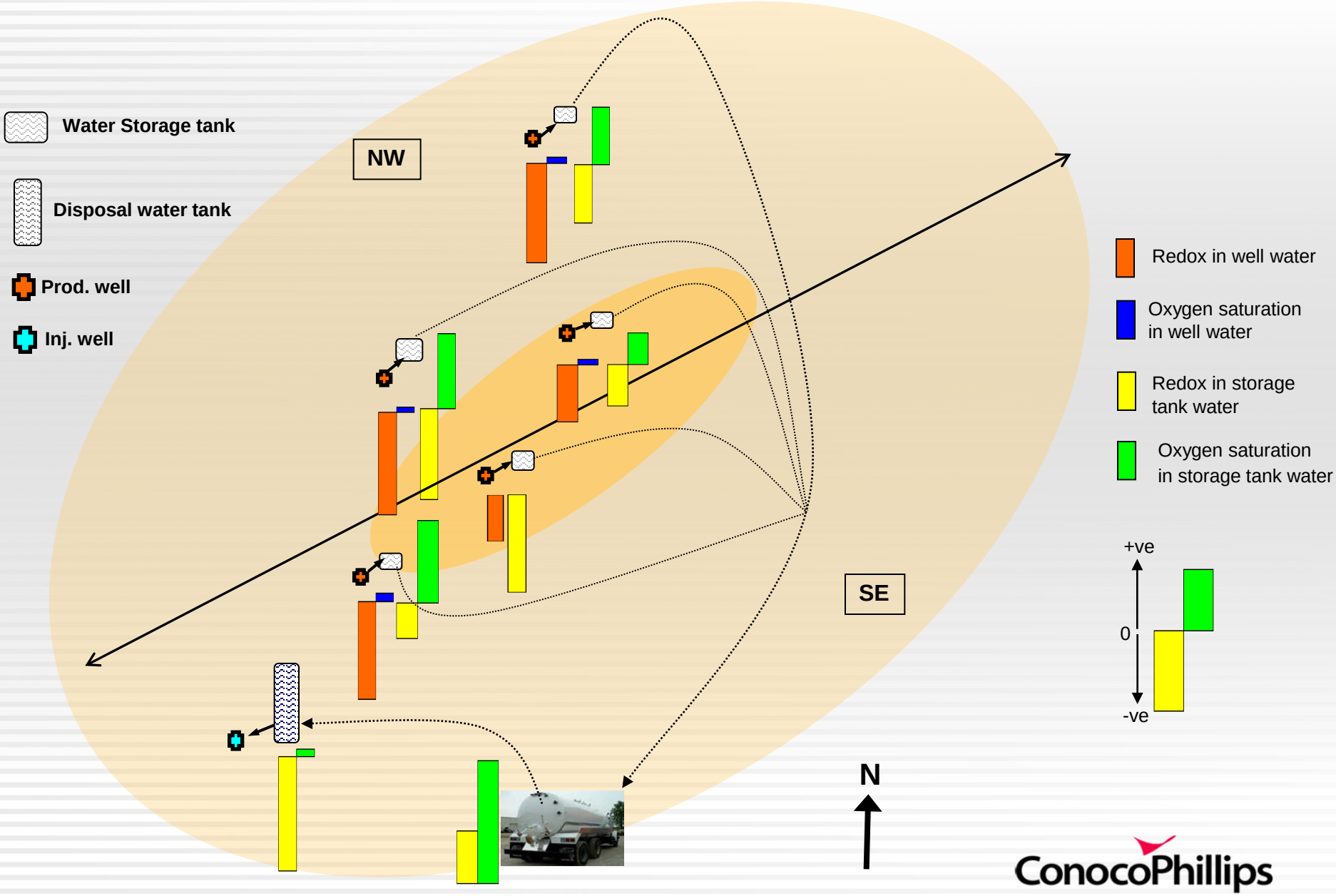
Redox and O_2 saturation of water across the field: wells and storage tank



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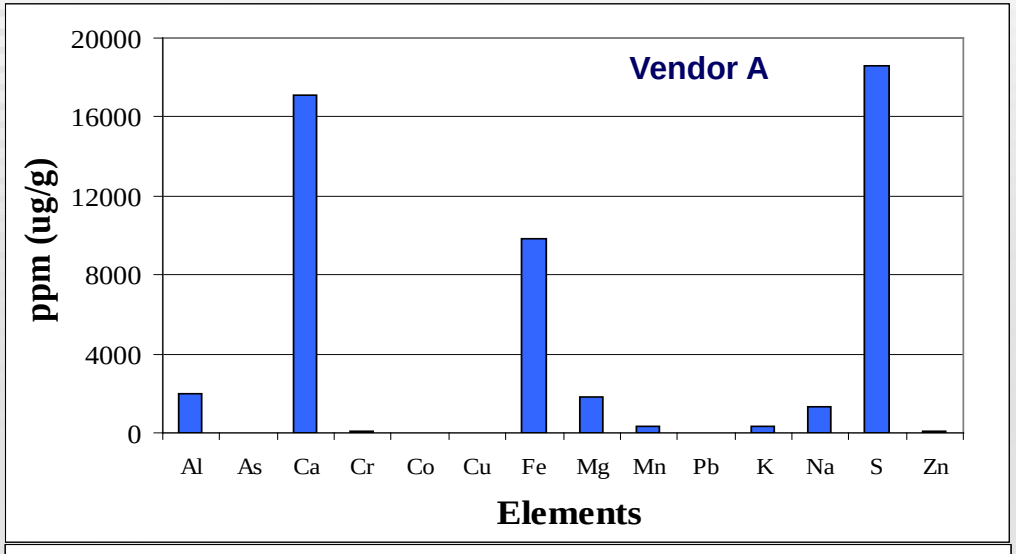
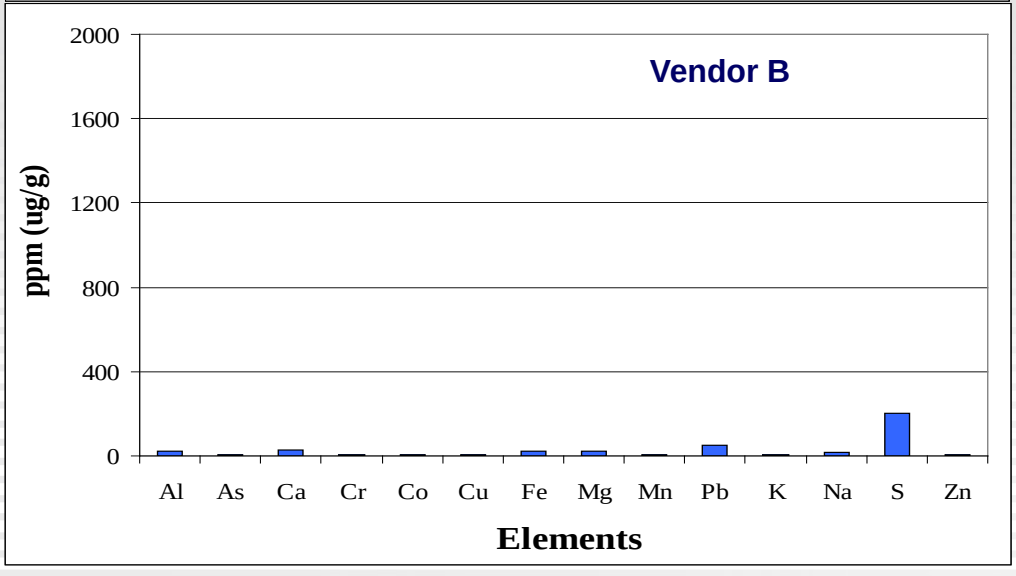
Purity of chemical reagents for nutrient recipe

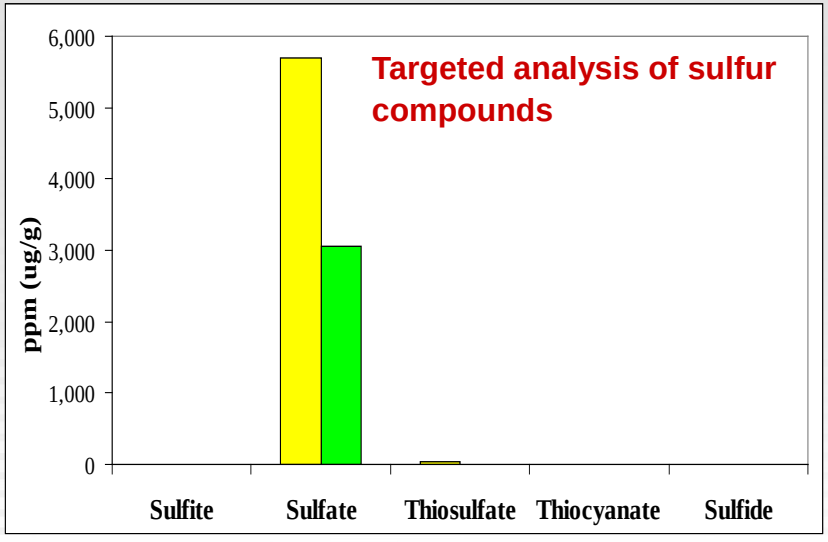
Elemental composition of a reagent from two different commercial vendors





- **Toxicity problems**
- **Need to avoid unwanted side reactions or products**

No H_2S!



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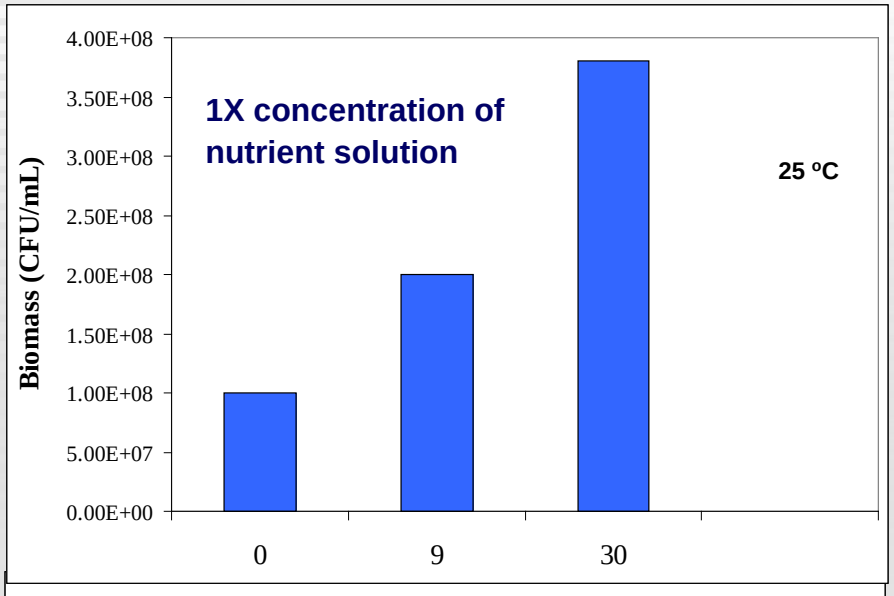
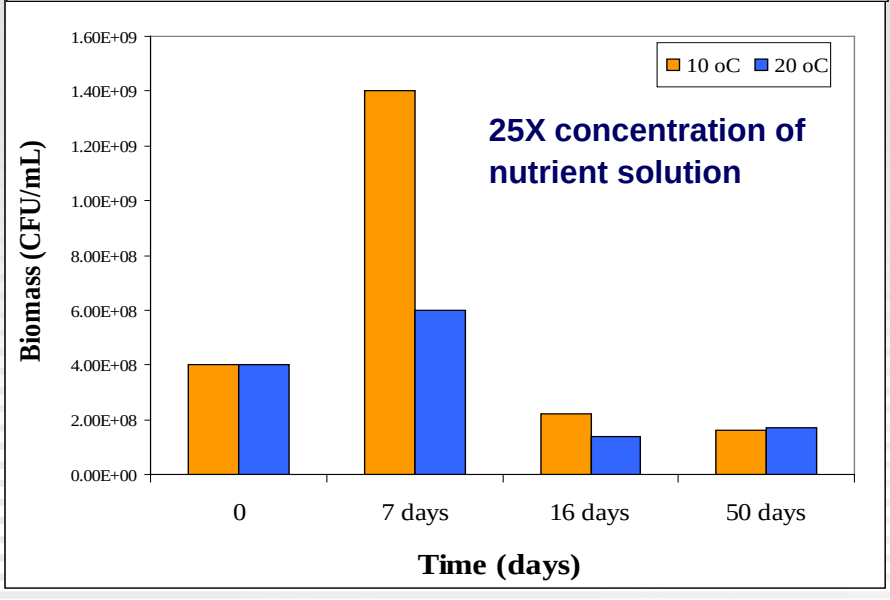
Biomass development in nutrient solution in tanks and injection line





Biofilm will likely develop in injection line and in injection well-bore but less likely in nutrient mixing and storage tank due to high nutrient concentration

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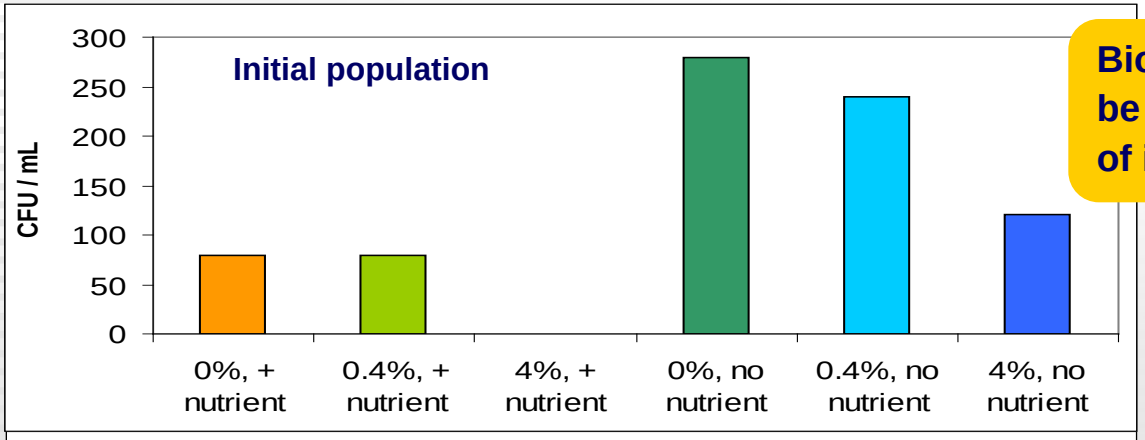
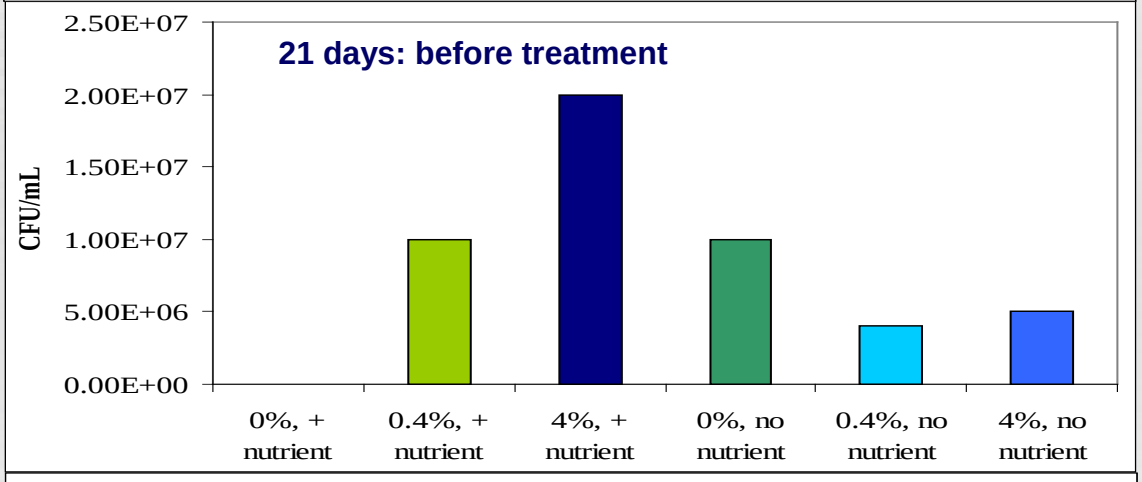
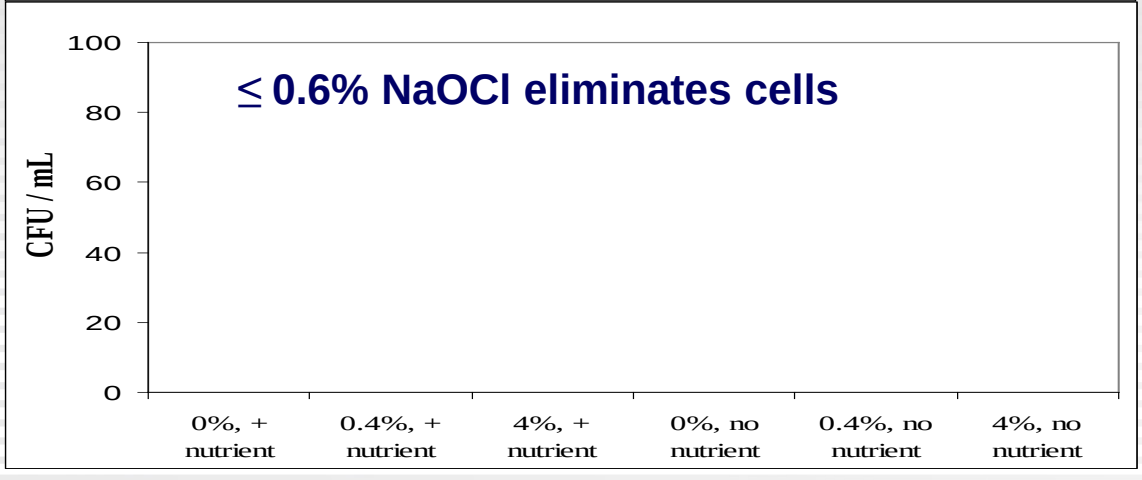


Biomass-induced injectivity problem can be avoided by intermittent "bleaching" of injection line & well-bore region



NaOCl solution was effective In eliminating biomass



0 – 4% oxygen (v/v)

With or without nutrients

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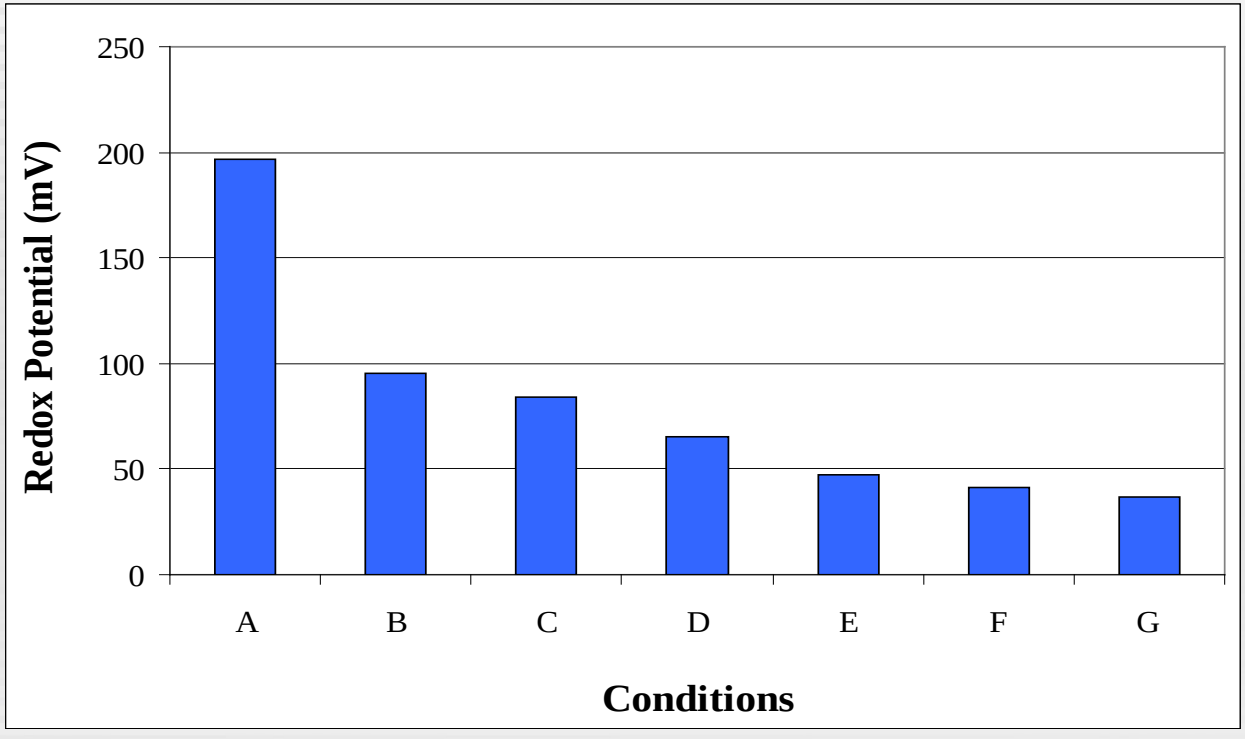
Non-sulfur oxygen scavengers decreased redox potential



A. Prod. water + nutrient
B. Prod. water + nutrient + 34 mg/L MAG
C. Prod. water + nutrient + 34 mg/L MAG + 1.9 mg/L HAQ
D. Prod. water + nutrient + 68 mg/L MAG + 3.7 mg/L HAQ
E. Prod. water + nutrient + 136 mg/L MAG + 7.4 mg/L HAQ
F. Prod. water + nutrient + 170 mg/L MAG + 9.3 mg/L HAQ
G. Prod. water + nutrient + 204 mg/L MAG + 11.2 mg/L HAQ

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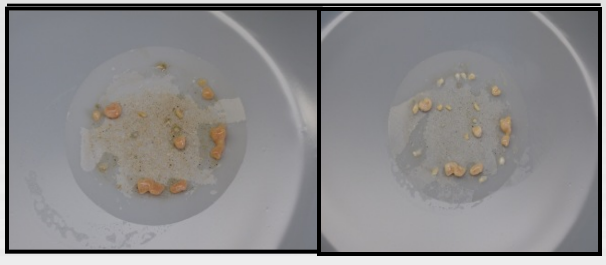
NaOCl and acid treatment of bio-sludge and inorganic particulates

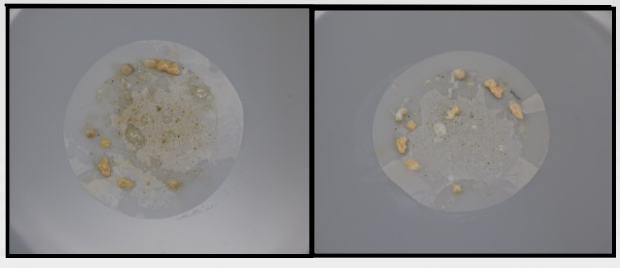
30 min treatment

30 min treatment



NaOCl treatment NaOCl + Acid

60 min treatment



NaOCl treatment NaOCl + Acid

Incubation period	Sample Start Weight (g)	After bleach treatment (g)	After bleach and HCl treatment (g)	Total % sample dissolved (%)
10 min	2.52	0.331	0.293	88.4
30 min	2.26	0.174	0.166	92.6
60 min	2.80	0.120	0.107	96.2

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Inorganic scale modeling and testing

1. Thermodynamic prediction modeling

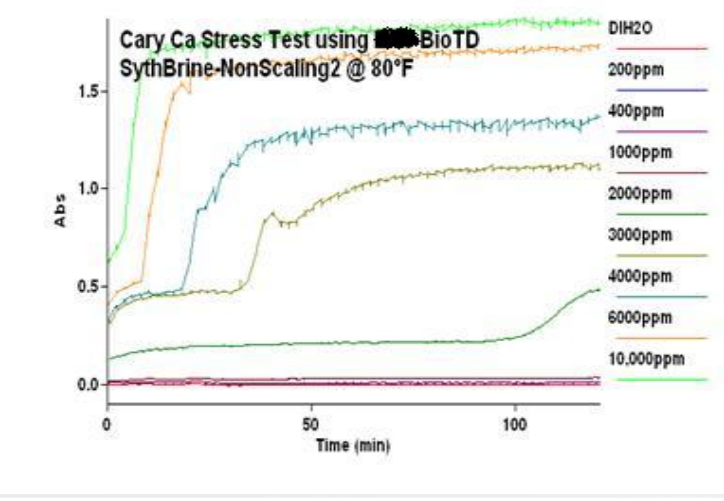
   - input: production water chemistry and nutrient composition

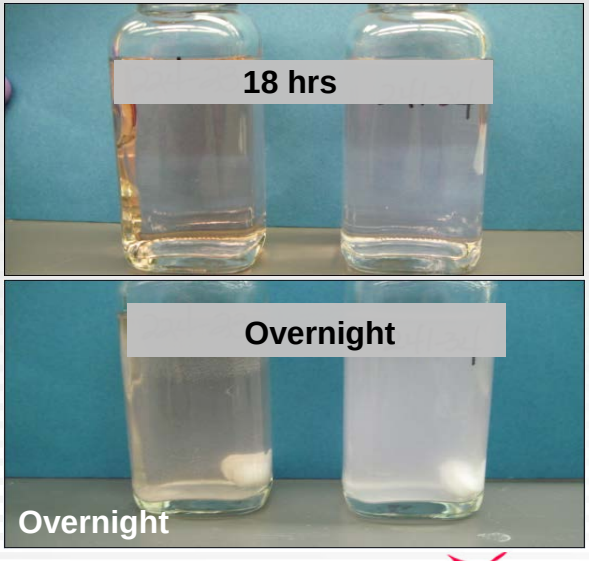
   - output: scale tendencies of potential products

2. Produced water filtered solids analysis by XRD/XRF and FTIR

3. Experimental testing: produced water + nutrient solution

4. Kinetics study of identified inorganic scale





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Conclusions

- Microbial community analysis, field geochemical studies and laboratory culture methods identified methanogens that are likely involved in methane production. This point to the likely methanogenic pathways
- Microbial population varies across the field and community composition correlates with field geochemical parameters and methane pathway
- Identified pathway and unique microbial association determines the initial composition of nutrient recipe developed for injection into the reservoir
- Risks related to nutrient injection were identified and mitigation plans proposed prior to the field trial
- Final composition of nutrient is not determined by microbial composition alone but also by a combination of reservoir or field specific conditions

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Acknowledgement

- ConocoPhillips
- Taxon Biosciences

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