



# Bioremediation of Heavily Contaminated Marine Sediments by Petroleum Hydrocarbons Using Sediment Microbial Fuel Cells (SMFCs)

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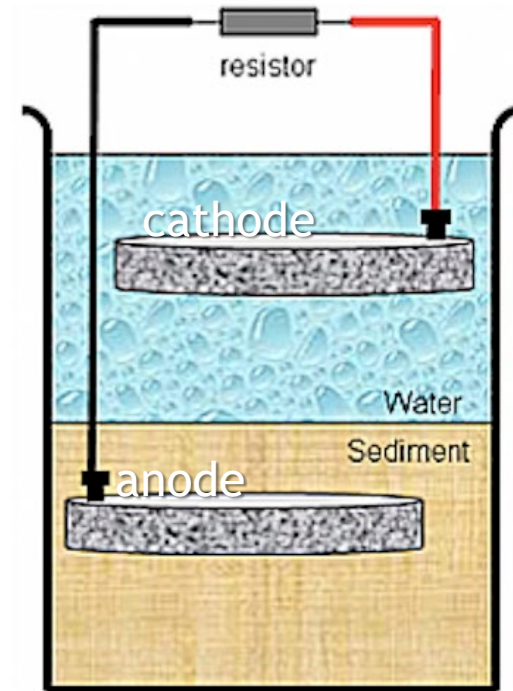
# Background

- ▶ Serious aquatic hydrocarbons contamination
  - ▶ Due to crude oil spills
  - ▶ Large amounts of oil into the environment
- ▶ Natural weathering
  - ▶ Variety of organic contaminants can still be detected
  - ▶ High concentrations in anaerobic sediments
- ▶ Various limitations
  - ▶ Stability of the organic compounds
  - ▶ Slow anaerobic processes
  - ▶ Insufficient terminal electron acceptors
- ▶ Important
  - ▶ Petroleum derived pollutants
  - ▶ Aliphatic and aromatic hydrocarbons
  - ▶ Adsorb onto sediments organic matter
  - ▶ Accumulate and persist



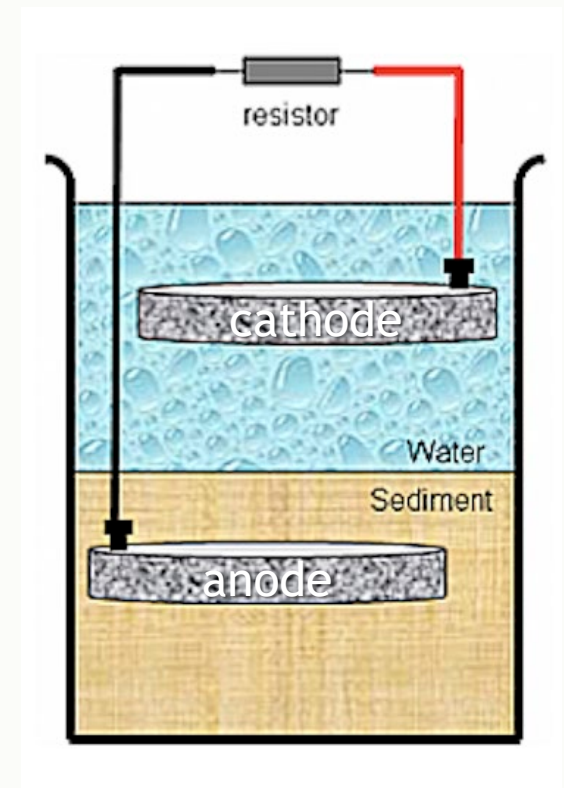
# Background

- ▶ Variety of physical, chemical and biological approaches
  - ▶ Handling an aquatic oil spill
  - ▶ Treatment of contaminated sediments
- ▶ Sediment Microbial Fuel Cells (SMFCs)
  - ▶ Importance for remediation the sediments
- ▶ Successful SMFCs implementation
  - ▶ Passive method for the treatment of lingering oil
  - ▶ Little external human intervention
- ▶ Important to assess SMFCs performance
  - ▶ Oil hydrocarbons attenuation
  - ▶ Rather than limiting investigations to few target pollutants
  - ▶ Results more relevant to field applications
  - ▶ Possible interactions among various contaminants



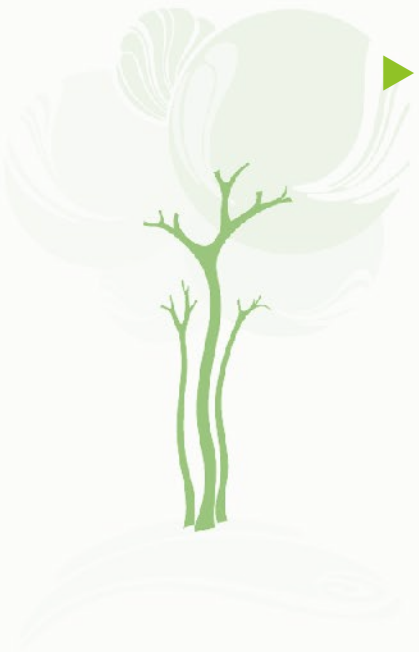
# Background

- ▶ Sediment microbial fuel cell (SMFC)
  - ▶ Microbial electron transfer
  - ▶ External terminal electron acceptor (TEA)
  - ▶ Exoelectrogens
- ▶ Anode
  - ▶ Anaerobic sediments
  - ▶ TEA
  - ▶ Enhanced organic compounds degradation
- ▶ Cathode
  - ▶ Oxygen rich water
  - ▶ Electrical current
- ▶ Oxygen
  - ▶ Ultimate TEA
  - ▶ Thermodynamic favorability



# Experimental design

- ▶ Ferric iron amended marine SMFCs
  - ▶ enhancement of biodegradation potential of TPH
  - ▶ Stimulation of FeRB
    - ▶ Amorphous ferric hydroxide
    - ▶ Importance of exoelectrogens
    - ▶ Limited in marine ecosystems
- ▶ Weathered light Arabian crude oil
  - ▶ Simulate a heavily contaminated marine environment

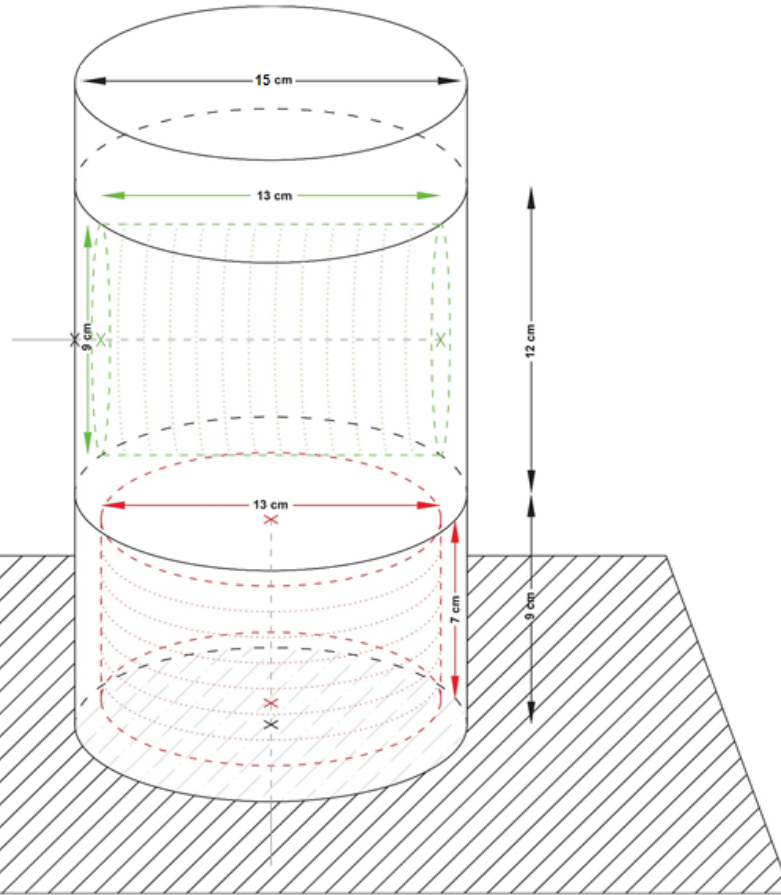


# Methodology: Sediment and Seawater

- ▶ Marine sediments
  - ▶ Jiyeh, Lebanon, near the jiyeh powerplant
  - ▶ 2006 oil spill
    - ▶ 15000 tons of heavy fuel oil
  - ▶ Daily contamination
    - ▶ Shipping
    - ▶ Loading/unloading
- ▶ Grab sediment samples
  - ▶ 5-6 meters below the surface
  - ▶ 30 cm below the sediment/water interface
- ▶ Preparation of sediment
  - ▶ Crude oil spiking
  - ▶ Iron amendment



# Methodology: SMFC design



# Methodology: SMFC operation

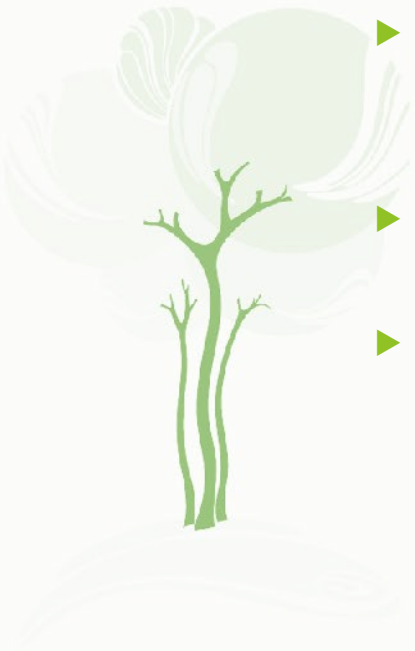
- ▶ Main treatment
  - ▶ Ferric iron stimulation
  - ▶ Anode reduction
- ▶ Two control conditions
  - ▶ Natural attenuation
    - ▶ Open circuit reactors
  - ▶ Ferric iron reducing condition
    - ▶ Open circuit
    - ▶ Monitor for the sole effect of ferric iron stimulation
- ▶ Sediments spiking
  - ▶ Weathered light Arabian crude oil
    - ▶ 1 g/Kg of dry sediment
  - ▶ Simulate a heavily contaminated marine environment



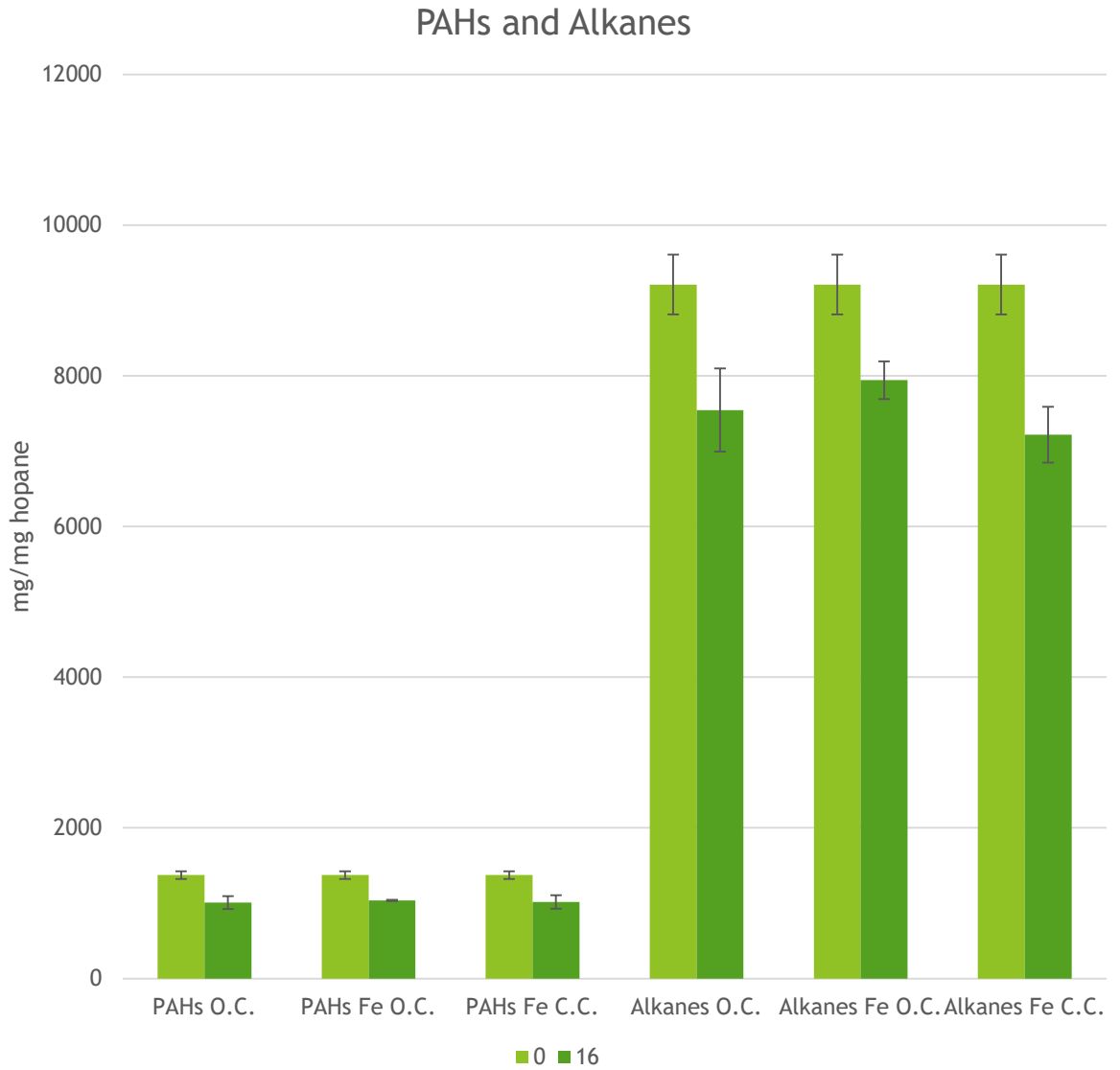
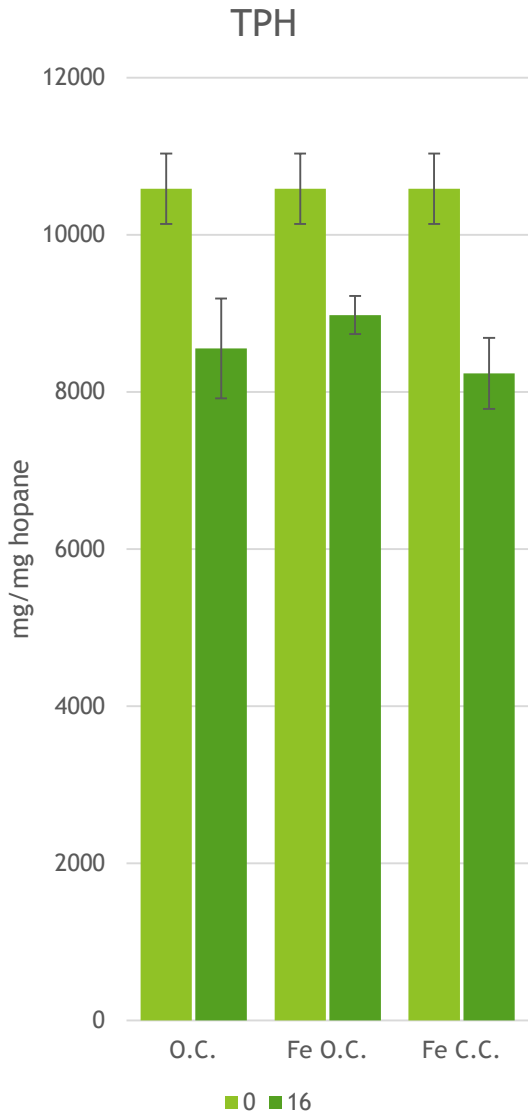


# Methodology: Monitoring

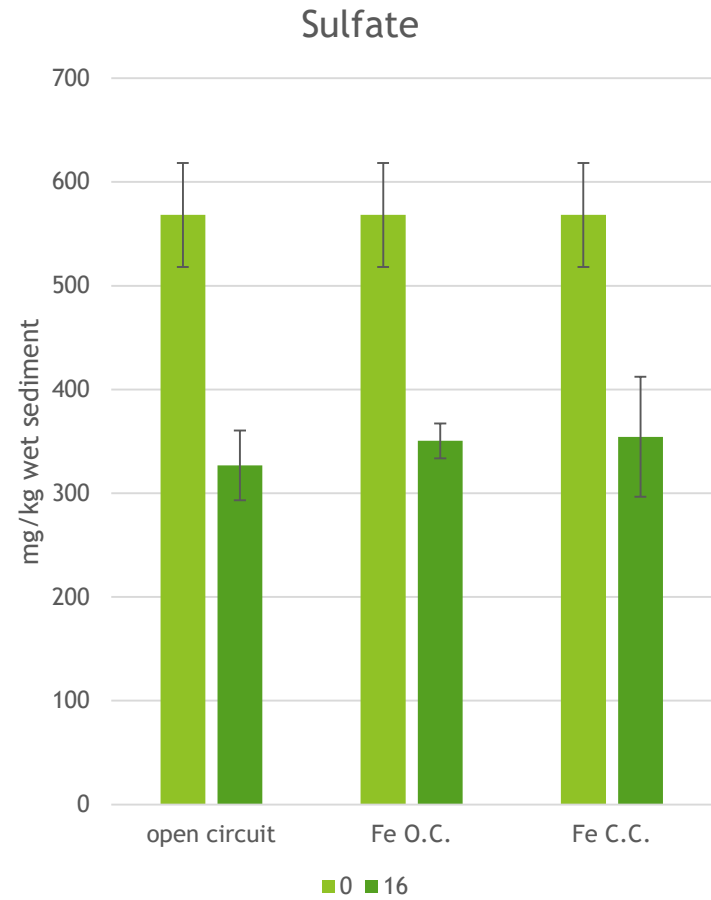
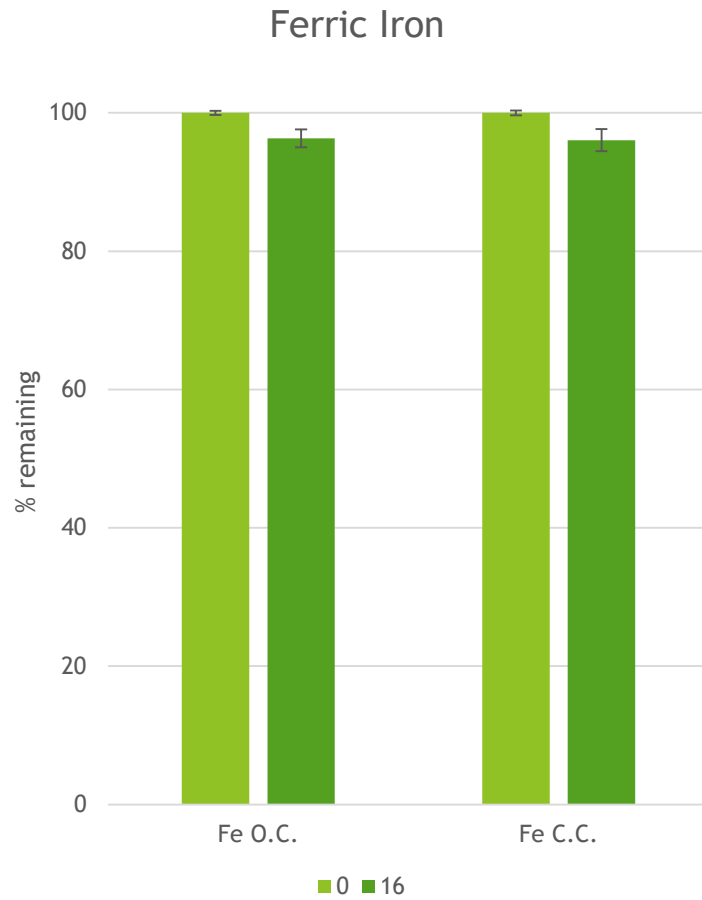
- ▶ Sets of triplicates
  - ▶ 16 weeks of operation
  - ▶ 5 sampling events
    - ▶ Week 1, week, 2, week 4, week, 8 and week 16
  - ▶ Disassembly process
  - ▶ Total Petroleum Hydrocarbons (TPH: PAHs+alkanes)
    - ▶ Accelerated Solvent Extraction (ASE)
    - ▶ GC analysis
  - ▶ Microbial Analysis
    - ▶ Extraction
    - ▶ Sequencing (MRDNA)
  - ▶ Sulfates and iron
    - ▶ Standard methods
  - ▶ Voltage recording
    - ▶ Data acquisition system



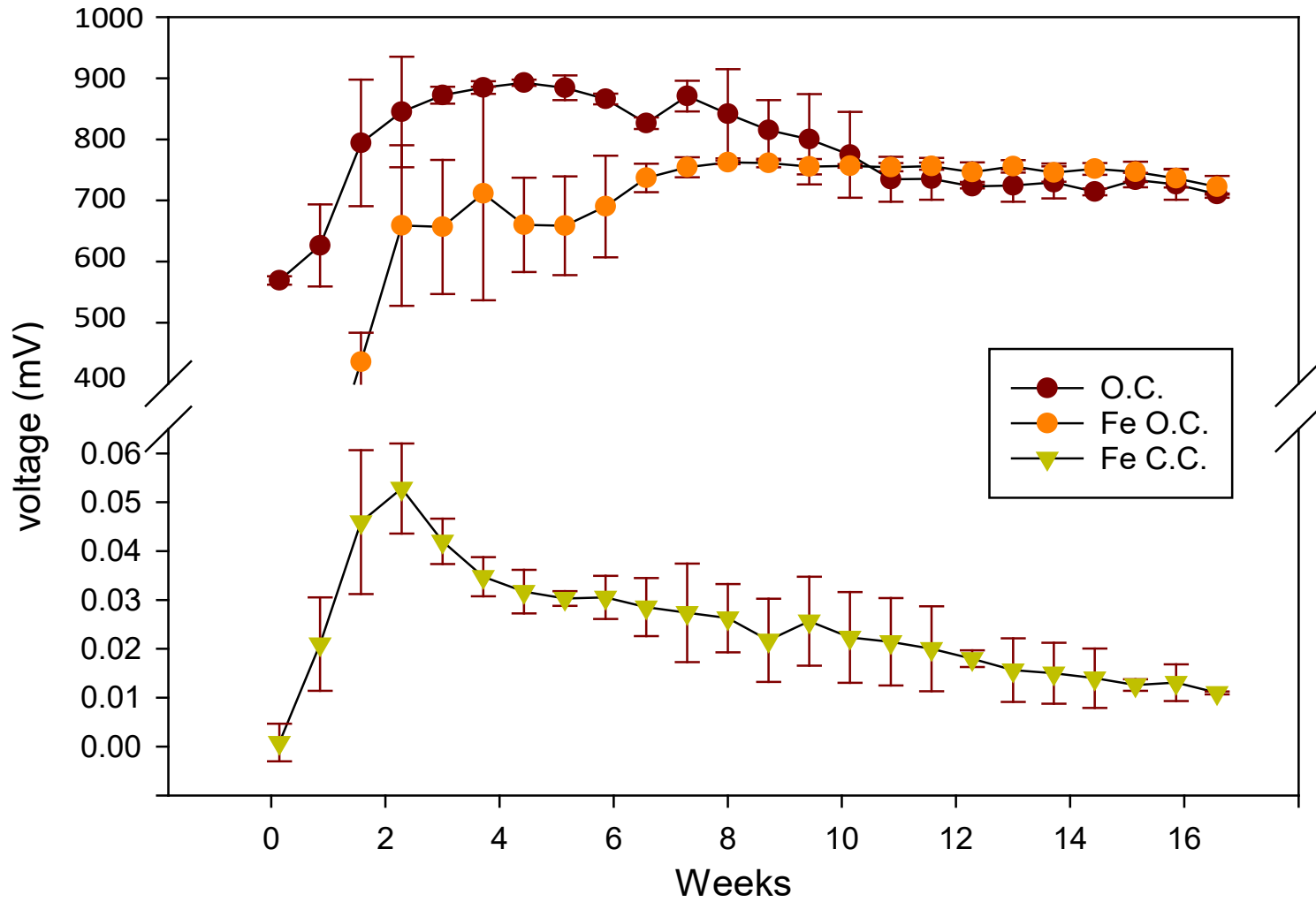
# Results: Crude Oil Biodegradation



# Results: TEAs

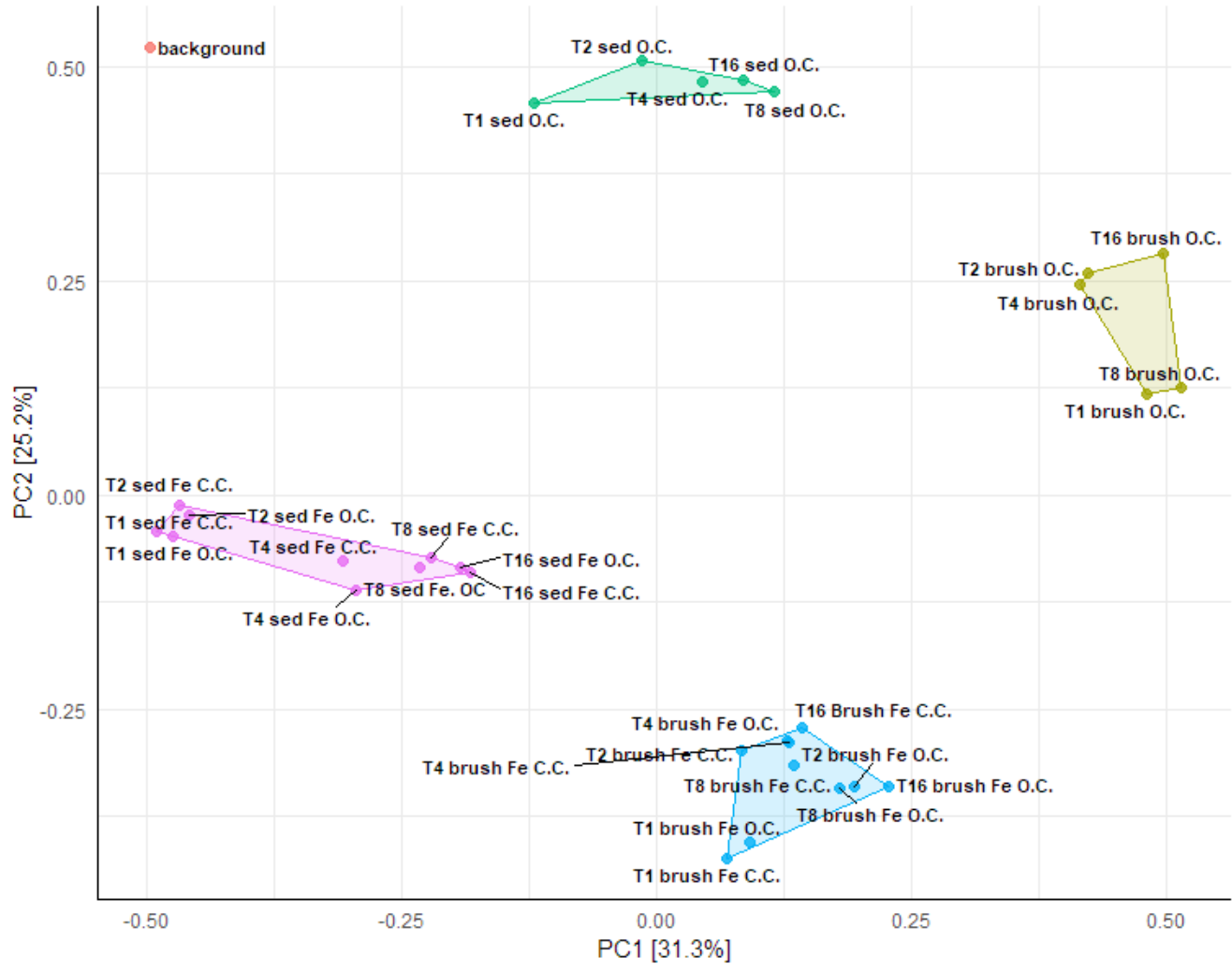


# Results: Voltage

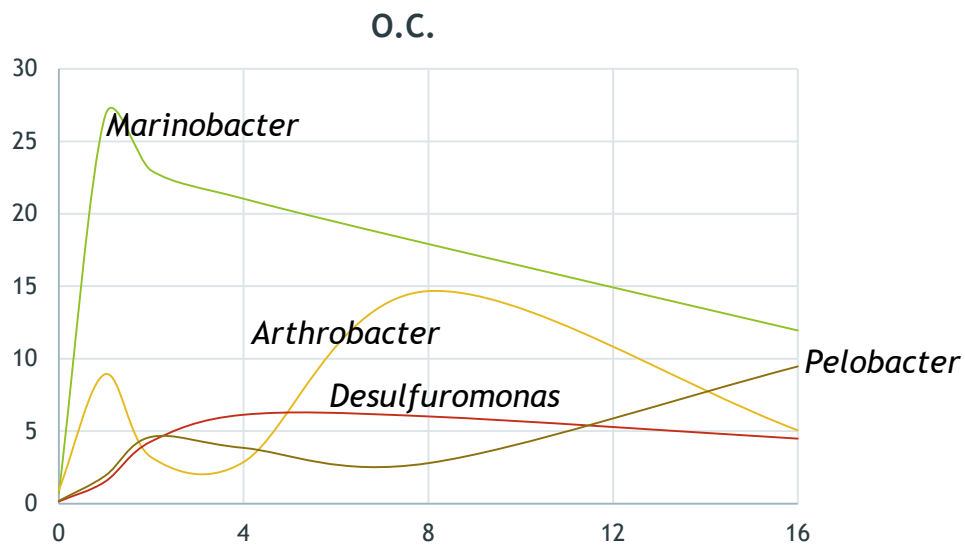
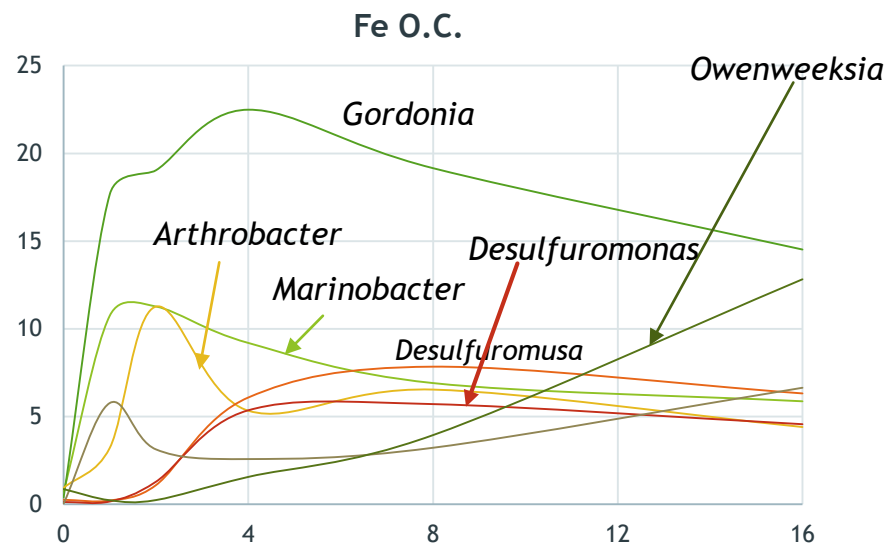
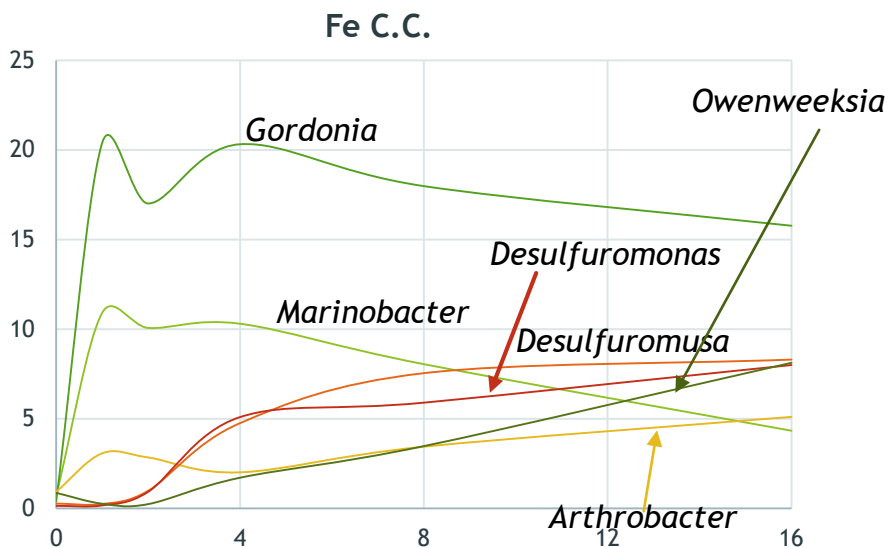


# Results: Microbial Community Analysis

## Principal component analysis (PCA)

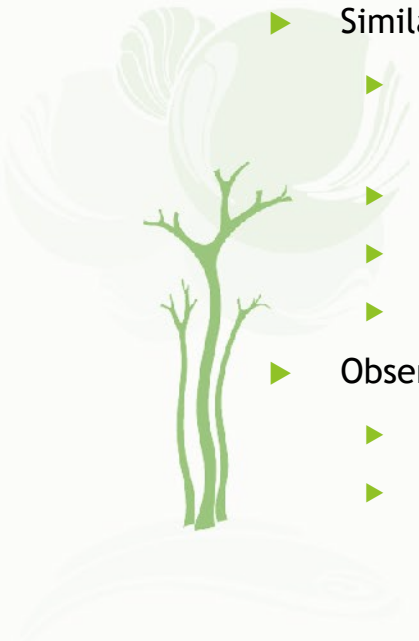
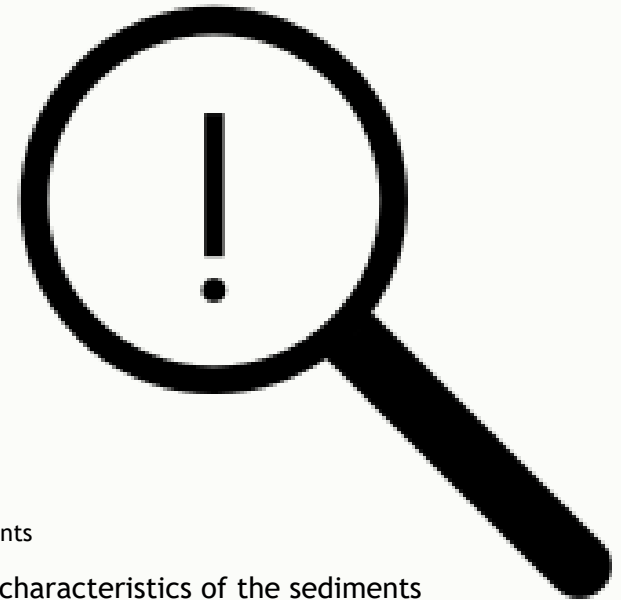


# Results: Microbial Community Analysis



# Conclusions

- ▶ TPH removal
  - ▶ Fe C.C. SMFCs performance similar to the controls
  - ▶ Insignificant enhancement to bioremediation of heavy crude oil contamination
- ▶ Microbial community structure and evolution
  - ▶ Similarity in Fe amended SMFCs
    - ▶ Fe C.C. and Fe O.C.
    - ▶ Irrespective of the application of anode as a TEA
  - ▶ Main factor affecting the evolution
    - ▶ Presence of ferric iron
    - ▶ NOT anode
- ▶ Similarity in bioremediation performance indicates
  - ▶ Bioremediation efficiency of heavy TPH contamination
    - ▶ Heavily driven by the total consortium of microbes within the sediments
  - ▶ Evolution of the microbial population is related to the specific characteristics of the sediments
  - ▶ Either no significant bioremediation enhancement by applying SMFCs
  - ▶ Or sediments bioremediation capacity was overloaded by the heavy contamination
- ▶ Observations from this study
  - ▶ Provide a baseline for better future assessments
  - ▶ A reference for further studies to address iron amended marine SMFCs



# Thank you for listening

## Questions are welcome



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