

Biodegradation of cyclohexane under different reclamation scenarios

Gloria Okpala, Luke Gjini, Alsu Kuznetsova, Ania Ulrich, Phillip Choi and Tariq Siddique

Renewable Resources and Civil and Environmental Engineering



UNIVERSITY OF
ALBERTA

Outline

- General overview of oil sands development
- Research rationale
- Biodegradation of cycloalkanes under different redox conditions
- Conclusions

Oil sands development in Alberta, Canada

Oil sands deposits

- Oil sands deposits: 1.7-2.5 trillion barrels
- Potentially recoverable: 315 billion barrels

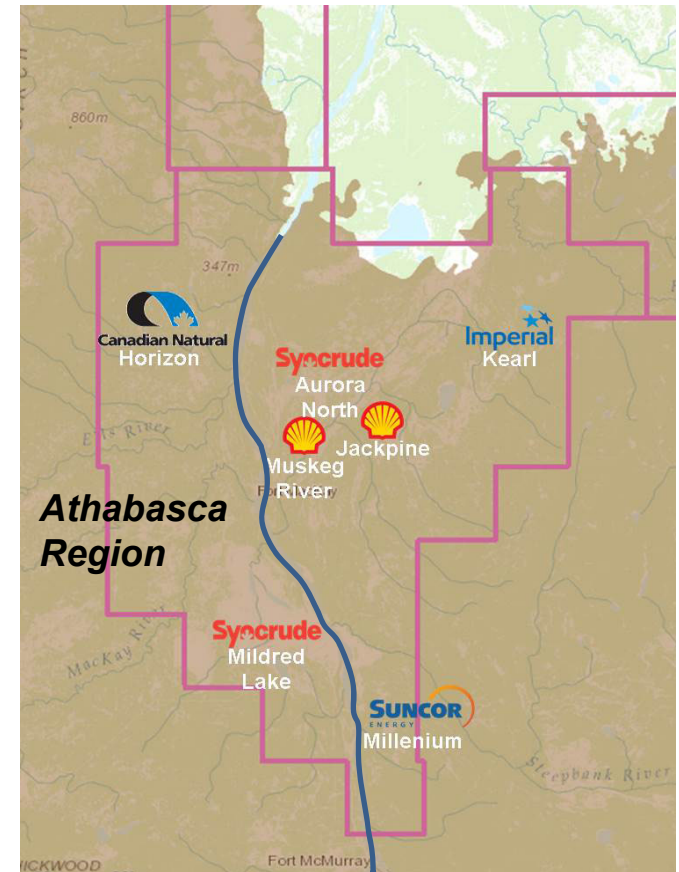
Bitumen production

- Current production: 2.8 million barrels day⁻¹ (2017)
- Projected production: 3.9 million barrels day⁻¹ (2027)

Oil sands tailings production (2016)

- Current tailings production: 1.3 million m³ day⁻¹
- Total volume of fluid fine tailings = ~ 1.21 billion m³
- Total area under tailings ponds = 257 km²
- Total liquid surface area of ponds = 103 km²

<https://www.energy.alberta.ca/OS/Pages/default.aspx>



Oil sands development

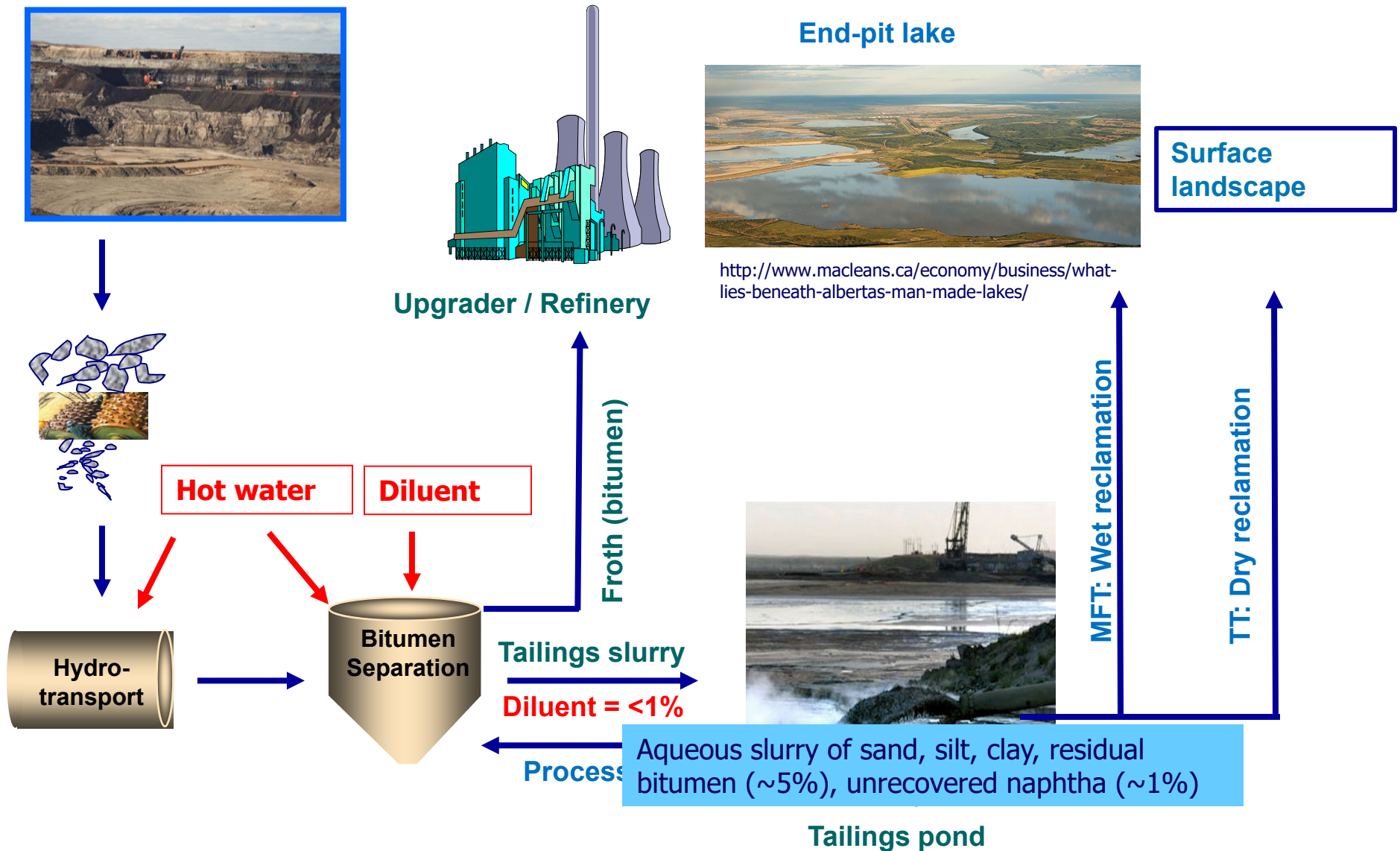


<http://climatestate.com/wp-content/uploads/2014/07/Tar-Sands-Alex-McLean-Oilsands-8-North-Steepbank-Extension-Suncor-140406-06091.jpg>



<http://news.nationalgeographic.com>

Surface mining and bitumen extraction process



Environmental issues associated with tailings

Mildred Lake Settling Basin

Methanogenesis

CH₄ Emissions = 3-30 million L day⁻¹
(Clearstone Engineering, 2007)

- Greenhouse gas emissions
- Slow dewatering and consolidation of tailings
- Constituents of concern
 - petroleum hydrocarbons
 - naphthenic acids
 - trace metals

Photo courtesy Geotechnical Engineering, UAlberta

Research Rationale

- Bitumen extraction with hydrocarbon solvent as a replacement for water extraction method eliminating fluid fine tailings and water consumption
- Generate low volume of “dry” Non-aqueous extraction (NAE) solids suitable for immediate disposal and rapid mine site reclamation

Challenge:

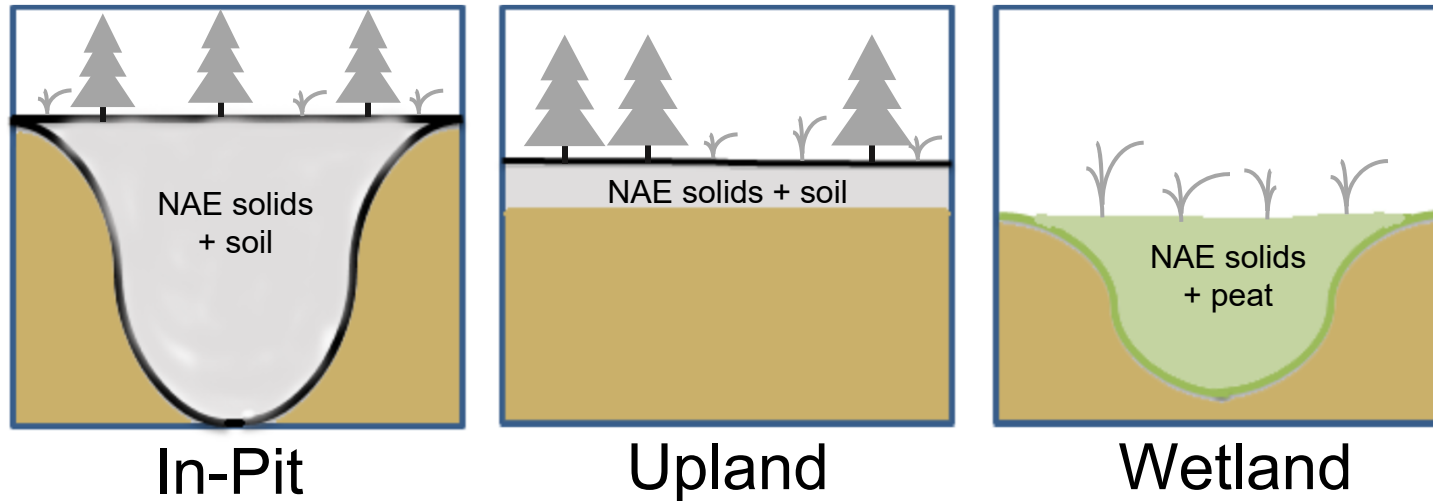
- Environmental fate(s) of the solvent (cyclohexane) *in situ* is unknown

Objectives:

- Investigate biodegradation of cycloalkanes under different redox conditions
- Assess the effect of nutrients (C:N:P) on the biodegradation kinetics
- Develop field-scale technology for the treatment of NAE solids under upland and wetland reclamation scenarios

Possible landscapes for biodegradation of residual solvents

simulating in-pit, upland and wetland reclamation scenarios



Redox conditions:

- Aerobic
- Nitrate-reducing
- Sulfate-reducing
- Methanogenic

Source of inoculum:

- Soil
- Fluid Fine Tailings (**FFT**)
- Oil sands process-affected water (**OSPW**) from tailings ponds

Experimental approach



Source of inoculum: FFT

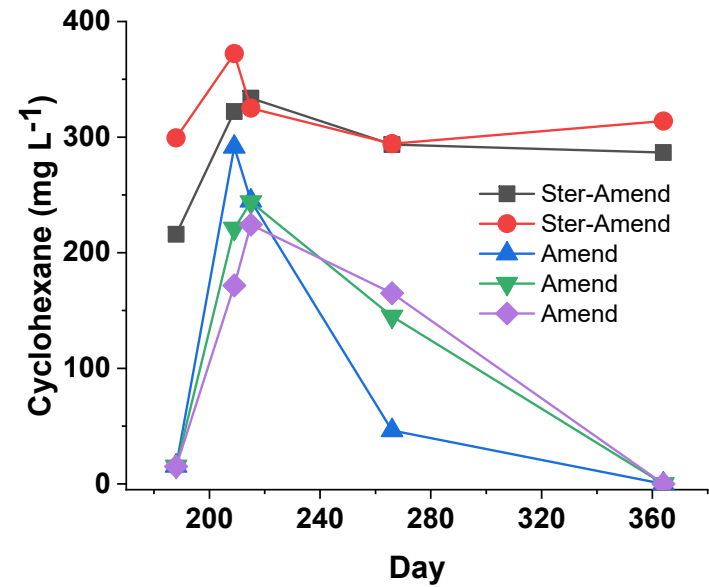
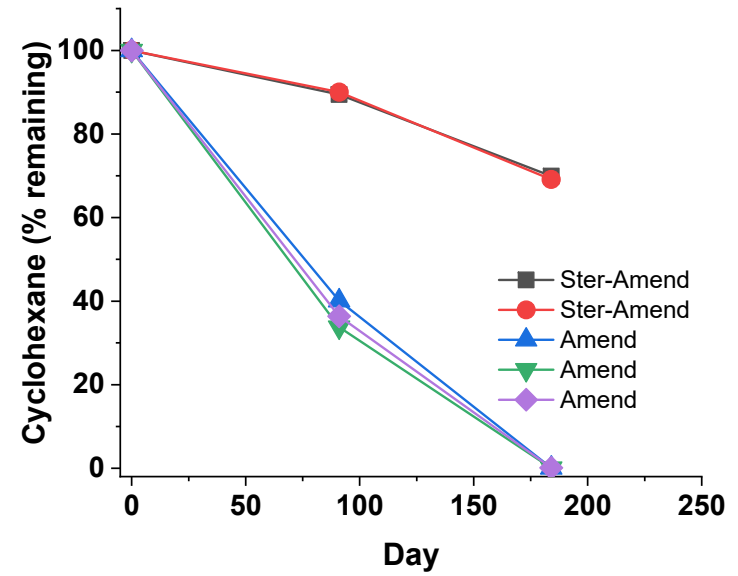
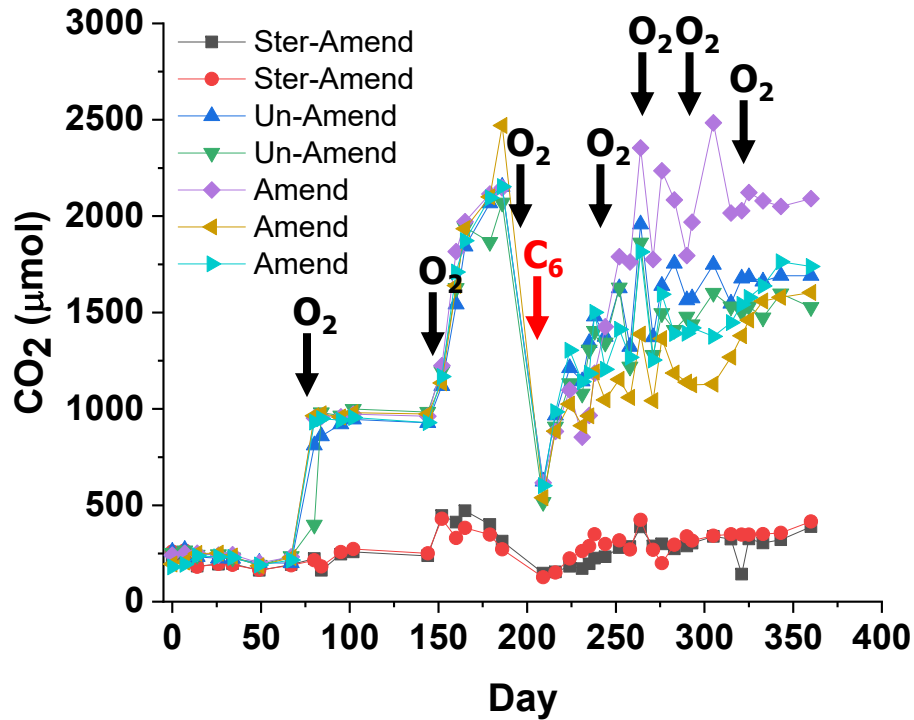
Biodegradation of cyclohexane in FFT under aerobic conditions

- Microcosms (160 mL) contain 35 mL FFT and 35 mL Bushnell-Haas medium
- Concentration of cyclohexane: 300 ppm
- Bottle headspace: sterile air or O₂

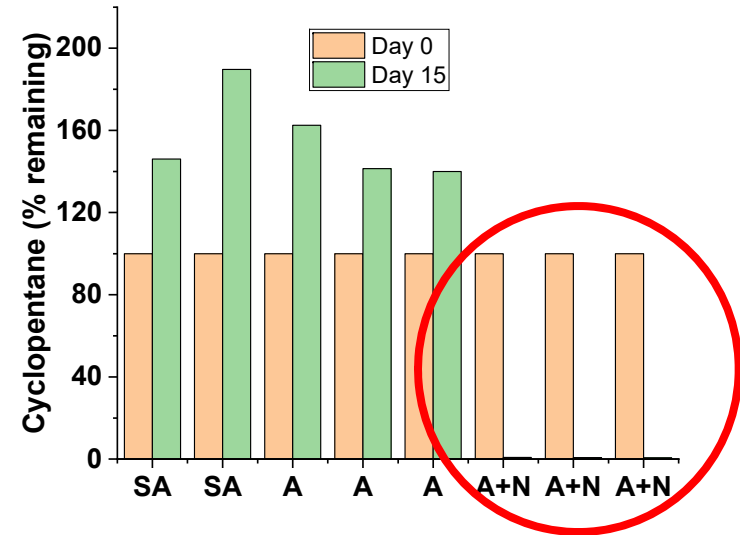
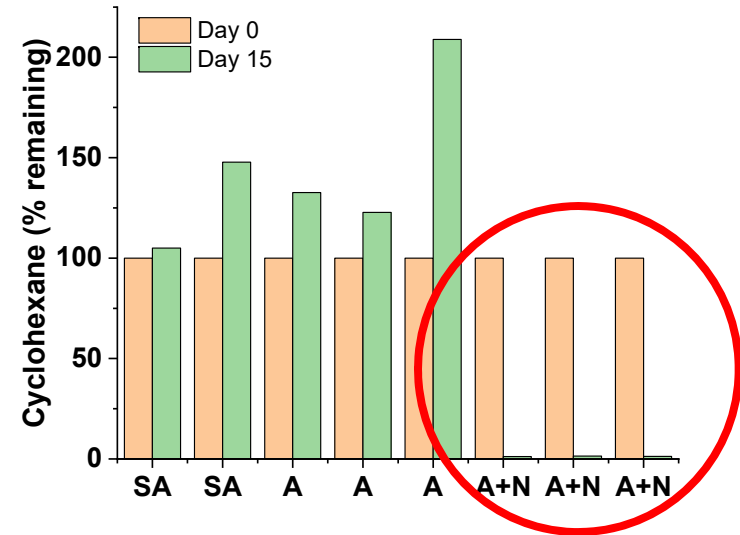
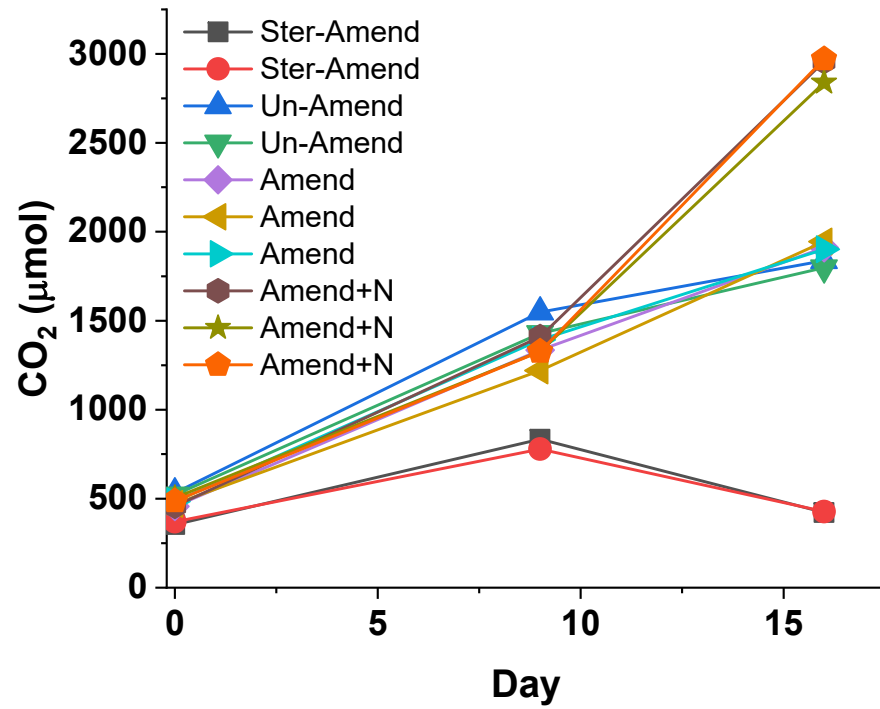
Biodegradation of cyclohexane in NAE solids under aerobic conditions

- Microcosms (500 mL) contain 75 g NAE solids, 75 mL FFT and 150 mL sterile water
- Concentration of cyclohexane and cyclopentane: 200 ppm each
- Nutrient treated bottles received sterile water with nitrogen and phosphorus at C:N:P ratio of 100:10:1
- Bottle headspace: sterile air or O₂

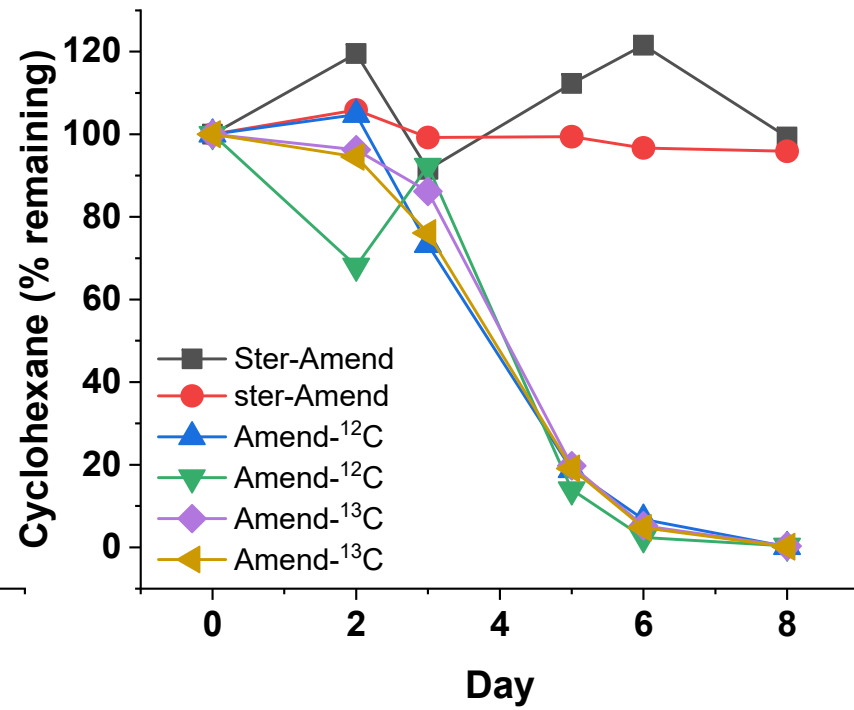
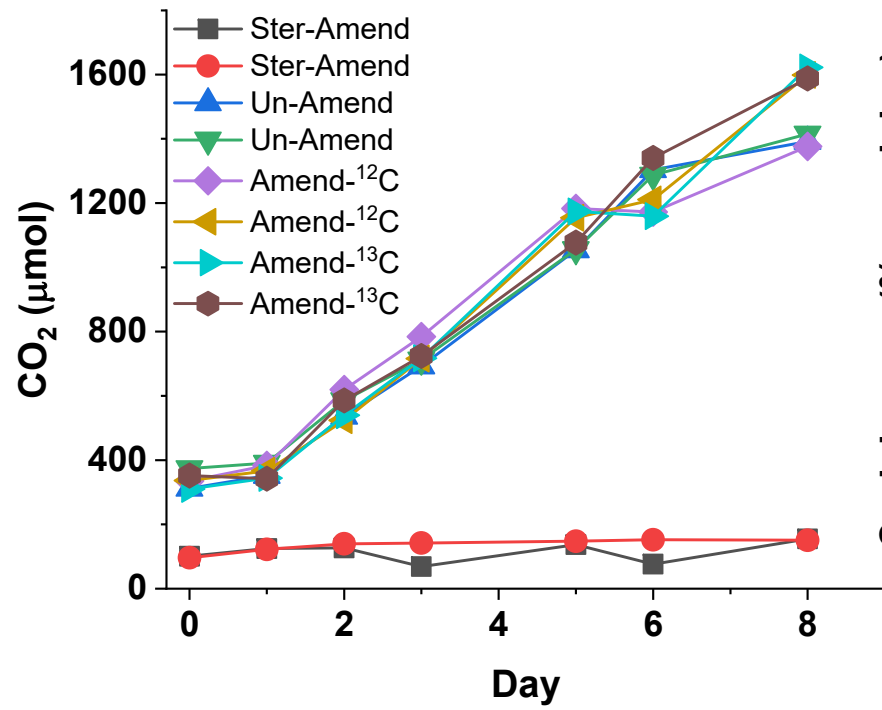
Biodegradation of cyclohexane in FFT



Biodegradation of cyclohexane and cyclopentane in non-aqueous extraction (NAE) solids



Biodegradation of cyclohexane in FFT for stable isotope probing



Experimental approach

Source of inoculum: OSPW



Biodegradation of cyclohexane in the presences of NH_4^+ under aerobic conditions

- Microcosms (160 mL) contain 50 mL sterile mineral salt medium (MSM)
- Cyclohexane: 300 ppm; NH_4^+ : 5mM
- Inoculum: OSPW cells collected at 0.22 μm filter added to microcosm
- Bottle headspace: sterile air + CO_2 (5%)
- Incubation: 37°C

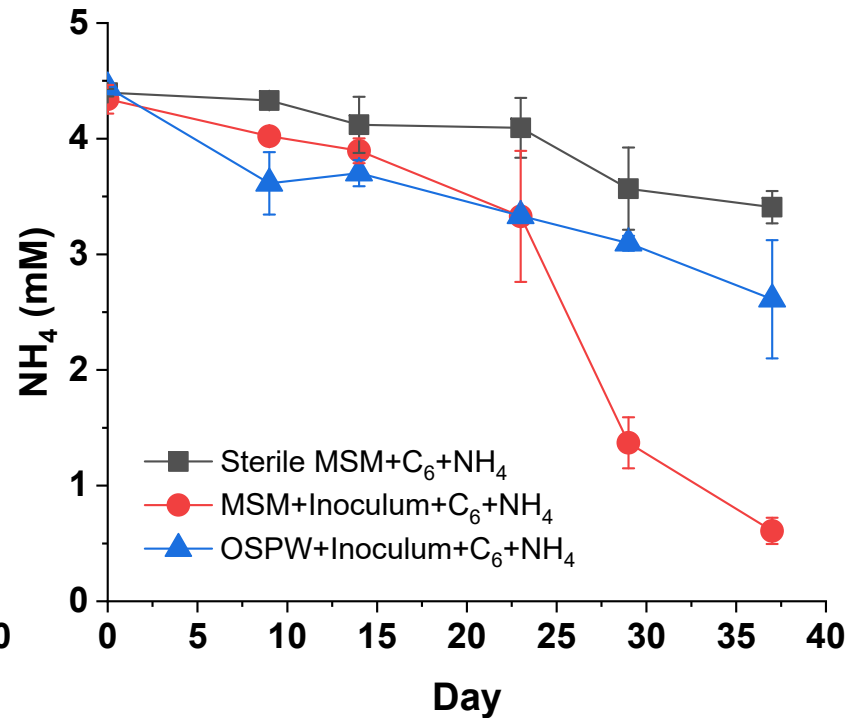
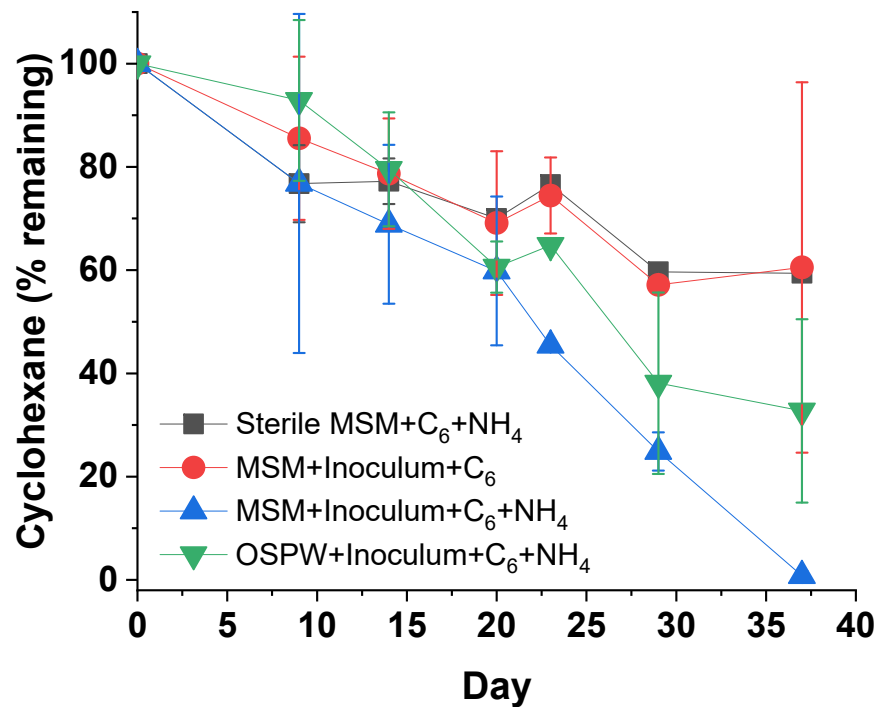
Biodegradation of cyclohexane in the presences of CH_4 under aerobic conditions

- Microcosms (160 mL) contain 50 mL sterile nitrate mineral salt medium (NSM)
- Cyclohexane: 300 ppm; CH_4 : 8-10% v/v
- Bottle headspace: sterile air + CO_2 (5%)
- Incubation: 25°C

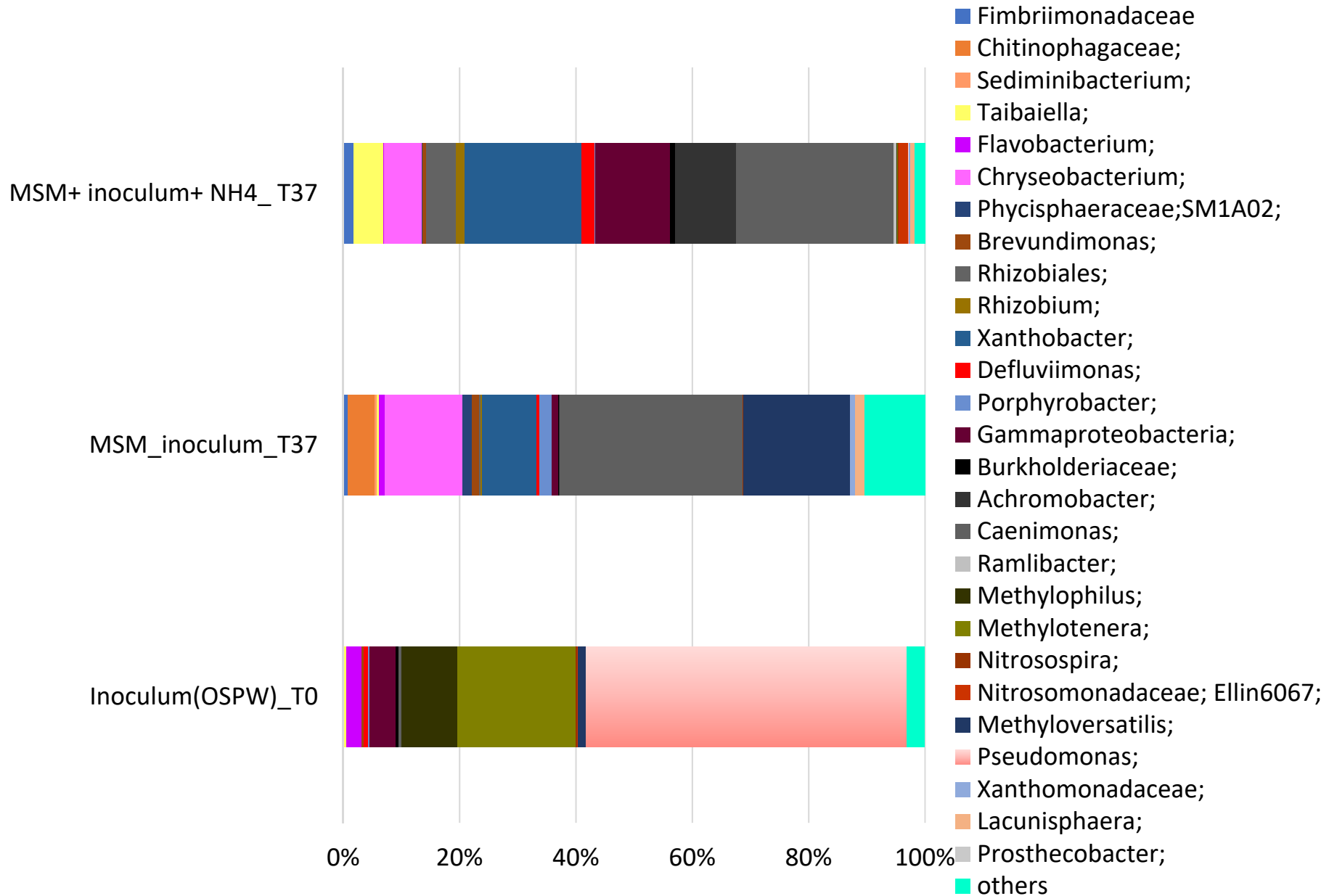
Biodegradation of cycloalkanes under methanogenic conditions

- Microcosms contain 50 mL sterile methanogenic medium and 50 mL FFT
- Cyclohexane, cyclopentane and *n*-heptane: 300 ppm each in different combinations
- Bottle headspace: N_2 (70%) + CO_2 (30%)
- Incubation: 25°C

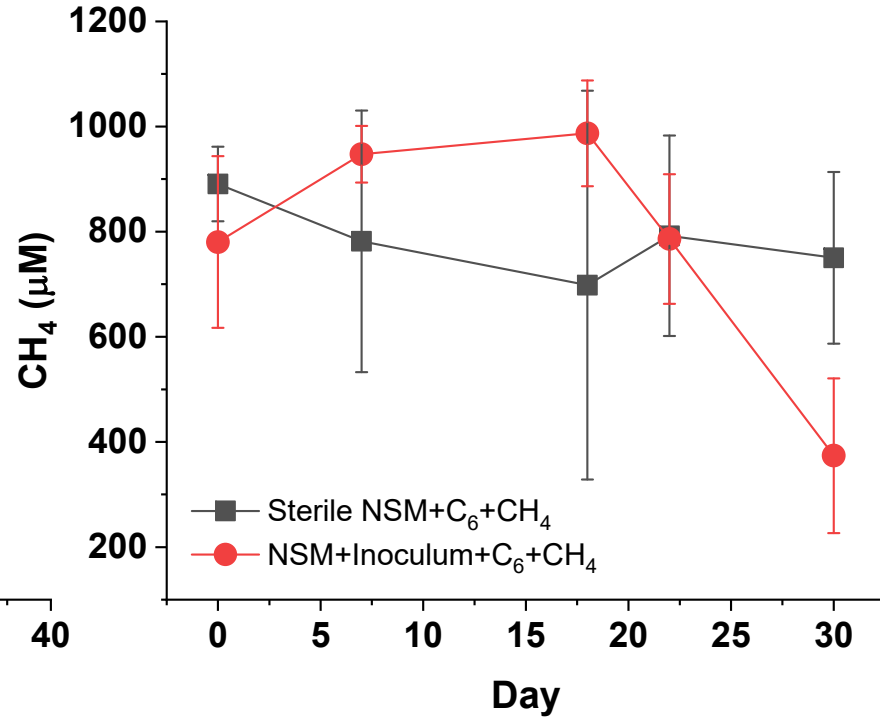
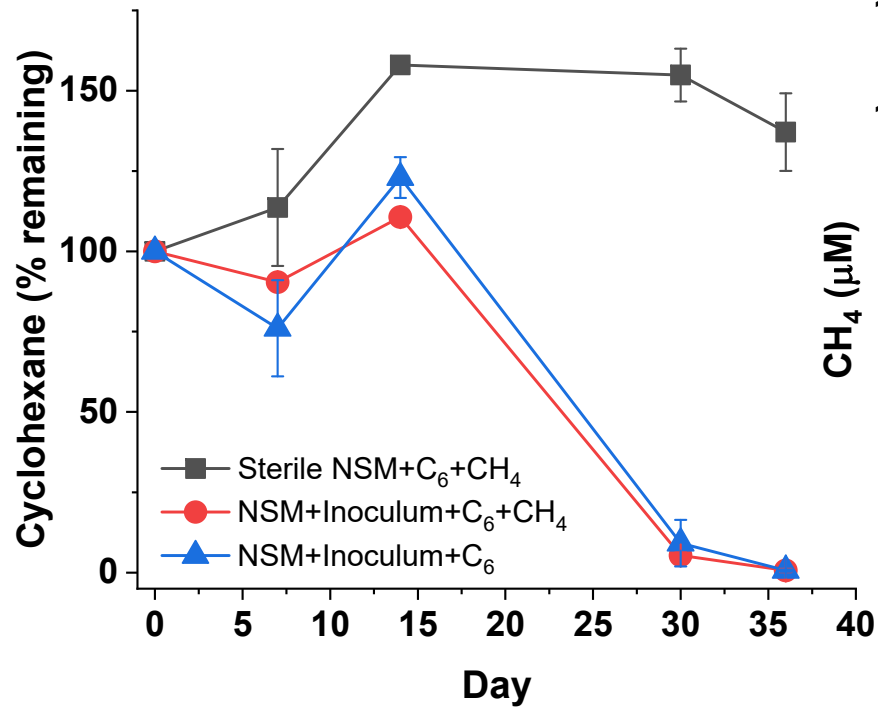
Cometabolic biodegradation of cyclohexane in the presence of NH_4^+



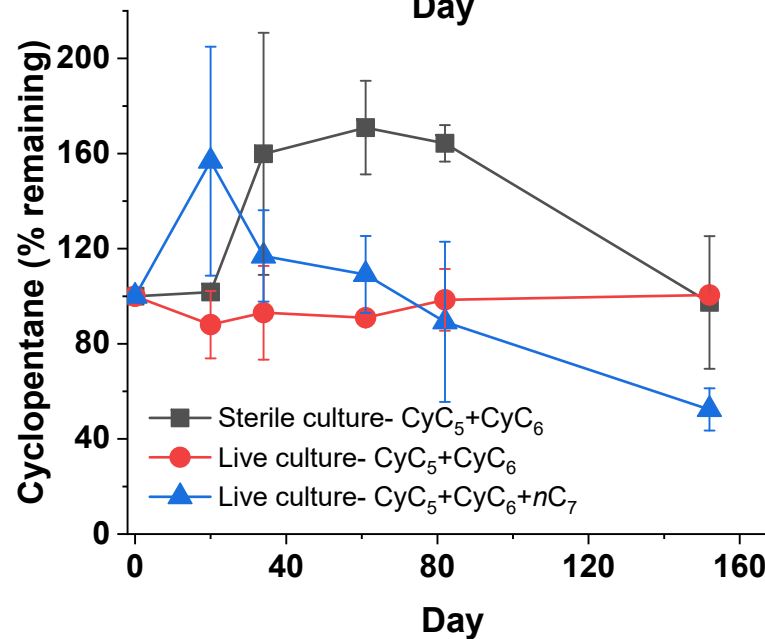
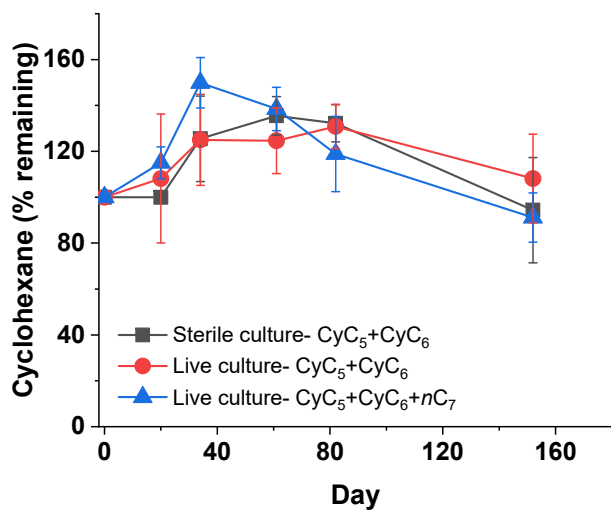
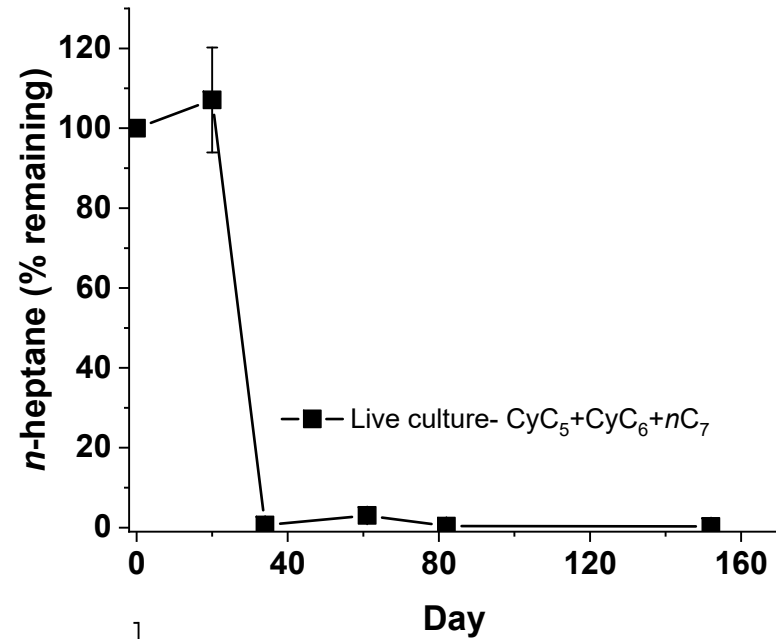
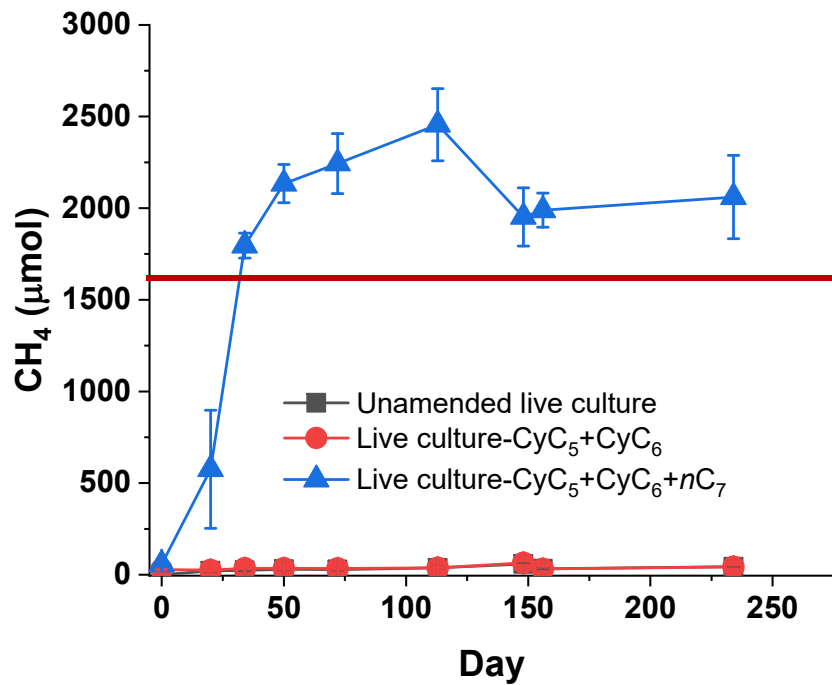
Microbial community



Cometabolic biodegradation of cyclohexane in the presence of CH₄



Biodegradation of cyclohexane in FFT under methanogenic conditions



Conclusions

- Cyclohexane and cyclopentane are biodegradable under aerobic condition
- Though Fluid Fine Tailings (FFT) contain anaerobic microbial community but when exposed to aerobic condition, they can biodegrade cycloalkanes
- Nutrients (nitrogen and phosphorus) are needed in the biodegradation process
- Indigenous microbes in oil sands process-affected water (OSPW) can also biodegrade cyclohexane but complete biodegradation is observed in the presence of NH_4^+ and CH_4 suggesting cometabolic biodegradation
- Cyclopentane is partially biodegradable under methanogenic conditions in the presence of labile *n*-heptane
- The results are important in the development of field-scale technology for cycloalkane-impregnated dry tailings

Acknowledgements



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