Cyprus University of Technology

Department of Chemical Engineering

Environmental Bioprocessing Laboratory

Application of Ozonation and Bioremediation for Integrated Treatment and Valorization of Drilling Waste: Technology Development and Monitoring of Microbial Dynamics

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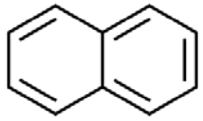
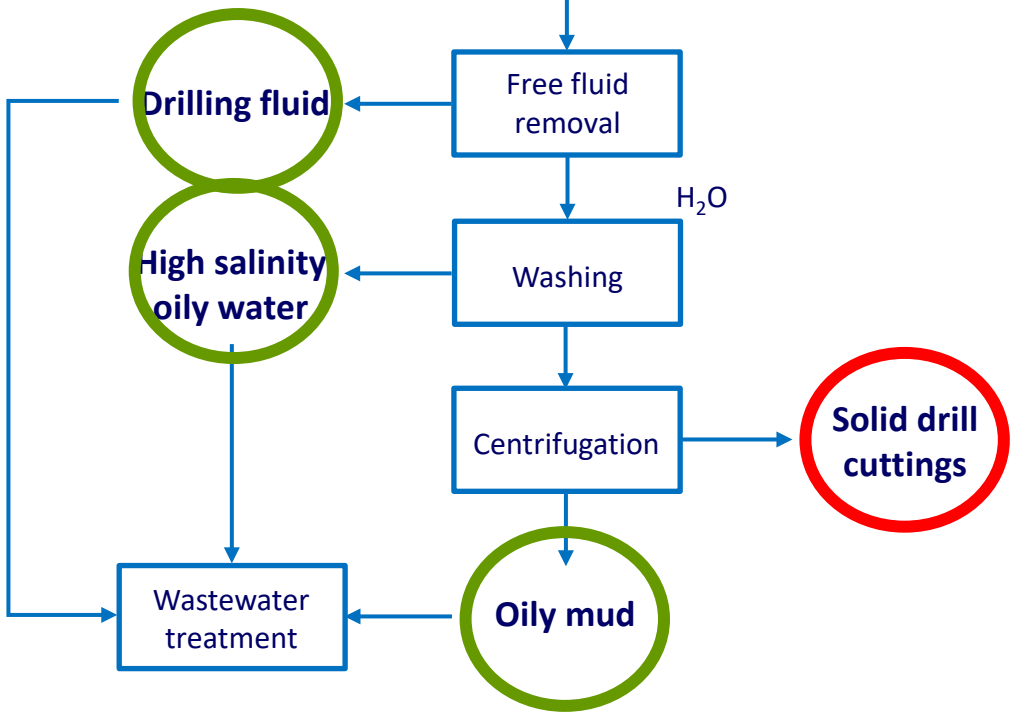
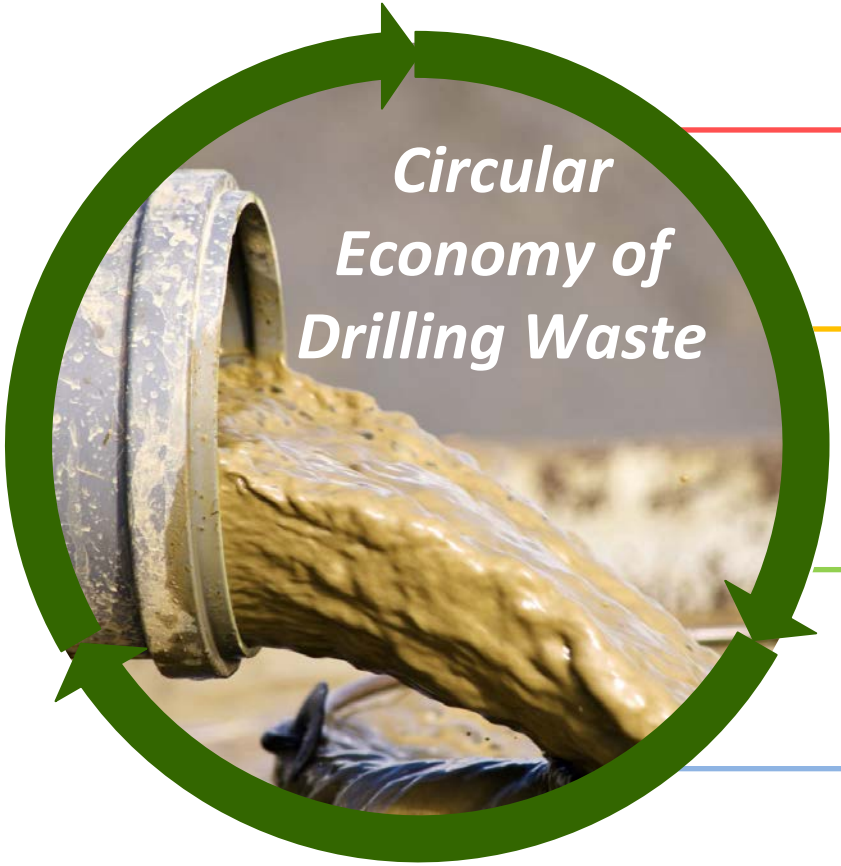
Drilling Waste: Need for Environmental Friendly Methods

- Drilling waste: **25×10^6 m^3 y^{-1}**
- O&G wastewater discharges: **14.5×10^9 m^3 y^{-1}**
- Drilling fluid: **11000-19000 m^3** per drill hole
- Toxic & persistent pollutants (**TPH**, **PAH**)

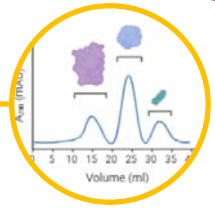




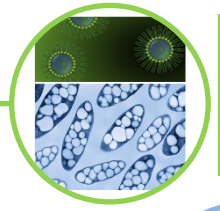
Biodegradation & Valorisation of Drilling Waste



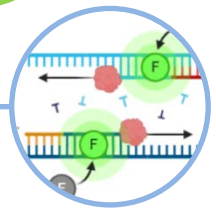
Drilling waste detoxification
1) Microbial isolation
2) Culture conditions
3) Drilling wastewater and oily mud biotreatment



Bioprocess analysis
1) COD, TPH and PAH biodegradation
2) Biosurfactant and PHA quantification and properties
3) Gene expression by qPCR

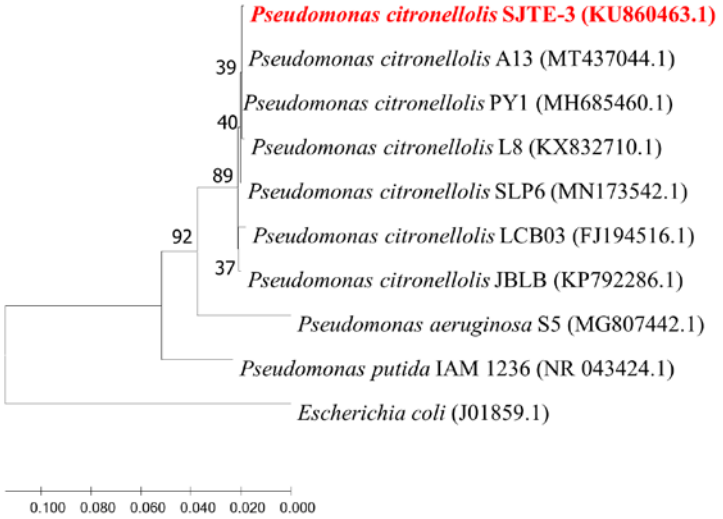


Valorization of drilling waste
1) Biosurfactant production
2) PHA production

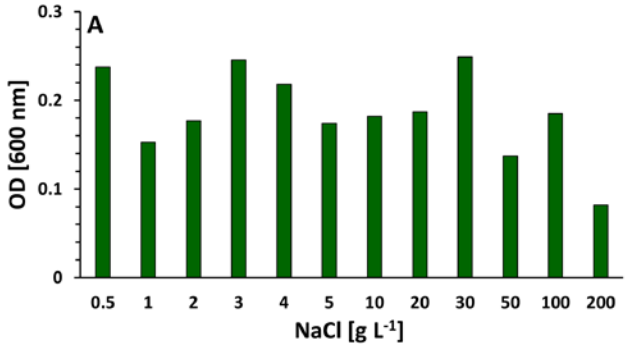


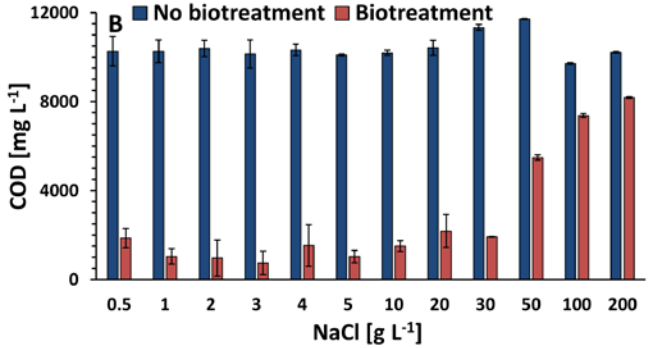
Gene transcription monitoring
1) Stimulation of TPH and PAH biodegradation pathways
2) Stimulation of biosurfactant and bioplastic bioproduction pathways
3) Insights into the metabolic basis of the bioprocess

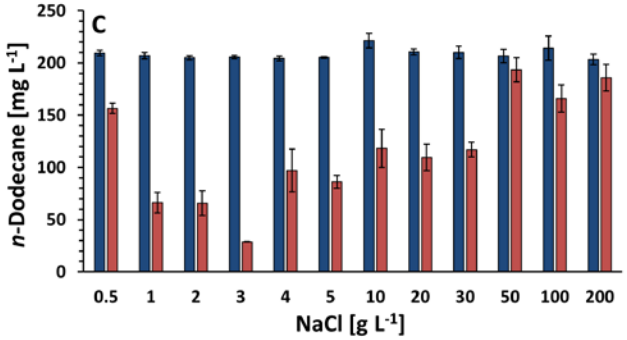
Drilling WasteWater Biodegradation

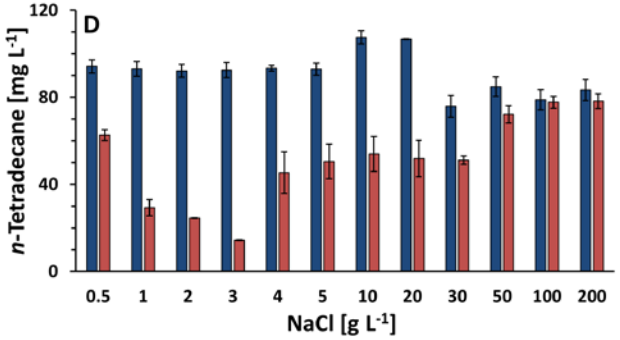


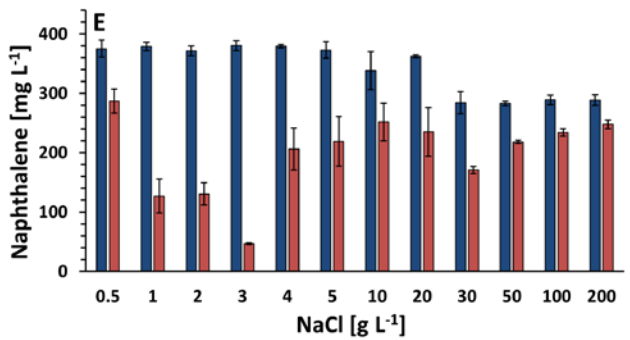
- Hydrocarbon contaminated **hypersaline** wastewater
- 0.5-200 g L^{-1} NaCl, 1% (v/v) DF, 60 h incubation
- 79-93% COD removal for 0.5-30 g L^{-1} NaCl
- 3 g L^{-1} NaCl: 177 mg L^{-1} ***n*-dodecane**, 79 mg L^{-1} ***n*-tetradecane** & 333 mg L^{-1} **naphthalene biodegradation**











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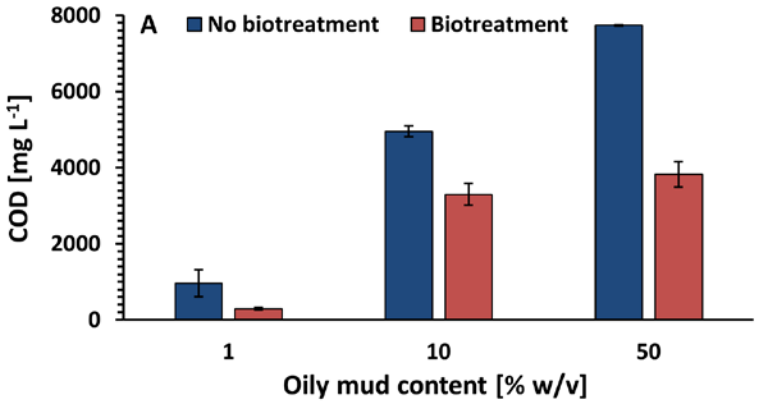
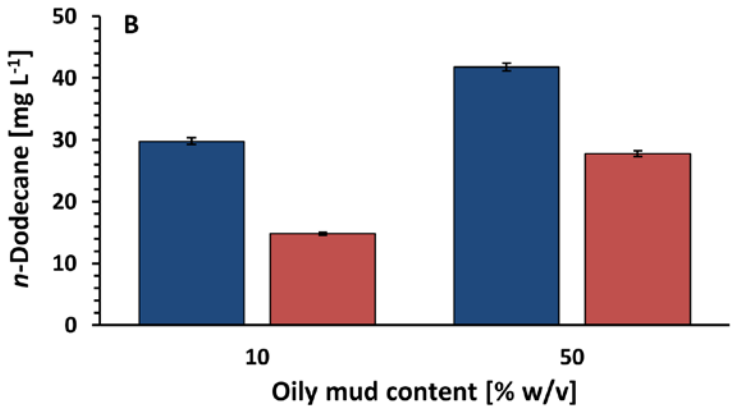
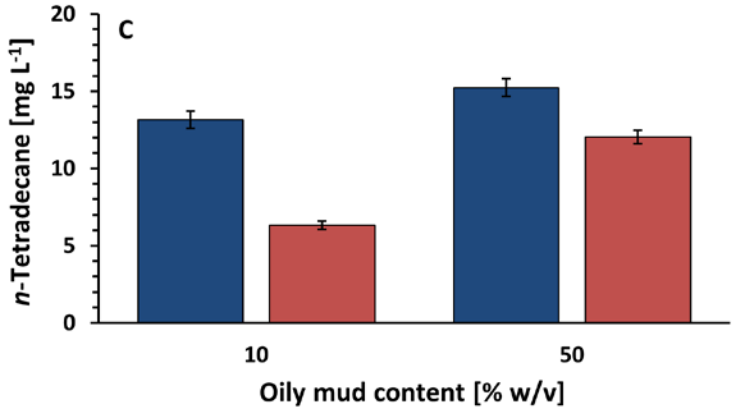
Oily Mud Biodegradation

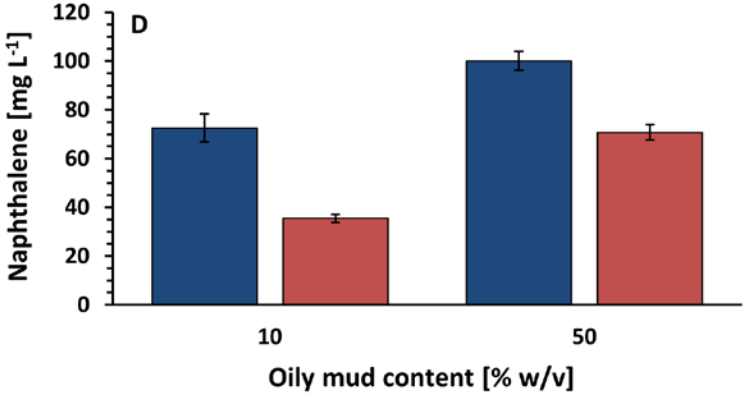
- 28 °C, pH 7, 3 g L^{-1} NaCl, 96 h incubation
- 71% COD removal using 1% (w/v) oily mud
- 51% COD removal using 50% (w/v) oily mud

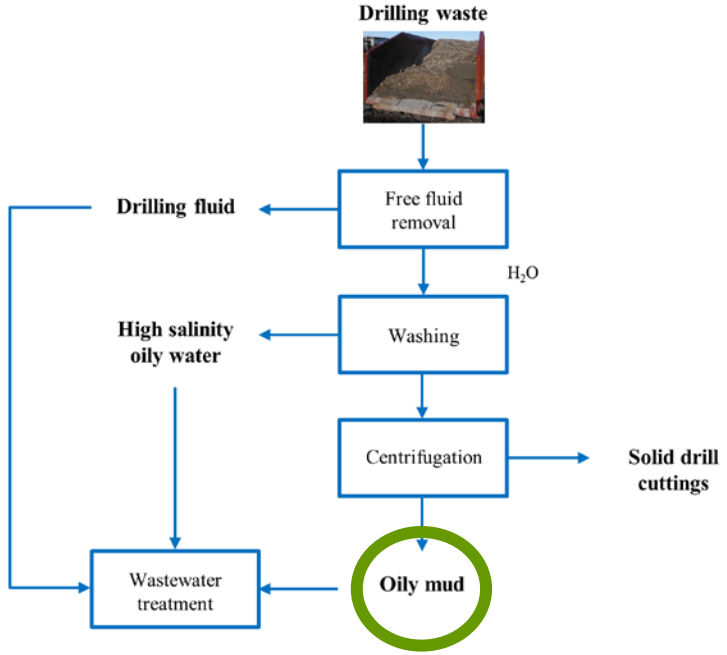
- 14-15 mg L^{-1} ***n*-dodecane**, 3-7 mg L^{-1} ***n*-tetradecane** & 29-37 mg L^{-1} **naphthalene biodegradation**
- 10% and 50% (w/v) oily mud is **difficult to treat** and requires optimisation







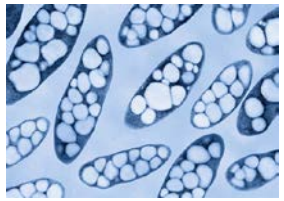




Drilling WasteWater Valorisation

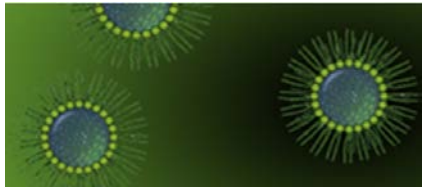
Experimental conditions	Methyl decanoate (% of DCW)	Methyl myristate (% of DCW)
30 °C, pH 7, 0.5 g L^{-1} NaCl	**17.9**	**6.1**
30 °C, pH 7, 1 g L^{-1} NaCl	13.9	3.9
30 °C, pH 7, 2 g L^{-1} NaCl	11.9	2.8
30 °C, pH 7, 3 g L^{-1} NaCl	11.8	4.1
30 °C, pH 7, 4 g L^{-1} NaCl	5.6	5.2
30 °C, pH 7, 5 g L^{-1} NaCl	5.3	4.9
30 °C, pH 7, 10 g L^{-1} NaCl	4.2	3.9
30 °C, pH 7, 20 g L^{-1} NaCl	5.0	4.6
28 °C, pH 7, 3 g L^{-1} NaCl	12.8	7.4
37 °C, pH 7, 3 g L^{-1} NaCl	8.0	4.3
28 °C, pH 6, 3 g L^{-1} NaCl	7.1	2.8

Medium-chain-length PHA



- 1% DF at different conditions
- **24% of DCW**
- Low salinity levels
- SJTE-3 converts DF into similar quantities of the promising biodegradable thermoelastomer to other studies **without additional strategy for hydrocarbons solubilisation** (e.g. surfactants, solvent)

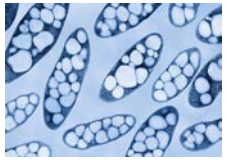
Biosurfactant



- **53%** water surface tension reduction
- **43.3%** emulsification index (E24)

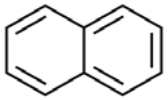
Expression from Biosynthetic & Biodegradation Routes

- Transcription of ***Pseudomonas* spp metabolic pathways** monitored at different time points during biodegradation of **1% (v/v) DF**
- ***phaG*** gene, putatively involved in the biosynthesis of **medium-chain-length PHA**



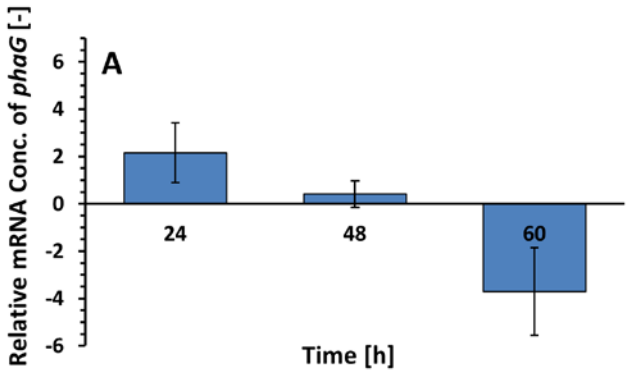
- ***arfB***, ***amsY***, ***psoA*** and ***rhlB*** genes associated to **arthrofactin**, **amphisin**, **putisolvin** and **rhamnolipid**

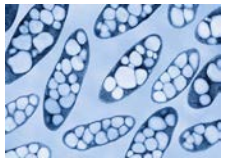
- ***ndoB*** gene encodes for naphthalene dioxygenase driving **naphthalene** biodegradation



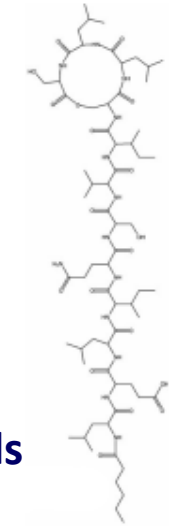
- ***alkB*** gene constitutes universal marker for **oil biodegradation**

Expression from Biosynthetic & Biodegradation Routes

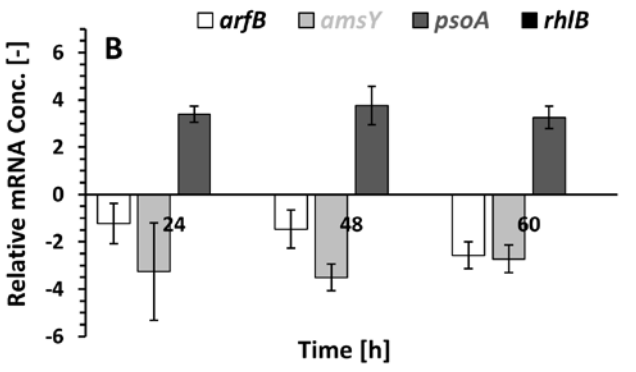


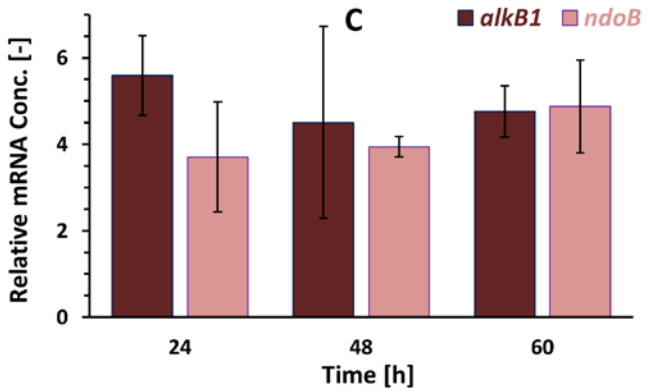


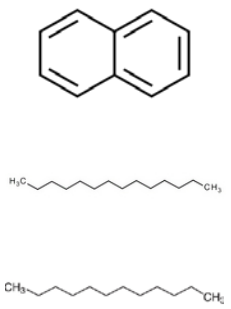
- **PHA** synthesis triggered during **exponential growth**



- ***rhlB*** mRNA was **not detected**
- ***arfB*** and ***amsY*** were **not expressed**
- ***psoA*** transcription remained at **high levels**
- *P. citronellolis* could potentially produce **putisolvin**







- ***alkB1*** and ***ndoB*** **highly induced** at all times

Hybrid Ozone-Bioprocess for Drill Cuttings Valorisation

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Drilling waste

Free fluid removal

Drilling fluid

H_2O

Washing

High salinity oily water

Centrifugation

Solid drill cuttings

Wastewater treatment

Oily mud

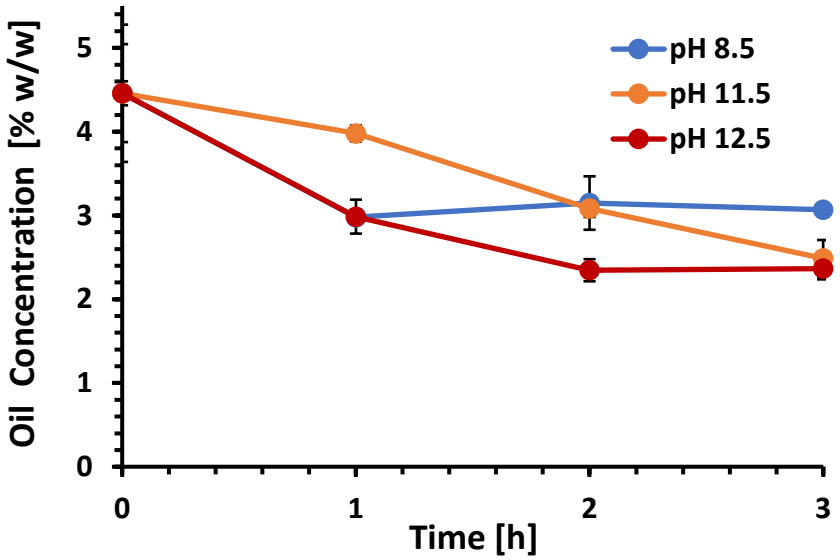
Ozonation

Bioremediation

Tree prunings
Activated sludge

Compost

Ozonation & Bioremediation as Single Drill Cuttings Treatments



- Untreated DC: pH 8.5 and 40% (w/w) moisture
- 150 Kg DC
- Faster kinetics in **pH 12.5 (47.3% removal)**
- 44.2% removal in pH 11.5
- Additional moisture inhibited the process

	Oil Concentration [% w/w]	
	7 d	110 d
Control (Composting only)	2.27	0.35
Ozonation + Composting	1.65	0.36
Ozonation + Composting + Biostimulation	1.74	0.27
Ozonation + Composting + Biostimulation + Bioaugmentation	1.79	0.21
Ozonation + Composting + Biostimulation + Bioaugmentation + Biochar	1.97	0.23

150 Kg DC

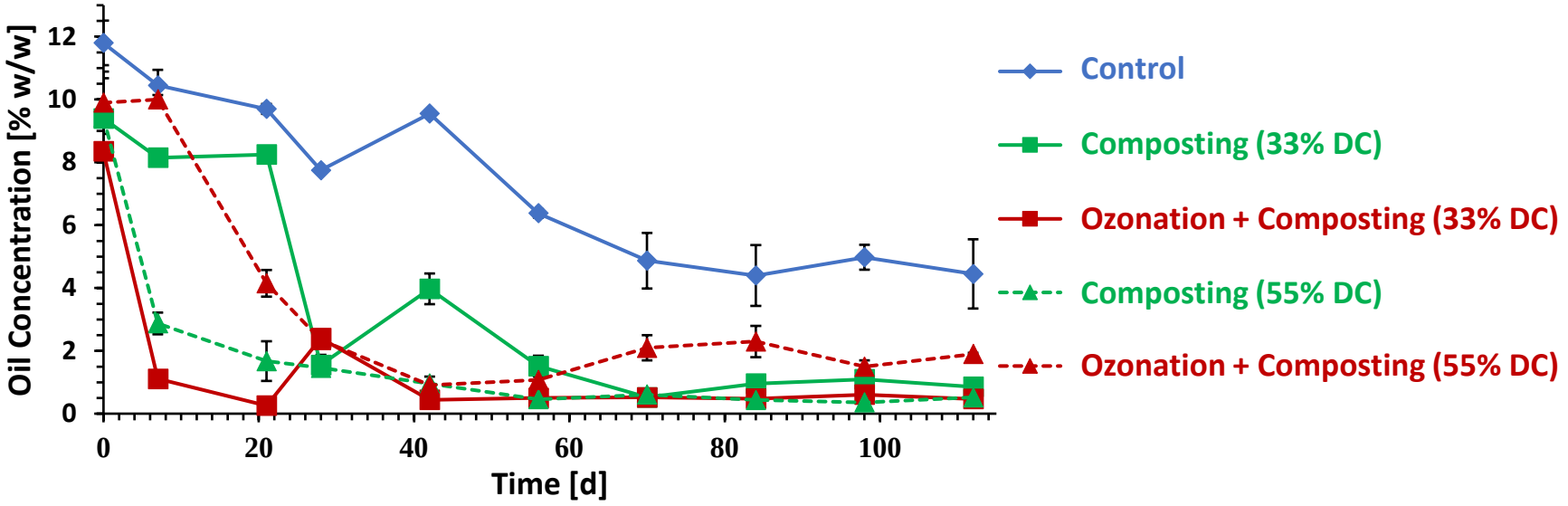
+

250 Kg Prunings

+

50 Kg Activated Sludge

Hybrid Ozone-Bioremediation for Drill Cuttings Valorisation



- **Ozonation vs no ozonation**
- 33% DC + 55% Prunings +12 AS
- **55% DC** + 44% Prunings +12 AS
- Ozonation + 33% DC fastest kinetics
- **0.3-0.6%** oil following 21 d
- 33% DC without ozonation: 0.6% oil at **70 d**
- 55% DC: reduced performance with ozonation
- Ozonation + 55% DC failed to reach 0.5% of oil
- 55% DC bioremediation performed 0.5% oil at **70 d**
- Increase of AS reduced performance of both systems

Microbial Dynamics and Use of Compost as End Product

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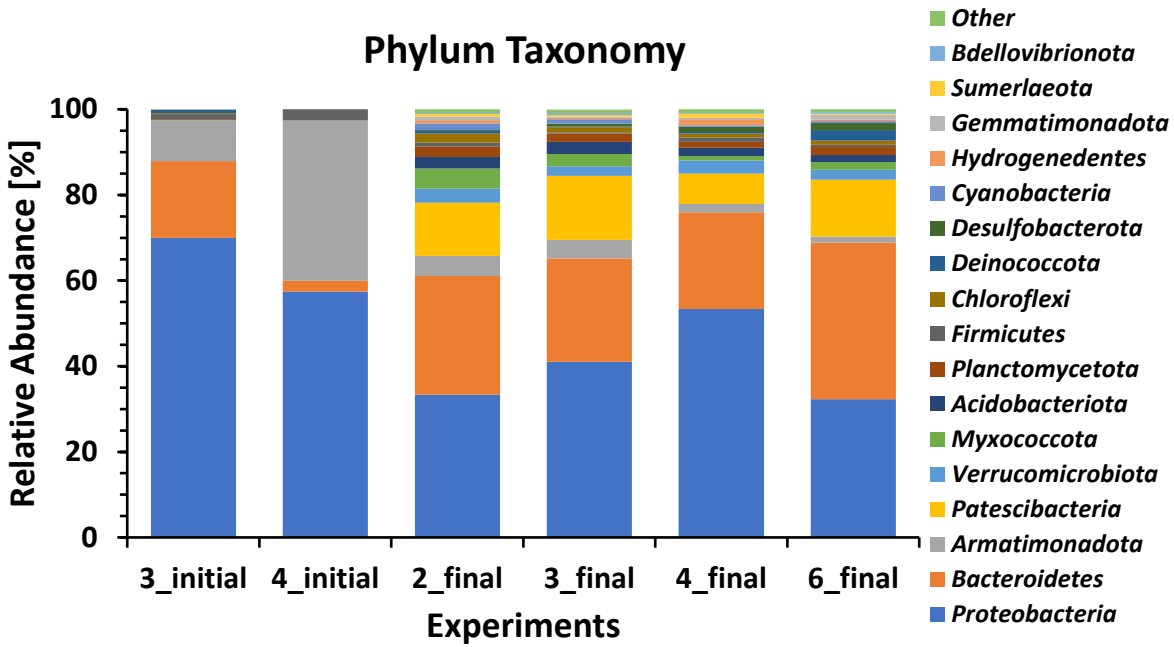
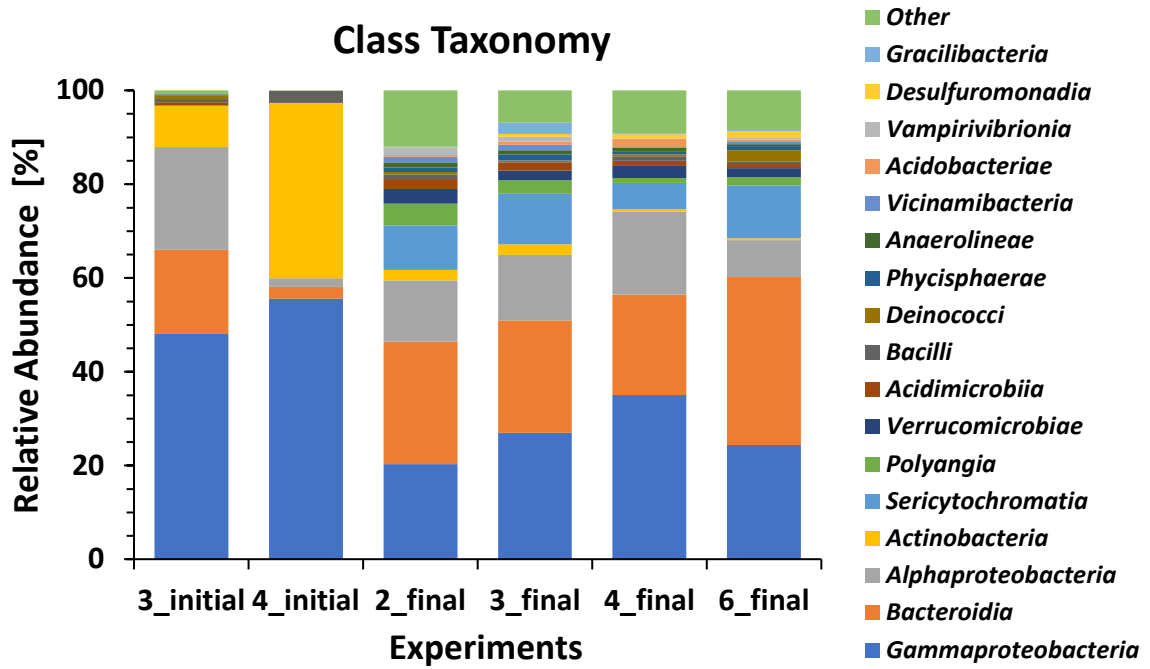
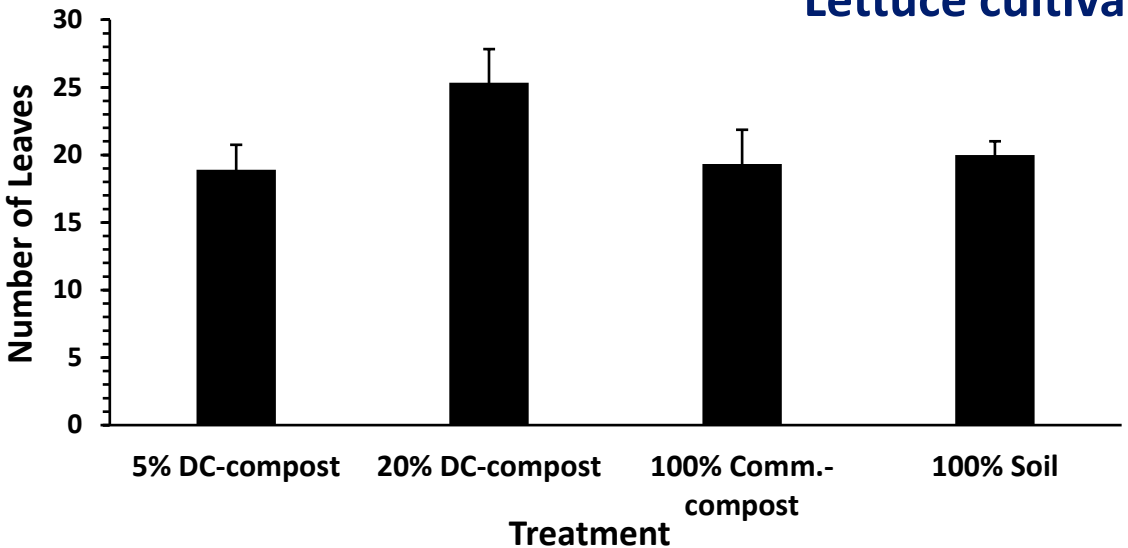
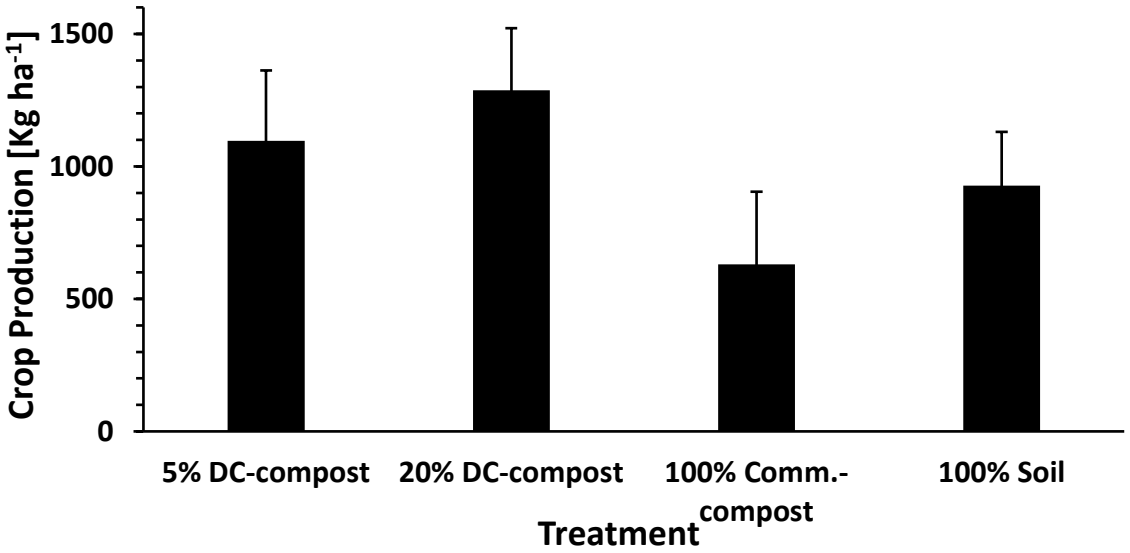




Lettuce cultivation





Profit and Loss for Each Treatment Approach

	Thermal - TCC	Hybrid Ozone-Bioprocess	Bioprocess Only
	(€)	(€)	(€)
SALES	2,280,960	2,160,000	1,296,000
COST OF SALES			
Raw materials	703,296	1,312,000	491,520
Labour	265,200	89,700	119,600
Manufacturing overhead	1,258,790	740,000	1,122,702
	2,227,286	2,141,700	1,733,822
Net annual (loss)/profit	53,674	18,300	(437,822)

- **47,520 t_{DC} yr^{-1}**, 10% oil and moisture, 24 h d^{-1} for 330 d
- Thermal desorption (Thermomechanical Cuttings Cleaner – TCC)
- 21 d of Ozone + Biotreatment (33% DC+55% Prunings+12% AS)
- 70 d Biotreatment Only (55% DC+33% Prunings+12% AS)

- TCC and hybrid treatments **exhibit profit**
- Biotreatment only: prolonged process duration
- Hybrid process: prunings transportation was a key cost parameter

Conclusions

- **Holistic approach** for sustainable drilling waste treatment
- *P. citronellolis* SJTE-3 enabled enhanced removal of **TPH** and **PAH** from DF
- **In situ** production of **bioplastics** and **biosurfactants**
- Activation of **putisolvin** biosynthetic pathway
- 47.3% oil removal via ozonation
- Similar microbial community composition in all treatments
- **Hybrid ozonation-bioremediation is cost-competitive**

Thank you!

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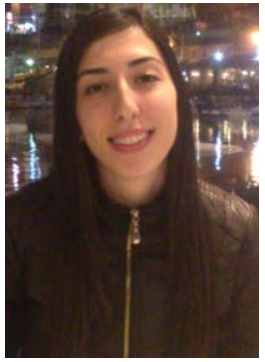
PhD Students



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Nikodemou A.

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