CENTA Project Proposal Form – 2024 entry

Project Title	Big problems need small molecules: A novel synergy of waste and microbiological innovations for creating sustainable chemical feedstocks
University (where student will register)	The Open University
Which institution will the student be based at?	As above
Theme (Max. 2 selections)	Climate & Environmental Sustainability ☒ Organisms & Ecosystems ☒ Dynamic Earth ☐
Key words	Bioremediation, Smouldering, Circular economy
Supervisory team (including institution & email address	**OU PI: Daniel Payne, Daniel.Payne@open.ac.uk** **OU Co-I: Michael Macey, Michael.Macey@open.ac.uk** **OU Co-I: Tarek Rashwan, Tarek.Rashwan@open.ac.uk** **CASE supervisor: Gavin Grant, ggrant@savronsolutions.com** **Jacobs supervisor: Siddharth Gupta, sgupt82@uwo.ca** **CEH supervisor: Susheel Bhanu Busi, susbus@ceh.ac.uk**
Is the PhD suitable for part time study?	Yes ☒ This is a requirement of NERC

Project Highlights:

- Integrating biological and thermochemical methods to reduce pollution and promote sustainable chemical feedstocks;
- An industrial placement with a world-leading environmental technology company;
- Training in state-of-the-art techniques across the fields of microbiology, chemistry, and environmental technology

Overview:

Over one billion people cannot access safe drinking water. Even a robust treatment network – like used in the UK – cannot adequately protect water resources, as a recent 2022 UK parliament report revealed that not a single river in England met good chemical status. Wastewater sources are littered with hazardous organic contaminants such as hydrocarbons, detergents, and personal care products. At the same time, small organic molecules – such as ethane, ethanol, acetone, and formaldehyde – are critical building blocks needed in chemical industries worldwide. Currently 85% of these compounds are derived from petroleum. Potential treatments for these organic contaminants may be tuned to also produce chemical feedstocks. Wastewater sources may therefore be used as a more sustainable sources of small organic molecules. However, it is often technically challenging or cost prohibitive to both treat hazardous contaminants and generate valuable small organic molecules.

Breakthrough multidisciplinary innovations are needed to achieve improved environmental sustainability and carbon neutrality within a safe, circular economy.

This project proposes to leverage emerging chemistry, microbiology, and environmental technology research at The Open University to economically treat wastewater and generate small organic molecules. Applied smouldering combustion has been shown as a novel method to economically treat

high moisture content wastewater sludge into high fractions of carbon monoxide. At the same time, breakthrough microbiology research has shown that, while high carbon monoxide concentrations are typically bactericidal, various types of extremophiles may be able to thrive in this environment, break down organic contaminants, and generate useful small organic molecules. Therefore, these research discoveries can be leveraged in a novel, sustainable wastewater treatment strategy that addresses the critical environmental challenge of pollution (Figure 1). However, there are many key knowledge gaps in combining the environmental technology innovations towards producing small organic molecules. This project will focus on developing our understanding of the key chemical and microbial processes that govern these transformations. The project will involve: (*i*) tracking the chemical inputs and outputs in all processes, (*ii*) identifying microbes that best reduce the contaminant concentrations and promote small organic molecule production, and (*iii*) exploring how smouldering emissions may support or hinder these microbes.

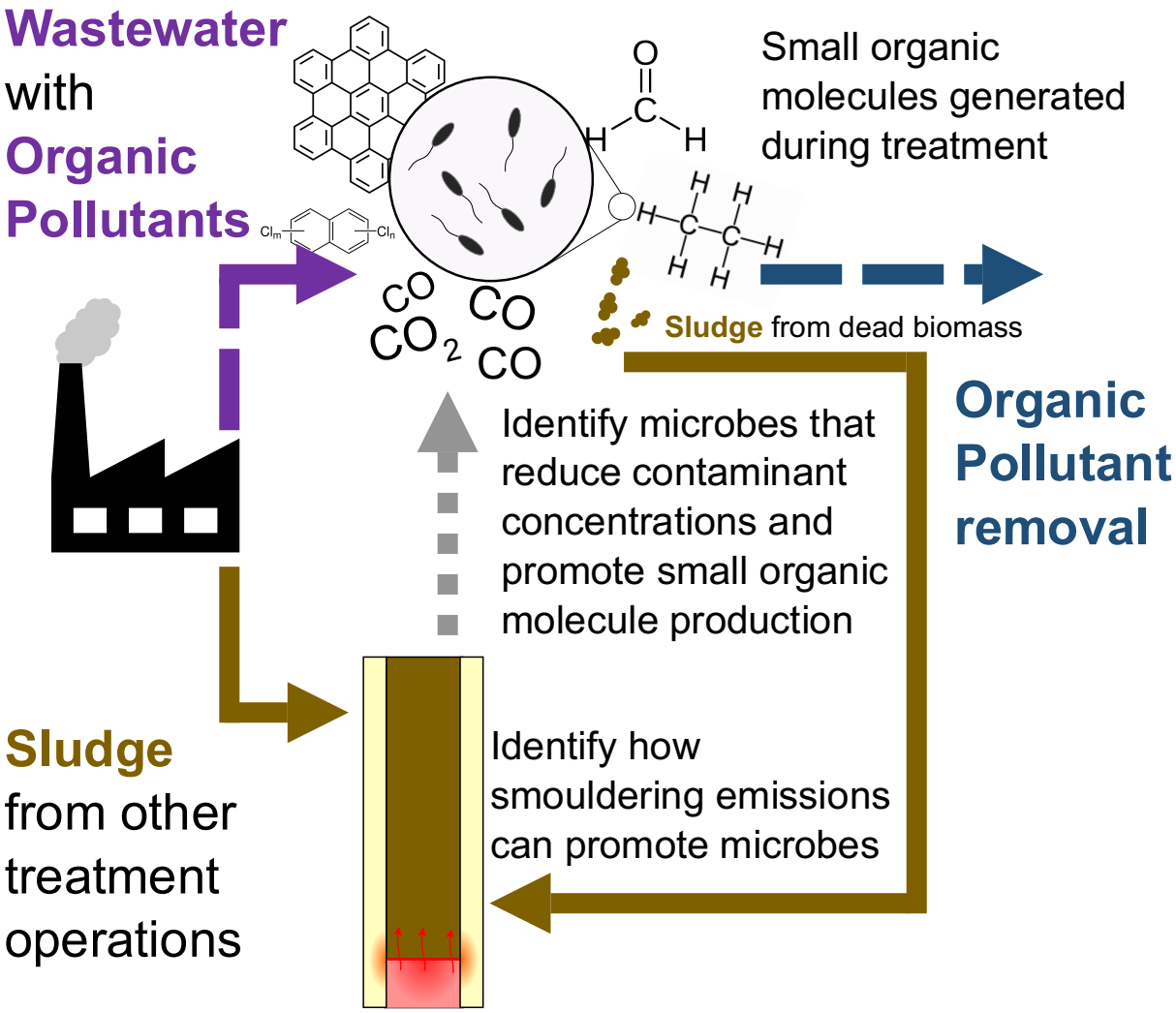

Figure 1: A process flow diagram detailing the key experimental approaches of this research project.

Alt text A process flow diagram showing the combination of environmental technologies proposed in this research project. The diagram details how the emissions from waste smouldering can support microbial-based organic contaminant treatment and small organic molecule generation.

Methodology:

A combination of chemistry, microbiological, and smouldering techniques will be applied to investigate the pathways to treat wastewater and generate small organic molecules. Standard smouldering experiments will be performed to capture emissions needed for the microbiological investigations. The microbiology experiments will identify and isolate keystones species in the community (e.g., smouldering-gas utilisers, contaminant degraders, and small organic molecule producers). Detailed analytical chemical techniques – such as GC-MS, HPLC-MS, in-situ IR, and flow photospectroscopies – will be used to track the fate of organic contaminants and the identification and quantification of generated small organic molecules. The student will have access to a range of additional techniques at the partner organisations that can be used to identify microbial interactions.

Training and skills:

Students will be awarded CENTA2 Training Credits (CTCs) for participation in CENTA2-provided and 'free choice' external training. One CTC equates to 1⁄2 day session and students must accrue 100 CTCs across the three years of their PhD.

The student will be trained in specific laboratory-based techniques in organic chemistry characterisation, molecular biology (e.g., DNA extraction, PCR, library preparation, and DNA sequencing), applied smouldering, analytical geochemistry, and culture-based microbiology by members of the research team. A placement with Savron will enable participation in research and deployment of novel environmental technologies worldwide. The student will also be trained in computer-based techniques, including bioinformatic analysis of sequencing data and smouldering data analysis. The student will benefit from additional skills development opportunities offered by The Open University, e.g., communication skills, time management, and academic writing.

Partners and collaboration (including CASE):

Name of L1/L2 Partner (where applicable)	Jacobs CEH
Name of CASE partner (where applicable – project proposal **must** be accompanied by a letter of support from the CASE partner)	Savron

Further information on partners and collaboration (including CASE):

Gavin Grant (Savron) is an environmental technology expert, specialising in hazardous materials treatment. Savron employs smouldering technologies to eliminate environmental liabilities. The research project and placement will expose the student to cutting edge remediation environmental technology development.

Susheel Bhanu Busi (CEH) has expertise in microbial ecology, cell fluorimetry and metagenomic analysis.

Siddhartha Gupta (Jacobs) is an expert in wastewater treatment and will provide insight into the industries appropriate for these innovations. Dr Gupta will also provide interpretation of the results, and guidance on appropriate pathways towards application.

Possible timeline:

Year 1: Perform a literature review of key processes. Complete training in chemical methods, molecular techniques, bioinformatics, applied smouldering, and statistical analysis of large-scale datasets. Undertake preliminary field work collecting wastewater and sludge samples and performing initial chemical surveys of organic contamination. Set up enrichments for bioremediation with smouldering waste gases.

Year 2: Undertake placement with the CASE partner. Conduct smouldering experiments to generate emissions needed and perform metagenomic analysis of the enriched samples to identify keystone species and chemical end-products. Present in-progress results at a national conference (e.g., Microbiology Society annual conference).

Year 3: Refine all experimental activities towards preparing and submitting a manuscript. Present data at an international conference (e.g., Gordon Applied and Environmental Microbiology). Write and submit thesis.

This project will benefit from access to various key research infrastructure from The Open University, including: (*i*) existing metagenomic datasets from wastewater treatment experiments, (*ii*) a robust array of relevant analytical chemistry equipment, (*iii*) purpose-built smouldering equipment, and (*iv*) a decade's worth of experimental smouldering data and in-house numerical modelling capabilities. This access to key experimental and digital research infrastructure bolsters project resiliency, as research work can be initiated rapidly. Moreover, in the instance of any potential restrictions to fieldwork or laboratory access, the supervisory team has multiple contingency strategies to progress the student's progress via the extensive virtual tools available.

Further reading:

García, J. L., & Galán, B. 2022. Integrating greenhouse gas capture and C1 biotechnology: a key challenge for circular economy. *Microbial Biotechnology*, 15, 1, 228–239.

Macey, M. C., Fox-Powell, M., Ramkissoon, N. K., Stephens, B. P., Barton, T., Schwenzer, S. P., Pearson, V. K., Cousins, C. R., & Olsson-Francis, K. (2020). The identification of sulfide oxidation as a potential metabolism driving primary production on late Noachian Mars. *Scientific Reports*, 10(1).

Macey, M. C., Pratscher, J., Crombie, A. T., & Murrell, J. C. (2020). Impact of plants on the diversity and activity of methylotrophs in soil. *Microbiome*, 8(1).

Rashwan, T. L., Fournie, T., Torero, J. L., Grant, G. P. & Gerhard, J. I. 2021. Scaling up self-sustained smouldering of sewage sludge for waste-to-energy. *Waste Management,* 135**,** 298-308.

Robb, F. T., & Techtmann, S. M. 2018. Life on the fringe: Microbial adaptation to growth on carbon monoxide. *F1000Research*, 7

Sorokin, D. Y., Merkel, A. Y., Messina, E., Tugui, C., Pabst, M., Golyshin, P. N., & Yakimov, M. M. 2022. Anaerobic carboxydotrophy in sulfur-respiring haloarchaea from hypersaline lakes. ISME Journal, 16, 6, 1534–1546.

Torero, J. L., Gerhard, J. I., Martins, M. F., Zanoni, M. a. B., Rashwan, T. L. & Brown, J. K. 2020. Processes defining smouldering combustion: Integrated review and synthesis. *Progress in Energy and Combustion Science,* 81**,** 100869.

Further details:

For additional details please the following profile pages:

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Michael Macey: https://www.open.ac.uk/people/mm34528

Tarek Rashwan: https://www.open.ac.uk/people/tr829

OU Astrobiology: https://www5.open.ac.uk/research-groups/astrobiology/