GeoNetZero Centre for Doctoral Training (CDT):
Geoscience and its Role in the Low Carbon Energy Transition
(2022 start)

Project Title: *Experimental and modelling appraisal of underground hydrogen storage: anything but a 'Rough' future!*

Host institution: Durham University	
Supervisor 1: Stuart Jones	
Supervisor 2: Julia Knapp	
Supervisor 3: Jon Gluyas	
Supervisor 4: Jeroen Van Hunen	

Project description (250 words max.):

Large-scale underground hydrogen storage (UHS) can potentially balance seasonal fluctuations in energy production from renewable energies (e.g., wind and solar), hydrogen can be stored in depleted oil and gas reservoirs, in salt caverns, and in aquifers but practical experience of UHS is still lacking. Challenges are concerned with the interaction of microbial communities and hydrogen in subsurface rocks. As microbial population density increases in subsurface formations, microbially formed biofilms and associated mineral precipitation can lead to pore clogging and therefore a reduction of hydrogen injectivity. Loss of injectivity or a reduction in flow rates due to biological activity is commonly encountered in geothermal applications and CO_2 storage and has recently been demonstrated by Charlaftis *et al.* (2021). Additionally, microbes using hydrogen as energy source will result in a loss of hydrogen and thus reduce the yield of UHS. The extent of this problem is currently unknown.

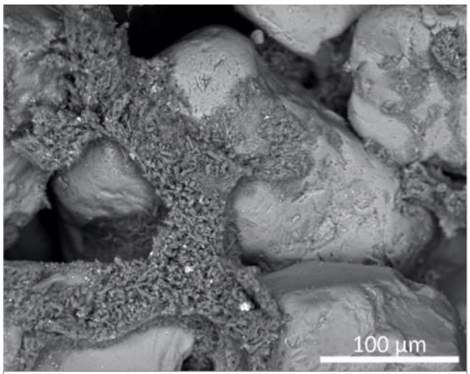


Fig.1: Biofilms grown on quartz grains and hydrothermally reacted at reservoir conditions. Authigenic clay minerals have precipitated using biofilms as templates.

This project will investigate the potential and interactions of hydrogen with naturally occurring mineral assemblages and microbial activity, specifically focusing on the occurrence of biofilms in sands and sandstones (Fig.1). The project will take a multidisciplinary approach using detailed rock characterization of potential subsurface reservoirs, hydrothermal experimental appraisal of the interaction of biofilms and authigenic mineral precipitates (e.g. clays), geochemical and petrophysical characterization, as well as reservoir scale models to accurately assess and predict the impact of seasonal hydrogen storage. This research can lead to informed decisions regarding operational strategies and long-term hydrogen storage.

Stated link to the overarching theme of the CDT i.e. The Role of Geoscience in the Energy Transition and the challenge to meet the net zero emission targets (NOTE: In order to qualify for NEO Energy CDT funding, there must be an explicit link to the Energy Transition with a clear application to the UK's Continental Shelf (UKCS). For projects supported by 100% matched funding from your University, links to the broader Energy Transition remit are sufficient):

Large scale underground hydrogen storage (UHS) offers the much-needed capacity to balance seasonal discrepancies between demand and supply of renewable energy, to decouple energy generation from demand and decarbonize heating and transport supporting decarbonization of the entire energy system. Despite the vast opportunity provided by UHS, the maturity and understanding of subsurface storage of hydrogen is still in its infancy. A specific challenge is the interaction of hydrogen with the reservoir rock and the potential for hydrogen loss due to microbial activity and production of biofilms in the reservoir and injection points. This project will specifically attempt to readdress this balance of pore-clogging due to microbes and how biofilms can act at sites of authigenic mineral growth (e.g., clay minerals, zeolites) that would impact the long-term storage and operation of hydrogen storage (Fig.1).

The postgraduate student will use data from the the Rough Gas Storage project. The former Rough Gas Field is located along the western margin of the Southern North Sea Gas Basin and will utilise the Leman Sandstones of the Lower Permian Rotliegends to store hydrogen and is sealed by the Upper Permian Zechstein evaporites. This is clearly in line with the CDT focus on energy transition in the UKCS.

Details of mapping/fieldwork locations/data to be used by the project and confirmation of access to key data being secured (please attach map as an appendix if relevant):

Experimental setup: The experimental setup will follow that of Charlaftis et al. (2021).* Hydrothermal reactor experiments will carried out in a Parr© Series 4560 Mini Reactor and Parker Autoclave Engineers 500 ml cylindrical 316 stainless steel pressure vessel with an operating temperature up to 350^{o}C and 100MPa. Bacterial strains will be cultivated using standard laboratory stocks. Hydrogen gas will be bottle fed under pressure into the reactors. All facilities are available in a purpose-built HPHT laboratory space at Durham University as set up by lead PI for this project.

Analysis: Micro-CT, Quantitative SEM, XRD and ICP-MS is available at Durham University. Access and training is offered to all postgraduate students for the duration of their PhDs.

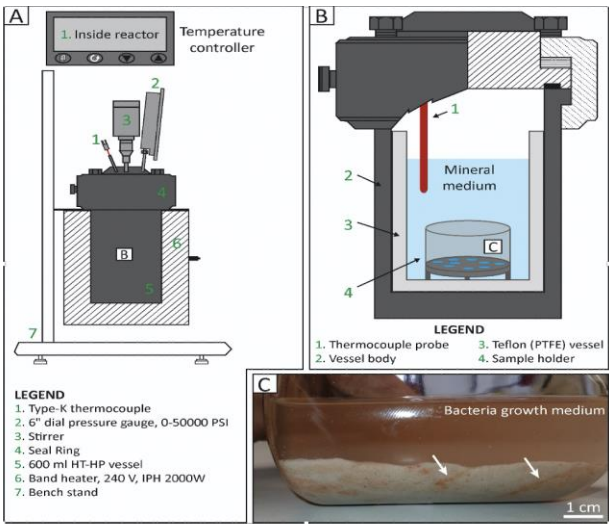
Datasets: Sand and bacterial cultures will be conditioned to replicate variability of the Lower Permian Leman Sandstone reservoir. Technical input will be given by Centrica. Samples for the Rough Field are openly available from the BGS and Centrica will directly support.

Modelling and upscaling: Pore scale flow modelling software including Permedia, Eclipse reservoir simulation, Aztec and development of our own suitable code will be incorporated into the project as needed. A full suite of software is available at Durham.

*Charlaftis, D., *Jones, S.J. Dobson, K.J. Crouch, J. Acikalin, S. (2021). Experimental study of chlorite authigenesis and influence on porosity maintenance in sandstones. Journal of Sedimentary Research, 91, 1-16.*

Outline of planned work schedule for the 4-year research period:

Year-1: Training in use of hydrothermal reactors (as below) and suitable selection and growth of biofilms (example culture grown on sand grains shown in image below). Further training provided in advanced scanning electron microscopy and geochemical techniques. Visit to BGS for sample collection from Leman Sandstone. Visits to Centrica for scientific discussions about the Rough Storage facility and the reservoir geology and engineering.



Year-2: Continued experiments using different key variables (e.g. temp, pressure, salinity, H_2 gas flow rate and saturation); initiation of modelling for up-scaling of pore scale processes. Input from the Centrica reservoir engineering team will full disclosure of results and data sets. Possible first early scientific publication on experimental data sets.

Year-3: Modelling of processes at pore and reservoir scale and link to subsurface Rough storage site. Completion of any final hydrothermal experiments as needed. Collect and simulate scientific results that will be written up in the form of several scientific publication. Presentation at a National (e.g. Geological Society, London) and International conference (e.g. EGU & AGU)

Year-4: Project completion. Finalising and submission of PhD thesis and submission of scientific manuscripts for publication. Attendance at an International conference.

Any Additional Research Costs (NOTE: Each CDT studentship includes an individual Research Training and Support Grant (RTSG) budget of £20k for the full 4-year study period)
Centrica Storage UK as part of the research will contribute £5k towards experimental costs of biofilm growth, XRD, ICP-MS and Qemscan analysis required to undertake the research. Centrica Storage UK will also substantially contribute to this project by adding their valuable experience and insight into operating a UHS project. Centrica will openly share data and their input with the postgraduate student and the wider CDT. Centrica readily endorse that results from this research should be published and freely presented amongst the CDT.

Supervisory arrangements and involvement of external partners (NOTE: Please indicate the area(s) of expertise covered by each supervisor. External collaboration is encouraged, but if proposed partner is not currently providing support to the CDT, please outline the extent of the partner's involvement with the project.)
Stuart Jones – PI for project and extensive knowledge of using hydrothermal reactors for understanding diagenesis of sandstones linked to advanced quantitative techniques.
Julia Knapp - second supervisor, expertise in (bio-)geochemistry and numerical modelling.
Jon Gluyas – Director of Durham Energy Institute and university lead for low-carbon energy transition.
Jeroen Van Hunen - Expertise in fluid flow and modelling of subsurface processes
Martin Scargill– (Centrica, UK). Project director for Centrica and will oversee interaction between the postgraduate student and reservoir engineers in Centrica to appropriately calibrate experimental models and deliver realistic upscaled subsurface models for use on the Rough Gas Storage project and wider application. All data will be open access and results shared with the GeoNetZero CDT.

Likely graduate career routes:
i) *Hydrogen geoscientist and engineers:* Larger-scale hydrogen value chains in the future will require a broader range of storage options of which geological storage is seen as the best option for large scale and long-term storage of hydrogen. This will require experienced highly skilled geoscientists to appraise potential subsurface reservoirs and be a key part of their development.
ii) *Low-carbon transition Earth Scientists:* Many of the skills acquired during this doctorate research will also be applicable to reservoir characterisation and modelling for CO_2 sequestration and underground storage. In fact, likely to be a combined process for many planned projects where CO_2 can act as a cushion gas for the hydrogen.
iii) *Low entropy mine water heat extraction and geothermal exploration and maintenance.*