Title: Efficient uncertainty quantification of CO_2 storage sites through machine learning to better assess the risk of leakage: **Principal supervisor**: Helen Lewis (EGIS / IGE)

Second supervisors: Vasily Demyanov, Dan Arnold, Saeed Ghanbari (TBD)

Summary: Carbon Capture and Storage (CCS) is potentially a game changer for CO2 mitigation, yet it is not widely used, in part because of significant risks of leakage to surface which are difficult to quantify. Top seal leakage occurs when any fracture or fault (new or pre-existing) opens through the sealing layer to allow CO2 to escape. This PhD project addresses sealing and leaking of topseals over CO_2 storage sites by simulating both the fracture development (geomechanical simulation) and the fluid scenarios (fluid flow simulation) to identify safe and unsafe scenarios.

The PhD will use a novel ***physics-based machine learning*** technique to rapidly quantify geomechanical risks and uncertainties. The companion to fault seal studies from which it borrows widely, this work acknowledges that all topseals are damaged and that fracture-and –matrix flow systems are particularly prone to extreme response changes from minor mechanical oo fluid pressure changes. By embedding some of the system's physics into the machine learning algorithm, the predictions should more realistically reproduce the essential mechanics of fracture development than a traditional machine learning approach would do, and be more interpretable. The machine learning predictions will represent the physical changes to the reservoir that influence flow by adjusting the fluid flow simulation model inputs (e.g. permeability) in a realistic way to allow more models to be run and so achieve a more accurate estimate of uncertainty.

Success in this project will create a way to properly evaluate geomechanical uncertainties and ultimately enable more CCS or geomechanically sensitive projects through better development planning and risk mitigation. The project aims to fix the current bottleneck to quantifying uncertainty in fracture development/opening/closing in shale and carbonaceous very low permeability topseals, reducing the unfeasibly large numbers of time-consuming coupled simulations. The proposed approach will provide a screening tool to identify the relevant physical mechanisms of the geomechanical deformation. Success will come from making uncertainty quantification of such systems feasible without the need for very large compute resources.

Student suitability and what they will gain

The topic is suitable for applicants with a good understanding of the subsurface such as reservoir engineers or numerate geoscientists. An understanding of CCS, reservoir and/or geomechanical simulation is advantageous. Some knowledge of machine learning and uncertainty quantification is helpful but no candidate will have a complete skillset.

The research will focus on key geomechanical challenges around cap rock integrity, with relevance to reactivation of faults/induced seismicity and within-reservoir geomechanically sensitive responses. These challenges are important in many geoenergy contexts, ranging from porous petroleum reservoirs to fractured/faulted basement/granite as geothermal reservoirs (GWatt). This PhD is part of a wider Machine learning-geomechanics research agenda at Heriot-Watt and may link to future Industry funded PhD projects.

Ultimately, the student will develop a novel expertise set at crucial intersections of machine learning, geomechanics, structural geology, and reservoir simulation - applicable to a wide variety of reservoir types, in and beyond CCS (geothermal, gas storage).