**SUMMARY REPORT: CO2TRAP.**

**INTRODUCTION:** Geologic storage of carbon dioxide, also known as carbon capture and storage (CCS), is one strategy to reduce the emission of greenhouse gases generated through the combustion of fossil fuels. Geologic sequestration of CO2 involves the injection of supercritical CO2 into underground brine formations such as oil bearing formations, deep un-mineable coal seams, and deep saline aquifers.

Sites where CO2 is stored could be closed and responsibility transferred with lower risk, higher confidence, thus greater insurability, if technologies existed that: i) would hasten the rate of CO2 trapping so long term stability could be reached in decades rather than centuries and ii) if rock formations could be sealed near wells, to prevent leakage through degraded steel and concrete in the closed injection well.

Previous work by the fellow has demonstrated such technology – via carbonate mineral forming bacteria and biofilms in the subsurface. This has been driven by enhancing rates of ureolysis, either by native organisms or by injected ureolytic organisms. Here, we have shown that carbonate mineral forming microorganisms and biofilms can enhance Geologic Carbon Storage (GCS) via solubility-trapping, mineral-trapping, and CO2(g) leakage reduction, by reducing flow though high permeability zones in porous media. This technology addresses EU Directive 2009/31/ to investigate methods to safely abandon GCS sites, with lower risk and higher confidence.

Such work has however, been performed under low pressure conditions for a simple brine composition. The CO2TRAP project has therefore developed this green-technology to address key knowledge gaps, specifically relating to simulating subsurface conditions. We have;

1. Determined the effect of pressure on the biomineralization process
2. Determined the stability of carbonate minerals to SC-CO2 / brine mixtures under reservoir conditions
3. Up scaled the process from the lab to the field.

The data produced will enhance the EU’s ability to develop energy efficient, low carbon water and air treatment technologies through the 21st century for a long term environmentally sustainable future.

**KEY RESULTS:**

- Ureolysis can occur under in situ geologic carbon storage reservoir conditions (dark, and high pressure up to 7.5 M).

- Ureolsysis can generate pH increases from 6 to 9 under reservoir conditions.

- Ureolysis driven calcium carbonate precipitation can occur under in situ geologic carbon storage reservoir conditions, and calcite was the predominant CaCO3 polymorph.

- Ureolytic colony forming units were consistently detected in the reactor effluents, indicating biofilm development and continued viability under reservoir conditions.

- Calcite precipitates exposed to dry supercritical CO2 (scCO2), water-saturated scCO2, scCO2-saturated brine, and atmospheric pressure brine indicate microbially formed carbonate minerals are generally resistant to potential corrosive subsurface fluids. Specifically calcite precipitates were resilient to dry scCO2, but suffered some mass loss in water-saturated scCO2.

- A range of radial and axial flow experiments at low pressure and under in situ reservoir conditions were performed with various porous media types (rocks and sand) and ureolyic organisms to test the ability to control the placement and rates of mineral formation for engineering CO2 trapping and leakage reduction at high porosity zones in rock and in micro fractures in well bore cement and cement-metal interfaces.

- Experiments demonstrated that at low and high pressure conditions, pulsed media injections of different media could achieve a homogenous distribution of biofilm-induced calcium carbonate (CaCO3) precipitates. This required a series of injections: i) urea media to promote biofilm growth, ii) Urea and Ca free media to lower CaCO3 saturation states to avoid injection inlet plugging (which would plug the injection well), and iii) urea and Ca inclusive media to raise CaCO3 saturation sate and induce CaCO3 precipitation, iv) Urea and Ca free media to displace the mineralisation zone to the required position.

- Flow experiments demonstrated the ability to plug fine fractures in porous media, offering new potential engineering options for subsurface engineering, surpassing industrial well bore cements used by oil companies which often fail to plug fine fractures.

- Field tests were conducted in the Black Warrior sandstone basin, Alabama, with project partners, Montana State University, Centre for biofilm engineering. This comprised of a attempting to seal a pancake fracture at 400m below surface level. Complete sealing due to micrbially induced carbonate precipitation occurred after ~3 days: 24 calcium injections, 6 inoculation injections, using 15 kg Ca. Fracture extension pressure 920 psi (before sealing) vs. 1140psi (after) indicates biomineralization sealing increased formation resistance to hydraulic fracturing.

**SOCIO-ECONOMIC IMPACTS:** CO2TRAP and associated partner projects have involved a number of industrial partners who have been central to steering aspects of the research. A number of provisional patents have been applied for indicating the potential socio-economic impact. Indeed, large scale mechanisms to reduce concentrations of atmospheric CO2, as offered via CCS and CO2TRAP technologies, are vital in our efforts to fight anthropogenically induced climate change. The International Energy Agency states that CCS could reduce global carbon dioxide emissions by 19% and that fighting climate change could cost 70% more without CCS. If developed at scale CCS could allow the safe removal and permanent storage of carbon dioxide emissions from coal and gas power stations as well as steel or cement factories. CCS is therefore a key tool in tackling climate change, providing energy security, creating jobs and economic prosperity. This technology addresses EU Directive 2009/31/ to investigate methods to safely abandon GCS sites, with lower risk and higher confidence.

**CONCLUSIONS:** CO2TRAP has demonstrated that microbially induced mineralization with the purpose of reducing the permeability of preferential leakage pathways during the operation of GCS are applicable in the scCO2 region and both the scCO2 saturated brine region and the brine saturated scCO2 region of the subsurface storage site where subsurface fluids are quasi static. New and novel tools to control subsurface permeability and CO2 leakage, as presented here, are required in inaccessible subsurface environments proximal to injection wells, where ‘traditional’ engineering approaches cannot be applied. This is particularly relevant in zones near to injection wells where even low viscosity cements cannot penetrate to seal fractures and leakage pathways.