The importance and challenges of characterizing CO_2 reactions in subsurface pore space storage complexes

Kirk Osadetz[a*], Nicholas Utting[b], Hamid Behmanesh[a], Joanna Cooper[a], Emma Martin- Roberts[c,d], Stuart M. V. Gilfillan[c], and Don Lawton[a,e]

[a]Carbon Management Canada Inc., T2L 2K8 Canada;
[b]Natural Resources Canada – CanmetENERGY, T9G 1A8 Canada;
[c]School of GeoSciences, The University of Edinburgh, Grant Institute, EH9 3FE, United Kingdom;
[d]Department of Energy Security and Net Zero, SW1A 2EG, United Kingdom (current address);
[e]Department of Earth, Energy and Environment, University of Calgary, T2N 1N4 Canada;

Injected CO_2 storage modes impact subsurface storage risks and capacity, as well as containment monitoring and accounting required to earn storage credits. The greatest impacts occur during the operational and post-closure intervals, especially when long-term liabilities are transferred from the Operator to the State. In general, subsurface CO_2 storage occurs as, a separate phase in pore space, in minerals, or because of pore space fluid interactions, commonly dissolution, but potentially also clathration. Storage can be complicated by chemical reactions and microbial activity that transforms or consumes injected CO_2, notably biogenic CO_2 reduction that produces CH_4. Some CO_2 pore space reactions that occur in situ, are also proposed as ex situ CO_2, capture or storage mechanisms, notably mineralization and dissolution. The widespread use of CO_2 in industrial chemistry assists the modeling of CO_2 reactions with formation water. However, the natural and disposal geochemistry of CO_2, includes the inferred persistence of natural CO_2 accumulations at geological age and epoch time scales, while lithological confirmation of reactive transport model predictions not always confirmed by observation. Widely used reservoir simulators suggest that up to 70% of injected CO2 dissolves rapidly in formation water, even where storage complex temperatures are elevated and formation waters are saline. Studies at CO_2 enhanced petroleum recovery projects are even more optimistic, suggesting that >80% of injected CO_2 can be dissolved or microbially transformed to CH_4 within a few decades – essentially during the operational life-span of a CCS Hub. If such processes are so effective, then one might find the geophysical monitoring inference of significant pore space fluid replacement by injected CO_2 paradoxical. However, other studies infer lower rates of pore space fluid interaction, including naturally occurring and anthropogenically engineered acid gas accumulations in Western Canada Sedimentary Basin and elsewhere. There are several challenges to improving our understanding of subsurface CO_2 behaviour. In addition to potential variations in the compositional and isotopic characterization of injected CO_2 over time, CO_2 migration out of the injection zone may be undetected, or in-zone mineralization, adsorption, or non-aqueous dissolution reactions may occur, particularly where residual petroleum phases and organic-rich sediments are present. Considerable efforts to employ intrinsic tracers, particularly trace noble gas components of the injected CO_2 are available. These are desirable tools because their intrinsic occurrence provides a cost-free monitoring technology. They are studied extensively at several scales in nature and the laboratory. We review these tools and their previous applications, as well as, describing opportunities for their application at current and future CCS Hubs in western Canada.