DEEP SUBSURFACE CO_2 SEQUESTRATION – A VIABLE GREENHOUSE MITIGATION STRATEGY

Andy Chadwick, Sam Holloway, Nick Riley.
British Geological Survey

Accelerating rise of global temperatures, an increased incidence of unusual and damaging weather patterns, freak storms, and recent sighting of open water at the North Pole are intensifying the debate about the possible worsening environmental consequences of global warming.

Because of the global warming threat posed by anthropogenic greenhouse gases there is an increasingly urgent need to develop permanent ways of lowering industrial CO_2 emissions. Such a strategy requires several parallel approaches, including more efficient energy use, reduction of reliance on fossil fuels, removal of CO_2 from the atmosphere (e.g through cultivating biomass storage), or sequestration of CO_2 emissions to a non-atmospheric sink. We wish to raise the profile of this last strategy as an effective alternative to biomass storage.

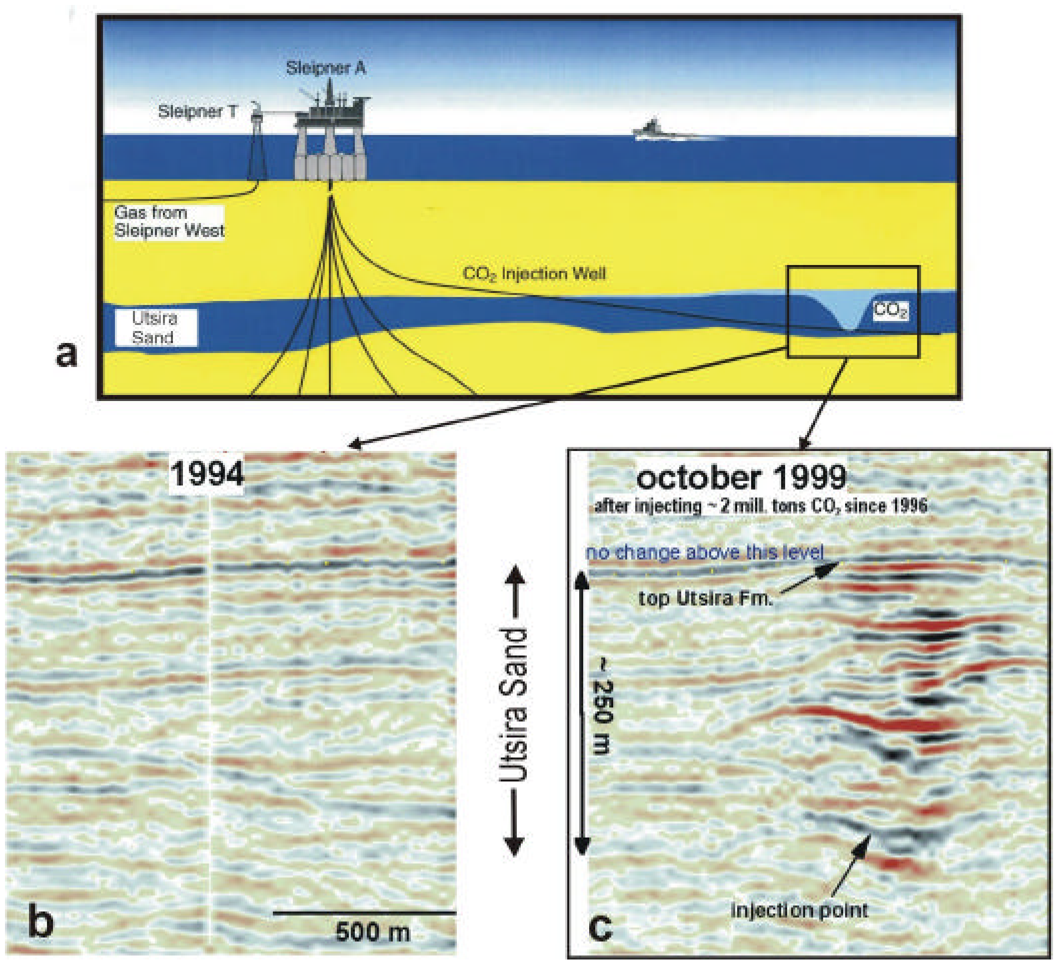
A recent article by Fred Pearce (New Scientist 26 August 2000) highlighted some of the difficulties and drawbacks associated with proposed CO_2 sequestration strategies based on tree planting. Pearce's arguments were partially theoretical, based on uncertainties in our understanding of the global carbon cycle. More practical considerations, particularly the worrying increase in the frequency of damaging wind-storms, cast further doubt on tree planting as a globally effective CO_2 sequestration option. In October 1987 a relatively small storm destroyed 17 million trees in southeast England. This event was dwarfed by the storm which swept across NW Europe last Christmas, destroying over 270 million trees in France alone. The fact that trees destroyed in the storm ranged in age up to 1000 years, suggests that, in historical terms, this was a freak event. The forest fires currently devastating the western US, and which destroyed drought stricken rainforest in Sumatra during 1997-8, may also be freak occurrences, but whatever their cause, the increasing frequency of such events will render a strategy of CO_2 sequestration by tree planting progressively more insecure - young trees in particular are susceptible to wind and fire damage.

Quantification and verification of carbon removal is a key aspect of the Kyoto protocol and any foreseeable future greenhouse gas reduction agreements. A viable CO_2 removal strategy will firstly have to quantify the amount of CO_2 initially sequestered and secondly be able to monitor and verify the subsequent fate of this CO_2, particularly in terms of the amounts 'leaking' back into the atmosphere. As Pearce pointed out, sequestration by tree planting is both difficult to quantify and, in many parts of the world, likely to become increasingly unreliable as a permanent CO_2 store.

Underground sequestration of CO_2 involves pumping the CO_2 underground, in fluid form, such that it becomes trapped in the pore spaces between grains of sedimentary rock in exactly the same way that hydrocarbons are trapped in oil and gas fields. The technique offers the opportunity to remove quantifiable, monitorable and ultimately secure amounts of CO_2 to a non-atmospheric sink, using technologies which are both currently available and constantly improving. It has the advantage over using the oceans or biomass as sinks in that underground storage completely isolates the CO_2 from the atmosphere, capturing it at the point of emission, and thereby ideally suited for large industrial point sources.

A major subsurface CO_2 sequestration project is currently running in the North Sea under the direction of the Norwegian oil company Statoil. In the Sleipner field, natural gas is contaminated by about 9% CO_2, which, after separation from the methane, would normally be vented to the atmosphere. At Sleipner it is injected into a deep saline aquifer, the Utsira Sand, which lies about 1000 metres beneath the seabed. The sequestration operation started in October 1996, with over 2 million tonnes of CO_2 injected since then. A demonstration project 'SACS' jointly funded by the EU, industry and national governments is currently evaluating the geological aspects of the subsurface disposal operation. This involves assessing the capacity, storage properties and performance of the Utsira reservoir, modelling CO_2 migration within the reservoir, and monitoring the subsurface dispersal of the CO_2 using time-lapse seismic techniques. It is clear from the illustrations that the underground situation is well imaged; the CO_2 is currently trapped within the reservoir above and around the injection point. Sophisticated seismic and reservoir modelling is now being carried out to further quantify and constrain the CO_2 subsurface distribution and predict its future behaviour.

Regional mapping of the Utsira Sand by SACS indicates that it has a potential storage volume of about 5.5 x 10^{11} m^3. A typical 500 MW(e) coal-fired power plant fitted for CO_2 capture would produce around 4.3 million tonnes of CO_2 per year for sequestration. An equivalent figure for a similar size natural gas-fired combined cycle power plant would be around 1.7 million tonnes of CO_2. The density of CO_2 at reservoir conditions in the Utsira Sand is approximately 725 kgm^{-3}. Thus one tonne of CO_2 would occupy about 1.38 m^3 of pore space in the reservoir rock. So, even if only about 1% of the storage volume of the Utsira Sand were utilised for CO_2 sequestration, this would be sufficient to sequester the annual output of about 925 coal-fired, or about 2340 gas-fired 500 MW(e) power stations.



a) Cartoon of the Sleipner CO_2 injection operation b) seismic reflection data acquired in 1994, prior to CO_2 injection c) seismic reflection data acquired in 1999, after 2 million tonnes of CO_2 injection, showing prominent high amplitude reflections corresponding to layers of CO_2 saturated rock.

The Utsira Sand is by no means unusual in terms of its storage potential and the Sleipner operation represents just one of many potential subsurface storage scenarios. The possibility of disposing of CO_2 in exhausted oil or gas bearing structures, which form proven long-term traps for buoyant fluids, is another option. Underground CO_2 injection is routinely used by the oil industry to assist with enhanced oil recovery (EOR), in the effective exploitation of oilfields. In October 2000 PanCanadian Resources will begin an unusual EOR project in Canada. This will involve using CO_2 stripped from emission gases from a coal gasification plant in North Dakota to improve recovery in the ageing Weyburn oilfield in Saskatchewan. A multinational research and monitoring project is being planned at Weyburn to further develop effective methods of CO_2 disposal whilst at the same time increasing understanding of EOR technology.

Many other countries have active research programmes aimed at identifying potential CO_2 undrground disposal sites. Notable amongst these are the Geodisc programme in Australia and various initiatives funded by the US Department of Energy and the European Union. In Europe a recently started project with the acronym GESTCO, partially funded by the EU, will evaluate the practicality of subsurface storage of CO_2 in a number of countries. As part of this project, a public hearing will be held, to gauge the reaction of the general public to the idea of CO_2 storage underground.

There are many naturally occurring underground accumulations of CO_2, which provide valuable natural analogues of the man-made CO_2 storage scenario. The CO_2 in one such accumulation, the Pisgah Anticline of Central Mississippi, is thought to have originated through the heating of Jurassic limestones by the Jackson Dome igneous intrusion. This intrusion was emplaced during Late Cretaceous times, some 65 million years ago, indicating that the CO_2 has remained underground since then. The study of these natural analogues is the subject of the part EU funded NASCENT Project which is looking at natural CO_2 accumulations (e.g. in eastern Europe) that have remained in the ground for millions of years.

With subsurface storage, realistic assessments indicate CO_2 retention times are likely to be of the order of thousands to millions of years. For all practical purposes, storage at a suitable site will mean that the CO_2 is removed from the atmosphere until all recoverable fossil fuels are likely to have been exhausted and any consequent greenhouse crisis has passed.

To conclude, irrespective of how quickly alternative, renewable energy technologies are realised, adherence to the Kyoto protocol, and the medium-term necessity of limiting atmospheric CO_2 levels to an environmentally acceptable limit, will make CO_2 sequestration a necessary fact of life. Subsurface storage offers a safe, verifiable and technologically feasible option. Costs will clearly be a significant factor, but where storage is linked to an enhanced oil recovery operation, these can be much reduced.