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Carbon Capture and Geological Storage: What are the Big Issues and Opportunities for the Petroleum Industry?

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Introduction

Fossil fuels such as coal, oil and natural gas, currently supply around 85 per cent of the world's energy needs, and according to predictions by the International Energy Agency, will continue to do so for many years to come. However, the burning of fossil fuels is a major source of CO_2, the gas most blamed for the increased concentration of greenhouse gases (GHG) in the atmosphere. Such GHG build-ups are linked to rapid, human-induced climate change, leading to growing public demand for reduction of atmospheric GHG emissions. Most anthropogenic CO_2 is emitted by coal fired power plants, though significant additional CO_2 is emitted from production and separation of large CO_2 – rich oil and gas accumulations, cement and mineral processing plants. Carbon management planning will have to include not only the technical aspects of carbon capture, transportation and storage but also issues of public acceptance, environmental, regulatory and liability constraints and the economics associated with carbon management.

There are various suggested options for global GHG reductions, including improving the conservation and efficiency of energy use; utilising non-fossil energy forms such as renewables (solar, wind, tidal, nuclear) and increasing the uptake of Carbon Capture and Storage (CCS). Whilst no one technology will be the "silver bullet" solution to make the necessary reductions to GHG buildups, a portfolio comprising all the options will be the most likely response.

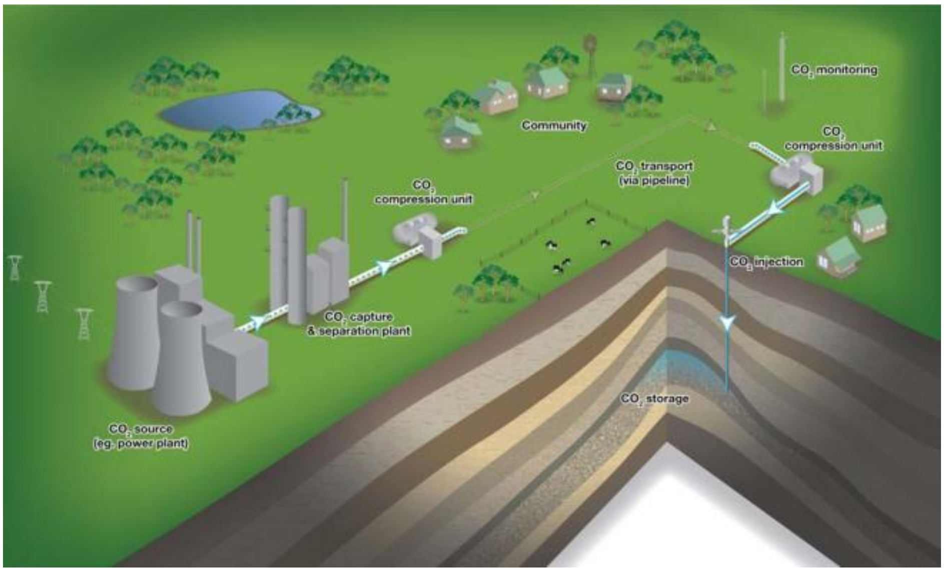

Figure 1: Integrated carbon capture, transport and storage process. Image courtesy CO2CRC

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CCS technology exists today and can be deployed commercially to make significant cuts in GHG emissions. CCS (also known as "Geosequestration") involves the long-term storage of captured CO_2 emissions in subsurface geologic formations. The technology comprises a number of steps (Figure 1): first, the CO_2 is captured at the source (eg a power plant or gas production facility); the captured CO_2 is then compressed to a supercritical state and transported, typically via pipeline, from the source to the geologic storage site; next, the CO_2 is injected via conventional wells into the geologic reservoir; and, finally, the CO_2 is stored (trapped) in the geologic reservoir, where any movement is carefully monitored and the quantity stored is regularly verified.

The storage of CO_2 involves keeping the CO_2 secured deep underground in an appropriate geologic formation. The principle geological options for secure, long-term storage are displayed schematically in figure 2. These options include injection and storage in a) depleted oil and gas reservoirs; b) use of CO_2 for enhanced oil or gas recovery; c) injection and storage in deep saline aquifers; d) storage in deep unmineable coal seams (where CO_2 is adsorbed onto coal matrix); e) use of CO_2 for enhanced coal bed methane recovery (where CO_2 is preferentially adsorbed onto coal matrix liberating methane); f) other "niche" options such as injection into basalts, salt caverns, or into shales. Each of these options have their specific pros and cons

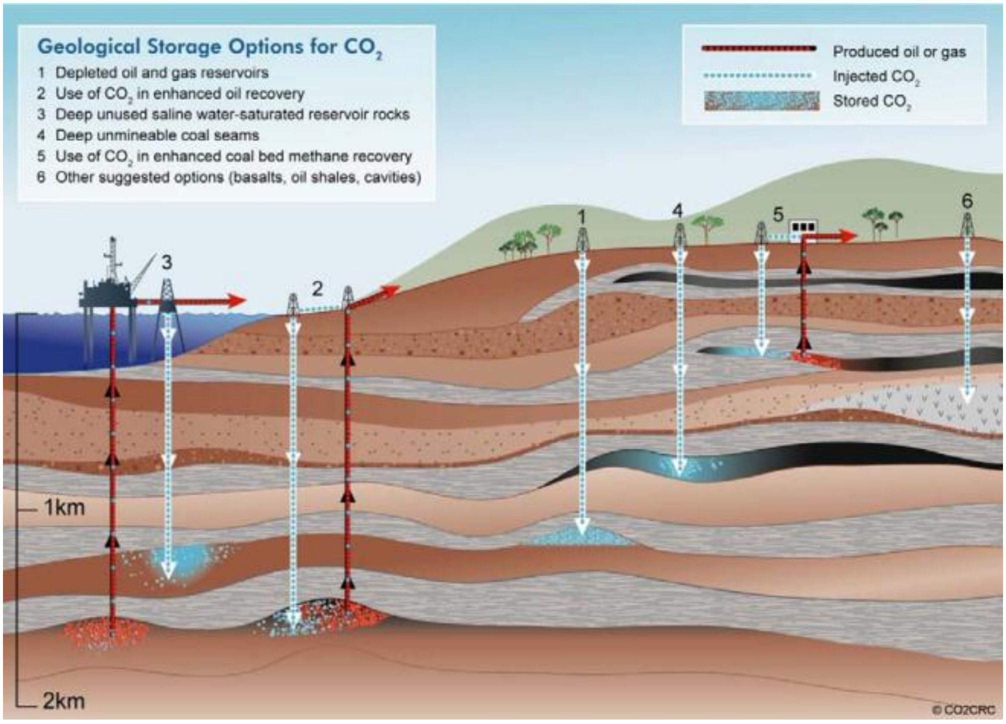

Figure 2: Geological options for secure long term storage of CO2 . Image courtesy CO2CRC.

The main geological conditions for secure, long term storage include: a porous and permeable reservoir rock, a trap, and an impermeable caprock. Expertise in locating such formations is well established within the exploration side of the oil and gas business, and geoscientists and engineers utilise mature technology to identify and evaluate specific sites for their geosequestration potential. Each site is evaluated for its potential storage capacity, its potential injectivity and containment properties so as to ensure that conditions for safe and effective long-term storage are present. Since the injected CO_2 is originally less dense than the formation water, it will naturally rise to the top of the reservoir, and a trap is needed to ensure that it does not reach the surface. The most common traps are structural (anticline or fault trap), stratigraphic (unconformity or "pinch-out" of reservoir rock against non-reservoir) or hydrodynamic (CO_2 is entrained in the groundwater flow and is constrained above and below by impermeable seal lithologies). An impermeable top seal (caprock) is required to keep the CO_2 within the trap. Such seals are generally very fine grained rocks with low porosity and, even more importantly, low permeability. Typical caprock seals are shales and mudstones. The caprock must be of sufficient thickness and ductility to prevent microfractures and through-going faults from developing as possible CO_2 leakage pathways.

Depleted oil and natural gas fields, which generally have proven geologic traps, reservoirs and seals are ideal sites for storage of injected CO_2. In such fields, it is important to ensure that hydrocarbon resources have already been produced from the specific target formation. Also, care must be taken that all existing wellbores are adequately cemented with CO_2 resistant cements (to prevent CO_2 reaction) before sequestration operations begin. Solubility and mineral trapping, which have little significance in petroleum systems are important trapping mechanisms for CO_2 storage. Solubility trapping involves the dissolution of CO_2 into the reservoir fluids. Recent research has shown that as the CO_2 moves through the geological formation along the flow path, a proportion of the CO_2 dissolves in the formation water. Modelling has shown that with time the CO_2 dissolved in the water increases its density and causes downward fingering of CO_2 rich waters. Mineral trapping involves the reaction of CO_2 with unstable minerals present in the host formation to form stable, solid compounds such as carbonates. Once the CO_2 has formed such minerals it is permanently locked.

Monitoring the behaviour of stored CO_2 includes an extensive array of established direct and remote sensing technologies that are deployed on the surface and in the borehole. These are generally planned for repeat assessments from a reservoir, containment, wellbore integrity, near surface and atmospheric perspective. These technologies record properties such as pressure, temperature, resistivity and sonic responses in both injection and observation wells. Other monitoring involves seismic, microseismic, petrophysical well logs and geochemical sampling such as tracer and isotope analysis allow tracking of movement of CO_2 in the subsurface. Baseline surveys of the distribution, type and origin of any existing CO_2 in a potential storage site is carried out through soil gas sampling prior to injection. Areal CO_2 migration and trapping are addressed through characterization of the hydrodynamic properties of the region. Geochemical sampling at surface localities will allow rapid detection of any seepage or leakage in the unlikely circumstance that this should occur.

Commercial-scale CCS projects already exist in several places around the world. One has been in operation at Statoil's Sleipner Field in the Norwegian North Sea since 1996. Other fields of note include Algeria's In Salah Field (operated by BP, Statoil and Sonatrech) and Encana's Weyburn Field in Saskatchewan, Canada, which is using CO_2 for EOR operations. There are a number of other storage projects underway or planned around the world but there is only one project in Australia actually injecting CO_2 underground at this time: The CO2CRC Otway Project is the world's largest non-commercial geosequestration research and demonstration project. Based in south- western Victoria (figure 3), the CO2CRC Otway Project has already safely injected, stored and monitored over 65,000 tonnes of CO_2 into a depleted gas field at a depth of approximately two kilometres (figure 4). A second stage of the project, now underway, will inject smaller amounts into a different geological formation as part of ongoing experiments designed to fill in some of the knowledge gaps regarding CO_2 storage in saline aquifers.

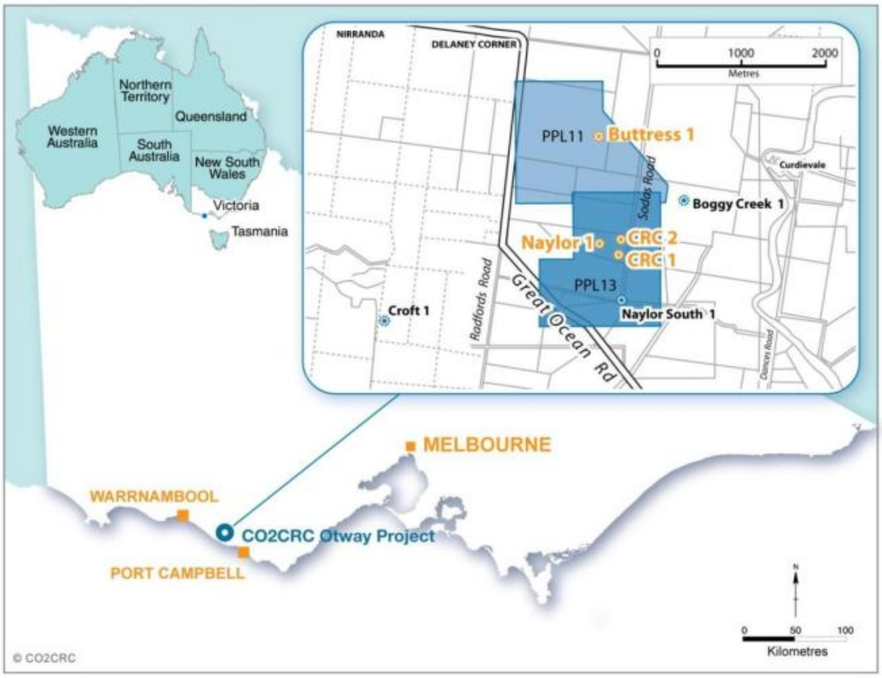

Figure 3: Location of the CO2CRC Otway Project. Situated in southwest Victoria, Australia, the Otway project comprises an array of 4 wells and surface facilities located on two separate Petroleum Production Leases (PPL 11 & 13). Buttress 1 supplies CO_2 for 2 injection wells: CRC-1 and CRC-2. Naylor-1 is a monitoring well. Image courtesy CO2CRC.

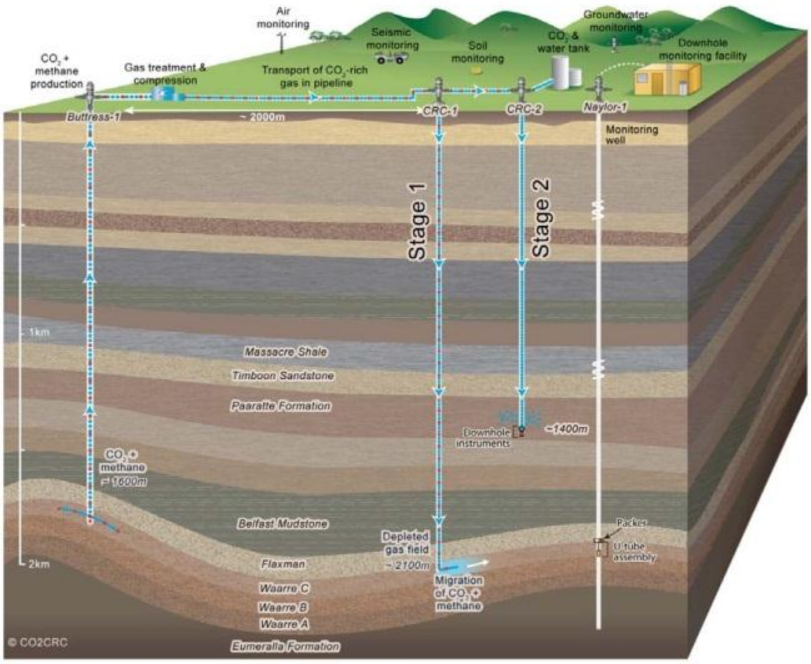

Figure 4: Schematic depiction of surface and subsurface facilities and geology at CO2CRC Otway Project. Principle components include CO2 production well (Buttress- 1); gas treatment and compression facilities; 3.4 kilometre pipeline; stage 1 injection well (CRC-1) injecting into depleted gas formation (Waarre-C formation) at depth of 2100 metres; stage 2 injection well (CRC-2) injecting into saline aquifer (Paaratte formation) at depth of 1400 metres; a monitoring well (Naylor-1) configured with down-hole seismic and geochemical sampling tools. In addition surface monitoring facilities include repeat 3-D seismic surveys, shallow groundwater testing wells, soil gas surveys and atmospheric monitoring devices. Image courtesy CO2CRC

A major feature of the Otway Project is a comprehensive monitoring and verification program, one of the most rigorous in the world, which allows researchers from Australia, the United States, New Zealand and Canada to better understand and model the behaviour of the injected CO_2. In planning the Otway Project, detailed geological models were built for the storage location, using regional and site-specific seismic data, depositional models and core data from well drilling. These models were then used as the basis for modelling the movement of the CO_2, in order to predict how the injected plume will behave and guide the monitoring program. These models predicted that the CO_2 'footprint' would be stable over long periods of time. Data from deep subsurface monitoring in the storage zone is used to calibrate and test the project's computer models. A major outcome of the project is that the models will provide reliable tools for understanding CO_2 storage that can in turn inform future large scale storage projects in Australia and elsewhere.

While subsurface storage of CO_2 is not without risk, a systematic risk assessment for all geosequestration sites considers both the engineered and natural systems. The engineered systems consist of the wells, the plant and the gathering line; the natural system includes the geology of the site, the reservoir formation, the overlying and underlying formations and the groundwater flow regimes. These criteria need to be agreed in conjunction with the relevant regulatory authorities and apply to the project through all phases to address responsibilities, liabilities and to provide assurance of safe storage to the satisfaction of the public at large.

In conclusion, carbon capture and storage will usher in an entire new global business model. Successful deployment of CCS will require top quality science, appropriate regulation, clarity on liability issues and acceptance by the community. Individual storage sites will need to be well characterised with respect to the physical and chemical processes which will take place during and after injection. Similarly, all the technologies available for monitoring the stored CO_2 need to be evaluated and the most appropriate ones selected and the risks associated with all phases of the process must be identified and understood. These aspects of CCS, all very similar to those commonly used in the petroleum industry, will provide tremendous opportunities for appropriately skilled organisations and individuals.