Technical and policy issues associated with sequestration of carbon dioxide emissions

J R Kessels and T W Matheson

CRL Energy Ltd, PO Box 31-244, Lower Hutt, Telephone: (04) 5703700, e-mail: crl@crl.co.nz

Abstract

This paper will examine the technical and policy issues associated with carbon dioxide capture and subsequent disposal into geological formations. There are potential opportunities for New Zealand petroleum companies to explore CO_2 disposal once the technical issues are solved. Carbon dioxide sequestration involves the capture and secure storage of carbon dioxide emissions that would otherwise have been emitted into the atmosphere. One option being examined by scientists internationally is how captured CO_2 can be injected into geological formations, including oil and gas reservoirs, deep coal seams and aquifers. Potentially, the use of technologies for carbon sequestration and the reduction of carbon emissions could play a major role in the future development of oil and gas fields and the utilisation of exhausted reservoirs. Substantial amounts of CO_2 are already being stored underground – in a deep saline aquifer (Sliepner), in oil wells to enhance oil recovery (e.g. Weyburn), and in a deep coal seam (New Mexico).

Introduction

Increasing concentrations of CO_2 and other greenhouse gases in the Earth's atmosphere may be enhancing the natural greenhouse effect, leading to changes in the climate. It is generally accepted that limits will have to be placed on the atmospheric concentration of the greenhouse gases in the atmosphere. The Kyoto Protocol requires developed counties to agree to reduce their emissions although this protocol has not yet been ratified.

The main techniques that could be used to reduce CO_2 levels in the atmosphere are:

- reduce energy consumption
- increase the efficiency of energy conversion or utilisation
- switch to lower carbon content fuels
- enhance natural sinks for CO_2
- capture and store CO_2.

This paper will focus on the capture and storage option. Fossil fuels will remain the world's dominant energy source for the foreseeable future (currently about 85% of the world's commercial energy needs are supplied by fossil fuels) and technical solutions for emission reduction, particularly capture and sequestration of CO_2, are realistic and achievable (IEA GHG R&D Programme, 2001, Audus, 2000).

Much of the work described here has been derived from studies carried out by the IEA Greenhouse Gas R&D Programme. This programme is an international collaboration of governments and industries from many counties (including New Zealand) with several linked objectives:

- to identify and evaluate technologies that could be used to reduce the emissions of greenhouse gases arising from the use of fossil fuels
- to disseminate the results of those evaluations
- to identify targets for research, development and demonstration, and promote the appropriate work.

The IEA GHG R&D Programme was established in 1991 and since then its major focus has been on capture and storage of CO_2.

CO_2 capture

Capture of CO_2 is best carried out at large point sources of emission, such as power stations, oil refineries, petrochemical, fertiliser and gas processing plants, cement works, steel works and pulp and paper mills. New Zealand has examples of each of these operations that offer capture possibilities. Generally in these emitters the CO_2 is a relatively small part of the waste gas stream and this low concentration means a large volume of gas has to be handled (Herzog, Eliasson and Kaarstad, 2000). The same can also be true where CO_2 is a contaminant in natural gas and has to be separated prior to distribution.

A way to increase CO_2 concentration is to use pre-combustion capture, where the fuel (e.g. coal and biomass) is reacted with oxygen and/or steam to give mainly carbon monoxide and hydrogen. The carbon monoxide is reacted with steam to give CO_2 and more hydrogen. The CO_2 is then separated and the hydrogen used as a fuel e.g in a combined cycle plant or fuel cells. The CO_2 is obtained at higher concentrations and pressure than from post-combustion processes. This technology is the basis of the "hydrogen economy" (Doctor, Molberg and Brockmeier, 2001; Rizeq, Kumar, West, Zamansky and Das, 2001) which is seen by many as a major way forward to a low emission, high efficiency future for energy in New Zealand.

Capture technologies

Solvent scrubbing

Amine scrubbing is the best established of the techniques available for CO_2 capture (Aldus, 2000). There are several facilities in which amines are used to capture CO_2 from flue gas streams – after leaving the scrubber the amine is heated to release high purity CO_2 and the amine is reused. Where CO_2 is present at reasonable concentration and high pressure a physical solvent can be used and the CO_2 released mainly by depressurisation. This is the technology used in the Sleipner gas field in the North Sea where CO_2 stripped from natural gas is injected into an underground saline reservoir.

This is the technology that is used at Kapuni.

Cryogenics

CO_2 can be separated from other gases by cooling and condensation and this is widely used commercially for streams that already have high CO_2 concentrations. Cryogenics would normally only be applied to high concentration, high pressure gases such as in pre-combustion capture processes.

Membranes

Gas separation membranes allow one component in a gas stream to pass through faster than the others. They cannot usually achieve high degrees of separation so multiple stages and/or stream recycle is necessary.

Adsorption

Solid adsorbents, such as zeolites and activated carbon, can be used to separate CO_2 from gas mixtures e.g. in pressure swing adsorption (PSA) and temperature swing adsorption (TSA). Adsorption is not yet considered attractive for large-scale separation of CO_2 from flue gas because the capacity and CO_2 selectivity of available adsorbents is low.

Transport

CO_2 would be transported to the storage site after capture. It is largely inert and easily handled and it is already transported in high-pressure pipelines. Millions of tonnes per year of CO_2 are currently piped for use in enhanced oil recovery.

Storage of CO_2

Natural CO_2 reservoirs are relatively common and are commercially exploited for CO_2 production for commodity use. In addition to these comparatively pure reservoirs, CO_2 is found in many other formations. Reservoirs of various kinds exist throughout the world containing mixtures of CO_2, methane, and other fluids. Many of these geologic settings are possible sinks for storage of CO_2. The main options for storing CO_2 underground are in depleted oil and gas reservoirs, deep saline reservoirs and unminable coal seams.

Depleted oil and gas reservoirs

Depleted oil and gas reservoirs consist of porous rocks covered by impermeable cap rock and have a number of attractive features as CO_2 storage reservoirs. They incur small exploration costs, are proven traps, their geology is well known and there is existing infrastructure that could be used for transport and injection. Injection of CO_2 into oil reservoirs to enhance oil recovery (EOR) is an established technique and about 33 million tonne per year is used in the USA for this purpose. Much of this CO_2 remains in the reservoir at the completion of oil production. An example of an EOR scheme using anthropogenic CO_2 is the Weyburn Project in Canada, where CO_2 captured in a coal gasification plant in North Dakota is piped to and injected into the Weyburn, Saskatchewan oil field (Wilson, Moburg, Stewart and Thambimuthu, 2000).

Depleted natural gas fields are also feasible sites for CO_2 storage. Underground storage in natural reservoirs has been an integral part of the natural gas industry for many decades, with routine injection, storage and withdrawal of natural gas.

Deep saline reservoirs

There are many underground, water-filled strata (aquifers) that could be potentially used to store CO_2. The aquifers used for CO_2 storage are deep underground, contain saline water and are unsuitable for supplying potable water. Suitable aquifers would have a cap rock of low permeability to minimise CO_2 leakage.

Nearly 1 million tonnes per year of CO_2 is already being injected into a deep saline reservoir beneath the Norwegian sector of the North Sea as part of the Sleipner Vest gas production project. This is the first example of CO_2 being stored in a geologic formation because of climate considerations. The flows of CO_2 injected at Sleipner (the project commenced in 1996) are being monitored and modelled as part of an international project established by Statoil (Arts, Brevik, Eiken, Sollie, Causse and Van Der Meer, 2000).

Unminable coal seams

Unminable coal seams offer another storage medium. CO_2 can be injected into suitable coal seams where it will be preferentially adsorbed onto the coal, displacing methane. Sequestration is achieved if the coal is not mined. Methane is already extracted from coal seams by depressurisation but this typically recovers only about 50% of the gas in place. Injection of CO_2 enables more methane to be extracted. In addition coal can adsorb twice as much CO_2 by volume as methane, so even if the recovered methane is combusted and the resulting CO_2 reinjected, the coal bed still provides net storage of CO_2. Recent work (Stanton, Flores, Warwick, Glustoker and Stricker, 2001) has shown that low rank coals can have a much bigger adsorption ratio of CO_2:CH_4 (up to as much as 10:1) and a correspondingly larger storage potential.

A substantial amount of coal bed methane is already produced in the USA and the potential exists in a number of New Zealand deposits. CRL Energy is currently investigating the development of methane from New Zealand's extensive deposits of low rank coals – where these are deep seams CO_2 sequestration offers the opportunity to enhance the production of methane.

At the Allison unit in New Mexico, USA (part of the most successful coal bed methane development in the world) over 100,000 tonnes of CO_2 has been injected over a three year period to enhance production of coal bed methane. The pilot operation has been running since 1996 (Stevens, Spector and Riemer, 1999).

The Alberta Research Council is carrying out a field test of enhanced coal bed methane production using CO_2 and nitrogen mixtures (Wong, Gunter, Law and Mavor, 2000). The focus of this study is flue gas injection rather than pure CO_2 as the expensive stage of CO_2 capture is removed.

The potential of using CO_2 capture and disposal in international emissions trading (IET) and the Clean Development Mechanism (CDM)

Capture and storage of CO_2 is not currently recognised as something that can be supported by the Kyoto mechanisms. A possible reason is that Kyoto was too early for these new technologies to be included. The IEA GHG R&D Programme has a study underway at present that will identify the barriers to recognising it under the

Kyoto mechanisms. However, CO_2 capture and disposal is a new field that offers the opportunity to explore linking the introduction of the technology with carbon credits.

At this stage the New Zealand Government is in the process of developing policies and measures to respond to their Kyoto Protocol commitments. There is no specific policy regarding CO_2 capture and disposal.

International Emissions Trading (IET) allows for trading between Annex B countries that have targets and assigned amount units allocated to them through the Kyoto Protocol. The trades are based on national assigned amounts to individual countries. The Clean Development Mechanism (CDM) is intended to promote sustainable development in developing countries through the allowance of trades between developed and developing countries. The rules for CDM were decided upon at COP7 in Marrakesh and now projects will be able to proceed under more certainty.

The premise for either IET or CDM is that in one country the marginal costs of carbon control will be higher than in the other. Since the increase in greenhouse gas emissions is a global issue it makes no difference environmentally where the reduction occurs. Hence, if the country with the higher marginal abatement costs was to compensate the country where the lower marginal abatement costs were possible it would be a win win situation. To illustrate, so long as the cost of the permits or CDM project is less than the costs of control for abatement in the high cost country then that country will benefit. Alternatively, as long as the cost is greater for the low cost marginal abatement country they would also benefit from the arrangement. CO_2 capture and disposal is one type of technology that could potentially capture these benefits with projects in the future.

Greenhouse gas credits from abatement will add an additional income stream to CO_2 capture and disposal technologies that are currently viewed in the commercial world as uneconomic. The Asian Development Bank in its review of energy policy has estimated the potential value of GHG trades in developing countries for the first Kyoto Protocol target period (2008 – 2012) to be $US11-19 billion annually. The project investments will be several times the value of the actual GHG trades. Internationally, many countries and institutions are trying to better understand the use of CDM Projects. The focus here is on two programmes promoting the use of Kyoto Protocol mechanisms. They are:

- World Bank Prototype Carbon Fund
- Dutch Emission Reduction Unit Procurement Tender (ERUPT).

The World Bank has a Prototype Carbon Fund with 6 countries and 17 private sector companies contributing a total of US$145 million. The countries include Norway, Holland and Sweden with major companies also participating such as BP and Tokyo Electric Power.

The primary objective of the fund is to provide parties with an opportunity to "learn by doing" in the development of policies, rules and business processes for reducing emission reductions under Joint Implementation (JI) and CDM. The price the Prototype fund is paying for credits is around US$5 for a ton of CO_2.

The Dutch Government recently announced the results of its first Eru-PT tender. As a result, the first greenhouse gas emission credits from East European countries have taken place. The Dutch Government purchased four mega tonnes of CO_2 reduction credits for 79 million guldens (US$31.5 million) over five years from Poland, Romania and the Czech Republic. The projects are:

- a 60 Megawatt wind-power park in Poland
- a series of biomass-fuelled boilers in the Czech Republic
- two urban heating projects and a hydropower plant in Romania.

The Dutch Government has now announced the beginning of its second tender, which will also include CDM projects. Both of these programmes encourage the use of the Kyoto Protocol mechanisms and it is expected that others will soon follow from other countries. There are opportunities to test out CO_2 capture and disposal technologies as mitigation and abatement measures for companies and countries to earn credits.

What is CDM?

The 1997 Kyoto Protocol established the CDM to facilitate sustainable development projects in developing countries that would reduce greenhouse gas emissions. The CDM allows transfers of certified emission reductions (CER) from projects in developing countries to developed countries. The latter are then able to use the CERs to meet their quantified emission limitation and reduction commitments. The advantage of this for a company is that a project to reduce emissions in a developing country could cost less than the cost of putting in place a similar project in its home country.

The CDM criteria are that projects:

- have the voluntary participation of each party involved
- assist developing countries in achieving sustainable development
- provide reductions in emissions that are additional to any that would occur in the absence of the certified project activity
- provide real, measurable and long-term benefits related to the mitigation of climate change.

One possible project for CDM is to explore whether a CO_2 capture and disposal project would be eligible under the CDM. However, as there are only a few test projects in this area it may be some time before a project could take place under the CDM.

The environmental and economic benefits of projects using CO_2 capture and disposal

The technology of CO_2 capture and storage would enable New Zealand to continue the use of fossil fuels but with much reduced emissions of CO_2. Given that a considerable proportion of New Zealand's energy needs are supplied by low cost fossil fuels a rapid change to non-fossil energy sources, even if possible, would result in large disruption to the energy supply infrastructure, with substantial consequences for the economy. In the future, fossil fuels will also play a key role in a low emission, high efficiency hydrogen economy.

The environmental benefits of CO_2 capture and disposal are that emissions are sequestered. The economic benefits will depend on Government policy and whether emissions trading or a carbon charge are policy instruments. In the case of a carbon charge it will depend on the level. An example of this is in Norway where the Sleipner project was viable partially because of a high carbon charge imposed by Government. Alternatively, in the case of emissions trading it will depend on the cost of capture and disposal competing against other projects that mitigate emissions or sequester them, such as renewable energy technologies.

The Asia Pacific Region has the fastest growing economies in the world. This also means that energy demand is continually increasing with the fuels of choice being coal and gas. One of the biggest challenges facing Asian countries will be dealing with the international community's concern over the growth in greenhouse gas emissions resulting from their economic growth. As a result of the Kyoto Protocol and its flexible mechanisms there will be future opportunities to develop projects in developing countries and generate carbon credits. One exciting opportunity is the development of technologies in CO_2 capture and disposal.

The Intergovernmental Panel on Climate Change (IPCC) predicted in its 1995 business as usual energy scenario that carbon emissions may potentially increase from 7.4 billion tonnes of carbon (GtC) per year in 1997 to approximately 26 GtC/year by 2100. One new option to manage carbon more efficiently is to capture and secure it from carbon emitted from energy transformation.

APEC forecasts for 2010, based on current trends, expect electricity output in the Asia Pacific to increase by 138% and coal consumption to increase by up to 180% as a consequence. Coal is the dominant energy source in India and China. Plans by these and other Asia Pacific countries to increase the utilisation of coal will require cost effective ways to manage the large increase in greenhouse gas emissions. Options include the adoption of clean coal technologies, the use of alternative energy sources, forestry development and CO_2 capture and disposal.

The first commercial CO_2 capture and disposal facility started in September 1996 with Statoil of Norway storing CO_2 from the Sleipner Vest gas field into a sandstone aquifer 800 metres beneath the North Sea. The rational for the project is that Norway has a carbon tax of $US50 per tonne of CO_2 and the costs of the operation are around $15/tonne of CO_2 avoided.

There is an opportunity for applying lessons from Sleipner and other capture and storage projects to New Zealand in the future. The discovery of more gas fields off the shores of Taranaki could be an opportunity to develop the option of disposing CO_2 in the depleted Maui field or enhanced oil recovery on and off shore. CRL Energy already has a FRST research initiative carrying out a scoping study of the range of geologic options in New Zealand for CO_2 sequestration. Key rating factors will include capacity and location. This will be followed by laboratory studies to evaluate screening criteria such as caprock integrity, trapping and transfer mechanisms and long-term stability. The programme will also evaluate and trial capture technologies appropriate to New Zealand.

The benefits of putting in place an early CO_2 capture and disposal project offer advantages to countries in a "learn by doing" process. It is a critical factor that for companies to take the risk of being involved in a project of this nature that there is support by governments in recognising the risk and recognising any credits as an incentive to companies willing to take explore this area of research.

Conclusions

Fossil fuels will remain the world's dominant energy source for the foreseeable future (currently about 85% of the world's commercial energy needs are supplied by fossil fuels).

Large reductions in emissions of CO_2 to the atmosphere may be needed to avoid climate change. Capture and storage of CO_2, in combination with other CO_2 abatement techniques, could enable these large reductions to be achieved.

CO_2 capture and storage technology provides a means of introducing a low emission, high efficiency hydrogen energy future to New Zealand.

Storage of CO_2 in geologic structures could have beneficial flow on to the oil and gas industry in terms of enhanced oil and gas production.

The Kyoto Protocol and its flexible mechanisms will provide opportunities to develop projects in developing countries and generate carbon credits.

References

Arts, R, Brevik, I, Eiken, O, Sollie, R, Causse, E and Van Der Meer, B. 2000. Geophysical Methods for Monitoring Marine Aquifer CO_2 Storage – Sleipner Experiences, Proc. Fifth International Conference on Greenhouse Gas Control Technologies, Cairns, Australia, 366.

Audus, H. 2000. Leading Options for the Capture of CO_2 at Power Stations, Proc. Fifth International Conference on Greenhouse Gas Control Technologies, Cairns, Australia, 91.

Doctor, R.D, Molberg, J.C and Brockmeier, N.F. 2001. Designing for Hydrogen, Electricity, and CO_2 Recovery from a Shell Gasification-Based System, Proc. 18th Annual International Pittsburgh Coal Conference, Newcastle, Australia.

Herzog, H, Eliasson, B and Kaarstad, O. 2000. Capturing Greenhouse Gases, Scientific American 282, 72.

IEA GHG R&D Programme. 2001. 10th Anniversary 1991 – 2001.

Rizeq, R.G, Kumar, R, West, J, Zamansky, V and Das, K. 2001. Advanced Gasification-Combustion Technology for Production of H_2, Power, and Sequestration-Ready CO_2, Proc. 18th Annual International Pittsburgh Coal Conference, Newcastle, Australia.

Stanton, R, Flores, R, Warwick, P D, Glustoker, H and Stricker, G D. 2001. Coal Bed Sequestration of Carbon Dioxide, US Geological Survey Report, 1.

Stevens, S, V, Spector, D and Riemer, P. 1999. Enhanced Coal Bed Methane Recovery by use of CO2, Journal of Petroleum Technology, 62.

Wilson, M, Moburg, R, Stewart, B and Thambimuthu, K. 2000. CO_2 Sequestration in Oil Reservoirs – A Monitoring and Research Opportunity, Proc. Fifth International Conference on Greenhouse Gas Control Technologies, Cairns, Australia, 243.

Wong, S, Gunter, W D, Law, D, and Mavor, M J. 2000. Economics of Flue Gas Injection and CO_2 Sequestration in Coalbed Methane Reservoirs, Proc. Fifth International Conference on Greenhouse Gas Control Technologies, Cairns, Australia, 543.

Authors

TREVOR MATHESON has a PhD in Inorganic Chemistry and is operations manager and deputy general manager at CRL Energy. He also manages the Coal Industry Research Programme for the Coal Association of New Zealand. Dr Matheson is the New Zealand representative on the International Energy Agency Greenhouse Gas R&D Programme and has represented New Zealand on the International Committee for Coal Research and the APEC Clean Coal Technologies Expert Group.

JOHN KESSELS has a MSc in Resource Studies. His Masterate thesis is a study of Activities Implemented Jointly (AIJ): a pilot programme for the JI concept embodied in the Climate Change Convention. Mr Kessels is employed by CRL Energy to undertake research into abatement projects for greenhouse gas emissions and policy advice to industry. He has produced reports and conference papers on Activities Implemented Jointly (AIJ); European climate change projects; emissions trading for New Zealand; and the WEC greenhouse gas reduction project.