Environmental Guidelines for Carbon Dioxide Capture and Geological Storage - 2009

Environmental Guidelines for Carbon Dioxide Capture and Geological Storage - 2009

Environmental Guidelines for Carbon Dioxide Capture and Geological Storage - 2009

© Copyright vests in the Commonwealth of Australia and each Australian State and Territory.

ISBN 1–921173–42–4 (Print)
ISBN 1–921173–43–2 (Electronic)

This work is copyright. It has been produced by the Environment Protection and Heritage Council (EPHC). Apart from any use as permitted under the *Copyright Act 1968*, no part may be reproduced by any process without prior permission from the NEPC Service Corporation. Requests and enquiries concerning reproduction and rights should be addressed to the Executive Officer, NEPC Service Corporation, Level 5, 81 Flinders Street, Adelaide SA 5000.

Environment Protection And Heritage Council
Ministerial Council On Mineral And Petroleum Resources

Environmental Guidelines for Carbon Dioxide Capture and Geological Storage - 2009

Introduction

The Australian Government has committed to reducing Australia's greenhouse gas emissions by 60 per cent of 2000 emissions by 2050. Capture and permanent geological storage of carbon dioxide, for example in depleted oil and gas reservoirs, saline aquifers or unmineable coal seams, is being proposed as a mechanism to reduce carbon dioxide emissions from the use of fossil fuels.

These Guidelines are intended to build on the *Carbon Dioxide Capture and Geological Storage – Australian Regulatory Guiding Principles* endorsed by the Ministerial Council on Mineral and Petroleum Resources in 2005. They provide regulators, proponents and the public with an understanding of the application of existing environmental laws to proposed carbon dioxide capture and geological storage projects. They are intended to demonstrate best practice and do not seek to place additional burden on existing state and territory government requirements.

Context

Concerns about the potential impact of climate change on communities, the environment and the economy have led to the need for significant reductions in greenhouse gas emissions. Carbon dioxide emissions from the use of fossils fuels for energy production account for approximately 70 per cent of all of Australia's greenhouse gas emissions, with the stationary energy sector contributing approximately 50 per cent of total Australian emissions.

In 2007, 84 per cent of electricity generation in Australia was based on the use of black or brown coal, with nine per cent natural gas and seven per cent from hydro-electricity, wind power and a variety of renewable energy sources. Electricity generation globally from coal is around 40 per cent and the use of natural gas for electricity generation is rapidly increasing. There has been a significant global growth in the number and scale of high emission industrial facilities such as iron and steel or cement production. As facilities involved in those processes represent point sources, capture or separation of carbon dioxide and other emissions is, in most cases, technically feasible.

With demand for energy increasing rapidly in developed and developing countries, energy production projections by the International Energy Agency indicate increased use of fossil fuels, with coal being the dominant source for the foreseeable future. Global carbon dioxide emissions are already higher than the scenarios used by Intergovernmental Panel on Climate Change in its Fourth Assessment Report (2007) and, if allowed to increase in line with projected energy production, are expected to accelerate the atmospheric warming that is already being observed.

The Australian Government has committed to reducing Australia's greenhouse gas emissions by 60 per cent of 2000 emissions by 2050. To facilitate this shift to a low emission economy, an emissions trading scheme is being introduced to effectively price carbon through a combination of emission permits and targets. An emissions trading scheme is expected to be supported by a range of complementary measures including energy efficiency and support for development and deployment of low emission technologies including renewable energy and carbon dioxide capture and permanent geological storage (CCS).

The Prime Minister formally launched the Global CCS Institute at the inaugural meeting of Foundation Members on 16 April 2009. At the launch, the Institute had signed over 85 Foundation Members and collaborating partners, including 16 Governments and over 60 companies and NGOs.

The Australian-based Institute will help deliver the G8's goal, agreed in July 2008, of developing at least 20 fully integrated industrial-scale demonstration projects around the world which will accelerate the broad deployment of CCS technology by 2020. It will promote the collaboration of existing efforts; share non-proprietary knowledge; seek out mechanisms to address technological and financial gaps; develop technology roadmaps; and produce assessments on the status of CCS technologies.

In its initial stages the Global CCS Institute will undertake a number of activities that will begin to work towards its primary objectives. The Institute will work towards its demonstration project portfolio by developing a baseline report on the current CCS activities. The GCCSI will work with its Foundation Members to establish its role as a global knowledge broker; and will work with existing international clean energy fora, such as the IEA and CSLF, to ensure the role of CCS within the future clean energy mix. The GCCSI will begin its supporting activities agenda by developing a globally accepted definition of CCS ready and establishing a Global CO_2 Storage Atlas.

CCS is being proposed as a mechanism to reduce carbon dioxide emissions from the use of fossil fuels. CCS is based on the concept of imitating natural geological systems which have stored natural gas, oil and carbon dioxide in geological formations for millions of years. It involves capture or separation of carbon dioxide from a source such as coal-fired or gas-fired power stations, natural gas production facilities, or high-emission industrial facilities such as cement or steel plants; transportation by tanker or pipeline; and injection and permanent storage in geological strata deep within the earth, including depleted oil and gas reservoirs, saline aquifers or unmineable coal seams.

The technologies required for each stage of CCS are available today and are being applied in a range of industrial processes. Capture or separation, and transport of carbon dioxide are practiced in the chemical, oil and gas industries in many countries. Injection of natural gas for underground storage, and of carbon dioxide for enhanced oil and gas recovery, is well understood and has been effectively managed for many years, with existing environmental regulation proving effective in protecting the environment and human health. However, the new element being introduced with CCS is the long term geological storage of carbon dioxide which introduces new uncertainties, the subject of intense research globally. Background information on CCS including barriers, technology status and indicative costs is at Appendix 1: Background on Carbon Dioxide Capture and Geological Storage.

With any new technology there is a need to learn from experience whilst ensuring that any projects are subject to an effective environmental risk management and approval regime. The Otway Project in Victoria is the only operational CCS project in Australia at this time. The Otway Project is designed to demonstrate the safe production, transport and geological storage of carbon dioxide, and provide a facility to develop monitoring and verification techniques. Background information on the Otway Project is at: Appendix 2: The Otway Project – Case Study. Although there are approximately a dozen Australian CCS project concepts, it is anticipated that only two or three demonstration or commercial projects will become operational in the next decade. These early projects and similar international projects (refer Appendix 3: CCS Projects) should be monitored closely so that the knowledge and learning experience can be used to guide the development of appropriate environmental management of future commercial projects.

Guiding Principles

CCS projects will be subject to the following principles which underpin the resource management and environmental protection regulatory framework that has been endorsed over time by the Council of Australian Governments (COAG):

- ***Ecologically Sustainable Development principles*** - COAG, 1992
- ***Occupational Health and Safety principles*** including those articulated in the National Minesite Safety Framework - COAG, 2002
- ***Principles of Good Regulation*** set out in the Principles and Guidelines for National Standard Setting and Regulatory Action by Ministerial Councils and Standard Setting Bodies - COAG, 1985 (amended 1997, 2004, 2007)
- The ***Intergovernmental Agreement on the Environment*** sets the framework for number of considerations that should apply to industrial and resource projects including the principles of polluter pays, intergenerational equity and the precautionary principle - COAG, 1992
- ***Carbon Dioxide Capture and Geological Storage – Australian Regulatory Guiding Principles*** sets the guiding framework to facilitate a nationally consistent approach to the application of CCS projects - Ministerial Council on Mineral and Petroleum Resources (MCMPR), 2005
- ***Principles for Stakeholder Engagement – Ministerial Council on Mineral and Petroleum Resources, 2005.***

Guidelines

The system of carbon dioxide capture and geological storage (CCS) is based on the concept of imitating natural geological systems which have stored natural gas, oil and carbon dioxide in geological formations for millions of years. Although permanent geological storage of carbon dioxide is a new concept, the technologies that are needed in a CCS system are being applied in a range of industries and have known risk profiles. What is needed is system integration at the scale necessary to achieve the major reductions in emissions envisaged by Governments.

These Guidelines seek to provide national level consistency and certainty for stakeholders in the application of current environmental regulatory processes. It is recognised that there are likely to be a small number of operational projects within the next decade and that the learning experience from these projects should be used to inform best practice regulation. The following provides guidance to environmental assessment, monitoring and site closure of CCS projects, and coordination of environmental regulation by jurisdictions.

Environmental Assessment:

- All CCS projects will be subject to environmental assessment and approval in the relevant jurisdiction under the appropriate legislative regime. The level of assessment will be determined based on the range of environmental and community values that may be impacted by a project.
- Capture or separation, transportation, injection and geological storage of carbon dioxide involves the application of existing industrial technologies, which have known risk profiles. Any change in risk profiles arising from new applications of CCS technologies, including in new locations, needs to be assessed within the relevant environmental assessment and approvals framework of each jurisdiction. It can also be addressed through appropriate conditions of approval that will apply within the footprint of an industrial facility, such as a power station or natural gas production plant, or in a manner consistent with agreed standards that apply for pipeline approvals or transport of hazardous substances.
- As the identification and characterisation of the sites chosen for the long term geological storage of carbon dioxide is the key factor in determining acceptability of risk, the storage site must be subject to a continuous risk assessment as an essential element of the environmental impact assessment and ongoing management of proposed CCS projects. Proponents will be required to provide a detailed site characterisation (capacity, porosity, stratigraphy, etc.) and reservoir modeling to underpin the assessment and identification of conditions of approval. Under current environmental regulatory regimes, this risk-based approach to approval of storage involves a continuous risk assessment regime for the life of a project.
- Groundwater resources must be included in all risk assessments to protect regional water resources. This will be particularly significant for the Great Artesian Basin and other regional groundwater resources.
- Approval will not be granted for ocean storage of carbon dioxide through injection into the water column, as this is not permitted under the Environment Protection (Sea Dumping) Act 1981 and London Protocol, which limits disposal at sea to materials listed in its Annex.
- CCS proponents are encouraged to consult with the relevant authorities early in the planning stages for any CCS proposal, with consultation including reference to all components of the proposal. Throughout the assessment and approvals process, and other operational phases of the project, CCS project proponents will be required to be open and transparent in dealings with regulators, the general public, and local communities and publicly report, at an appropriate level, on outcomes of monitoring programs.
- Consistent with the internationally agreed definition set out in the London Protocol, the CCS injection stream will be “overwhelmingly carbon dioxide”. The only additional substances are those that are naturally present and/or incidental to the capture or separation stream, or additives such as tracers required to assist in monitoring of injected streams.

Any proposal to include additional quantities of substances already in a CCS stream from sources other than the capture/separation process (i.e. from a facility not related to the primary capture) will be subject to a separate assessment and approval process. Such an assessment must include a full risk assessment and include identification of impacts on the reservoir storage efficiency that arises through changing the composition of the CCS stream.

Monitoring:

- Monitoring of injected carbon dioxide will be essential to provide confidence in CCS. Until experience determines otherwise, CCS projects that become operational in the next decade must include inter alia comprehensive monitoring regimes, including air, groundwater and soil chemistry, in-hole geochemical monitoring, geophysical, including seismic, monitoring and modeling of the carbon dioxide plume.

  Appropriate monitoring will be an essential element in the conditions of approvals for all CCS projects. Monitoring will be required for site safety, environment protection, public health and resource management. In addition, monitoring of stored carbon dioxide will be essential to underpin the verification regime that will be required for the markets arising from introduction of the emission trading scheme.

  Monitoring regimes for CCS projects needs to include baseline monitoring prior to injection and normally include regional scale monitoring beyond the actual CCS injection site. Although proponents will be required to undertake and meet the cost of monitoring, there will be independent assessment of design of monitoring systems as well as independent review of outcomes to ensure environmental and resource management and market objectives are being met.

  In the longer term it is anticipated that the knowledge and understanding gained through the comprehensive monitoring of the earlier projects, such as the Otway Project, will enable regulators and proponents to develop the most appropriate monitoring and verification regime to meet the environmental outcomes and market objectives for large scale commercial projects.

Site Closure:

- Consistent with current practice for industrial facilities and contaminated sites, proponents will be liable for all aspects of a CCS project during the life of the project and be required to meet agreed performance standards for closure, including meeting the cost of post closure monitoring.

  The issue of post closure ownership and liability is yet to be resolved on a nationally consistent basis. The design of the emission trading scheme may impact on ownership of storage reservoirs and stored carbon dioxide through emergence of subsidiary markets. Until these issues can be resolved, the principle of “polluter pays” should apply with proponents being responsible, either through continuing legal liability or by agreement - with a jurisdiction transferring responsibility subject to a mechanism, such as performance bonds or insurance, being in place to meet any costs incurred.

Coordination:

- Jurisdictions will continue to coordinate and consult widely to develop a nationally consistent approach for the environmental outcomes that CCS proponents are required to meet. Although the offshore and onshore environments give rise to significant differences in environmental risk and application of mitigation measures, jurisdictions will seek to ensure consistency in the environmental approval and management regime between offshore and onshore projects.

  Jurisdictions are examining specific CCS legislative options to address a range of uncertainties including access and property rights, third party accesses, cross jurisdiction and boundary issues, risk mitigation, monitoring and verification techniques and liability. Jurisdictions will also continue to consult on streamlining environmental regulation and ensuring consistency in application of environmental approvals.

Useful references

The following websites and key publications provide a range of factual information on CCS science, technologies and projects. Collectively they also provide access to a large number of reference documents and a gateway to the policies, programs, and regulatory framework for projects in many countries.

Websites

International Energy Agency (IEA): www.iea.org

Intergovernmental Panel on Climate Change (IPCC): www.ipcc.ch

Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC): www.co2crc.com.au

Carbon Sequestration Leadership Forum: www.cslforum.org

Publications/Reports

Carbon Dioxide Capture and Geological Storage – Australian Regulatory Guiding Principles, Ministerial Council on Mineral and Petroleum Resources (MCMPR), 2005.

Geological Storage of Carbon Dioxide – Staying Safely Underground – International Energy Agency (IEA) Working Party on Fossil Fuels, January 2008.
http://www.cslforum.org/documents/geostoragesafe.pdf

Intergovernmental Panel on Climate Change, Carbon Dioxide Capture and Storage: Special Report IPCC, 2005.

BACKGROUND ON CARBON DIOXIDE CAPTURE AND GEOLOGICAL STORAGE

Information in this appendix is drawn primarily from published International Energy Agency sources.

Background

Carbon capture and geological storage (CCS) is a system for permanent removal of Carbon Dioxide (CO_2) from industrial sources such as power stations where it is produced as waste product from the combustion of fossil fuels, or from oil and gas production facilities where is produced from natural accumulations in oil/gas fields or as a waste from the process. CCS is a system that is based on imitating the natural storage of oil and gas and carbon dioxide in geological formations for millions of years.

The system of CCS involves capture from power plants, industrial sources, natural gas production facilities with or other point sources; transport via pipelines (or tankers in smaller volumes) to a storage site; and geological storage in deep saline formations, depleted oil/gas fields, unmineable coal seams, and enhanced oil or gas recovery sites.

It is estimated that the global geological storage potential is approximately 80 years current emissions of 2,000 $GtCO_2$ (based on saline formations 400-10,000 Gt; depleted oil/gas fields 900 Gt; unmineable coal seams 30 Gt).

In the case of coal which provides for the basis for 40 per cent of global electricity generation CCS could facilitate the use of large world coal reserves whilst reducing global carbon dioxide emissions. Since coal based power plants have long lifetimes, CCS deployment would imply retrofitting highly-efficient existing plants, which is generally considered to be more expensive than building new power plants with CCS - although there is little consensus on this point.

Based on current understanding, the IEA has estimated that CCS could reduce CO_2 emissions from power plants by more than 85 per cent but with a lowering of power plant efficiency and an emissions increase of up to one third. In the case of power generation from natural gas, studies suggest that an efficiency penalty of only three per cent could be incurred for later retrofitting of new gas power plants conceived for CCS integration.

CCS in biomass-fuelled power plants may result in net CO_2 removal from the atmosphere. However, biomass plants are typically small (25-50 MW vs. 500-1,000 MW coal power plants) leading to the cost per kW for CCS being almost double the cost in coal plants.

While the technical and economic feasibility of CCS is being demonstrated, the construction of CO_2 capture-ready power plants for later retrofitting is becoming an accepted pathway to deal with the uncertainties of the future CCS market. The economics of retrofitting versus new plant may be impacted by the price of carbon and speed with which governments move to impose any emissions penalty. Assuming successful efforts with research, development and demonstration, and the adoption of emissions reduction incentives, significant commercial deployment of CCS could start from mid next decade.

Barriers

The most significant barrier to CCS deployment is cost with capital investment estimated in the order involving hundreds of millions of dollars for a single power plant. With such high overall cost, broad application of CCS is not commercially feasible at this point in time. Although the specific technologies needed for each stage of a CCS system are in use in a range of industrial applications, there is a need for large scale demonstration to establish system integration processes in a commercial operation and to prove safe permanent storage. Such demonstration projects are needed to assist in reduction in the cost of technology as well as building confidence in the safety and effectiveness of CCS for regulators and the general public.

Reducing the cost of CCS also needs to be pursued through enhanced research and development. Research is needed to complement demonstration projects to reduce costs of technologies; identify and develop new capture and storage technologies; develop monitoring and verification methodologies; build knowledge to underpin regulation; and facilitate commercial deployment. In Australia the research is focussed through the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), CSIRO and the Centre for Low Emission Technologies (CLET) which collectively bring together universities, government agencies and private companies from a range of industries. COAG has identified increased research and development effort as a priority in its climate change strategy as the current level of research funding is not regarded commensurate with the scale and urgency of the problem.

The challenge for governments is to stimulate the investment needed to bring about the change to a low emissions economy by de-linking energy consumption, and the related emissions, and economic growth. For the energy sector this will involve demand management measures and the introduction of measures to stimulate deployment of low emission power generation technologies. This requires a long-term approach to the policy and regulatory framework.

Technology Status

Capture

In combustion processes, CO_2 can be captured either in pre-combustion mode conversion of the primary fossil fuel or in post-combustion mode from flue gas.

Pre-combustion capture technology involves gasification of coal or reformation of natural gas to produce a mix of hydrogen and/or carbon monoxide and production of CO_2 in a relatively pure waste stream which is separated by physical or chemical processes. Whilst the technology required for these processes is already applied in the chemical industry, it has not been used at any significant level in the power generation sector. However, there are a range of new projects that are focussed on developing precombustion technology for power generation in integrated coal gasification combined cycle (IGCC) or natural gas combined cycle (NGCC) plants.

In IGCC plants, coal is converted into a hydrogen-rich syngas (hydrogen and carbon monoxide) that is cleaned and burned in a gas turbine. The syngas may be sent to a shift reactor to convert carbon monoxide into CO_2 and further hydrogen.

This process produces highly concentrated CO_2 that is readily removed with relatively low efficiency penalties and cost. Hydrogen is then burned in a gas turbine. In NGCC plants with pre-combustion CO_2 capture, natural gas is converted into hydrogen and CO_2. The hydrogen is used for power generation and the CO_2 is removed for storage.

Post combustion capture is achieved by separation of CO_2 from flue gas in either coal-based or gas-based power stations using processes such as absorption (using amines), adsorption (using zeolites) or physical separation (using membranes). Although some capture technologies are available commercially their application at power stations is not cost effective under current market conditions. However, the long life of existing plants suggests that post combustion capture will be needed to enable national emission targets to be achieved.

The oxyfuel process is an alternative process with either pre-combustion or post-combustion capture and involves the use of pure oxygen rather than air to burn the fuel. This produces a highly concentrated CO_2 stream which facilitates separation from the resulting flue gas. Even though an oxygen supply needs to be produced for this process, oxyfuel is being investigated as it may lead to more cost effective capture.

At oil and gas production facilities, carbon dioxide which is a variable component of the produced gas, is separated and generally vented to the atmosphere. Because CO_2 separation is already part of the production process at many such facilities, it provides a ready made stepping-off point for capture and underground injection. However, more cost-efficient separation technologies are needed for this to become commercially widespread.

There are other technologies being developed which may have application for CCS. The IEA and CO2CRC have detail of current research and development of such technologies on their websites.

Storage

The technologies needed for gas compression, injection underground and monitoring of CO_2 are already commercially applied in gas storage or enhanced oil/gas recovery projects throughout the world. In addition the knowledge and understanding of geological structures and the movement of fluids underground that underpins the existing the oil and gas industry is applicable to long term geological storage of CO_2.

Although globally there are only a handful of operational pilot or demonstration projects, with a combined storage capacity of with 3-4 $MtCO_2$/year, there are proposals for a number of large scale projects in Australia, United States and elsewhere. Around the world there are over 70 enhanced oil recovery (EOR) projects using 40 $MtCO_2$/year from natural and industrial sources, helping increase oil recovery from 5-15 per cent. Whilst EOR projects involve use of technology necessary for CCS and, thus, provide industry with relevant experience, permanent storage of the CO_2 is not an objective for almost all of these projects.

There is a range of other existing industrial projects which can provide experience and understanding that will be applicable to long term geological storage of CO_2. Permanent geological storage of acid gas (mixtures CO_2, SO_2, H_2S and NO_2) produced from some gas fields is undertaken in places such as Canada and provides an analogous system to CCS where safety and permanency of geological storage of a gas/fluid is a key outcome.

There are naturally occurring reservoirs of CO_2 which are exploited to produce supplies for industrial applications including the production of soft drinks. In Australia CO_2 is extracted from naturally occurring geological reservoirs in western Victoria near Warrnambool and at the Caroline project near Mt Gambier in South Australia.

Another analogous system that is practiced widely is storage of natural gas to provide producers with a buffer for continuous supply to the markets. It is most commonly held in inventory underground under pressure in one of three types of structure: depleted reservoirs in oil and/or gas fields; aquifers; or salt cavern formations. Reconditioned mines are also in use as gas storage facilities. The most important characteristics that determines suitability of an underground storage reservoir are its capability to hold natural gas for future use and the rate at which gas inventory can drawn down to meet market demand. Underground gas storage is undertaken at Port Campbell in western Victoria and at the Moomba field in South Australia.

Indicative Cost of CCS

CO_2 capture from combustion processes is expensive and energy-consuming. In the case of power generation, the increased use of fossil fuels resulting from CCS could be as high as 35-40 per cent. This is expected to decline to 10-30 per cent in next-generation plants, and could be as low as six per cent for more speculative designs. Recent IEA analysis indicates that the typical cost of CCS in power plants ranges from US \$30-90/tCO_2 or even more, depending on technology, CO_2 purity and site. This cost includes capture \$20-80/t; transport \$1-10/t per 100 km; storage and monitoring \$2-5/t. The impact on electricity cost is 2-3 UScents/kWh. Assuming reasonable technology advances, IEA projections suggest a cost of CCS by 2030 around \$25/tCO_2, with impact on electricity cost of 1-2 UScents/kWh.

CO_2 separation from natural gas wells is considered to be easier and cheaper to undertake, with estimates of the cost being as low as \$5-15/tCO_2. Although there is not much information available on the cost of capture from other high emission industrial processes such as cement or steel production, it is generally considered that it will be higher that the costs associated with capture at power stations.

THE OTWAY PROJECT – CASE STUDY

Drawn from material provided by the CO2CRC.

The CO2CRC Otway Project is located off the Great Ocean Road, around 40 km from the town of Warrnambool in South-West Victoria (Figure 1). The Otway Project is Australia's first project to demonstrate that carbon dioxide (CO_2) can be safely produced, transported, injected and stored underground.

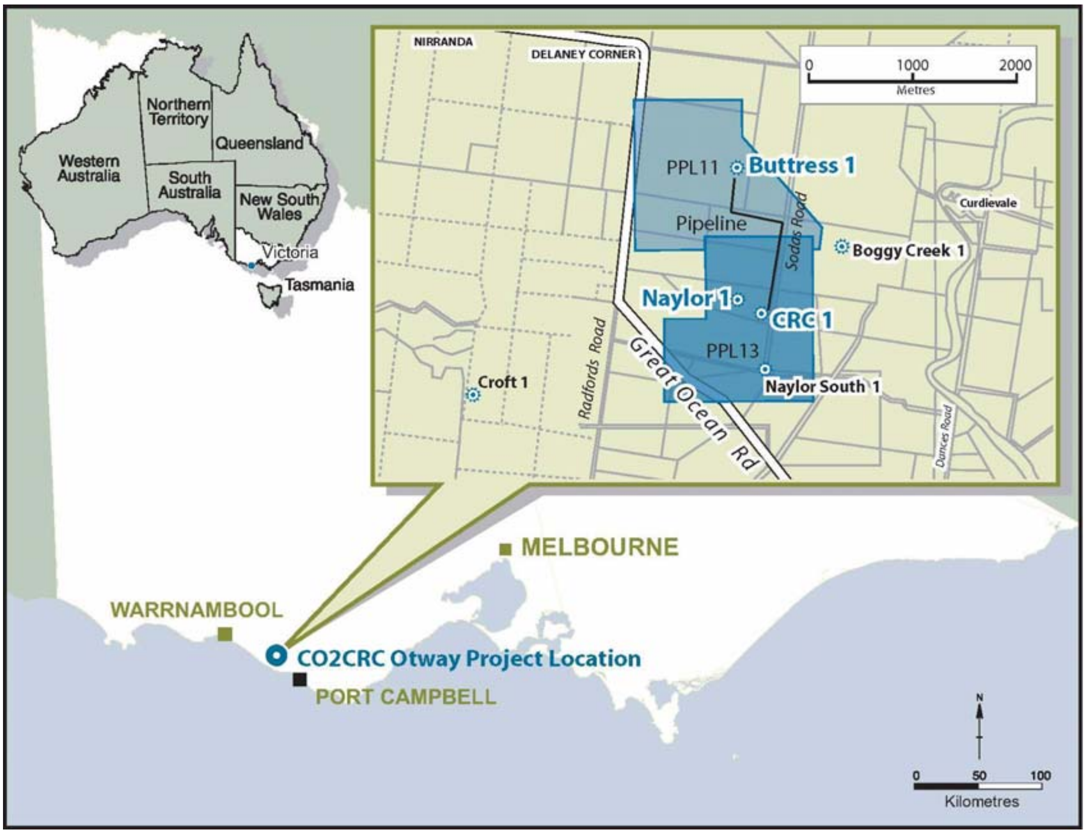

Figure 1: The Otway Project Location

The CO_2-rich gas (80 per cent CO_2; 20 per cent methane) is extracted from an existing well (Buttress-1), processed and compressed through a newly built surface plant before being transported via a new, underground, 2.25 km long, stainless steel pipeline to a new injection well (CRC-1). Over two years, up to 100,000 tCO_2-rich gas stream will be injected via the CRC-1 well, at supercritical state, into a depleted gas field – the Waarre C Formation - at a depth of 2,050 m (Figure 2). The CO_2 will migrate up-dip within the 31m thick reservoir sandstone, which is capped by the impervious thick seal rock, the Belfast Mudstone. Based on the reservoir simulation, it will take 6-9 months after the start of injection for the CO_2 to reach the existing Naylor-1 well, located 300 m from CRC-1. The Naylor-1 well is now equipped with geochemical and geophysical downhole monitoring sensors to detect the CO_2 arrival. The Monitoring & Verification (M&V) program of the Otway Project is one of the most comprehensive ever undertaken anywhere in the world and will help to prioritise requirements for future commercial scale projects and to develop a CCS regulatory framework suitable for Australia.

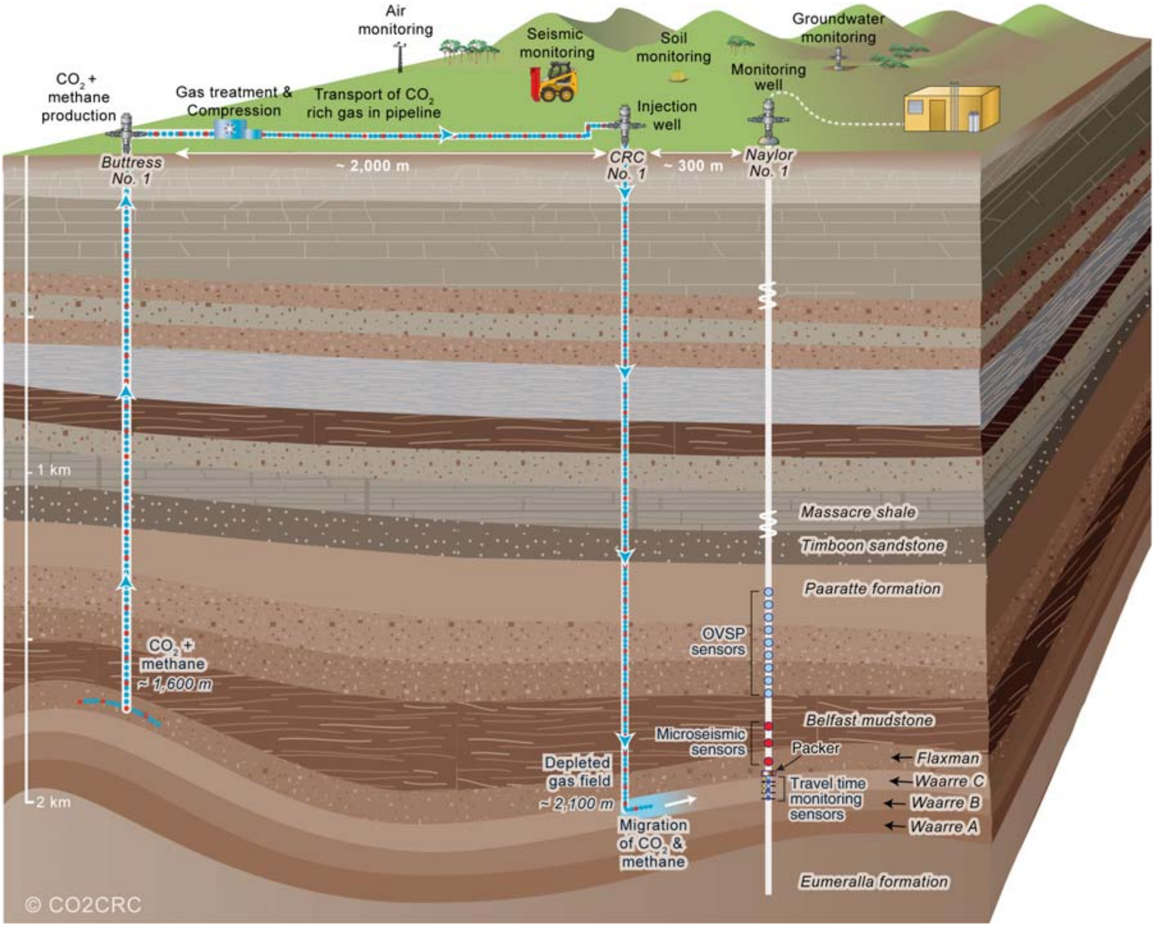

Figure 2: Otway Project description

The absence of a legislative CCS regime in Australia meant that the project faced both organisational and regulatory challenges. A new company, CO2CRC Pilot Project Limited (CPPL), was established to address the issues of asset ownership. CPPL, made of a consortium of 10 major companies, purchased the two oil & gas tenements (PPL 11 & 13), accessing the CO_2 source and the existing gas wells (Figure 1). Whilst CPPL carries on site operational liabilities, the day to day operation of the project is carried out by a lead contractor (AGR). CO2CRC coordinates the research activities and any IP generated from the project is transferred to CO2TECH, the CO2CRC commercial arm. The $30 million project funding, received from Government agencies (~$20 million) and from Industry ($10 million), is managed by the CO2CRC.

The regulatory approval processes associated with development of the Otway Project has cut new ground in testing the existing regulations. By working closely with the Victorian regulators, the approval process for the project was clarified and summarised (Table 1). *The Petroleum Act 2000*, administered by the Department of Primary Industries (DPI), applied to all surface operations including the production and compression of CO_2. The construction of the pipeline was carried out under the gathering line of the Victorian Petroleum Act (VPA), with an exemption from the Pipeline Act granted. The drilling operations of the injection CRC-1 well were also conducted under the VPA. As the result of the 2006 amendments to the Planning Scheme Amendment, the proposed Otway Project area was rezoned from “Rural” to “Farming” which prohibits new activities such as CO_2 geosequestration.

An exemption to the *Planning and Environment Act 1987* was successfully sought to allow the project to proceed. A Cultural Heritage survey was performed during the pipeline installation to comply with the Cultural Heritage Act and the project area was thought to be of low cultural sensitivity.

Activity	Application Process
Production of CO_2	• Petroleum Act 2000 (DPI).
Compression & Transport of CO_2: 1) Plant (compressor) 2) Gathering line 3) Other facilities (centre, etc…)	• Petroleum Act 2000 (DPI) • Ministerial Amendment request of the Planning & Environment Act 1987 (Moyne Shire/DSE) • Exemption of Pipeline Act 2005 (DPI) • Cultural Heritage Act (DPI) • Compensation agreement: consent to land access • Project of State Significance and Compulsory Acquisition (DOI) • Exemption of Rural Fire Service (CFA)
Drilling of New well	• Well being drilled under exploration license.
Injection of CO_2 (CRC-1)	• Water Act 1989 Section 76 & 67: Application for approval to dispose of matter by means of a bore) • Compensation agreement: consent to land access
Storage of CO_2	• Environment Protection Act 1970: Research Development and Demonstration (RDD) Approval
Monitoring & Verification 1) Atmospheric 2) SOBN Water wells 3) Downhole Monitoring	• Ministerial Amendment request of the Planning & Environment Act 1987 (Moyne Shire/DSE) • Consent to use State Observation Bores Network (SOBN) bores (DSE) • Compensation agreement: consent to land access

Table 1: Summary of the Otway Project regulatory approvals

Rights to access the privately owned land including the production, injection and monitoring sites was obtained through compensation agreements with various landowners, or through the *Planning and Environment Act 1987* (declared as Project of State Significance).

The injection approval process was granted under Section 76 of the *Water Legislation Act 1989* – approval to dispose of matter underground by means of a bore - through the Southern Rural Water. The CO_2 storage conditions were approved by the Victorian Environment Protection Authority (EPA) under the research, development and demonstration provisions of the *Environment Protection Act 1970*. Conditions of approval are underpinned by a set of key performance indicators (KPIs). Five phases (pre-injection, during, post-injection, post-closure and long term) were determined with each phase having a set of KPIs based on expected monitoring outcomes. Key monitoring activities are determined in the sub-surface, near-surface, surface and atmospheric domains to detect migrating CO_2 or to verify performance of predicted behaviour. Monitoring emphasis and frequency vary depending on the phase. The M&V plan also defines trigger points and contingency actions, should the storage site not function as anticipated.

Detailed site characterisation was essential to establish a robust risk assessment and M&V plan, both of which are regularly updated and peer-reviewed throughout the project in the light of new data. The baseline conditions are now successfully established across all domains.

The project was also referred to the Australian Government under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), to determine if assessment was required for potentially significant impacts on matters of National Environmental Significance, such as listed threatened and migratory species. It was determined that assessment and approval was not required under the EPBC Act.

It took over two years to obtain all the regulatory approvals for the project. Long term liability issues have been resolved as CPPL has accepted to take on the long term liabilities at common law, in addition to liabilities associated with field operations. CO_2 injection started in March 2008.

The Otway Project has addressed a range of technical and non-technical challenges through a team-based approach involving scientists, engineers, industry partners, regulatory agencies and the community. Through the Project, proponents and regulators are gaining insights into carbon storage approval and regulatory issues which will assist in developing CCS legislation. The monitoring and verification regime for Otway Project is providing knowledge and experience that will inform development and regulation of future commercial projects.

CCS PROJECTS

Information drawn from publications of the International Energy Agency (IEA) and the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC)

Operational International projects

Weyburn (Canada)
The Weyburn CO_2-enhanced oil recovery (CO2-EOR) project is located in the Williston Basin, a geological structure extending from south-central Canada into north-central United States. The project aims to permanently store almost all of the injected CO_2 by eliminating the CO_2 that would normally be released during the end of the field life. The source of the CO_2 for the Weyburn CO2-EOR Project is the Dakota Gasification Company facility, located approximately 325 km south of Weyburn, in North Dakota, USA and where coal is gasified to make synthetic gas (methane), with a relatively pure stream of CO_2 as a by-product. Over the life of the CO2-EOR project (20-25 years), it is expected that some 20 $MtCO_2$ will be stored in the field. Since CO_2 injection began in late 2000, the EOR project has performed largely as predicted. Currently, some 1,000 tCO_2 per day is reinjected; this will increase as the project matures. Monitoring involves high-resolution seismic surveys and surface monitoring to determine any potential leakage. Surface monitoring includes sampling and analysis of potable groundwater, as well as soil gas sampling and analysis. To date, there has been no indication of CO_2 leakage to the surface and near-surface environment.

In Salah Gas (Algeria)
The In Salah Gas Project, a joint venture among Sonatrach, BP and Statoil located in the central Saharan region of Algeria, is the world's first large-scale CO_2 storage project in a depleted gas reservoir. The Krechba Field at In Salah produces natural gas containing up to 10 per cent CO_2 from several geological reservoirs. The project involves re-injecting the CO_2 into a sandstone reservoir at a depth of 1,800 m and storing up to 1.2 $MtCO_2$ per year. Carbon dioxide injection started in April 2004 and, over the life of the project, it is estimated that 17 $MtCO_2$ will be geologically stored. Processes that could result in CO_2 migration from the injection interval have been quantified and a monitoring program is planned involving a range of technologies, including noble gas tracers, pressure surveys, tomography, gravity baseline studies, microbiological studies, four-dimensional seismic and geomechanical monitoring.

Sleipner (Norway)
The Sleipner Project, operated by Statoil in the North Sea about 250 km off the coast of Norway, is the first commercial scale project dedicated to geological CO_2 storage in a saline formation. The CO_2 is produced in the gas stream at the Sleipner West Gas Field and is separated and injected into a deep saline formation 800 m below the seabed of the North Sea. Approximately 1 $MtCO_2$ is removed from the produced natural gas and injected underground annually in the field. The CO_2 injection operation started in October 1996, and over the lifetime of the project a total of 20 $MtCO_2$ is expected to be stored. The saline formation into which the CO_2 is injected is a brine-saturated unconsolidated sandstone about 800-1,000 m below the sea floor. The fate and transport of the CO_2 plume in the storage formation has been monitored successfully by seismic time-lapse surveys. The surveys also show that the caprock is an effective seal that prevents CO_2 migration out of the storage formation.

Today, the footprint of the plume at Sleipner extends over an area of approximately 5 km^2. Reservoir studies and simulations covering hundreds to thousands of years have shown that CO_2 will eventually dissolve in the pore water, which will become heavier and sink, thus, minimising the potential for long-term leakage.

Snohvit (Norway)
The Snohvit Project is Europe's first Liquefied Natural Gas plant and is the first offshore gas field found in the Barents Sea. Snøhvit will be the first major development on the Norwegian continental shelf without a fixed or floating unit. Instead, a subsea production system on the seabed will feed a land-based plant on the north-western coast of Melkøya via a 160 km gas pipeline. The natural gas from the Snøhvit field contains five to eight per cent carbon dioxide. The carbon dioxide is removed at the land based facility and piped back to the field rather than being released into the atmosphere. A total of 0.7 $MtCO_2$ produced with the gas on the Snøhvit field is to be stored 2,600 m beneath the seabed at the edge of the reservoir. Carbon dioxide will be reinjected into the Tubåsen sandstone formation, which is between 45 and 75 m thick and lies somewhat deeper than the gas formations. A sealing formation which lies above the sandstone will ensure that the carbon dioxide does not leak out. Carbon dioxide storage on the Snøhvit field is the second large storage project initiated by Statoil.

There are a range of small research projects and proposed large scale projects in a number of countries. The IEA includes details of these projects on their website.

Australian Projects

Operational

CO2CRC Otway Project, Victoria
This is Australia's first storage project which commenced injection of 100,000 tCO_2 from a nearby gas well, in April 2008, initially into a depleted gas field at a depth of 2 km. A major program of monitoring and verification has been implemented. The $40 million Project, which is supported by 15 companies and 7 governments, involves researchers from Australia, New Zealand, Canada, Korea and the USA. CO2CRC Pilot Project Ltd, the operating company, has its members AngloCoal, BHP Billiton, BP, Chevron, Schlumberger, Shell, RioTinto Solid Energy, Woodside and Xstrata.

Proposed

CallideOxyfuelsProject,Queensland

This demonstration project launched in November 2008 involves conversion of an existing 30 MW unit at Callide A (currently underway), and capture of CO_2. The second stage of the project will involve the injection and storage of up to 50,000 tCO_2 captured in saline aquifers or depleted oil/gas fields, and will continue for up to five years, commencing in 2010. This project is expected to cost $200 million. Participants in the project include CS Energy (who own the power station), IHI – a major Japanese boiler maker - J-Power – a Japanese power generator - Mitsui & Co, Xstrata Coal, Schlumberger, ACA and CO2CRC.

Coolimba Power Project, Western Australia
Aviva Corporation Ltd released it Public Environmental Review on 28 May 2009, closing 23 June 2009. Located 270km north of Perth, Coolimba consists of 2x200 MW oxyfuel coal fired power station, a 360MW gas fired power station and 2.9 million tonne per annum CCS when feasible. Construction is anticipated 2010 – 2014.

Gorgon Project, Western Australia
Chevron (operator) - Shell - Exxon are planning a major sequestration project linked to the Gorgon LNG Project. The separated CO_2 will be injected under Barrow Island to a depth of about 2.5 km, with injection of 3-4 $MtCO_2$ per year, and a total of 125 $MtCO_2$ injected over the life of the project, which is planned to commence around 2012-2013. A data well has been drilled and a major study of the subsurface is underway.

Hazelwood and Loy Yang PCC Projects, Victoria
These projects involve drying of brown coal and retrofitting of post combustion capture of CO_2. International Power is developing a large scale facility at Hazelwood that will capture and chemically sequester CO_2 at a rate of 10,000-20,000 tCO_2 per annum. Partners include Alstrom, RWE, Process Group AND Co2CRC. A CSIRO mobile pilot PCC facility commenced trails at the Loy Yang power station in July 2008 capturing around 5000 tCO_2 per annum. The $5.6million Latrobe Valley PCC Capture Project is a collaboration between Loy Yang Power, International Power Hazlewood, the Victorian Government, CO2CRC and CSIRO. Storage is not involved.

PCC Demonstration Project, Latrobe Valley, Victoria
The definition of a demonstration project aimed at integrated capture and storage of at least 50,000 tonne per annum of CO_2 from a PCC retrofit of an existing generator in the Latrobe Valley is on hold pending the outcome of a Victorian Government Request for Proposal under its Energy Technology Innovation Scheme anticipated in December 2009.

HRL IDGCC Project, Victoria
A proposed 400 MW power generation plant in Victoria will involve integrated drying gasification combined-cycle (IDGCC) using brown coal. CO_2 emissions will be captured at a pilot scale initially. The total project is estimated to cost over $750 million. Partners include HRL Technology, Harbin and CO2CRC.

Monash CTL Project, Victoria
This proposed project, on hold as of December 2008, will involve drying and gasification of brown coal, for conversion to synthetic diesel, followed by the separation of the produced CO_2 (up to 10 Mt a year), and its transport and injection into a suitable storage site. This project which has an indicative start date of 2015 is estimated to cost $6-7 billion. Capture and offshore storage is expected to commence in 2015. Partners involved in this project include Monash Energy, Anglo American and Shell.

Moomba Carbon Storage Project, South Australia
This project, on hold as of April 2009, will involve establishing a regional carbon storage hub in the Cooper Basin. The first (demonstration) phase, will involve the capture of CO_2 from existing gas processing facilities and injecting 1 $MtCO_2$ commencing in 2010, to re-pressure oil reservoirs for enhanced oil recovery. Partners in this project include Santos and Origin.

Munmorah PCC Project, New South Wales
This research scale pilot project is investigating the post carbon capture (PCC) ammonia absorption process, and the ability to adapt it to suit Australian conditions. Capture of up to 3,000 tCO_2 for the pilot phase, using the CSIRO technology developed in the Victorian pilot trials commenced in 2009. Delta Electricity has developed a business case for the next stage demonstration of integrated capture and storage of at least 50,000 tonne per annum and is proceeding to pre feasibility. The definition of the project is dependent on the results of storage availability currently under investigation.

Perdaman Urea Project, Collie ,WA
In March 2009 Perdamin Chemicals and Feriliser released details of a plan to construct a urea manufacturing plant in Collie. The plant will have a 2 million tonne per annum capacity. A 214MW IGCC power station is proposed as part of an integrated facility. The project will be carbon capture ready.

Tarong PCC Project, Queensland
Commencing September 2008 CSIRO and Tarong Energy is conducting a $5million PCC pilot capture only program at Tarong Power station , south of Kingaroy. The pilot plant is designed to capture at 1,500 tonne per annum in a program building on the work at Loy Yang in Victoria and Munmorah in NSW. The capture process will be amine based and will operate from July 2009 until 2011.

Wandowan IGCC Project, Queensland
The Queensland Gasification Power Consortium (GE Energy and Stanwell Corporation) are proposing to construct a 700-750 MW commercial scale IGCC with CCS power station to be located at Wandoan in Queensland's Surat Basin. The Consortium has formed an alliance with Xstrata coal and Santos. Xstrata Coal is expected to provide coal for the life of the project from their proposed new mine at Wandoan. Storage is under investigation at sites in Queensland and South Australia. An initial business case has been lodged with RET

ZeroGen Project, Queensland
This Queensland Government project seeks to deploy commercial scale IGCC with CCS by 2015-2017. ZeroGen, in partnership with a Japanese consortium lead by Mitsubishi Heavy Industries, proposes a 550MW IGCC with CCS power plant capturing 65 – 90 per cent of carbon dioxide emissions for injection and safe storage of 2million tonne per annum in deep underground reservoirs in the Northern Denison Trough. The project is proceeding to pre-feasibility with a Final Investment Decision anticipated mid 2011. The Queensland Government and the Australian Coal Association have committed $300million to an IGCC project. At estimated cost of $4b, any IGCC project will require substantial Australian Government funding