

Carbon Capture and Storage

CCS IN AUSTRALIA

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Executive Summary

Large scale carbon capture and storage projects have been world-widely deployed, aiming to mitigate the climate change by reducing the main component of the greenhouse gases - carbon dioxide. By either upgrading the existing power plants to CCS capable ones or building new integrated CCS power plants, a number of countries have invested billions of dollars on study, develop and implement the new technology. CCS technology alone might not work best without the assistance from political regulations, such as carbon tax. Integrated climate change mitigation portfolio standards combining CCS technology and political regulations will be the primary choice in the future.

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Carbon Capture and Storage

Introduction

Background

It is widely recognized that global warming is occurring due to increasing levels of carbon dioxide and other greenhouse gases in the atmosphere, as shown in Figure 1. It has led many countries to study innovative solutions to reduce these emissions without sacrificing the standard of living that the combustion of fossil fuels and other industries has afforded. One of the mitigation approaches for the main component in greenhouse gas, carbon dioxide, is direct sequestration: CO₂ is separated from burning fossil fuels from large power plants, compressed into a liquid-like form and transported by trucks or pipes, injected into deep underground, and stored to avoid its release to the atmosphere. Carbon capture and storage (CCS) is still quite a new technology and is at an early stage of deployment. There have been several major CCS projects proposed and undertaken since the technology was introduced. Although CCS has a relatively small market penetration [1], it has the potential to play an important role in the portfolio of climate change mitigation technologies, supplementing the carbon emission reductions to be achieved by energy efficiency, conservation, and renewable energy technologies.

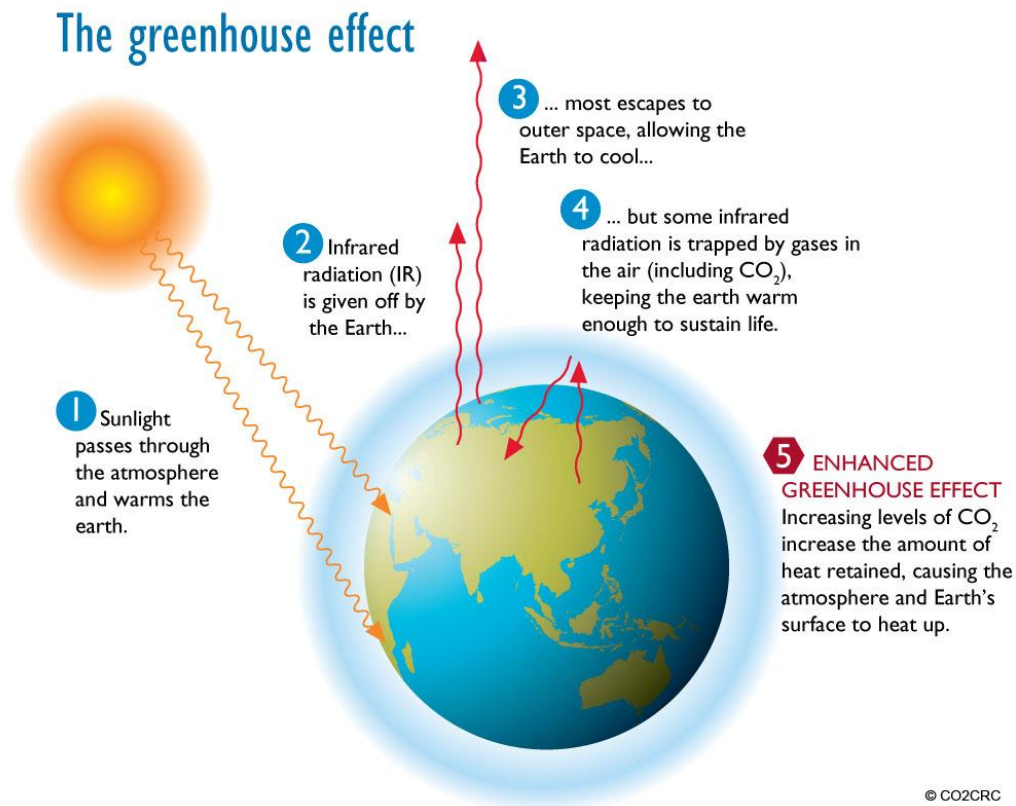


Figure 1 - The greenhouse effect [2]

Technology Innovation

CCS technology is not only an approach to reduce carbon dioxide emissions, but a technology innovation. Every new technology has to go through an innovation process before it is deployed at full scale. The process generally goes by RDD&D - Research, Development, Demonstration, and Deployment [3]. Table 1 describes the characteristics of each of these stages, taking CCS technology as an example.

Table 1 - Stages in the technology development process [4]

Stage	Description	Current CCS examples (2010)
Research	Fundamental research and experimental proof of concept, led by academic or industrial research organizations. Relatively low-cost exploration of a wide range of potential options. Definition of a "road map" detailing further fundamental and applied research requirements. Broad-brush estimate of eventual deployment costs and commercial viability.	Amine-facilitated transport membrane for post-combustion CO ₂ separation from flue gas
Development	Progress along the development road map; applied research focusing on process engineering and system integration; laboratory- and pilot-scale demonstration of the process. Additional fundamental research may be spawned as further implementation issues are identified. Refined construction and operating cost estimates and indications of commercial viability.	Hybrid combustion-gasification chemical looping using calcium compounds
Demonstration	Initial industrial-scale implementation, often funded by government and industry partnerships. May involve the integration of existing, proven technologies in a new application. Evaluation and improvement of the design, construction, and operating processes. Budget-level definition of construction and operating costs.	Air-separation plant using ion transport membrane to supply oxy-fuel combustion
Deployment	Progressive commercial implementation, which in the early stages, may be accelerated by economic incentives in the form of capital grants or premium prices.	Transportation of CO ₂ by pipeline; geological storage for enhanced oil recovery

Given the many and varied technologies that are being developed to address the challenges of CCS and the global record of technical innovation and progress of the past century, pursuit of these technologies has a high likelihood of delivering solutions that can meet the challenge. However, success in this venture also requires a globally shared political will and sense of urgency to create the enabling conditions for the deployment of these technologies on a massive scale [5]. Whether that consensus and urgency will develop at a pace equal to the challenge is perhaps a bigger uncertainty than whether the technologies can deliver.

Overview of Carbon Capture and Storage (CCS)

Definition

CCS is an integrated process, made up of three distinct procedures: carbon capture, transport, and storage (including measurement, monitoring and verification) [6]. Figure 2 shows how carbon capture and storage works.

Carbon capture is the most energy-intensive part of the process. Carbon capture systems have yet to be applied to a single utility scale coal-fired power station anywhere in the world. Costs for installation are estimated to result in a near doubling of plant costs. Retrofits could be even more costly.

CO₂ can be transported to a storage location via pipelines, ships, rail or road transport. Cost considerations and proximity to water bodies leaves pipelines as the likely choice for most CCS operations.

The construction of network of pipelines for CCS is likely to require a considerable outlay of capital. Costs will depend on a number of factors. Pipelines built near population centers or on difficult terrain will be more expensive. Costs also increase the further CO₂ needs to be transported.

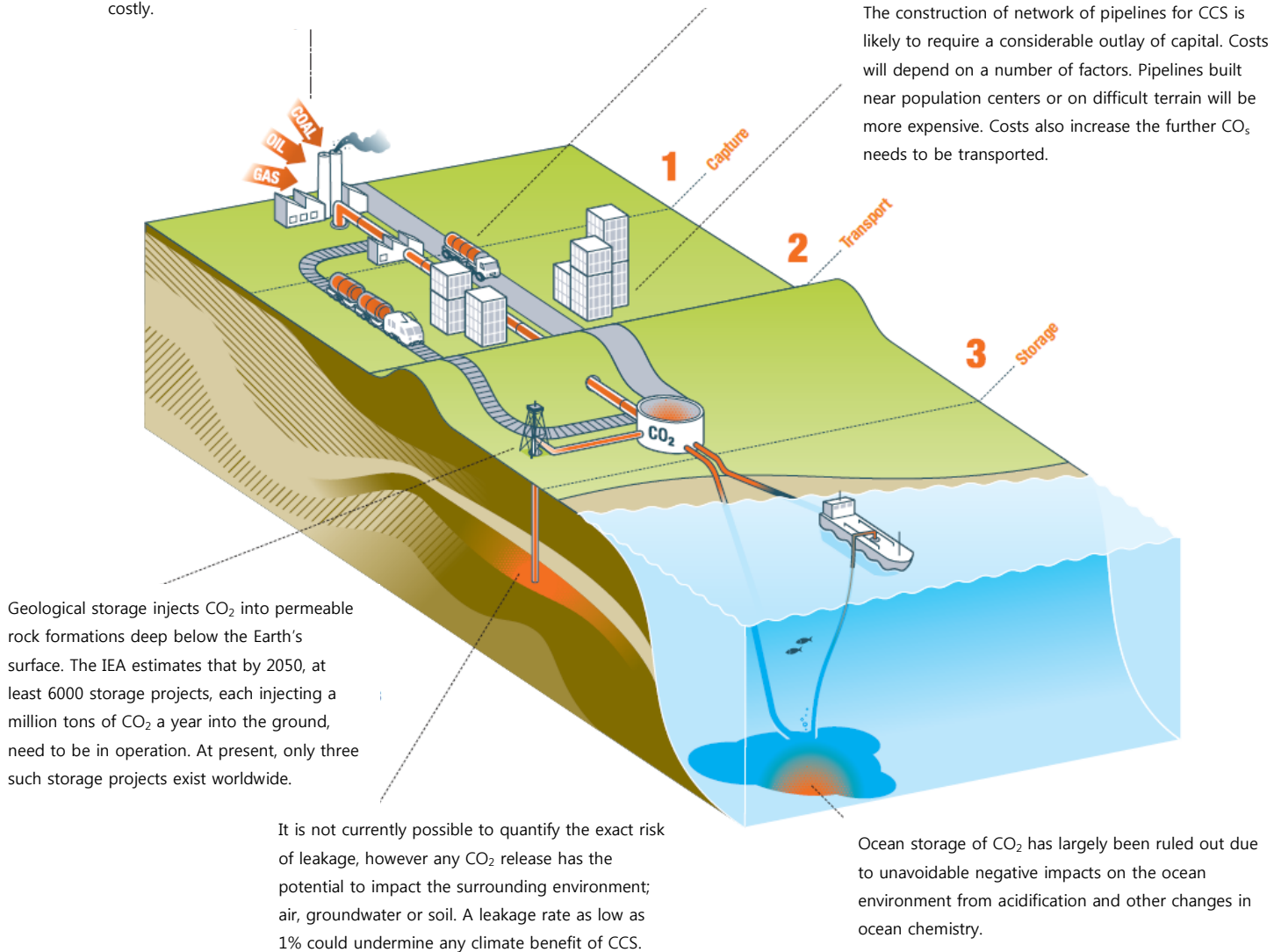


Figure 2 - Carbon capture and storage at a glance [6]

The three distinct processes are briefly described in Figure 2.

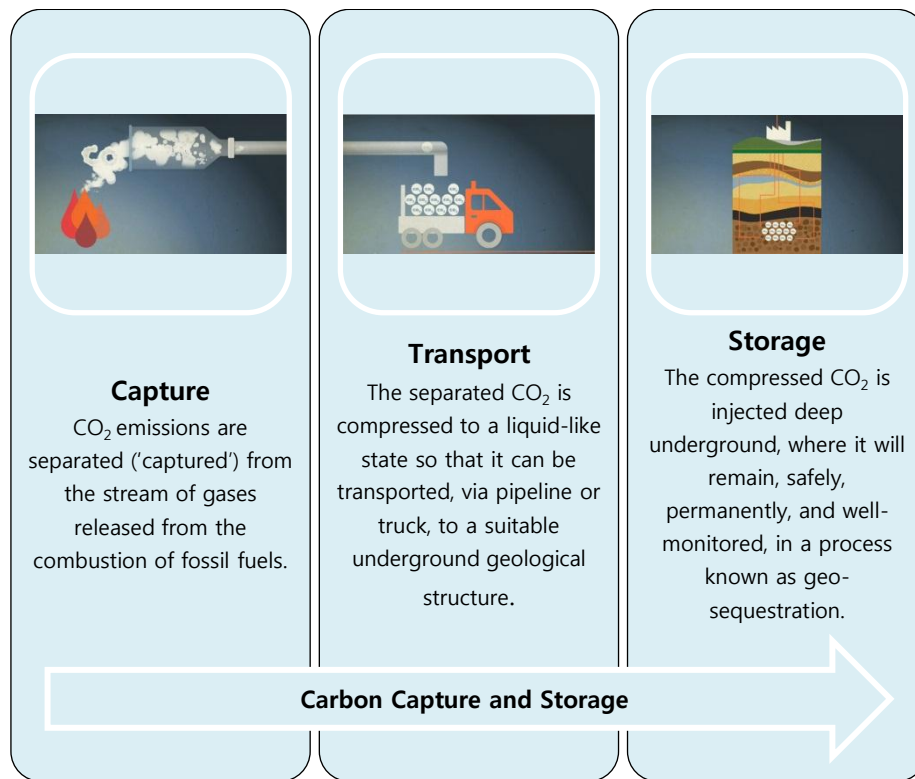


Figure 3 - Processes of CCS [7]

Capture

To date the most energy intensive portion of the CCS process, carbon capture produces a concentrated stream of CO₂ that can be compressed, transported, and eventually stored. Depending on the process or power station, three approaches to capture exist; pre-combustion, post-combustion and oxy-fuel combustion.

Pre-combustion capture process removes CO₂ from fossil fuels before combustion by converting it into a gas (gasification), which consists of carbon monoxide, methane and hydrogen. The carbon monoxide is reacted with water, usually by a physical or chemical absorption process [8], to produce hydrogen and CO₂ – the CO₂ is then captured. Pre-combustion technology is not yet mature but is intended for deployment in conjunction with Integrated Gasification and Combined Cycle (IGCC) power stations. However, significant engineering challenges need to be overcome before large-scale integration of coal-based IGCC and CCS can occur [9].

Post-combustion capture process separates CO₂ from the gas stream produced after coal or other fossil fuels are burnt (combusted) for electricity. For CO₂ capture, chemical absorption with amines, such as monoethanolamine (MEA), is currently the process of choice. Once recovered, the CO₂ is cooled, dried and compressed for transport. It's the most well-developed capture process, capable of removing up to 90% of emitted CO₂, and its systems are promoted as a carbon mitigation solution for existing coal-fired power plants worldwide [7].

Oxy-fuel combustion capture burns fossil fuels in 95% pure oxygen instead of normal air. Virtually all the gas that's emitted is composed of CO₂ (greater than 80%) and water vapor: the vapor is condensed out and the CO₂ is then captured. However, substantial issues relating to controlling combustion and the cost of producing

oxygen must be overcome before this technology is viable. To date, this form of carbon capture has only been demonstrated at laboratory and pilot scale (up to 3 MW) [6].

Figure 4 shows the pre-combustion, post-combustion and oxy-fuel combustion processes for carbon dioxide capture.

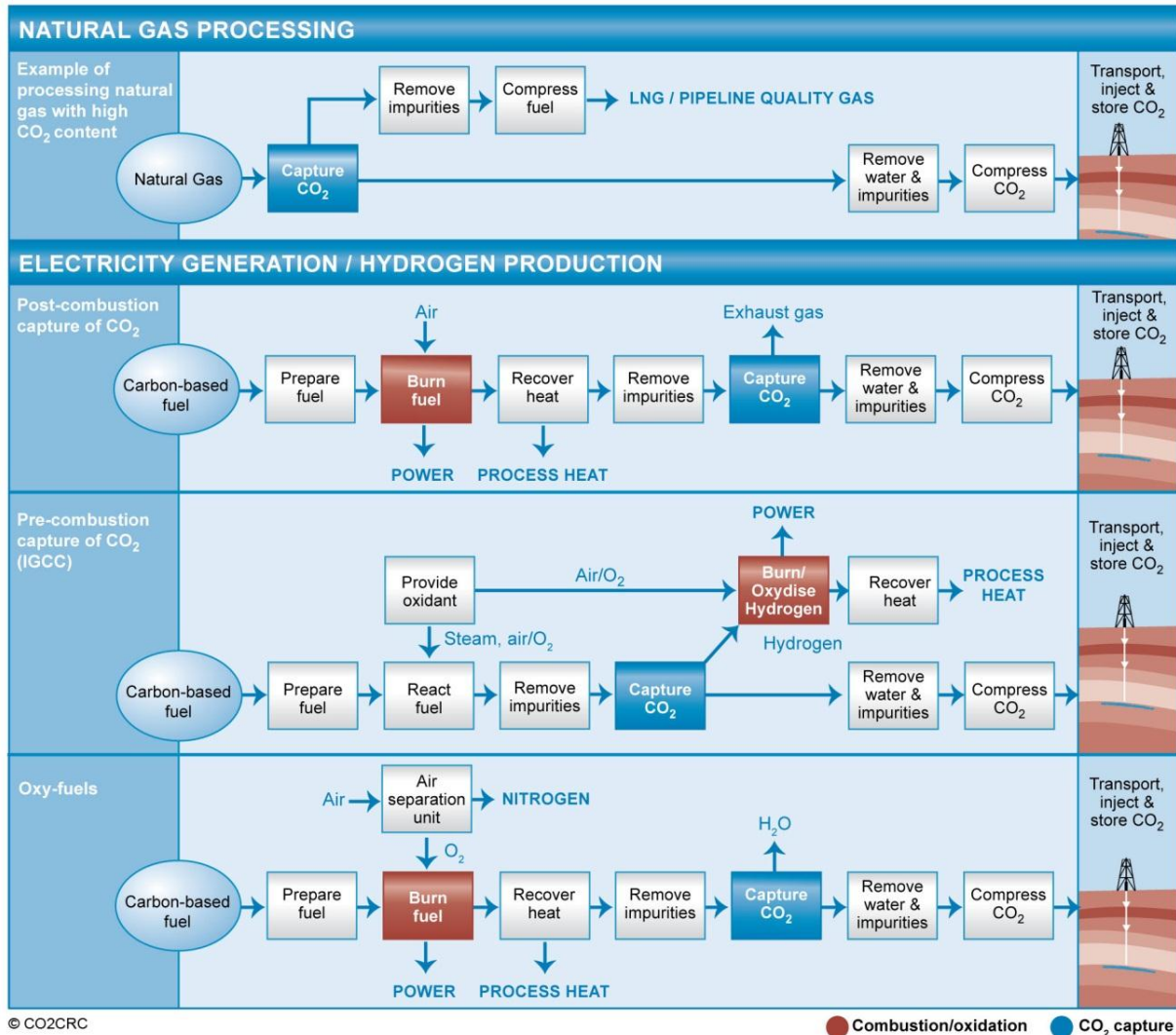


Figure 4 - Carbon dioxide capture processes [10]

Transportation

Before CO₂ can be transported it must first be compressed at high pressure into a liquid-like state. The technologies available to transport CO₂ are very similar to those used for many years in the natural gas industry [11]. However, unlike natural gas, CO₂ is essentially a stable and inert substance [7].

The best way to transport CO₂ depends on the quantity, terrain and transport distance required [4]. Tanker trucks may be used for smaller volumes over short distances. Pipelines are a logical choice for large volumes over short, medium or long overload distances.

Transporting carbon dioxide via pipelines requires compression of the gas to a supercritical (dense) or liquid state to reduce its volume. It also requires a dry, pure stream of CO₂ to reduce the risk of pipeline corrosion.

The dangers [12] associated with transporting CO₂ are relatively low as it is neither flammable nor explosive. However, CO₂ is denser than air and tends to pool in low-lying, poorly ventilated areas posing a hazard to human health if it reaches concentration levels higher than 3% by volume.

Thousands of kilometers of CO₂ pipeline are already in existence in the US, and have been transporting CO₂ for Enhanced Oil Recovery for many years.

Storage

The final stage of CCS is storage, which is the long-term isolation of CO₂ from the atmosphere. There are several geological storage options as shown in Figure 5.

Overview of geological storage options

1. Deep coal seams

In these formations, CO₂ is stored via a mechanism that leads to the release of methane. Substantial technical concerns related to the injection of CO₂ and subsequent storage processes limit the immediate attractiveness of these sites.

2. Depleted oil and gas reservoirs

These reservoirs tend to be the best characterized of all available storage options. However, the multiple bore holes and wells drilled to find and extract oil and gas can increase the leakage risk for storage operations.

3. Enhanced Oil Recovery (EOR)

EOR involves injecting CO₂ into geological formations to achieve greater oil recovery. EOR sites are ultimately too few and too geographically isolated to accommodate much of the CO₂ from widespread capture operations.

4. Deep saline formations (a) onshore (b) offshore

Deep saline aquifers are porous rock, which contain very saline water. The major obstacles to full exploitation of this storage option are accurate characterization and demonstration that safety and environmental protection can be assured.

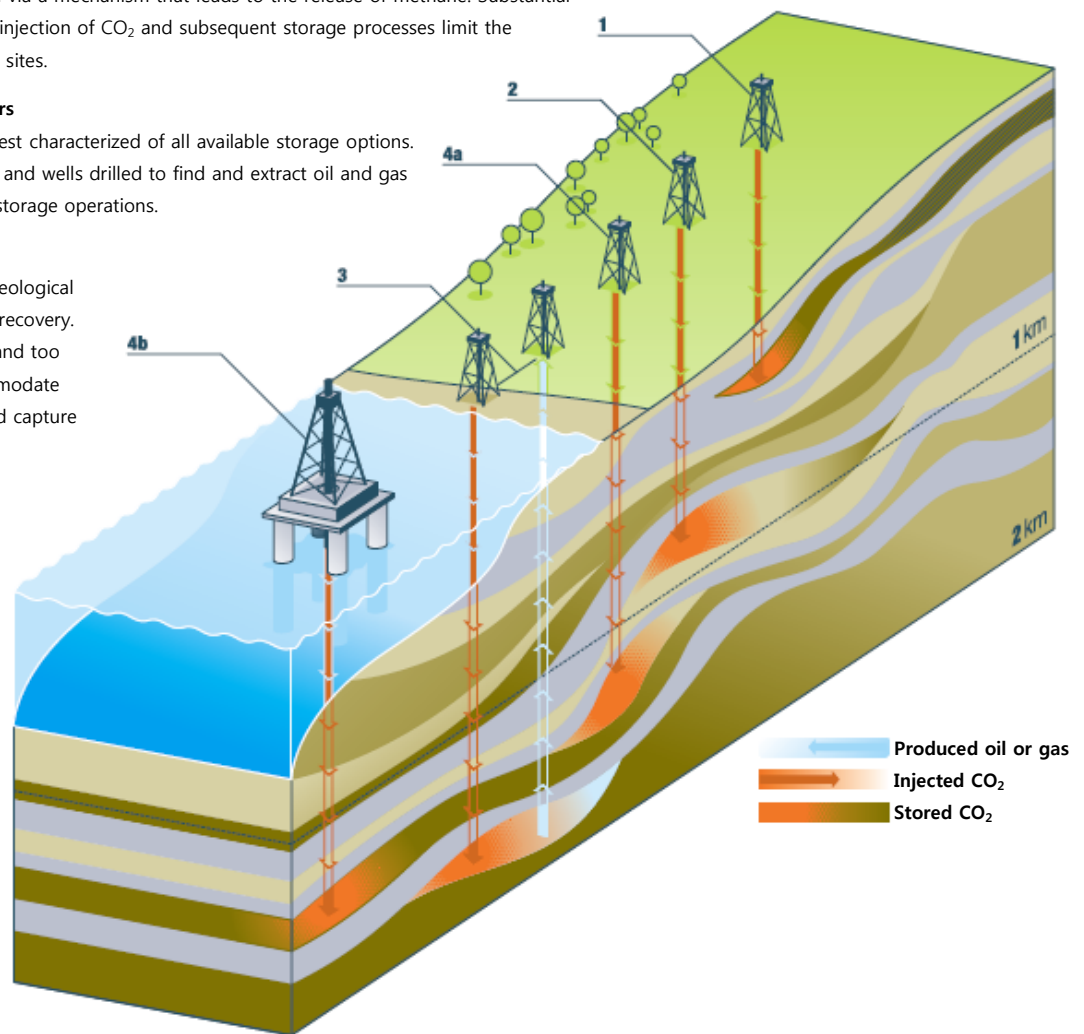


Figure 5 - Geological storage options for CO₂ [6]

The comparison of different storage method is shown in Table 2, together with pros and cons of each method.

Table 2 - Comparison of different CO₂ storage methods [11]

Storage Method	Description	Pros	Cons
Underground Storage	In geological reservoirs such as depleted oil / gas fields, unmineable coal beds or deep saline formations. This method of storage is also referred to as 'geo-sequestration'.	Most advanced CO ₂ storage technology. Individual parts of the CCS process chain already operate at demonstration or commercial scales.	The entire, integrated CCS process chain has not yet been proved. This technology is also expensive compared to the current price of carbon.
Ocean Storage	Direct release into the ocean; either into the water column or onto the seafloor.	Oceans have a large capacity to absorb and store CO ₂ .	The ocean is an open system and it would be difficult to contain and monitor stored CO ₂ . The impact of raised levels of CO ₂ on marine ecosystems is also poorly understood.
Use in Industrial Processes	e.g. in fertilizer production, refrigeration, food & beverages, etc.	These processes and industries already exist on a commercial scale.	Only a very small amount of CO ₂ is used for these purposes, and it is only stored for days to months, so would not contribute meaningfully to climate change mitigation.
Solid Storage	Transform CO ₂ gas into solid carbonate minerals.	Results in inert, natural mineral compounds which are stable over long periods of time, and do not release CO ₂ back into the atmosphere.	This technology is costly and energy inefficient, and still only at the research phase.

CO₂ is injected at depth below 0.8 km (2600 feet). CO₂ increases in density with depth and becomes a supercritical fluid below 0.8 km. Supercritical fluids take up much less space, as shown in Figure 6, and diffuse better than either gases or ordinary liquids through the tiny pore spaces in storage rocks. The numbers next to the 'balloons' and 'water drops' show the volume of CO₂ at each depth compared to a volume of 100 at the surface. CO₂ is best stored in sedimentary basins which contain porous rock, such as sandstone, which can absorb the liquefied CO₂ [13]. Deep saline aquifers which contain highly saline water and sandstone rocks are the most suitable formations for storage of liquefied CO₂. Sandstones have high porosity and permeability, as shown in Figure 7, and clay rich rocks with low porosity and permeability can be good seals. The method of trapping the CO₂ is similar to how natural gas remains trapped deep beneath the earth for millions of years. A covering layer of impermeable shale rock ensures the CO₂ will remain trapped deep beneath the earth.

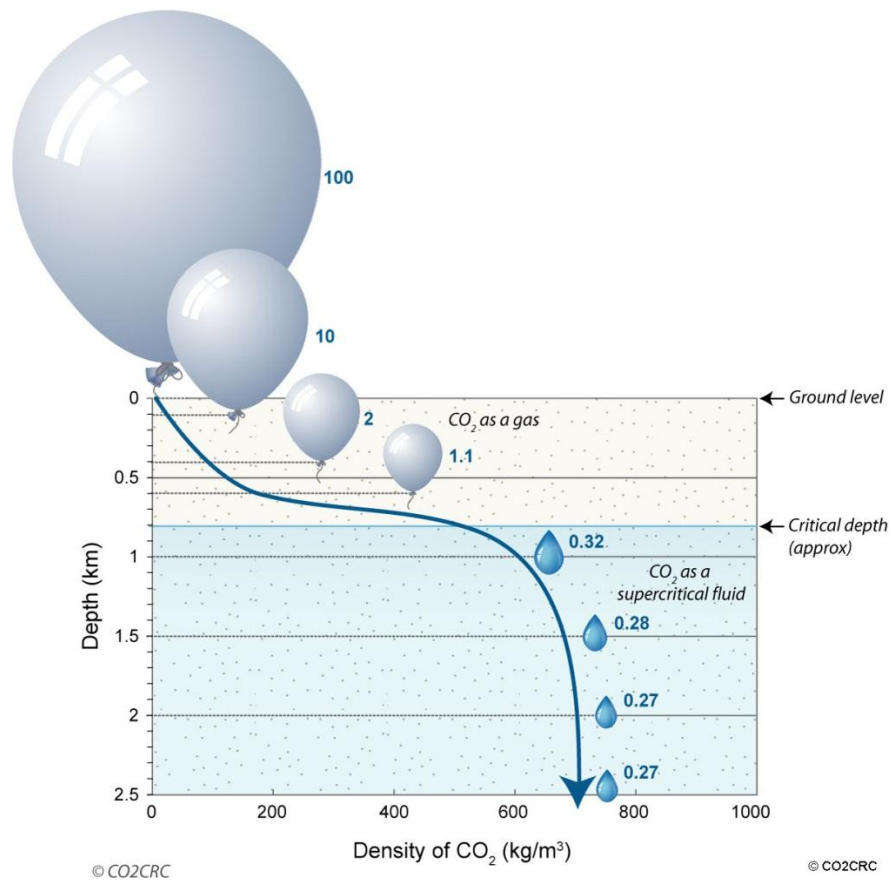


Figure 6 - Supercritical state of carbon dioxide [14]

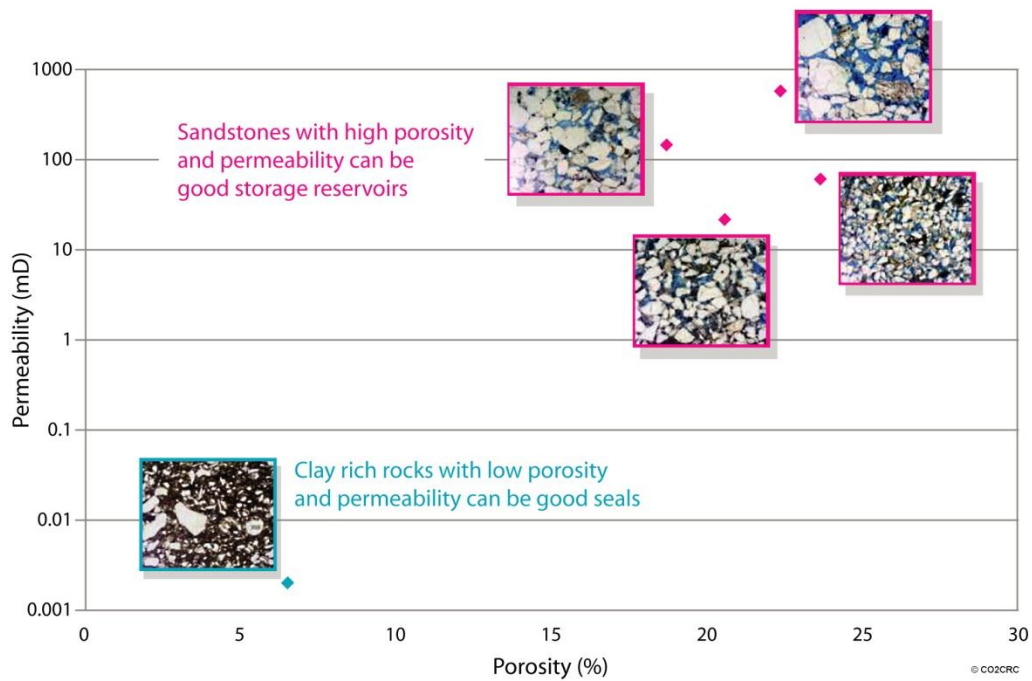


Figure 7 - Porosity versus permeability [14]

There are three monitoring levels [7] after the CO₂ is trapped underground – subsurface level monitoring, soil level monitoring, and above atmosphere level monitoring.

Current CCS Technology (CCS Projects in Different Countries)

Climate change is a global issue, and every country in the world need to get involved in the campaign to reduce greenhouse gas emissions, especially carbon dioxide.

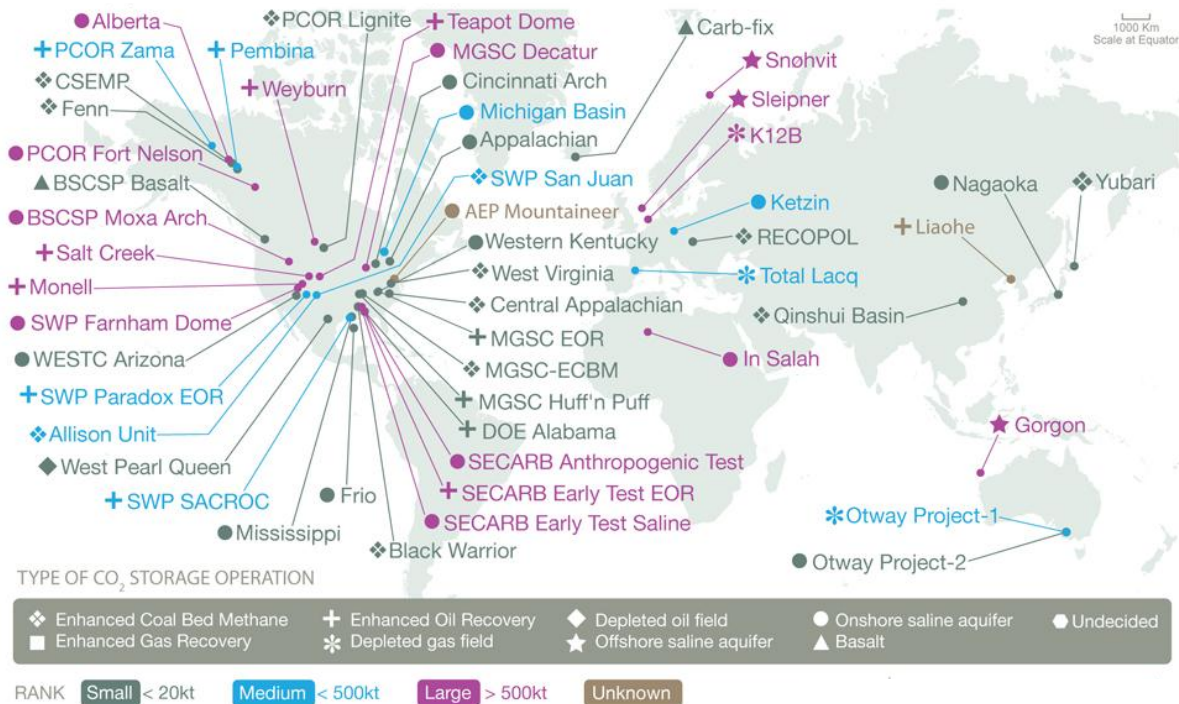


Figure 8 - Active carbon dioxide storage projects around world [15]

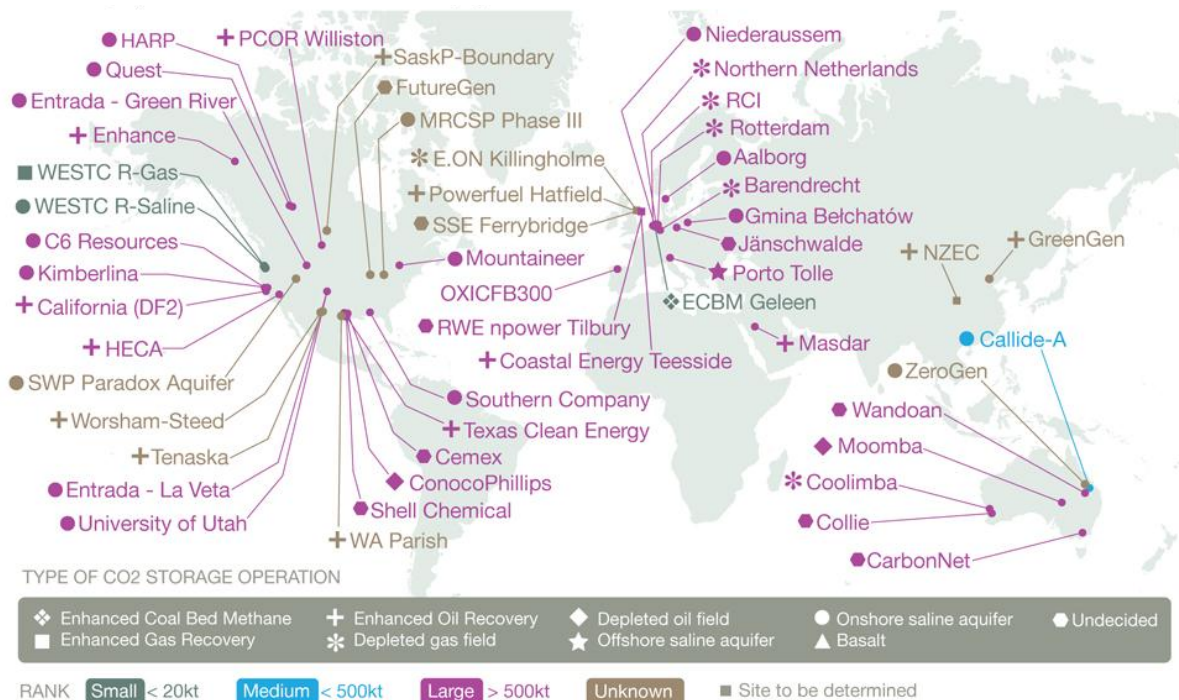


Figure 9 - Proposed carbon dioxide storage projects around world [15]

Figure 8 shows the active carbon dioxide storage projects around the world (last updated 16/04/10). It is noticeable that the United States are in favor of CCS technologies and pioneering in deploying them. Most Enhanced Oil Recovery storages and Onshore Saline Aquifer storages are based in the US. There are only three Offshore Saline Aquifer storages around the world - Northwest of Australia in the Indian Ocean, North Sea between UK and Denmark, and the junction of Norwegian Sea and Barents Sea. Figure 9 shows the proposed carbon dioxide storage projects around the world, 90% of which are large scale ones.

Table 3 shows the currently CCS projects around the world. Most of the projects cost billions of dollars.

Table 3 - CCS projects around the world [16]

Project	Overview	Location (Cost)	Planned Start Date
FutureGen (Suspended) http://www.CO2captureandstorage.info/project_specific.php?project_id=116	A US \$1 billion, 10 year research project to build the world's first coal-fuelled plant to produce electricity and hydrogen with zero emissions. The FutureGen plant was to have established the technical and economic feasibility of producing electricity and hydrogen from coal while capturing and storing CO ₂ generated in the process (approximately 1-2 million metric tons/year).	USA (US \$1.5 billion)	Timeframe not stated
ZeroGen Stanwell IGCC (Integrated Gasification Combined Cycle) and CO ₂ Capture & Storage plant http://www.CO2captureandstorage.info/project_specific.php?project_id=162	ZeroGen is a world-first demonstration project investigating the viability of integrating coal-based gasification and carbon capture and storage (CCS) to produce low emission base load electricity.	Australia (AU \$1.2 billion)	2011
Lacq Pilot Project http://www.CO2captureandstorage.info/project_specific.php?project_id=168	The project includes an integrated CO ₂ capture process with a 30MWth oxycombustion steam boiler, CO ₂ transportation via a 30 km pipeline and CO ₂ storage into a depleted gas reservoir.	France (EU €60 million)	2009 - 2010
RWE IGCC¹ power plant http://www.CO2captureandstorage.info/project_specific.php?project	RWE's aim is to commission a zero- CO ₂ power plant with a capacity of between 400 MW to 450 MW.	Germany (cost not stated)	2014

¹ Integrated Drying Gasification and Combined Cycle.

Shell & Statoil Joint industrial model of CO ₂ value chain (Draugen field) (http://www.CO2captureandstorage.info/project_specific.php?project_id=163)	In March 2006, Statoil and Shell launched their plan for a project to utilize CO ₂ captured from a large natural gas fired power plant and methanol production facility in mid- Norway for enhanced oil recovery offshore at the Shell operated Draugen field and at the Statoil operated Heidrun field. The plan aims to store CO ₂ for climate change reasons underground, whilst at the same time achieving increased oil recovery and electricity supply to large industrial consumers.	Norway (cost not stated)	2010 - 2011
DF1 Miller (http://www.CO2captureandstorage.info/project_specific.php?project_id=164)	BP is developing an industrial scale project to generate electricity using hydrogen manufactured from natural gas to create "decarbonized fuels. CO ₂ emissions should be reduced by around 90%. The project will take natural gas from the North Sea fields and convert it into hydrogen and carbon dioxide. The hydrogen would be used as a fuel at the Peterhead power station in Scotland and the CO ₂ will transported by an existing pipeline and injected in the Miller Field for CO ₂ -EOR and long-term geological storage.	UK (US \$600 million)	Timeframe not stated
DF2 Carson (http://www.CO2captureandstorage.info/project_specific.php?project_id=165)	BP is planning to develop a first-of-its-kind plant to convert petroleum coke produced at California refineries into hydrogen and CO ₂ with around 90% of the CO ₂ being captured. The hydrogen gas would be used to fuel a gas turbine to generate electricity. The captured CO ₂ would be transported by pipeline to an oilfield where the injected CO ₂ would stimulate additional oil production and permanently trap CO ₂ .	USA (US \$1 billion)	2011

Leakage and Environmental Effects

Because CO₂ is difficult to remove from rocks once injected, it is highly unlikely to escape to the atmosphere in any amounts that would pose any danger of significant ill health or environmental effects. It is true that at very high concentrations, CO₂ can displace oxygen in the air and pose risk of asphyxiation. That said, geysers such as Old Faithful in Yellowstone National Park emit significant streams of mixed water and CO₂ surrounded by happy onlookers without any ill effect [17].

Unfortunately, some opponents of carbon capture and storage use as a scare tactic the specter of an incident that occurred in 1986 at Lake Nyos in Cameroon [18], in which 1746 lives were lost because of a highly unusual

natural release of CO₂. Experts agree that the tragedy² is no relevant to the risks associated with CCS. It does, however, illustrate one reason for public concern about the siting of CCS repositories.

Geologic sequestration would never be performed in geology like that at Lake Nyos, and, moreover the sequestration process must be carefully monitored. At the first sign of unexpected CO₂ migration, a warning could be relayed to a control facility through a comprehensive subsurface monitoring program. An operator would then cease injection to reduce pressure and curtail the CO₂ movement and investigate and remedy the problem or shut down operations in that area.

According to NewGenCoal [7], the potential leakage area is the CO₂ injection wells. As long as they are well monitored and manipulated, the CO₂ will be safely kept underground.

Issues and Barriers

It is said that CCS in terms of geological sequestration will cause human-induced earthquakes. When fluids are injected into rock at a pressure that exceeds the strength of the rock, such as in shale gas exploration, small cracks may form. This process, commonly known as “fracking³”, occasionally results in microseismicity - mini-temblors measurable by extremely sensitive instruments, yet at levels rarely noticed by humans. However, unlike in gas exploration, CCS practices are designed to avoid fracturing. This is because microfractures reduce rather than enhance the volumes of CO₂ that can be stored in the reservoir rock.

The real risk of geological sequestration is contamination of groundwater by movement of underground CO₂ toward a fresh water aquifer. A comprehensive system of monitoring is required to detect such movement.

CCS technologies have been used around the world today, but their deployment faces obstacles.

CCS cannot deliver in time to avoid dangerous climate change.

The earliest possibility for deployment of CCS at utility scale is not expected before 2030 [19]. To avoid the worst impacts of climate change, global greenhouse gas emissions have to start falling after 2015.

CCS wastes energy.

Adding CCS technology to a power plant requires energy. The CCS process uses between 10 and 40% of the energy produced by a power station [20]. Wide scale adoption of CCS is expected to erase the efficiency gains of the last 50 years, and increase resource consumption by one third [21].

Storing carbon underground is risky.

² Lake Nyos fills a very recent (400 year old) crater in an active volcanic area. In that tropical setting, very large quantities of CO₂ are released from volcanic fissures into the cold water at the lake bottom where, over a long period of time, the dissolved CO₂ becomes concentrated in enormous amounts. In 1986, the cold water layer at the bottom of Lake Nyos was disrupted by a landslide releasing, all at once, two million metric tons of CO₂, equivalent to the annual emissions of a small coal power plant. Being heavier than air, this blanket of CO₂ settled on a local village and asphyxiated its residents (CO2CRC).

³ Termed by ‘hydraulic fracturing’, and also called frac jobs, frac’ing, fracking, fraccing or hydrofracking (Schlumberger Oilfield Glossary).

Safe and permanent storage of CO₂ cannot be guaranteed. Even very low leakage rates could undermine any climate mitigation efforts.

CCS is expensive.

It could lead to a doubling of plant costs, and an electricity price increase of 21-91% [22]. Money spent on CCS will divert investments away from sustainable solutions to climate change. The initial cost for building CCS facilities will be very high and it is difficult to make its deployment at commercial scale.

CCS carries significant liability risks.

It poses a threat to health, ecosystem and the climate. It is unclear how severe these risks will be.

World already has the solutions to the climate crisis.

Emission Trading Systems and Carbon tax have been introduced to reduce greenhouse gas emissions by producing less CO₂.

Summary

Carbon capture and storage aims to reduce the climate impact of burning fossil fuels by capturing carbon dioxide from power station smokestacks and disposing of it underground. Its future development has been widely promoted by the coal industry as a justification for the construction of new coal-fired power plants [6] (either separated or integrated [7]). With lots of uncertainties, the technology still needs time to be fully employed to save the climate.

CCS in Australia

Background

Australia is a country with large land area, relatively small population and high GDP per capita (7.7 million km², 22.6 million people and AU \$64994, respectively in 03/2011 [23]). The population is geographically dispersed around the coast of the country. The high GDP per capita is coupled with a high per-capita annual energy consumption based on extensive use of private transport and the development of energy-intensive industries. This has resulted in Australia's annual per-capita equivalent carbon dioxide (CO₂e) emission is among the highest in the developed world.

Australia has a high level of education and actively contributes to the global-warming science research. This has resulted in a population that is broadly conscious of global-warming issues and environmental movement.

Australia is the world No 1 coal exporter. Coal provides approximately 83% of Australia's electricity, with Australia having among the lowest electricity prices in the developed world.

The electricity industry is a major emitter of greenhouse gases, being responsible for 198 million tons of CO₂e emissions, or about 35% of the nation's total CO₂e emissions, in 2006 [11]. That Australia's economic well-being will continue to be based on low-cost coal for electricity generation, energy security and export income for some time to come, has been well recognized by successive governments and also some key environmental action groups. However, global warming is also projected to have a serious impact in Australia.

Because of Australia's position as a carbon-intensive economy and as a developed and scientifically advanced nation, it has a responsibility to take strong action to develop CO₂-mitigation strategies for fossil fuels. Although the actual and trend CO₂ emission decreased in recent years [24], as show in Figure 10, greenhouse gas reduction still need to be emphasized. To this end, Australia has now set long-term targets for CO₂ emissions at 60% of year 2000 emissions, to be achieved by 2050 [25].

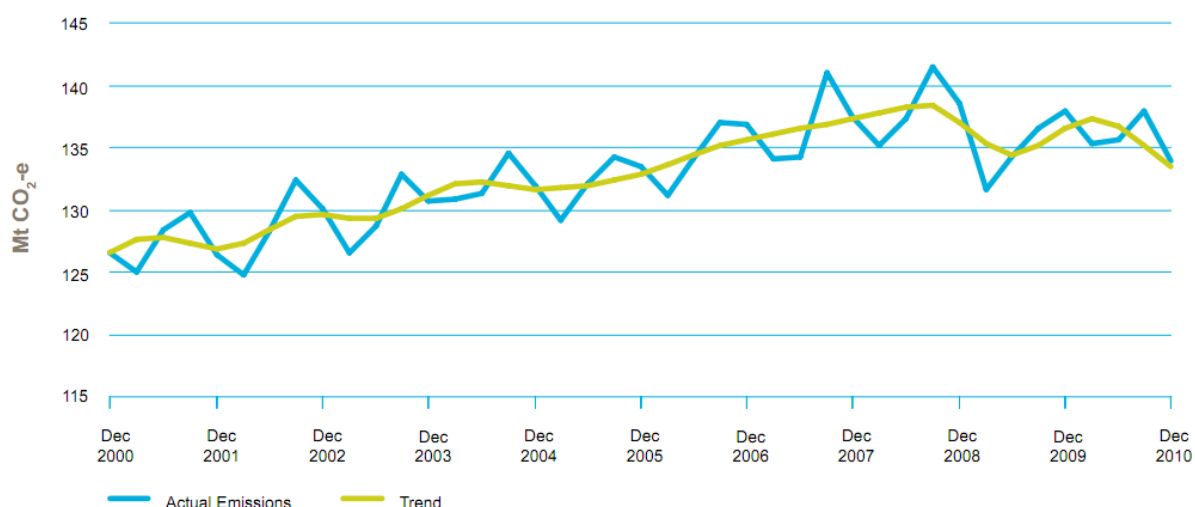


Figure 10 - National Inventory, actual and trend emission estimates [24]

Carbon Capture and storage has been seen as a key strategy for achieving this target. To implement CCS in Australia, three prerequisites should be required:

- **Technology:** CCS technology must be available at commercial scale from reputable suppliers able to offer performance guarantees.
- **Commercial:** the CCS project must be financially viable in a competitive market place.
- **Regulatory:** the regulatory environment in which the projects operate must be clear and transparent.

Other strategies such as Emission Trading System and Carbon Tax can also be used. Despite the challenges of implementation of CCS, the technology remains one of the key avenues available to Australia to achieve the long-term greenhouse gas reduction.

CCS Programs and Strategies

General Policy

Commonwealth and State governments have supported the development of demonstration projects by private organizations as the initial approach to CCS technology. Through strong support of CCS R&D and by contributing to the capital cost of the projects, the initial approach was achieved. While continuing with, and expanding on these initiatives, the Australian Government has now introduced the new Carbon Pollution Reduction Scheme (CPRS) as the primary policy approach to achieving domestic greenhouse gas emission reduction targets. The CPRS, in effect a carbon 'cap and trade' scheme, is expected to be implemented from mid-2011 [26].

- 1. Carbon Pollution Reduction Scheme (CPRS)** is a proposed cap-and trade system of emissions trading for manmade greenhouse gases, introduced in 2010 by the Rudd government [27], as part of its climate change policy. It is a market-based scheme to provide a price for carbon. It is seen as the primary mechanism by which low-carbon technologies, such as CCS, can achieve take-up in Australia's market-based economy. The key features of the CPRS are included in Table 4.

Table 4 - key features of CPRS [4]

Features	Brief Description
Mechanism	The scheme will employ a 'cap and trade', emission-control mechanism, based on the creation of Australian Emission Units (AEU) equal in number to the annual amount of carbon pollution permitted under the scheme. In the next five and ten years, the government will announce scheme caps and provide indicative gateway ranges respectively.
Obligations	The core obligations of liable entities are to report emissions, and to surrender AEUs equal in number to the tons of emissions reported.

Coverage	The Scheme will cover all six GHG gases listed under the Kyoto protocol. It has been designed to achieve the maximum practicable coverage of greenhouse-gas emissions and will initially include stationary energy, transport, industrial process, waste, forestry and fugitive emissions.
Targets	The Government has set national targets of from 5 to 15% below year 2000 greenhouse-gas emission levels by 2020, and at 0% below 2000 levels by 2050.
Recognition of CCS	Carbon that is transferred to carbon capture and storage facilities will not be counted towards the originating entities gross emissions.
Price Setting	The primary avenue will be by monthly auction, starting at AU \$40 per ton CO ₂ e and rising at 5% in real terms per year.
Coal Fired Power Generation	An electricity-sector adjustment scheme will be implemented to provide some protection of existing investments in certain high-emission assets.
Transitional Assistance to Industry	Certain energy-intensive industries will be provided with an administrative allocation of AEU's for transitional support and to reduce the likelihood of carbon leakage overseas.
International Linkages	Provision has been made for an entity to surrender certain "Kyoto" emission units to satisfy its liabilities.

2. **Carbon Sequestration Leadership Forum (CSLF)**
3. **Asia Pacific Partnership on Clean Development and Climate (APP)**
4. **Global Institute for Carbon Capture**

Governmental CCS Initiatives and Funding

Both Commonwealth and State Governments have recognized that CCS projects require support both in terms of technology development through continued R&D and in financial support to achieve penetration in a market-based economy. This is particularly the case where carbon emission-reduction technologies impose additional costs of business, but emissions of carbon are free, as is presently the case, or allowed at relatively low cost [11].

CCS R&D Activities in Australia

CCS Research in Australia can be broadly considered as a three-level hierarchy comprising funding organizations, special purpose research vehicles and research providers [26].

1. **Australia's Commonwealth Scientific and Research Organization (CSIRO)**

The CSIRO is Australia's national science agency and, with a current budget of over AU \$1 billion, is one of the larger and more diverse research agencies in the world. It is a key research provider to the Australia's CCS technology programs. It maintains a strong in-house R&D program on post-combustion capture technology and also operates a pressure-entrained flow reactor for coal-gasification studies.

2. Cooperative Research Center for Greenhouse Gas Technologies (CO2CRC)

The CO2CRC was set up to research and demonstrate CO₂ capture and storage technologies in Australia. CO2CRC aims to plan, direct, fund, and manage research, with the majority of R&D effort being carried out by either the participant Universities, CSIRO or under sub-contract to specialist firms. The major CO2CRC program themes include: Capture Research, Storage Program, Regional Studies, and Development Program.

3. Center for Low Emission Technology (cLET)

cLET is researching coal gasification and syngas cleaning technologies as a prerequisite to moving to an IGCC-based, low-carbon coal cycle using hydrogen as an energy carrier. The program has five main research areas as follows: Gasification Core Facility, Gas Cleaning Program, Gas Processing Program, Gas Separation Program, and Social and Economic Integration.

4. University Research Activities

The following universities have been actively participating in the CCS research activities: University of Newcastle, University of New South Wales, Monash University, University of Melbourne, University of Adelaide, Western Australian Energy Research Alliance, and University of Queensland.

CCS Projects in Australia

The Australian coal industry has committed a billion dollars to accelerating low-emissions coal technologies like CCS. The COAL21 National Action Plan adopted in 2004 provided a blueprint for demonstrating the technologies that would allow Australians to continue to use affordable coal-fired electricity in future, but with significantly lower greenhouse gas emissions. There is a wide range of projects at both commercial and demonstration scale around Australia. However, in the absence of strong cost drivers and the only-recent enactment of appropriated enabling legislation, these presently remain either relatively small-scale or at pre-feasibility level. Table 5 and Figure 11 show the currently active projects.

Table 5 - Active CCS projects around Australia [26]

Project	Overview	Location (Cost)	Planned Start Date	Scale
ZeroGen	ZeroGen is a world-first demonstration project investigating the viability of integrating coal-based gasification and carbon capture and storage (CCS) to produce low emission base load electricity. The Queensland Government has earmarked \$A300 million for the project, with the remainder expected to be raised through normal financing channels.	Queensland (AU \$1.2 billion)	Late 2012	Commercial-Scale Project Incorporating CCS

Monash Energy	A joint development of Anglo American plc. and Shell Gas and Power, aiming to capitalize on the brown-coal. Project is currently placed under review.	Victoria (cost not stated)	Timeframe not stated	Commercial-Scale Project Incorporating CCS
HRL IDGCC	The project is a 400 MW plant, with two 200 MW gasification systems feeding a gas turbine combined-cycle power block. It will be the first full-scale demonstration of IDGCC, however, it will not include CCS.	Victoria (AU \$750 million)	Timeframe not stated	Commercial-Scale Project
Coolimba Power Project	It is a 400 to 450 MW power project, being developed by Aviva and AES Corporations and envisages two 200 MW, circulating fluid bed (CFB) boiler/turbine units firing high-moisture, high-ash sub-bituminous coal.	Perth, Western Australia (cost not stated)	2013	Commercial-Scale Merchant Power Project
FuturGas	FuturGas is developing a coal-to-liquids project to utilize the Kingston lignite. The project will produce approximately 1.6 million tons per annum of CO ₂ which is extracted from the process during synthesis-gas cleanup, and piped to the Otway Basin for storage.	South Australia (cost not stated)	Early Stage	Commercial-Scale Project
Gorgon	The project will produce some 15 million tons per annum of LNG, 100 PJ per annum of domestic gas and associated condensates.	Western Australia (cost not stated)	2007	Commercial-Scale Project Incorporating CCS
Callide Oxy-Fuel	The project involves the conversion to oxy-fuel of an existing 30 MW coal-fired boiler at CS Energy's Callide A Power Station. The Australian-Japanese project has the objectives of the demonstration include the establishment of design and operating requirements for large-scale retrofit and new-build oxy-fuel plants, including geological aspects.	Queensland (AU \$206 million)	2008 - 2011	Large-Scale Demonstration Projects
Hazelwood 2030 Project	The project includes installation of coal-drying equipment to boost power-station efficiency and of an amine-based PCC plant, with an innovative approach applied to sequestration of the CO ₂ .	Victoria (AU \$370 million)	Timeframe not stated	Large-Scale Demonstration Project
CSIRO Pilot Plant - Loy Yang Power Station	The project is designed to assess the performance of the amine technology where the brown-coal flue gas is not pre-treated with either flue gas desulfurization (FGD) or de-NO _x . It is part of broader Latrobe Valley Post Combustion Capture Project.	Victoria (cost not stated)	2008	Large-Scale Demonstration Project

CSIRO Pilot Plant - Munmorach Power Station	The plant is trialing a chilled-ammonia-based capture technology under Australian conditions with low-sulfur black coal, but without FDG or catalytic de-NO _x .	New South Wales (AU \$150 million)	2008 - 2013	Large-Scale Demonstration Project
Tarong Power Station	The plant is designed to capture 1500 tons per annum of CO ₂ and operates without FDG or de-NO _x applied up-stream of the pilot plant.	Queensland (cost not stated)	2011	Large-Scale Demonstration Project
Otway Pilot Project	The project is Australia's first demonstration of geological storage of CO ₂ .	Victoria (AU \$40 million)	2008	Storage Project
Santos Cooper Basin Hub	The project will be developed in three phases, with initially the collection and injection of all CO ₂ presently separated at the site as a result of the natural-gas processing activities. The second stage would link to the development of a clean-coal power project in New South Wales or Queensland and the development of the CO ₂ -transport infrastructure, while Stage 3 would take CO ₂ from the major point sources in New South Wales, Queensland and South Australia.	South Australia (AU \$700 million)	2011	Storage Project

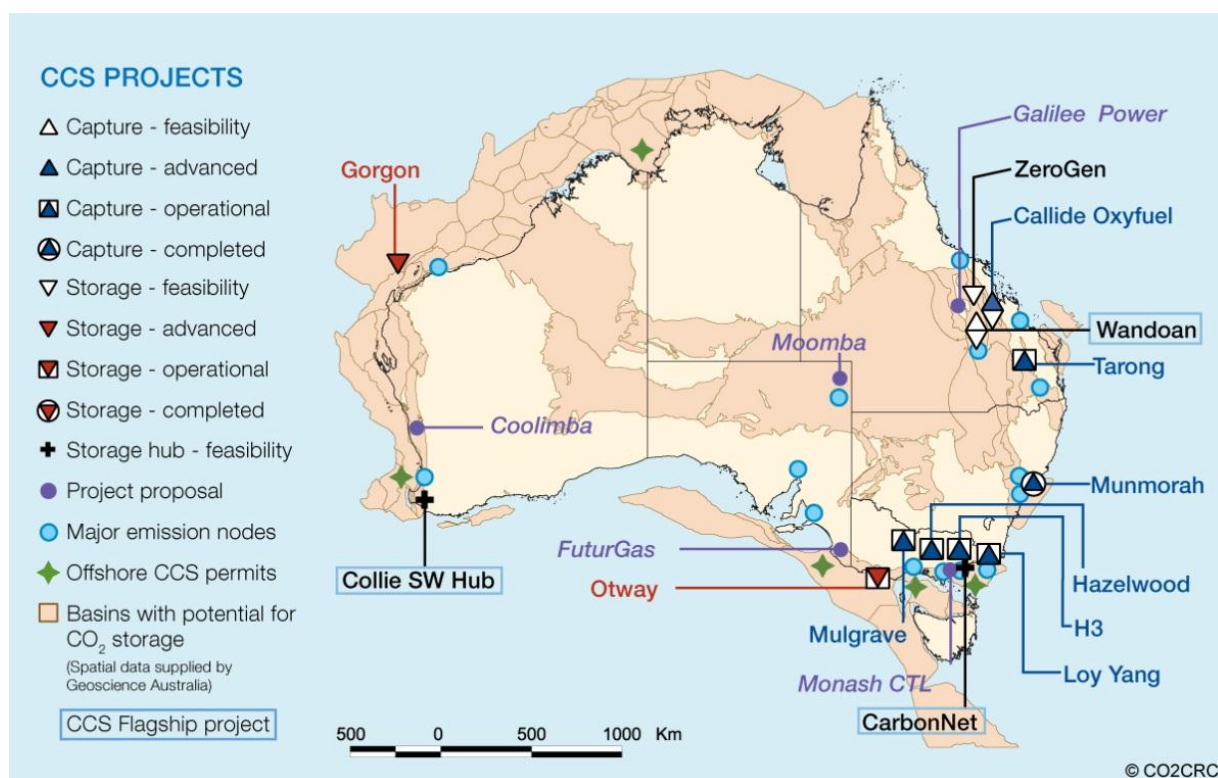


Figure 11 - CCS projects in Australia [28]

CCS Challenges in Australia

It is clear that substantial progress has been made toward implementation of CCS in Australia. Despite this intensive effort, no commercial-scale CCS project has yet been implemented in Australia, although several currently are in the planning stages. It is clear that widespread implementation of CCS is immensely challenging, especially to a country of Australia's size and nature.

So far, due to the efforts that have been made, commercial-scale CCS projects need the following pre-conditions [11] to be fully implanted:

1. Legislation enabling CCS activities in a number of jurisdictions.
2. Policies and support programs designed to assist CCS projects to overcome the natural hurdles for new technologies seeking market entry.
3. A sound knowledge base of CCS technology within government, academia and industry.
4. A growing skill base in research and in design and construction of CO₂ capture and storage facilities.

However, several key challenges [26] remain to be addressed before CCS can make a significant contribution to CO₂ reduction in Australia. These are summarized as follows:

1. CCS project are not **COMMERCIALY** viable, as the costs of capture must be borne by the project and there is as yet no commensurate return for storing the CO₂.
2. Legislation is now in place to enable the active exploration for and proving-up of geological **STORAGE** reservoirs. The capacity and quality of a reservoir for a commercial-scale CCS operation will require a substantial commitment of time and cost, involving extensive seismic and geological surveys and so forth.
3. Difficulties in **INDUSTRY CONVERGENCE**. Resource exploration is characterized by large, up-front and at-risk exploration expenditure, with expectations of high return to justify the risk.
4. A basic **LEGAL** structure is available in most states to allow the implementation of CCS projects. However, there are significant differences between jurisdictions with regard to key issues, which will increase the cost, time and complexity of project development.
5. Large-scale **INFRASTRUCTURE** for the transport of CO₂ does not presently exist in Australia. Most of the current pipeline infrastructure is operated on a commercial basis with some regulatory overview.
6. **TECHNOLOGY OBSOLESCENCE**. Large-scale applications of CCS technology to the power industry are rare and the technology still needs more research.
7. The **TIMING** of targets setting is not totally feasible, i.e. it requires a reduction in emissions below the 'business as usual' case.

In spite of these challenges, much has already been achieved with CCS in Australia. The Commonwealth Government has set ambitious targets for near-term implementation of commercial-scale CCS [11]. CCS therefore remains a key technology for Australia to achieve substantial CO₂ reduction in the future, also Australia will be pioneering in greenhouse gas reduction among the developed countries.

Carbon Tax in Australia

Carbon tax is a tax on energy sources which emit carbon dioxide. It is a pollution tax, which some economists favor because they tax a 'bad' rather a 'good' (such as income) [29]. It is a fee emitters must pay for every metric ton of CO₂ emitted about a threshold or per metric ton emitted cumulatively. A carbon tax, unlike a cap-and-trade system, provides a stable price per metric ton of CO₂. This price signal allows emitters to budget how much they will be impacted by regulation [1].

There are some political supports for a carbon tax in Australia as a means of implementing a carbon price. The Howard Government's taskforce that examined options for dealing with climate change [29], and the Garnaut Climate Change Review [30], rejected carbon taxes in favor of an emissions trading scheme (ETS).

However, in his updated climate change review on May 31, 2011, the climate adviser, Ross Garnaut, illustrated his standing point by writing "*Better climate, better tax*" [31], after the Julia Gillard Government has introduced a AU \$10 per ton carbon tax [32]. In his new final report, by learning that the government is offering to increase the 2050 emissions reduction target from 60% to as high as 80% to win support from the Greens for other parts of the carbon tax package, Garnaut has provided a potential compromise on the most contentious issue dividing the multi-party committee on climate change - who should set Australia's crucial 2020 greenhouse gas reduction target [33].

Coupled with Julia Gillard's mobilizing activates in supporting the carbon tax proposal [34], different opinions on carbon tax have formed. Table 6 shows the pros and cons that the introduction of carbon tax in Australia.

Table 6 - Pros and cons for carbon tax in Australia

Pros	Cons
Big companies will pay more.	Extra pressure on hard working families.
Renewable energies can be invested.	Electricity prices increase.
People will be less stressed on bills.	Petrol prices increase.
More jobs will be created.	Grocery prices increase.
Clean air is good for kids' health.	Negative impact on all trade-exposed industries.
Solution for climate change.	It is a TAX, therefore it is politically unpopular by its nature.

Australia needs more effort if it wants to achieve the ambitious targets. However, how the carbon tax really works in Australia still remains a question, and different parties will continue to discuss the optimized carbon tax mechanism.

Conclusion

With global energy demand rapidly outstripping efforts to reduce greenhouse gas emissions, carbon capture and storage is a safe technology to be adopted now to reduce the climate impact of fossil fuel use. Employing the same skills that petroleum geologists use to produce oil and gas, we should be able to safely inject and store carbon dioxide underground for millions of years. Australia, as the world number one coal exporter, has the opportunity and responsibility to develop and implement large-scale CCS projects nationwide. As a CCS technology active proposer and pioneer, Australia also has the opportunity to spread the new technology to other countries, especially developed countries. Carbon tax is still at its early stage, and what is the best carbon dioxide emission reduction mechanism for Australia requires each party's participation and discussion. Borrowing the successful European examples of combined programs - CCS technology and greenhouse gas regulations (such as carbon tax and cap-and-trade), Australia will successfully achieve its emission reduction target in the future.

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