Centre for Energy and Environmental Markets

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Inquiry into geosequestration technology

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The Centre for Energy and Environmental Markets

The UNSW Centre for Energy and Environmental Markets (CEEM) provides Australian leadership in interdisciplinary research in the design, analysis and performance monitoring of energy and environmental markets and their associated policy frameworks. CEEM brings together UNSW researchers from the Faculty of Commerce and Economics, the Faculty of Engineering, the Australian Graduate School of Management, the Institute of Environmental Studies, and the Faculty of Arts and Social Sciences, working alongside a growing number of international partners. Its research areas include the design of spot, ancillary and forward electricity markets, market-based environmental regulation and the broader policy context in which all these markets operate.

Summary

Geosequestration, also termed Carbon Capture and Storage (CCS), is a promising but, at this time, still somewhat unproven set of technologies for capturing CO_2 emissions from fossil fuel combustion and a range of other industrial processes, and then safely sequestering them in geological reservoirs. The motivation for considering potential widespread deployment of such technologies is the growing consensus of the risks of dangerous climate change with current levels of greenhouse gas emissions.

The key context for this Parliamentary inquiry, then, is firstly our present understanding of climate change and the likely scale and timing of emissions reductions required to avoid dangerous warming; and secondly what are our technical options for achieving such reductions and how might they be compared.

The key questions for this inquiry are firstly what action the Australian Government can and should take to facilitate such reductions, and the role of geosequestration technologies in such a response; and secondly the appropriateness of the current policy framework in light of such an assessment.

Climate change: Avoiding dangerous climate change seems likely require to global emissions to peak before 2020, followed by substantial overall reductions by 60% or more from current levels in 2050. Earlier and more drastic action will be needed if we want to retain the option of pursuing even lower stabilisation levels.

Note that delays in taking action will then require faster reductions to a lower level of emissions by 2050. For example, a 20 year delay in undertaking emission reductions might require levels to then be reduced at three to seven times the rate if action begins now.

Abatement options: Fortunately we have a wide range of technologies capable of reducing energy related climate change emissions – these include a wide range of end-use energy efficiency options, lower emission fossil-fuel technologies including Natural Gas Combined Cycle (NGCC) and Combined Heat and Power (CHP) plants, a range of renewable energy sources and nuclear power.

Technical progress, however, is clearly essential as present options are almost certainly inadequate for the scale of change required. Much of this progress will certainly be ongoing improvement of our existing options, however, there are also important innovation opportunities in promising but still emerging technologies including CCS.

Assessing and comparing these options requires a technology assessment framework that considers factors including current technical status, delivered energy services, present costs where known and possible future costs, potential scale of abatement, potential speed of deployment and other possible societal outcomes.

All of these factors need to be considered in a framework that explicitly acknowledges and represents the different uncertainties involved with particular abatement options. In particular, we need to apply the precautionary principle to technology policy decision making with a focus on downside risks.

In this regard, CCS should be considered as a promising, but still somewhat unproven, option that potentially offers very significant abatement potential and good integration into the existing energy industry. For Australia, its success would also have additional value in supporting continued coal exports. There are, however, some outstanding questions regarding its effectiveness and safety, its delivered abatement is likely to come at significant cost and it is unlikely to be able to make a significant contribution to emission reductions for a decade or more.

Formulating a policy response: A policy response will certainly be required. The various fossil fuels represent bountiful, low direct cost, energy dense and highly convenient energy sources. In the absence of appropriate policies it will always be lower cost to vent CO_2 from combustion directly to the atmosphere than capture and sequester it. Furthermore, there would seem to be more than enough fossil fuel reserves to support continued use at current or even expanded rates sufficient to cause catastrophic global warming.

Governments have important policy roles in all phases of technical progress and change: *Invention* by supporting R&D into promising socially beneficial yet unproven technologies; *Commercialisation* through support for the demonstration and initial deployment of promising but still unproven technologies; and *Diffusion/Adoption* through regulatory and market-based mechanisms to drive greater use of existing but currently only niche technologies.

With respect to climate policy, the general priority should clearly be driving the greater diffusion and adoption of existing technology options that can reduce greenhouse emissions. R&D and demonstration of promising yet still emerging technologies is a second-tier priority given the urgency of achieving short-term emission reductions.

There are more specific policy issues regarding whether and which technologies might deserve particular support, and how this support might best be delivered. The inherent uncertainties of technical progress and change mean that there are risks for governments attempting to pick winners - they have regularly demonstrated their ability in picking losers.

Valuable formal risk management approaches given such uncertainties include the use of market-based environmental instruments such as emissions trading and carbon taxes that allow different abatement options to compete against each other, diversification through support for a range of technology options and flexibility by making choices that keep other choices available later on. However, limited public resources do require some degree of prioritisation for support.

Policy needs for CCS: Each of the key CCS concepts of capture, transport and storage have been demonstrated in various industrial applications around the world. However, they have generally not been combined on an end to end basis, nor at the scale required to prove its application for large scale power generation. Considerable uncertainty remains as to the potential technical performance, costs and safety of integrated large-scale systems.

One key policy need, therefore, is publicly funded support for R&D and demonstration of some key CCS technology components. There is also, however, a need for more general market-based mechanisms that put a price on greenhouse emissions. For example, important early applications of CO_2 injection into geological formations have been driven by a carbon tax in Norway (the Sleipner Vest project) and potential abatement credits under the Kyoto Clean Development Mechanism (CDM) for the In Salah project in Algeria. More generally, such market mechanisms send a clear signal to private participants in the energy industry of the value of investing in R&D and in demonstrating abatement technologies.

More generally, an appropriate CCS policy has to sit within a wider coherent policy framework that supports a range of abatement options. Otherwise, possible unpleasant surprises in the effectiveness or costs of CCS could completely invalidate the policy response.

Current Australian policy context: CCS is clearly a strategic abatement technology for some countries including Australia, which has a heavy reliance on fossil fuels for both domestic energy provision, and internationally traded exports. Its per-capita greenhouse emissions are amongst the highest in the world – twice the developed world average and many times that of developing countries. While the Australian Government has acknowledged the need for major emission reductions in the longer term, stationary energy sector emissions under the present policy framework are projected to increase over 40% above 1990 levels by 2010, and nearly 80% by 2020.

This present policy framework is very focussed on development of future technologies with a particular emphasis on CCS. Policy support includes significant public funding of CCS R&D and demonstrations of low emission technologies where CCS is likely to receive considerable support. There would seem to be less interest and only limited support for increasing the deployment of existing energy efficiency, gas-fired generation and renewable energy options. For example, the Government has ruled out for now the introduction of national emissions trading or carbon taxes to put a price on greenhouse emissions, and chosen not to expand its very modest targets for new renewable energy supply.

We don't know yet what role CCS can play in our abatement efforts and shouldn't rely on it, or any other particular technology for that matter, to answer all our challenges. What is needed is a policy framework that will resolve the question of what role CCS might play in the medium to longer term for Australia and elsewhere, while reducing risks and maximising opportunities through much greater and immediate support of existing, technically proven, abatement options.

In our view, the present R&D and demonstration support for CCS is entirely appropriate and should be greatly expanded. There are, however, limits to what Australia can achieve through such demonstrations and much will rely on international technology developments. Support for greater international effort on climate change policies would be helpful in this regard.

More importantly, Australia needs a coherent policy framework that supports greater deployment of existing abatement options. This could help drive early, low cost, CCS options in gas processing and some industrial facilities. More generally, such a framework would drive greater use of lower emission gas Natural Gas Combined Cycle (NGCC) generation. These off-the-shelf technologies can provide early emission reductions, be integrated with coal gasification technologies when and if they become commercially available and offer direct CCS opportunities. Such deployment policies would also drive greater energy efficiency and renewables deployment providing a more diversified and hence robust, lower risk response.

We concur with the IEA 2005 Energy Policy Review on the risks of present Australian energy policy. They note that "Australia is taking a technological approach to reducing emissions from its energy sector… While new technologies will be a key component in tackling the long-term problem of climate change, there is no certainty when and to what extent the necessary technologies will be developed. Such technologies would most likely require a carbon price signal to facilitate their implementation."

With regard to specific issues raised in the terms of reference of this inquiry, we will only briefly comment directly here. More details are provided in the body of the report which takes a somewhat different structure.

The science underpinning geosequestration technology: There would seem to be three key technology options for CO_2 capture; post-combustion, oxy-fuel combustion or pre-combustion capture using Integrated Gasification Combined Cycle (IGCC). There is ongoing debate, indeed disagreement, amongst researchers regarding both the general question of which of these processes is likely to achieve the highest performance, and numerous technology choices within each approach.

Therefore, while it is apparent that there are number of promising technology developments that could offer commercial solutions to separation and capture of $C0_2$, there is considerable ongoing uncertainty as acknowledged, for example, by the IPCC Special Report on CCS that states that despite decades of research into alternative and more efficient fossil fuel combustion systems "It is generally not yet clear which of these emerging technologies, if any, will succeed as the dominant commercial technology for energy systems incorporating CO_2 capture." This is promising in terms of risk management as it means we are not reliant on a single technology being proven to work. However at the same time it highlights the R&D and demonstration efforts, and hence potential time delays, required to identify and then improve the better options.

The main options for storing CO_2 underground over the hundreds to thousands of years required for effective emissions abatement appear to be depleted oil and gas reservoirs, deep saline aquifers and unmineable coal seams.

There are good physical reasons and some experience to date that suggest that CO_2 injection into appropriately chosen geological reservoirs can stay securely sequestered for thousands of years. Early demonstration projects are promising although there continue to be surprises. However, it will still likely take decades to achieve a very high degree of certainty that injection does indeed equate to effective storage, and properly understand all of the many issues involved in selecting appropriate sites.

The potential environmental and economic benefits and risks of such technology: These can only be sensibly assessed in terms of our other options for reducing greenhouse emissions. CCS on coal-fired generation seems likely to be a low emission technology with current estimates suggesting emissions of around 150-200kgCO_2/MWh generated. This is a four-fold improvement over conventional coal plant, but is less significant in comparison with existing low emission fossil fuel generation from NGCC (400-450kgCO_2/MWh or cogeneration facilities which can deliver electricity and heat at effective emission intensities of around 200kgCO_2/MWh. Existing renewables and nuclear have effectively zero operating emissions.

There are environmental risks associated with virtually all energy technologies but CCS does raise some particular questions. The most proven and safe storage of CO_2 is clearly to leave the carbon in the fossil fuels. These have demonstrated effective CO_2 storage for many millions of years. Storing CO_2 through geosequestration is clearly less safe and proven and there are some risks of both immediate harms from rapid release of the gas into the atmosphere or ground waters close to the surface, or in terms of climate change with slower leaks. The use of fossil fuels is also associated with a range of other air, water and solid pollutants and land-use impacts that would seem to be more significant than some of our other options.

The economic benefits of CCS also depend on our other options. For moderate levels of emission reductions there would seem to be lower cost options available right now – for example, increased NGCC generation in Australia appears competitive against current coal plant at a carbon price of around \$20/tCO_2, some renewables would perhaps become competitive at prices of around \$30-40/tCO_2 while there are certainly many low-cost or even no-regrets energy efficiency options to pursue. These all appear to be highly competitive against current cost projections for CCS when it finally becomes commercially available. However, the major emissions reductions required in the longer-term are almost certain to exceed the capabilities of present options. Continued use of fossil fuels will certainly require CCS technology; alternatively very significant progress in other technologies will be required. CCS's key role might therefore be in the longer term with very significant emission reduction targets. It is also important to note that CCS applications for NGCC plant are arguably as promising as coal applications.

The potential economic benefits of CCS for countries such as Australia that export coal are also clearly important but difficult to assess. Burgeoning demand, the low cost of coal and growing concerns with gas availability and costs in some parts of the world are key factors currently driving increased global coal use. Serious action on climate change will necessarily involve drastic reductions in such use if CCS is not available, and may still see use fall with CCS given the additional costs involved and competition from other abatement options. However, in the longer term, CCS for coal technologies might form the basis for a large proportion of transport as well as stationary energy provision through hydrogen and electricity production.

In terms of international competitiveness, CCS for coal-fired generation may well erode some of Australia's present competitive advantage in low cost generation. This advantage is built on low cost, lower quality coal available from mining operations largely focussed on export, low transport costs and lower capital cost power plants due to lesser requirements on air pollutants than in many other countries. CCS will raise capital costs and it is likely that much of this technology will be imported. A key issue is the availability of effective and low cost geological reservoirs. Again, some countries would appear to have lower cost and lower risk opportunities than ourselves, although Victorian opportunities certainly appear to be quite promising. Increased costs for coal-fired generation will also increase the competitiveness of countries utilising other energy sources such as gas and renewables.

The economic risks of CCS include the potential that it proves to be not effective, or considerably more expensive than had been estimated. The impact of either of these depends largely on the rest of the policy framework. If CCS is the only option being seriously pursued then such failure could be very serious. If CCS is only part of a portfolio of activities these risks are far more manageable.

The skill base in Australia to advance the science of geosequestration technology: Australia has world leading research and expertise in some areas of geosequestration technology including the mapping and assessment of potential geological reservoirs through the work of centres such as CO2CRC. We also have good expertise in some areas of coal characterisation and lignite technologies. Australia would seem to currently have more limited capabilities in the development of cost-effective carbon capture technologies and may have to rely largely on international developments.

Regulatory and approval issues governing geosequestration technology and trials: The main issues here relate of course to the injection of CO_2 into what are hoped to be appropriate geological reservoirs. Such trials are a key step in demonstrating and then proving up CCS technologies however they also carry some risks.

Such trials can be categorised as 'social experiments' and therefore should require what is effectively societal consent before being undertaken. Obtaining such consent requires transparent and open consultation processes with input from the widest possible range of stakeholders.

A key and particular question for regulation and approval is also that of liability, and this has formed a large part of the debate to date. Risks of low probability but potentially very adverse events are always difficult to manage and there are limits to what private organisations will accept or, indeed, can have imposed upon them by regulation.

It is almost certain that the public, through their governments, will end up underwriting these risks over the longer-term. That may be necessary in order to get the technology developed, however, it is important that such public support is transparent and properly counted when evaluating the economics of the technology against other options.

How to best position Australian industry to capture possible market applications:

Australia has no track record of being able to compete in the development of such large energy technology – for example, we don't have a manufacturer of either coal or gas power station technology apart from construction and component assembly. We can support local demonstration of these technologies and while much of the technology would have to be acquired from elsewhere there will be valuable lessons in integrating these components.

In terms of sequestration, Australia doesn't appear to have some of the high value early EOR opportunities offered by some other countries. There are, however, some potentially low-cost and early gas processing opportunities. It has also built an internationally regarded expertise on characterising sequestration reservoirs through groups such as CO2CRC.

In our view, policy support to help Australian industry position itself should include an early carbon price signal so that they can begin to transition their operations and begin to invest in R&D and demonstration of new technologies. The development of greater baseload NGCC generation in Australia can also support the uptake of CCS by providing a lower risk path for the technologies development. NGCC plants will reduce emissions and could be integrated with coal gasification technologies when and if they arrive. They may also be suitable for direct application of CCS.

1 Context

This submission first briefly outlines the key context for this Parliamentary inquiry; our present understanding of climate change and the likely scale and timing of emissions reductions required to avoid dangerous warming; and what are our technical options for achieving such reductions and how might they be compared.

In Section 2 we consider the current technical status of CCS. The potential economics of CCS in comparison to conventional generation and other abatement options are considered in Section 3.

Finally we consider two key questions for this inquiry – firstly what action the Australian Government can and should take to facilitate such reductions, and the role of geosequestration technologies in such a response; and secondly the appropriateness of the current policy framework in light of such an assessment.

1.1 The Challenge of Climate Change

While there are continuing modelling uncertainties, recent work highlights the scientific community's growing concerns about dangerous climate change.[1] The EU amongst others has now formally adopted a target of keeping global warming to less than 2ºC above pre-industrial temperatures.

Major emission reductions are likely to be required to meet such a target, and there is only a short timeframe available for such action. Limiting global warming to 2ºC with relatively high certainty may require atmospheric greenhouse gas levels to be stabilized at 400ppm (CO_2 equivalent). Stabilisation at 550ppm would be unlikely to keep global temperature rise below 2ºC, while 450ppm gives only a 50% likelihood of meeting the target.[2]

Achieving 400ppm will likely require global emissions to peak before 2020, followed by substantial overall reductions by as much as 60% from present levels in 2050.[3] Improving our chances will require earlier and more drastic action. Furthermore, delays in taking action will require faster reductions to a lower level of emissions by 2050. It has been estimated that a 20 year delay in undertaking emission reductions will require levels to then be reduced at three to seven times the rate if action begins now. Options only available in 20 years time would then need to be three to seven times faster in reducing emissions at equivalent cost and effort than existing options for it to be worth waiting.

1.2 Assessing our abatement options

In the stationary energy sector on which we will be focussing, there is a range of power generation options of varied status and promise for reducing greenhouse emissions, including:

- the latest conventional coal-fired base-load and gas-fired peak-load plant
- Improved end-use energy efficiency
- lower emission and distributed fossil fuel technologies including Natural Gas Combined Cycle (NGCC) and Cogeneration
- nuclear power
- a range of both existing and emerging renewable technologies
- emerging Carbon Capture and Storage (CCS) technologies for large-scale applications
- other promising but still emerging technologies such as, for example, fuel cells

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[1] DEFRA. *Avoiding Dangerous Climate Change*, Summary Report of the Conference held in the UK, February 2005.

[2] Meinhausen. Presentation at the *Avoiding Dangerous Climate Change* Conference, February 2005.

[3] Kalbekken, Presentation at the *Avoiding Dangerous Climate Change* Conference, February 2005.

These options include a number of existing, well proven, technologies. Technical progress, however, is clearly essential as these options are almost certainly inadequate for the scale of change required. Much of this progress will certainly be ongoing improvement of such existing options, however, there are also important innovation opportunities in promising but still emerging technologies including CCS.

A possible framework for assessing our different abatement options to help guide policy support highlights the need to assess:

- technical status: from unproven to emerging to mature. This is key in terms of managing uncertainties and evaluating possible time lags in achieving significant deployment
- delivered services and benefits – emission reductions of course, yet also potentially flexibility and ease of integration with existing energy infrastructure
- present costs where known, and possible future costs
- potential scale of abatement including possible technical constraints and changing costs with different levels of deployment
- potential speed of deployment
- other possible societal outcomes – for example, a range of other environmental impacts, energy security implications and economic development opportunities

All of these factors need to be considered in a framework that explicitly acknowledges and represents the different uncertainties involved with particular abatement options. In the next section we consider CCS in the light of some of the key assessment questions identified above, with a particular focus on these present uncertainties:

- overcoming current technology limitations of CCS for application to electricity generation
- determining whether existing power plants can be retro-fitted for separation and capture
- identifying whether the major sources of emissions in Australia are sufficiently matched to the required natural features for successful long term storage
- evaluating how the likely timeframe for commercial deployment of CCS affects its contribution to meeting emissions abatement targets
- determining to what degree the long-term deployment of CCS can be cost effective when compared to other methods of CO_2 abatement

2 The current technology status of CCS

CCS is generally evaluated in terms of the 3 basic components:

- separation and capture of CO_2
- transportation from emissions source to storage site
- storage and monitoring

While each of these components has been used in various industrial applications around the world, they have generally not been combined on an end to end basis, nor at the scale required to prove CCS's application for large scale power generation. The status of the scientific and technology development for each of these components is assessed in turn below.

2.1 Separation and capture of CO_2

The 3 main options being considered as solutions for the separation and capture of CO_2 emissions are evaluated below.

2.1.1 Pulverised Coal with post combustion capture using solvent absorption

Solvent absorption is currently used for the removal of CO_2 in a number of industrial applications including natural gas and ammonia production. Due to this proven application, solvent absorption is considered the capture technology of choice for power generation in the short term. This also means that the current cost of solvent absorption will be used as the benchmark against which to measure new technologies. [4]

These current uses of solvent absorption are applied where the concentrations of CO_2 are relatively high.[5] However the flue gases from both gas and coal-fired power generation typically have much lower concentrations of CO_2, requiring much greater energy use for capture. This energy penalty is seen as one of the major impediments to the use of the solvent absorption method in electricity generation[6]. It is expected that newly built power plants will be able to use waste heat from the power generation to regenerate the solvent.

There is significant debate about what the level of this energy penalty will be for purpose-built generation with CCS. A study undertaken into each of three proprietary processes currently used for solvent absorption in a variety of industries (not including power generation) was undertaken by Roberts et al in 2004[7]. They argued that previous estimates of the energy penalty have overstated the cost of capture because they did not assume a purpose-built and integrated plant for both generation and capture. They estimated an energy penalty of just 8-9% for both NGCC and Ultra Supercritical Pulverised Coal (USPC) generators. However a more recent study (Ruben et al 2005) claimed a penalty of 16-17%.[8]Pulverised Coal with post combustion capture using alternative methods

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[4] CO2CRC - "Carbon Dioxide Capture and Storage: Research Development and Demonstration in Australia: A Technology Roadmap." September 2004. Cooperative Research Centre for Greenhouse Gas Technologies.

[5] IPCC 2005 - Intergovernmental Panel on Climate Change - Special Report "Carbon Dioxide Capture and Storage" September 2005

[6] IEA 2003 – Gielen D "The Future Role of CO2 Capture and Storage - Results of the IEA-ETP Model" November 2003.

[7] Roberts C, Gibbins J, Pansar R & Kellsall G "Potential For Improvement In Power Generation With Post-Combustion Capture Of CO^2" IEA Greenhouse Gas R&D programme 2004

[8] Ruben E, Anand B, & Chao Chen "Comparative Assessments of Fossil Fuel Power Plants" with CO2 Capture and Storage" Proceedings of 7th International Conference on Greenhouse Control Technologies Sept 2004

In Australia some R&D support targets further development of existing membrane technologies and gas liquid membranes.[9] However some observers claim that membrane technology would involve a higher energy penalty and produce a lower percentage of CO_2 removal than existing solvent absorption technologies.[10,11]

In the longer term there are other technologies such as membrane-based reactors, cryogenic separation and so called "Novel Concepts". Each of these concepts are speculative and require significant scientific breakthroughs over at least 10 to 15 years before they may be proven for commercial deployment.

The energy penalty and the possibly high cost of implementing post-combustion capture are the drivers behind the pre-combustion capture technologies being investigated.

2.1.2 Oxy-fuel combustion with post combustion capture

While not deployed in the electricity industry, key steps of oxyfuel combustion are currently practiced in a number of industries including iron & steel, aluminium and glass production. The IPCC notes that a number of countries are planning demonstration of oxy-fuel combustion for electricity generation[12]. One of the early examples is a 30MW demonstration plant being proposed at the Callide A site in Queensland. CS Energy is expecting to commence trial operation in 2009.

Implementation of oxy-fuel combustion on a commercial scale is faced with two key issues. Firstly it requires the large-scale production of an economic supply of oxygen, with the current process carrying a significant energy penalty. Secondly, the much higher operating temperatures are problematic for current plant materials.[13,14] These issues currently come at a significant cost premium and accordingly research is focused on finding more economic methods.

2.1.3 Pre-combustion capture

Integrated Gasification Combined Cycle (IGCC) has been in use as a power generation process since the 1980's. IGCC provides significant benefits over conventional coal generation in terms of reduced waste gas volumes and increased purity and pressure of the CO_2. Separation and capture of the CO_2 can then be performed in a much more efficient manner. Due to the relatively higher cost of production for IGCC generation, only 1GW has been installed worldwide. None of these plants have incorporated capture of the CO_2.[15] An additional benefit of IGCC is its potential to be adapted to the production of hydrogen.

Stanwell Corporation have announced an integrated gasification open cycle (IGOC) demonstration plant in Queensland (ZeroGen), aiming for commissioning in 2010.[16]

The USDOE is currently supporting the development of the 275MW IGCC "FutureGen" power plant incorporating hydrogen production and CO_2 capture in the US. The project was first announced in 2003, and is still in the site selection phase. Construction of the plant is expected to commence in 2009, with operation by 2012.[17]

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[9] CO2CRC 2004 (Op Cit)

[10] IPCC 2005 Op cit

[11] Herzog H "What Future for Carbon Capture and Sequestration?" Environmental Science and Technology April 1, 2001 / Vol 35 , Issue 7 / pp. 148 A – 153 A

[12] IPCC 2005 (Op Cit)

[13] Herzog 2001 (Op Cit)

[14] IPCC 2005 (Op Cit)

[15] IPCC 2005 (Op Cit)

[16] ZeroGen (2006) *Project Overview*, ZeroGen, Stanwell Corporation.

[17] Available from www.futuregenalliance.org/

2.1.4 Assessment of Separation and Capture technologies

At this stage there is no consensus amongst the proponents of CCS regarding which technology option is likely to offer the best performance from the perspective of cost and availability for commercial deployment. This view is supported by the IPCC who note that despite many decades of research into alternative and more efficient fossil fuel combustion systems *"It is generally not yet clear which of these emerging technologies, if any, will succeed as the dominant commercial technology for energy systems incorporating* CO_2 *capture."*[18]

This uncertainty does highlight that there are a range of options should any particular approach prove to be ineffective or very high cost. It does, however, has three serious implications from an emissions abatement policy perspective:

- the R&D effort (and the available funding) is fragmented
- commercial deployment for the eventual preferred technology could be delayed
- reduced economies of scale (and "learning by doing") that would otherwise be available for a single option

2.2 Transportation from emissions source to storage site

There are two proven methods of moving large quantities of gas: by high pressure pipeline or by specialised ship. Both of these methods are mature and have been proven over decades of operation in the natural gas industry. Almost 3,000 km of dedicated CO_2 pipelines have been built in the USA for use in Enhanced Oil Recovery.

However, a very large pipeline capacity would be required to transport the liquefied CO_2 generated by Australian fossil fuel power stations. It is also worth noting that transporting CO_2 over distances greater than 500km may be unlikely to be economically viable.[19]

2.3 Storage and Monitoring

There are numerous examples of CO_2 storage in the oil and gas industry. The oldest examples are generally associated with enhanced oil recovery, which means they have not been managed or monitored as an active means of CO_2 reduction. In particular there are three examples of CO_2 storage that are often quoted in the CCS literature, namely: Weyburn in Canada, Sleipner in Norway, and In Salah in Algeria.

These sites have come under increased scrutiny in recent times due to the fact that they provide CCS researchers the opportunity to monitor their effectiveness in storing CO_2. CO_2 injection into deep saline aquifers potentially offers by far the largest geological storage capacity, however, we currently have only a limited understanding of such reservoirs and their distribution and geology; primarily because they have not had any commercial value until now. The major concern being raised is that not enough is known about the long-term behaviour of CO_2 once injected, and whether the storage is permanent. This is due to the imperfect knowledge of geological structures and the great potential variation in sites being used for CCS.

Two examples of the unpredictable behaviour of the injected CO_2 have been noted for:

- the Sleipner field, where the CO_2 did not fan out within the saline aquifer as expected[20]
- a test storage of 1,600 tonnes of CO_2 in a saline aquifer in Dayton, Texas.[21] The injected CO_2 made the brine acidic and dissolve minerals in the cap rock. This could lead to the formation of pathways and contamination of water tables or the leakage of CO_2.

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[18] IPCC 2005 (Op Cit) pg 122

[19] Bradshaw J, Bradshaw B, Allinson G, Rigg A, Nguyen V, and Spencer L, "The Potential for Geological Sequestration of CO2 in Australia: Preliminary Findings and Implications for New Gas Field Development" APPEA Journal 2002

[20] Saddler H, (et al) 2004

2.4 Retro-fitting existing generation plant for CCS

Given the long operating life of coal-fired plant, one of the critical factors affecting the speed of deployment of CCS will be the ability to retrofit CO_2 separation and capture processes to existing plant. Unfortunately, there is a near consensus view by the research community that the retro-fitting of existing plant with CCS, using the envisaged technology options, is not commercially viable.[22,23,24,25] In addition there is the specific issue for Australian generators of the incompatibility of solvent technologies without additional SOx and NOx filtering.

The counter view presented by some is that Oxyfuel Combustion could prove a candidate for retrofitting of existing plants.[26, 27] Retrofitting, however, would appear to suffer from the same issue as noted for solvent absorption, in that there is a much higher energy penalty where there is no purpose-built integration with the waste steam cycle. Also the study by Dillon et al (2005) is based on Advanced Super Critical Plants, and suggests retrofit applications are limited for the Pulverised Coal (PC) plants in Australia.

2.5 Source to sink matching

A detailed study of Australia's suitable storage sites was undertaken by the Australian Petroleum Co-operative Research Centre as part of the GEODISC program. Its findings included:

- that Australia had a potential CO_2 storage capacity for all its emissions for over 1000 years
- based on broad geographic grouping of Australia's emissions into "nodes", that 4 of Australia's nodes were sufficiently matched with viable sink locations.

However this analysis also highlights a number of issues for the viability of CCS for Australia[28]:

- most of Australia's CO_2 storage potential is in the NW Shelf region of WA, which is a considerable distance from the major sources of generation emissions in the South East
- in particular, there don't at this time appear to be any viable sinks to enable storage of CO_2 for the two nodes of Newcastle/Sydney/Wollongong and Port Augusta/Adelaide. Together these account for approximately 42% of Australia's CO_2 emissions from generation
- That the cost of transport and storage may not be viable for generators producing less than 2 million tonnes of CO_2 per annum given that the cost is more impacted by the amount of throughput of CO_2 than the distance of the source from the sink.[29] Unless these smaller sources can be consolidated, it is estimated that up to a further 5% of the maximum available CCS contribution could be at risk

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[21] Kharaka Y, Cole D, Hovorka S, Gunter W, "Gas-water-rock interactions in Frio Formation following CO2 injection: Implications for the storage of greenhouse gases in sedimentary basins" Geology, March 2006, Vol. 34, No. 7, pp. 577

[22] IPCC 2006 (Op Cit)

[23] COAL21: Reducing Greenhouse Gas Emissions Arising from the Use of Coal in Electricity Generation. A National Plan of Action for Australia. Australian Coal Association, Canberra, March 2004

[24] IEA 2003: Gielen D "The Future Role of CO2 Capture and Storage Results of the IEA-ETP Model" International Energy Agency Nov 2003

[25] Saddler H, Reidy C & Passey R "Geosequestration - What is it and how much can it contribute to a sustainable energy policy for Australia?" The Australia Institute, discussion paper no. 72. 09/ 2004

[26] COAL21: Reducing Greenhouse Gas Emissions Arising from the Use of Coal in Electricity Generation. A National Plan of Action for Australia. Australian Coal Association, Canberra, March 2004

[27] D J Dillon , R S Panesar , R A Wall 2, R J Allam V White , J Gibbins & M R Haines 2005 "Oxy-Combustion Processes For Co2 Capture From Advanced Supercritical PF And NGCC Power Plant" Proceedings of 7th International Conference on Greenhouse Gas Control Technologies. Volume I: Peer Reviewed Papers and Overviews, Elsevier Science, Oxford, UK, 211-220.

[28] Bradshaw J, Bradshaw B, Allinson G, Rigg A, Nguyen V, and Spencer L, "The Potential for Geological Sequestration of CO2 in Australia: Preliminary Findings and Implications for New Gas Field Development" APPEA Journal 2002

[29] Allinson W, Nguyen D, and Bradshaw J "The Economics of Geological Storage in Australia" APPEA Journal 2003

Passey and MacGill discussed the potential scenario that as generation plant is retired in non viable storage areas, new plant may be relocated. However the relocation would come at considerable cost for the large transmission capacity required to deliver the electricity.[30]

2.6 Timeframe for commercial deployment of CCS

While there would appear to be some broad consensus amongst these research forecasts for initial deployments of CCS between 2015 and 2020, there are numerous other factors that would determine the broad deployment of an effective CO_2 abatement strategy based on CCS. While many of these factors apply equally to all abatement measures, there are major factors that specifically apply to CCS and are likely to influence its deployment. For example

- both the initial cost and the potential for reductions over time
- whether the technology can be retrofitted
- in the absence of retrofitting, how quickly existing coal plant will be retired

In their efforts to prove commercial deployment, the proposed demonstration plants will need to prove their cost effectiveness, not just that the technology works. Without some level of cost certainty, it is questionable whether investors will proceed with construction of commercial scale CCS capable plants, and existing technology roadmaps may underestimate this factor.

The significant uncertainty created by all these variables is best illustrated by the IPCC who have developed a number of scenarios for the potential contribution of CCS to global CO_2 abatement. The contribution of two of their scenario models – MiniCAM and MESSAGE are shown below[31]:

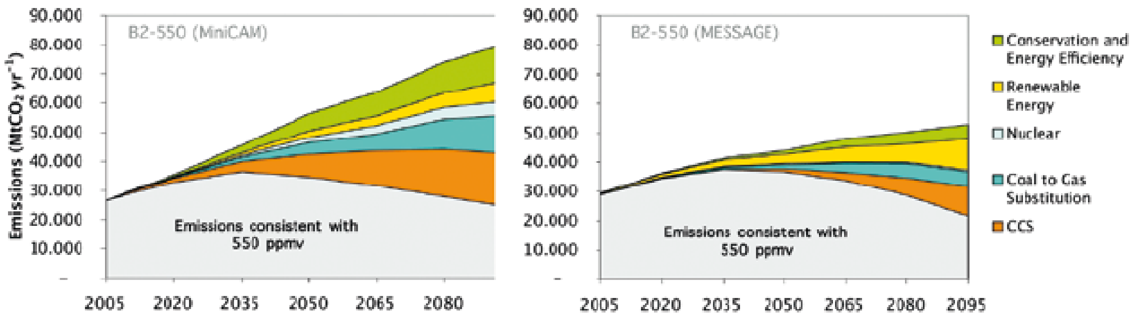

Figure 1 – IPCC emissions abatement models

These models show greatly differing forecasts in terms of both the date at which CCS begins driving significant abatement (ie 2015 versus 2040) and its contribution to the abatement mix. The contribution from CCS to CO_2 abatement in the MESSAGE model (in percentage terms) is consistent with that developed by Beck & Cook for Australia, who show minimal abatement impact from CCS until after 2030.[32]

Unfortunately the IPCC does not specify what the relative influence each barrier / or factor has on the take-up of CCS. However they have noted that it is likely that the models overestimate the contribution of CCS, because of numerous barriers including investment risk and regulatory uncertainty. In their words, "the interaction between CCS deployment and the policy regime in which energy is produced and consumed cannot be overemphasized; the magnitude and timing of early deployment depends very much on the policy environment."[33]

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[30] Passey R, and MacGill I, "The Australian Electricity Industry and Geosequestration – Some Abatement Scenarios" Destination Renewables ANZSES 2003

[31] IPCC 2005 (Op Cit) pg 352

[32] Beck, B and Cook P, "Modelling the Potential of Geosequestration" AETF Review pg 6 Feb/March 2005

[33] IPCC 2005 (Op cit) pg 351

3 The potential economics of CCS

3.1 Forecast costs for CCS

Australian fossil fuel wholesale generation prices are generally some of the lowest in the world. This is illustrated by the IPCC's reference plants being shown at generating prices substantially higher than for Australia. The main reason for this is the significantly higher prices for both gas and coal, which are shown in the following table, converted at the exchange rate of $US 1.0 equals $AUS 0.76.

	Range in $MW/h		
GENERATOR TYPE	**LOW**	**HIGH**	**COMMENT**
PC (BLACK COAL)	**57**	**68**	*Coal price range between $1.3 and $2.0 per GJ*
NGCC	**41**	**66**	*Gas price range between $3.7 and $5.8 per GJ*

Figure 2 – IPCC reference plant cost of generation (without CCS)[34]

This difference in prices is important when translating international estimates of the cost of generation with CCS, to the Australian market.

The uncertainty in price for CCS is illustrated by the fact that the Australian government was unable (or perhaps unwilling) to provide estimates for the cost of coal fired generation with CCS for its cornerstone energy policy document "Securing Australia's Energy future"[35], and also by the wide range of estimates found in the available literature.

The following table details a number of recent estimates of the cost of generation with CCS, converted to Australian dollars and normalized for lower Australian generation prices (for the respective new build plant). It includes two international studies both utilizing a comparison of numerous sources[36,37] and a more recent Australian study[38]. The comparison is provided for SCPC (black coal), NGCC, and IGCC generation.

These estimates are for the full cycle of separation, capture, transport and storage. Transport and storage was added in to one study to aid comparison.

Notably each study believes that NGCC offers the lowest current cost range for generation with CCS ($64-78 MW/h). The cost of NGCC has the potential to be even lower if the Australian Government altered the existing tax regime which currently sees coal paying $1 per GJ less than gas. The studies do not provide a consensus view as to ranking of SCPC and IGCC.

It should be noted that the cost of CCS for Victorian brown coal based generators are likely to experience costs higher than this due to:

- the requirement for offshore storage, which is estimated to add between 40% and 70% more costs than onshore pipelines[39]; and
- the requirement for an additional coal drying process for IGCC and oxy-fuel applications, given the high moisture content of Victoria's brown coal.

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[34] IPCC 2005 (Op Cit)

[35] Australian Government "Securing Australia's Energy Future" 2004

[36] IPCC (Op Cit 2005)

[37] Ruben et al (2004)

[38] McLennan Magasanik Associates Pty Ltd, "Renewable Energy – A Contribution to Australia's Environmental and Economic Sustainability" June 2006

[39] IPCC 2005 (Op Cit)

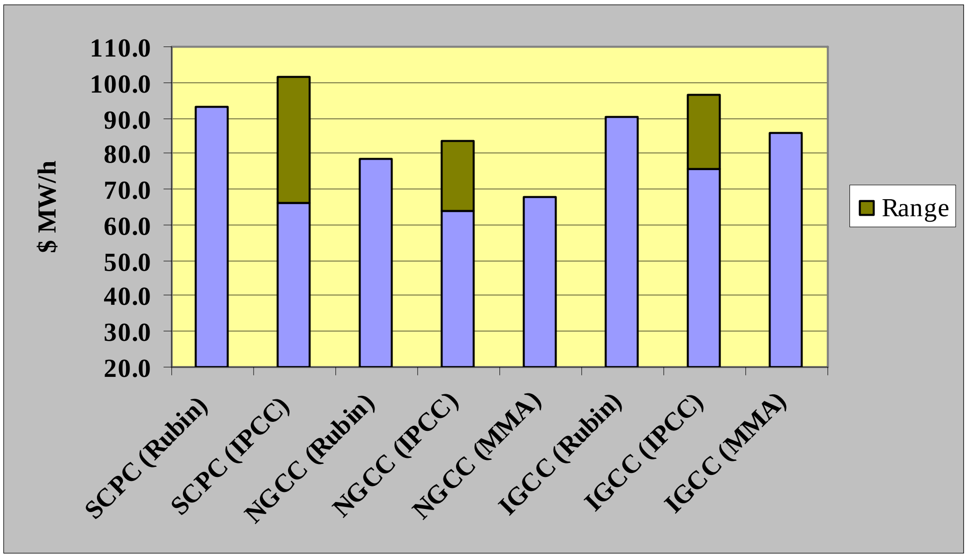

Figure 2 – Comparison of wholesale price for generation with CCS

3.2 How fast can the price of CCS fall

The question of "How fast can the price of CCS fall" is perhaps the most critical question in determining the viability of Geosequestration for Australia. However it also faces the greatest level of uncertainty. The industry generally sees cost reductions arising from experience, or "learning by doing".

One study tried to estimate the likely impact of "learning by doing" by looking at the experience of sulfur dioxide reduction technologies introduced to coal generation since the 1970's.[40] They found that the required capital investment declined by 13% for each doubling of capacity worldwide, and given the similarity in technologies this factor could equally apply to CCS. A more recent study used a similar approach based on improvements in various generation technologies. This estimated a reduction in price of between 9.7% and 17.6% for various CCS technologies after the installation of 100GW of capacity. However this study also noted that historically the actual cost of generation always rose compared to pre-commercial estimates.[41]

However neither of these analyses was able to provide a forecast of the likely timing of cost decreases for various CCS technologies. Forecast for the declining costs of generation for both NGCC and IGCC with CCS have been developed by MMA for the Australian market.[42] However, given the uncertainty surrounding even the immediate cost forecasts for CCS technologies (that are some time from being commercialized), we would support the view that longer term forecasts are not particularly reliable.

[40] Riahi K, Rubin E, Taylor M, Schrattenholzer L, Hounshell D, "Technological learning for carbon capture and sequestration technologies", Energy Economics 26(4) 2004

[41] Rubin S, Yeh S, Antes M, "Estimating Future Costs of CO2 Capture Systems Using Historical Experience Curves", 8th International Conference on Greenhouse Gas Control Technologies: June 2006

[42] MMA 2006 (Op Cit)

3.3 Costs for alternative CO_2 abatement options

The report by MMA also provided an estimate of the likely price decrease in generation costs over time for non-fossil fuel alternatives. This analysis is reproduced below[43]:

This chart shows the current cost of Nuclear, Biomass and Geothermal as being around $70MWh, which is comparable with for the ranges for NGCC with CCS. The cost reductions are justified under similar "learning by doing" assumptions used for CCS, which explains why nuclear (being more mature) has a lower capacity for cost reductions. Most notable is the cost of geothermal generation, with expectations that further deployments could lead to costs that would make it comparable to current coal generation without CCS. While these technologies are generally more developed than CCS, we would again use some caution in the relying on forecasts over such a long timeframe.

The Federal Government's own sources give a range of costs for wind generation with potentially lower costs than MMA, at $55-80 per MWh[44]. ABARE is also more optimistic about cost reductions in wind, and believes it could fall to $35 per MWh by 2020 and even lower in Tasmania[45].

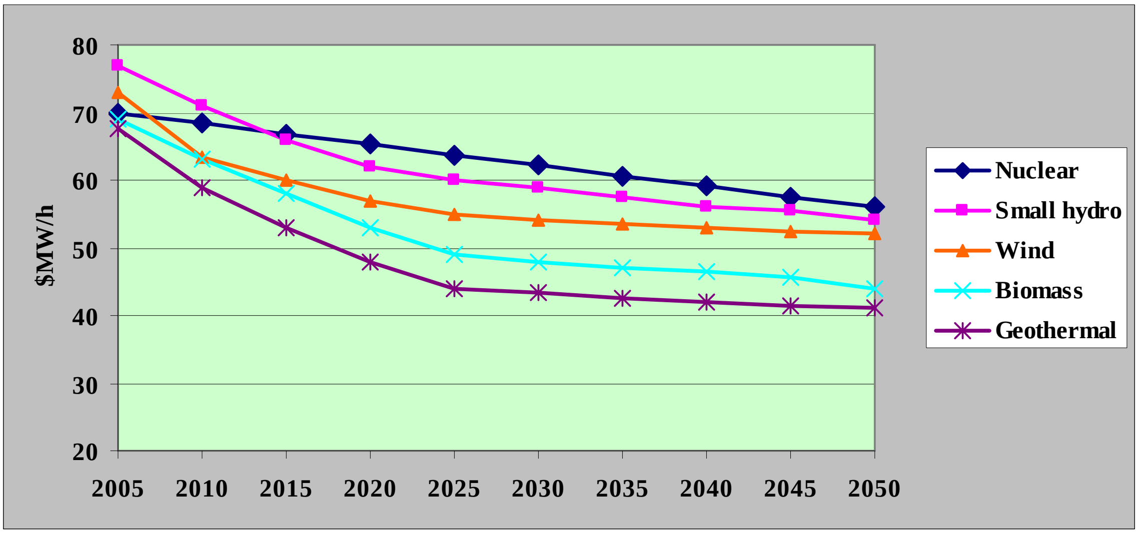

Figure 3 – Some estimates of the comparative declining cost per MW/h of a range of non-fossil fuel generation types

When comparing the various generation types, it should also be acknowledged that renewable energy generally offers 100% CO_2 abatement. CCS on the other hand only offers 80-90% capture efficiency[46]. If a CO_2 cost penalty was applied to cover the balance of emissions then the prices of the respective CCS types would further increase by a modest amount.

3.4 The impact of risk on investment decisions

Under an emissions trading scheme, any investment decisions about new generation will inevitably evaluate the level of risk inherent in any new technology. The capital markets generally deal with high risk investments by placing a higher discount rate on the capital being deployed,

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[43] MMA 2006 (Op Cit)

[44] Securing Australia's Energy Future 2004 (Op Cit)

[45] Short C and Dickson A, "Excluding technologies from the Mandatory Renewable Energy Target", ABARE eReport 03.12, AbareEconomics, June 2003.

[46] IPCC 2005 (Op Cit)

which in turn increases the wholesale cost of generation. However, most of the literature would appear to have applied equal discount rates to all abatement technologies regardless of risk.

We would argue that a quantitative risk assessment based on the probability of each of the research barriers for CCS being overcome would probably conclude that the CCS has a relatively high risk compared to such alternative methods of CO_2 abatement. The alternatives can generally be assessed as being further along the development path, with the risk being more dependent on achieving economies of scale to reduce costs. If the capital markets did apply a higher discount rate to CCS, then it may affect either its cost competitiveness or reduce its scale of deployment.

4 Policy implications for CCS

4.1 A coherent policy framework for CCS

In light of the above assessment CCS should be considered as a promising, but still somewhat unproven, option that potentially offers very significant abatement potential and good integration into the existing energy industry. For Australia, its success would also have additional value in supporting continued coal exports. There are, however, some outstanding questions regarding its effectiveness and safety, its delivered abatement is likely to come at significant cost and it is unlikely to be able to make a significant contribution to emission reductions for a decade or more.

The implications for CCS policy are clear. Governments have important policy roles in all of:

- *Invention*: support R&D into promising socially beneficial yet unproven technologies
- *Commercialisation*: support the demonstration and initial deployment of promising but still unproven technologies, and
- *Diffusion/Adoption:* ensure markets reflect societal preferences through regulatory and market-based mechanisms to drive greater use of existing but currently only niche technologies that can help achieve wider policy objectives.

With respect to climate policy, the general priority should clearly be driving the greater diffusion and adoption of existing technology options that can reduce greenhouse emissions. The key policy response should therefore be based around 'market pull' deployment measures for existing technologies including regulatory requirements, the creation of niche technology markets and a price on carbon through taxes or emissions trading. R&D and demonstration of promising yet still emerging technologies is a second-tier priority given the urgency of achieving emission reductions.

CCS falls largely into this later, lower priority, policy category. There is certainly a need for some publicly funded support for R&D and demonstration of some key CCS technology components. We are seeing growing worldwide efforts in these regards as noted in Section 2 and Section 3.

There is also, however, a need for more general market-based mechanisms that put a price on greenhouse emissions. For example, important early applications of CO_2 injection into geological formations have been driven by a carbon tax in Norway (the Sleipner Vest project) and potential abatement credits under the Kyoto Clean Development Mechanism (CDM) for the In Salah project in Algeria. More generally, such market mechanisms send a clear signal to private participants in the energy industry of the value of investing in R&D and in demonstrating abatement technologies.

More generally, an appropriate CCS policy has to sit within a wider coherent policy framework that supports a range of abatement options. Otherwise, possible unpleasant surprises in the effectiveness or costs of CCS could completely invalidate the policy response.

4.2 The current Australian policy context

CCS is clearly a strategic abatement technology for some countries including Australia, which has a heavy reliance on fossil fuels for both domestic energy provision, and internationally traded exports. Its per-capita greenhouse emissions are amongst the highest in the world – twice the developed world average and many times that of developing countries.[47]

[47] IPCC, Third Assessment Report, 2001.

While the Australian Government has acknowledged the need for major emission reductions in the longer term, stationary energy sector emissions under the present policy framework are projected to increase over 40% above 1990 levels by 2010, and nearly 80% by 2020.[48]

This present policy framework is very focussed on development of future technologies with a particular emphasis on CCS. Policy support includes significant public funding of CCS R&D through a range of Cooperative Research Centres and leveraged demonstration funds for low emission technologies where CCS is likely to receive considerable support. There would seem to be less interest and only limited support for increasing the deployment of existing energy efficiency, gas-fired generation and renewable energy options. For example, the Government has ruled out for now the introduction of national emissions trading or carbon taxes to put a price on greenhouse emissions, and chosen not to expand its very modest targets for new renewable energy supply.[49]

We don't know yet what role CCS can play in our abatement efforts and shouldn't rely on it, or any other particular technology for that matter, to answer all our challenges. What is needed is a policy framework that will resolve the question of what role CCS might play in the medium to longer term for Australia and elsewhere, while reducing risks and maximising opportunities through much greater and immediate support of existing, technically proven, abatement options.

In our view, the present R&D and demonstration support for CCS is entirely appropriate and should be greatly expanded. There are, however, limits to what Australia can achieve through such demonstrations and much will rely on international technology developments. Support for greater international effort on climate change policies would be helpful in this regard.

More importantly, Australia needs a coherent policy framework that supports greater deployment of existing abatement options. This could help drive early, low cost, CCS options in gas processing and some industrial facilities. More generally, such a framework would drive greater use of lower emission gas Natural Gas Combined Cycle (NGCC) generation. These off-the-shelf technologies can provide early emission reductions, be integrated with coal gasification technologies when and if they become commercially available and offer direct CCS opportunities.[50] Such deployment policies would involve some mix of emissions trading or carbon taxes with mandated niche markets for particular technologies and additional regulatory measures. These would also drive greater energy efficiency and renewables deployment providing a more diversified and hence robust, lower risk response.

We largely concur with the IEA 2005 Energy Policy Review on the risks of present Australian energy policy. They note that "Australia is taking a technological approach to reducing emissions from its energy sector… While new technologies will be a key component in tackling the long-term problem of climate change, there is no certainty when and to what extent the necessary technologies will be developed. Such technologies would most likely require a carbon price signal to facilitate their implementation." We would add that such a carbon price signal would also play an important role in driving other abatement options as well, improving the likely effectiveness and robustness of our policy response.

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[48] Australian Greenhouse Office, *Tracking to the Kyoto Target*, 2005.

[49] Australian Government, *Energy White Paper*, 2004.

[50] Outhred and MacGill, "Some comments on 'The Economic and Environmental Impact of Scale-efficient IGCC plant in the NEM: A Stanwell Corporation discussion paper provided by CO2CRC, May 2004,'" *ERGO draft discussion paper 0104,* August 2004.