Carbon Capture and Storage: An appropriate technology for New Zealand?

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Abstract

Carbon capture and storage (CCS) has been widely touted as a practical way to reduce carbon dioxide emissions from fossil fuel combustion, and if successfully implemented, could permit the continued use of coal and gas for many decades, whilst at the same time meeting greenhouse gas targets. In this paper we discuss the applicability of CCS technology to existing coal-fired electricity generation in New Zealand, and to new thermal generation using Integrated Gasification Combined Cycle (IGCC) technology, with specific reference to the time frames signalled for deep cuts in New Zealand's greenhouse gas (GHG) emissions and those required for major works of this nature. Energy penalty estimates show that adoption of CCS with IGCC would involve the consumption of at least 22% additional coal for the capture and compression stages only. The current global absence of full-scale coal fired power plants with operational CCS systems, and the planning and construction times likely for adoption and construction of new plant, indicate that CCS technology will not assist New Zealand to meet interim GHG reductions of 20-40% by 2020. If applied to a 900 MWe (IGCC) thermal power plant, the technology could contribute 7% of annual GHG reductions starting from 2024-2030. However, considerable technical, commercial and legal uncertainties remain to be resolved. On balance we consider CCS technology to be inappropriate for New Zealand conditions and recommend alternative investment of research funds into the use of woody biomass, a permanent and sustainable resource, for future thermal heat and power generation.

Introduction

The need for an urgent response to climate change has been acknowledged by many governments, and with it a corresponding need for significant greenhouse gas (GHG) emissions reductions. A call for 50% reduction in global emissions from 1990 levels by 2050 has been made by Stern (2008), but for reasons of equity, high per capita emitters such as the USA, the EU, Australia, Japan and New Zealand are signalled to require around 90% reductions by 2050 in order to stabilize GHG concentrations in the atmosphere at 450-550 ppm CO_2-equivalent (CO_2e) (Meyer, 2000; Monbiot, 2006; Stern, 2006; IPCC, 2007). Early action is being urged in order minimise risks and costs (Meyer, 2000; Stern, 2008). Stern, (2008) proposes that global emissions must peak "within the next 15 years", and that the cluster of countries with per capita emissions of 20-25 tonne-CO_2e need to adopt interim emissions reductions targets of "20 to 40% by 2020".

New Zealand was ranked 11th highest gross GHG emitter in the world based on 2000 data, at 18.9 tonne-CO_2e per capita (Baumert et al., 2005) and emissions have risen by 26% over the period 1990-2006 (MfE, 2008). Recent modelling has indicated that continued emissions growth is likely, despite various policy measures including a planned Emissions Trading Scheme (ETS) (NZ Government, 2007). The New Zealand ETS is projected to only slow the rate of further emissions growth, by approximately 50% over business-as-usual in the best case scenario (Infometrics, 2008).

The combustion of fossil fuels for electricity generation has been identified as one of the major contributors to GHG emissions worldwide, accounting for 10.9 Gt-CO_2, or approximately 22% of GHG emissions in 2005 (IEA, 2007; IPCC, 2007). The majority of these emissions were from coal fired power generation (7.9 Gt-CO_2) with gas-fired generation accounting for 2.1 Gt-CO_2 (IEA, 2007). In New Zealand fossil-fuel fired thermal electricity generation generates only a minor fraction of total GHG emissions, but these plants presently contribute a significant proportion of electricity output (MfE, 2007) and generation capacity (31.3% in 2006) (MED, 2007a), and provide important peak load capability. Despite a proposed moratorium on new thermal base load generation construction (NZ Government, 2007), keen interest in future coal utilisation remains, both for thermal electricity generation and liquid fuels production.

Carbon Capture and Storage (CCS) has been widely touted as a practical way to reduce carbon dioxide emissions from fossil fuel combustion e.g. (Davison and Thambimuthu, 2005; Deutsch and Moniz, 2007; Kintisch, 2007; Gale, 2008). CCS involves capturing point source carbon dioxide emissions, compressing or liquefying the gas, transporting the CO_2 and permanently storing it in appropriate geological formations or under the sea (Herzog and Golomb, 2004; IPCC, 2005). Recent comment in the scientific press has suggested that claims of CCS retrofits for coal-fired electricity generation being "just around the corner" lack substance, citing withdrawal of significant funding in the USA and Europe (Webb, 2008). Whilst proponents of CCS have acknowledged that this technology is not a "silver bullet" for climate change mitigation, being but a key part of a portfolio of approaches e.g. (Davison, 2005), it has nonetheless been promoted as a leading transitional technology for reducing greenhouse gas emissions en route to complete implementation of renewable energy systems, and recently highlighted as a key component of decarbonisation strategies (IPCC, 2007; Stern, 2008).

The objective of this paper is to examine the applicability of CCS to New Zealand electricity generation in light of our distinctive energy and GHG profiles, the present status of CCS technology, the timeframes being suggested for significant GHG reductions, and the constraints on CCS implementation. We proceed with an overview of the NZ energy scene, a brief review of the technology, an examination of timeframes for meaningful action on GHG emissions and plant construction, and then examine a case studies involving building new state of the art plant in Waikato and Southland.

Electricity generation and GHG emissions

Although electricity generation in New Zealand remains dominated by the use of renewable resources, the amount of fossil-fuel fired generation has increased markedly over recent years. In 2005, coal and natural gas fired generation accounted for 14260 GWh or 34.3% of electricity generated in New Zealand, and produced 8.4 Mt or 10.9% of total GHG emissions (Table 1). GHG emissions from coal and gas generation in 2005 have risen by 144% over 1990 levels.

A number of Ministry of Economic Development (MED) scenario projections (Table 2), covering growth from 145PJ (in 2005) electricity generation to around 195PJ in 2030, allow for some future fossil-fuel fired generation. Some of these MED projections assume the availability and affordability of CCS in the medium term future.

Table 1: GHG data for New Zealand (Mt-CO_2-e) (MED, 2007b)

Source	1990	1995	2000	2005
Gas-fired electricity generation	3.002	2.379	4.054	3.468
Coal-fired electricity generation	0.477	0.553	0.887	4.942
Total	3.449	2.932	4.941	8.410
Increase in fossil-fuel electricity emissions since 1990 (%)	0	-15	43	144

Table 2: Projections for GHG emissions from electricity generation (Mt CO_2-e)

Description	2020	2030	2050	Assumptions	Reference
Base Case 1	8.6	10.8		Business as usual	MED 2006
Low Gas Discoveries Sensitivity case	8.6	15.6	-	No gas discoveries, no LNG imports, resulting in increased coal-fired generation (without CCS)	MED 2006
Renewable Electricity Sensitivity case	4.2	4.3	-	Huntly closed down after 2014, no additional coal-fired generation. No additional gas-fired generation build, with existing plants moving to imported LNG. All new generation is renewable	MED 2006
Renewable Scenario	2.8	1.3	-	Same as above but with coal replaced by biomass or gas in industrial boilers by 2019, no LNG imports before 2030, and some wave energy available after 2015	MED 2006
CCS Scenario	3.8	2.3	-	CCS technology widely available by 2020 with lignite CCS 393MW in 2025, 648MW in 2030. Huntley retrofitted with CCS resulting in a efficiency decrease of 25% and a cost increase of 50%. Gas or biomass replaces coal in industrial boilers	MED 2006
Base Case 2	8.9	9.7	10.9	Existing generation technologies used with mix determined by current knowledge and cost	MED 2007c
Demand reduction, renewables CCS and/or additional renewables	4.4	1.8	0.4	Huntley phased out, CCS economically viable from 2020 with 900MW coal with CCS built between 2030 and 2050	MED 2007d

Of particular interest are a) the "CCS scenario" in which CCS becomes available by 2020, and b) the "Demand reduction" scenario, in which CCS becomes economic by 2020 and implemented between 2030 and 2050. In this paper we focus on coal on the basis that indigenous natural gas reserves are limited, and there are a number of potential impediments to the use of imported LNG, notably security of supply.

Coal resources and reserves

New Zealand has a large energy resource in its recoverable coal (Table 3). However, coal reserves (defined as those resources which are economically and technically recoverable under current conditions) are substantially lower. New Zealand's lower rank coals are expensive to produce, as evident from coal imports that accounted for more than half of New Zealand's coal fired electricity generation in 2006 (MED, 2007a).

Table 3. New Zealand's coal resources and reserves

Type	**Resources** [a]	**Recoverable resources** [a]	**Reserves** [b]	**Reserves/recoverable**
	PJ gross	PJ gross	PJ gross	%
Bituminous	28 174	10 017	1 115	11.1
Sub-bituminous	70 740	24 224	13 298	54.9
Lignite	151 649	94 341	*na* [c]	*na* [c]
Total	250 562	128 581	14 413	-

[a] calculated to December 2006 from StatisticsNZ (2002), and MED (2002, 2007a)

[b] calculated using BP (2007) (December 2006 figures)

[c] not available

At the 2006 rate of indigenous coal production, (152 PJ/yr) the recoverable resources would last for about 850 years while the reserves would last for around 95 years.

The present status of CCS technology

The principles of CCS have been known for many years and 3 individual elements of a CCS system (separation, transport of CO_2 and subterranean injection) have been demonstrated at a commercial level. For example, carbon dioxide has been supplied to the beverage industry for decades by capturing CO_2 arising from fossil fuel combustion. Currently, there are three sites storing a total 3 – 4 Mt of carbon dioxide a year, a relativity small amount compared to the 8000 Mt emitted globally from coal-fired power stations (IPCC, 2005). The CO_2 for these storage projects is mostly derived from natural gas "sweetening" e.g. the Sliepner project operating on North Sea gas. To date however there are to our knowledge no coal-fired power plants either in operation, or construction, which have a complete and functioning CCS system.

Energy requirements for the separation of the CO_2 from flue gas from a power plant may be expressed as either an "energy penalty" or an "efficiency penalty" (Page et al., in press) as follows:

$$\text{Energy penalty} = 100\left(\frac{\text{Power output without CCS} - \text{Power output with CCS}}{\text{Power output without CCS}}\right) \tag{1}$$

$$\text{Efficiency Penalty} = \text{Efficiency without CCS (\%)} - \text{Efficiency with CCS(\%)} \tag{2}$$

Eq. 1 gives the proportional loss in power output capacity with reference to a base case without capture, whilst Eq. 2 shows the decrease in plant efficiency percentage points due to capture. To date all such values have arisen from simulations for capture and compression, although they are often presented as being actual data (Page et al., in press). For pulverised coal (PC) power plants quoted energy penalty values with capture range from 15-28%, whilst simulated efficiency penalties range from 8-15.4%. For newer technologies in terms of industry practice, the penalties are lower. In the case of natural gas combined cycle (NGCC) plants, the estimated efficiency penalty range is 6.0-11.3%, with three energy penalty values of approximately 15-16% reported. Integrated gasification combined cycle (IGCC) plant energy penalty estimates range widely from a low of 4.9 to a high of 20%, with efficiency penalty simulations in a slightly narrower band from 5.0-10.3%. To estimate the energy and efficiency penalties for sub-critical PC plants which comprise the majority of existing coal-fired power stations the present authors have calculated an energy penalty of 37% (assuming 90% capture and CO_2 compression to 11Mpa) (Page et al., in press). These calculations do not include transport and storage as these are site specific. Power requirements for two existing partial capture operations for which data are available are considerably greater than the modelled data suggest (Page et al., in press).

A 275 MW coal fired power plant incorporating a full scale CCS system in the USA (the FutureGen plant) was proposed in 2003 at a cost of US1.5 billion, with the design and build phase predicted to take around 5 years, with at least 5 years of operation beyond that (IEA, 2003). A site for the plant was selected in 2007, but subsequent withdrawal of US Department of Energy funding has effectively mothballed the project (DOE, 2008). We note that the FutureGen plant was to be of the IGCC type with pre-combustion capture, and thus if built, would not be useful for proving technical or economic viability of CCS for the vast majority of existing and planned coal fired power stations which require post combustion capture. In April 2008, the DOE announced a “Restructured FutureGen” program in which funding will be distributed to number of coal/gas power plants with complete CCS systems. However, we note that one of the main objectives of the program is to “establish technical feasibility…of producing electricity from coal with very low, or near-zero, emissions (including CO_2)”. In addition, the plants are only required to begin operation sometime before 2015, and are only expected to operate for 3-5years with a minimum 81% CO_2 capture specified.

New Zealand research into CCS has focused on geological storage. In 2004, a consortium comprising three New Zealand state-owned companies Solid Energy, the Institute of Geological and Nuclear Sciences (GNS) and Genesis Energy committed to an investment of A$1.75 million from 2004-2011 into the Australian Co-operative Research Centre for Greenhouse Gas Technologies (CO2CRC) programme. The CO2CRC group has recently commissioned a geo-sequestration trial at Otway, Victoria to inject 100,000 t-CO_2, separated from natural gas and compressed to a supercritical state, into to a depleted natural gas field at a depth of 2 km. As of 2 July, 2008, 10,000 t-CO_2 had been successfully injected, but no information on the energy requirement was available. Funnel et al. (2008) reported GNS studies on potential storage sites within New Zealand on the basis that this work would allow “fossil fuels to be used for energy production until renewables are developed”. Quantitative estimates of storage capacity ranged from 14 Mt in the Huntly coalfields to 300 Mt in the Maui gas field (once depleted). Qualitative assessments included “significant potential” in Taranaki offshore sites, “small-moderate potential” at the Ohai coal mine in Southland, “moderate potential” in western Southland (but with seismic risk) and “small potential” in eastern Southland. A “potentially large capacity” is signalled for the Solander and Great South offshore basins. In a joint FRST-funded project, the University of Auckland, Coal Research Limited and GNS are to determine the feasibility of sub-surface CO_2 storage in the Waikato and Taranaki regions (GNS, 2007). Solid Energy has assumed a leading role in developing carbon capture and storage. They announced a six month program of detailed geological data and analysis in order to identify potential sites, which if successful would be followed up with a drilling program (Solid Energy, 2006). A New Zealand CCS Steering group comprising FRST, Crown Minerals, Genesis Energy, Coal Ass., L&M Mining and

Solid Energy was established in 2006, with funding of NZ$1.5M per year for three years (CRL, 2008).

Time frames

GHG reductions

The time frame required for cuts in greenhouse gases depends on the desired stabilization level of CO_2e, which in turn depends on an accepted level of climate change. Modelling reported by the IPCC indicates that for a temperature rise of 2.4-2.8 ^{o}C, and a corresponding sea level rise of 0.5-1.7 m, global GHG emissions must reduce by 30-60% by 2050 compared to 2000 levels, with the peaking year between 2000-2020 (IPCC, 2007). This scenario assumes a stabilization level of 490-535 ppm CO_2e. Assuming global per capita equity (Meyer, 2000) the specific GHG reduction for New Zealand must take into account the future population of New Zealand and the world, together with historic population and GHG emissions. The implications for New Zealand, (UN, 2006; Statistics NZ, 2006; Statistics NZ, 2007, IPCC, 2007), are that total emissions must be reduced to 10.6-18.6 Mt CO_2-e, equating to reductions of 84.9–73.5% compared with emissions in 2000.

CCS implementation

Major projects such as power plants involve considerable time periods in planning, consenting, design and construction. In the case of power plants with CCS we have the added complication of early full-scale implementation of an unproven system. Recent estimated time frames for all project stages for standard coal fired power plant constructed in New Zealand, assuming that things run "reasonably smoothly", range from 5.0-9.1 years, with 6.6 years considered "likely" (MED, 2004). In comparison the time for design and build new power plant in the UK has been given as 3 y (Odeh and Cockerill, 2008), but it is not clear whether this includes planning permissions. Given present uncertainties over CO_2 transportation and storage in New Zealand we suggest that a 10 y period from initial decision to full commercial operation is reasonable. It is unlikely that an initial decision will be taken soon however, as New Zealand is expected to be a "fast follower" of CCS systems, and as yet there is no full-scale plant on which to base system design and assess performance under commercial conditions. As of 2006, no power plant designed with a complete CCS system was under construction at any scale (IEA 2006) and we are not aware of any subsequent plant construction. Assuming that construction on a pilot-scale power plant that includes a complete CCS system began overseas immediately, allowing for a build time of 3 years and a further 3 years operation allowed to provide data and costs, a decision could be taken in 6 years, giving a likely decision date of 2014 and a thus commercial operating date of in New Zealand of 2024. This agrees with the most recent IPCC assessment report that states CCS will become viable for power plants before 2030 (IPCC, 2007), however, it has been estimated that significant development will not occur the before 2050 (IPCC, 2005).

Site requirements for power plants with CCS are estimated to involve considerable areal footprint increases compared to a conventional plant without CCS. Figures presented by Davison (2005) for a 750 MWe combined cycle plant show an area of 3.0 ha for the power plant, an additional 2.6 ha for a pre-combustion capture retrofit and an additional 17.8 ha for a gasification retrofit.

We do not consider diesel production from lignite here since there is no practical way to capture the associated GHG emissions from motor vehicles. The government has agreed to a target of halving per capita GHG emissions from the domestic transport by 2040, relative to

2007 level (MOT 2007). Even with CCS at the plant, such a lignite to diesel conversion would cause New Zealand's transport GHG emissions to increase markedly.

Application to New Zealand

Technical issues

The existing sub-critical PC power plant at Huntly is now 28 y old and is in our view unlikely to be considered a suitable candidate for retrofitting a post-combustion CCS system. Thus a new build IGCC plant fitted with CCS would be indicated in order to utilise Waikato sub-bituminous coal. If lignite is to be utilised then a new build IGCC plant fitted with CCS and located in Southland is an option. Davison (2005) reported that at that time there were four coal IGCC demonstration plants in existence and that availability had been poor, although improving. IGCC was not the preferred technology for new coal-fired power plants at that time and incurred generally higher costs than PC plants.

The efficiency of an IGCC plant without CCS is taken as 42% and 40% for the Waikato and Southland options respectively, taking into account the higher thermal value of sub-bituminous coal compared to lignite. Assuming a mid-range modelled efficiency penalty of 7.5% for capture and compression, the overall plant efficiencies become 34.5 and 32.5%. In other words, the consumption of coal will increase by 22-23% for given electrical output. Adopting the MED scenario of 900 MWe thermal generation with CCS and assuming that this would be implemented in a single plant in either Waikato or Southland, sub-bituminous and lignite consumption would be 2.3 and 3.7 Mt/y a year respectively. Given 90% capture, a saving in CO_2e emissions of 4.58 or 4.64 Mt/y is predicted if Huntly was replaced by an IGCC plant incorporating CCS. Given the overall need to reduce New Zealand's emissions to 10.63 Mt/y in 2050 (from 77.2 Mt/y in 2005), an IGCC plant with CCS would represent a reduction of approximately 7%, from the commissioning date. However, given the increased coal consumption from CCS operations, the associated GHG outputs must also be considered. A study cited by Odeh and Cockerill (2008) for a 1000 MWe power plant, with a 70% load factor and 30 year lifetime indicated that coal mining, fugitive methane emissions and coal transport would contribute 8.0% of total plant GHG emissions.

Non-electricity generation applications of CCS, for example the removal of CO_2 from boiler flue gases at industrial, hospital and educational institution sites will be subject to similar timing issues. However, they will involve retrofitting CCS systems to sub-critical boilers, incurring significantly greater energy penalties (Page et al., in press) than given here for IGCC power plants.

Policy implications

In relation to the timeframe for achievement of interim emissions reduction targets of 20-40% as advocated by Stern (2008) our analysis indicates that investment in CCS technology will not be helpful. The lead times involved, given the current status of the technology, that New Zealand is signalled to be a follower rather than leader in this area, and the current lack of proven storage sites, mean that implementation by 2020 is not feasible. However, in addressing longer-term targets out to 2050, we show that CCS could potentially contribute 7% of required annual emissions reductions, assuming coal fired generation continues at the same rate as present, if implemented from 2024-2030. This is contingent on favourable commercially realities, including acceptable cost overruns, and on legal permissions being granted in a timely fashion, neither of which are without considerable uncertainty.

Projections of "peak coal" production by around 2030 are particularly relevant here (Mason, 2007; Tao and Li, 2007; Zittel and Schindler, 2007).

We now ask whether the money currently invested in CCS might better be spent elsewhere. Using coal for heat and power production is clearly an unsustainable activity. It is recognised at best by proponents and opponents, even with the application of CCS, as a transitional technology. Is there a permanent solution for New Zealand? In relation to base-load thermal generation an alternative carbon-neutral resource suitable exists in the form of woody biomass. A recent study has indicated that realistic areas of 2.5-2.7 million ha are available for planting without competing with food crops (Hall and Gifford, 2007). We estimate that a plantation of about 434,000 hectares (using marginal farmland) could produce the same amount of electrical output as the Huntly power plant in 2006, at arguably less risk (financially and environmentally) and with a greater chance of public acceptance. Whilst it is not presently clear whether woody biomass thermal generation could practically assist in meeting interim GHG targets, it could certainly contribute to achieving long-term GHG reductions. The technology is mature and widely implemented in Scandinavia and to a lesser extent elsewhere, including New Zealand. In the New Zealand context therefore, investment of research and development funds into an investigation of the full implications of this permanent and sustainable solution to thermal electricity generation, rather than a temporary and unsustainable one, seems to us to be a path worthy of serious consideration by policy makers.

Spreng et al. (2007) argue that CCS appears to be a classic Faustian bargain. In New Zealand we are fortunate that we have no need to enter into such an uncomfortable arrangement, and given our abundance of renewable energy resources, propose that we should not do so.

Conclusions

1. Carbon capture and storage (CCS) technology will not assist New Zealand to meet interim GHG reduction targets of 20-40% by 2020.

2. Applied to a 900 MWe IGCC thermal power plant, the technology could contribute 7% of annual GHG reductions from 2024-2030. However, considerable technical, commercial and legal uncertainties remain to be resolved.

3. On balance the technology is considered inappropriate for New Zealand, given the timing issues, the unsustainability of the primary energy resource and the availability of renewable energy options.

4. Alternative investment of research and development funds into the use of woody biomass as a permanent and sustainable resource for thermal electricity generation and other heat and power uses is recommended.

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