International Journal of Technology (2011) 1: 65-73
ISSN 2086-9614

THE ROLE OF CARBON CAPTURE AND STORAGE IN THE GLOBAL ENERGY PORTFOLIO

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(Received: November 2010 / Revised: December 2010 / Accepted: January 2011)

ABSTRACT

This review provides an insight for Carbon Capture and Storage (CCS) technology implementation possibilities in the niche of coal power generation plants. A brief explanation of the technology is necessary for understanding the technological and economic constraints affecting successful implementation. Barriers and opportunities for the technology are addressed, and the advantages for achieving climate change mitigation goals are discussed. Possible solutions to protect the technology and its implementation support are provided as well. This study maintains that international collaboration, government incentives, a positive investment climate, public awareness, and learning by doing experiments are needed to ensure that CCS technology operates successfully within coal power plants. Based on the conducted review, we conclude that renewable energy technologies must be developed rapidly and implemented as soon as possible; and until that time, CCS technology can provide a temporary solution by contributing to climate change mitigation plans.

Keywords: CCS; Coal-fired power plant; Niche management

1. INTRODUCTION

In this paper, the Carbon Capture and Storage (CCS) technologies for reducing the CO_2 emissions of existing coal power plants will be addressed. Global electricity generation capacities based on coal-fired power plants are approximately 1142 GW (Page et al., 2009). However, 970 GW from this capacity is generated by so called sub-critical pulverized coal power plants, which are not suitable for current CCS technology implementation.

Currently, from the technological point of view, CCS reduces the overall efficiency of the coal power plants because of the extra energy required for operation of CCS technology itself, such as thermal and electrical energies necessary for CO_2 and N2 separation. Furthermore, considerable energy is required to compress and liquefy CO_2 for transportation and storage. Transportation also requires energy and additional financial expenses. One current constraint is that CCS technology lacks financial support after completion of the R&D stage. The other constraint can be addressed as a lack of communication between different countries and companies engaged in the field of CCS technology development and implementation (Coninck et al., 2009).

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After research and development is completed, CCS technologies are mostly left without sufficient funding for further market penetration because of the complexity and high cost of the technology. This is the fundamental reason why CCS remains primarily at the governmental level.

CCS technology leads to an increase in the cost per kWh of electricity, representing a main reason for not implementing CCS at this time. However, coal power plants contribute 40% of annual CO_2 emissions, and this number must be reduced to achieve various targeted energy development scenarios set for 2020 until 2050 (Coninck et al., 2009). Given this perspective, policy makers at national and global levels could force the implementation of the policy of tax per ton of CO_2 produced; CCS technology could be widely integrated with coal plants under the tax of €30 (30 Euros) per ton of CO_2 (Martinsen et al., 2007). Under this scenario, CCS technology will start to be widely implemented in Germany as early as 2020.

Furthermore, new coal power plants must be designed simultaneously with CCS technology to ensure suitability for implementation, as the majority of operating coal power plants is not suited for CCS implementation. In this paper, we address the reasons for including CCS technology as an integral part of the global energy portfolio. Technical and non-technical aspects are addressed to evaluate the feasibility of integrating CCS in the overall energy supply system. Furthermore, we examine n a specific niche market, the coal-fired power plant.

2. EVOLUTION OF THE CCS TECHNOLOGY AND ITS APPLICATION IN A CERTAIN NICHE MARKET – COAL POWER GENERATION

2.1. Brief Description of CCS Technology

Studies on the development of CCS technologies in the frame of climate change mitigation strategies have been carried out for more than 20 years already (Coninck & Anderson, 2006). Although CCS technology is not yet mature, a vast number of coal-fired power plants exists and contributes a big share of global CO_2 emissions and environmental pollutants.

Three main technologies of CO_2 capture processes exist: post-combustion capture, pre-combustion capture and Oxyfuel capture technologies (Figure 1) (Gibbins, 2008). The post-combustion capture method, based on best current commercial technologies for coal power plants, is considered to be more efficient for conversion to electricity than the pre-combustion method with integrated gasifier (Gibbins, 2008). Consequently, total electricity costs from plant operations based on the post-combustion capture method appeared to be lower than from plants with pre-combustion capture. In addition, costs of electricity produced from the coal plants with the Oxyfuel capture method appear even higher than the costs from plants using the pre-combustion method (Gibbins, 2008).

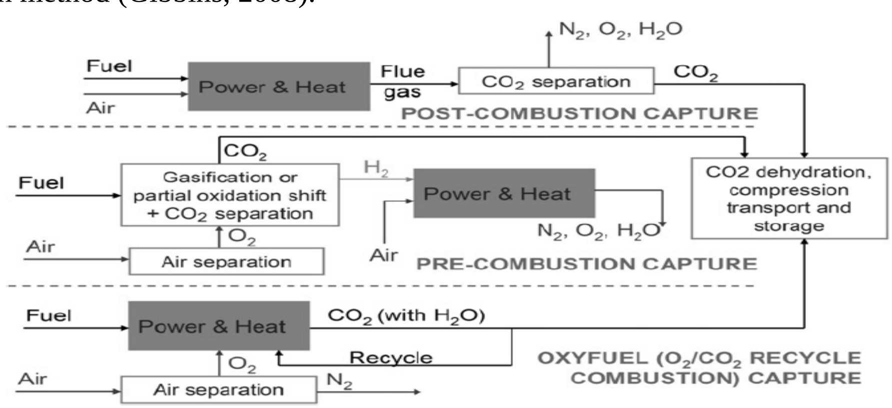

Figure 1 Three main technologies of CO_2 capture processes (Gibbins, 2008)

2.2. Carbon Dioxide Storage

The procedure for storing CO_2 underground is based on injection of the gas to the underground where the gas can be stored under high pressure. Also noteworthy is the fact that CO_2 can also be injected into depleted oil and gas reservoirs to increase the current production rate (Gibbins, 2008).

Carbon dioxide storage in the deep ocean is considered the most applicable, as well as energy and cost efficient for certain locations. This storage technique has been studied for more than 30 years (Sheps, 2009). Captured CO_2 can be transported and injected in liquefied form to the deep ocean layers below 3000 m. Time scale for ocean storage of CO_2 is estimated to be from 30-500 years, which is considered to be the longest possible storage period (Sheps, 2009).

One has to assess the environmental impact of deep ocean storage because the increase of CO_2 concentration in the ocean increases seawater acidity. However, sequestration in the oceans is a relatively new topic and was not considered in the London Convention on Marine Pollution of 1972, nor later in the Marine Pollution protocol of 1996. Therefore, no defined constraints for CO_2 disposal in the oceans currently exist. The legal status of carbon storage in the oceans has not yet been determined (Sheps, 2009).

2.3. Application for Niche Market (Coal Power Generation)

The promotion and development of CCS technology is traced to the UN Convention on the Law of the Sea 1982 (UNCLOS); momentum took force in 1994 (Coninck & Anderson, 2006). The convention implied that CCS should first be applied to the seabed and beneath its subsoil. It should be mentioned also, that CCS as climate change mitigation option was not addressed clearly in the UN's Kyoto Protocol.

Today, there are 20 completely new electricity generation projects. They have been proposed around the world and are technically cited in a feasibility study with implications for advancing CCS technology. Projects are also proposed for the European Union, with 12 flagship demonstrational projects to be in operation by 2015 (Gibbins, 2008). For example, there is a governmental competition for a post-combustion 300-400 MW project with "onboard" CSS technology in the UK, which is aimed to capture CO_2 emissions from a slipstream of produced gases by a supercritical pulverized coal power plant (PC). Captured carbon dioxide emissions will be transported to offshore storage.

Successful projects of operational and pilot plants with implemented CSS technology are already operating in many countries in various parts of the world (MIT, 2010). Germany and Norway were the first countries to introduce the technology within their power plants. One of these projects is the Schwarze Pumpe pilot project, carried out by Vattenfall and Gaz de France companies southeast of Berlin, Germany. The power plant operates on coal, uses Oxyfuel combustion and post-combustion CCS technologies, and has a capacity for 300 MW in a pilot scale. Projected output of 1000 MW on a commercial scale is anticipated by 2020. Sequestrated CO_2 is stored in a depleted gas field (MIT, 2010). The first developmental steps in carbon dioxide storage projects were initiated by Norway and Canada toward the end of the 90s, with integrated carbon dioxide storage technology applications at Sleipner in Norway and Weyburn in Canada. These plants are operating today, capturing 1 Million-tons of emissions each year (MIT, 2010).

3. ANALYSIS OF NICHE DYNAMIC OF CCS TECHNOLOGY

3.1. Barriers

Many barriers are inherent in the process of introducing new technology. The involvement of technical, economic, and political dimensions makes the process more complex. Cost is still a big question among the many stakeholders (Hansson, 2009). One could expect a lower price for CCS technology in the future due to technical improvements and learning by doing experiences. However, due to many uncertainties, the exact cost of a large CCS application is difficult to predict. Internalizing externalities and safety issues also need to be considered.

Long term funding mechanisms must be established since CCS is still in the development and introduction phase. However, the funding committee should be careful not to authorize excessive funding for CCS development. Otherwise, extreme failure might occur at some point due to over-budget for a specific niche market. Intellectual properties also become an issue since it is difficult for independent researchers to legalize assumptions and estimate costs of their own CCS researches. The value of learning rate for coal related technologies is in the range from 3.75% to 15.1% as shown by history of coal related technologies. Cost uncertainty of CCS implementation recently led to withdrawal of the FUTUREGEN project (Hansson, 2009). This kind of setback could contribute to a loss of momentum for CCS technology. Uncertainty also comes from government. Several stakeholders in China and Canada (Bohm et al., 2009; Reiner & Liang, 2009) are concerned that an unstable investment environment may hinder the implementation of CCS.

Another barrier is the reliability of underground CO_2 storage (Gerlagh, 2008). The rate of CO_2 leakage from underground storage has to be taken into account when ones want to evaluate the overall performance of CCS. Otherwise, the fundamental goal of CCS is eliminated if a high rate of CO_2 leakage is observed (Zwaan, 2009). However, due to complex physical processes involving geological formations, the actual seepage rate of the CO_2 is hard to pinpoint. An annual leakage rate below 0.1%/year is to be expected when choosing an appropriate storage location, but cannot be achieved in underground ocean storage (Gerlagh, 2008 ; Zwaan, 2009). A high leakage rate will cause CO_2 mitigation costs to rise to 150€/tCO_2 (Zwaan, 2009). Only 37% of the total CO_2 stored will be intact after 100 years, compared to an expected 90% retention with 0.1% annual leakage rate for a more appropriate storage location. Based on this study (Gerlagh, 2008), the value of CO_2 leakage rate from geological point of view is still well above to cause significant effect on the performance of CCS in terms of the economic and climate perspective. Hence, the selection of a storage location is not the most important factor of CCS performance.

CCS is considered a complex technology, challenging the actors who are involved in CCS implementation. Efficiency could drop by 15 % for the latest state of the art coal power plant (Hansson, 2009; Page et al., 2009). Energy used is more compromised. An energy penalty up to 45 % of is expected to take effect. Transportation is normally considered a trivial issue, but transporting large amounts of CO_2 is certainly a serious matter. Building pipeline networks is a complicated issue that becomes more complex when geopolitics is taken into account. Delivering CO_2 to oil producers for the purpose of enhanced oil recovery (EOR) creates another complexity in CCS implementation. Oil companies do not need a constant supply of CO_2, although the amount of CO_2 required per year for one single oil reservoir is the same as the CO_2 produced by one single power plant (Hansson, 2009).

CCS may also introduce other environmental problems. Human toxicity, eutrophication, and ozone layer depletion are examples of environmental issues that may arise due to CCS (Hansson, 2009).

The IGCC (Integrated Gasification Combined Cycle) power plant is believed to be suitable for CCS implementation. However, since the first introduction of IGCC technology 20 years ago, IGCC has not yet achieved commercial status due to technical complexity.

3.2. Opportunities

Global economic growth, especially in India and China, and reliance on coal-powered technologies, point to the possibility that CCS might be the only technology capable of reducing CO_2 emissions from fossil fuel power plants, at least for the short term. With CCS power plants currently operating (MIT, 2010), the technology is expected to reach a mature phase soon.

Perceived barriers can be overcome; several European countries are already very positive about CCS implementation, especially Norway, United Kingdom and the Netherlands (Shackley et al., 2007). Experts believe that CCS, along with renewable technology and nuclear power plants, are the means for reaching climate goals (Zwaan, 2009).

Many actors from outside Europe and USA have shown considerable interest in CCS. For example, China has expressed a willingness to learn how to implement CCS (Reiner & Liang, 2009). Same interest regarding CCS has also been shown by the Integrated CO_2 network group of companies in Canada (Bohm et al., 2009). They believe that CCS implementation supports the sustainability aspect of oil, gas and chemical industries. Australia's cement industry has also shown interest in CCS implementation (Puyvelde, 2009). Twenty demonstration projects are currently running in Australia. Malaysia and Indonesia can benefit from CDM (Clean Development Mechanism) programs where CCS is part of the CDM implementations (Othman et al., 2009).

CCS promotes social sustainability. Coal is abundant in large parts of the world and thus transcends geopolitics. Coal can be e accessed easily and is economically viable even for poor regions. If industrialized countries can become models for economic development while maintaining environmental conditions, it is likely that developing countries will follow in the same way. Some people say that excluding CCS from the global energy portfolio is just a delayed action towards overcoming the CO_2 problem (Hansson, 2009). This makes solving the problem more costly in the future. It is also believed that prohibitions regarding the use of fossil fuel for developing countries will hamper them from gaining access to transportation, education and healthcare.

Furthermore, if one considers the current societal structure and trends, CCS is clearly one of the solutions to meet emission targets, maintain economic growth and reduce environmental pressure due to growing demand for biomass (Hansson, 2009). It is impossible to stop consuming coal on a global scale. In addition, CCS acts as a bridge to reach the target of renewable by introducing CO_2 tax, for example.

CCS implementation will also lead to a hydrogen society. Currently, hydrogen feedstock still comes from fossil fuels, either natural gas or coal. The problem with current hydrogen production is capturing and sequestering CO_2 produced from the hydrogen production (Hansson, 2009; Annaland, 2010).

3.3. Network-building

A strong network consisting of many actors at different levels is very important for the development of niche. There are many stakeholders that could be identified in CCS implementation: public authorities, research institutes, industries and society as a whole. Public authorities are mainly involved in providing financial support to the research institution and providing an incentive mechanism for the industry.

Collaboration among international governments must be established. Once the international agreement has been formulated, public awareness, global trust and public confidence will be strengthened.

One research study (Coninck et al., 2009) identified institutional fragmentation which hinders effective CCS implementation. International cooperation is required for CCS implementation, focusing on global coordination, transparency, cost sharing and communication.

Governmental incentive mechanisms will influence the economic viability of CCS implementation. For example, CCS technology will start up when the CO_2 penalty price is €30/ton CO_2 (Martinsen et al., 2007). Another example comes from China. Without any extra cost offset for carbon reduction, companies will not be permitted to receive any extra profit (Dapeng & Weiwei, 2009). Government must take care of the incentive to conduct CO_2 injection and leakage monitoring (Tokushigea & Akimotoa, 2009) proposed an incentive scheme similar to Reducing Emission from Deforestation and Degradation in Developing Countries (REDD).

The importance of regulatory framework is emphasized by Samuela Vercelli and his colleague (Vercelli & Lombardi, 2009). Government collaboration with scientific institutions and a good communication mechanism with the general public help enforce regulations and promote cooperation when necessary measurements are needed. A good regulatory framework has not been implemented yet in China, which has resulted in disappointment from the industrial sectors (Dapeng & Weiwei, 2009).

Research institutes are mainly involved in technology development, but they must also promote reductions in costs of CCS operation and implementation. They also need to address non-technical problems to assess which dimension of CCS is not yet optimal. There are still many technological disadvantages, such as lower efficiency and energy penalties coming from shift reaction (Gibbins, 2008).

Societal acceptance is very important to ensure that CCS is implemented successfully. A recent research conducted in the Netherlands shows that the societal acceptance could be considered as ‘reluctant’ (Alphen et al., 2007).

3.4. Vision and Expectation

Researchers in Sweden (Odenbergera & Johnssona, 2009) shared their high expectations for CCS technology, stating that the target to reduce CO_2 emission by 85% in Europe could be met providing that CCS is implemented widely. They also assume that CCS will enter the market in 2020 and become a competitive option economically going forward. They anticipate that CCS will penetrate the market significantly after commercialization in 2020, projecting that it will account for 300 GW from 2020 until 2045. However, many technical and non-technical uncertainties are yet to be identified and solved. When difficulties surface in efforts to build one CCS plant, hesitations occur regarding the feasibility of installing and operating CCS on a larger global scale (Hansson, 2009).

It is important to be aware of these uncertainties and overly optimistic expectations. To be addressed correctly, policy makers must have scientific scenarios and experts’ comments for their decision making process. In addition, uncertainties must reach public debate.

3.5. Learning Process

CCS is a fairly young technology. According to the data from MIT (2010), carbon dioxide storage was initiated in 1996 in Norway. The first CCS project began in 2008 in Germany. In the course of these projects, it is expected that many identified uncertainties could be solved through learning by doing. Cost learning curve is also expected to improve through these demonstration projects. Historically, the learning rate for coal- related technologies ranges from 3.75% to 15.1% (Hansson, 2009). However, this value might not be accurate for CCS. Coal industries are not familiar with subsurface related technologies, indicating that the transfer of knowledge from oil and gas industries should be conducted appropriately.

One study in Germany has shown that CCS is a temporary solution albeit this will be determined by growth rates and market development (Viebahn et al., 2007). In the long term, renewable technology could develop faster and become more affordable than CCS technology.

The project for investigation CCS implementation possibilities showed the necessity of the integration of CCS in order to support energy programs in Germany. The project was coordinated by the Wuppertal Institute for Climate, Environment and Energy and concludes that if CCS could be widely applied to all new and renewed fossil-fired power plants from 2020 on, CO_2 emissions would decrease by 80% and climate protection goals would be reached. The calculations showed that the introduction of CCS technology reduces CO_2 emissions by 72-90% per kWh produced. If the CO_2 emissions credits are introduced in whole volume and the price per credit stays constant until 2050, then the total price per kWh of produced electricity increases with further installation of coal-burning power plants. Introduction of the CCS technology appears to be a temporary solution for reduction of CO_2 emissions. After implementation of CCS technology, CO_2 emissions will be reduced significantly but not eliminated, and the credit penalty will still be applicable, causing additional costs per kWh. However, rapid development and introduction of renewable energy leads to cost stabilization per kWh in the long term and seem to appear cheaper in the long term than the CCS technology.

4. PROPOSED SOLUTIONS OF CCS APPLICATION AND POSSIBILITY OF PROTECTION ON THE CERTAIN NICHE MARKET

CCS should be implemented in the energy portfolio all around the world. There are many negative consequences occurring when CCS is excluded from the energy portfolio (Odenbergera et al., 2009). First, excluding CCS will increase the biomass demand by a factor of 10. Second, it will also increase the cost of electricity by €5-10/MWh and the CO_2 abatement cost by €/10 ton CO_2. From economic and environmental perspectives, CCS is obviously a cost efficient technology and could reduce environmental stress by reducing biomass production.

International collaboration on CCS development and implementation is tremendously important. The target to reduce CO_2 emission is not just a local or regional target; it is a target on a global scale. Such an international collaboration has been successfully promoted by an organization, ITER (International Thermonuclear Experimental Reactor), where China, EU, India, Japan, Korea, Russia and the USA are cooperating to develop and explore the possibilities for a nuclear fusion power plant. CCS communities could also form a single international collaboration on CCS development so that technical and non-technical uncertainties are addressed effectively.

Currently available technologies of CCS implementation shows that best options in terms of energy efficiency and cost is the post-combustion method of carbon dioxide capture and sequestration. The solution for storage is underground reservoirs, avoiding the injection of captured carbon dioxide in the oceans in order to preserve marine life and sea biodiversity. Underground storage can also provide benefits relative to depleted oil reservoirs recovery by injection of captured CO_2 (EOR) from power plants. The overall technical improvement can be expected in the future under a healthy investment environment.

Long term funding mechanisms must be established on both governmental and private levels since CCS technology is still in the developmental and pilot scale phase. One must also understand that the CCS implementation just needs to be executed to prevent perceived barriers from becoming permanent. .

For the near future it is impossible to stop consuming coal for electricity production, but the impact of emissions to the atmosphere could be mitigated. Thus, developed countries must act as examples for other countries, especially for those with large emerging economies like China and India. If the countries having large developed economies, like US and EU countries will not show their models of broad CCS implementation then it would be hard to expect this implementation from developing countries. Cooperation between international governments and communities must be established to promote public awareness of climate change and the need for CO_2 emissions reduction, as well as global trust for CCS technology and a favorable investment climate.

Moreover, one single legislative authority could be organized, possibly at the UN level, to require each country to assign a certain share of their geographical areas (1-5%) for CO_2 emissions storage reservoirs. One single international authority is needed in this case for oversight. No territory problems are anticipated, as most countries currently possess oil, gas and coal reservoirs which are already under deep development and depletion. For the countries that are not able or do not want to enter the CCS, a penalty for emission per ton CO_2 could be established. Currently, the economically feasible penalty for successful CCS implementation is estimated to be around €30 per ton of CO_2 emitted per year.

International cooperation on CCS technology development will also help in issues of fragmentation of institutional and private level development of the CCS technology. This will result in a guiding principle of CCS implementation which is global coordination, transparency, cost sharing and communication. It has to be understood that development of complex technologies such as CCS has to be executed under transparent and idea sharing relationships between industry and private sectors as well.

5. CONCLUSION

Based on the results of this research, we propose to protect CCS technology development on the coal power generation level of the energy market in order to proceed with reduction of CO_2 emissions from coal power plants. Otherwise, there are only two options for dealing with CO_2 emissions on our planet – put them underground or in the oceans, or simply release them to the atmosphere. The latter option clearly presents no benefits to mankind or the planet. Successful CCS technology application can be achieved by:

- International collaboration on CCS development and implementation
- Carbon dioxide storage in the underground reservoirs
- Long term funding mechanisms established on governmental and private levels
- An example model from industrialized countries
- Cooperation between international governments and communities
- Establishment of a single international authority

Successful CCS technology application can also be aided by enforcing global adoption of a tax per ton of produced $CO_{2,}$ design of new coal power generation plants equipped for CCS technology implementation, for example, by introducing IGCC and oxyfuel plants.

The current level of CO_2 emissions from coal-operated power plants indicates that CCS technology needs to be implemented right away and collaboratively with all new coal power plants under design and construction.

If we do not consider CCS seriously at the present time, CO_2 concentration in the atmosphere will only increase until we meet intermediate goals with renewable energy implementation. That means that we will produce more and more unsustainable energy from coal as energy demand escalates, contributing to further climate change.

6. REFERENCES

Alphen, K.v., et al., 2007. Societal Acceptance of Carbon Capture and Storage Technologies. *Energy Policy*, 35: p. 4368-4380.

Hansson, M.B.A., 2009. Expert Opinions on Carbon Dioxide Capture and Storage - A Framing of Uncertainties and Possibilities. *Energy Policy*, 2009.

Annaland, M.v.S., 2010. Presentation: Novel Reactor Concepts For Syngas, H_2 and Electricity. *Hydrogen Technology Course*: 2010.

Zwaan, K.S.B.v.d., 2009. CO_2 Capture and Storage with Leakage in an Energy Climate Model. *Environmental Model Assesment*, 14: p. 135-148.

Bohm, M., et al., 2009. An Integrated Approach to CCS: A Canadian Environmental Superpower Opportunity. *Energy Procedia*, 1(1): p. 4419-4425.

Coninck, H.d. & Anderson, J., 2006. Acceptability of CO_2 Capture and Storage: A Review of Legal, Regulatory, Economic and Social Aspects of CO_2 Capture and Storage, *in ECN-C---6-026*.

Dapeng, L. & Weiwei, W., 2009. Barriers and Incentives of CCS Deployment in China: Results from Semistructured Interviews. *Energy Policy*, 37: p. 2421-2432.

Coninck, H.d., Stephens, J.C., Metz, B. 2009. Global Learning on Carbon Capture and Storage: A Call for Strong International Cooperation on CCS Demonstration. *Energy Policy* 37(6): p. 2161-2165.

Gerlagh, B.v.d.Z.R., 2008. The Economics of Geological CO_2 Storage and Leakage. *Climate Change Modelling and Policy*.

Gibbins, H.C.J., 2008. Carbon Capture and Storage. *Energy Policy*.

Martinsen, D., Peter Markewitz, Stefan Vogele, 2007. CCS: A Future CO_2 Mitigation Option for Germany?--A Bottom-Up approach. *Energy Policy*, 35(4): p. 2110-2120.

MIT, 2010. *Carbon Dioxide Capture and Storage Projects*. Available at <http://sequestration.mit.edu/tools/projects/index.html> [Accessed 2010 June 19,2010]

Odenbergera, M., Unger, T., Johnsson, F., 2009. Pathways for the North European Electricity Supply. *Energy Policy*, 37: p. 1660-1677.

Odenbergera, M. & Johnssona, F., 2009. The Role of CCS in the European Electricity Supply System. *Energy Procedia*, 1: p. 4273-4280.

Othman, M.R., et al., 2009. Strategic Planning on Carbon Capture from Coal Fired Plants in Malaysia and Indonesia: A review. *Energy Policy*, 37: p. 1718-1735.

Page, S.C., Williamson, A.G., Mason, I.G., 2009. Carbon Capture and Storage: Fundamental Thermodynamics and Current Technology. *Energy Policy*, 37(9): p. 3314-3324.

Puyvelde, D.R.V., 2009. CCS Opportunities in the Australian “Industrial Processes” Sector. *Energy Procedia*, 1: p. 109-116.

Reiner, D. & X. Liang, 2009. Opportunities and Hurdles in Applying CCS Technologies in China - With a Focus on Industrial Stakeholders. *Energy Procedia*, 1(1): p. 4827-4834.

Shackley, S., et al., 2007. Stakeholder Perceptions of CO_2 Capture and Storage in Europe: Results from a Survey. *Energy Policy*, 35: p. 5091-5108.

Sheps, K.M., 2009. A Case for Deep-Ocean CO_2 Sequestration. *Energy Procedia*, 1: p. 4961-4968.

Tokushigea, K. & K. Akimotoa, 2009. A Framework to Add Incentives for Managements After CO_2 Injections. *Energy Procedia*, 1: p. 4633-4639.

Vercelli, S. & S. Lombardi, 2009. CCS as Part of a Global Cultural Development for Environmentally Sustainable Energy Production. *Energy Procedia*, 1(1): p. 4835-4841.

Viebahn, P., et al., 2007. Comparison of Carbon Capture and Storage with Renewable Energy Technologies Regarding Structural, Economic, and Ecological Aspects in Germany. *Greenhouse Gas Control*, 1: p. 121-133.