Scholars Journal of Physics, Mathematics and Statistics
Sch. J. Phys. Math. Stat. 2014; 1(1):22-28
ISSN 2393-8056 (Print)
ISSN 2393-8064 (Online)

Carbon dioxide Capture and Sequestration to Mitigate Greenhouse Effect

Yang LI,* Yuxue SUN, Mingxing BAI, Chi AI, Jianpeng Sun
Department of Petroleum Engineering, 163318, Northeast Petroleum University, China

***Corresponding Author:**
Yang LI
Email: nalane@163.com

Abstract: Climate change is a major challenge. Secure, reliable and affordable energy supplies are needed for economic growth, but increases in the associated carbon dioxide (CO_2) emissions are the cause of major concern. Carbon dioxide Capture and Sequestration (CCS) in deep geological formations is a promising technology to reduce CO_2 emissions to the atmosphere. CO_2 is injected as a supercritical fluid deep below a confining geological formation that prevents its return to the atmosphere. In this paper, the procedures and related principles will be introduced, and the advantages and disadvantages will also be discussed.
Keywords: CCS, Carbon dioxide, Geological sequestrations, Well integrity

INTRODUCTION

Almost all produced hydrocarbon is, and will be, used as fuel and therefore produce CO_2 that eventually will be released into the atmosphere. More and more carbon dioxide makes the earth that we live in be a big green house, which keeps the temperature very high and not suitable for human beings to live. CO_2 is the main gas which causes atmospheric greenhouse effect in the six kinds of the greenhouse gas: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride. Furthermore, carbon dioxide accounts for about 64% of the total, and its degradation time is long, making the largest contribution to the greenhouse effect [1]. Carbon dioxide Capture and Sequestration (CCS) in deep geological formations is a promising technology to reduce CO_2 emissions to the atmosphere. CO_2 is injected as a supercritical fluid deep below a confining geological formation that prevents its return to the atmosphere. CCS is an important strategic choice of the global response to climate change [2]. The only technology available to mitigate greenhouse gas (GHG) emissions from large-scale fossil fuel usage is CCS. There have been many developments and significant gains in CCS technology and the enabling policy frameworks. However, given today's level of fossil fuel utilization, and that a carbon price as a key driver for CCS remains missing, the deployment of CCS is running far below the trajectory required to limit long-term global average temperature increases to 2 °C [3].

There are four steps in the procedure of CCS: CO_2 capture, gas compression, pipeline transport, and geological sequestration.

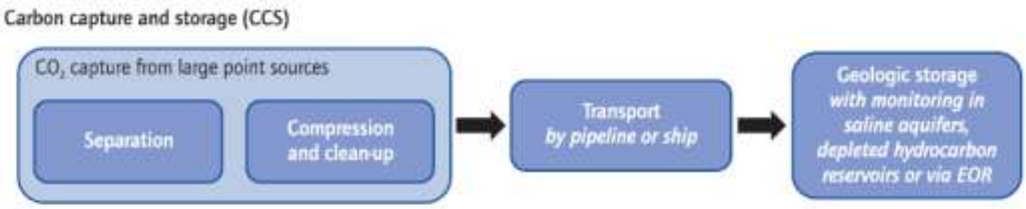

Fig. 1: CCS Chain [3]

CO_2 CAPTURE

Carbon capture is not suitable for mobile source and scattered emissions. It is simple in structure and economically feasible only when CO_2 is captured from large stationary sources. 60% of the CO_2 emissions come from stationary sources: power plants, cement plants, petrochemical plants. That makes CO_2 capture possible to realize. The use of CCS technology can reduce 20% of CO_2 emission. At present, there are three kinds of method to capture CO_2: Post-combustion capture, oxy-combustion, and pre-combustion capture. Three methods have their individual advantages and disadvantages, but the second method is relatively of great popularity and utility.

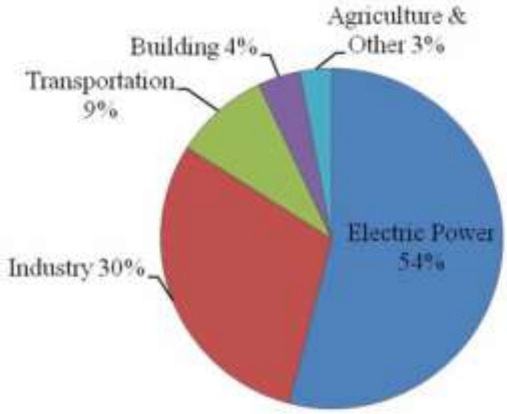

Fig. 2: CO_2 emissions proportion in each sectors in China [4]

Post-combustion capture is an earlier method that scientist studied. The process route is based on mature chemical solvents method: amine absorption. We first burn the fuel (petroleum products, coal, etc.) and collect the gas that produced. Amine reacts with carbon dioxide to form a carbon containing compounds. And then the solvent is heated, the compound is decomposed, thus we can get carbon dioxide with high purity [5-6]. In June 2010, the global first whole-process CCS project in saline layers, the Shenhua Group CCS industrialization demonstration project is started building. The Shenhua CCS project uses post-combustion capture technology to capture CO_2 after burning coal to produce electricity. The Shenhua CCS project is designed for the capture capacity of 100 000 t CO_2 annually. This can be used to capture CO_2 from electricity generation plants (and indeed is the only option for CO_2 capture from existing power plants), although it is energy-intensive and so entails an energy penalty.

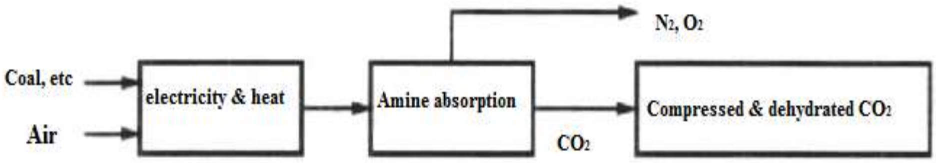

Fig. 3: Flow diagram of Post-combustion capture process

Oxy-combustion capture refers to the fuel combustion in the mixed gas of oxygen and carbon dioxide, the products of combustion are mainly carbon dioxide, water vapor and small amounts of other ingredients. High purity carbon dioxide is generated after burning, approximately 80%~98%. Usually, the oxygen is produced by air separation, a small part of fuel gas recirculates into the combustion chamber with oxygen by a certain proportion [7]. The use of oxygen and carbon dioxide mixture is to control the flame temperature. If the combustion occurs in pure oxygen, flame temperature will be too high to control. This method is relatively simple and easy to purify produced gas.

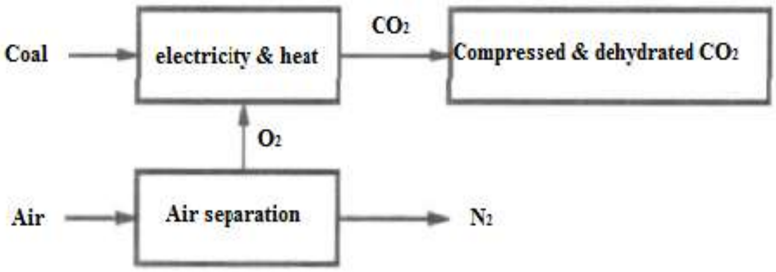

Fig. 4: Flow diagram of Oxy-combustion capture process

Pre-Combustion is more complicated than the first method. By the reaction with the fuel and oxygen, a mixed gas is generated which mainly consists in carbon monoxide and hydrogen. The gas mixture is cooled, and reacts with steam in a catalytic converter. The carbon monoxide turns into carbon dioxide, and it produces more hydrogen. Then, the carbon dioxide is separated, and the hydrogen is used as gas fuel and injected into gas turbine in combined cycle system. “Pre-combustion” separation of CO_2 can occur during the partial combustion of fossil fuels, used for example in the production of hydrogen or hydrogen-rich fuels. Electricity generation from Integrated Gasification Combined Cycle (IGCC) plants also requires pre-combustion separation of CO_2.

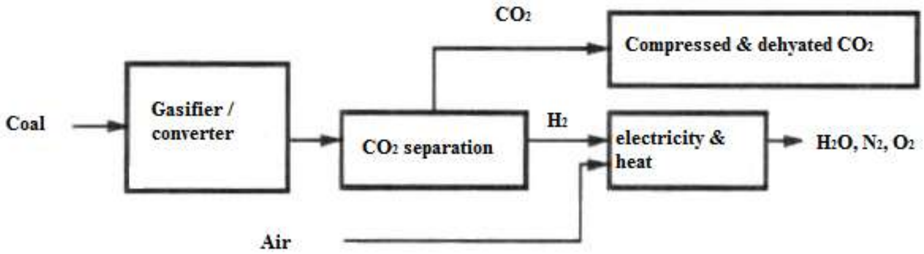

Fig. 5: Flow diagram of Pre-combustion capture process

GAS COMPRESSION

At standard temperature and pressure, the density of carbon dioxide is around 1.98 kg/m^3, about 1.67 times that of air. Carbon dioxide has no liquid state at pressures below 5.1 standard atmospheres (520 kPa). Liquid carbon dioxide forms only at pressures above 5.1 atm; the triple point of carbon dioxide is about 518 kPa at -56.6 °C. The critical point is 7.38 MPa at 31.1 °C. At temperatures and pressures above the critical point, carbon dioxide behaves as a supercritical fluid known as supercritical carbon dioxide [8].

CO_2 is injected as a supercritical fluid deep below a confining geological formation that prevents its return to the atmosphere. After nearly a hundred years of accumulation, compression technology has been very mature for industrial use. Carbon dioxide will be liquid above 10 MPa. CO_2 will be compressed in order to transport easily.

PIPELINE TRANSPORT

Carbon dioxide transport refers to transport the compressed carbon dioxide through a pipe or conveyance to storage location. Carbon dioxide is in gaseous, liquid or solid state. Gaseous carbon dioxide transport can be used by the highway, railway canned or waterway transportation, or by pipeline. Pipeline transport for carbon dioxide is a mature commercial technology method of transporting large amounts of carbon dioxide. In fact, the most economical is pipeline transportation. Commercial-scale transport of CO_2 via pipeline and ship/tankers already occurs. Pipeline transport is normally of compressed (gaseous) CO_2, whereas transport on ships is often of liquefied CO_2, as this takes less volume. Liquefaction of gases is routinely used, e.g. for the transport of liquefied petroleum gas (LPG) or liquefied natural gas (LNG).

GEOLOGICAL SEQUESTRATION

Good potential geological formations to store captured CO_2 are depleted and disused oil and gas fields, deep saline aquifers and unminable coal seams [9].

Table 1: The amount of CO_2 in a variety of configurations can be archived (converted into emission years)

Depleted oil and gas reservoirs	60
Unminable coal formations	80
Saline aquifers	1000

One ideal scenario is to inject CO_2 into a permeable aquifer underneath a very low permeable caprock. When injected, CO_2 will dissolve in the reservoir water, increasing the density. After hundreds to thousands of years the injected CO_2 will react to form carbonates and precipitate and this is the safest storage mechanism [10]. However, migration of the CO_2 beyond the natural reservoir seals could become problematic. The trapping contributions of the various storage mechanisms as function of time is indicated in figure 6.

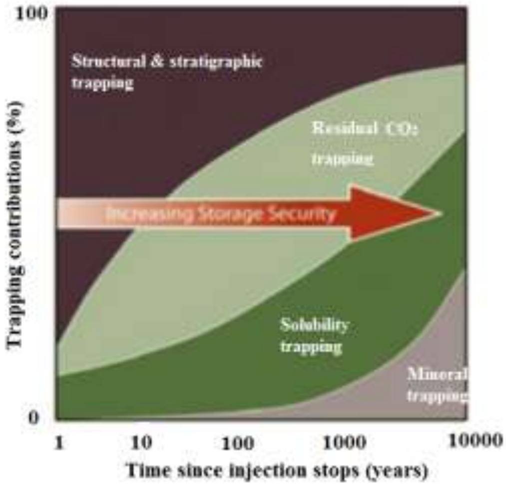

Fig. 6: Trapping contributions of the various mechanisms as function of time [11]

Structural trapping: migration of injected CO_2 is blocked by impermeable cap rocks. This the first barrier to prevent CO_2 from leaking into atmosphere or other channels.

SECONDARY TRAPPING MECHANISMS INCREASING OVER TIME

Residual gas trapping

CO_2 is trapped by capillary forces: capillary forces and adsorption onto the surfaces of mineral grains within the rock matrix immobilize (residual) parts of the injected CO_2.

Solubility trapping

CO_2 dissolves in water: CO_2 dissolves and become trapped in the pore water. Dissolving CO_2 in water increases the density; hence the water with CO_2 will descend.

Mineral trapping

CO_2 converts to solid minerals: Dissolved CO_2 forms carbonic acid, in time the surrounding mineral dissolves and reacts with the CO_2 to form solid carbonates.

In 1996 Statoil Sleipner gas field CCS projects carried out in the North Sea, is the world's first carbon sequestration projects for greenhouse gas emission reduction targets. It has built the world's first industrial-grade carbon dioxide capture facility, with alcohol amine solvent trapping carbon dioxide from natural gas, salt water formations by drilling reinjection archived on the seabed 914 m below, the processing capacity of approximately of 100×10^4 t/a. 12-year cumulative emissions of carbon dioxide is about 1000×10^4 t. And studies have shown that the carbon dioxide is stored in salt water layer is not abnormal, there is no leakage. This is the first CCS project in the world.

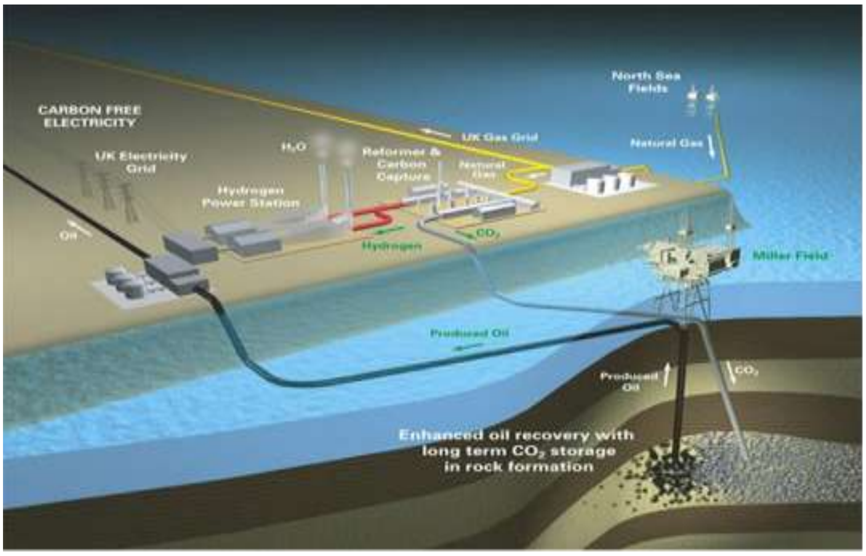

Fig. 7: Schematic of Sleipner project [12]

For the safety concern of CCS to avoid potential release pathways, following aspects should be taken into consideration:

- Well leakage (injection and abandoned wells)
- Poor site characterization (undetected faults)
- Excessive pressure buildup damages seal

CO_2 sequestration is a complex coupled multiphysic process (THMC, short for thermal-hydraulic-mechanical-chemical), which incorporate multi-phase fluid flow, energy and mass conservation, and mechanical equilibrium. So ensuring well integrity is the key to keep the safety of CCS. Various models and simulations are built to predict and deduce the situations that well integrity may happen [13-15].

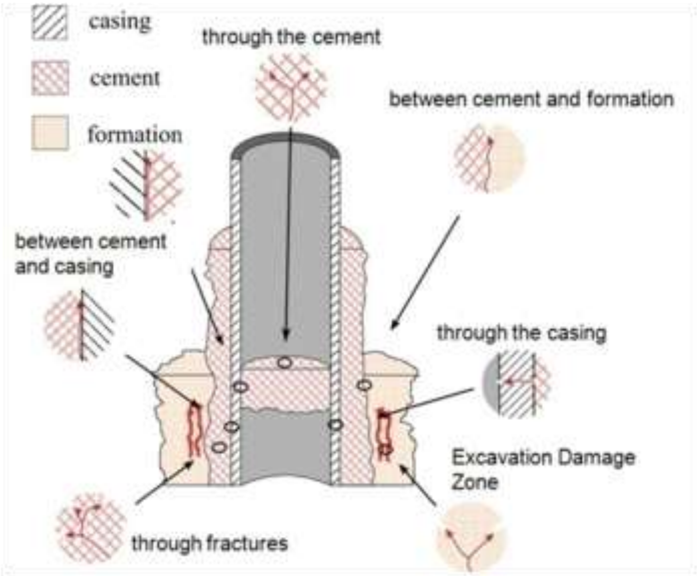

Fig. 8: Leakage pathways [16]

Monitoring

As leaks from the CO_2 storage site may occur mostly through the point sources, faults and wells, monitoring of this site should include two elements. This includes monitoring of the subsurface CO_2 plume, and some above-ground monitoring (e.g. relatively small areas – where the plume may meet faults or wells, allowing for easier detection and remediation). Only the CO_2 trapped via primary mechanisms (stratigraphic and structural) has a potential to be released through fractures and faults or wells and any such leaks are likely to be relatively slow. Remediation techniques include reducing injection or reservoir pressure, sealing damaged wells and, in the extreme case, emptying the reservoir and re-injecting of CO_2 in a different location.

ADVANTAGES OF CCS TECHNOLOGY

Low long-term cost

The IEA study showed that, the use of CCS technology can reduce the total abatement costs -- to achieve the 2050 emission reduction targets without using CCS technique, the total emission reduction costs will increase 70% than the use of CCS technology [17].

Huge potential of application

With the rapid development of the world economy, energy consumption and carbon emissions will definitely keep rising for a long period of time.

DISADVANTAGES OF CCS TECHNOLOGY

Unless there is a value to store CO_2 there is virtually no driver for the deployment of these technologies –except perhaps in the case of a few EOR projects. However, these costs vary widely between sites. Costs also vary depending on which type of capture technology, transportation and geographical storage are used, the depth at which CO_2 is stored, as well as whether CO_2 separation is routinely carried out or not, the required CO_2 purity, and whether CCS is designed to apply to an existing, or new, system [18].

The high cost

According to the International Energy Agency, the cost of CO_2 capture per ton is $50. The IPCC study shows, CO_2 capture technology makes the cost of power generation supercritical power plant, NGCC plant and IGCC plant increased by 40% ~ 80%, 40% ~ 85% and 20% ~ 55% respectively [19-20].

Technology reliability

Although CO_2 is not toxic, it may still pose a risk to human beings and other living creatures. If the leakage of carbon dioxide storage occurs, fresh water can be polluted, and the chemical composition of soil may be affected.

Other restrictions

There are still many aspects which restrict CCS. Regulations and specifications, long term liability, legal frameworks, public acceptance, etc. are crucial and cannot neglect. Only by solving these problems can this technology have considerable development.

CONCLUSION

In this paper, the four main CCS procedures are introduced, and the advantages and disadvantages of this technology are discussed. Carbon capture and storage will be a critical component in a portfolio of low-carbon energy technologies if governments undertake ambitious measures to combat climate change. Given current trends of increasing global energy and cement sector carbon dioxide emissions and the dominant role that fossil fuels continue to play in primary energy consumption, the urgency of CCS deployment is only increasing. CCS technologies will be increasingly recognized for their capacity to provide a large contribution to the mitigation of greenhouse gas emissions in the coming decades. CCS is definitely a feasible method to release greenhouse effect. However, more research need to be done if this technology is used on a large scale according to different situations in different countries, and CCS technology should be used in conjunction with other techniques to get the maximum benefits, such as clean energy, bio-sequestration, EOR, etc. And international co-operation is clearly needed to accelerate CCS deployment. We should make efforts to improve relevant laws and regulations.

ACKNOWLEDGEMENT

This work is supported by the National Natural Science Foundation of China (Grant No. 51304049), the Scientific Foundation for Returned Scholars of Heilongjiang Province in China (Grant No. LC2011C28), the State Administration of Work Safety Supervision (Grant No. 2012-140), and the Scientific Foundation for Young Teachers of Northeast Petroleum University in China (Grant No. ky120238). Furthermore the authors would like to thank all members of the research team.

REFERENCES

1. Bachu S; Sequestration of CO_2 in geological media: criteria and approach for site selection in response to climate change. Energy Conversion & Manage, 2000; 41(9): 953-970.
2. Carbon Dioxide Capture and Storage, DTI, March 2005.
3. IEA; Carbon capture and storage technology roadmap, 2013 edition, 2013:10~11.
4. GDCCSR-GIEC Team; Analysis of CO_2 Emission in Guangdong Province. China, 2013:13~14.
5. GDCCSR-GIEC Team; Analysis of CO_2 Emission in Guangdong Province. China, 2013:13~14.
6. Leo E, Hakka; Removal and recovery of sulphur dioxide from gas streams. US, 5019361. 1991-05-28.
7. Magnus R, Anders L; Using steam reforming to produce hydrogen with carbon dioxide capture by chemical-looping combustion. International Journal of Hydrogen Energy, 2006; 31: 1271-1283.
8. Crook J, Donnellan J; Kinetics and mechanism of the reaction between carbon dioxide and amines in aqueous solution. Journal of the Chemical Society, Perkin Transactions, 1989; 4: 331-333.
9. Carbon dioxide. Available from: http://en.wikipedia.org/wiki/Carbon_dioxide
10. Bachu S, Stewart S; Geological sequestration of anthropogenic carbon dioxide in the Western Canada Sedimentary Basin Suitability analysis. J Can Pet Technol., 2002; 41: 32–40.
11. Bjørnarå TI, Aker E, Skurtveit E; Safe storage parameters during co_2 injection using coupled reservoir geomechanical analysis. COMSOL Conference, Milan, 2009.
12. IEA; Carbon capture and storage technology roadmap. Paris, 2009: 4.
13. Houdu E, Poupard O, Meyer V; Supercritical CO_2 leakage modeling for well integrity in geological storage project. Excerpt from the Proceedings of the COMSOL Conference, Hannover, 2008.
14. Reinicke KM, Fichter C; Measurement strategies to evaluate the integrity of deep wells for CO_2 applications. Proc. Sino-German conference on underground storage of CO_2 and energy, July 6-13, Beijing, 2010
15. IPCC; Carbon dioxide capture and storage. Cambridge University Press, 2005:16, 27.
16. Sun YX, Li Y, Xu B, Bai M, Chen Z, FU S; Prediction method on wellbore stability based on analytic hierarchy process and fuzzy evaluation. Sch J Eng Tech., 2014; 2(2B): 247-252.
17. Global CCS Institute; Annual Review. 2013:35-37.

18. IEA; Carbon Capture and Storage in the CDM. 2007: 55-56.
19. Benson, Sally M; Monitoring carbon dioxide sequestration in deep geological formations for inventory verification and carbon credits. Society of Petroleum Engineers 102833, 2006.
20. IPCC; IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA, 2005: 442.