Carbon capture and storage (CCS) [i]

1. Introduction

The capture of CO_2 is only economically feasible from large point sources of emissions. Power plants, which account for around one third of global CO_2 emissions, offer the most likely sources. Other sources include gas processing, liquefied natural gas (LNG) and synfuel production facilities, oil refineries and other industrial processes such as cement, iron and steel and chemical production. A brief synopsis of each is provided below (IEA, 2007).

1.1 Power generation

The principal technologies used to generate power from fossil fuels worldwide are, currently pulverized coal-fired steam cycles and natural gas combined cycles. Integrated Gasification Combined Cycle (IGCC) is an emerging option for power generation, although they are not widely deployed due to the complexity of plant operation. CO_2 capture could be incorporated into all of these types of plant.

- Pulverised coal-fired generation
- Gas boilers and turbines
- Integrated gasification technology
- Biomass power generation

1.2 Natural gas processing

Depending on its source, raw natural gas extracted from reservoirs often contains varying concentrations of CO_2along with hydrogen sulphide (H_2S), which must be reduced for technical and safety reasons. Pipeline specifications often require that the CO_2 concentration be lowered to around 2% by volume to prevent pipeline corrosion, to avoid excess energy use in transport, and to increase the heating value of the gas. As such, CO_2 removal is sometimes an integral part of natural gas field development engineering. Appropriate incentives such as the CDM could provide a trigger to mitigate significant portion of CO_2 emissions form this source.

There are now two operational natural gas plants which store CO_2; BP's In Salah plant in Algeria and Statoil's plant at the Sleipner field in the North Sea, both of which store around 1 $MtCO_2$ per year.

1.3 Liquefied natural gas production

Liquefied natural gas (LNG) is natural gas that has been processed to remove impurities and heavy hydrocarbons and then condensed into a liquid, i.e. 'liquefied' at almost atmospheric pressure by cooling it to approximately -163 degrees Celsius. LNG is around 1/600th of the volume of natural gas at the standard temperature and pressure making it much more cost-efficient to transport over long distances where pipelines do not exist.

Two planned LNG projects, the Snohvit gas field in Norway and the Gorgon field in Australia propose to re-inject the stripped reservoir CO_2 into geological formations.

1.4 Refineries

Refineries process crude oil, natural gas liquids, and synthetic crude oils to produce final refined products (primarily fuels and lubricants). For this transformation to occur, part of the energy content of the products obtained from the crude oil is used in the refinery. Refineries produce large amounts of CO_2 emissions, of which about two thirds of the CO_2 emissions are from combustion of oil in fired heaters. The flue gas from these heaters is similar to the flue gas in power stations, so CO_2 could be captured using the same techniques and at broadly similar costs. Where refineries are integrated with other facilities (for example, upgraders or cogeneration plants) significant potential could exist for process optimization to create more concentrated point sources suitable for CO_2 capture.

1.5 Synthetic fuel production

Synfuel plants produce synthetic petroleum products from coal, condensates or natural gas. Coal-to-liquids (CTL) and Gas-to-liquids (GTL) technologies are not yet widely deployed. These processes are expected to become increasingly used over the coming decades, especially if high oil prices (if more than US$70 barrel) are sustained over the medium term.

The first stage of synfuel production in CTL and GTL technologies involves the forming of a syngas from the hydrocarbon input fuel to yield a mixture of hydrogen and CO_2. There are four main processes for producing the syngas:

i) Steam reforming
ii) Partial oxidation (POX)
iii) Autothermal reforming
iv) Combined or two-step reforming

The choice of syngas former is usually dependent on the scale, ease of operation, cost of fuel. It will have an impact on the overall thermal efficiency of the process, as well as the quality of the syngas input into the next step. Optimization with the second step is also a major challenge.

The second step involves the reaction of the produced syngas with a catalyst in a process known as the Fischer Tropsch synthesis, from which a range hydrocarbon products are produced (including gasoline, diesel, solvents, waxes and tars).

There are two main categories of natural gas-based Fischer-Tropsch process technology: the high and the low temperature versions (Royal Dutch Shell web site).

- The high-temperature, iron catalyst-based Fischer-Tropsch GTL process produces fuels such as petrol (gasoline) and gasoil that are closer to those produced from conventional crude oil refining. The resultant GTL products are virtually free of sulphur, but contain aromatics.
- The low-temperature, cobalt catalyst-based Fischer-Tropsch GTL process, however, produces an extremely clean synthetic fraction of gasoil called GTL Fuel that is virtually free of sulphur and aromatics.

1.6 Cement production

CO_2 emitted in the flue gases from cement production also represents a potential source of emissions for capture. Emissions from this sector account for 6% of the total emissions of CO_2 from stationary sources worldwide.

In cement manufacture, CO_2 is produced during the production of clinker, an intermediate product that is ground to produce cement. During the production of clinker, limestone is heated and ‘calcinated’ to produce lime, with CO_2 as a by-product. The lime then reacts with silica, alumina, and iron oxide in the raw materials to make the clinker. Cement production requires large quantities of fuel to drive the high temperature, energy-intensive reactions associated with the calcination of the limestone. CO_2 emissions are directly related to clinker production rates and the fuel combusted. Process CO_2 emissions are determined from the weights and compositions of all carbonate inputs from all raw material and fuel sources, the emission factors for the carbonates and the percentage of calcination achieved.

1.7 Other industries

- Chemical manufacture
- Iron and steel production

2. Technology Characteristic

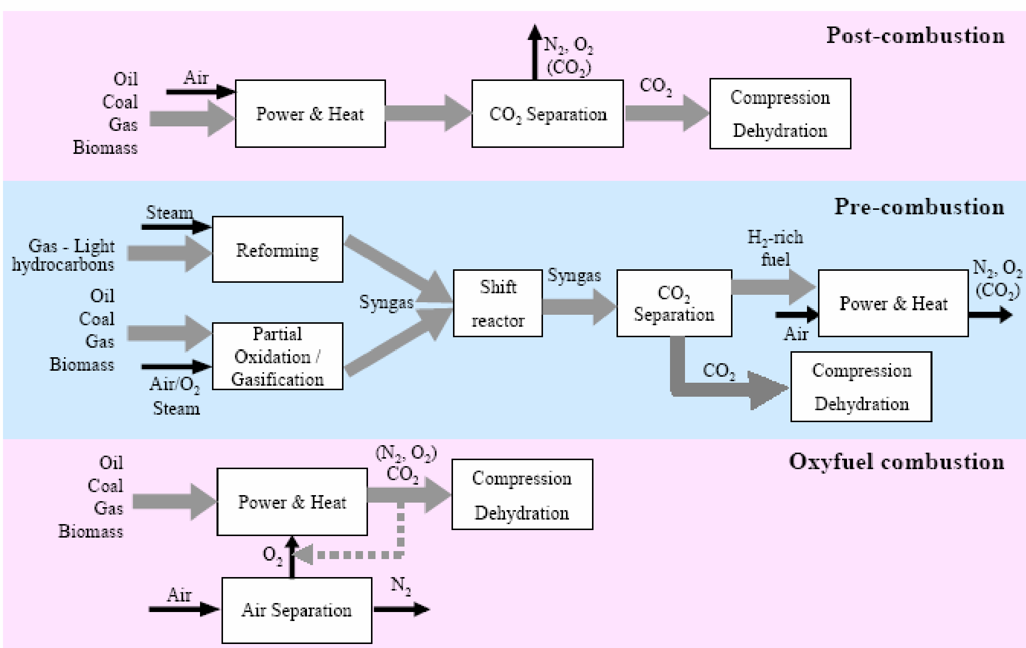
In this paper, there are three main parts of CCS as follows:

2.1 Capture technologies

Carbon capture technologies have long been used for high-concentration, high-pressure CO_2 sources. The three primary methods, as shown in Fig A 15 and compared in Table A 13, for CO_2 capture today are pre-combustion capture, post-combustion capture, and oxyfuel firing for CO_2 capture (IEA, 2009).

- **Pre-combustion capture**

Pre combustion is the process in which the fuel gases resulting from gasification are "shifted" to produce CO_2 and hydrogen, after which the CO_2 is separated. Pre-combustion CO_2 capture from an integrated gasification combined cycle power plant has yet to be demonstrated. However, elements of the technology are already well proven in other industrial processes.



Source: (IPCC, 2005)

Fig A 15 Capture technologies

- **Post-combustion capture**

Post combustion involves scrubbing CO_2 out of the flue gases from the combustion process. Post-combustion capture using solvent scrubbing is one of the most established methods for CO_2 capture, and several facilities use amine solvents to capture significant flows of CO_2 from flue gas streams today.

- **Oxyfuel firing,**

In principle, this technology involves combusting the fuel in high concentrations of oxygen to get a high CO_2 concentration in the flue gas. Oxy-coal combustion is currently being demonstrated at pilot scale in Germany, Australia, and the UK, and oxyfuel combustion has been demonstrated in the steel manufacturing industry with commercially operating plants of up to 250 MW in capacity.

2.2. CO_2 Transport

In principle, CO_2 can be transported using pipelines, marine tankers, trains, trucks, compressed gas cylinders, as a CO_2 hydrate, or as solid dry ice. However, given the quantities of CO_2 that need to be transported to achieve abatement goals, pipelines appear to be the only realistic and viable option for the large volumes associated with deployment. Trains and trucks are currently used in some small-scale pilot projects and may be appropriate for transporting small volumes of CO_2 over short distances. Transport of CO_2 through pipelines is not new; for instance, there are several decades of experience in North America, with more than 30 million short tons of CO_2 /year transported through 3,500 miles of CO_2 pipelines in the United States and Canada. Eventually, CO_2 pipeline grids, similar to those used for natural gas transmission, will be built as CCS becomes more widely deployed (CSLF, 2009).

Table A 13 CO_2 Capture concepts and technologies

Capture Concept	Post combustion	Pre combustion
Separation task	CO_2/N_2	CO_2/H_2
Capture Process		
Absorption	Chemical solvents	Physical solvents
		Chemical solvents
Adsorption	Zeolites	Zeolites
	Activated carbon	Activated carbon
Membranes	Polymeric	Polymeric
Cryogenic	Liquefaction	Liquefaction

Source: (Isaenko Anastasia, 2012)

2.3 CO_2 Storage

A number of projects currently inject CO_2 into oil reservoirs, primarily in the United States and Canada. A majority of these projects focus on enhanced oil recovery (EOR), but some also intentionally store and monitor CO_2 concurrently with EOR operations. The main options for geological CO_2 storage are saline formations, depleted or partially depleted oil and gas reservoirs, and deep, unminable coal seams (IEA, 2009). Of the three options, saline formations are expected to be able to store the greatest quantities of CO_2, followed by oil and gas reservoirs. In addition, our practical knowledge of how CO_2 moves through a variety of geologic formations when permanently stored is limited to a small number of projects, the longest of which has been injecting for more than a decade. However, there is considerable experience in monitoring and modeling of "CO_2 analogues" (such as aquifer water movement, volcanic activity, and fault lines), which will assist in fast tracking global capabilities in both these areas. While monitoring data at existing injection sites has shown that the CO_2 has performed as anticipated after injection and no leakage has been observed at any of the sites where injection is occurring (IPCC, 2005), the CCS industry and governments need to put in place responses to community concern about "learning by doing."

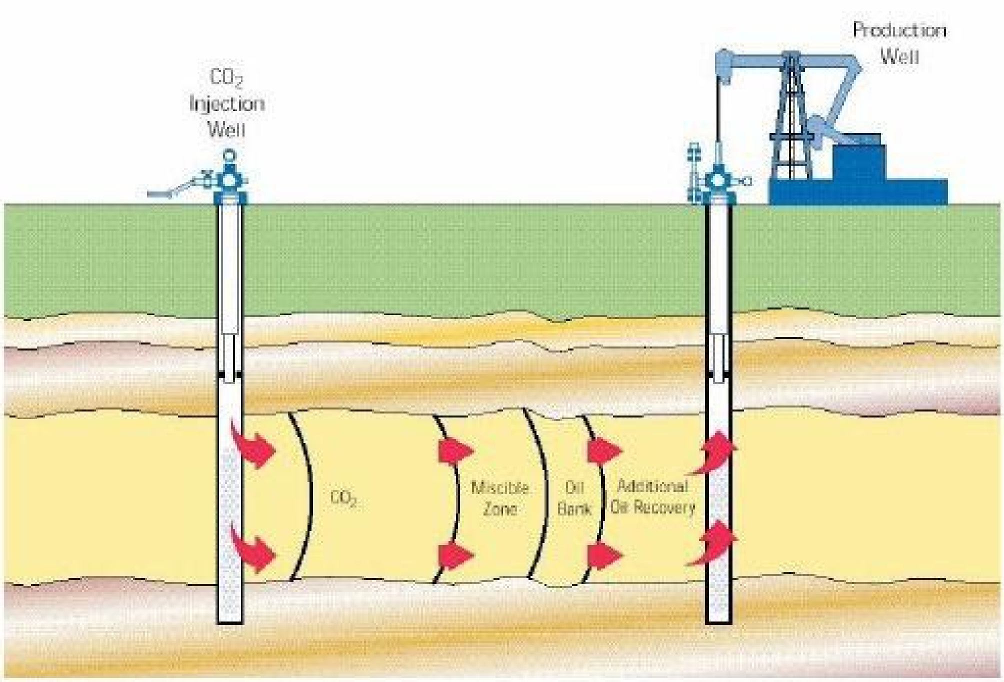
Typical geological target formations comprise three key features including (i) must have sufficient volume (capacity),(ii) must have sufficient permeability for injection (injectivity) and (iii) must overlain by a gas tight sealing formation (caprock) which keeps the buoyant CO_2 from migrating upwards (containment)(Isaenko Anastasia, 2012).

2.4 CO_2 Use

In addition to EOR, CO_2 can be used in certain industrial processes such as mineralization (or carbonation), pharmaceutical and chemical processing and agricultural and biological applications. None of the current uses consumes large amounts of CO_2. Emerging technologies that could absorb larger amounts tend to be in the research or pilot stage. Some CO_2 uses do not represent a permanent storage solution, but could be used to offset the costs of capture while technologies are refined, suitable storage sites are identified and costs of CCS are reduced (CSLF, 2009).

- **Enhanced Oil and Gas Recovery**

Conventional oil production techniques may only recover a small fraction of oil in reservoirs, typically 5%–15%, although initial recovery from some reservoirs may exceed 50%. For the majority of reservoirs, secondary recovery techniques such as water flooding can increase recovery to 30%–50%. Tertiary recovery techniques such as CO_2 injection, as shown in Fig A 16, which is already used in several parts of the world (particularly in the United States), push recovery even further. Currently, most of the CO_2 used for enhanced oil recovery is obtained from naturally occurring CO_2 fields or recovered from natural gas production. Buying CO_2 for this purpose introduces another cost and the CO_2 is recycled as much as possible throughout the EOR process. Nevertheless, the CO_2 left in the reservoir at the end of recovery is regarded as being permanently stored.



Source: (IEA, 2007)

Fig A 16 CO_2 enhanced oil recovery

- **Mineralization**

Nature's way of geologically storing CO_2 is the very slow reaction between CO_2 and naturally occurring minerals, such as magnesium silicate, to form the corresponding mineral carbonate. Among all forms of carbon, carbonates possess the lowest energy, and are therefore the most stable. Carbon dioxide stored as a mineral carbonate would be permanently removed from the atmosphere, and research is under way to increase the speed of carbonation. However, the mass of mineral that would have to be quarried would be many times the mass of CO_2 captured. A novel example of a pilot-scale mineralization project involves the chemical conversion of refining wastes, such as bauxite residue (red mud), by combining them with CO_2. While ideally suited to lower CO_2 volumes, the process addresses CO_2 storage needs while reducing the environmental issues associated with the caustic form of the residue.

- **Biofixation**

Biofixation is a technique for producing biomass using CO_2 and solar energy, typically employing microalgae or cyanobacteria. Horticulture (in glass houses) often uses CO_2 to enhance the growth rates of plants by artificially raising CO_2 concentrations.

- **Industrial Products**

CO_2 captured from ammonia reformer flue gas is now used as a raw material for manufacturing urea in the fertilizer industry, and purified CO_2 is used in the food industry. Possible new industrial uses of CO_2 include catalytic reduction of light alkanes to aromatics, formation of alkylene polycarbonates in the electronics industry and production of dimethyl carbonate as a gasoline additive. CO_2 is thermodynamically stable. Significant energy is needed to convert it for use as a chemical raw material. The additional energy requirement and cost means that its use as a chemical raw material is limited to a few niche markets.

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[i] **This fact sheet has been extracted from TNA Report – TECHNOLOGY NEEDS ASSESSMENTS REPORT FOR CLIMATE CHANGE MITIGATION – Thailand. You can access the complete report from the TNA project website http://tech-action.org/**