1. EUSUSTEL Report on CO$_2$ Capture & Sequestration

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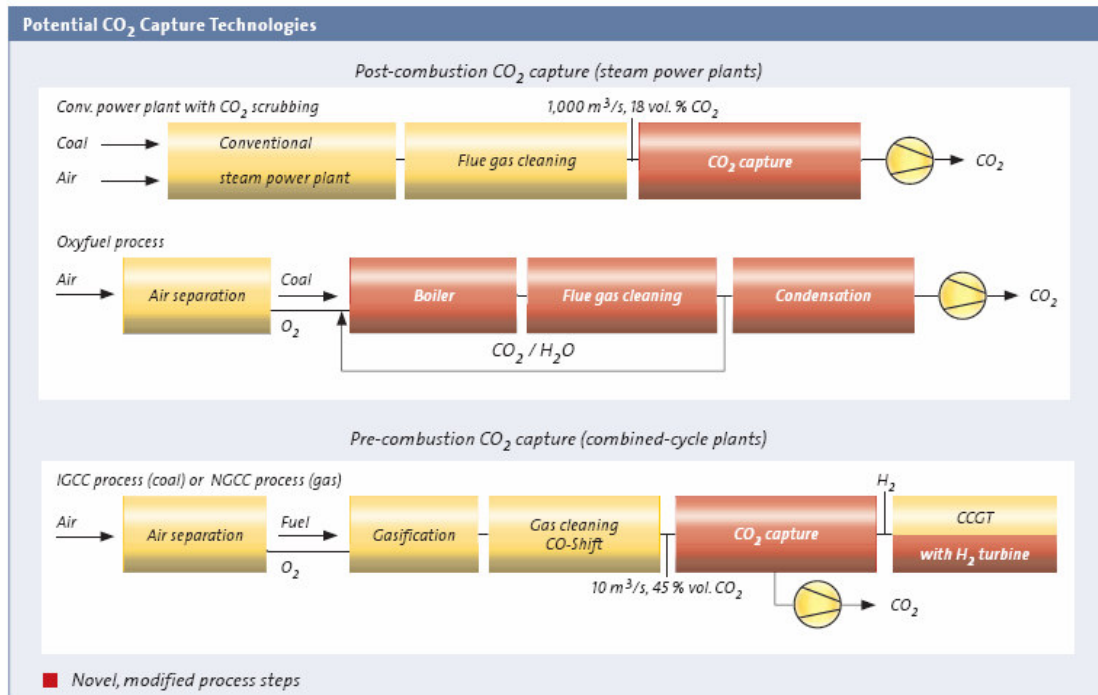
1.1 CO2 Capture

1.1.1 General

One way to reduce emissions from electricity generation is to switch to less carbon intensive fuels such as natural gas or non-fossil fuel based renewable energy systems. Another approach is to reduce emissions resulting from the use of coal through improved efficiency and/or by capturing and permanently storing (sequestering) carbon dioxide (CO_2). (Australian Coal Association 2004).

While capture and geological storage of CO_2 has not yet been demonstrated for the specific purpose of abating emissions from power stations, CO_2 separation is common in natural gas production and in gasification processes at petrochemical refineries. The injection of CO_2 into geological formations is being carried out routinely at more than 70 sites in enhanced oil recovery (EOR) operations, primarily in North America, North Africa and Europe (Australian Coal Association 2004).

It is unlikely that any technology combination that includes CO_2 capture and storage will be competitive with conventional coal-based PF generation, basically because of the additional efficiency loss and infrastructure. There are several projects under way aiming at cost reduction of CO_2 capture and storage. For example, as reported by (WCI 2005b), the FutureGen project aims at producing electricity from a coal-fired power station incorporating carbon capture and storage at no more than 10% higher cost than one without CCS. While costs are certain to fall significantly over time, there is considerable uncertainty about both the cost of abatement and the impact on generation costs (Australian Coal Association 2004).

Aus EURACOAL 2005: CO2 capture at conventional power plants and combined-cycle facilities

1.1.2 Generic approaches for capturing CO2 from power plant

Capture of CO_2 can be achieved by separation either from the flue gas produced in conventional combustion or from the fuel gas before the combustion in gas turbines. Based on these two basic principles there are three generic approaches for capturing CO_2 from power plants: (APGTF 2004, BMWA 2003)

a) Post-combustion capture

b) Pre-combustion capture

c) Oxyfuel combustion

'Post-combustion capture' involves the separation of CO_2 from the flue gas. Flue gas separation and capture methods include the following technologies: chemical or physical absorption, adsorption/desorption, cryogenic separation and membrane separation (IEA 2002; APGTF 2004). The preferred technique for post-combustion capture at present is to scrub the flue gas with a chemical solvent and following to heat the solvent to release high purity CO_2 (APGTF 2004). The most common solvents used for neutralizing CO_2 in chemical absorption systems are alkanolamines such as monoethanolamine (MEA), diethanolamine (DEA), and methyldiethanolamine (MDEA) (IEA 2002).

The alternative methods for separating CO_2 from flue gases - physical solvent scrubbing (absorption), adsorption/desorption, cryogenics and membranes are presently more suited to pre-combustion and oxyfuel methods (APGTF 2004).

'Pre-combustion capture' involves reacting fuel with oxygen or air, and in some cases steam, to produce a gas consisting mainly of carbon monoxide and hydrogen (syngas). In a following shift reaction the carbon monoxide is reacted with steam in a catalytic shift converter to hydrogen and carbon dioxide. Finally the carbon dioxide is separated and the hydrogen can be burned in a gas turbine or, in future application, used in fuel cells (APGTF 2004, WCI 2005b).

The advantage of pre-combustion capture relative to post-combustion capture is that a smaller volume of gas being richer in CO_2 has to be treated. This reduces the size of the gas separation plant and thus reduces capital costs. Furthermore the higher concentration of CO_2 enables less selective gas separation techniques to be used. (e.g. physical solvents, adsorption/desorption). These require less energy to operate. Most of the technologies for pre-combustion capture is well proven in ammonia plant (APGTF 2004). However the combustion system has to be completely redesigned and modified, thus costs and new risks arise.

'Oxyfuel combustion': This CO_2 capture technology is based on the production of a concentrated, pressurised stream of CO_2, which can directly be captured. 'Oxyfuel combustion' involves burning fuel in an environment of oxygen together with recycled CO_2-rich flue gas (APGTF 2004). The oxygen used is derived from an air separation unit. The oxygen/CO_2 mixture at the combustion is produced by recirculating some flue gas to the combustor. This oxygen/ CO_2 mixture is needed to control flame temperature, which would be too high, if combustion took place in pure oxygen. The exhaust from oxyfuel combustion is flue gas with high CO_2 concentration. This is achieved by elevating O_2 levels and reducing the N_2 content in the combustion air. (WCI 2005b). As further result the volume of inert gas is reduced, which can increase boiler thermal efficiency (IEA 2002). The highly enriched CO_2 flue gas stream enables simple and low cost CO_2 purification methods to be used (APGTF 2004).

The major drawback of this approach is that the production of O_2 using conventional cryogenic air separation plants is expensive, both in terms of capital cost and energy consumption (APGTF 2004).

This technique can be applied to boilers and gas turbines, although a different design of gas turbine would be needed to work with highly concentrated CO_2, which rules out retrofit to existing Gas Turbine Combined Cycle (GTCC) stations (APGTF 2004).

A fourth method mentioned for capturing CO_2 from power plants is

    d) Chemical looping combustion (WCI 2005b)

In chemical looping combustion a direct contact between the fuel and the combustion air is avoided by using a metal oxide to transfer O_2 to the fuel. That way coal is indirectly combusted. An air-fired boiler uses a continuously looping solid oxygen-carrier, which oxidises the fuel into primarily water and carbon dioxide. Water is easily separated by condensation, thus yielding a fairly pure stream of CO_2 that can be compressed and liquefied (WCI 2005b).

1.2 Transportation of CO2

After capture, CO_2 can be transported by high-pressure pipeline or by tanker.

There is about 3000 km of large land-based CO_2 pipelines in existence throughout the world, primarily in North America, that have been transporting CO_2 since the early 1980s. Most pipeline systems are designed so that recompression is not required beyond the power plant. Additionally, considerable offshore oil and gas pipeline infrastructure exists that may have the potential to support offshore CO_2 storage sites. (WCI 2005b, IEA 2002)

Internationally recognised standards for the design, construction, and monitoring of CO_2 pipelines are in place in the U.S. and Canada, and largely represent an extension of industry best practices for natural gas and other hazardous gas pipelines (IEA 2002). The IEA GHG R&D Programme compiled current CO_2 pipeline design data (IEA 2003a).

1.3 Storing CO_2

In order to prevent that anthropogenic CO_2 emissions from burning fossil fuels increase the concentration in the atmosphere to levels that may lead to harmful global warming, long-term storage of CO2 has been proposed. The prime objective of CO_2 sequestration is to develop effective, verifiably safe, and environmentally sound storage sites that are acceptable to the public (IEA 2002).

Various technical options for the long-term storage of CO_2 are being researched. They include geological storage and mineral carbonation (WCI 2005b). Ocean sequestration is another option **[which will be further discussed in the next revision of this report]**. However, for the time being there are major public and legal issues that must first be addressed before this sequestration approach can be applied.

1.3.1 Geological Storage

Injection of CO_2 into natural geological appropriate 'reservoirs' (Figure 1) offers potential for the permanent storage in different media of very large quantities of CO_2. This is the most comprehensively studied storage option (WCI 2005b). The CO_2 is compressed to a dense state, then it is injected deep underground. The goal is store (and possibly monitor) CO_2 either trapped in the bedrock or dissolved in solution for very long time (WCI 2005b). Large volumes of CO_2 can potentially be stored long-term in a variety of geological structures, including saline aquifers, depleted or nearly exhausted oil and gas reservoirs and unmineable coal seams.
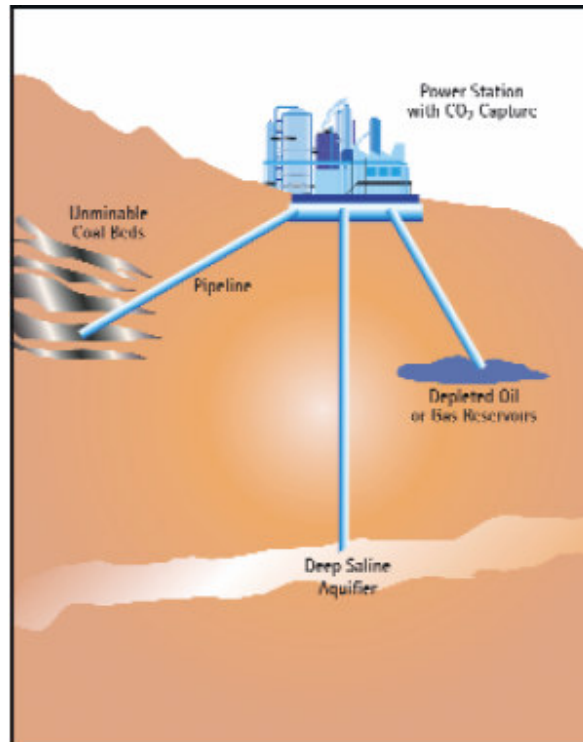
Figure 1   Options for CO_2-storage in geological structures (IEA 2003b).

Research is being conducted in a number of countries to assess the viability and acceptability of each of these options (Australian Coal Association 2004). Several projects investigating the potentials for the storage of CO_2 have been and are being carried out for different countries and regions. Table 1 summarises the results of projects investigating the CO_2 storage potential for Europe.

Table 1 CO$_2$ storage potentials for Europe.

Europe	Gas fields (depleted)	Oil fields (depleted, EOR)	Aquifers	Unminable coal seams (ECBM)	Sum	unit
Europe						
1	IEA GHG, R&D program, 2000	26	6	773	nn	**806**	Gt CO$_2$
West-Europe						
2	Dooley/Friedmann, 2004	42	7	215	4	**268**	Gt CO$_2$
3	GESTCO, 2004 (Denmark, Germany, Norway, UK, Netherlands, Greece)	30	7	91	nn	**128**	Gt CO$_2$

1.3.1.1 Storage in saline aquifers

Storing large amounts of CO$_2$ in deep saline water-saturated reservoir rocks offers great potential (WCI 2005b). Deep saline aquifers are widely distributed below the continents and the ocean floor and are within easy access to a number of power plants. Deep aquifer sequestration (Figure 2) is currently being demonstrated and has proven to be technically feasible (IEA 2002).

Since October 1996 the Norwegian company Statoil is injecting about 1 million tonnes a year of CO$_2$ into the Utisira Formation at the Sleipner field in the Norwegian section of the North Sea, at a depth of about 800-1000 metres below the sea floor (WCI 2005b). This is equivalent to about 3% of Norway's total annual CO$_2$ emissions. (IEA 2002)

A comprehensive analysis of the storage potential of saline reservoirs is undertaken in Australia. As part of the GEODISC (Geological Disposal of Carbon Dioxide) project, the storage potential of Australian saline aquifers is estimated. The conclusion was that these reservoirs have the potential to store the total CO$_2$ emitted by the country at current rates for many hundreds of years (WCI 2005b). It is hoped that a major CO$_2$ storage demonstration project will be under way in Australia in 2005-06 (Australian Coal Association 2004).
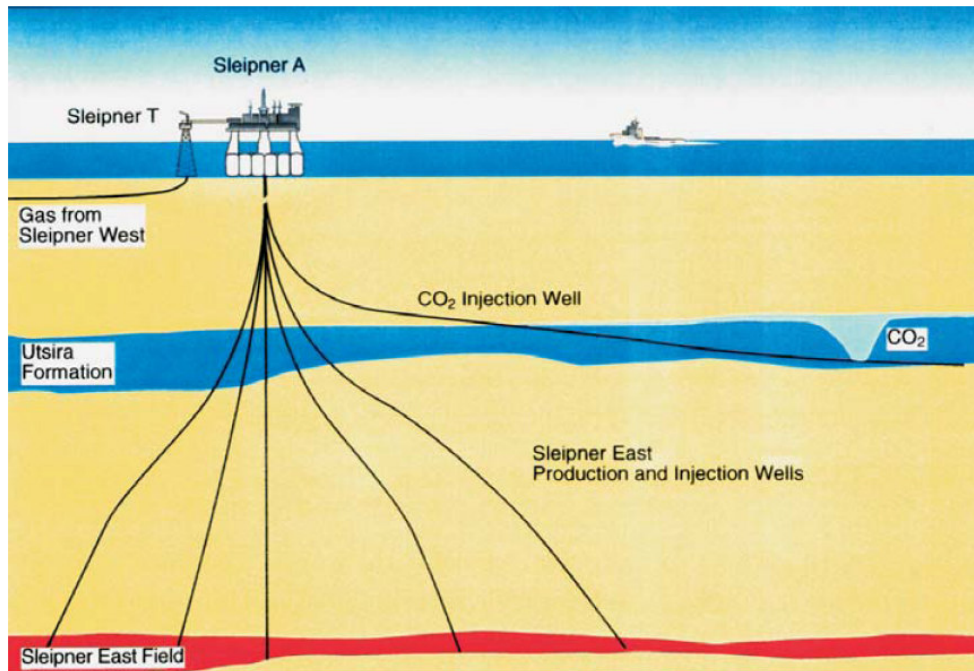
Figure 2 CO_2-storage in deep saline aquifers (IEA GHG 2001).

1.3.1.2 Storage in depleted gas reservoirs

Depleted gas reservoirs offer promising sites for geological storage of CO_2 (WCI 2005b). Natural gas fields have demonstrated the ability to store gases for millions of years. The first successful natural gas storage project in depleted reservoirs was in Canada in 1915. An advantage of many of these sites is that they are an integral component of natural gas pipeline delivery systems, which can improve the economics of CO_2 transport and sequestration (IEA 2002). The US Department of Energy (DOE) estimated that the storage capacity of depleted gas reservoirs in the USA is about 80-100 Gigatonnes, or enough to store US emissions of CO_2 from major stationary sources for 50 years or more (WCI 2005b)

1.3.1.3 Enhanced Oil Recovery (EOR)

Enhanced Oil Recovery (EOR) is a process already widely used in the oil industry to increase oil production (Figure 3). CO_2 is injected into oil fields helping to pump out oil out of the underground (IEA 2002). The reservoirs are natural stratagraphic traps that have held oil and gas over geological time. Furthermore, the geologic structure and physical properties of most oil fields have been extensively characterised and sophisticated computer models have been developed to predict the displacement behavior and trapping of CO_2 for EOR. Finally, industry has a significant amount of experience, technology, and expertise that can be applied to CO_2 storage at these sites (IEA 2002). Without such methods of enhanced production, many oil fields can only produce half or less of the original resource (WCI 2005b).

So far, there are about 70 currently active enhanced oil recovery operations, located primarily in Canada and the United States using about 60 million cubic metres per day of CO_2 (see Weyburn CO_2 flood project).[1] Most of the CO_2 used for EOR comes from natural CO_2 reservoirs (IEA 2002).
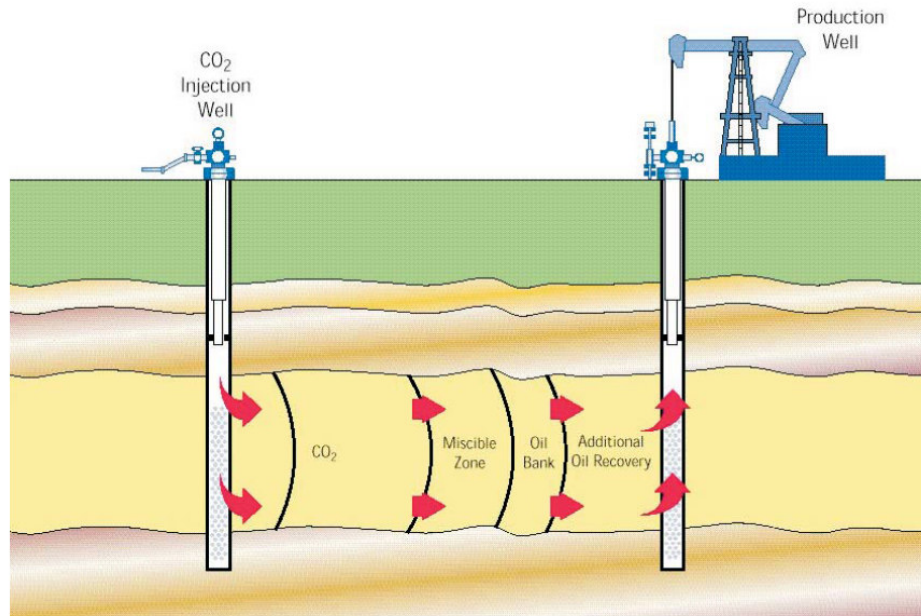

Figure 3   Principle of Enhanced Oil Recovery (EOR) (IEA GHG 2001).

1.3.1.4 Unmineable Coal Seams – Enhanced Coalbed Methane (ECBM)

Coals seems in high depths cannot economically be mined with current best available technology. However these coal seams contain methane, which can be exploited and used as fossil feedstock.

Methane production from deep coalbeds can be enhanced by injecting CO_2 into coal formations (Figure 4), a process known as enhanced coalbed methane extraction (ECBM). Enhanced Coalbed Methane is a potential opportunity for storing CO_2 in unmineable coal seams and obtaining improved production of coalbed methane as a valuable by-product (WCI 2005b). At least two to three molecules of CO_2 are sequestered for each molecule of methane produced. Unlike in oil and gas reservoirs, the methane in coalbeds is retained by absorption rather than by trapping. CBM technology is commercially available today and widely practiced in the U.S., and to some extent elsewhere. Since the early 1940s CBM extraction has been used for degassing exploitable

[1] http://www.encana.com/operations/upstream/weyburn_scope_co2.html

coal and improving occupational safety. When conditions are economic, CBM extraction is practiced by industry to produce electricity or heating fuel. The first commercial pilot application has been underway since 1996 at Burlington Resources' Allison Unit in the San Juan Basin in New Mexico, United States (IEA 2002).
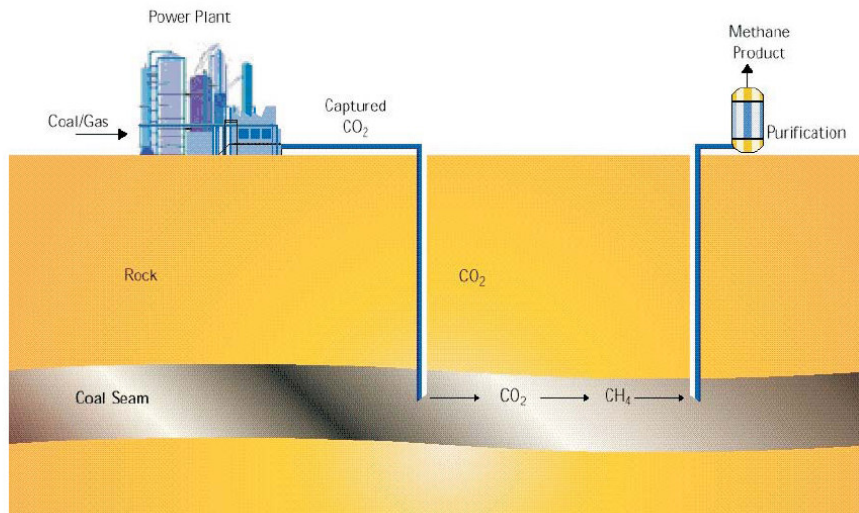

Figure 4   Principle of Enhanced Coal Bed Methane (IEA GHG 2001).

1.3.2 Mineral Carbonation

Another option for permanent storage is mineral carbonation. In this process, CO_2 is reacted with naturally occurring substances to create a product chemically equivalent to naturally occurring carbonate minerals (WCI 2005b). CO_2 can be reacted with minerals such as magnesium silicate (e.g., peridotites or serpentinites) to form stable, environmentally benign carbonates (IEA 2002). This process resembles the natural weathering of alkaline rocks, which normally occurs over long periods of time (WCI 2005b). CO_2 mineral storage could be obtained speeding up the reactions, but this is still at the laboratory stage of development.

1.4 Economics of CO_2 capture and sequestration

In the longer term, technologies for carbon capture and storage (CCS) present one of the most promising options for economic and environmentally acceptable route to large-scale reductions in CO_2 emissions from fossil energy use (WCI 2005b). CCS have also the potential to enable coal and natural gas to contribute to form the basis of a future hydrogen economy (WCI 2005b) (see Section on IGCC with CO_2 capture). As described in the previous Sections, besides obtaining permanent storage of CO_2, some processes can have economic benefits, like improving oil and coalbed methane extraction (WCI 2005b).

Carbon storage is not yet commercial, but some of the required technologies are proven and have been used in commercial applications in other contexts (WCI 2005b). Technologies for capturing CO_2 from emission streams are being used in small scale to produce pure CO_2 for use in the food processing and chemicals industry. Petroleum companies routinely separate CO_2 from natural gas before it is transported to market by pipeline (WCI 2005b). However, development is still necessary for cost-efficient post-combustion capture technologies for separating CO_2 from high volume, low CO_2 concentration flue gases, as produced in conventional PC power plants (WCI 2005b).

An integrated CO_2 capture and sequestration system has three basic cost components: capture/compression, transport, and injection/storage. These costs are highly variable and depend on many factors including the source of CO_2, capture option, infrastructure availability, transport distance, and type and characteristics of the storage site.

The paragraph on costs will be further specified within the next revision of this report
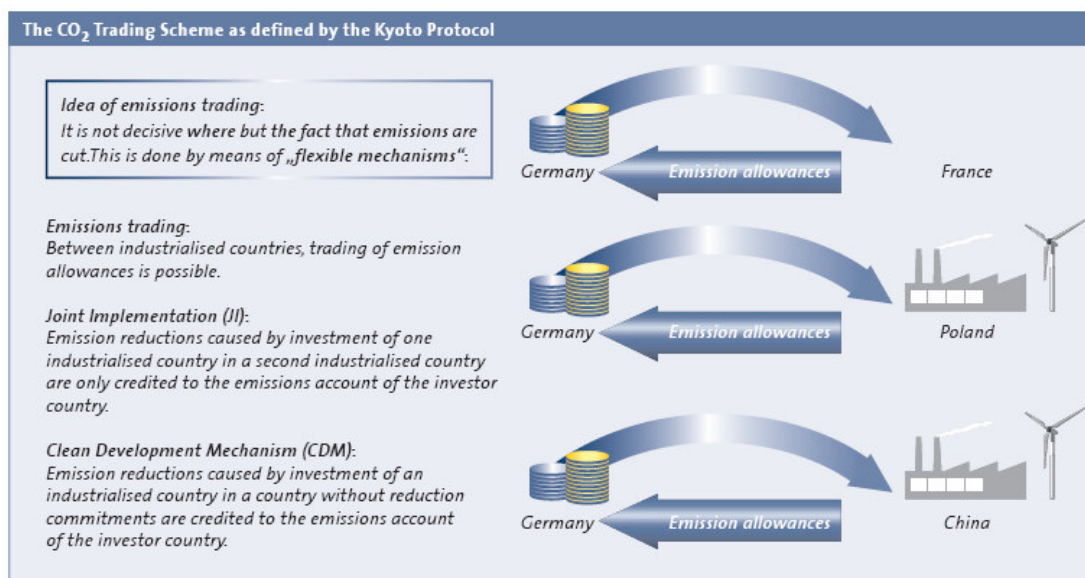
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