Carbon Capture & Storage Systems in Power Production

Assessment of Accident Risks within the Main Components of the CCS-System: Carbon Dioxide Capture, Transmission, Injection & (Long-term) Storage in Geological Formations.

Internship-Report

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EXCECUTIVE SUMMARY.

In recent years numerous studies on Carbon Capture and Storage technologies and their potential to mitigate CO_2-emissions have been conducted, basic regulations have been set up, as well as several pilot and demonstration activities have been initiated. Several of these studies address the great number of e.g. economical and ecological risks surrounding CCS. However, further risks of various types of accidents with possibly severe adverse effects on humans, are not very well understood yet; both in terms of their potential frequency of occurrence and consequences. Only few studies address these risks primarily. However, accident risks are an essential factor in decision making processes and can also strongly impact public perception and opinion. Therefore, objective and accurate facts are needed to avoid emotional or subjective decisions on a potential CO_2 mitigation technology.

Amongst others a qualitative review of (accidental) risks associated with the CO_2-capture, -transmission, -injection and -(long-term) storage in geological formations was done herein based on peer reviewed as well as grey literature and industrial experience with the aim to provide more comprehensive assessment of accident risks related to CCS. This is complemented with experts' judgement gained from a survey to identify potential hazards and crucial issues in the current discussion on CCS-risks. Based on recorded hazardous events first approximations of the frequency of occurrence are made. Potential consequences of hazardous events related are analysed by single historic events and with use of available tools to model atmospheric dispersions.

One of the main issues related to CCS is the uncontrolled leakage and release of CO_2 to surrounding environments, the surface and the atmosphere. CO_2 is gaseous, colourless and odourless at normal ambient conditions and is normally present with about 0.03 vol% in the atmosphere. Apart from its global climate effects, it does have local effects on humans and ecosystems as well, particularly if it occurs at elevated (toxic) concentrations. In addition, it displaces oxygen and acts as asphyxiate therefore, especially if it appears as cold vapour (e.g. sublimating from dry ice) that stays close to the ground due to its density which is greater compared to that of air.

The effect a certain released amount of CO_2 has depends largely on the atmospheric and topographical surrounding conditions, the type of release and the dispersion behaviour of CO_2. CO_2 tends to accumulate on the ground especially in depression areas and at low wind velocity. A low release rate of small leaks (that are hardly detectable in addition) will favour the accumulation, whereas high release rates of even great amounts can result in mixing with the surroundings. Examples for the adverse effect that a leakage and accumulation of CO_2 in a topographically favouring area can have are severe accidents at meromictic lakes in Cameroon (Nyos, 1986, ca. 1746 fatalities and Monoun, 1984, 37 fatalities). In addition to the effects on human safety, animals are similarly affected and vegetation and ecosystems are disturbed by acidified soil leading potentially to tree kills. Finally the release of CO_2 diminishes the positive effect of the storage on the atmospheric CO_2 concentrations and the subsequent climate change.

Hazardous situations with CO_2 can occur in every step of the CCS process chain, i.e. the capture, transport (by e.g. pipeline), injection into the subsurface and (long-term) storage in geological media of various types onshore and offshore.

The risks the CO_2-capture and separation, liquefaction and compression add to a given power plant have not been widely addressed so far. Generally it can be assumed, that the risks of a given power plant are increased due to the additional steps added to the process. Furthermore are additional emissions caused due to the use of chemicals etc. and their production in a life cycle prospective which are assumed to increase the risks of the given power plant. In addition needs the loss in efficiency be taken into account when analysing the risk of a power plant with carbon capture.

Hazardous situations related to CO_2 pipelines result mainly from a slow or sudden release of CO_2 and contained impurities. A number of studies address the risks related to pipeline-transport of CO_2 in

different approaches. Often it is assumed that the risks of these pipeline are similar, or even lower, compared to that of natural gas pipelines. However, further studies that demonstrate that CO_2 pipelines can not be evaluated accurately on basis of the risk of natural gas pipelines due to its different properties: Concerning the frequency of hazardous events, it must be noted that the corrosion-behaviour is different due to the dissolution of CO_2 and impurities (e.g. H_2S, NO_x, SO_x) in the wet gas stream, forming acids. However, dehydration lowers corrosion rates. Furthermore, poor lubricant properties of dry CO_2 and different material compatibility as well as other operating conditions (dense supercritical conditions, dense liquid conditions, two phase flow, cooling in decompression, etc.) make the approximation by natural gas pipelines difficult. Concerning the severity of an accident, it needs to be considered that CO_2 is non-flammable and does not explode but has toxic and asphyxiating properties, posing different risks compared e.g. to natural gas. Furthermore can harmful or even toxic impurities be contained in the transported CO_2-stream (e.g. CO, H_2S), resulting in severe accident consequences.

The frequency and consequences of failure and (severe) accidents posed by the injection, sequestration and especially the (long-term) storage of CO_2 are less well understood and greater uncertainties exist. Possible hazards include not only the CO_2 migration and leakage, but dependent on the addressed on- and offshore storage option (depleted oil-fields and enhanced oil recovery, depleted gas-fields and enhanced gas recovery, unmineable coal seams and enhanced coal bed methane recovery, saline aquifers) also methane leakage, induced seismicity, induced ground movement, brine displacement, groundwater acidification and its contamination with brine or by acidification dissolved heavy metals.

The injection of any fluid in the subsurface has geomechanical and hydrodynamic effects as well as geochemical effects in the long-term. It needs to be noted that the different storage options addressed show major geological differences and therefore processes will vary from storage type to storage type and also from storage site to storage site depending on the given ambient conditions. In general, it can be stated that with increased storage duration, geochemical processes can take place and add to the security of the storage. Consequently is migration and leakage from the injection and sequestration much more likely than from a long-term stored reservoir, as e.g. adsorption, stratographical and hydrodynamic mechanisms are much more reversible compared to the geochemical processes, especially mineral trapping.

Slow (upward) leakage of CO_2 can result from reservoir fractures and faults or any wells in the storage area (e.g. injection wells in saline aquifers, injection or production wells in EOR, monitoring wells, etc.). “Positive” buoyancy due to the lower density of CO_2 compared to water and possibly brine pushes CO_2 upwards in saline aquifers. Contrary forces “negative” buoyancy the saturated water (1-2% CO_2 in water) that is heavier compared to non-saturated water and CO_2 towards the bottom of the storage aquifer. However, in ECBM other mechanisms act (e.g. adsorption instead of dissolution) and CO_2 adsorbed onto the coal surfaces will be immobile as long as the pressure does not drop. Sudden rapid (upward) leakage of CO_2 can result from reservoir fractures, faults and wells and especially well-failure or well blow-outs induced by changes in pressure and temperature.

Analysis of recorded events in the CCS-Industry (CO_2-pipelines, CO_2-EOR) as well as industrial (e.g. Acid Gas Injection, Natural Gas Storage etc.) and natural (natural CO_2 fields) analogues for underground CO_2-storage indicate event frequencies that can serve as starting point for further detailed quantification. However, data are very limited or not available for research and limitations have to be taken into account. Additionally, an “event” can not be consistently specified for its consequences based on the current knowledge and therefore the indicated “event” frequencies can only serve as very rough estimate with no information on the uncertainty that exists. Potential consequences of hazardous events related to CCS are equally precarious to analyse. Therefore, a strong focus should be laid on the establishment of a database that includes hazardous situations and accidents that occur in relation to existing CCS-components (existing capture-, injection- and storage-projects as well as pipelines for which a database at least in the USA already exists) and their consequences, to make an accurate quantification of CCS-risks possible.

KEY WORDS. CCS, Carbon Dioxide, Pipeline, Geological Storage, Accident Risk, Hazard

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