RESULTS AND CONCLUSION OF CO_2

Storage site at emitter E

The CO_2 terminal will receive CO_2 from the CO_2 capture installation from the emitter. The captured CO_2will enter the terminal via two incoming pipelines. The CO_2 will be liquefied in the liquefier and stored in two storage vessels. CO_2 from the storage tanks will be transferred to the loading facility where it is loaded into barges. On a yearly basis 250 barges will be loaded from the storage tanks. An overview of the site is shown in Figure 8.

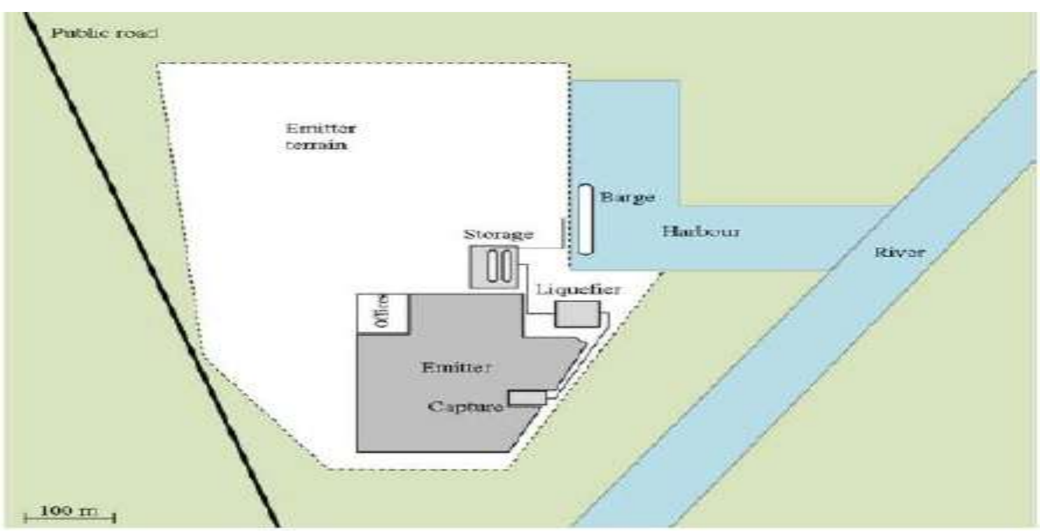

Figure 8: Overview of the CO_2 terminal at emitter E

At the storage facility at emitter E there are several activities that could lead to LOC of CO_2. The CO_2storage tanks could rupture or a leak could be formed due to corrosion, external damage or overfilling.

Rupture of the loading arm used for filling the ship could take place, possibly caused by external impact from accidents. The pumps used at the hub could be damaged and leak, or the suction line could be ruptured. Some piping will be present at the hub, which will be above ground. A leak or rupture of these pipes could be initiated by external interference or internal causes such as corrosion. Similar risk are related to the heat exchangers.

The risk caused by the CO_2 terminal does not reach the external population located outside the plant boundary. Therefore, the calculation of societal risks is not required. The individual risk calculations for the terminal generated a maximum individual risk outside the terminal in the order of 10^{-5}/year or less. The area that is exposed to these contours does not contain other industrial and residential activities, therefore these results do not conflict with regulatory requirements.

Barge

The CO_2 transported by barge could pose an external risk due to collision scenarios or an accidental release from the above-deck piping of the barge. Accident scenarios of barges in transit consist out of LOC scenarios due to internal failure (e.g. leak of piping) or due to external failure (e.g. collision). Emitter E is at a distance of approximately 160 kilometers from the terminal. Transportation of the $CO_2$is done by river barges.

The barges depart from emitter E and follow partly the river Maas, the Maas-Waal channel, the Waal, the Boven-Merwede, the Oude-Maas, the Hartelkanaal and finally arrive at the Beerkanaal (Maasvlakte) in the Port of Rotterdam. The route is shown in Figure 9.

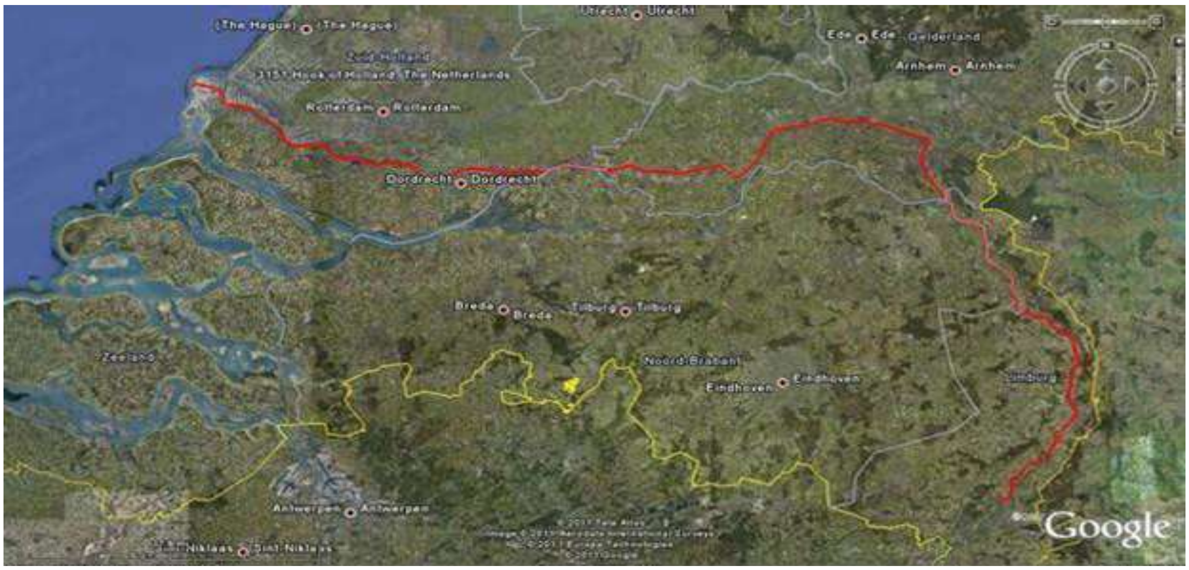

Figure 9: Barging route from emitter E to Port of Rotterdam

The individual risk caused by the CO_2 barges at the waterway sections in the route is in the range of 10^{-8} per year and therefore the criterion that no vulnerable object is present within the 10^{-6} contour is not breached. As the 10^{-8} contour barely reaches shore it can also be concluded that societal risk will be negligible.

Onshore pipeline

Transport pipelines can fail due to internal causes (e.g. corrosion, pressure above design pressure) and due to external interference (e.g. groundwork). The safety study will assess two possible LOC scenarios: a rupture of the pipeline and a leak of the pipeline.

Dangerous CO_2 concentrations at ground level can reach up to 420 meters distance of a ruptured pipeline in a tunnel and 440 meters for a ruptured pipeline in a waterway crossing. This is caused by the loss of momentum of the jet, which lowers the air entrainment and thereby lowers the dilution of CO_2. The 1 % lethality contour for a pipeline in a tunnel reaches up to a distance of 370 meters, and 380 meters (diameter circle) for a waterway crossing. The consequences of an LOC of an underground pipeline are minor because the CO_2 jet is directed vertically and the CO_2 concentration is quickly diluted before reaching the ground. Hazardous CO_2 concentrations occur only directly above the release location. The risk contour is actually a line following the pipeline trajectory.

The calculations were done for the different possible locations of the pipeline: underground, crossing the waterway or in a tunnel. For all sections the individual risk is below the maximum acceptable individual risk criteria of 10^{-6} per year. The societal risk for all the sections is below the target criteria.

CO_2 terminal at the port of Rotterdam

The CO_2 terminal will receive CO_2 transported via land and water. Liquid CO_2 will be received by the terminal via barges, while pressurized CO_2 will be received at the terminal via incoming pipelines. It is expected that yearly 250 barges will deliver liquid CO_2 to the terminal. The liquid CO_2 is stored in four pressurized storage vessels. Pressurized CO_2 will enter the terminal via the low pressure pipeline network in the Port of Rotterdam and emitter B. The pressurized CO_2 will be liquefied in the liquefier. After the liquefaction process 64 % of the CO_2 will be sent to the storage tanks and 36 % will be sent to the send-out pumps, which pump the CO_2 at 150 barg to an offshore location. CO_2 from the storage tank will be transferred to the loading facility where it is loaded into carriers. An overview of the CO_2terminal is given in Figure 10.

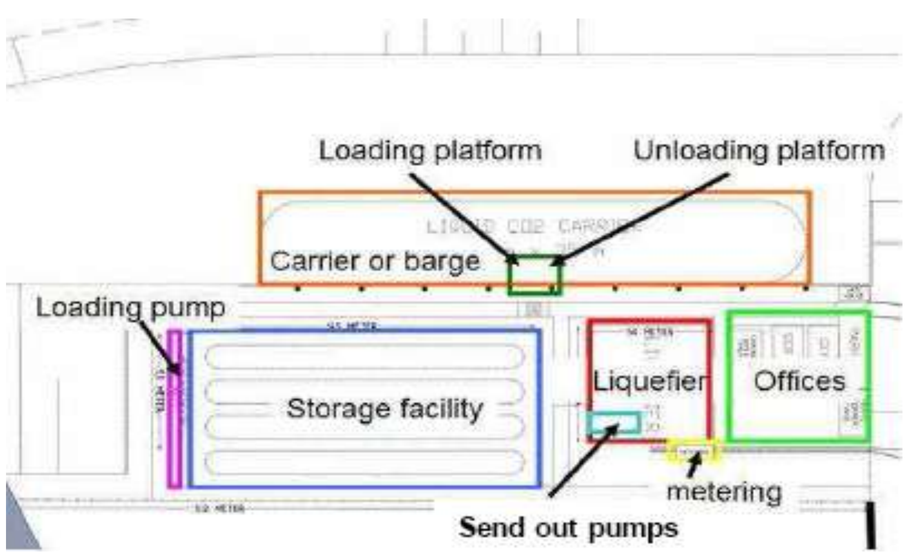

Figure 10: Overview of the CO_2 terminal at the port of Rotterdam [1]

At the hub there are several activities that could lead to LOC of CO_2. The low temperature pressurized CO_2 storage tanks could rupture or a leak could be formed due to corrosion, external damage or overfilling. Rupture of the loading arm used for filling the ship could take place, possibly caused by external impact from accidents. The pumps used at the hub could leak or the suction line could be ruptured. Also, some piping will be present at the hub, which will be above ground. A leak or rupture of these pipelines could be initiated by external interference or internal causes as corrosion. Similar risks are related to heat exchangers.

The maximum calculated individual risk outside the terminal boundary is in the order of 10^{-5}/year or less and is thereby higher than the maximum acceptable individual risk criteria of 10^{-6}/year. The individual risk contour of 10^{-5} and 10^{-6}/year crosses the plant boundary at an area that is reserved for chemical activities. Because this area is not reserved for vulnerable objects, these results do not conflict with regulatory requirements in the Netherlands.

Seagoing ship

Accident scenarios of seagoing vessels in transit consist of LOC scenarios due to internal failure (e.g. leak of piping) or due to external failure (e.g. collision). The first group includes aspects like mechanical failure, material/construction errors, fire/explosions, failure of cooling system etc. which are not waterway related. Collision accidents on the other hand are related to a waterway.

Areas that are possibly affected when a leak at one of the cargo tanks of the seagoing vessel occurs are limited to the industrial Maasvlakte area. Vulnerable objects are not located in this area and therefore a risk assessment is not needed according to the Dutch risk criteria. Furthermore the Dutch regulations do not apply for more than 12 miles offshore. Beyond 12 miles offshore an installation is considered an "offshore installation" to which different legislation applies. Offshore an extensive HAZOP is performed in combination with class rules and additional safety standards and guidelines that apply offshore (these vary per territorial waters) and shall be treated on a case by case basis. Obviously everything shall be undertaken to assure a safe operation for both onboard crew, personal on nearby platforms and the environment.

High pressure pipeline (offshore)

Transport pipelines can fail due to internal causes (e.g. corrosion, pressure above design pressure) and due to external interference (e.g. groundwork). The safety study will assess two possible LOC scenarios: a rupture of the pipeline and a leak of the pipeline. The consequence assessment calculated the effects of two LOC scenarios, rupture and leak, for the pipeline.

The calculations were done for the different possible locations of the pipeline: underground and crossing the waterway.

The individual risk calculations for the high pressure pipeline generated a maximum individual risk of 10^{-6}/year at the offshore section and less than 10^{-6}/year at the onshore section. The societal risk is below the target criteria.

Conclusion

The safety study simulated the LOC scenarios for the different LLSC activities. Table 5 presents the 1 % lethality distance and the maximum risk levels for all the different activities in the logistic chain.

The lethality distance of a certain LOC scenario is determined by calculating the dose at a specific location and using this as input for the CO_2 probit function to calculate the fatalities. The dose is a combination of concentration and exposure time. The 1 % lethality distance, present in the table below, is the distance where 1 % of the humans are expected to die. The individual risk is the risk of a fatality at a specific location when a person would be present at the location 100 % of the time.

The individual risk is calculated by combining the risks of all identified LOC scenario of an activity, which means that the individual risk presents the total risk of an activity.

The risk of a LOC scenario is a combination of the effects and the probability of that scenario to occur.

Table 5: Results QRA contours

Activity	1 % lethality distance (m)	Maximum individual risk (per year)
CO_2 emitter terminal	280	10^{-5}
Barges	510	10^{-8}
Low pressure pipeline	380	10^{-7}
CO_2 terminal in Rotterdam	680	10^{-5}
Seagoing vessels	710	–
High pressure pipeline	740	10^{-5}

The results show that the maximum 1 % lethality distances of the activities is in the range of 280 meters up to 740 meters from the location of the accidental CO_2 release. This means that the different activities might affect persons present in the direct vicinity. However, these distances do not say anything about the risk of the activities since likelihood has not been taken into account here. The individual risk levels appear to be the highest in the direct vicinity of the terminals, which is caused by the process installations and the (un)loading activities. In the direct vicinity of the terminals no vulnerable objects, such as housing, should be present and this is not the case. The CO_2 transportation activities do not result in onshore risk levels higher than 10^{-7} per year.

Based on the results it can be concluded that all of the CO_2 activities could pose an effect on the direct vicinity when an unintentional release occurs. However, the corresponding risk levels appear to be below the Dutch risk criteria. Therefore, it can be stated that the safety risks associated with the LLSC are acceptable for all of the considered activities.

Source: http://hub.globalccsinstitute.com/publications/co2-liquid-logistics-shipping-concept-llsc-safety-health-and-environment-she-report/42