CLEEN
Cluster for Energy and Environment

Research Report nr D129
Helsinki 2015

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DATA PACKAGE ABOUT ENVIRONMENTAL, HEALTH, AND SAFETY REQUIREMENTS RELATED TO THE CAPTURE, TRANSFER, AND INTERMEDIATE STORAGE OF CARBON DIOXIDE IN FINLAND

ccsp
Carbon Capture and Storage Program

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ISBN
ISSN

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Key words: Carbon capture, carbon dioxide, Finnish legislation

Abstract

This Data Package is a Deliverable D129 of the five-year Carbon Capture and Storage Program (CCSP) by CLEEN Ltd. The overall long term objective of the program is to develop CCS related technologies and concepts relevant for Finnish conditions enabling piloting and demonstrations, which are a prerequisite for a commercial breakthrough of CCS technologies.

No permanent storage of CO_2 is foreseen in Finland. Consequently the CO_2 must be exported. Currently the generally accepted concept is to transfer the captured CO_2 by pipeline to one or more Finnish harbours for further transport abroad by ship.

The CCS Program will investigate the impact various CCS concepts will have on the environment, on the safety and health of workers and the public, on the sustainability, and on the perception and acceptability of the stakeholders and the public. The current Data Package is forming the basis for future environmental, health and safety (EHS) assessments.

The focus of this Data Package is on what current legal environmental, health, and safety requirements an operating company must fulfil, when introducing various technologies for carbon capture in Finland. Although CO_2 is generally not classified as a hazardous substance, various sections in the Finnish legislation will apply when carbon capture technologies are introduced at power plants and other industrial establishments in Finland. Foreseeable changes in international, European and Finnish legislation and requirements concerning CCS are also reviewed.

As no permanent storage of carbon dioxide is envisaged in Finland, the study comprises only the following three types of onshore facilities:

- Industrial facilities (including power plants) in which CO_2 is formed,
- Pipelines for carbon dioxide transfer to Finnish harbours,
- Harbour facilities including intermediate storage tank(s) and ship loading facilities.

This Data Package covers EHS-issues relevant for the various life-cycle phases of establishments introducing some of the best documented CCS technologies like post-combustion, pre-combustion and oxy-fuel combustion. In addition to these CCS technologies, a brief overview of EHS-issues of chemical-looping-combustion is also made. Chemical-looping-combustion is considered to be promising novel CCS technology. In addition, a pipeline case and an intermediate storage and harbour facility are used as examples.

This report covers not only the requirements of the CO_2 capture unit but those of the establishment as a whole. Although the Data Package covers EHS requirements for the whole establishment, emphasis is put on those obligations, which, when carbon capture technologies are employed, will be different from those of conventional installations.

This Data Package has been compiled by Ramboll Finland Oy and VTT Technical Research Centre of Finland. The authors wish to thank Fortum Oyj, Gasum Oy, Neste Oil, AF.Consult Oy and University of Tampere for their input.

Disclaimer: The information given in this Data Package is meant to give a quick overview of the relevant EHS requirements in the Finnish legislation. In order to make the text easier to read, some generalisations have been made. In other words, the wording in this document is not exactly following the text in the original Finnish versions of the legislation. Some sentences, paragraphs or even acts and decrees, which have been seen as less important in this context, have been left out (e.g. regulations concerning electrical safety). Therefore, always check not only the original regulations mentioned in this report, but also other acts, decrees and decisions relevant to your work after you have read this Data Package. Guidance given in Finnish or European standards or published by the competent authorities in Finland has not been considered in this Data Package. Neither is any reference made to EU regulations and directives or to international conventions – with a few exceptions.

Helsinki, June 2015

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1 INTRODUCTION TO THE CCS PROGRAM

This Data Package is a Deliverable D129 of the five-year Carbon Capture and Storage Program (CCSP) by CLEEN Ltd. CCSP is one example of several platforms created by CLEEN Ltd. The overall long term objective of the program is to develop Carbon Capture and Storage (CCS) related technologies and concepts relevant for Finnish conditions enabling piloting and demonstrations, which are a prerequisite for a commercial breakthrough of CCS technologies.

The CCS Program has three major goals. If significant (80 – 90 %) global greenhouse gas emission reductions are pursued, CCS plays an important role in reducing CO_2 emissions from coal based energy production. In addition, CCS provides opportunities for various industries, which have no CO_2 neutral alternatives for fossil resources. Furthermore, capture of CO_2 from biogenic sources creates CO_2 sinks, and this creates globally remarkable opportunities for countries like Finland with significant biomass sources and bioenergy production.

Although CCS is still in an early demonstration phase, intensive and focused research has remarkable opportunities for global breakthrough solutions. The CCS program lays ground for the involvement of Finnish actors. The research is focused on integrating the CCS technology to the existing Finnish energy and environmental high tech. Knowledge on Combined Heat and Power (CHP) production and fluidized bed combustion are utilized for applying carbon capture in special conditions of Finnish energy production.

Connecting carbon capture to CHP production offers unique opportunities for Finland in improving the overall energy efficiency of carbon capture processes. Since CCS in connection to CHP is one of the focus points of the program, gas turbine combined cycles and opportunities in near and longer term are being assessed in real case surroundings. As carbon dioxide is bound to biomass in photosynthesis, carbon capture from biomass fired installations would lead to negative emissions on a life cycle basis, in other words removing CO_2 from the carbon cycle and thus lowering the CO_2 content of the atmosphere. Based on the existing strong Finnish expertise and knowledge on bioenergy R&D and industry, the leading role in Bio-CCS will be necessary for Finland.

Chemical Looping Combustion and Carbonate Looping are carbon capture technologies that increase the efficiency of carbon capture processes in the future. These technologies are of special interest because of the existing Finnish high level know-how on fluidized bed technology. Due the similarities in the processes, this know-how can be harnessed to create future innovations. These technologies are expected to be one of the long-term breakthrough technologies in the CCSP research program.

Environmental, health, safety and sustainability impacts of CCS must be recognised by operators introducing CCS technologies. Although CO_2 is generally not considered to be a hazardous substance, various sections in the Finnish legislation will apply when carbon capture technologies will be introduced at power plants and other industrial establishments in Finland.

No permanent storage of CO_2 is foreseen in Finland. Consequently the CO_2 must be exported. Currently the generally accepted concept is to transfer the captured CO_2 by pipeline to one or more Finnish harbours for further transport abroad by ship.

The CCS Program will investigate the impact that various CCS concepts will have on the environment, on the safety and health of workers and the public, and on the sustainability and on the perception and acceptability of the stakeholders and the public. The current report is forming the basis for the environmental, health and safety studies while sustainability and acceptability issues will be reported separately.

This Data Package has been compiled by Ramboll Finland Oy and VTT Technical Research Centre of Finland. The authors wish to thank Fortum Oyj, Gasum Oy, Neste Oil, AF.Consult Oy and University of Tampere for their input.

2 SCOPE

The scope of this Data Package is on what current legal environmental, health, and safety requirements an operating company must fulfil, when introducing various technologies for carbon capture in Finland.

As no permanent storage of carbon dioxide is envisaged in Finland, the study comprises only the following three types of onshore facilities:

- Capture plants (including power plants and various industrial facilities),
- Pipelines for carbon dioxide transfer to Finnish harbours,
- Harbour facilities including intermediate storage tank(s) and ship loading facilities.

Partly based on the results of an EU study, some typical environmental, health and safety issues related to the capture and transfer of carbon dioxide, which are valid also in Finland, are briefly described in Table 1.

Table 1 . Some typical EHS issues related to the capture and transfer of carbon dioxide in Finland.

Capture*	Transfer*	Harbour storage
1. Emissions of other pollutants to various media (such as SO_x, NO_x, solid waste and upstream impacts through greater fuel use, balanced against the environmental benefits of CO_2 capture). 2. Occupational and local environmental health and safety (EHS) risks posed by the presence of large volumes of pressurised CO_2 at capture plants. 3. Any other environmental concerns from construction and operation of the capture process, taking into consideration the use of best available technology as a potential. 4. Any other health and safety concerns related to equipment and chemicals used.	1. Pipeline routing – pipeline construction and maintenance will have impacts on the environment and landscape. 2. Global risk – that the pipeline leaks and the captured CO_2 is re-emitted back to the atmosphere compromising the effectiveness of CCS as mitigation option. 3. Local EHS risk – that any leaked CO_2 poses to the surrounding local populations and the environment (from asphyxiation of flora and fauna and acidifying effects on soil, surface and groundwater).	1. Storage and pipeline construction and maintenance will have impacts on the environment and landscape. 2. Global risk – that a storage tank or pipeline leaks and the captured CO_2 is re-emitted back to the atmosphere compromising the effectiveness of CCS as mitigation option. 3. Local EHS risk – that any leaked CO_2 poses to the surrounding local populations and the environment (from asphyxiation of flora and fauna and acidifying effects on soil, surface and groundwater).

* Source: Zakkour [1].

This Data Package covers EHS-issues relevant for the various life-cycle phases of establishments introducing post-combustion, pre-combustion and oxy-fuel combustion technologies for carbon capture. In addition to these technologies, EHS-issues relevant for chemical-looping-combustion are also reviewed.

The report covers not only the requirements of the CO_2 capture unit, but those of the establishment as a whole. An ‘establishment’ is defined as the whole area under the control of an operating company including one or more installations and common or related infrastructures or activities. Although the Data Package covers EHS requirements for the whole establishment, emphasis is put on those obligations, which, when carbon capture technologies are employed, will be different from those of conventional installations.

Requirements concerning safety of machinery and pressure equipment are outside the scope of this Data Package. In addition, general safety issues such as electrical safety and the safety of buildings in general are also excluded from this report.

3 CASE STUDIES CONSIDERED

The main parts of this chapter are taken from a summary of CCS literature published in Teir & al. [2]. The reader is kindly asked to consult that report for data on the original publications.

Carbon dioxide contained in a flue gas can be trapped in various ways, most commonly via absorption or adsorption using a solvent or an agent with a strong bonding to CO_2 (chemically or physically). In order to re-use the agent in a cyclic manner, the CO_2 must be stripped off, whereby the agent regains its bonding capability. The stripping requires energy, either as a heat input (temperature swing) or electric power (pressure swing). Other ways of separating CO_2 go via energy demanding cryogenic processes, especially in combination with oxy-fuel combustion. Thus a major challenge is associated with the separation work.

Three main technological methods under development in order to realise CCS for power plants – broadly characterised according to where or how the CO_2 is removed are: post-combustion capture, pre-combustion capture, and oxy-fuel combustion capture. Although these technologies can reduce CO_2 emissions, they also have a high energy penalty, which results in a reduction of energy efficiency of the processes and an increase in the price of energy. All these technologies have undergone a great development during the last years and some of them are available at commercial scale [3]. Of these three alternatives only the post-combustion alternative can easily be retrofitted to old installations. Pre-combustion and oxy-fuel technologies require major changes to an old installation and are feasible alternatives mainly when new developments are considered.

Great efforts have been carried out to develop new low-cost CCS technologies. Emerging carbon capture technologies range from improvements of existing processes to completely new approaches. During the last years chemical-looping-combustion has arisen as a very promising alternative to reduce the economic cost of CO_2 capture [3]. In Table 2 on the next page the main characteristics of the above mentioned CCS technologies – variations of which are used as case studies in this report – are summarised for reference.

Compression of the captured CO_2 represents an integral part of any CCS concept. Usually and preferably, the CO_2 is dehydrated and transformed into dense phase at super-critical pressure for pipeline transport – or it should be liquefied at pressurised conditions and low temperature for tank shipment (typically around 5 – 10 bar and close to –50 °C). Various restrictions may be imposed on the purity of the CO_2 depending on the transport system and the specific requirements of the sink – mainly for reasons that owe to overall economics, health and safety issues, material selection versus corrosion, energy demand for compression, and precautions to avoid hydrate formation.

This Data Package also covers EHS issues related to CO_2 transfer via pipeline to a Finnish harbour and finally to tanks for intermediate storage in the harbour and the equipment needed for loading CO_2 onto a ship.

Table 2. Some typical technologies for the capture of carbon dioxide.

	Post-combustion*	Pre-combustion*	Oxy-fuel combustion*	Chemical looping combustion **
Technology description	Separation of CO_2 from flue gas or other process gases – either via chemical absorption or physical adsorption.	Separation of CO_2 at high pressure from a shifted syngas (rich in CO and H_2). The resulting hydrogen-rich gas is combusted in a gas turbine-based cycle. Gasification of the fuel requires oxygen.	Oxygen (instead of air) is used as an oxidant, flue gas consists mainly water and CO_2. In order to reduce the temperature of the combustion zone, flue gas re-circulation is preferred.	Solid metal oxide used as an oxygen carrier. The oxygen carrier is circulated between two interconnected reactors: the air reactor and the fuel reactor. Metal oxide reduces and reoxidizes in the process.
CO_2 treatment	Chemical absorption (usually amine-based solutions, or physical adsorption (at higher CO_2 concentrations).	Physical adsorption.	Cryogenic purification of CO_2 prior to compression.	Combustion in the fuel reactor produces only CO_2 and water. CO_2 can be recovered by condensing water vapour.
Key technology status	Absorption technologies are known from gas processing and chemical industries, although in considerably smaller units than what is needed in the power sector.	Several operational IGCC plants around the world. But no integrated CCS system so far.	Small-scale plants around 30 MW are operational.	Operational experience in small-scale (0,3-120 kW th) has allowed to demonstrate the technology. Oxygen carrier material development is important.
Main features	Low CO_2 concentration (i.e. typically 12 – 15 % with coal and around 3 % with natural gas). Conventional power cycle. Large extraction rate of steam at around 4 bar.	Typical CO_2 concentration ~ 40 % (pressure ~ 30 bar). Offers a high development potential owing to combined power cycle. Lower demand for oxygen than that of oxy-fuel combustion schemes, as only a small amount is needed for auto-thermal oxidation in the gasifier.	High concentration of CO_2 and water vapour in the flue gas. Possibility for knocking out process water. Typical CO_2 concentration > 90 % with coal and > 85 % with natural gas (both cases with 3 % excess oxygen).	Inherent CO_2 capture, no additional CO_2 capture is needed. Pure CO_2 after water vapour condensation.
EHS-challenges	Slippage of solvent may become a health, safety and environmental issue.	Leaking oxygen, hydrogen and carbon monoxide may result in intense fires and explosions.	Leaking oxygen may result in an intense fire.	Metals (like nickel and cobalt) in oxygen carriers can cause health and environmental problems.

* Source: Teir & al. [2]. ** Source: Adanez & al. [3].

3.1 Post-combustion (power plants)

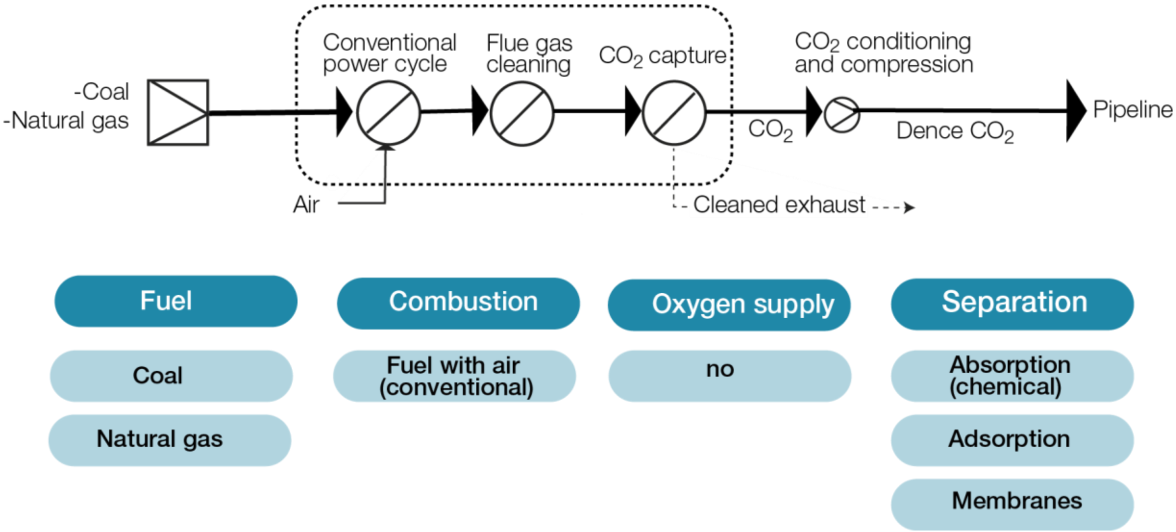

Figure 1. A typical set-up for post-combustion capture of carbon dioxide at a power plant.

Post-combustion capture (see Figure 1 above) is applied to conventional power-plants, in which the CO_2 (up to around 90% of it) can be removed from the flue gas. This requires mainly heat for the regeneration of the solvent and electric power for compression, pumps and fans. These techniques may be suitable both for new plants and for retrofitting of existing power plants with a carbon capture unit.

Post-combustion capture is based on a system using either absorption or adsorption technology (see example in Figure 2 on the next page). Although numerous chemical and physical solvents are considered suitable agents, a generic aqueous solution of monoethanolamine (20 – 30% MEA) is used in many studies and pilots, however, with some proprietary additives that prevent corrosion and foaming. In systems based on absorption technology, the solvent absorbs CO_2 at typically 40 – 60°C.The solvent leaving at the bottom of the desorber is then heated to typically 120°C in a reboiler, where the CO_2 is stripped off, and a hot CO_2/steam mixture is introduced to the lower section of the desorber unit. The CO_2 stream will then ascend through the column (counter-current of the trickling rich solvent) and leave the column at the top. It then diverts to compression and dehydration throughout multiple stages before a sufficiently pure and dense CO_2 stream is ready for transport to the storage site.

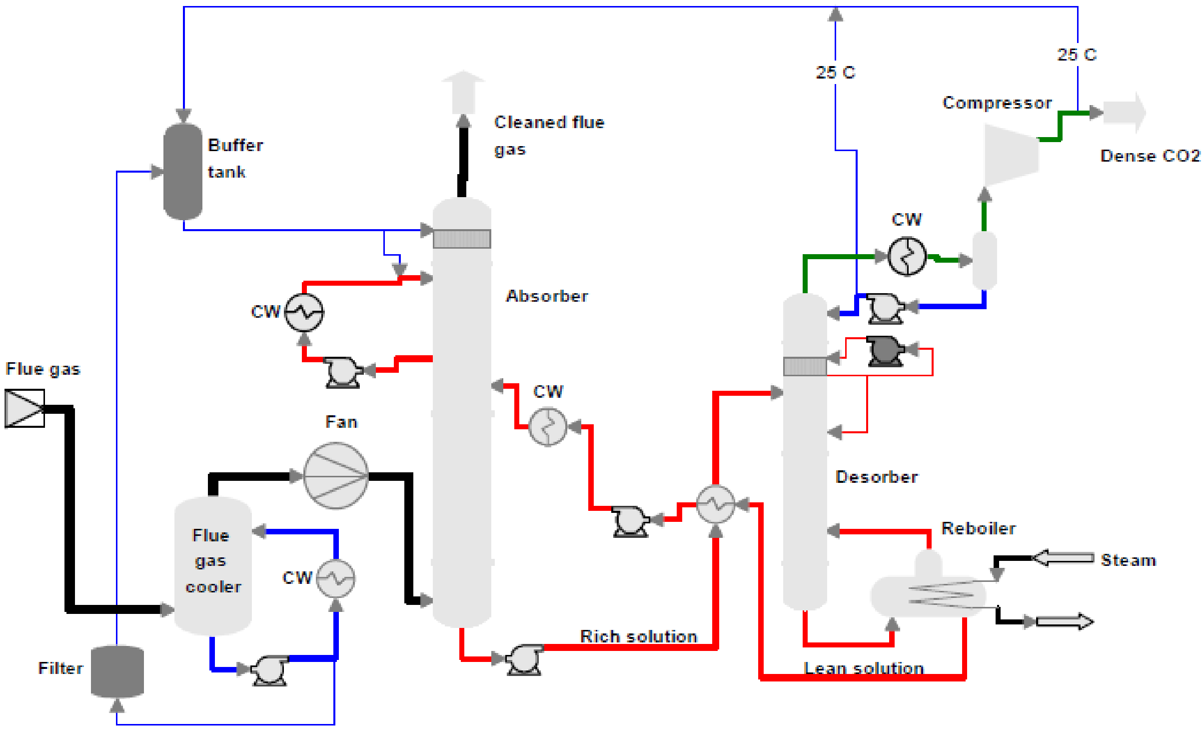

Figure 2. Example of a post-combustion unit for capture of carbon dioxide based on chemical absorption.

In this Data Package a monoethanolamine (MEA) based system as described above will be used as reference. The power plant fitted with a post-combustion carbon capture unit considered in this Data Package has the following features:

- Coal fired power plant with a capacity of approx. 500 MW,
- 100 % of the purified flue gas, i.e. approx. 3,5 Mt CO_2/a, is fed to the carbon capture unit,
- The carbon capture unit has a capture degree of over 90 %,
- Monoethanolamine is used as solvent in the absorption process, maximum amount (as 100 % MEA) present being 80 tonnes,
- The carbon dioxide is essentially pure, with trace amounts of H_2S, CH_4, etc.
- CO_2 is compressed on site to a dense phase at 100 bar (10 MPa) and led into a pipeline for transfer to a harbour.

3.2 Post-combustion (industrial plants)

Industries such as iron and steelmaking, pulp and paper, cement and chemical plants represent a significant share of the large point sources of CO_2 in Finland. The main difference between post-combustion capture in power plants and industrial plants is that at industrial sites suited for carbon capture there are typically several geographically separated smaller CO_2 sources, which adds to the complexity of the carbon capture system. In addition, process gases in certain industrial applications might have higher concentrations of CO_2 and are therefore more suitable to CCS than those of the power sector.

CO_2 capture from industrial processes has not generally been widely studied. Consequently, in this report a MEA based system as described in Chapter 3.1 will be used as reference also for industrial establishments.

The industrial establishment (not a power plant) fitted with a post-combustion carbon capture unit considered in this Data Package has the following features:

- The establishment is covered by EU's Seveso II Directive, being a top tier establishment (requiring a Safety Report),
- 1 Mt CO_2/a of purified flue gas is fed to the carbon capture unit,
- The carbon capture unit has a capture degree of over 90 %,
- Monoethanolamine is used as solvent in the absorption process, maximum amount (as 100 % MEA) present being 50 tonnes,
- The carbon dioxide is essentially pure, with trace amounts of H_2S, CH_4, etc.,
- CO_2 is compressed on site to a dense phase at 100 bar (10 MPa) and led into a pipeline for transfer to a harbour.

3.3 Pre-combustion

Carbon dioxide can be captured prior to combustion as shown in Figure 3. By gasification, a solid or liquid fuel is converted into a gas mixture mainly composed of hydrogen, carbon monoxide and carbon dioxide. After cleaning, this gas can be utilised in gas turbine applications (IGCC, Integrated Gasification Combined Cycle) or in gas processing. With water gas shift the carbon monoxide in the gas mixture can be shifted so that the gas mainly contains hydrogen and carbon dioxide. Because of the relatively high partial pressure of carbon dioxide either physical or physiochemical absorption can be used to capture the CO_2.

In comparison to chemical solvents used in post-combustion capture processes, physical solvents generally have a lower energy demand per unit captured CO_2. After separation of CO_2 the obtained hydrogen rich gas can fuel a gas turbine or fuel cell or be used as a raw material in the chemical industry.

Physical solvents are commercially available by names such as Selexol, Rectisol and Purisol. Although the capture technology is available, turbines capable of firing pure hydrogen or fuel cells remain to be developed and scaled up to industrial scale typical of the power sector. It should be noted, however, that chemical absorption requires special care when used in IGCC-CCS schemes, as some slippage of the solvent may have a detrimental impact on the gas turbine, which needs to be further scrutinised.

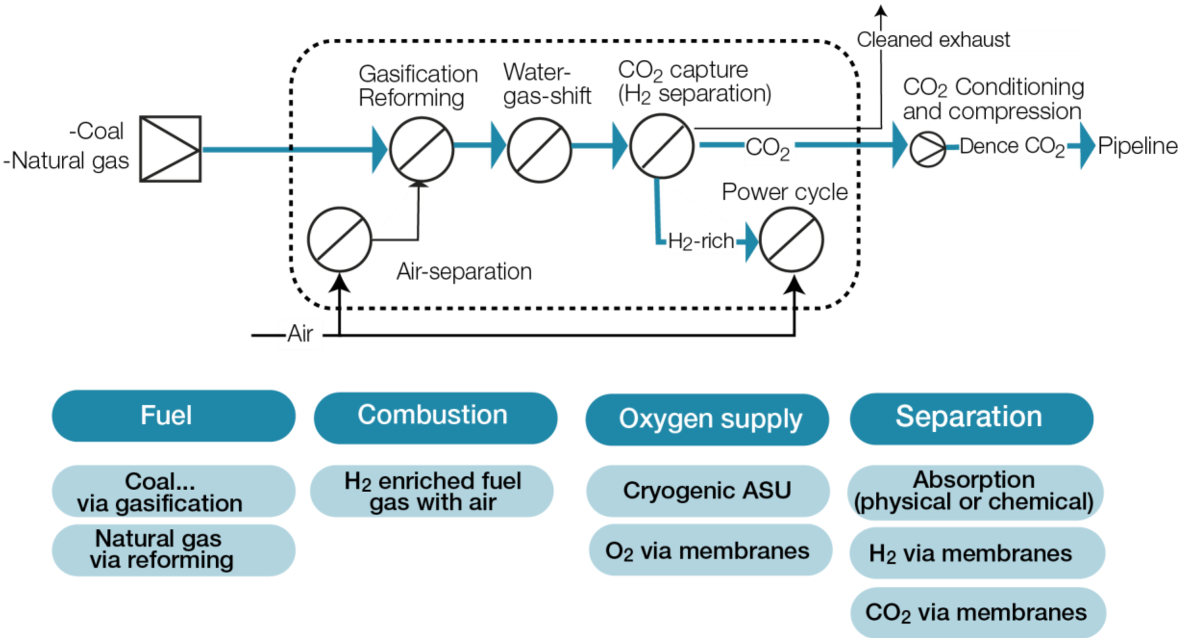

Figure 3. A typical set-up for pre-combustion capture of carbon dioxide.

Although the gasification and gas turbine processes are more complex and expensive than technologies used in conventional coal-fired power plants, the separation is easier because of the higher partial pressure of CO_2 that allows the use of physical solvent processes. Due to the energy required by the capture process, the electric efficiency of the power plant would be approximately 5 – 8 % units lower than an IGCC plant without any carbon capture. Very few power plants based on gasification exist today, so in the power sector the main application would be for new power plants.

At the moment similar CO_2 capture methods are used in industrial processes e.g. in hydrogen production. One of Europe's biggest industrial plants producing CO_2 as a by-product alongside H_2 is located in Porvoo, Finland. At this location natural gas is used as the starting material. The CO_2 plant is owned by Linde Gas AGA and it produces 0.4 Mt CO_2/a.

Unlike post-combustion and oxy-fuel combustion techniques, pre-combustion offers the option of co-producing coal-derived synthetic fuels (Figure 4).

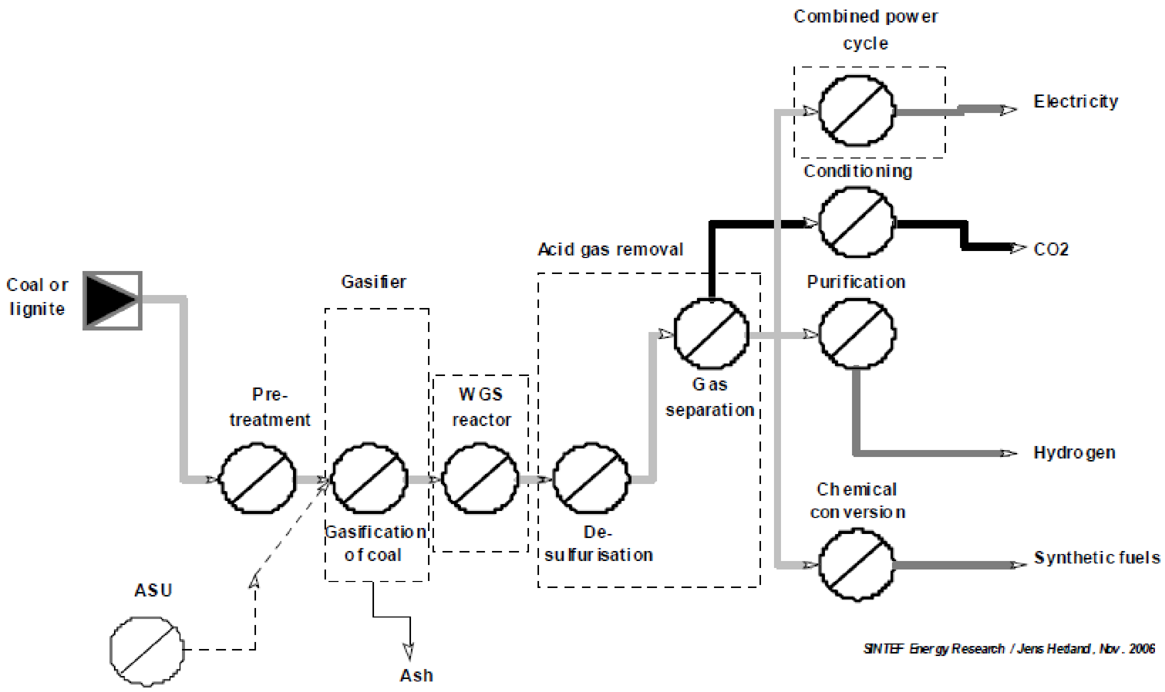

Figure 4. Pre-combustion offers the option of co-producing coal-derived synthetic fuels.

The plant based on a pre-combustion carbon capture philosophy considered in this Data Package has the following features:

- Hydrogen plant using natural gas as the main fuel,
- Hydrogen is transferred by pipeline to the customer (power plant, refinery, etc.),
- Part of the purified CO_2 stream is fed to the carbon capture unit,
- The carbon capture unit has a capture degree of over 90 %,
- SELEXOL^{TM} is used as solvent in the absorption process,
- The carbon dioxide is practically pure, having trace amounts of H_2S, CH_4, etc.,
- CO_2 is compressed on site to a dense phase at 100 bar (10 MPa) and led into a pipeline for transfer to a harbour.

3.4 Oxy-fuel combustion

In comparison to a conventional power plant, some new components are needed in an oxy-fuel combustion power plant: most notably an air separation unit in the forefront and a CO_2 processing unit at the tail end (See Figure 5). These units increase the auxiliary electricity consumption and are therefore lowering the electric efficiency of the power plant by approximately 5 – 13 % units. To decrease the electric power demand of an air separation unit, alternative processes are being developed such as air separation via oxygen transfer membranes.

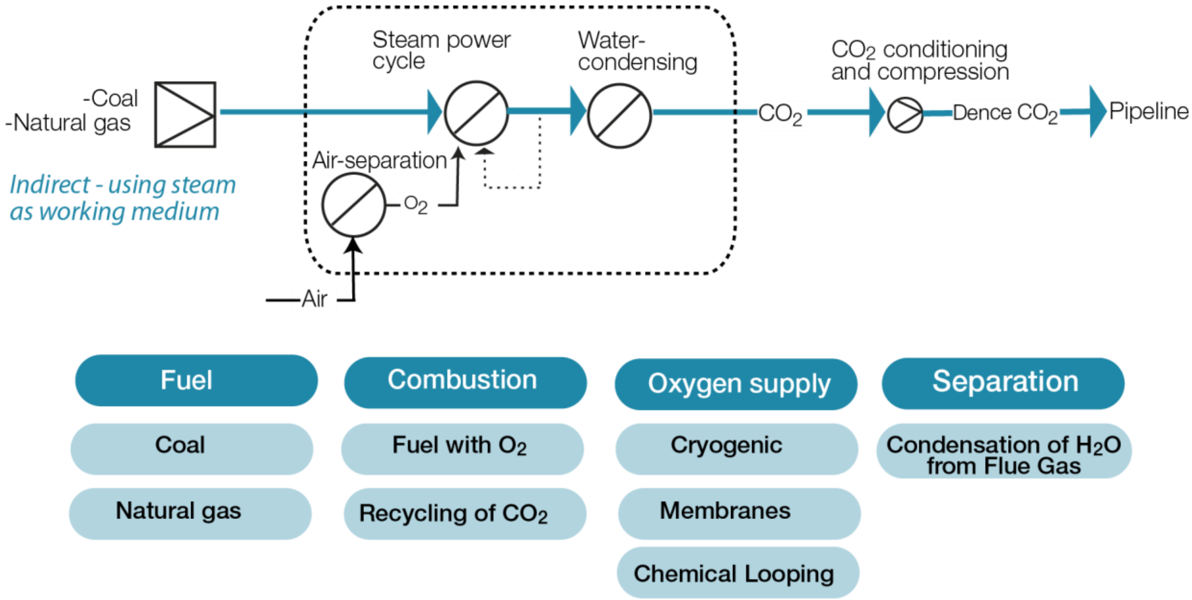

Figure 5. A typical set-up for oxy-fuel combustion combined with carbon dioxide capture.

Oxy-fuel combustion technology is currently in the demonstration phase in the scale of tens of megawatts (e.g. Schwarze Pumpe 30 MWth) and (in principle) oxy-fuel combustion schemes are applicable for both greenfield and retrofit installations, although the gas flow is reduced to only around one third of that of conventional boiler systems. In this report the emphasis will be on the handling and storage of oxygen.

Carbon dioxide separation with oxygen firing and flue gas recirculation, which has been identified as most beneficial by several power companies, means that if a cooling tower is required, the new cooling tower section needs frequent deliveries of sodium hypochlorite, and the concept requires significant amounts of cooling tower make up water.

The oxy-fuel power plant fitted with a post-combustion carbon capture unit considered in this Data Package has the following features:

- Coal fired power plant with a capacity of approx. 200 MW,
- 100 % of the purified flue gas is fed to the carbon capture unit,
- The carbon capture unit has a capture degree of over 90 %,
- Monoethanolamine is used as solvent in the absorption process, maximum amount (as 100 % MEA) present being 50 tonnes,
- The carbon dioxide is practically pure, having trace amounts of H_2S, CH_4, etc.,
- CO_2 is compressed on site to a dense phase at 100 bar (10 MPa) and led into a pipeline for transfer to a harbour.

3.5 Chemical looping combustion (CLC)

Chemical-looping- combustion process is based on the transfer of oxygen from air to the fuel by means of a solid oxygen-carrier avoiding direct contact between fuel and air. Metal oxides like nickel, copper, cobalt, iron, and manganese are good oxygen carrier candidates. Fig. 6 shows a general scheme of chemical-looping- combustion [3].

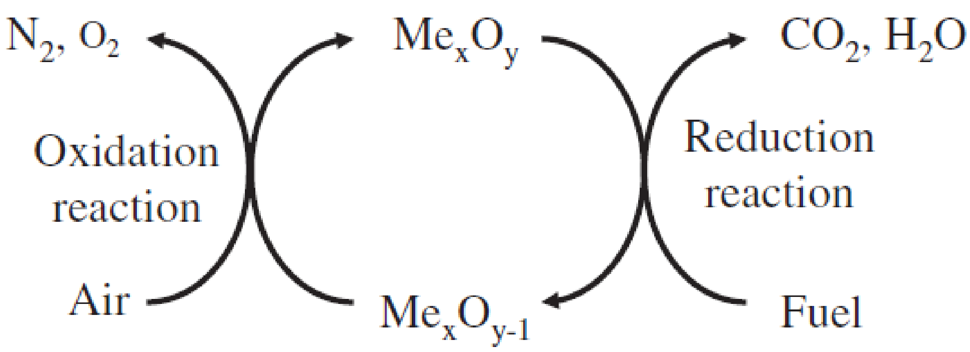

Figure 6. General scheme of chemical-looping-combustion for gaseous fuels.

The fuel is oxidized to CO_2 and H_2O by a metal oxide (Me_xO_y) that is reduced to a metal (Me) or a reduced form Me_xO_{y-1}. The gas produced contains primarily CO_2 and H_2O. After water condensation and purification, a highly concentrated stream of CO_2 ready for transport and storage is achieved. This concept is the main advantage of the process in relation with other CO_2 capture technologies. In this sense, CLC is a combustion process with inherent CO_2 separation, i.e. avoiding the need of CO_2 separation units and without any penalty in energy. The metal or reduced metal oxide is further oxidized with air in an air reactor and the material regenerated is ready to start a new cycle. The flue gas obtained from the air reactor contains N_2 and unreacted O_2 and can be released to the atmosphere with minimum negative environmental impact [3], [4].

The net chemical reaction over the two steps, and therefore the combustion enthalpy, is the same to conventional combustion. Therefore, the total amount of heat evolved in the chemical-looping-combustion process is the same as in conventional combustion. The main advantage of this process resides in the inherent separation of both CO_2 and H_2O from the flue gases. In addition chemical-looping-combustion minimizes NO_x formation since the fuel burns in the fuel reactor in an air free environment and the reduced oxygen carrier is re-oxidized in the air reactor in the absence of fuel, at comparatively low temperatures.

The large-scale application of CLC is still contingent upon the availability of suitable oxygen carriers. In addition to favourable reductive/oxidative thermodynamics, good oxygen carrier candidates should also have: (a) high oxidation and reduction activity, (b) stability under repeated oxidation/reduction, (c) mechanical strength in fluidized beds and resilience to agglomeration [4].

The chemical-looping concept showed in Fig. 6 has been proposed to be accomplished in different type of reactors and configurations, namely (a) two interconnected moving or fluidized-bed reactors; (b) alternated packed or fluidized-bed reactors; or (c) a rotating reactor. At the moment the majority of the chemical-looping-combustion processes use the configuration composed of two interconnected fluidized-bed reactors (see Fig. 7), one of them being the fuel reactor and the other the air reactor. In addition, two loop-seal devices must be used in order to avoid gas leakage between reactors [3].

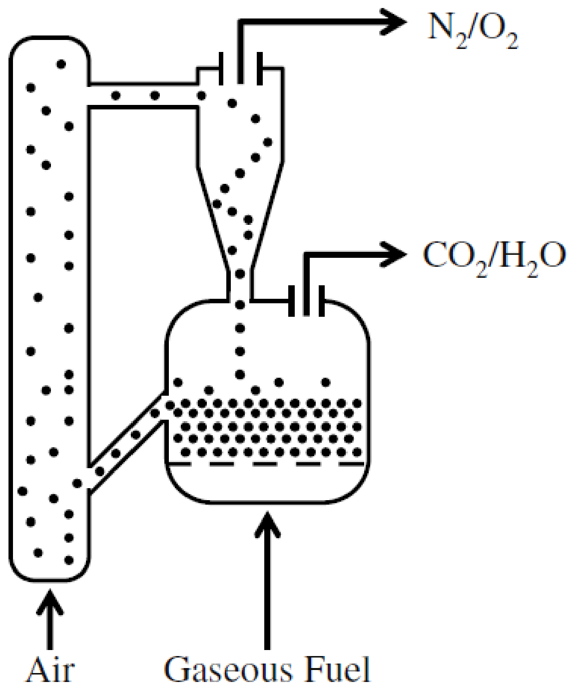

Figure 7. Interconnected fluidized-bed reactor concept for chemical-looping combustion

The establishment fitted with chemical looping combustion unit considered in this Data Package has the following features:

- The main oxygen carriers used in chemical-looping-combustion are expected to be CuO, Fe_2O_3, NiO, Mn_3O_4 or CoO supported on different inert materials.
- The CO_2 removed is pure.
- CO_2 is compressed on site to a dense phase at 100 bar (10 MPa) and led into a pipeline for transfer to a harbour.

3.6 Carbon dioxide pipeline

In Finland, carbon dioxide captured from a power plant or an industrial source must be transported to an intermediate storage site in a Finnish harbour. Transmission of CO_2 on-shore by pipeline is relatively simple and can be considered a mature technology that has been in use by the oil industry in the United States for enhanced oil recovery since the 1970's. To avoid pipe corrosion the gas must not contain free water and it must therefore be dehydrated before transmission. To be transferred in a pipeline, CO_2 should be compressed to ensure that a single-phase flow is achieved. A two-phase flow could result in pressure surges.

Gaseous CO_2 is typically compressed for transfer to a pressure above 80 bar (8 MPa) in order to avoid two-phase flow regimes at a wide range of temperatures and to increase the density of the CO_2, thereby making it easier and less costly to transfer by pipeline. The most widely used operating pressure is between 74 and about 210 bar. Compared with carbon dioxide in dense phase, the density of liquid carbon dioxide is very similar, which could allow pressures as low as 35 bar at 0°C.

The CO_2 flows need to be well known beforehand in order to determine the optimal pipeline size, especially in case of a trunk line with multiple connected CO_2 sources. Pipelines with larger diameters or thicker walls imply higher capital costs. Too small pipe diameters in turn increase the flow velocity and consequently induce pressure loss, which has to be accounted for by shorter distances between booster pump stations along the pipeline.

Other modes of transportation on-shore, i.e. transportation by road or railway, lack the needed capacity and cannot be realistically seen as cost effective options for CCS infrastructure.

The carbon dioxide pipeline considered in this Data Package has approximately the following features:

- Carbon dioxide in dense phase, pressure approx. 100 bar (10MPa),
- Length 150 km, diameter 0,5 meter,
- No booster pump stations, one pig station at each end for cleaning purposes,
- Line is buried at least 1 m deep.

3.7 Intermediate CO_2 storage and ship loading facility

Distances from CO_2 point sources in Finland to potential geological storage sites exceed 1.000 km. Consequently ship transportation is the fastest and most flexible means to realize the logistics needed for CCS. Carbon dioxide transported by tankers requires intermediate storage with loading facilities in one or more harbours in Finland. For some establishments located along the Finnish coastline, the storage tanks might be on-site.

Intermediate storage is likely to be in semi-refrigerated tanks at about 20 bar. Apart from the storage tanks needed in the harbours, it is unlikely that intermediate storage tanks will be built as part of any Finnish pipeline network to allow power stations or other industrial installations to keep running without venting CO_2 to the atmosphere in case of a disturbance in the transfer system.

Liquefaction of CO_2 to conditions near the triple point, where CO_2 has its highest density, sets strict purity requirements, as even low amounts of volatile gases such as argon or nitrogen may cause dry ice to form.

So far the largest carriers for CO_2 shipment are in the range of 10.000 t/ship.

The intermediate storage of carbon dioxide and the ship loading facility considered in this report have the following features:

- Intermediate storage capacity of approx. 25.000 tonnes (~23.000 m^3) dense phase CO_2, distributed over 15 pcs of cylindrical pressure vessels with a capacity of 1.700 tonnes each,
- One loading station,
- Ship capacity max. 20.000 m^3.

4 PROPERTIES OF CHEMICALS INVOLVED

In addition to carbon dioxide, there are several other chemicals involved in the various carbon capture technologies. The absorption or adsorption of CO_2 can be obtained by using many different reagents and solvents. Some common chemical reagents are given in Table 3 and some physical solvents in Table 4. Other chemicals used in post-combustion processes are, for instance, ammonia, metal organic frameworks (MOFs), and ionic liquids.

Table 3. Common chemical reagents Used for absorption of carbon dioxide*.

Chemical Reagent	Acronym	Process Licensors using the reagent
Monoethanolamine	MEA	Dow, Exxon, Lurgi, Union Carbide
Diethanolamine	DEA	Elf, Lurgi
Diglycolamine	DGA	Texaco, Fluor
Triethanolamine	TEA	AMOCO
Diisopropanolamine	DIPA	Shell
Methyldiethanolamine	MDEA	BASF, Dow, Elf, Snamprogetti, Shell, Union Carbide, Coastal Chemical
Hindered amine		Exxon
Potassium carbonate	“hot pot”	Eickmeyer, Exxon, Lurgi, Union Carbide

* Source: National Energy Technology Laboratory [5].

Table 4. Common physical solvents Used for absorption of carbon dioxide*.

Solvent	Trade Name	Process Licensors
Dimethyl ether of poly-ethylene glycol	Selexol	UOP
Methanol	Rectisol	Linde, Lurgi
Methanol and toluene	Rectisol II	Linde
N-methyl pyrrolidone	Purisol	Lurgi
Polyethylene glycol and dialkyl ethers	Sepasolv MPE	BASF
Propylene carbonate	Fluor Solvent	Fluor
Tetrahydrothiophenedioxide	Sulfolane	Shell
Tributyl phosphate	Estasolvan	Uhde, IFP

* Source: National Energy Technology Laboratory [5].

In pre-combustion technologies carbon monoxide and hydrogen are also present in high concentrations, while pure oxygen or oxygen enriched air is needed for pre-combustion and oxy-fuel applications.

This Data Package will cover EHS issues related to the handling and storage of six common chemicals present in the various CCS reference technologies, which have been briefly described in Chapter 3. These chemicals are:

- Carbon dioxide,
- Carbon monoxide,

- Hydrogen,
- Monoethanolamine,
- Oxygen,
- Selexol™ solvent.

In addition to the above mentioned chemicals, EHS issues related to solid oxygen carriers used in chemical-looping-combustion technology are also described.

In this Data Package the various fuels (e.g. coal, natural gas, fuel oil) and their hazardous properties are not considered. In addition, sulphur and nitrogen oxides and other substances, which are present in relatively low concentrations, are also neglected.

4.1 Carbon dioxide

4.1.1 Impacts on the environment

Leaks of CO_2 from, for example, a buried pipeline can find its way to the surface. While elevated CO_2 concentrations in ambient air will enhance plant growth and photosynthesis, the negative effect from high CO_2 levels in the soil will probably be dominating. CO_2 fluxes large enough to significantly increase concentrations in the free air will typically be associated with very high CO_2 concentrations in soils. The main characteristic of long term elevated CO_2 zones at the surface is the lack of vegetation. New CO_2 releases into vegetated areas cause noticeable die-off. In those areas where significant impacts to vegetation have occurred, CO_2 makes up about 20 – 95 % of the soil gas, whereas normal soil gas usually contains about 0.2 – 4 % CO_2. Carbon dioxide concentrations above 5 % may be dangerous for vegetation and as concentration approach 20 % CO_2 becomes phytotoxic. Carbon dioxide can cause death of plants through 'root anoxia', together with low oxygen concentration.

4.1.2 Impacts on human health

Carbon dioxide is a normal component of blood gases at low concentrations. The dangers of breathing in elevated concentrations of CO_2 are well known to people such as divers and anaesthetists. Outside these groups of specialists knowledge about the impact of breathing elevated concentrations of CO_2 is generally low. Table 5 gives a summary of the effects at moderately elevated CO_2 concentrations (see Table 6 for higher concentrations).

Table 5. Health effects of elevated concentrations of CO_2.

CO_2 concentration	Exposure	Effect on humans
2 % v/v in air.	Several hours.	Headache, difficult breathing upon mild exertion.
3 % v/v in air.	1 hour.	Mild headache, sweating, difficult breathing at rest.
4 – 5 % v/v in air.	Within a few minutes.	Headache, dizziness, increased blood pressure, uncomfortable breathing.
6 % v/v in air.	1 – 2 minutes. < 16 minutes. Several hours.	Hearing and visual disturbances. Headache, difficult breathing (dyspnoea). Tremors.

4.1.3 Safety impacts

A major release of CO_2 has a potential to become a major accident hazard. It is a substance, which released in sufficient quantity, has the potential to cause harm to a large number of people. Humans are very sensitive to changes in carbon dioxide concentrations. Apart from increasing the ventilation rate, the human body has no other significant means for controlling CO_2 concentration in the blood and body fluids. With greatly elevated CO_2 concentrations the capacity of the blood buffering system will be exceeded, which leads to abnormal acidity of the blood (respiratory acidosis).

Depending on the CO_2 concentration inhaled and exposure duration, toxicological symptoms in humans range from headaches, increased respiratory and heart rate, dizziness, muscle twitching, confusion, unconsciousness, and coma. Although not classified as a hazardous chemical, at high inhalation levels CO_2 is lethal (see Table 6).

Table 6. Safety effects of high concentrations of CO_2.

CO_2 concentration	Exposure	Effect on humans
7 - 10 % v/v in air.	Few minutes. 5 minutes to 1 hour.	Unconsciousness, near unconsciousness. Headache, increased heart rate, shortness of breath, dizziness, sweating, rapid breathing.
10 – 16 % v/v in air.	1 minute to several minutes.	Dizziness, drowsiness, severe muscle twitching, unconsciousness.
17 – 30 % v/v in air.	Within 1 minute.	Loss of controlled and purposeful activity, unconsciousness, convulsions, coma, death.

Breathing air with a CO_2 concentration of around 5 % will within a few minutes cause headache, dizziness, increased blood pressure and uncomfortable and difficult breathing (dyspnoea). At CO_2 concentrations greater than 17 %, loss of controlled and purposeful activity, unconsciousness, convulsions, coma, and death occur within 1 minute of initial inhalation.

The potential for persons to be exposed to CO_2 inhalation are usually localised and the associated safety risks can be effectively managed through localised hazard management measures.

CCS pipeline systems will contain thousands of tonnes of dense phase CO_2 and consequently the potential for widespread population exposure to air with hazardous concentrations of CO_2 will exist. In addition, a high CO_2 level in the atmosphere often means that the oxygen concentration in the air is reduced. Exposure to atmospheres containing 8 – 10% or less oxygen will quickly bring about unconsciousness without warning, leaving individuals unable to protect themselves. The risks of a major accident associated with large scale CO_2 handling must therefore be robustly assessed in CCS projects.

The assessment of major accident hazards must be both suitable and sufficient, meaning that it must be based on sound understanding, use appropriate techniques and tools, have a breadth and depth proportionate to the possible magnitude of the risk, and provide a basis for demonstrating that the risks associated with the hazards are being managed effectively.

4.2 Carbon monoxide

In the following the impacts of pure carbon monoxide is considered, in spite of the fact that in cases relevant to the capture of carbon dioxide CO is present only as one of the main component of synthesis gas (syngas, oxogas), which is produced by the steam reforming and partial oxidation of hydrocarbons or a combination of both processes (tandem reforming). The other main component in syngas is hydrogen. The gas mixture is then further processed depending on the desired final products. In the case of purified hydrogen, taken as a case study in this Data Package, the process includes the conversion of CO into CO_2.

4.2.1 Impacts on the environment

Carbon monoxide is absorbed and metabolised by plants in varying rates dependent on the ecological conditions. Oxidation to carbon dioxide in aerobic conditions has been found to vary between bacteria species. CO degrades by photochemical reactions in the atmosphere.

4.2.2 Impacts on human health

Carbon monoxide is not detectable by odour. Headache should be taken as a warning that a dangerous CO concentration is being inhaled. Long term exposure to moderate concentrations leads to nausea, vomiting, loss of appetite, headache, dizziness, visual disturbances, blood and heart disorders, reproductive effects and birth defects, heart, nerve and brain damage.

4.2.3 Safety impacts

Carbon monoxide causes a severe fire hazard. Gas/air mixtures are explosive.

In sudden exposures to high CO concentrations, weakness and dizziness may be the only symptoms preceding collapse. Rapid death from respiratory or cardiac arrest usually occurs at a carboxyhaemoglobin level of above 70 – 80 % in the blood. Short term exposure to CO might also cause changes in body temperature, changes in blood pressure, nausea, vomiting, chest pain, difficulty breathing, irregular heartbeat, headache, drowsiness, fatigue, disorientation, hallucinations, pain in extremities, tremors, loss of coordination, hearing loss, visual disturbances, eye damage, bluish skin colour, suffocation, blood disorders, and convulsions.

4.3 Hydrogen

Hydrogen is present in pre-combustion technologies both as one of the two main component of synthesis gas – the other being carbon monoxide – and as an essentially pure substance, which is used in, for instance, power generation and in oil refineries. In the following the impact of pure hydrogen is considered.

4.3.1 Impacts on the environment

No adverse ecological effects are expected.

4.3.2 Impacts on human health

Exposure to moderate concentrations of hydrogen may cause dizziness, headache, nausea and unconsciousness. Hydrogen concentrations of less than 4 % in air are not flammable at standard conditions.

4.3.3 Safety impacts

Hydrogen is generally considered as safe, apart from the physical risks, which arise from its flammability. Hydrogen poses an immediate fire and explosive hazard when concentrations exceed 4 vol-% at standard conditions. It is much lighter than air and burns with an invisible flame. High concentrations will cause suffocation due to a reduction in the oxygen concentration in air. It should be noted that before suffocation could occur, the lower flammability limit of hydrogen in air would be exceeded causing an explosive atmosphere.

4.4 Monoethanolamine

Monoethanolamine is used as an absorption agent in order to capture carbon dioxide.

4.4.1 Impacts on the environment

Environmental fate: As monoethanolamine is highly soluble in water models estimate that this material will preferentially partition to water versus air or soil. Spillage must be prevented from entering drains or watercourses (due to the pH-value of the product, neutralisation is generally required before discharging sewage into treatment plants). Monoethanolamine will leach into soil. In the ambient atmosphere monoethanolamine is expected to exist solely as a vapour. The vapour is degraded in the atmosphere.

Degradation and Persistence: Monoethanolamine is biodegradable, passing the OECD tests for ready biodegradability. This material will biodegrade relatively rapidly in both soil and water, and will not persist in the environment. Monoethanolamine is biodegraded or transformed into other compounds under both aerobic and anaerobic conditions even at concentrations greater than 1500 mg/kg. Ammonium, acetate, and nitrogen gas are the dominant by-products. The generation of nitrogen gas suggests that simultaneous nitrification and denitrification occurs because of the existence of anoxic zones resulting from diffusion limited oxygen transport into the soils. Low temperatures (+5 °C) reduced the biodegradation rates significantly compared to rates at room temperature.

Bioaccumulation: Because of this monoethanolamine's high solubility and rapid biodegradability, it is unlikely that bioaccumulation will occur in aquatic or terrestrial systems.

Ecotoxicity: Under present Finnish legislation monoethanolamine is not toxic to aquatic life. Laboratory toxicity tests indicate that monoethanolamine is not significantly toxic to fish and aquatic invertebrates, although amphibians may be more sensitive. Wildlife species may be more susceptible since mammals and birds do not readily metabolise this material. The odour and flavour of monoethanolamine may attract some wildlife and cause them to consume spilled material.

4.4.2 Impacts on human health

Effects of prolonged exposure to monoethanolamine through inhalation: Prolonged exposure or high concentrations of monoethanolamine may cause damage to the respiratory tract, with chemical pneumonitis and pulmonary oedema, and liver and kidney damage.

Effects of skin contact: Prolonged or widespread skin contact may result in absorption of harmful amounts.

Effect of contact with eyes: Even dilute solutions may cause severe irritation, chemical burns and permanent corneal damage. Low vapour or mist concentrations may cause temporary blurring of vision, “halo vision”, which usually disappears after the exposure is discontinued.

Effects due to ingestion: Ingestion is not a normal route of prolonged industrial exposure.

4.4.3 Safety impacts

Effects of acute exposure to monoethanolamine through inhalation: Because of low vapour pressure, monoethanolamine poses little inhalation hazard at normal temperatures. However, when heated, vapour can be released that is irritating and can cause coughing and discomfort in the nose, throat, and chest.

Effects of acute exposure to monoethanolamine through skin contact: Contact may cause chemical burns. Undiluted methanolamine is corrosive and solutions greater than 10 % can cause moderate irritation to severe burn depending on length of contact.

Effects of acute contact with eyes: Even dilute solutions may cause severe irritation, chemical burns and permanent corneal damage.

Effects due to ingestion: Monoethanolamine has low oral toxicity, but may cause burns in the mouth, throat, oesophagus, and stomach, with pain or discomfort in the mouth, chest, and abdomen, nausea, vomiting, diarrhea, dizziness, drowsiness, faintness, weakness, collapse, and even coma. Because monoethanolamine is corrosive, aspiration, which can easily occur during ingestion or vomiting, can result in severe, life-threatening lung damage, chemical pneumonitis, or pulmonary oedema.

Acute effects due to flammability: Monoethanolamine can form explosive mixtures with air at or above +85 °C.

Chemical Stability: Monoethanolamine is normally stable, but it is hygroscopic. It reacts with carbon dioxide to form salts. It is decomposed by light, slowly oxidized by air, turning yellow, then brown.

Incompatibility with other substances: Monoethanolamine can react vigorously, violently, or explosively with strong acids, strong oxidising agents, acid chlorides, acid anhydrides, strong reducing agents. It attacks copper and its alloys, reacts with aluminium above +60 °C, releasing explosive hydrogen gas. Monoethanolamine and iron form a complex molecule, triethanolamino-iron. This material can spontaneously decompose at temperatures between +130 °C and +160 °C.

4.5 Oxygen

Oxygen is used in pre-combustion and oxy-fuel combustion alternatives instead of air (see Chapter 3).

4.5.1 Impacts on the environment

If a large-scale accidental release of liquefied oxygen occurs, the oxygen can form a cold high-density ground-level plume that floats off-site causing local burns to the vegetation. Eventually the oxygen will dissipate in the air.

4.5.2 Impacts on human health

The primary health hazard from oxygen at atmospheric pressure is respiratory system irritation after exposure to high oxygen concentrations. Up to 50 % oxygen can be breathed for more than 24 hours without adverse effects.

4.5.3 Safety impacts

The chief physical hazard associated with releases of oxygen gas is its oxidising power, which can greatly accelerate the burning rate for both common and exotic combustible materials. Emergency personnel must practice extreme caution when approaching oxygen releases because of the potential for intense fire.

Contact with cryogenic liquid can cause frostbite and cryogenic burns. Also contact with rapidly expanding gas may cause burns or frostbite.

Exposure to high oxygen concentrations may cause skin, eye and respiratory system irritation. Breathing high concentrations (greater than 75 molar %) causes symptoms of hyperoxia, which includes cramps, nausea, dizziness, hypothermia, amblyopia, respiratory difficulties, bradycardia, fainting spells, and convulsions capable of leading to death.

Oxygen is extremely reactive or incompatible with oxidising, reducing, and combustible materials. Possible reactions can lead to severe secondary consequences.

4.6 SELEXOL™

SELEXOL™ is a physical solvent developed by Allied Signal in the 1950's and is used for treating gas streams. The solvent has been used in over 50 applications for the removal of CO_2, H_2S, mercaptans, etc. The SELEXOL solvent is a mixture of dimethyl ethers of polyethylene glycol. SELEXOL solvents are true physical solvents and do not react chemically with the absorbed gases. This avoids the formation of heat-stable salts that plague amine systems. The SELEXOL technology is currently owned by Union Carbide Corporation.

4.6.1 Impacts on the environment

SELEXOL™ solvent is of low volatility and is miscible in water. Once introduced to water, the chemical will tend to remain in water. It has low potential to bind to soil or sediment. SELEXOL is inherently biodegradable under aerobic conditions and will be removed by sewage treatment plants. SELEXOL is not likely to accumulate in the food chain (the bio-concentration potential is low) and is practically nontoxic to fish and other aquatic organisms on an acute basis.

4.6.2 Impacts on human health

SELEXOL™ solvent is essentially non-irritating to the eyes. Prolonged skin contact may cause slight skin irritation with local redness, but is unlikely to result in absorption of harmful amounts. Brief inhalation exposure is not likely to cause adverse effects. Prolonged, excessive inhalation exposure may cause adverse effects. SELEXOL has low toxicity if swallowed. Small amounts swallowed incidental to normal handling are not likely to cause injury; however, larger amounts may cause injury. In animal testing, effects have been reported on the testes. SELEXOL solvent may also cause central nervous system effects. Excessive exposure may interfere with reproduction.

4.6.3 Safety impacts

Central nervous system and testicular effects have been reported at doses many times higher than any dose levels expected from recommended use. In animal testing, this product has been toxic to the foetus at doses toxic to the mother.

4.7 Oxygen carriers

Oxygen carriers are the key components in the chemical looping combustion. Metal oxides such as nickel, copper, cobalt, iron and manganese oxides are considered good oxygen carrier candidates. Environmental and health issues of oxygen carriers must be considered to ensure that the CLC-process meets future high standards of environmental performance and workplace safety. However, little information has been published related to the possible environment and health problems derived from the use of the above materials in CLC-process [3].

4.7.1 Impacts on the environment

Some of the metals, like cobalt and nickel, used as oxygen carriers in the chemical looping combustion are classified to be toxic. Many of these metals are also hazardous for aquatic organisms. The particles used as oxygen carriers can be different sized. Particles less than 2.5 µm in diameter are called fine particles (PM2.5). The particles less than 0.1 µm in diameter are called nanoparticles or ultrafine particles.

The smaller the particle size is the more unpredictable are the effects of the compound or element. Thus, if fine particles are released in the environment the effects might be much more severe than with the same amount of the same compound but with larger particle size. The reactivity of the ultrafine particles is mostly due to high surface area. Many of the ultrafine particles are catalysts, so the compound itself might not be toxic but the effects caused by it might be harmful. Altogether, the possible adverse effects on environment caused by ultrafine particles are not yet known and the studies are only in the beginning.

Depending of the size, particles behave distinctly also in the air. The finest particles (<80 nm in diameter) tend to agglomerate and thus do not stay long in the air. Also the large particles

(>2 000 nm) are settled by gravity. However, the middle sized particles (80 – 2 000 nm), which also might be applicable in chemical looping combustion, are expected to stay the longest time in the air [6].

Waste issues: When burning solid fuel, the oxygen carrier and unburned ash are subject to mixing. The mixture might be needed to be removed from the process. In such case the ash contains oxygen carrier in different compounds (oxidized/reduced forms). This might affect to the disposal of the ash, i.e. depending of the metal quality and content, the ash might end up to be classified as hazardous waste. Without toxic components, the ash might be suitable for recycling or at least could be placed to ordinary waste dump.

4.7.2 Impacts on human health

In general, nickel and cobalt are considered the materials exhibiting the highest risk of oxygen carriers possible for CLC-process. Emissions containing nickel particles from the air-reactor deserve special attention since nickel derived compounds have carcinogenic properties, and the effects and health impacts on the surroundings have to be considered. Nickel fumes are respiratory irritants and may cause pneumonitis. Exposure to nickel and its compounds may result in the development of a dermatitis known as “nickel itch” in sensitized individuals.

Also cobalt derived compounds have carcinogenic properties. Cobalt dust may cause an asthma-like disease with symptoms ranging from cough, shortness of breath and dyspnea to decreased pulmonary function, nodular fibrosis, permanent disability, and death.

On the contrary, iron and manganese are considered as non-toxic materials for CLC applications [3].

4.7.3 Safety impacts

Although more work regarding environmental and health aspects is necessary for the scale-up of CLC technology, it can be said that these aspects have not been identified as immediate showstoppers of the process [3].

5 EHS-ISSUES AND THE LIFE CYCLE OF AN INSTALLATION

The implementation of various technological options for carbon capture and transfer can due to environmental, safety and health (EHS) issues be a lengthy procedure, which has to be started several years before the installation is taken into use. Also after commissioning, the lifespan of the installation is likely to include several points, where the EHS issues have to be revisited, related documents updated, and training courses and dissemination schemes repeated.

Figure 8 on the next page gives an overview of the main EHS steps during the entire life cycle of installations designed to enable carbon capture and transfer within Finland.

The next chapters in this Data Package are mainly following the steps shown in Figure 8. Thus Chapter 6 covers Preliminary Planning, Research Phase, and Basic Planning, Chapter 7 Detailed Planning and Construction Phase, and Chapter 8 Operation and Maintenance Phase.

In the following chapters each topic starts with a General Requirements section. In this section the basis of a law is explained as are those requirements in the legislation that concerns carbon dioxide sources (power plants and other industrial installations), transfer lines as well as intermediate storage facilities. The General Requirements section is followed by Case Specific Requirements sections, in which additional specific requirements concerning each of the various types of installations are described.

As capture, transfer and intermediate storage of carbon dioxide can be carried out in many different ways. There has been a need to restrict the discussion to a limited amount of technology options. The CO_2-capture case studies considered are post-combustion, pre-combustion and oxy-fuel combustion presented in Chapters 3.1- 3.4.

Note that for installations differing substantially from the cases given, the requirements might be either more stringent or they do not apply. Also additional laws may apply. The information given in chapters 6 to 8 is therefore only indicative and the up-to-date Finnish legislation, found, for instance, at www.finlex.fi, shall always be consulted.

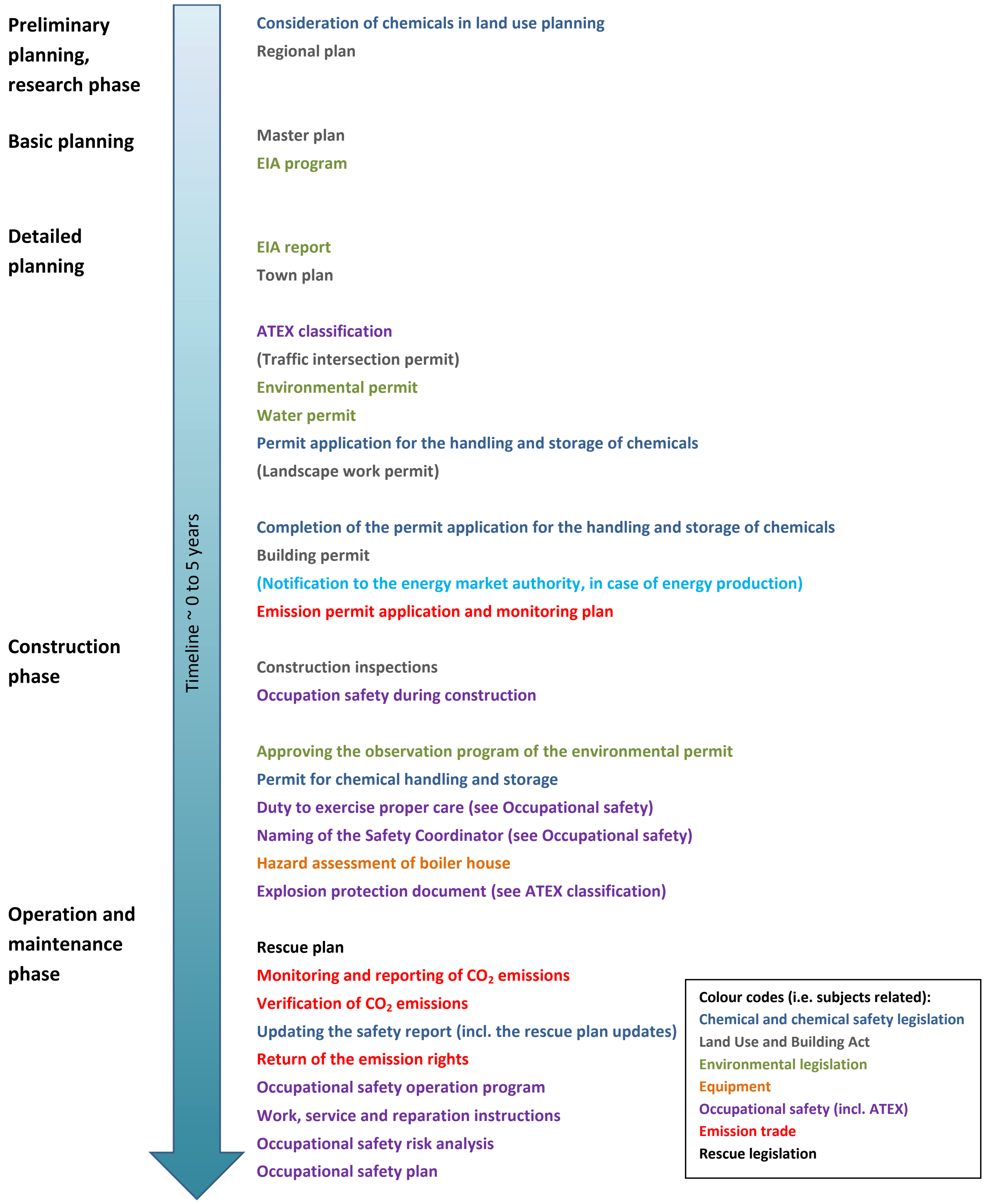

Figure 8. Key milestones of a project for capture, transfer and intermediate storage of CO_2.

6 PRELIMINARY PLANNING, RESEARCH PHASE, AND BASIC PLANNING

6.1 General requirements

6.1.1 Environmental impact assessment

- **Legislation:** Act on environmental impact assessment 468/1994 and Decree 713/2006.

- **Key requirements:** An Environmental Impact Assessment (EIA) aims to integrating environmental considerations into the preparation of projects, plans and programmes in the early stage of planning. Consultation of stakeholders and public participation is an integral part of the assessment.

  An EIA procedure is required for a project, which might have significant environmental impacts. The EIA will be performed in the planning stage of the project and background information will be collected for the basis of subsequent decisions (EIA does not include any decisions). The aim of the procedure is also to increase the knowledge of the citizens and enhance their possibilities to participate in and have an impact on the project planning.

  Environmental impacts (direct and indirect effects) considered:
  - Human health, living conditions and amenity,
  - Soil, water, air, climate, organisms and biological diversity,
  - Community structure, buildings, landscape, townscape and cultural heritage,
  - Utilization of natural resources,
  - Interaction between the factors in 1 – 4.

  The EIA procedure consists of a program and a report phase. The assessment program is a plan for organising the EIA procedure and the settlements related. The assessment report presents the features and technical solutions of the project and the integral evaluation of the environmental impacts of the project as the outcome of the assessment procedure.

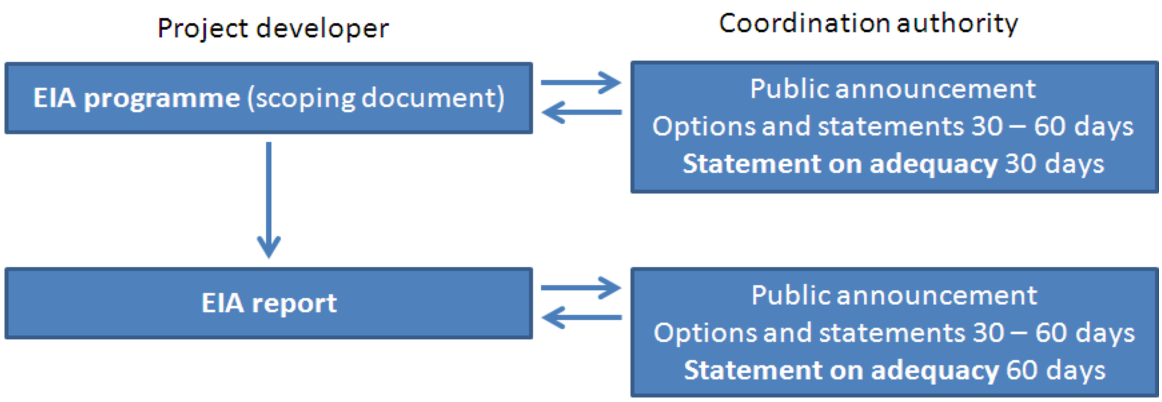

Figure 9. The Finnish Environmental Impact Assessment procedure.

In Finland an EIA is required for:

- Plants that are meant for CO_2 capture for geological storage from the facilities reported in the list of projects within the scope of application or other facilities, if the total amount of captured CO_2 is 1,5 megatons per year at minimum.
- Pipelines that are for CO_2 transfer from the capture plants to the place of storage having the dimensions over 800 mm in diameter (DN) and a length over 40 km, including the stations for increasing the pressure.
- Projects that the authorities on a case-by-case basis consider to have comparable environmental effects to the project listed in Decree 713/2006.

A typical Finnish EIA consists of the following steps:

- Assessment of environmental impacts,
- Alternatives for implementing the project (with 0-alternative = do-nothing),
- Public participation,
- Mitigation measures,
- Proposal for monitoring programme.

An EIA procedure is officially initiated when the project executer delivers the EIA programme to the competent authority, the regional Centre for Economic Development, Transport and the Environment (ELY centre). After public hearing the ELY centre collects the given statements and issues its own statement, after which the assessment work continues. The results will be collected in the EIA report, which will go through a similar hearing procedure as the EIA programme.

The EIA procedure ends when the ELY centre issues the statement of the EIA report to the one in charge of the project. The report will be delivered also to the authorities and the municipalities dealing with the project, and, if needed, to the union of provinces and other competent authorities.

- **Time needed for the stage:** Altogether the EIA process might take about a year.
- **Responsibility:** By the executer.
- **Decision maker:** Regional Centre for Economic Development, Transport and the Environment (ELY centre).
- **Hearing and interaction:** An open process, in which all who are concerned can share their views. The ELY centre announces the assessment program and report (30 to 60 days).
- **Appeal:** Only the authority has the right of appeal in case when an EIA is missing or insufficient.
- **Connections to other stages:** An EIA is required for environmental permit if the project might cause significant adverse environmental impacts. The EIA report and the statement issued by the authority might also be required for the building permit.
- **Significance of the stage (i.e. possible showstopper?):** The significance might be remarkable. It might be an obstacle when applying for an environmental permit (and further, the building permit).

6.1.2 Land use and building

- **Legislation:** Land use and building act 132/1999.
- **Key requirements:** The objective of the Act 132/1999 is to ensure that the use of land and water areas and building activities on them create preconditions for a favourable living environment and promote ecologically, economically, socially and culturally sustainable development. The provisions of the act shall be observed in the planning, building development and use of land and water areas, unless otherwise prescribed.

  On the highest level of planning in Finland are the national land use objectives. On the middle level of planning is the regional plan. Land use in municipalities is organised and steered by local master plans and local detailed plans. The local master plan indicates the general principles of land use in the municipality. The local detailed plan indicates how land-areas within a municipality are used and built.

  A regional plan specifies the overall use of land in the area and it guides the master and town plans. The province union prepares and province council accepts the regional plan and the Ministry of Environment (in some cases alternatively the Council of State) ratifies the plan.

  A master plan specifies the overall use of land in the municipality. When preparing the master plan, legislation (such as Environmental protection act, Water act and Waste act) needs to be taken into account.

  Town plan is guided by the regional and master plan and it specifies the detailed use of the land in the municipality. The town planning is initiated by municipal council. The land owner/holder can apply for the preparation of the town plan for the land without a plan or change for the town plan from the municipal council.

  New installations or remarkable expansions of an installation cannot be situated in regions lacking a plan, since they cause a need for design stated in the Act. Industrial projects outside the town plan are mainly construction with significant impacts, which require adequately versatile assessment and usually a town plan.

  Provisions concerning areas requiring planning apply to construction where the environmental impact is so substantial as to require more comprehensive consideration than the normal permit procedure.

- **Time needed for the stage:** Years, if plans are lacking.
- **Responsibility:** Regional plans by the province union (preparation) and the province council (approval), master and town plans by the municipality.
- **Decision maker:** Decision of approval by the province council, the Ministry of Environment (or the Council of State) ratifies the regional plan. Decision of approval by the municipality, Ministry of Environment ratifies the master plan. Municipal council is taking the decisions concerning the town plan.
- **Hearing and interaction:** The procedure is open and interactive, thus such persons and bodies on whose circumstances or benefits the plan may have substantial impact (such

as land owners, inhabitants and relevant authorities) have a possibility to influence the planning process.

- **Appeal:** An appeal against a decision of the regional plan acceptance by the province council can be made to the Ministry of Environment. In a case when the decision of approval by the Ministry of Environment (or Council of State) is contrary to the law, there is a right of appeal to the Supreme Administrative Court.

  The appeal against a decision of the master plan approval can be made to the Administrative Court in cases when the decision is contrary to the law (time for appeal is 30 days). All the complainants (e.g. citizens, authorities, institutes and foundations) have the right to appeal. The appeal can be made further to the Supreme Administrative Court in case of negative decision from the Administrative Court.

  An appeal regarding the decision concerning the town plan and building order is possible in the case when the decision has been made in the wrong order, the authority that made the decision has exceeded its jurisdiction, or the decision is otherwise contrary to the law. The appeal will be made to the Administrative Court within 30 days of the decision. All the complainants (e.g. citizens, authorities, institutes and foundations) have a right for appeal. In case of minor effects on the town plan, the appeal can be made only by those who are directly affected by the town plan. A further appeal can be made to the Supreme Administrative Court in case of negative decision from the Administrative Court. If the usage of the land has been decided in the master plan, there is no right for an appeal.

- **Connections to other stages:** Any function against the relevant plans cannot obtain an environmental permit. Thus planning has an impact on all subsequent stages of a CCS project.

- **Significance of the stage (i.e. possible showstopper?):** Might be significant in case when the area is reserved for another use in the plan.

6.2 Case specific requirements for industrial facilities

6.2.1 Environment

No additional requirements to what has been described in the General Requirements section apply to environmental impact assessments of power plants and other industrial facilities, but according to the Environmental protection act 527/2014 activities posing a risk of pollution must be located so that they will not cause pollution or pose a risk thereof and so that pollution can be prevented, whenever feasible.

The following shall be taken into account when the suitability of a location is being assessed:

- the nature of the activity, the probability of pollution occurring and the accident risk,
- the present and future land use indicated in a legally binding land-use plan for the area and its surroundings and the plan regulations that concern the area,
- other possible locations in the area.

6.2.2 Land use planning

In addition to what has been described in the General Requirements section, the following requirement might apply to industrial facilities:

Pre-combustion and oxy-fuel combustion units might not be allowed on plots planned for conventional power plants due to the amounts of oxygen and flammable gases present. The town plan shows the common and private intentions for the land use, the amount of constructions, and the location of the constructions, as well as the principles for the construction work, if needed. The markings and orders essentially relate to the town plan. Thus the markings need to be taken into account when designing a plant in a town plan area. Markings suitable for carbon capture plant are presumed to be T (for industry area) or EN (for energy supply area). Also marking T/kem might be required (in case of significant amount of chemical storage). T/kem marking needs a risk assessment when the plan is prepared.

6.2.3 Chemical safety

- **Legislation:** Act on safe handling of chemicals and explosives 390/2005.
- **Key requirements:** When planning the location of a production facility producing, handling or storing hazardous chemicals, the operator of the establishment shall take into consideration that the facility must be located at such a distance from residential areas, public buildings and areas, schools, nursing institutions, industrial facilities, warehouses, traffic lanes, areas of environmental importance, recreation areas, and other external functions that explosions, fires, and chemical releases considered possible are not causing danger to man, the environment or property in these locations.
- **Time needed for the stage:** See section on land use planning above.
- **Responsibility:** The operator of the establishment.
- **Decision maker:** See section on land use planning.
- **Hearing and interaction:** See section on land use planning.
- **Appeal:** See section on land use planning.
- **Connections to other stages:** This requirement is closely connected to land use planning as described above.
- **Significance of the stage (i.e. possible showstopper?):** See section on land use planning.

6.3 Case specific requirements for pipelines

6.3.1 Environmental impact assessment

As described in the General Requirements section, the pipelines for CO_2 transfer with the dimensions of 800 mm in diameter and length over 40 km need environmental impact assessment (EIA) according to the EIA decree 713/2006. With the measures less than mentioned, the EIA is discretionary."

6.3.2 Land use planning

No additional requirements to what has been described in the General Requirements section apply to land use planning related to pipelines for CO_2 transfer. Note, however, that the pipeline is likely to cross several municipalities, which might have an impact on the process. The pipelines need certain protection zones and set conditions for the land use in the surrounding, thus locating the pipelines need to be done according to the other functions in the area.

6.4 Case specific requirements for harbour facilities

6.4.1 Environmental impact assessment

In addition to what has been described in the General Requirements section, the following requirement might apply to environmental impact assessments of harbour facilities, in which CO_2 is temporarily stored and loaded onto a ship:

An EIA is needed for sea routes, harbours, loading docks or discharge quays mainly for mercantile shipping for ships with weight over 1 350 tons as well as for channels and inland waterways/docks for ships over 1 350 tons.

If the harbour has previous actions for chemical storage, CO_2 storage does not need a new EIA procedure.

6.4.2 Land use planning

It is unclear whether an intermediate storage for CO_2 can be built in a harbour without changes in the land use plans.

7 DETAILED PLANNING AND CONSTRUCTION PHASE

7.1 General requirements

7.1.1 Building permit

- **Legislation:** Land use and building act 132/1999 and Decree 895/1999.
- **General requirements:** A building permit or acceptance from the authority is needed for nearly all construction work and for major repair or modification of an existing construction. A building permit can be applied from the municipal building inspector authority in a written form. The building permit can be applied for by the owner or holder of the construction place. The application must include a clarification of the fact that the applicant is the holder of the construction place. Also general drawings must be included (as well as other attachments on request).
- **Time needed for the stage:** A few months.
- **Responsibility:** By the executer.
- **Decision maker:** Building inspector authority of the municipality.
- **Hearing and interaction:** Notification of the building to the neighbours and at the construction site are mandatory.
- **Appeal:** The complainants, such as neighbours and the municipality in question, have a right for appeal (instructions in the permit decision).
- **Connections to other stages:**
  - The environmental permit might be required to become legal prior to handing of the building permit,
  - En EIA procedure might be required for the building. In that case the EIA report need to be attached to the building permit application,
  - The building has to be according to the town plan.
- **Significance of the stage (i.e. possible showstopper?):** Significant.

7.1.2 Landscape work permit

- **Legislation:** Land use and building act 132/1999.
- **Key requirements:** Landscape work permit might be needed in case of landscape excavation. Excavation work changing the landscape cannot be done without authorisation: within a town plan area (except in case when carrying out the town plan), in a master plan area in the case when excavation work is prohibited or in the area with a building ban. The prohibition does not include work covered by other permits (e.g. the construction permit) or authorized plans (e.g. the road plan).

  The landscape work permit can be applied from a building inspector authority of the municipality using an appropriate form.

A landscape work permit cannot overtake the Environmental Protection Act, Forest Act or other legislative regulations.

- **Time needed for the stage:** A few months.
- **Responsibility:** By the executer.
- **Decision maker:** Building inspector authority of the municipality (or some other authority ordered by municipality).
- **Hearing and interaction:** Public hearing, during 14 days after decision of approval, also in the place of action.
- **Appeal:** Complainants have a right to appeal.
- **Connections to other stages:** May delay subsequent stages.
- **Significance of the stage (i.e. possible showstopper?):** Not expected to be significant.

7.1.3 Occupational safety and health

- **Legislation:** Occupational safety and health act 738/2002, Government decree on the safe use and inspection of work equipment 403/2008, Government decree on the safety of construction work 205/2009.
- **Key requirements:** According to Act 738/2002, it is the responsibility of the employer to ensure that the safety and health of employees are taken into account, when structures of the working environment, working premises, working or production methods or the use of machinery, work equipment and other devices used at work as well as the use of hazardous substances, are designed, and that they are suitable for the intended use.

  In the design and planning phase, both the physical and mental capacities of employees shall be taken into account in order to avoid hazards or reduce risks from workload factors to the safety and health of the employees.

  If the design work is assigned to an external designer, the employer shall give the designer adequate information on the workplace under design. Although the main responsibility of the work environment to be design remains with the employer, anyone who by commission provides a design concerning a structure in the working environment, working premises, a working or production method, machinery, work equipment or other device shall also ensure that the provisions of the Act have been taken into consideration in the design of the item in question according to its intended use as stated by the designer.

  According to Government decree 403/2008 the employer:

  - shall, for the employees' use, choose safe work equipment that is suitable for the work and the working conditions,
  - shall see to that the manufacturer's instructions are taken into account when installing work equipment.

Any hazard or risk caused by failure, damage or wear of the work equipment must be eliminated, if possible already during the design phase. Control systems and safety devices must be designed to function faultlessly.

In connection to the installation of the work equipment, the employer must ensure, for instance, that:

- any arrangements and measurements necessary for the safety of the work will be carried out in the workplace,
- appropriate personal protective equipment, instruments and other equipment are in place,
- any unnecessary access to the danger area is being prevented.

Government decree 205/2009 covers a broad range of construction work as well as the preparation and planning of construction projects. In addition to requirements directed towards the building company, which are not covered here, the Decree also includes paragraphs regarding the responsibility of the construction client – for instance a power company.

It is the responsibility of the construction client (or the developer) to make sure that the construction phase is planned and the related hazards are identified in advance so that the construction work can be executed safely and without causing any health problems to the builders. The construction client, the engineering company and all employers shall together and separately see to that their work will not cause any danger to those working at the construction site and to others that may be affected by their work. In addition, the main building company is responsible for that all workers at the construction site has enough knowledge of safe ways of work and are familiar with the hazard and harm issues at the construction site and with the ways these can be eliminated.

The building client/developer shall draw up a Safety Document, in which hazards and other data about occupational safety and health at the construction site are identified. The document shall also cover hazards and other issues caused by any industrial or other activity that might affect the safety at the construction site.

For every building project, a qualified Safety Coordinator shall be appointed to function as the responsible representative of the construction client (or developer) in looking after occupational safety obligations. The Safety Coordinator’s most important task is to ensure that the project is controlled in accordance with high safety objectives. The Safety Coordinator is in charge of, for instance, organising occupational safety tasks and giving attention to them during the project's planning and preparation stage, and of taking responsibility for the compilation and maintenance of the developer's safety documents. During the construction stage, the Safety Coordinator ensures that the safety planning and management conducted by the contractor is in accordance with laws, regulations and the client's safety requirements as issued.

- **Influence of CCS (i.e. new aspects or significantly changed requirements):** On a general level CCS is not likely to introduce any new or significantly changed occupational safety and health requirements in comparison with similar industrial projects. It should be noted, however, that in case the construction site is at an existing establishment (e.g. an oil refinery), the hazards caused by the existing activities must be included in the Safety Document of the construction site (and the Rescue Plan of the establishment should be updated to include the hazards caused by the construction site).

- **Time needed for the stage:** Taking occupational safety and health issues into consideration should be an integral part of all tasks during the detailed design and construction phases.
- **Responsibility:** Although the execution of the design work is typically outsourced to an engineering company, the employer of the workers who will be operating the designed item will still be responsible for the safety of the design. In most cases the operating company is the responsible employer.

  The construction client has the main responsibility for planning the safety at a building site, while the main construction company has the main responsibility for the safety of the workforce present.
- **Decision maker:** The employer and/or the construction client, which in most cases is the coming operator of the installation being designed and constructed (e.g. the power company).
- **Hearing and interaction:** Labour inspectors have the right to inspect the occupational safety and health at any Finnish construction site.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the occupational health and safety authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** Deficiencies in the detailed planning or in the construction work may affect the health and safety of the workers at the installation once this is in operation.
- **Significance of the stage (i.e. possible showstopper?):** A major breach of the requirements may result in the authorities interrupting the work at the construction site or forbidding taking the installation in use until the deficiencies are rectified.

7.1.4 Pressure equipment

- **Legislation:** Decision by the Ministry of Trade and Industry on the safety of pressure equipment 953/1999.
- **Key requirements:** Pressure equipment shall be located and the surrounding space and structures shall be designed and implemented so that the consequences of a loss of containment are as low as possible. In addition, the location shall be such that the pressure equipment can be appropriately operated, checked and maintained.
- **Time needed for the stage:** The selection and location of pressure equipment is an integrated part of a typical design procedure.
- **Responsibility:** The coming owner (or holder) of the pressure equipment, although the design, construction, and installation work is carried out by others.

- **Decision maker:** An inspector must inspect the pressure equipment prior to use and can demand that changes are made to the equipment.
- **Hearing and interaction:** Interaction with the manufacturer of the pressure equipment is crucial.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** Deficiencies in the detailed planning or in the construction of the pressure equipment may affect the health and safety of the workers at the installation once this is in operation.
- **Significance of the stage (i.e. possible showstopper?):** Reconstruction or replacement of a large pressure vessel, which has failed the inspection, may at a very late stage result in a major delay to the schedule of the investment.

7.2 Case specific requirements for industrial facilities

In addition to what has been described in the General Requirements section, the following requirements apply to power plants and other industrial facilities:

7.2.1 Environmental permit

- **Legislation:** Environmental protection act 527/2014 and Decree 713/2014.
- **Key requirements:** An environmental permit is required for actions, which constitute a danger of environmental pollution. According to Act 527/2014, plants for capturing CO_2 need an environmental permit, in which the claims of the 2009 EU Directive on the geological storage of carbon dioxide (CCS Directive; includes regulations of the CO_2 capture) have to be taken into account.

  An environmental permit is an administrative decision, in which, case specifically, the acceptable models, limits or modes for use or load of the environment are determined. In the decree a plant capturing carbon dioxide has been explicitly listed as an action needing an Environmental permit.

  The procedure initiates, when a written environmental permit application is delivered to the regional administrative agency. The application has to include clarification of the activities, impacts, parties and other aspects related to the permit. When an environmental impact assessment(EIA) is needed for the action, an EIA report has to be appended to the application and for granting the permit the authority must have the statement of the EIA report by the EIA contact authority.

  If a project (such as a plant construction) or plan within or nearby a Natura network presumably significantly weakens by itself or cumulatively the value of nature, which is the basis of other projects or plans, the impacts need to be adequately evaluated. If the evaluation threshold is exceeded, the impacts of the project on the value of nature in the Natura area need to be evaluated. The evaluation can be done as a part of the EIA procedure.

- **Time needed for the stage:** Preparation time approx. 2 – 4 months and the application handling time usually being around 6 – 10 months (without appeals). However, the procedure might take over 2 years, if an appeal is to be handled in the Supreme Administrative Court.

- **Responsibility:** By the executer.

- **Decision maker:** Regional administrative agency.

- **Hearing and interaction:** The environmental permit application and decision will be announced for 30 days as a minimum. The interested parties, i.e. the residents and authorities of the affected zone, have the right to present remarks, claims and opinions on the application.

- **Appeal:** A right for appeal is with such persons and bodies on whose circumstances or benefits the plan may have substantial impact, i.e. the affected municipality, associations/foundations aiming for environmental protection, the ELY centre, environmental authorities, and the authorities controlling the general benefits. The appeal will be delivered to the authority, which made the decision of the environmental permit. The authority delivers the information regarding the environmental permit decision and the appeals to the Vaasa Administrative Court immediately after the time of appeal. There is a possibility for a further appeal to the Supreme Administrative Court.

- **Connections to other stages:**
  - An EIA procedure is required for the environmental permit, when building a facility listed in the Decree 713/2006.
  - In some cases, when the construction has significant changes on the environment, the environmental permit must be legally valid before the construction permit can be handled.
  - An environmental permit will not be granted, if the actions are against the town plan.
  - According to environmental permit, the project executer is obligated to monitor the actions and effects of the operation. As a condition of environmental permit the executer is obligated to fixed-term reporting. The executer must follow the emissions and stay in the limits of emission standards and report in case of disturbance. The executer must also give an environmental notification of temporary actions causing a risk for environmental harm. The environmental permit is checked in fixed-terms or when the actions change essentially. The actions are supervised by ELY-centre.

- **Significance of the stage (i.e. possible showstopper?):** Highly remarkable, the environmental permit must be in order prior to starting the activities. If the impacts are found to be significantly harmful for a Natura area, the matter might have significant effects on carrying out the project. Even though there are some possibilities for exception, the conditions are so tight that the CCS project is not likely to pass them.

7.2.2 Permit for chemical handling and storage

- **Legislation:** Act on safe handling of chemicals and explosives 390/2005, Government decree on the supervision of handling and storage of dangerous chemicals 685/2015, Government decree on the safety requirements of handling and storage of dangerous chemicals 856/2012.

- **Key requirements:** The objectives of the act are to prevent and mitigate accidents to man, the environment or property caused by chemicals and explosives handled at fixed installations. Carbon dioxide is not classified as a hazardous chemical and consequently the act applies to CCS installations only based on the presence of chemicals classified as hazardous.

  The handling and storage of hazardous chemicals is divided into 1) large scale establishments and 2) small scale establishments. The category of an establishment is determined by the amount and classification of the chemicals handled or stored.

  On the basis of the amount of hazardous chemicals present at the establishment an operating company shall calculate whether it is a large scale or a small-scale establishment. Amounts for flammables and explosives as well as for chemicals dangerous to health or to the environment are calculated separately. Large scale establishments are supervised by the Finnish Safety and Chemicals Agency (Tukes) and small scale establishments are supervised by regional rescue authorities.

  A permit for chemical handling and storage is needed for large scale establishments, while a notification to regional rescue authorities is sufficient for small scale establishments. Prior to detail planning and the commencement of construction large scale establishments are obliged to apply for a permit from the Finnish Safety and Chemicals Agency (Tukes).

  According to Act 390/2005:

  - installations and equipment used for production, storage and handling of hazardous chemicals must be designed, built and located in such a way that they in normal use and in foreseeable abnormal situations do not cause explosions, fires or chemical releases, which lead to immediate harm to man, the environment or property in or around the establishment,
  - installations and equipment must be located in such a way that they can be appropriately operated, maintained and checked,
  - installations of the establishment must be located, built and protected so that accidents spreading to near-by facilities is prevented or the consequences are confined to the smallest possible area,
  - facilities used for handling and storing hazardous chemicals must be located away from areas, where persons are carrying tasks that are not directly related to handling and storage of chemicals,
  - installations and equipment must be located and constructed in such a way that in case of an emergency persons in the area have the possibility to escape safely,

those taking part in the mitigation activities have access to the place of the accident, and the process or other activities can be closed down safely.

Government decree 856/2012 further specifies:

- that installations, equipment and systems must be designed and constructed so that accidents can be prevented and harmful consequences can be limited effectively,
- processes must be equipped with necessary control and alarm systems in order to detect hazardous situations in good time so that propagation of dangerous events can be restricted or prevented and the consequences can be limited to the minimum.

According to Decree 685/2015 the permit application must show that the above mentioned requirements will be met. Consequently, the application will include a substantial amount of data about the establishment, including, for instance, process safety analyses. Any major modifications and/or expansions of an existing establishment is considered comparable to the criteria of the construction of a new establishment and also legally bound to apply for a permit for chemical handling and storage.

The Finnish Safety and Chemicals Agency (Tukes) also undertakes a commissioning inspection of large-scale establishments prior to the commencement of operations.

- **Time needed for the stage:** Several months.
- **Responsibility:** By the executer.
- **Decision maker:** The Finnish Safety and Chemicals Agency (Tukes)
- **Hearing and interaction:** When dealing with the permit for chemical handling and storage application Tukes must hear the regional occupational safety, environmental and rescue authorities. Tukes must also inform above-mentioned authorities and the building inspector authority of its decision concerning the permit for chemical handling and storage.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by Tukes is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** Delays in getting a permit will delay the start-up of the new production unit or storage.
- **Significance of the stage (i.e. possible showstopper?):** Significant, the permit for chemical handling and storage has to be issued before the establishment is taken into use.

7.2.3 Water permit

- **Legislation:** Water act 587/2011.
- **Key requirements:** When water is taken from or released to the watercourse, the water permit is required. However, actions which might cause harm to the environment are within the scope of the environmental permit. A water permit application must include clarifications of the purpose and impacts of the project.

- **Time needed for the stage:** Approx. 1 – 3 years.
- **Responsibility:** By the executer.
- **Decision maker:** Regional administrative agency. When considering the permit, the benefits and disadvantages are estimated. If the benefits are significant and possible disadvantages coverable, the compensations will be decided in the permit process.
- **Hearing and interaction:** The application for the water permit will be announced for 30 to 45 days.
- **Appeal:** Complainants have a right to appeal. The appeals will be delivered to Vaasa Administrative Court (30 days from the decision).
- **Connections to other stages:** Causes delays to subsequent stages. The executer might be obligated to monitor the actions and effects of the operation, to pay compensations to those suffering from the disadvantages.
- **Significance of the stage (i.e. possible showstopper?):** Remarkable.

7.2.4 Emission permit

- **Legislation:** Emission trading act 311/2011.
- **Key requirements:** Plants for capturing of greenhouse gases (notably CO_2) are covered by the scope of the Act 311/2011 and thus need an emission permit. No later than 6 months prior to the initiation of operations, the executer must deliver an application for an emission permit to the energy market authority. The permit application has to include clarifications of the plant, of the actions, and of the sources of emissions, as well as a plan for emission monitoring. In addition, it must be clear in the application that the plant can be operated on the grounds of the Environmental protection act 527/2014.

  Emission trading is a market-based scheme for pollution control that economically encourages for reductions in pollutant emissions. In the scheme, the executer is required to hold a number of emission permits equal with their emissions. If the executer needs to increase the amount of emission permits, the extra permits have to be purchased from those who require fewer permits. Besides the emission permit, the executer needs emission rights. Emission right applications are handled by the Ministry of Employment and the Economy and the emission rights for the plants are granted by the Council of the state.
- **Time needed for the stage:** The emission trade authority is obligated to give its decision no later than 2 months from the delivery of the application and possible supplements.
- **Responsibility:** By the executer.
- **Decision maker:** Emission permits are granted by the emission trade authority, which in Finland is the energy market authority.

- **Appeal:** Complainants have a right to appeal to the Administrative Court during 30 days of notification. If the situation requires, cancellation of an emission permit can be initiated by the executer or the emission trade authority.
- **Connections to other stages:** For granting the emission permit, it is required that the plans for emission observation and delivery of the reports clarifying the emissions to the emission trade authority are adequate, and that the executer is allowed to practice the operations according to Environmental Protection Act. The permit is usually granted until further notice (in a special case for a fixed-term).
- **Significance of the stage (i.e. possible showstopper?):** Significant.

7.2.5 Explosion prevention

- **Legislation:** Government decree on the prevention of hazard to workers caused by explosive air mixtures 576/2003.
- **Key requirements:** According to Decree 576/2003 (ATEX) the employer shall see to that a facility is designed and constructed so that the risk of having explosive atmospheres present during normal operation modes is as low as possible. Based on a hazard analysis, zones, where an explosive air mixture might be present, shall be classified based on the properties of the substance(s) mixed in air and the likelihood of such a mixture being present. The employer shall then make sure that all mechanical and electrical equipment to be placed within or brought into these EX zones are approved for use in the respective zones.
- **Influence of CCS (i.e. new aspects or significantly changed requirements):** ATEX is highly relevant especially for pre-combustion installations as hydrogen and high concentrations of carbon monoxide are present in the plant. Also some other CCS technologies might introduce new flammable chemicals in addition to the fuels (natural gas, coal dust, light fuel oil, etc.) and process chemicals used, but in the selected case studies in this Data Package, ATEX is a major task only during the design of pre-combustion installations. The location and the design of those parts of the installation where flammable chemicals are handled or stored must be carefully selected and designed in order to minimise the hazardous zones.
- **Time needed for the stage:** In addition to the time needed to design and construct an installation, which is handling or storing flammable chemicals (e.g. coal dust), some extra days must be allocated for explosion hazard analyses, zoning and selection of approved equipment. In addition, the paperwork needed for the Explosion Protection Document takes several work days to complete.
- **Responsibility:** The employer, who will operate the new facility. The execution is typically outsourced to an engineering company.
- **Decision maker:** The employer, which in most cases is the operating company.
- **Hearing and interaction:** N/A.

- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** ATEX issues must be taken into consideration if a licence application is required.
- **Significance of the stage (i.e. possible showstopper?):** Mistakes made during the process design, the EX-zoning, and the selection of suitable equipment are likely to go unnoticed, but can lead to an explosion later during the operation phase of the unit resulting in severe losses of lives, property and production.

7.2.6 Pressure equipment

- **Legislation:** Decision by the Ministry of trade and industry on the safety of pressure equipment 953/1999.
- **Key requirements:** Finland has special requirements in the pressure equipment legislation concerning boiler plants. According to the Decision, a boiler plant hazard assessment must be carried out for certain boiler plants. The plant's owner or holder must identify potential hazards, their causes and consequences. Furthermore, the significance of the identified hazard scenarios and the appropriateness of the risk reduction measures and safety precautions must be assessed. All this, i.e. the description of the plant's hazard assessment process and its results, must be in the form of a written report (Boiler Plant Hazard Assessment) to be presented to the inspection body for approval before the boiler is approved for use.

  According to the hazard assessment requirement, the owner or holder of the plant must identify and assess accident risks related to the operation of the plant. The owner or holder must also prove that sufficient precautionary measures have been taken in order to avoid these risks.

  The requirement for a boiler plant hazard assessment applies to both existing and new boiler plants with a steam boiler above 6 MW or a hot water boiler above 15 MW, and to boiler plants that are below ground level.

  For new boiler plants including carbon capture technology, also this part of the installation must be included in the hazard assessment. Adding a carbon capture unit to a boiler plant automatically means that the boiler plant hazard assessment must be amended.

  The hazard assessment shall include the following main points:
  - hazardous situations and conditions related to the operation of the boiler plant that can lead to an accident,
  - hazardous situations related to the way of operating the boiler plant (e.g. manned vs. unmanned plant),
  - a description of the typical and most significant potential hazards and their causes – operation errors, malfunctions, equipment failures and damages, and other causes.

Precautionary measures must be taken against hazardous situations identified in the hazard assessment process – many of them already during the design stage. At least the following precautionary issues must also be described in a hazard assessment report:

- the precautions taken to prevent potential hazardous situations during the normal operation of a boiler plant, during repair and maintenance work and various disturbances,
- the measures taken as a result of the hazard assessment study,
- the safety-related systems that are used to prevent the identified hazards or to minimise the consequences, the demands set for functional characteristics and reliability of these systems and how it is ensured that these demands are met.

- **Time needed for the stage:** The boiler plant hazard assessment should be an integral part of the design phase. The time needed for the assessment is dependent on the complexity of the boiler plant and its surroundings.
- **Responsibility:** By the executer.
- **Decision maker:** The Finnish Safety and Chemicals Agency (Tukes) has the right to forbid the use of pressure equipment considered to be hazardous.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** The boiler plant hazard assessment shall be completed when the operation starts. Minor deficiencies in the assessment are not likely to hinder the start-up of the facility.
- **Significance of the stage (i.e. possible showstopper?):** Moderate.

7.2.7 Rescue

- **Legislation:** Rescue act 379/2011, Government decree on rescue services 407/2011.
- **Key requirements:** The purpose of the act is to improve the safety of people and to reduce the number of accidents. The act lays down provisions on the duty of enterprises:
  - to prevent fires and other accidents,
  - to prepare for accidents and operations when there is the threat of an accident or when an accident occurs,
  - to limit the consequences of accidents;
  - to construct and maintain civil defence shelters.

  Some of the requirements of the act should be taken into account already during the detailed planning stage. These are, for instance, related to:
  - emergency exits from buildings,
  - emergency access roads,
  - fire fighting equipment, fire and rescue equipment and response equipment,

- equipment facilitating fire extinguishing and rescue work,
- fire detectors, alarm devices and other devices indicating accident risk,
- signs indicating escape routes and lighting,
- civil defence shelters.

In addition, an emergency plan covering the measures referred to above shall be drawn up for any building or other site which, with regard to evacuation safety or rescue operations, is exceptionally demanding or where the risk to the safety of persons, to fire safety or the damage caused by any accident, may be considered serious. The drawing up of the emergency plan is the responsibility of the occupant of the site. The emergency plan shall contain the details of:

- the conclusions on the assessments of the dangers and risks,
- the safety arrangements of the facilities used for the operations carried out at the site,
- the instructions on how to prevent accidents and what action to take in accidents and dangerous situations,
- any other measures related to self-preparedness at the site.

Note that establishments that handle or store hazardous chemicals must according to Act 390/2005 write an internal emergency plan covering the major chemical hazards at the establishment. The two emergency plans can be merged into one document.

- **Time needed for the stage:** Writing an emergency plan may require a couple of days once the decisions regarding how the emergency response will be arranged have been taken.
- **Responsibility:** By the occupant of the site.
- **Decision maker:** The regional fire authorities.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** The emergency plan should be completed when the new unit is taken into operation, but is not likely that minor deficiencies in the plan will delay the start-up of the facility.
- **Significance of the stage (i.e. possible showstopper?):** Moderate.

7.3 Case specific requirements for pipelines

EU's CCS Directive includes requirements for CO_2 transportation in pipelines. However, in Finland CO_2 transportation by itself does not need an environmental permit

When planning the pipeline locations, it should be noted that there are areas containing legally protected habitat types or species (Nature protection act 1096/1996 and Decree 160/1997). In such case, special permission is needed before the actions (such as placing the pipelines) can be carried out. A special permit can be granted only, if the action does not compromise the protected object, or, if the protection prevents actions, which are highly important for the common welfare.

It should be noted, that there is a similar permit procedure for certain surface water locations mentioned in the Water act 587/2011. Time needed for the special permit is several months. The matter might be highly significant, if the special permit will not be granted (re-planning, re-location etc. required). In addition, pipeline construction on areas in or nearby the Natura-network might have restrictions.

7.4 Case specific requirements for harbour facilities

In addition to what has been described in the General Requirements section, the following requirements apply to the detailed design and construction of harbour facilities, in which CO_2 is temporarily stored and loaded onto ships. Note that requirements applied to any Finnish harbour (e.g. security requirements) are not included in this study.

7.4.1 Environmental permit

- **Legislation:** Environmental protection act 527/2014 and Decree 713/2014.
- **Key requirements:** An environmental permit is required for actions, which constitute a danger of environmental pollution. An environmental permit is an administrative decision, in which, case specifically, the acceptable models, limits or modes for use or load of the environment are determined. In the decree a plant capturing carbon dioxide has been explicitly listed as an action needing an environmental permit.

  The procedure initiates, when a written environmental permit application is delivered to the regional administrative agency. The application has to include clarification of the activities, impacts, parties and other aspects related to the permit. When an EIA procedure is needed for the action, an EIA report has to be appended to the application and for granting the permit the authority must have the statement of the EIA report by the EIA contact authority.

  If a project (such as a plant construction) or plan within or nearby a Natura network presumably significantly weakens by itself or cumulatively the value of nature, which is the basis of other projects or plans, the impacts need to be adequately evaluated. If the evaluation threshold is exceeded, the impacts of the project on the value of nature in the Natura area need to be evaluated. The evaluation can be done as a part of the EIA procedure.
- **Time needed for the stage:** Preparation time approx. 2 – 4 months and the application handling time usually being around 6 – 10 months (without appeals). However, the procedure might take over 2 years, if an appeal is to be handled in the Supreme Administrative Court.
- **Responsibility:** By the executer.
- **Decision maker:** Regional administrative agency.
- **Hearing and interaction:** The environmental permit application and decision will be announced for 30 days as a minimum. The interested parties, i.e. the residents and authorities of the affected zone, have the right to present remarks, claims and opinions on the application.
- **Appeal:** A right for appeal is with such persons and bodies on whose circumstances or benefits the plan may have substantial impact, i.e. the affected municipality, associations/foundations aiming for environmental protection, the ELY centre, environmental authorities, and the authorities controlling the general benefits. The appeal will be delivered to the authority, which made the decision of the environmental permit.

The authority delivers the information regarding the environmental permit decision and the appeals to the Vaasa Administrative Court immediately after the time of appeal. There is a possibility for a further appeal to the Supreme Administrative Court.

- **Connections to other stages:**
    - An EIA procedure is required for the environmental permit, when building a facility listed in the EIA Decree.
    - In some cases, when the construction has significant changes on the environment, the environmental permit must be legally valid before the construction permit can be handled.
    - An environmental permit will not be granted, if the actions are against the town plan.
    - According to environmental permit, the project executer is obligated to monitor the actions and effects of the operation. As a condition of environmental permit the executer is obligated to fixed-term reporting. The executer must follow the emissions and stay in the limits of emission standards and report in case of disturbance. The executer must also give an environmental notification of temporary actions causing a risk for environmental harm. The environmental permit is checked in fixed-terms or when the actions change essentially. The actions are supervised by ELY-centre.

- **Significance of the stage (i.e. possible showstopper?):** Highly remarkable, the environmental permit must be in order prior to starting the activities. If the impacts are found to be significantly harmful for a Natura area, the matter might have significant effects on carrying out the project. Even though there are some possibilities for exception, the conditions are so tight that the CCS project is not likely to pass them.

7.4.2 Rescue

- **Legislation:** Rescue act 379/2011, Government decree on rescue services 407/2011.

- **Key requirements:** The purpose of the Act 379/2011is to improve the safety of people and to reduce the number of accidents. The Act lays down provisions on the duty of enterprises:
    - to prevent fires and other accidents,
    - to prepare for accidents and operations when there is the threat of an accident or when an accident occurs,
    - to limit the consequences of accidents;
    - to construct and maintain civil defence shelters.

  Some of the requirements of the Act 379/2011 should be taken into account already during the detailed planning stage. These are, for instance, related to:
    - emergency exits from buildings,
    - emergency access roads,
    - fire fighting equipment, fire and rescue equipment and response equipment,
    - equipment facilitating fire extinguishing and rescue work,
    - fire detectors, alarm devices and other devices indicating accident risk,

- signs indicating escape routes and lighting,
- civil defence shelters.

In addition, an emergency plan covering the measures referred to above shall be drawn up for any building or other site which, with regard to evacuation safety or rescue operations, is exceptionally demanding or where the risk to the safety of persons, to fire safety or the damage caused by any accident, may be considered serious. The drawing up of the emergency plan is the responsibility of the occupant of the site. The emergency plan shall contain the details of:

- the conclusions on the assessments of the dangers and risks,
- the safety arrangements of the facilities used for the operations carried out at the site,
- the instructions on how to prevent accidents and what action to take in accidents and dangerous situations,
- any other measures related to self-preparedness at the site.

- **Time needed for the stage:** Writing an emergency plan may require a couple of days once the decisions regarding how the emergency response will be arranged have been taken.
- **Responsibility:** By the occupant of the site.
- **Decision maker:** The regional fire authorities.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** The emergency plan should be completed when the new unit is taken into operation, but is not likely that minor deficiencies in the plan will delay the start-up of the facility.

8 OPERATION AND MAINTENANCE PHASE

8.1 General requirements

8.1.1 Occupational safety and health

- **Legislation:** Occupational safety and health act 738/2002, Government decree on the safe use and inspection of work equipment 403/2008.

- **Key requirements:** The objectives of Act 738/2002 are to improve the working environment and working conditions in order to ensure and maintain the working capacity of employees as well as to prevent occupational accidents and diseases and eliminate other hazards from work and the working environment to the physical and mental health of the employees.

  The Act 738/2002 applies to work carried out under the terms of an employment contract, but also to work carried out by leased labour. At so called shared workplaces the act applies both to employers exercising the main authority, other employers and self-employed workers.

  According to the Act 738/2002 an employer:
  - has a general duty to exercise care,
  - shall have a Policy for action needed in order to promote safety and health and to maintain the employees' working capacity,
  - shall systematically and adequately analyse and identify the hazards and risk factors caused by the work, the working premises, other aspects of the working environment and the working conditions and, if the hazards and risk factors cannot be eliminated, assess their consequences to the employees' safety and health,
  - shall, if the assessment of risks at work shows that the work may cause a particular risk of injury or illness, see to that such work is done only by an employee who is competent and personally suitable for it,
  - shall ensure that the impact of the work environment on the safety and health of employees is taken into account and that machinery, tools etc. used are suitable for the intended use,
  - shall provide instruction and guidance for the employees,
  - shall provide personal protective equipment, auxiliary equipment and other devices for use,
  - shall cooperate with the employees in maintaining and improving safety in workplaces.

  Please, consult the Act 738/2002 for more details and additional requirements.

  Government Decree 403/2008 applies to the use and inspections of machinery, equipment and other technical devices (work equipment) and their installations in work referred to in Act 738/2002. According to the Decree 403/2008 the employer shall:
  - for the employees' use, choose safe work equipment that is suitable for the work and the working conditions,

- see to that the manufacturer's instructions are taken into account when installing, using, maintaining or inspecting work equipment, and when carrying out other activities in connection with those operations,
- systematically analyse and evaluate the safety of the work equipment. This has to be done especially in connection with changes in production or work methods.

Any work equipment must be kept safe throughout its whole operational life by regular service and maintenance. Any hazard or risk caused by failure, damage or wear must be eliminated. The control system and safety devices must function faultlessly.

In connection with installation, service, repair and other maintenance work, the employer must ensure that:

- the employee has received enough information, training and guidance concerning special circumstances,
- when necessary, the persons representing the employer and carrying the responsibility for the work have accepted the work to be carried out and given their permission to begin the work,
- any arrangements and measurements necessary for the safety of the work have been carried out in the workplace,
- any pressure and flow of gas and fluids have been switched off,
- electric tension has been switched off,
- the load on lifting machinery has been secured in such a way that a failure of the machinery cannot cause any danger,
- starting work equipment under repair has been prevented in a reliable way during the repair work, if the employee is situated in the danger zone,
- the work equipment in use is in order and suitable for the intended purpose,
- it has been taken care of that dangerous substances or lack of oxygen do not cause any danger during work in tanks or enclosed places,
- appropriate personal protective equipment, instruments and other equipment are used,
- sufficient arrangements have been made to ensure the stability and carrying capacity of scaffolds, work platforms and ladders,
- any unnecessary access to the danger area has been prevented.

- **Influence of CCS (i.e. new aspects or significantly changed requirements):** The installation's occupational health and safety management (incl. occupational safety assessments, work instructions, and training) should take into consideration that CCS is likely to introduce new chemicals, higher inventories of chemicals, and/or equipment at relatively high pressures. Although carbon dioxide is not classified as a hazardous chemical, during major releases of CO_2 the safety of the workers (and the public) will be at risk and based on the Occupational safety and health act the employer must take this occupational safety risk into consideration.

- **Time needed for the stage:** All required occupational safety and health management elements must be in place when the employees start working and must be kept up-to-date during the entire lifespan of the installation.
- **Responsibility:** Employer.
- **Decision maker:** Employer.
- **Hearing and interaction:** Involvement of the employees is required. Labour inspectors have the right to inspect all occupational health and safety arrangements of the establishment.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** Occupational health and safety issues must be taken into consideration already during the design and construction phases.
- **Significance of the stage (i.e. possible showstopper?):** A major breach of the requirements in the Act may result in the authorities forbidding further work at the workplace in question.

8.1.2 Chemical safety

- **Legislation:** Act on safe handling of chemicals and explosives 390/2005, Government decree on the supervision of handling and storage of dangerous chemicals 685/2015, Government decree on the safety requirements of handling and storage of dangerous chemicals 856/2012.
- **Key requirements:** The objectives of the Act 390/2005 are to prevent and mitigate accidents to man, the environment or property caused by chemicals and explosives handled at fixed installations. Carbon dioxide is not classified as a hazardous chemical and consequently the act applies to CCS installations only based on the presence of chemicals classified as hazardous.

  According to Act 390/2005 an operating company:
  - shall require all necessary information about the chemicals handled in order to fulfil the requirements of the Act,
  - shall, within reasonable limits, choose from the alternatives available the least hazardous chemical or method,
  - shall exercise adequate care and caution in order to prevent accidents to man, the environment and property, and, should prevention not be possible, take all possible measures to systematically limit the consequences of an accident,
  - shall see to that organisational factors, the operation and maintenance of the installation, and other relevant functions are at an adequate level in order to prevent accidents.

According to Decree 685/2015 an operating company:

- shall on the basis of the amount of hazardous chemicals present at the establishment calculate whether the establishment is a small-scale or large scale handling and storage of chemicals,
- of a small-scale or large scale handling and storage of chemicals shall send a start-up notification to the local rescue authorities well before the operation starts.

- **Influence of CCS (i.e. new aspects or significantly changed requirements):** As carbon dioxide is currently not classified as a hazardous chemical, hazards related to CO_2 are not regulated by Finnish chemical safety regulations. At the industrial establishments given as examples in this report, CCS is introducing new hazardous chemicals and/or higher inventories of these. See the Industrial Installations sections below for further details.

- **Time needed for the stage:** Chemical safety requirements, if required, must be in place when the chemical is introduced at the installation and must be kept up-to-date during the entire lifespan of the installation.

- **Responsibility:** Operating company.

- **Decision maker:** Operating company.

- **Hearing and interaction:** The authorities have the right to inspect all arrangements of the installation related to chemical safety.

- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.

- **Connections to other stages:** Chemical safety issues must be taken into consideration already during the design and construction phases.

- **Significance of the stage (i.e. possible showstopper?):** A major breach of the requirements in the act may result in the authorities forbidding further use of the hazardous chemical in question until the problem has been remedied.

8.1.3 Environment

- **Legislation:** Environmental protection act 527/2014.

- **Key requirements:** Act 527/2014 applies to all activities that lead or may lead to environmental pollution as laid down in this act. This act also applies to activities that generate waste and to waste disposal.

According to the act the following principles apply to activities that pose a risk of pollution:

- harmful environmental impact shall be prevented or, when it cannot be prevented completely, reduced to a minimum (principle of pollution prevention and minimizing harmful impact),
- the proper care and caution shall be taken to prevent pollution as entailed by the nature of the activity, and the probability of pollution, risk of accident and

opportunities to prevent accidents and limit their effects shall be taken into account (principle of caution and care),
- the best available technique shall be used (principle of best available technique),
- combinations of various methods, such as work methods, shall be used and such raw materials and fuels shall be selected as provide appropriate and cost-efficient means to prevent pollution (principle of best environmental practice).

According to the act it is the duty of parties engaged in activities that pose a risk of pollution to prevent impact and eliminate or minimize harmful environmental effects (principle of 'polluter pays').

According to Act 527/2014:
- operators must have sufficient knowledge of their activities' environmental impact and risks and of ways to reduce harmful effects (knowledge requirement).
- if the activities cause or may directly result in environmental pollution, the operator must take the appropriate action without delay in order to prevent pollution, or, if pollution has already resulted, to reduce it to a minimum (obligation to prevent pollution).
- in addition, the general duties and principles laid down in Waste act 646/2011 must be observed in activities posing a risk of pollution.

- **Responsibility:** Operating company.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** Environmental protection should be taken into consideration already during the design phase.
- **Significance of the stage (i.e. possible showstopper?):** If the requirements of the Environmental protection act are not complied, operation of the plant may be suspended.

8.1.4 Pressure equipment

- **Legislation:** Pressure equipment act 869/1999, Decision by the Ministry of Trade and Industry on pressure equipment 938/1999, Decision by the Ministry of Trade and Industry on the safety of pressure equipment 953/1999.
- **Key requirements:** According to Act 869/1999 pressure equipment must be constructed, placed, maintained, operated and inspected so that they don't endanger anybody's health, safety or property. The owner (or holder) of pressure equipment shall see to that the pressure equipment is safe after being put into service, if necessary, by carrying out a risk assessment and by taking precautions against hazardous situations. The owner (or holder) shall also designate a competent person for supervising the operations of registered pressure equipment.

  The conformity of pressure equipment with requirements laid down in the act is to be verified with inspections carried out by inspection bodies.

Decision 938/1999 covers mainly obligations of the company that put pressure equipment and aggregates thereof on the market, and although utterly relevant for CCS installations, these requirements are not within the scope of this report.

Decision 953/1999 applies to the location and use of pressure equipment and requires that the owner (or holder) of the equipment compiles the data on each piece of pressure equipment into a Pressure Equipment Document. The owner (or holder) of the pressure equipment shall see to that the equipment is inspected before it is taken into operation and after that at regular intervals.

Please, consult the act and the decisions for further details.

- **Influence of CCS (i.e. new aspects or significantly changed requirements):** CCS technologies are likely to introduce pressure equipment that are at higher pressures than in conventional solutions. This will not, however, change the requirements.
- **Time needed for the stage:** Time for the inspections of the pressure equipment must be allocated, most conveniently during scheduled shutdowns. updating the required paperwork requires a minimum amount of work.
- **Responsibility:** The owner (or holder) of the pressure equipment.
- **Decision maker:** The inspection body will inform Tukes about pressure equipment causing an immediate hazard, and Tukes has the right to forbid the use of such equipment.
- **Hearing and interaction:** The authorities have the right to inspect all arrangements of the establishment related to pressure equipment.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by Tukes is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** N/A.
- **Expenses:** Expenses caused by inspections.
- **Significance of the stage (i.e. possible showstopper?):** Failing the pressure equipment inspection may lead to an interruption in the use of – or even replacement of – that piece of equipment.

8.1.5 Rescue

- **Legislation:** Rescue act 379/2011, Government decree on rescue services 407/2011.
- **Key requirements:** The purpose of Act 379/2011 is to improve the safety of people and to reduce the number of accidents. The purpose of the Act is also to ensure that when there is the threat of an accident or when an accident has occurred, people are rescued, important functions are secured, and the consequences of the accident are successfully limited. The act lays down for instance the following provisions on the duty of enterprises:
  - to prevent fires and other accidents,

- to prepare for accidents and operations when there is the threat of an accident or when an accident occurs,
- to limit the consequences of accidents,
- to construct and maintain civil defence shelters.

The owner and occupants of a building and business and industrial operators shall, for their part, ensure that the building and structure and their surroundings are kept in such a condition that:

- in the event of a fire or other dangerous situation arising suddenly, all persons in the building are able to leave the building or they can be rescued using other means,
- rescue operations can be carried out in the event of a fire or other accident,
- consideration has been given to the safety of the rescue personnel.

The owner and occupants of a building and the business and industrial operators shall for their part:

- prevent fires and other dangerous situations,
- prepare for the protection of persons, property and the environment in dangerous situations,
- prepare for extinguishing fires and taking other such rescue action which they are capable of performing independently,
- take measures to ensure safe exit during fires and in other dangerous situations and to facilitate rescue operations.

According to this act, hazardous substances shall be handled with care and sufficient precautions shall be taken.

An emergency plan covering the above mentioned measures shall be drawn up for a building or other site, which with regard to evacuation safety or rescue operations, is exceptionally demanding, or where the risk to the safety of persons or to fire safety or the risk to the environment or cultural property, or the damage caused by any accident, may be considered serious. The drawing up of the emergency plan is the responsibility of the occupant of the building or the site.

The emergency plan shall contain the details of:

- the conclusions on the assessments of the dangers and risks,
- the safety arrangements of the building and the facilities used for the operations carried out in the building or at the site,
- the instructions for building residents and other persons on how to prevent accidents and what action to take in accidents and dangerous situations,
- any other measures related to self-preparedness at the site.

According to Decree 407/2011, the rescue plan must be kept up-to-date and its content must be disseminated to those concerned. The rescue plan must in addition to normal operations also include unusual circumstances.

- **Influence of CCS (i.e. new aspects or significantly changed requirements):** The vast amounts of carbon dioxide and hazardous gases such as carbon monoxide, hydrogen, and oxygen at elevated pressures may have a significant impact on the emergency procedures at the establishment.
- **Time needed for the stage:** setting aside time for regular rescue drills is recommended.
- **Responsibility:** The occupant of the site, i.e. the operating company.
- **Decision maker:** Regional Rescue Services.
- **Hearing and interaction:** The Rescue Services have the right to inspect the rescue arrangements of the establishment.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** N/A.
- **Significance of the stage (i.e. possible showstopper?):** Poor emergency planning may lead to severe consequences should an accident happen, which in turn means lengthy interruption in production due to the accident investigation and/or replacement of destructed equipment.

8.2 Case specific requirements for industrial facilities

In addition to what has been described in the General Requirements section, the following requirements apply to power plants and other industrial facilities:

8.2.1 Occupational safety and health

- **Legislation:** Government decree on the prevention of hazard to workers caused by explosive air mixtures 576/2003.
- **Key requirements:** The objective of Decree 576/2003 (ATEX) is to prevent and mitigate hazards caused by explosive air mixtures in order to protect the safety and health of the workers, to maintain general safety, and to prevent damage to property.

  According to Decree 576/2003, the employer shall:
  - identify hazards caused by explosive atmospheres and assess their significance,
  - take technical and organisational measures to prevent explosions and to mitigate the consequence should an explosion happen,
  - classify the zones where an explosion hazard might exist,
  - prepare an Explosion Protection Document and keep it updated.
- **Influence of CCS (i.e. new aspects or significantly changed requirements):** The Explosion Protection Document of the installation must be updated whenever relevant changes are made to chemicals, operations, structures or equipment, but the updating is

not a major task (see chapter on the design and construction phases, if an investment is involved).

- **Time needed for the stage:** The updating of Explosion Protection Document is not requiring much time.
- **Responsibility:** The employer, i.e. in most cases the operating company.
- **Decision maker:** The Finnish Safety and Chemicals Agency (Tukes) or the occupation health authorities.
- **Hearing and interaction:** The authorities have the right to inspect all arrangements of the establishment related to chemical safety.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** Explosion prevention and protection issues must be taken into consideration already during the design and construction phases.
- **Significance of the stage (i.e. possible showstopper?):** Tukes will probably not require the equipment to be closed down even if the inspector notices a failure to identify the explosion hazards or to compile the Explosion Protection Document. However, unidentified hazardous zones might lead to the use of equipment, which can ignite an explosive air mixture.

8.2.2 Chemical safety

- **Legislation:** Act on safe handling of chemicals and explosives 390/2005, Government decree on the supervision of handling and storage of dangerous chemicals 685/2015, Government decree on the safety requirements of handling and storage of dangerous chemicals 856/2012.
- **Key requirements:** The objectives of Act 390/2005 are to prevent and mitigate accidents to man, the environment or property caused by chemicals and explosives handled at fixed installations. Carbon dioxide is not classified as a hazardous chemical and consequently the Act applies to CCS installations only based on the presence of chemicals classified as hazardous.

  According to the Act a company operating a production facility:
  - shall undertake all necessary actions to prevent chemical accidents and to restrict the consequences to man, the environment or property, should such an accident happen,
  - shall identify the hazards and execute the needed preventive actions in a systematic way based on set goals and methods,
  - shall follow and assess how the actions have been materialised and what effect they have had and, if needed, undertake actions to rectify the situation,
  - shall see to that changes are carried out according to pre-set operational principles and without endangering the safety of the establishment,

- shall see to that the installations and equipment are operated safely and according to given use instructions, so that under normal operation and foreseeable disturbances no explosions, fires or chemical releases causing direct danger to man, the environment or property in or around the establishment can happen,
- shall see to that installations, equipment and safety related systems are maintained and often enough make sure that they can be operated safely and that they work properly.

Please, consult Act 390/2005 for further details and additional requirements.

According to Decree 685/2015 a company operating a production facility with the obligation to draw up a Major Accident Prevention Policy, a Safety Report and/or an Internal Rescue Plan shall keep these documents updated as long as the establishment is in operation. At any establishment, where hazardous chemicals are present on a large scale, at least one supervisor responsible for the use and storage of these chemicals shall be nominated. Such an establishment must also send a notification to the Finnish Safety and Chemicals Agency (Tukes) concerning minor changes to the establishment. Major changes require a permit.

- **Influence of CCS (i.e. new aspects or significantly changed requirements):** The updating of safety management documentation may increase during the operational phase, if the introduction of a carbon capture technology means that the establishment now is classified as an establishment for which a Safety Report is required. For retrofits including post-combustion carbon capture technologies a change in classification is not likely.
- **Time needed for the stage:** The required chemical safety requirements must be in place when the chemical is introduced at the installation and must be kept up-to-date as long as the chemical is used, but the time needed for updates is minimal.
- **Responsibility:** Operating company.
- **Decision maker:** Operating company.
- **Hearing and interaction:** The authorities have the right to inspect all arrangements of the establishment related to chemical safety.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** Chemical safety issues must be taken into consideration already during the design and construction phases. Permits to operate might be required if the amount of hazardous chemicals present is high (mainly in the pre-combustion alternative).
- **Significance of the stage (i.e. possible showstopper?):** A major breach of the requirements in the Act may result in the authorities forbidding further use of the hazardous chemical in question until the problem has been solved.

8.2.3 Pressure equipment

- **Legislation:** Decision by the Ministry of Trade and Industry on the safety of pressure equipment 953/1999.

- **Key requirements:** According to Decision 953/1999 a Boiler Plant Hazard Assessment has to be completed prior to the start-up of the facility and shall then be kept updated. The obligation applies, if the boiler plant includes at least one registered steam boiler, the effect of which is over 6 MW, or a registered hot water boiler of more than 15 MW, or if the boiler plant is located underground. The Decree also includes obligations regarding ways in which such a boiler plant shall be operated.

  Regarding boiler plants the hazard assessment and its up-to-date status will be checked every second year in the periodic inspections of the boiler plant by the inspection body.

- **Influence of CCS (i.e. new aspects or significantly changed requirements):** Carbon capture is not directly influencing these requirements, but as it is unclear when the carbon capture unit is seen as a part of an boiler plant, and when it is not, it might be possible that the carbon capture unit must be included in the Boiler Plant Hazard Assessment Document.

- **Time needed for the stage:** Up-dating the paperwork is not a significant task. Inspection of the pressure equipment will require a shutdown of the unit concerned.

- **Responsibility:** The owner (or holder) of the pressure equipment.

- **Decision maker:** The inspection body will inform the Finnish Safety and Chemicals Agency (Tukes) about pressure equipment causing an immediate hazard, and Tukes has the right to forbid the use of such equipment.

- **Hearing and interaction:** N/A.

- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.

- **Connections to other stages:** The Boiler Plant Hazard Assessment Document is to be completed during prior to the start-up of the facility, i.e. during the detailed design phase (See Chapter 7).

- **Significance of the stage (i.e. possible showstopper?):** Failing the pressure equipment inspection may lead to an interruption in the use of – or even replacement of – that piece of equipment.

8.2.4 Environment

- **Legislation:** Environmental protection act 527/2014, Waste act 646/2011.
- **Key requirements:** Act 527/2014 applies to all activities that lead or may lead to environmental pollution. The following principles apply to activities that pose a risk of pollution:
  - Harmful environmental impact shall be prevented or, when it cannot be prevented completely, reduced to a minimum (principle of pollution prevention and minimizing harmful impact).
  - Proper care and caution shall be taken to prevent pollution as entailed by the nature of the activity. The probability of pollution, risk of an accident, and opportunities to prevent accidents and limit their effects shall be taken into account (principle of caution and care).
  - The best available technique shall be used (principle of best available technique).
  - Combinations of various methods, such as work methods, shall be used and such raw materials and fuels shall be selected, which provide appropriate and cost-efficient means to prevent pollution (principle of best environmental practice).

  The same principles related to the activities that pose a risk of pollution stated in the general section apply during the whole lifecycle of a plant. According to Act 527/2014 the parties engaged in activities that pose a risk of pollution are obligated to prevent impact and eliminate or minimise harmful environmental effects ('polluter pays' principle). The Act also applies to activities that generate waste and to waste disposal.

  According to Environmental protection act 527/2014:
  - operators must have sufficient knowledge of their activities' environmental impact and risks and of ways to reduce harmful effects (knowledge requirement).
  - if the activities cause or may directly result in environmental pollution, the operator must take the appropriate action without delay in order to prevent pollution, or, if pollution has already resulted, to reduce it to a minimum (obligation to prevent pollution).

  In addition, the general duties and principles laid down in the Waste act 646/2011 must be observed in activities posing a risk of pollution:
  - Waste or other substances shall not be dumped or discharged on the ground/soil resulting deterioration of the soil quality and possibly endangering or causing harm to health or the environment (soil contamination prohibition).
  - Actions endangering the quality of groundwater have to be prevented (groundwater pollution prohibition).

  If a substance which may cause contamination has entered the soil or groundwater, the polluter shall notify the supervisory authority immediately (duty to notify). Any party whose activities have caused the contamination of soil or groundwater is required to restore the soil or groundwater to a condition that will not cause harm to health or the environment or represent a hazard to the environment (Duty to treat soil and groundwater).

Environmental permit is checked in fixed-terms or when the actions change essentially. According to environmental permit:

- The project executer is obligated to monitor the actions and effects of the operation (stated also in water permit).
- As a condition of environmental permit the executer is obligated to fixed-term reporting.
- The executer must follow the emissions and stay in the limits of emission standards and report in case of disturbance.
- The executer must also give an environmental notification of temporary actions causing a danger of environmental harm.

If an accident or production disturbance etc. causes emissions or generates waste that may pose an immediate and obvious risk of environmental pollution, the operator responsible for the activity must notify a supervisory authority of the incident without delay.

- **Responsibility:** Operating company.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on the Administrative judicial procedure act 586/1996.
- **Connections to other stages:** Environmental protection should be taken into consideration already during the design phase.
- **Significance of the stage (i.e. possible showstopper?):** If the requirements of the Environmental protection act are not complied, operation of the plant may be suspended.

8.3 Case specific requirements for pipelines

No additional requirements on top of those given in the General Requirements section have been identified for CO_2 pipelines

8.4 Case specific requirements for harbour facilities

In addition to what has been described in the General Requirements section, the following requirements apply to harbour facilities:

- **Legislation:** Environmental protection act 527/2014.
- **Key requirements:** Act 527/2014 applies to all activities that lead or may lead to environmental pollution. The following principles apply to activities that pose a risk of pollution:
  - Harmful environmental impact shall be prevented or, when it cannot be prevented completely, reduced to a minimum (principle of pollution prevention and minimizing harmful impact).
  - Proper care and caution shall be taken to prevent pollution as entailed by the nature of the activity. The probability of pollution, risk of an accident, and opportunities to

prevent accidents and limit their effects shall be taken into account (principle of caution and care).
- The best available technique shall be used (principle of best available technique).
- Combinations of various methods, such as work methods, shall be used and such raw materials and fuels shall be selected, which provide appropriate and cost-efficient means to prevent pollution (principle of best environmental practice).

The same principles related to the activities that pose a risk of pollution stated in the general section apply during the whole lifecycle of a plant. According to Act 527/2014 the parties engaged in activities that pose a risk of pollution are obligated to prevent impact and eliminate or minimise harmful environmental effects ('polluter pays' principle). The Act also applies to activities that generate waste and to waste disposal.

According to Environmental protection act 527/2014:
- operators must have sufficient knowledge of their activities' environmental impact and risks and of ways to reduce harmful effects (knowledge requirement).
- if the activities cause or may directly result in environmental pollution, the operator must take the appropriate action without delay in order to prevent pollution, or, if pollution has already resulted, to reduce it to a minimum (obligation to prevent pollution).

According to an environmental permit, the project executer is obligated to monitor the actions and effects of the operation. As a condition of an environmental permit the executer is obligated to fixed-term reporting. The executer must follow the emissions and stay in the limits of emission standards and report in case of disturbance. The executer must also give an environmental notification of temporary actions causing a danger of environmental disadvantages.

Environmental permit is checked in fixed-terms or when the actions change essentially. According to environmental permit:
- The project executer is obligated to monitor the actions and effects of the operation.
- As a condition of environmental permit the executer is obligated to fixed-term reporting.
- The executer must follow the emissions and stay in the limits of emission standards and report in case of disturbance.
- The executer must also give an environmental notification of temporary actions causing a danger of environmental harm.

- **Responsibility:** Operating company.
- **Appeal:** As with any administrative decisions, an appeal against the decisions taken by the competent authorities is possible based on Administrative judicial procedure act 586/1996.
- **Connections to other stages:** Environmental protection should be taken into consideration already during the design phase.

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