ASSESSMENT OF THE MARKET POTENTIAL FOR CO2 STORAGE IN DENMARK

ENERGISTYRELSEN

MAY 2021

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CONTENTS

ABBREVIATONS

Abbreviation	Explanation
AC	Active current
BECCS	Bio-energy carbon capture
CAPEX	Captial expenditures
CCC	Climate change committee (UK)
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CCUS	Carbon capture utilisation and storage
CfD	Contract for difference
CO2	Carbon dioxide
CPH	Co-generator of power and heat
DK	Denmark
EE	Estonia
FSU	Floating storage unit
GHG	Greenhouse gas
HFO	Heavy fuel oil
IPCC	International panel of climate change
IRR	Internal rate of return
km	kilometre
LNG	Liquid natural gas
LT	Lithuania
LULUCF	Land-use, land-use change and forestry
LV	Latvia
MSW	Municipal solid waste
Mt	Megaton (1,000 ton)
MtCO2/y	Megaton carbon dioxide per year
MtCO2e	Megaton carbon dioxide equivalent
NL	The Netherlands
NO	Norway
NPV	Net present value
OPEX	Operational expenditures
PL	Poland
Pre-FID	Pre-finale investment decision
SDE++	Stimulation of sustainable energy production
T&S	Transport and storage
UK	United Kingdom

1. BACKGROUND AND INTRODUCTION

Ramboll has been commissioned by The Danish Energy Agency to conduct market study of transport and storage of CO2 in Northern Europe, which will impact the extent to which CCS-capacity will be planned and developed in Denmark. The report assesses whether and to what extent there is market potential for storing CO2 exports from Northern European countries in Denmark as well as Denmark's competitiveness in being a potential European CO2 storage provider. Possible set-ups for transporting and storing CO2 in Denmark from countries deemed to have highest potential to export CO2 to Denmark are mapped to identify a selection of market-based (i.e. relevant and competitive; hereunder, cost-effective and convenient transport and storage solution for emitters) business case set-ups. An important distinction is made between business case set-ups and business models. Business case set-ups bring forth the most relevant market-based cases for which the profitability and break-even is calculated, whereas business models incorporate the organisational aspects; In this case, pivotal institutional considerations necessary to develop transport and storage infrastructure and operate it. Institutional considerations are discussed to highlight the need for state- and Government's involvement, as without it, the development of CCS solutions will not be likely since private players are not incentivised at present to establish CCS themselves. The report culminates in the presentation of selected competitive business case set-ups, including their expected profitability and a discussion of their underlying prerequisites, e.g., the necessary institutional prerequisites to achieve the estimated business case results and the advantages and disadvantages of each case.

Background

The Intergovernmental Panel on Climate Change (IPCC) has stated that carbon removal technologies will be needed to reach the climate goals set in the Paris agreement, limiting global warming to 1.5C by 2100. Carbon capture and storage (CCS) has been highlighted as an essential means to remove CO2[1].

Although there is a significant potential for CCS technologies, a well-established market does not yet exist in Northern Europe. The most advanced CO2 storage developments are not expected until the end of 2024.

In Denmark, both GEUS and The Danish Energy Agency have amongst others been proponents of CCS technology, but it was not until 2020 that CCS was discussed at the political level. Additionally, the Danish Waste Association published a memorandum in 2019, in which CCS was a pivotal part of the vision for a CO2-neutral waste sector. In 2020, the climate agreement for industry and energy ("Klimaaftalen for Industri og Energi m.v. af 22. juni 2020") was signed, stating that funding will be allocated and increased towards 2029 for market-based CCS or similar technologies, which have the aim to reduce CO2 in the atmosphere[2].

Denmark possesses many suitable reservoirs in the subsoil for storing CO2, and the Danish Energy Agency wants to be well-equipped to prepare a CCS strategy to position themselves in this emerging market. To do this, they need to understand the market for CCS, the potentials and particularly Denmark's competitiveness in the market.

As such, Ramboll has been requested to investigate the market potential for CO2 storage from Northern Europe in Denmark, an assessment of Denmark's competitiveness in this market and associated market-based business case set-ups, including the necessary prerequisites. The results of the investigating will indicate and have an impact on the extent to which CCS capacity will be planned in Denmark.

Introduction

The report is structured into three main chapters ("CCS potential", “Overview and evaluation of possible set-ups for transport and storage of CO2 in Denmark” and “Profitability assessment of CO2 storage in Denmark”), that investigates the following topics:

- Potential for CCS and exports to Denmark from ten selected Northern European countries (UK, Norway, Sweden, Finland, Poland, Estonia, Latvia Lithuania, The Netherlands and Germany);
- Mapping of possible set-ups for transport and storage of CO2 and their associated costs;
- Institutional considerations for a CCS business model in Denmark;

[1] BBC – The device that reverses CO2 emissions

[2] Regeringen - Klimaaftale for energi og industri mv. 2020

- Assessment of Denmark's competitiveness as a CO2 storage provider; and
- A business case evaluation of business case set-ups where Denmark is deemed to have a competitive advantage

CCS market potential

The aim of this assessment is to provide a thorough understanding of the market potential for CCS in the Northern European countries covered in this analysis, with a particular emphasis on identifying import opportunities, specified as the share of capturable CO2 intended for storage, that cannot be stored within the country's own CO2 storage capacity. Thus, the assessment covers estimated CCS potential within each of the ten analysed counties, the CO2 storage capacity, and, on this basis, a potential gap for the country's need to export CO2 to be stored abroad is found. The assessment will, in this sense, provide input to the volumes used in the business cases.

Overview and evaluation of possible set-ups for transport and storage of CO2 in Denmark

Potential set-ups for storage and transport are assessed to outline various options that are possible for transport and storage of CO2, as well as to calculate the costs and compare them between the options. This to identify relevant market-based business case set-ups, which are cost-efficient and where Denmark can be competitive. The input from this assessment is applied when constructing the business cases and the associated cost inputs.

This part of the analysis also discusses institutional considerations, which are important to consider in a CCS business model since there is a need for state and Government involvement as well as a mix of various bodies to establish the CCS infrastructure and operate the business. The input from this assessment will serve as some of the prerequisites for the business case set-ups in the following chapter.

Profitability assessment of CO2 storage in Denmark

This part of the analysis provides a view on whether and when selected business case set-ups will be profitable and under which pre-requisites. The business cases are chosen based on the previous analyses, which indicate potential set-ups where Denmark is competitive. These business cases will provide decision-making material for the Danish Energy Agency who will compare the different business cases.

2. DANISH ABSTRACT

CCS markedspotentiale

Den politiske opbakning til CCS varierer meget imellem de ti lande, denne analyse omfatter (Finland, Sverige, Norge, Tyskland, Storbritannien, Holland, Polen, Estland, Letland og Litauen). De lande, hvis **nationalpolitik er mest imødekommende over for CCS, er Norge og Storbritannien**. Begge har stærke støtteordninger for CCS, der målrettet udvikler teknologien og understøtter projekter, som sænker omkostningerne for CCS. Desuden har landene udviklet fordelagtige lovgivningsmæssige rammer og konkrete CCS-mål eller forpligtelser, der er fremsat med henblik på at implementere CCS på nationalt plan. De lande, hvis **nationalpolitik er mindst imødekommende over for CCS, er Polen og de baltiske lande** (Litauen, Letland og Estland). Ingen af disse har inkluderet CCS som en del af deres nuværende klimastrategi eller foreslået støtteordninger, lovgivning eller konkrete mål med henblik på at udvikle eller implementere CCS teknologi på nationalt plan. Imidlertid har disse lande anerkendt, at CCS teknologien potentielt kan blive relevant i fremtiden, hvilket indikerer en voksende politisk interesse for emnet.

De lande (som analysen behandler) med **den største CO2 udledning fra store kilder** er Tyskland, Polen, Storbritannien og Holland. I 2017 havde de en udledning på hhv. MTCO2 ~406, ~166. ~146, and ~95. Af disse lande anses **Storbritannien, Tyskland og Polen for at have de største totale CCS-potentialer**. I Tyskland og Polen kan den største del af CCS-potentialet tilskrives fossile kraftværker, hvor det i Storbritannien kan tilskrives både kraft- og varmesektoren samt de CO2-tunge industrier (olie og gas raffinaderier, mineral-, jern og stål-, kemikalie- og madvareproducenter). **Det totale CCS-potentiale i Sverige, Finland** (i begge tilfælde tilskrives det hovedsageligt papirmasse- og papirindustrien) **og Holland** (tilskrives det en kombination af både naturgasværker og de CO2-tunge industreri) **er vurderet til at være forholdsvis mindre relevant**. Derudover er CCS-potentialet i de baltiske lande vurderet til at være ubetydeligt. I denne sammenhæng grundet deres relativt lave CCS volumener.

Både **Storbritannien og Norge har høje ambitioner for national CO2 lagring** (og endda for import af CO2 fra udlandet), hvor Tyskland, Polen og Sverige er mere tilbageholdende overfor national lagring af CO2. Lagringskapaciteten i de baltiske lande anses desuden for at være uegnet til CO2 lagring.

Tyskland, Sverige og Finland anses for at have det største potentiale for at eksportere CO2 (med henblik på lagring) til Danmark, hvor **Holland og Polens anses for at være af sekundær karakter.** Storbritannien og Norge er de vigtigste konkurrenter for Danmark ift. disse Nordeuropæiske CO2- strømme. CCS-potentialet i Baltikum (Estland, Litauen og Letland) er så lavt, at det anses som værende ubetydeligt.

Overblik og evaluering af mulige set-ups for transport og lagring af CO2 i Danmark

De vejledende **CO2-volumener, som er relevante for danske CO2-lagre (inklusiv de nationale CO2 volumener), er vurderet til at være op imod ~45 MtCO2/år**. For de danske lagre anses import af CO2 fra Tyskland, Sverige og Finland som værende mest relevant. Import af CO2 fra Holland og Polen har også betydning for dem, men er vurderet til at være i relativt mindre volumener og tilskrives større usikkerhed. CO2-import fra Baltikum, Norge og Storbritannien forventes desuden at være af ubetydelig størrelse (de to sidstnævnte lande har veludviklede nationale lagringsprojekter).

Danmarks potentielt bedste lagringsmuligheder ligger i Havnsø (onshore), Gassum (onshore), Hanstholm (nearshore) og i den nordlige del af de danske olie- og gasfelter i Nordsøen. Transportmuligheder inkluderer tankskibe, fartøjer og rørledninger. Udenlandske lagre, der potentielt kan konkurrere med danske lagre, er fortrinsvist placeret i Norge eller Storbritannien.

For at sammenligne omkostningerne for forskellige sammensætninger af CO2 transport- og lagringsmuligheder er ni mulige set-ups opstillet. Dette er blevet gjort med henblik på at vurdere deres konkurrencedygtighed individuelt såvel som i kombination. De ni opsætninger inkluderer en række kombinationer af transport og lagringsmuligheder, hvilket betyder, at nogle opsætninger har behov for havne med mellem-lagringsmuligheder, mens andre ikke har. Rambøll har desuden vurderet, at det ikke er muligt at håndtere 45 MtCO2/år ved anvendelse af ét enkelt danske lager, hvilket betyder, at hvis en lagringskapacitet på 45 MtCO2/y er ønsket, er en kombination af de opstillede set-ups nødvendigt.

Table 1: Enhedsomkostninger (DKK/t) for hvert set-up ved 5 MtCO2/år (bestående af transport og lager; CAPEX, akkumuleret OPEX og nedluknings omkostninger)

Set-up	#1	#2	#3	#4	#5	#6	#7	#8	#9
	Onshore; Tankskib -> havn -> lager via rørledning	**Onshore**; Tankskib & rørledning (fra KBH) -> havn -> lager via rørledning	**Nearshore;** Tankskib -> havn -> lager via rørledning	**Nearshore;** Tankskib & rørledning (fra KBH) -> havn -> lager via pipeline	**Offshore**, Tankskib -> havn -> lager via rørledning	**Offshore**, Fartøjer -> CO2 lager	**Offshore**, Tankskib -> permanent tøjret FSU -> CO2 lager	**Offshore**, Tankskib & rørledning (fra DE) -> havn -> lager via rørledning	**Offshore,** Tankskib (SE, FI, PL & DK) -> havn -> lager via rørledning + rørledning (fra NL & DE) -> lager
DKK/t	106	91	136	133	175	207	185	166	221

Bemærk: Enhedsomkostninger præsenteret ovenfor er vist som dagens priser og ekskl. forrentning (ikke levelised)

Generelt viser omkostningssammenligningerne, at **onshore lagre generelt er de mest omkostningseffektive** (uafhængigt af transportløsningen), **efterfulgt af nearshore lagre**, og med offshore lagre som den dyreste løsning. Desuden, **giver rørledninger skaleringsfordele, hvilket betyder, at det er den mest omkostningseffektive transportløsning ved stor skala.**

Alle lagertyper og transportløsninger har fordele og ulemper udover deres respektive omkostningseffektivitet. Udover at være den billigste løsning, **har onshore lagret i Havnsø også den fordel at være placeret tæt ved store nationale CO2 kilder** (fra Københavnsområdet). Det er desuden usikkert, om lageret overhovedet kan anvendes (hvilket understreger vigtigheden af at udføre forundersøgelser i form af seismiske test og boringer), og den generelle **risiko for modstand fra offentligheden,** som kan lede til en forlænget godkendelsesproces sammenlignet med offshore lagre.

Selvom offshore lagerløsningen er den dyreste løsning, har den en række fordele, især i form af at **man ved at det praktisk muligt at etablere lageret.** Desuden er tæthedsgraden for de geologiske strukturer veldokumenteret, hvilket betyder, at det muligvis er **nemmere at få de nødvendige tilladelser** til at etablere lageret (især sammenlignet med onshore løsningen). Desuden kan noget af det **eksisterende udstyr** (i form af platforme og hjælpesystemer) **potentielt genanvendes** eller eftermonteres. Dermed har offshore lagret **potentiale for at være tidligere klar,** end onshore og nearshore løsninger.

Set-ups, der inkluderer rørledninger fra Tyskland, vil formentligt resultere i mere stabile og pålidelige CO2-volumener fra udlandet, hvilket muligvis vil gøre det nemmere (og billigere) at finde investorer. Denne type transportløsning giver kun mening når et set-up på stor skala planlægges fra starten. Set-ups baseret på skibstransport muliggør derimod en start ved mindre skala og muliggør derefter en gradvis udbygning efter behov. Bemærk, at gradvis udbygning også er muligt for onshore lageret, hvor efterfølgende etablering af rørledninger fra udledningskilder eller anden tilhørende infrastruktur også er muligt.

Dansk konkurrenceevne for CO2-lagring vurderes på baggrund af følgende kriterier for konkurrencedygtighed: løsningen er omkostningseffektivt, har lave marginalomkostninger og inkluderer muligheden for at indbygge fleksibilitet for kunden. Ud fra dette har Rambøll vurderet, at **Danmark kan tilbyde en konkurrencedygtig løsning, som er både omkostningseffektiv, fleksibelt og praktisk for de mest relevante lande (især Tyskland, Sverige, Finland og potentielt Polen)**. De mest omkostningseffektive løsninger er baseret på set-ups, hvor store mængder CO2 transporteres gennem rørledninger og efterfølgende lagres i onshore eller nearshore lagre.

Institutionelle overvejelser har ledt til disse tre key take-aways:

- Det er nødvendigt med **statslig indblanding** ift. finansiering (af forudbetalte kapitalomkostninger), risikostyring og støtte af CCS initiativer/projekter, da markedsspillere på nuværende tidspunkt hverken har kapaciteten eller økonomisk incitament til at udvikle CCS teknologi. Dermed er der stor sandsynlighed for at støtte og aktiv involvering fra den danske stat og regering vil blive nødvendigt

- Der er et behov for, at der **involveres en organisation, der på vegne af staten administrerer og bevarer et strategisk overblik** over projektet, og som sikrer at projektet forløber i overensstemmelse med planen, samt at incitamentsstrukturen effektivt demonstrerer markedsbaseret succes
- Det er nødvendigt, at en eller flere af de deltagerende parter har **operationel og teknisk ekspertise** til at drive forretningen

Rentabilitetsvurdering af CO2-lagring i Danmark

Baseret på Rambølls vurdering af Danmarks strategiske konkurrencefordele fremgår tre typer forretningsmodeller som værende de mest konkurrencedygtige.

Table 2: Overblik over forretningsmodeller

Case 1 & 2: Danmark kommer primært til at være en national CO2-lagringsudbyder på lille-til-mellemstor skala og bliver en mindre spiller på det internationale marked	**Case 3:** Danmark etablerer sig selv som en stor international CO2-lagringsudbyder samtidig med, at det nationale markedsbehov også imødekommes
I dette tilfælde lagrer Danmark hhv. 5 MtCO2/y (case 1) eller 10 MtCO2/år (case 2) og fokuserer primært på de nationale CO2 volumener; **Der er tre forskellige lagertyper, som kan anvendes i disse tilfælde:** • **1) Offshore lagring på lille skala med skibstransport til Nordsø-felterne,** hvor fartøjer transporterer CO2 primært fra kilder i Danmark direkte til Nordsø-felterne, hvor det bliver lagret • **2a): Onshore lagring på mellemstor skala i Havnsø**, rørledningstransport fra København, og skibstransport fra andre kilder • **2B): Nearshore lagring på mellemstor skala i Hanstholm**, rørledningstransport fra København og skibstransport fra andre kilder • **2C): Offshore lagring på mellemstor skala i Nordsø-felterne**, rørledningstransport fra København til Esbjerg og skibstransport fra forskellige CO2-kilder til Esbjerg (som er forbundet til offshore lageret via en rørledning) **Bemærk, at løsninger på lille skala også kan udvikles for hhv. onshore og nearshore lagre, hvor begge disse lagertyper muligvis kan være mere fordelagtige hvis sammenlignet med offshore løsningen i case 1. imidlertid omfatter denne rapport kun beregninger af omkostningerne for offshore lagre ved lille skala.*	I dette tilfælde udbyder Danmark lagring af CO2 på en stor-skala for det internationale marked. Danmark har en geografisk konkurrencefordel i form af at være strategisk tæt placeret på Tyskland – Europas størst CO2 udleder – Sverige, Finland, Polen og Holland. Danmark har desuden mulighed for at tilbyde attraktive og omkostningseffektive rørledningsløsninger til tyske CO2-volumener; rørledningen ville gå fra Nordtyskland til Esbjerg og have en kapacitet på 20 MtCO2/år. I alt vil Danmark lagre 40 MtCO2/år; 20 MtCO2/år fra Tyskland, 15 MtCO2/år fra Sverige, Finland og Polen samt 5 MtCO2/år fra nationale kilder. Denne case forudsætter involvering i det internationale CO2-lagringsmarked og anses som værende i stor skala, hvilket betyder, at denne case har en mere udbredt CO2 transport- og lagringsinfrastruktur ift. case 1 & 2, fordi flere lagrings- og transportløsninger kombineres med henblik på at opnå den ønskede skala og dermed mere effektiv udnyttelse af driftsaktiver.

Table 3: Enhedsomkostninger (DKK/tCO2) for hver underliggende forretningsmodel (bestående af transport og lager; CAPEX, akkumuleret OPEX og nedluknings omkostninger)

	Case 1 (5 MtCO2/y)	**Case 2A** (10 MtCO2/y)	**Case 2B** (10 MtCO2/y)	**Case 2C** (10 MtCO2/y)	**Case 3** (10 MtCO2/y)
DKK/t	172	82	109	132	101
NPV	-2.0 BDKK	11.5 BDKK	5.5 BDKK	2.1 BDKK	26.6 BDKK
IRR	0.2%	12%	7%	5%	9%

Bemærk: Enhedsomkostninger præsenteret ovenfor er vist som dagens priser og ekskl. forrentning (ikke levelised)

Fire ud af fem cases har en positiv NPV (nettonutidsværdi) inden for deres 30-årige livstid og har en tilbagebetalingsperiode på 8-25 år. **Det er vigtigt at bemærke, at de ovennævnte forretningsmodeller tager udgangspunkt i en antagelse om, at der vil være forretning i at udbyde CO2 lagerplads, og at prisen vil være en kombination af f.eks. CO2 priser, CO2 skatter, bevillinger, etc.** Imidlertid anses det ikke for at være nødvendigt at kende den præcise sammensætning af CO2 lagringssubsidierne for at kunne vurdere rentabiliteten og break-even for de ovennævnte cases. Tværtimod er det vigtigere at kunne estimere en repræsentativ pris for CO2 transport- og lagring baseret på et plausibelt markedsbaseret (og dermed konkurrencedygtigt) scenarie. Derfor har Rambøll udviklet en referencepris, der er baseret på de omkostninger et Nordeuropæisk land ville have i forbindelse med eksport af CO2 til et offshore lager i Storbritannien. Dette anses som værende repræsentativt for et muligt alternativ til de danske CO2-lagringsløsninger. Referenceprisen er baseret på et gennemsnit af omkostninger for en række af danske offshore lagerløsninger, som fremgår i set-ups (kapitel 5.3). Desuden er anvendelsen af en referencepris anset som værende den mest repræsentative forudsigelsesmetode, eftersom forudsiger af CO2-priser og støttemekanismer indebærer høj usikkerhed og en række uforudsigelige sammensætningsmuligheder (f.eks. usikkerhed omkring indkomst fra CO2-priser, skatter og bevillinger, allokeres eftersom den indkomst ikke udelukkende går til transport- og lagringsudbyderne i CCS værdikæden).

Forretningsmodellen med den højeste **NPV; DKK ~26.6 milliarder, er case 3** (stor-skala international CO2 lagringsløsning), primært baseret på høje årlige omsætningsvolumener (40 MtCO2/år) og stordriftsfordele, der kommer til udtryk via effektiv udnyttelse af driftsaktiver samt integration af transport- og lagerløsninger med synergi, f.eks. rørledninger, der bliver anvendt som transport til flere lagre. Desuden anvendes alle lagertyper i denne case, hvilket betyder CAPEX er lavere sammenlignet med udelukkende at anvende offshore lagre. Selvom case 3 har væsentligt højere totale omkostninger, end de nationalt fokuserede cases, forventes tilbagebetalingsperioden (**på 11 år)** at være kortere end case 1, 2B og 2C. Dette skyldes som førnævnt de høje omsætningsvolumener kombineret med stordriftsfordele/ udnyttelse af omkostningseffektive lager- og transportløsningerne.

Selvom case 1 (offshore CO2 lagring udelukkende med direkte skibstransport) **har tydelige fordele i form af fleksibilitet, giver case 1 en negativ NPV på DKK ~(2.0) milliarder** og **den længste tilbagebetalingsperiode (25 år)**. Dette skyldes primært OPEX omkostningerne for denne case, som er betydeligt højere, end de andre nationaltfokuserede cases. Bemærk, at denne case forudsætter, at CO2 udelukkende transporteres med fartøjer (den dyreste transportløsning) igennem hele projektets 30-årige livstid. Hvis transportløsningen blev optimeret i løbet af projektets levetid, ved f.eks. at udbygge med en rørledning eller en permanent FSU, kunne forretningsmodellen i denne case potentielt forbedres. Desuden medfører den generelle usikkerhed omkring omsætning en del usikkerhed i case beregninger. Rentabiliteten for denne case ville forbedres, hvis omsætningen er højre end antaget for business cases i denne rapport.

Case 2C (mellemstor skala, nationalt fokuseret case med offshore lager), giver en **NPV på DKK ~2.1 milliarder** og en **tilbagebetalingstid på 15 år**. Selvom NPV er positiv for denne case, er den dyrere end 2A og 2B, eftersom offshore lagerløsninger har højere omkostninger, end onshore og nearshore løsninger.

Case 2A (mellemstor skala, national fokuseret case med onshore lager), **har den anden højeste NPV på DKK ~11.5 milliarder** og den **korteste tilbagebetalingstid (8 år)**. **Case 2B** (mellemstor skala, nationalt fokuseret case med nearshore lager) har en **NPV på DKK ~5.5 milliarder og en tilbagebetalingstid på 13 år**. Den case har den højeste CAPEX og den anden højeste OPEX af all mellemstore cases (2A, 2B og 2C).

De ovenstående resultater er baseret på en række forudsætninger, som bl.a. inkluderer størrelsen af de forventede CO2-volumener, effektiv projektledelse, identificering af kvalificerede parter med henblik på at give ansvar for projektets implementering, finansiel støtte (både national og for case 3 også international), at de nødvendige tilladelser tildeles uden store forsinkelser, at teknologien fortsat forbedres, og at det er muligt at begynde drift senest i 2030 (i det mindste på linje med den forventede hastighed på udbygningen af den årlig lagringskapacitet). Desuden har nogle cases specifikke forudsætninger, f.eks. at de udvalgte lagre (især de mindre kendte onshore og nearshore lagre) kan anvendes til lagring af CO2, og at adgang til den pågældende offshore rørledningsinfrastruktur er godkendt før anlægsarbejdets begyndelse (og at det er muligt at eftermontere rørledningen til at håndtere store CO2-volumener), samt at de nødvendige internationale aftaler er indgået på forhånd, f.eks. en aftale med tyske firmaer og stat om eksport af CO2-volumener.

Desuden er **fordelene og ulemperne** for både case 1 & 2 (national løsning) og case 3 (international løsning) blevet **opstillet og sammenlignet** nedenfor.

Her er det vigtigt at bemærke, at nationalt orienterede løsninger er mindre komplekse og billigere (især case 2A har en konkurrencedygtig pris, den højeste IRR og den korteste tilbagebetalingsperiode). Imidlertid kan det være svært, når man starter på mindre skala, efterfølgende at udvide til større skala med fokus på internationale markedsløsninger sammenlignet med at planlægge efter stor skala fra begyndelsen. Bemærk, at for den nationalt fokuserede case i lille skala med fartøj transport (case 1), har den største grad af fleksibilitet. Det betyder, at der er mulighed for efterfølgende at udbygge til mellemstor skala (og endda stor skala, selvom denne form for udbygning til stor skala kan betyde tabt omsætning og spildte muligheder) og modificere til trinvis udvidelse. Dermed giver denne case mulighed for at udforske markedet og udskyde den endelige beslutning for den strategiske retning for projektet. Case 1 har dog de højeste enhedsomkostninger (DKK/tCO2).

Den internationalt orienterede løsning (case 3) muliggør fuld udnyttelse af markedspotentialet (og Danmarks strategiske placering tæt ved Tyskland, Sverige, Finland og Polen), ved at tilbyde en konkurrencedygtig, praktisk og potentielt bindende løsning. Denne løsning har også potentiale til at blive en del af EU's ambitiøse plan for CO2 reduktionsmål, og dermed sikrer international finansiering og risiko-/omkostningsdeling. Denne løsning er kompleks (dog ikke urealistisk, som senest vist ved etableringen af Baltic Pipe), hvor det blev demonstreret, at det er nødvendigt med meget statslig indblanding og investering. Det samme gælder, hvis en udbredt CCS-infrastruktur skal etableres. Dette ville også kræve EU's samarbejde ift. at få finansiel støtte samt hjælp til implementering af politik, der kan bidrage til at etablere et internationalt CO2 lagringsmarked. Desuden har denne løsning mere gennemslagskraft ved en eventuel forhandling, hvis den er planlagt til at være i stor skala fra begyndelsen – efterfølgende tilføjelse af ekstra lagre og infrastruktur kan have en negativ effekt på konkurrencedygtigheden af dette system samt størrelsen af de forventede CO2-volumener.

Refleksioner og anbefalinger til fremadrettet arbejde

Ud fra de vurderinger der er blevet præsenteret i rapporten og anbefalingerne til det fremadrettede planlægningsarbejde af CO2 lageringsløsninger i Danmark, er det nødvendigt at:

- **Beslutte om import af udenlandsk CO2 er ønsket**
- **Kortlægge realistiske lagerløsninger** baseret på interne præferencer og ambitioner. Dette skal opfølges med en vurdering af, om der er et økonomisk optimeringspotentiale udover de præsenterede løsninger i denne rapport (f.eks. ved store-til-middelstore løsninger)
- **Igangsætte forundersøgelser** af de potentielle lagre, med henblik på at få en fuld forståelse for deres potentiale og begrænsninger. Dette vil gavne og potentielt fremskynde godkendelsesprocessen, eftersom mere anerkendt data kan undersøges og dermed begrænse usikkerheder og risici
- Hvis ambitionen er, at Danmark etableres som en international CO2-lagringsudbyder, er det nødvendigt at **påbegynde strategiske partnerskaber og samarbejder (især med tyske stakeholders) snarest muligt**. Lignende partnerskaber findes inden for vindenergisektoren – f.eks. North Sea Wind Power Hub, som er et konsortium mellem Energinet, Gasunie og TenneT, som sammen faciliterer en accelereret implementering af offshore vindenergi i Nordsøen. Dette partnerskab kan anvedes som inspiration.

3. EXECUTIVE SUMMARY

CCS market potential

The political support for CCS varies considerably among the ten analysed countries (Finland, Sweden, Norway, Germany, UK, the Netherlands, Poland, Estonia, Latvia and Lithuania). The **countries with the most favourable national policies are Norway and UK**, both of which have strong policies aimed at CCS, support schemes aimed at advancing the technology and projects to drive down costs, favourable regulatory CCS frameworks as well as targets or commitments towards its deployment. The **countries with the least national focus on CCS include Poland and the Baltic countries** (i.e., Lithuania, Latvia, and Estonia) since none of the countries currently pursue CCS as a strategy to reach climate targets, i.e. there no supporting policies, funding schemes, regulation or targets in place to enhance CCS deployment. However, even these lowest ranking countries have acknowledged that CCS might potentially be relevant in the future, which may indicate growing political interest in the topic.

Among the analysed countries, the **highest emissions levels** from large sources are found in Germany, Poland, UK, and the Netherlands, with MtCO2 emissions in 2017 at ~406, ~166, ~146, and ~95, respectively. Concerning CCS potential, the report assesses that **UK, Germany, and Poland demonstrate the highest total capturable volumes intended for CCS** among the analysed countries. In Germany and Poland, a large share of CCS potential is linked to fossil power plants. In contrast, in UK the CCS potential is linked to both the power & heat sector and hard-to-abate industries (mineral oil & gas refineries, minerals, iron and steel, chemicals and food). **CCS potential is also assessed in Sweden, Finland** (in both cases mainly related to the pulp & paper industry), **and the Netherlands** (a combination of natural gas plants and industry). The CCS potential in the Baltic countries is assessed to be insignificant due to low volumes.

Both **UK and Norway have high ambitions for domestic storage** (and even import of CO2 from abroad), while Germany, Poland and Sweden are more reluctant to domestic store CO2. No suitable storage capacity is assessed in the Baltic region.

Germany, Sweden and Finland are deemed to have the most potential to export CO2 to Denmark with the intention of carbon storage. In contrast, the **Netherlands and Poland have secondary potential**. UK and Norway are the major competing countries for CO2 streams in Northern Europe. The potential in the Baltics (Estonia, Lithuania and Latvia) have such small amounts of CCS volumes, and thus, the potential is almost insignificant.

Overview and evaluation of possible set-ups for transport and storage of CO2 in Denmark

The indicative CO2 **volumes relevant for storage in Denmark (including domestic CO2 volumes) are estimated at up to ~45 MtCO2/y**. Import of CO2 for storage in Denmark is mainly relevant from DE, SE and FI. However, lower and more uncertain potential for CO2 import is also assessed from PL and NL, while no or insignificant import is expected from the Baltics, NO or UK (the latter two have well-developed domestic storage projects).

Available options for storage are Havnsø (onshore), Gassum (onshore), Hanstholm (nearshore) and the Northern oil and gas fields in the North Sea (offshore). Available options for transport are shuttle tankers, vessels, and pipelines. The foreign storages that could potentially compete with the Danish CO2 storages are mainly UK and Norway.

Nine different set-ups for transport and storage of CO2 in Denmark have been outlined to compare their costs and to assess which set-ups or combinations of set-ups in Denmark is the most competitive. They include different transport and storage possibilities, meaning some set-ups will require ports and intermediate storage. It is Ramboll's assessment that no single storage site in Denmark is capable of handling 45 MtCO2/y alone. Meaning, that if a capacity of up to 45 MtCO2/y is desired, a combination of different set-ups must be used.

Table 4: Cost per ton for each set-up at 5 MtCO2/y (comprise transport and storage; CAPEX, accumulated OPEX and abandonment costs)

Set-up	#1	#2	#3	#4	#5	#6	#7	#8	#9
	Onshore; Shuttle tankers -> port -> storage site via pipeline	**Onshore**; shuttle tankers & pipeline (from CPH) -> port -> storage site via pipeline	**Nearshore;** Shuttle tankers -> port -> storage site via pipeline	**Nearshore;** Shuttle tankers & pipeline (CPH) -> port -> storage site via pipeline	**Offshore**, Shuttle tankers -> port -> storage site via pipeline	**Offshore**, Vessels -> injection site	**Offshore**, Shuttle tankers -> permanently moored FSU -> injection site	**Offshore**, Shuttle tankers & pipeline (from DE) -> port -> storage site via pipeline	**Offshore**, Shuttle tankers (SE, FI, PL & DK) -> port -> storage via pipeline; Pipeline from DE & NL -> storage
DKK/t	106	91	136	133	175	207	185	166	221

Note: Costs presented above are not levelised

In general, cost comparisons show that **onshore storage is the most cost-effective solution** (both when pipeline and sea transport is applied), **followed by nearshore storage** and with offshore storage as the most expensive solution. On the other hand, **pipelines provide scale advantage and is thus the most effective transport solution at large-scale**.

When other aspects than costs are considered, both onshore and offshore solutions and transportation options (pipeline and sea transportation) have advantages and disadvantages. In addition to being the least expensive option, **the onshore storage has the advantage of being located close to the large domestic CO2 emission sources** (Copenhagen area). However, **uncertainty whether the site can be used** (and thus need for seismic tests and drilling) and the general **risk of public opposition** can lead to a longer permitting process than in case of the offshore site.

Although the most expensive option, offshore storage offers several advantages, especially in the form of **general feasibility** and demonstrated tightness, and that it can be potentially **easier to obtain necessary permits** (especially for the onshore site). Furthermore, some of the **existing equipmen**t (platforms and support systems) **can be potentially reused**, meaning that the offshore solution can be **potentially even quicker implemented** than the onshore or nearshore solution.

Solutions with a pipeline from Germany would provide a more certain CO2 stream from abroad, making it potentially easier (and cheaper) to find investors. On the other hand, this type of solution is only meaningful when the full-scale operations are planned for construction from the beginning, while sea transportation enables small-scale start with gradual build-up. Note that a more gradual start is also possible in case of the onshore storage, where pipelines from sources and other connecting infrastructure can be added afterwards.

When assessing the competitiveness of Danish CO2 storage, the general criteria for competitiveness have been defined: a low-cost solution with low marginal cost and the ability to create a solution that allows flexibility. Based on that, it is Ramboll's assessment that **Denmark can offer a competitive solution highly that is both cost-effective, flexible and a convenient option for the target countries (especially Germany, Sweden, Finland and potentially Poland)**. The most cost-competitive solutions include set-ups where large CO2 amounts are contracted via pipeline and those that comprise or combine onshore and nearshore storage sites.

Institutional considerations suggest three main key take-aways:

- The necessity of **state involvement** in terms of funding (upfront capital expenditure), risk management and supporting the initiatives, since other actors do not have the capacity or economic incentive at present to drive the development for CCS on their own. Thus, there is most likely a need for state-aid and state involvement in Denmark as well, and the Danish Government will probably need to take a supportive role in the CCS initiative
- The need for a **body which acts on behalf of the state and administers and maintains the strategic overview** of the project progress and follow-up to ensure the project is progressing accordingly and the incentive structures are in place working efficiently to demonstrate market-based success

- The need for parties who possess **operational and technical experts** who can execute the business

The institutional considerations are one of the key prerequisites for the results of the business case set-ups. Mainly, it is important to note that the reference price presented in the profitability assessment entails state-aid. Thus, without state-aid, the revenue price and the business case results would not be feasible.

Profitability assessment of CO2 storage in Denmark

Based on the assessment of Denmark's competitive traits, three overarching business cases are considered to be the most competitive:

Table 5: Overview of the business cases

Case 1 & 2: Denmark to become primarily a small-to-medium sized domestic CO2 storage provider, while serving the international market in small-scale	**Case 3:** Denmark to become an established large-scale international CO2 storage provider while serving the domestic market simultaneously
In this case, Denmark is storing CO2 for 5 MtCO2/y (case 1) or 10 MtCO2/y (case 2) and will focus primarily on domestic CO2 volumes; There are **three different storage placement options for these cases**: • **1): Offshore small-scale storage with sea transportation only (no pipelines or ports) in the North Sea fields**, with vessels transporting CO2 directly from source points in Denmark to the offshore North Sea fields where it is injected • **2A): Onshore medium-scale storage in Havnsø**, with a pipeline from Copenhagen, and sea transport from other sources • **2B): Nearshore medium-scale storage in Hanstholm**, with a pipeline from Copenhagen and sea transport from other sources • **2C): Offshore medium-scale storage in the North Sea fields**, with a pipeline from Copenhagen to Esbjerg and shuttle tankers from various CO2 sources to Esbjerg (which is connected with the offshore site via a pipeline) **Note that small-scale cases could also be developed for onshore and nearshore storage, and these solutions could potentially have similar advantages and lower costs than the offshore solution in case 1. However, the scope of this report only comprises the offshore storage for the small-scale solution.*	In this case, Denmark is a large-scale CO2 storage provider for international markets. Denmark has a competitive advantage in terms of its location, as Denmark is strategically located in close proximity to Germany – the largest CO2 emitter in Europe – as well as Sweden, Finland, Poland and The Netherlands. Denmark can provide an attractive and cost-effective pipeline solution for German CO2 volumes, a pipeline spanning from Northern Germany to Esbjerg serving 20 MtCO2/y. In total, Denmark will store 40 MtCO2/y; 20 MtCO2/y from Germany; 15 MtCO2/y in total from Sweden, Finland and Poland, as well as 5 MtCO2/y domestically from Denmark. The large-scale international case is much more widespread in terms of the required CCS infrastructure than compared to case 1 & 2 and combines various storage and transport solutions to achieve desired scale and economies of scale.

Table 6: Cost per ton underlying each business case (comprise transport and storage; CAPEX, accumulated OPEX and abandonment costs)

	Case 1 (5 MtCO2/y)	**Case 2A** (10 MtCO2/y)	**Case 2B** (10 MtCO2/y)	**Case 2C** (10 MtCO2/y)	**Case 3** (10 MtCO2/y)
DKK/t	172	82	109	132	101
NPV	-2.0 BDKK	11.5 BDKK	5.5 BDKK	2.1 BDKK	26.6 BDKK
IRR	0.2%	12%	7%	5%	9%

Note: Costs per ton presented above are not levelised

Four out of five cases result in positive NPV values within a 30-year lifetime and range from a payback period between 8-25 years. However, it is **pivotal to note that the assessed business cases take a point of departure in the assumption that there will be a business case for CO2 storage providers, and the price will be a combination of, e.g., CO2 prices, CO2 taxes, grants etc**. However, the way in which the price is subsidised is not deemed necessary to assess the profitability and break-even of the business cases. Rather, it is important to forecast a price that is representative of a feasible market-based (i.e. competitive) scenario, and thus, we have developed a reference price for transport and storage, which is based on what it would cost for the export countries to export their CO2 to an offshore UK storage, which is deemed a representative, competitive and feasible alternative to Danish CO2 storage solutions. The reference price is based on an average of the various Danish offshore storage alternatives presented in the set-ups (Chapter 5.3). Further, utilising a reference price is seen as the most representative methodology, since forecasting the CO2 price and subsidy mechanisms includes high uncertainty and an array of the possible pathway (e.g., uncertainty around how income from CO2 costs, taxes and grants are allocated, since they are not solely allocated to CCS).

The business case scenario showing the highest positive **NPV; DKK ~26.6 billion, is case 3** (large-scale international CCS solution), which is mainly due to the high revenue volumes per year (40 MtCO2/y) and economies of scale from large-scale operations and from combining solutions e.g., pipelines utilised for different types of storages. Furthermore, this case includes all types of storages, meaning that CAPEX is lower than if only offshore storage was applied. Although case 3 has a significantly higher total cost than the domestic cases, the investment payback (**payback period is 11 years**) is expected sooner than for 1, 2B and 2C, again due to expected large CO2 volumes combined with economies of scale/ use of price-effective storage and transport solutions.

Although providing a clear advantage in form of flexibility, Case 1 (small-scale, domestically focused case with sea transportation only) **results in a negative NPV (DKK ~ (2.0) billion)** and the **longest payback period (25 years)**. The main reason is that this case has a considerably higher OPEX than the rest of the domestically focused cases and the highest cost per ton CO2 among all cases. However, it is important to note that the case is built on the assumption that only vessels will be used for the transportation of CO2 (which is the most expensive transportation solution) during the 30-year business case period. If the transportation is optimised during the ramp-up, by, e.g. adding a pipeline or permanently moored FSU, the business case could improve. At the same time, the revenue applied in the model is difficult to determine, and there is therefore associated uncertainty with regards to the business case results – i.e. business case would improve with higher revenue.

Case 2C (medium-scale, domestically focused case, with offshore storage) **posts an NPV of DKK ~2.1 billion** and a **payback period of 15 years**. While this is a positive NPV it is more expensive than 2A and 2C since offshore storage sites are more expensive than onshore and nearshore solutions.

Case 2A (medium-scale, domestically focused case, with onshore storage) **results in the second-highest NPV of DKK ~11.5 billion** and has the **shortest payback period (8 years)**. **Case 2B** (medium-scale, domestically focused case, with nearshore storage) has a **NPV of DKK ~5.5 billion and a payback period of 13 years**. This case has the highest CAPEX of all medium-size cases (i.e. 2A, 2B, 2C). However, OPEX is the second-lowest.

The results above are based on several prerequisites, including expected CO2 volumes, strong project management and identification of qualified, responsible parties, financial support (both nationally and in case 3 also internationally), that necessary permits are obtained without major delays, technological enhancement and ability to start the operations no later than 2030 (or at least in line with the volume uptake). Furthermore, some case-specific prerequisites apply, e.g. that the reservoirs (especially the less known onshore and nearshore storages) can be used for storage of CO2 and availability of the existing offshore pipeline infrastructure in time for the start of constructions works (and that it is possible to fully retrofit it to handle the large CO2 volumes) and that necessary international agreement, e.g., with German companies and state are secured upfront before the pipeline is constructed. For case 1 (small-scale and domestically focused case), one important prerequisite is that oil and gas companies possessing the concession rights are willing to switch from oil & gas activities to CO2 storage.

Furthermore, **pro's and con's have been compiled** for both case 1 & 2 (domestic solution) and case 3 (international solution).

It is essential to highlight that the domestic-oriented solutions are less complex and more affordable options (especially case 2A, which offers a highly price competitive option with the highest IRR and with the shortest payback period). However, when starting at a smaller scale, it can be in many cases more difficult to move towards large-scale and international market solutions than starting at large-scale from the beginning. On the other hand, the small-scale domestic case with vessel transportation (case 1) is the one providing the highest degree of flexibility, as it can be ramped up to the medium-scaled solution (or even large-scale, although choosing this way around can lead to lost opportunities), and modified into other solutions stepwise. Consequently, this case gives the possibility to explore the market before making the final decision on the strategic direction. However, this case has also the highest total cost per ton of CO2.

The internationally oriented solution (case 3) enables full utilisation of the market potential (and Denmark's strategic location, with close proximity to DE, SE, FI and PL) by offering a price competitive, convenient, and potentially binding solution. This solution can also play into the EU's plan to reach ambitious CO2 reduction targets and thus secure international financing and cost/risk-sharing. On the other hand, this solution is significantly more complex (although not unrealistic, as proven by the recent Baltic Pipe project), it would imply need for extensive state involvement and investments in widespread CCS infrastructure and also require EU to cooperate in continuing to support and pass policies that will aid the CCS market. Furthermore, this solution is the most meaningful if planned at large scale from the beginning - adding storages or infrastructure at a later time can impair the competitiveness of this system and also expected CO2 volumes.

Reflections on recommended next steps

Based on the assessment presented in this report, following next steps are recommended to move forward with planning of the CCS solution in Denmark:

- **A decision needs to be made with regards to whether import of foreign CO2** is desired
- **Realistic storage options should be mapped** based on internal preferences and ambitions. This should be followed by an assessment of whether there is economic optimisation potential in other combinations than presented in this report (e.g. large-to-medium-sized solutions)
- **Feasibility studies should be carried out** to gain a complete understanding of the potential and limitations of the considered solutions. This will also benefit and potentially speed up the process, as more detailed and reliable data can be presented and thus limit uncertainties and risks
- If the ambition is to become an established large-scale international CO2 storage provider, **initiation of strategic partnerships and collaborations (especially with German stakeholders) should be launched as soon as possible**. Similar alliances are currently existing within renewable energy – e.g. the North Sea Wind Power Hub, which is a consortium between Energinet, Gasunie and TenneT, jointly facilitating an accelerated deployment of large-scale offshore wind in the North Sea, and can be used for inspiration

4. CCS MARKET POTENTIAL

This chapter aims to provide a thorough understanding of the market potential for CCS in the Northern European countries covered in this analysis, with a particular emphasis on import opportunities, specified as the share of capturable CO2 intended for storage, that cannot be stored within the country's CO2 storage capacity.

The chapter, therefore, provides an overview of the link between CCS needs and the CO2 storage capacity within each of the Northern European countries and, based on this potential deficit, an assessment of the potential volumes that need to be exported to other countries.

4.1 KEY CONCLUSIONS ON THE CCS POTENTIAL IN NORTHERN EUROPE

This section provides a general overview of this chapter's key conclusions. For detailed elaborations, the report refers to the following sections covering each country concerning assessments of CCS potential in the country based on reviews of CO2 national targets and policies, estimations of volumes relevant for CCS, and estimations of CO2 storage potential.

Among the analysed countries, the highest emissions levels from large sources are found in Germany, Poland, UK, and the Netherlands, with MtCO2 emissions in 2017 at ~406, ~167, ~146, and ~95, respectively. However, **among the analysed countries, the report finds that the political support for CCS varies considerably**. The **countries with the most favourable national policies are Norway and the UK**, both of which have strong policies aimed at CCS, support schemes aimed at advancing the technology and projects to drive down costs, favourable regulatory CCS frameworks as well as targets or commitments towards its deployment, yet both countries highlight that deployment of CCS at scale is subject to costs coming down sufficiently. The Netherlands is ranked as the third-most CCS favourable country with respect to policy support, having strong policies aimed at CCS in place and targets for its deployment, yet considering CCS to be a transition solution. Countries ranked medium include Sweden, Germany, and Finland, which acknowledge CCS as necessary for reaching climate neutrality and have some supporting policies in place yet assessed not to be sufficient for large-scale CCS deployment. The **countries with least national focus on CCS include Poland and the Baltic countries** (i.e., Lithuania, Latvia, and Estonia) since none of the countries currently pursue CCS as a strategy to reach climate targets, indicated by the lack of supporting policies, funding schemes and regulation as well as lack of targets for its deployment. However, even these lowest ranking countries have acknowledged that CCS might potentially be relevant in the future, which may indicate growing political interest in the topic.

With respect to CCS potential, the report assesses that **UK, Germany, and Poland demonstrate the highest total volumes of capturable CO2 intended for storage ("CC potential")** among the analysed countries, with total estimated Mt CCS potential between 2022-2050 at 1,986, 871, and 591, respectively. In Germany, a large share of CCS potential is linked to fossil power plants (natural gas and biomass-fire plants), which is similar to Poland (coal and biomass CHP and natural gas), while in the UK the CCS potential is linked to both the power & heat sector (hydrogen) and hard-to-abate industries (mineral oil & gas refineries, minerals, iron and steel, chemicals and food). Although somewhat lower, **CCS potential is also assessed in Sweden, Finland, and the Netherlands** – in Sweden and Finland, the potential is mainly related to the pulp & paper industry, while in the Netherlands, the potential is a combination of both power plants (natural gas) and industry. The capturable potential in the Baltic countries is assessed to be insignificant due to low volumes.

The countries with their own CO2 storage capacity include the most significant emitters (Germany, Poland, UK, and the Netherlands) and Norway and Sweden, with estimated MtCO2 storage potential at 95,000, 78,000, 78,000, 4,000, 103,000 and 6,000, respectively. However, the **attitude towards domestic storage varies among the countries with storage potential** - while **UK and Norway have high ambitions for domestic storage (and even import of CO2 from abroad), Germany, Poland and Sweden are more reluctant towards domestic storage of CO2**. Low storage potential is estimated in Latvia and Lithuania, and for this reason, political attention to domestic storage is low, while unsuitable geological conditions in Finland and Estonia make domestic storage impossible.

The assessment of each country's possible needs to export CO2 for storage abroad, in order to reduce the deficit between CCS potential and domestic storage capacity finds that **the highest potential in relation to CO2 storage in Denmark is assessed with regards to Germany, Sweden and Finland**, as these countries have significant CCS potential and limited, or no storage capacity (or no intentions to use own storage). **Some potential, although more uncertain, could also be from the Netherlands,** since industry cluster projects, such as the CO2TransPorts, identify the risk that CO2 transport demand might exceed the storage capacity[3] and the Dutch Government acknowledges that it will be challenging for The Netherlands to achieve emissions reduction by scaling up renewables and thus, CCS could be a potential source to make up for this potential gap[3]. **Similarly, CO2 imported from Poland may also become relevant for storage in Denmark**, as it is highly uncertain whether (and when) Poland will utilise its own storage. The potential for Denmark is assessed below with regards to Norway and UK due to the high possibility that the countries will capture and store the CO2 domestically. In addition, no potential for Denmark is assessed in the Baltic countries, as emissions are insignificant and CCS potential is uncertain. The table below provides a quick overview of each individual country's CCS potential.

Table 7: Summary of CCS potential in selected countries

Country	FI	SE	NO	DE	UK	NL	PL	EE	LT	LV
CO2 emissions 2017 (MtCO2)	46.8	51.3	25.4	406.2	146.3	95.0	166.7	24.7	5.2	1.0
National CCS focus/support	◑	◑	●	◑	●	◕	◔	◔	◔	◔
CCS targets set	✗	✓	✓	✗	✓	✓	✗	✗	✗	✗
Total CCS potential (MtCO2) 2022-2050	279[4]	349	111	871	1,986	274	591	6	7	2
Average quantity of capturable CO2 intended for storage (MtCO2): - 2022-2040 - 2041-2050	7 16	14 19	4 6	35 49	50 119	12 15	19 34	0.2 0.4	0.4 0.3	0.1 0.1
Own storage capacity (Mt)	-	6,000	103,000	95,000	78,000	4,000	78,000	-	2,286	3,400
Own storage potential/support	N/R	◔	◕	◔	◕	◑	TBD	N/R	◔	◔
Potential for DK storage	HIGH	HIGH	LOW	HIGH	LOW	MEDIUM	MEDIUM	LOW	LOW	LOW

✓ The green tick mark indicates that the conditions for CCS are assessed to be favourable; ✗ The red cross indicates that the conditions for CCS are assessed to be unfavourable.
▬ The yellow bar indicates that it is uncertain whether the conditions for CCS are favourable or unfavourable. ○ Low value ● High Value

[3] European Commission, "Candidate PCI projects in cross-border carbon dioxide transport networks"
[4] IEA – The Netherlands 2020 Energy Policy Review

4.2 COUNTRY DEEP-DIVES

4.2.1 Finland

4.2.1.1 Summary of CCS potential in Finland

Finland's CO2 emissions from large sources in 2017 were ~47 MtCO2[5]. The largest emissions sources are pulp and paper (43%) and thermal power and heat (36%).

Finland aims to become carbon neutral in 2035, which is the most ambitious target of all countries. However, the country does not have any CCS specified targets and is relying heavily on natural carbon sinks from forests and soils to balance its emissions in 2035.

No national support systems for CCS development and deployment are in place in Finland.

CCS potential in Finland is estimated at 279 MtCO2 between 2022 and 2050 and on average 7 MtCO2/y between 2022 and 2040 and 16 MtCO2/y between 2041 and 2050 for both the power & heat sector and the industry sector. The potential has been assessed primarily with respect to BECCS, as Finland has the largest pulp and paper industry in Europe.

CO2 storage is not possible in Finland since the country does not have suitable geological formations.

The relevance for storage in Denmark is potentially high since potential bio-CCS is high, and Finland will not develop national storage sites.

Below is an overview of the CCS potential in Finland.

Table 8: Summary of CCS potential in Finland

SUMMARY OF CCS POTENTIAL		
Category	**Indicator**	**Comments**
CO2 emissions 2017 (MtCO2) Plants >100 ktCO2	46.8	CO2 emissions from the largest point sources, mainly generated by the pulp and paper industry using biomass, followed by the power and heat industry.
Co2 reduction targets	✓	• 2030: -39% from 2005 levels (non-EU ETS)[6] • 2035: Carbon neutral (all sectors) • 2050: -80-95% emissions mitigation from 1990 levels
National CCS focus/Support	◐	CCS has not been in the spotlight in Finnish policies and targets. However, in Finland's long-term GHG development strategy, CCS is presented in one of two potential pathways where Finland can achieve its long-term CO2e 2050 reduction goals[7].
CCS targets	✗	Finland has no CCS targets and has not mentioned CCS in its national energy and climate plan. Finland plans to phase out fossil fuels and rely on natural carbon sinks to achieve net-zero emissions.
Total CCS potential (MtCO2) 2022-2050	279	Finland's CCS potential is mostly comprised of potential from bio-CCS derived from the pulp and paper industry as well as power plants utilising biomass as fuel.
Own storage capacity (Mt)	-[8]	No suitable geological formations for CO2 storage are present in Finland
Own storage potential/support	○	Not relevant
Potential for DK storage	**High**	**Potentially high significance to DK due to high CCS potential, and the fact that Finland will not develop national storage sites.**

[5] EEA and E-PRTR

[6] Finland's Integrated National Energy and Climate Plan (NECP 2030) – CO2 reduction target for EU ETS sectors not available

[7] Finland will publish an updated Climate Act soon, which will enter into force in the spring of 2021, in which the target for 2050 (-80% emissions reduction) will be updated along with 2030 and 2040 targets that are in line with the path towards carbon neutrality in 2035

[8] Technical Research Centre of Finland "CO2 Capture, Storage and Reuse Potential in Finland"

4.2.1.2 CCS national targets and policies Finland

Finland is aiming to become carbon neutral in 2035. In the context of the Finnish Government Programme, "carbon neutrality" refers to a balance between Finland's regional GHG emissions and removals by sinks. Finland prioritises emissions reduction (mitigation) but notes in its government programme that it will heavily rely on natural carbon sinks (from forest and soil) as a supplemental measure. Current actions are not aligned with the target as these actions account for only 16 Mt of emissions reductions of the 35 Mt that will be necessary. To meet the gap (19 Mt), The Finnish Climate Change Panel estimates that carbon sinks will need to be at least 21.4 Mt.[9] The emissions reductions measure are carried out in a way that is fair from a social and regional perspective which involves all industries and sectors of society.

Finland does not have any CCS targets. However, in Finland's long-term greenhouse gas emission strategy, two pathways are described to reach carbon neutrality in 2035, one of which includes the usage of CCS (mainly from bio-CCS), where the total emissions reduction is estimated at 14 MtCO2e in 2050. The other pathway outlines extremely stringent emission reduction across all sectors (-87.5% reduction vs. -82% in the scenario with CCS in 2050), including industrial processes where it is deemed most difficult to achieve substantial reductions.

Finland has no national support system for CCS in place at the time. However, in 2011-2015 they ran a Carbon Capture and Storage research program allocating EUR 15 m for the CCS research.

Finland has implemented The Act on CCS, providing a general framework for CCS, with activities subject to the general environmental licensing system under the Environmental Protection Act. In addition, Finland has ratified the London Protocol that allows CO2 export to other states for storage purposes. Additionally, Finland prohibits CO2 storage due to the lack of suitable geological formations.

Table 9: CCS national targets and policies in Finland

CCS NATIONAL TARGETS AND POLICIES		
Category	**Indicator**	**Comments**
Country CCS policy maturity/potential	◐	The policy maturity considered low/medium since Finland follows the EU directive and has also implemented specific CCS legislation.
National CO2 reduction targets	✓	• 2030: -39% from 2005 levels (non-EU ETS)[10] • 2035: Carbon neutral (all sectors) • 2050: -80-95% emissions mitigation from 1990 levels[11]
National CCS targets	✗	CCS targets have not been set.
CCS policies and legislations	—	Finland's CCS legal and regulatory framework is based upon the EU storage Directive and regulates activities through CCS-specific legislation, most notably The Act on CCS[12].
CCS funding	✗	No national support systems in place.
CCS storage-related policies	—	Finland has legislative limitations on geological storage in the Finnish territory because of the lack of suitable geological formations. However, storing volumes up to 100,000 tonnes for the purposes of research and development of technology may be permitted.[13]

[9] Finnish Government, "A fair transition towards a carbon neutral Finland"

[10] Finland's Integrated National Energy and Climate Plan (NECP 2030) – CO2 reduction target for EU ETS sectors not available

[11] Finland will publish an updated Climate Act soon, which will enter into force in the spring of 2021, in which the target for 2050 (-80% emissions reduction) will be updated along with 2030 and 2040 targets that are in line with the path towards carbon neutrality in 2035.

[12] The Act on CCS provides the general framework for CCS, with activities subject to the general environmental licensing system under the Environmental Protection Act. CCS projects will also be subject to a mandatory Environmental Impact Assessment under national EIA legislation, whenever they are executed in facilities for which an EIA is mandatory, as well as whenever the overall amount of captured CO2 under the project is 1.5 megatonnes or more.

[13] Legislation on carbon capture and storage

4.2.1.3 CCS potential (capturable CO2 intended for storage) in Finland

In 2017, Finland's large stationary sources emitted in round numbers ~47 MtCO2 in 2017, of which the power sector comprises ~17 MtCO2 and the industry ~29 MtCO2.

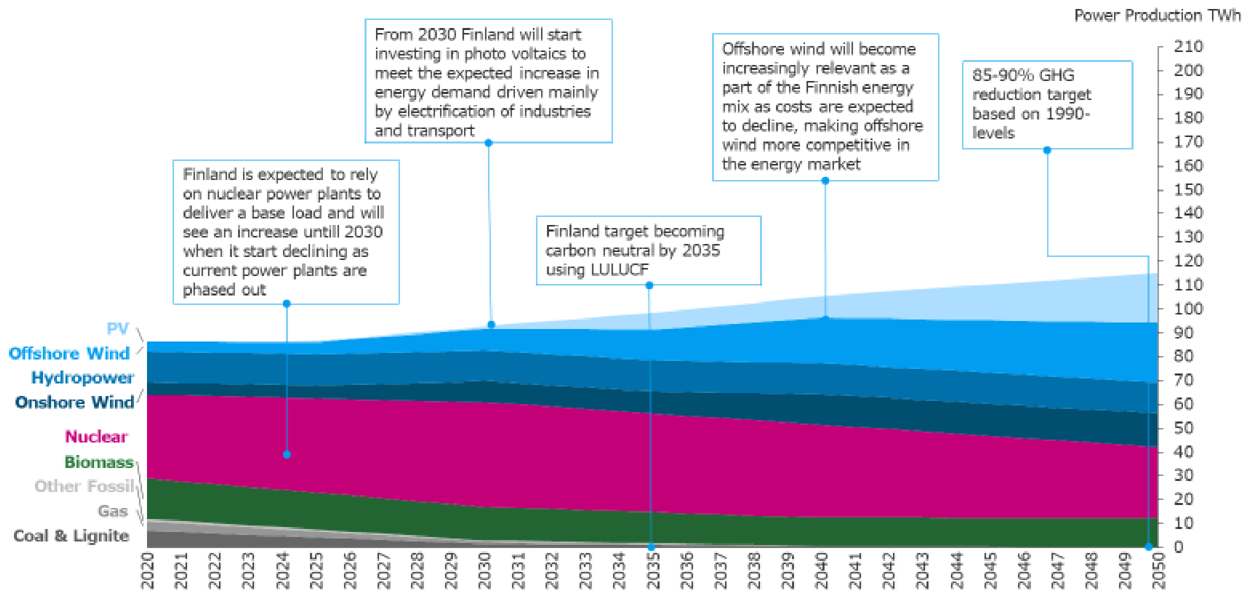
Finland is one of the leading pulp and paper producers in Europe and thus, has significant biogenic emissions from the pulp and paper industry - estimated at ~20 MtCO2 in 2017.

Additionally, the other industry sectors comprise mineral oil & gas refineries, cement production, iron and steel production as well as chemicals production, where some CCS potential is identified. CCS could pose a medium-term solution to remove fossil fuel CO2, according to the Ministry of Economic Affairs and Employment of Finland; especially if Finland is to achieve their ambitious carbon neutrality target in 2035, they will need to look into all mechanisms[14]. In the long-term, however, the goal is to remove all usage of fossil fuels in Finland, and this reduces the potential for CCS with regards to CO2 from fossil fuels.

Thermal power and heat generation (16.9 MtCO2 in 2017) sources are considered to have low to moderate potential since Finland is using and will use large shares of biomass at their CHP and district heating plants where bio-CCS could otherwise have potential.

The calculated capturable quantity of CO2 intended for storage (CCS potential) is estimated at an average 7 MtCO2/y between 2022 and 2040 and 16 MtCO2/y between 2041 and 2050 for both the power & heat sector and the industry sector.

Figure 1: Finland's potential energy mix towards 2050



Source: Ramboll Analysis; Ministry of Economic Affairs and Employment of Finland, "Finland's long-term low greenhouse gas emissions development strategy"

[14] Interview with Ministry of Economic Affairs and Employment of Finland

Table 10: CCS potential in Finland

Sector	CO2 emissions 2017, MtCO2	Capturable quantity of CO2, MtCO2 (avg. MtCO2/y[15])		Comment
		2022-2040	2041-2050	
Power & Heat	**17.1**	**32** **(2)**	**57** **(6)**	• The overall significance of CCS within the Finnish power & heat sector is considered low to moderate due to Finland's large usage of biomass within this sector, which could be relevant for BECCS. Finland is to date one of the leading countries in forest-based biomass to energy, and this is expected to remain at stable levels, while other forms of energy such as renewable and nuclear are making up for the power and heat growth going forward[16]. Finland has some of the largest power plants situated by the shore in Helsinki, which incentivises the usage of BECCS since the country does not have to transport these amounts by land • The potential for BECCS is estimated to begin from 2025 as Finland is assumed to deploy carbon reduction measures sooner due to its carbon neutrality target already in 2035. The capture share for BECCS is assumed to increase from 5% in 2025 and increases to 80% in 2050 • The capturable volume of CO2 intended for storage within the segment is estimated at ~5.7 MtCO2/y in 2050
Industry	**29.4**	**87** **(5)**	**103** **(10)**	• Finland has quite small amounts of emissions coming from the fossil fuel-driven industry, which is relevant for CCS, including mineral oil & gas refineries (3.1 MtCO2/y), cement production (1.3 MtCO2/y), iron and steel production (1.5 MtCO2/y) as well as chemicals production (0.7 MtCO2/y) • The significance of CCS for the fossil driven industrial sector is low since Finland is prioritising natural carbon sinks as opposed to carbon removal technologies. However, if Finland is to reach their ambitious carbon neutrality target in 2035, it will need to consider all options to reduce its emissions • Ramboll has assumed that CCS could be used in the industry already starting from 2025 to achieve the climate goals and continue from a 5% capture share up to 30% towards 2050. However, according to the Ministry of Economic Affairs and Employment, CCS for fossil fuels will be a medium-term solution since coal, and natural gas will be phased out in the long term, and according to scenario studies, 82-87.5% (compared to 1990 levels) of emissions are mitigated by 2050[17].**Error! Bookmark not defined.** Thus, Ramboll has estimated a decrease of CO2 within the industry to follow this trajectory • The total capturable volume intended for storage is estimated at up to ~1 MtCO2/y in the early 2030s and decreases to 0.5 MtCO2/y in 2050, as fossil fuels are phased out • In addition to the industries above, Finland has a significant pulp and paper industry, and thus, bio-CCS could be relevant. Pulp & paper plants are often located close to coastlines and rivers (as their processes require significant amounts of water), making it potentially easily accessible to collect emissions. • Additionally, bio-CCS is not part of Finland's current climate strategy, but they might deploy it to meet their climate goals. As with the other industries above, the deployment is assumed from 2025 with a 5% capture rate until however in contrast to the above, the rate increases to 60% in 2050 • The total capturable volumes intended for bio-CCS (pulp and paper industry) is estimated at up to 9.7 Mt/y (from ~2035)
Other	**2.9**	**-**	**-**	• No other significant potential areas have been assessed

[15] Average CO2 capturable amount is calculated for the time period 2025-2040 as well as 2041-2050

[16] Ministry of Economic Affairs and Employment of Finland, "Finland's long-term low greenhouse gas emission development strategy", 2020

[17] Ministry of Economic Affairs and Employment of Finland, "Finland's long-term low greenhouse gas emission development strategy", 2020

4.2.1.4 CO2 storage potential in Finland

Finland does not have any geological structures suitable for carbon storage[18].

Moreover, the country does not currently have any carbon capture projects[19]but has allowed carbon export, as described in section 4.2.1.2. The Finnish attitude to CCS technology is favourable, but legislative barriers are currently preventing implementation[20].

Finland will not be able to domestically store captured carbon from any upcoming CCS activity and will have to utilise CO2 storage capacity in other countries.

4.2.2 Sweden

4.2.2.1 Summary of CCS potential in Sweden

Sweden's CO2 emissions from large sources in 2017 were ~51 MtCO2. Most emissions relate to the pulp and paper industry using biomass (22.8 MtCO2).

Sweden is committed to achieving climate neutrality by 2045, and CCS is acknowledged as a means of achieving negative emissions, mainly through the deployment of BECCS. CCS policy measures such as investment support are in place, though currently not identified to be sufficient for the realisation of full-scale projects. CCS targets have been set for 2030 (3.7 MtCO2e total, of which 1.8 MtCO2 from BECCS) and 2045 (10.7 MtCO2e total, of which 3-10 MtCO2 from bio-CCS). To achieve Sweden's climate targets, ~9% of required emissions reductions by 2030 and 15% by 2045 can be achieved through other complementary means such as CCS.

Support systems for CCS are in place through, e.g., the Swedish Energy Agency, allocation of SEK 100 million to CCS and BECCS pilot projects, and initiatives to support R&D projects within bio-CCS with SEK 50 million annually from 2020-2027.

CCS potential in Sweden is estimated at 349 MtCO2 between 2022 and 2050 and 14 MtCO2/y between 2022 and 2040, and 19 MtCO2/y between 2041 and 2050. The majority of these emissions relate to the pulp and paper industry.

Storage potential in Sweden is estimated at 6,000 Mt in aquifers. Although offshore CO2 storage is permitted, Sweden is expected to rely on the transport of CO2 as the Swedish official report on a strategy for negative greenhouse gas emissions concluded that rather than prioritising establishing a storage site, Sweden should depend on sea transport to storage outside Sweden.

The relevance for storage in Denmark is deemed high, as Sweden has national plans to develop CCS technology but not for the development of national storage sites.

Below is an overview of the CCS potential in Sweden.

Table 11: Summary of CCS potential in Sweden

SUMMARY OF CCS POTENTIAL		
Category	**Indicator**	**Comments**
CO2 emissions 2017 (MtCO2) Plants >100 ktCO2	51.3	CO2 emissions from largest point sources; mainly by the pulp and paper industry using biomass, followed by the heat and power generation, and iron and steel industry
CO2 reduction targets	✓	• 2030: -20% from 2005 levels (EU ETS) and -63%[21] from 1990 levels (non-EU ETS)[22] • 2040: -75% from 1990 levels (national target)[23] • 2045: Net zero emissions

[18] Technical Research Centre of Finland, "CO2 capture, storage and reuse potential in Finland"

[19] The Global CCS Institute, "Global Status of CCS 2020"

[20] Interview with Ministry of Economic Affair and Employment of Finland

[21] Equivalent to -59% reduction from 2005 levels

[22] Sweden's Integrated National Energy and Climate Plan (NECP 2030)

[23] Regeringens Proposition 2019/20:65: "En samlad politik för klimatet – klimatpolitisk handlingsplan"

National CCS focus/Support	◑	Sweden recognises the important role that CCS will have in reaching CO2 reduction targets, yet current policy measures may not be sufficient for realisation of full-scale CCS projects.
CCS targets	✓	Sweden has set CCS targets for 2030 (3.7 MtCO2e total, whereof 1.8 MtCO2 from bio-CCS) and 2045 (10.7 MtCO2e total, whereof 3-10 MtCO2 from bio-CCS). ~9% of the required reductions in CO2 emissions by 2030 and 15% by 2045[24] can be achieved through other complementary means such as CCS.
Total CCS Potential (MtCO2) 2022-2050	349	The majority of these emissions is related to the pulp and paper industry.
Own storage capacity (Mt)	6,000[25]	6,000 Mt of storage in aquifers
Own storage potential/support	◔	Offshore CO2 storage is permitted. However, Sweden is expected to rely on the export of CO2 as uncertainty regarding national storage capacity was deemed too high while reliable storage sites in the North Sea were available
Potential for DK storage	**High**	**High significance to DK as Sweden has national plans to develop CCS technology but not to develop storage sites.**

4.2.2.2 CCS national targets and policies Sweden

Sweden is aiming to become carbon neutral in 2045, expecting 85% of reductions to be delivered through emissions reduction activities while the remaining 15 percentage points may be covered by supplementary measures such as CCS (incl. BECCS)[26]. Sweden has set CCS targets for 2030 (3.7 MtCO2e total, whereof 1.8 MtCO2 from bio-CCS) and 2045 (10.7 MtCO2e total, whereof 3-10 MtCO2 from bio-CCS). To reach Sweden's -63% CO2 reduction target by 2030, ~9% of the required reductions in CO2 emissions may be achieved through other means such as CCS[27].

Policy measures such as investment support are in place, though currently not identified to be sufficient for the realisation of full-scale CCS projects. The Swedish government has recently decided to ratify the amendment to the London protocol. This was mentioned as a necessary action in the national energy and climate plan to allow for the development of CCS in the country[28].

The Swedish state has in place some financing mechanisms for CCS-related projects through the Swedish Energy Agency. In 2019, the Swedish government allocated SEK 100 million to pilot projects aimed at accelerating the deployment of CCS and BECCS. Through the Industriklivet initiative, support is given to R&D projects which contribute to negative emissions, for example, bio-CCS. The support is planned to be at SEK 100 million annually until 2020, thereafter SEK 50 million annually until 2027.[29]

Sweden regulatory framework for CCS is primarily stand-alone and based upon the regulatory permissions model found in the Swedish Environmental Code. In addition, further permissions are required under the Continental Shelf Act and the Certain Pipelines Act. While the Swedish regulatory framework addresses many key issues, some critical elements have not been fully addressed, including the explicit definition of CO2 and CO2-specific transportation provisions. Sweden has placed restrictions on where CO2 may be stored and the activities that may take place within the Swedish Economic Zone and offshore sites[30].

Sweden's official report on a strategy for negative GHG emissions considered storage from Swedish CCS. While the report specified that it is likely that there is domestic storage in Sweden, knowledge about their capacities was deemed to be poor. The strategy concluded that Sweden should not prioritise establishing a storage site but rather depend on sea transport to storage outside Sweden, for example, Norway or another North Sea country.

[24] Klimat politiska rådet "2020: Report of the Swedish Climate Policy Council"
[25] Uppsala University "A Probabilistic Assessment of the Effective CO2 Storage Capacity within the Swedish sector of the Baltic Basin
[26] 2020 Report of the Swedish Climate Policy Council
[27] Klimat politiska rådet "2020: Report of the Swedish Climate Policy Council"
[28] Regeringens Proposition 2019/20:65: "En samlad politik för klimatet – klimatpolitisk handlingsplan"
[29] THEMA Consulting Group "The role of Carbon Capture and Storage in a Carbon Neutral Europe"
[30] Global CCS Institute CO2RE database

Table 12: CCS national targets and policies in Sweden

CCS NATIONAL TARGETS AND POLICIES		
Category	**Indicator**	**Comments**
Country CCS policy maturity/potential	◐	CCS recognised as a potentially important means of reaching climate targets, and CCS target has been specified, yet lack of sufficient policy measures and restrictions in the legal framework creates a medium maturity level.
National CO2 reduction targets	✓	• 2030: -20% from 2005 levels (EU ETS) and -63%[31] from 1990 levels (non-EU ETS)[32] • 2040: -75% from 1990 levels (national target)[33] • 2045: Net zero emissions
National CCS targets	✓	Sweden has set CCS targets for 2030 (3.7 MtCO2e total, whereof 1.8 MtCO2 from bio-CCS) and 2045 (10.7 MtCO2e total, whereof 3-10 MtCO2 from bio-CCS). ~9% of the required reductions in CO2 emissions by 2030 and 15% by 2045[34] can be achieved through other complementary means such as CCS.
CCS policies and legislations	—	Policy measures such as investment support are in place, though currently not identified to be sufficient for the realisation of full-scale projects. Sweden's regulatory framework for CCS is primarily stand-alone and based upon the regulatory permissions model found in the Swedish Environmental Code.
CCS funding	—	The Swedish state has in place some financing mechanisms for CCS-related projects through the Swedish Energy Agency.
CCS storage-related policies	—	Offshore CO2 storage is permitted. The Swedish official report on a strategy for negative greenhouse gas emissions specified that there is likely domestic storage in Sweden. Yet, knowledge about their capacities was deemed to be poor. The strategy concluded that Sweden should not prioritize establishing a storage site but rather depend on sea transport to storage outside Sweden, for example, Norway or another North Sea country.[35]

4.2.2.3 CCS potential (capturable CO2 intended for storage) in Sweden

Sweden's emissions from large sources were 51 MtCO2 in 2017, of which 16.5 MtCO2 were from the power & heat industry, 11.8 MtCO2 from the energy-intensive industries and 22.8 MtCO2 from pulp and paper production.

The calculated capturable quantity of CO2 from large sources is estimated at on average 14 MtCO2/y between 2022 and 2040 and 19 MtCO2/y between 2041 and 2050. The majority of these emissions is related to the pulp and paper industry.

[31] Equivalent to -59% reduction from 2005 levels

[32] Sweden's Integrated National Energy and Climate Plan (NECP 2030)

[33] Regeringens Proposition 2019/20:65: "En samlad politik för klimatet – klimatpolitisk handlingsplan"

[34] Klimat politiska rådet "2020: Report of the Swedish Climate Policy Council"

[35] THEMA Consulting Group "The role of Carbon Capture and Storage in a Carbon Neutral Europe"

Table 13: CCS potential (intended for storage) in Sweden

Sector	CO2 emissions 2017, MtCO2	Capturable quantity of CO2, MtCO2 (avg. MtCO2/y[36])		Comment
		2022-2040	2041-2050	
Power & Heat	**16.5**	**43** **(4)**	**48** **(5)**	• The overall significance of CCS within the Swedish power & heat sector is low due to renewable power generation. However, BECCS has been emphasised as an important additional measure to achieve negative emissions in 2045 (although no specific CCS targets have been made for CCS) • Forest is the largest source of bioenergy in Sweden (63% of land cover). Bioenergy is primarily used for heating – both in private homes and in district heating – as well as for electricity production and for industrial processes[37] • In order to meet the ambitious carbon neutrality targets towards 2045, the first projects are expected to be introduced before 2030 • The capturable volume of CO2 intended for storage within the segment is estimated at up to ~5 MtCO2/y, and is executively related to emissions from biomass-fired energy and heat plants (incl. waste-to-energy plants)
Industry	**11.8**	**116** **(11)**	**143** **(14)**	• Process emission within the energy-intensive industry were 11.8 MtCO2 in 2017, mainly related to the production of iron and steel (4.1 MtCO2), cement (2.8 MtCO2) and refining (2.7 MtCO2) • For the remaining industries, green hydrogen and electricity are expected to be preferred • The total capturable volume intended for storage is estimated at up to ~3 MtCO2/y • In addition to the industries above, Sweden is one of the major pulp and paper producers in Europe. Associated emissions were estimated at ~22.8 MtCO2 in 2017. Pulp & paper plants are often located close to coastlines and rivers (as their processes require significant amounts of water), making it potentially easily accessible to collect emissions. • The total capturable volumes intended for CCS are estimated at up to 11 MtCO2/y (in 2014; ramping gradually up from 2028 where the technology is assumed to be introduced)

4.2.2.4 CO2 storage potential in Sweden

Sweden has 6,000 Mt of total carbon storage situated in aquifers[38]. While the storage capacity is adequate to cover all upcoming CCS activity, no investments in developing the storage sites have been made, as described in section 4.2.2.2.

The Swedish attitude towards CCS is generally positive[39], as incentive schemes are in place to develop CCS technology. Moreover, several studies are currently underway to hook up local fossil fuel power generation and industry in the Gothenburg area to CO2 export infrastructure, enabling storage of Swedish carbon in the North Sea area[40].

As a result, Sweden seemingly has no intention of developing domestic carbon storage sites and prioritises developing carbon export infrastructure while looking for international opportunities to store the captured carbon.

[36] Average CO2 capturable amount is calculated for the time period 2030-2040

[37] Sweden.se/ Swedish Institute

[38] Uppsala University, "A Probabilistic assessment of the effective CO2 storage capacity within the Swedish Sector of the Baltic Basin"

[39] IOGP, "The potential for CCS and CCU in Europe"

[40] DEA/Ramboll, "Catalogue of Geological Storage of CO2 in Denmark"

4.2.3 Norway

4.2.3.1 Summary of CCS potential in Norway

Norway's CO2 emissions from large sources in 2017 were ~25 MtCO2. Most emissions relate to the energy-intensive energy sector (11.2 MtCO2) since power generation is mainly from hydroelectric plants.

Norway has created favourable conditions for the development and use of CCS through solid policy and regulatory support and dedicated action plans for CCS. Yet, no specific targets for CCS deployment have been set. However, the processing industry has created a roadmap for achieving climate targets towards 2050, including 33% from CCS and 20% from BECCS.

Extensive support systems for CCS are in place through various organisations and research centres, among others the Norwegian CCS Research Centre (NCCS) in 2016, with 30 research and industry partners and a budget of NOK 570 million over eight years. Key drivers for Norway's successful CCS development projects have been the supporting policy framework and high CO2 prices.

Norway's CCS potential within the processing industry is high; 111 MtCO2 in total between 2022 and 2050, and on average 4 MtCO2/y between 2022 and 2040 and 6 MtCO2/y between 2041 and 2050. Energy majors are expected to see CCS as a way of protecting their existing extraction and refining business. At the same time, fossil-reliant industries such as steel could choose to use CCS rather than invest in options like hydrogen.

Storage potential in Norway is estimated at 103,000 Mt, of which 76,000 Mt of storage in aquifers and 27,000 Mt of storage in depleted oil & gas fields.

The relevance for storage in Denmark is deemed low, as Norway has national plans to develop CCS technology and develop storage sites.

Below is an overview of the CCS potential in Norway.

Table 14: Summary of CCS potential in Norway

SUMMARY OF CCS POTENTIAL		
Category	**Indicator**	**Comments**
CO2 emissions 2017 (MtCO2) Plants >100 ktCO2	25.4[41]	CO2 emissions from the largest point sources; mainly from the power and heat generation industry, followed by the iron and steel, non-ferrous metals and mineral oil and gas industry
CO2 reduction targets	✓	• 2030: -50% from 1990 levels[42] (economy wide) and -30% from 2005 levels (non-EU ETS)[43] • 2050: -90-95% from 1990 levels (economy wide)
National CCS focus/Support	●	Strong policy and regulatory support, as well as dedicated actions plans for CCS, create favourable conditions for the development and use of CCS in Norway.
CCS targets	✓	Norway has not set specific targets for CCS deployment, with the justification by the Norwegian Ministry of Climate and Environment that it is not possible to quantify the emission reductions that might be realized through Norway's CCS policies as it will, for most parts, take place in the industry covered by the EU ETS[44]. However, the Norwegian processing industry has created a roadmap for 2050 for achieving its long-term national climate targets: deploy CCS to reduce as much as 33% of planned emission reductions and ~20% from CCS combined with combustion of biogenic matter. Further, long-standing policy and research commitments suggest that CCS will become an important means to achieving Norway's long-term target of

[41] EU Emissions Trading Scheme data – Does not include biogenic emissions

[42] Norway's Fourth Biennial Report. In its National Determined Contribution (NDC) under the Paris Agreement and committed to reduce emissions by at least 50 per cent and towards 55 per cent by 2030 compared to 1990.

[43] Norwegian Ministry of Petroleum and Energy "Longship – Carbon Capture and Storage"

[44] Norwegian Ministry of Climate and Environment "Norway's Fourth Biennial Report"

		reducing CO2 emissions by 90-95% by 2050, despite the current lack of specified targets for CCS.
Total CCS Potential (MtCO2) 2022-2050	111	Primarily related to refining and other fossil-reliant industries (e.g. iron & stell)
Own storage capacity (Mt)	103,000[45]	76,000 Mt of storage in aquifers; 27,000 Mt of storage in depleted oil & gas fields;
Own storage potential/support		Large offshore storage sites are being developed with large investments from the government
Potential for DK storage	**Low**	**Low significance to DK as NO has national plans to develop CCS technology but also to develop storage sites (and has sufficient storage capacity)**

4.2.3.2 CCS national targets and policies in Norway

Norway aims to become a low-emission society by 2050, targeting reducing greenhouse gas emissions between 90-95%[46]. Norway has identified CCS as important for achieving these targets. Overall, the policy maturity is considered high as CCS strategies, policies, supportive legislative frameworks, and support systems have created favourable conditions for CCS in Norway.

The Norwegian Government has developed a CCS strategy, which includes research, development and demonstration, an ambition to realize a full-chain demonstration facility, transportation, storage and alternative use of CO2 and international work for the implementation of CCS as a mitigation measure[47]. Important parts and tasks are given to the Research Council of Norway and Gassnova (a state-backed body whose mission is to realise CCS solutions)[48]. In 2020, the Norwegian government proposed to launch a CCS project called "Longship", which will demonstrate a full, but flexible value chain with carbon capture from cement production and potentially from waste management and shipping, and CO2 storage beneath the seabed.

Norway has not set specific targets for CCS deployment, with the justification by the Norwegian Ministry of Climate and Environment that it is not possible to quantify the emission reductions that might be realized through Norway's CCS policies as it will, for most parts, take place in the industry covered by the EU ETS[49]. However, the Norwegian processing industry has created a roadmap for 2050 for achieving its long-term national climate targets, according to which it needs to deploy CCS to reduce as much as 33% of planned emission reductions and ~20% from CCS combined with the combustion of biogenic matter[50]. Further, long-standing policy and research commitments suggest that CCS will become an important means to achieving Norway's long-term target of reducing CO2 emissions by 90-95% by 2050, despite the current lack of specified targets for CCS.

Norway has demonstrated a commitment to the deployment of CCS and to drive down technology costs through extensive support systems targeted at CCS research and projects. Norway established the Norwegian CCS Research Centre (NCCS) in 2016, with 30 research and industry partners and a budget of NOK 570 million over eight years[51]. Further, Norway's Technology Centre Mongstad (TCM) has established itself as a leading international competence centre for the demonstration of capture technology[52]. The Norwegian Government and the current industry owners of TCM have entered into a new operating agreement from the end of August 2020 until the end of 2023[53]. In addition, the national research programme CLIMIT is an essential source of funding for research and demonstration of IS technology. In addition, the government has established a strategic committee for clean energy research called ENERGI21, under which CCS is one of six priority focus areas. Other key funding programmes include SkatteFUNN, which

[45] Nordic CCS Competence Centre "CO2 Storage Potential in the Nordic Region"
[46] Norwegian Ministry of Climate and Environment "Norway's National Plan"
[47] Norwegian Ministry of Climate and Environment "Norway's Fourth Biennial Report"
[48] Norwegian Ministry of Petroleum and Energy "Longship – Carbon Capture and Storage"
[49] Norwegian Ministry of Climate and Environment "Norway's Fourth Biennial Report"
[50] Norwegian Ministry of Petroleum and Energy "Longship – Carbon Capture and Storage"
[51] Norwegian Ministry of Petroleum and Energy "Longship – Carbon Capture and Storage"
[52] Norwegian Ministry of Petroleum and Energy "Longship – Carbon Capture and Storage"
[53] Norwegian Ministry of Petroleum and Energy "Longship – Carbon Capture and Storage"

provides tax incentives for CCS related research, as well as Accelerating CCS Technology (ACT), which is a European initiative managed by Norway to establish CCS.

The supporting policy framework and high CO2 prices have been crucial drivers for the development of Norway's successful CCS projects. The Longship project proposed by the Norwegian government requires funding of USD 2.7 billion, and will also comprise funding for the transport and storage project Northern Lights, a joint project between Equinor, Shell and Total[54]. The CCS projects from natural gas on the Sleipner, Gudrun and Snøhvit petroleum fields are the only CCS projects currently in operation in Europe and the only projects in the offshore industry.

Norway does not have CCS-specific legislation; however, amendments to existing regulation have created a comprehensive regulatory framework for the transport and storage of CO2 in Norway. National pollution, environmental and petroleum legislation is sufficient to cover CCS, and amendments have been made to regulations concerning the storage of CO2 in offshore sub-sea reservoirs on the Norwegian continental shelf. Norway has implemented the EU CCS Directive, which has provided a basis for amendments to existing legislation. In addition, Norway has ratified the London Protocol that allows CO2 export to other states for storage purposes. Yet, the Protocol has not entered into force as too few countries have ratified it.

Table 15: CCS national targets and policies in Norway

CCS NATIONAL TARGETS AND POLICIES IN NORWAY		
Category	**Indicator**	**Comments**
Country CCS policy maturity/potential	●	The policy maturity is considered high due to CCS strategies, policy, legislative frameworks and support systems, creating favourable conditions for CCS.
National CO2 reduction targets	✓	• 2030: -50% from 1990 levels[55] (economy wide) and -30% from 2005 levels (non-EU ETS)[56] • 2050: -90-95% from 1990 levels (economy wide)
National CCS targets	✗	CCS targets have not been set.
CCS policies and legislations	✓	The Norwegian government has developed a national CCS strategy, created state-sponsored CCS authorities and recently proposed a project to demonstrate a full but flexible value chain with carbon capture from cement production and potentially from waste management and shipping, and CO2 storage beneath the seabed. Norway does not have CCS-specific legislation; however, amendments to existing regulation have created a comprehensive regulatory framework for the transport and storage of CO2 in Norway.
CCS funding	✓	The government supports CCS through various supporting schemes and R&D funding. National CCS centres, CCS funding programmes have been influential in the development of Norway's successful CCS projects.
CCS storage-related policies	✓	Offshore storage is permitted.

[54] Norwegian Ministry of Petroleum and Energy "Longship – Carbon Capture and Storage"

[55] Norway's Fourth Biennial Report. In its National Determined Contribution (NDC) under the Paris Agreement and committed to reduce emissions by at least 50 per cent and towards 55 per cent by 2030 compared to 1990.

[56] Norwegian Ministry of Petroleum and Energy "Longship – Carbon Capture and Storage"

4.2.3.3 CCS potential (capturable CO2 intended for storage) in Norway

Norway's emissions from large sources were 25 MtCO2 in 2017. The majority of emissions is related to energy-intensive sectors since power generation in Norway is almost entirely from hydroelectric power plants.

Norwegian government accords great importance to CCS. Energy majors are therefore expected to see CCS as a way of protecting their existing extraction and refining business. Furthermore, fossil-reliant industries such as steel could use CCS rather than invest in options like hydrogen. CCS will also be needed to deploy blue hydrogen.

The calculated capturable quantity of CO2 is estimated at an average of 4 MtCO2/y between 2022 and 2040 and 6 MtCO2/y between 2041 and 2050.

Table 16: CCS potential (intended for storage) in Norway

Sector	CO2 emissions 2017, MtCO2	Capturable quantity of CO2, MtCO2 (avg. MtCO2/y[57])		Comment
		2022-2040	2041-2050	
Industry	**11.2**	**33** (**3**)	**49** (**5**)	• Process emission within energy-intensive industry were 11.2 MtCO2 in 2017, mainly related to refining (2.6 MtCO2), iron and steel production (2.5 MtCO2) and non- ferrous metals (2.7 MtCO2) • The significance of CCS within the industrial sector is assessed to be relatively low and is mainly relevant for cement and refining (where there are currently no other ways to reduce the process emissions significantly). It is often only one of the available options (and less preferred) within other industrial subsectors, including iron and steel and chemicals. Moreover, in many countries, the industrial sector prefers CCU instead of CCS. However, in Norway, the government accords great importance to CCS. Energy majors are therefore expected to see CCS as a way of protecting their existing extraction and refining business. Furthermore, fossil-reliant industries such as steel could use CCS rather than invest in options like hydrogen. CCS will also be needed to deploy blue hydrogen. • The total capturable volume intended for storage is estimated at up to ~5 MtCO2/y
Fuel combustion	**14.2**	**15** (**1**)	**14** (**1**)	• Fuel combustion is presumably related to oil & gas activities • The significance of CCS is assessed to be high in this context, as energy majors are expected to prioritise CCS, due to governmental focus on this decarbonisation measure. The total capturable volume intended for storage is estimated at up to ~2 MtCO2/y (peak between 2033 and 2040)

[57] Average CO2 capturable amount is calculated for the time period 2030-2040

4.2.3.4 CO2 storage potential in Norway

Norway has 103,000 Mt of carbon storage in suitable geological structures, of which the majority (76,000 Mt) is situated in aquifers and 27,000 Mt in located in oil and gas field units[58]. All known storage units are located offshore in the North Sea and the Norwegian Sea on the Norwegian Continental Shelf near current oil and gas fields[59].

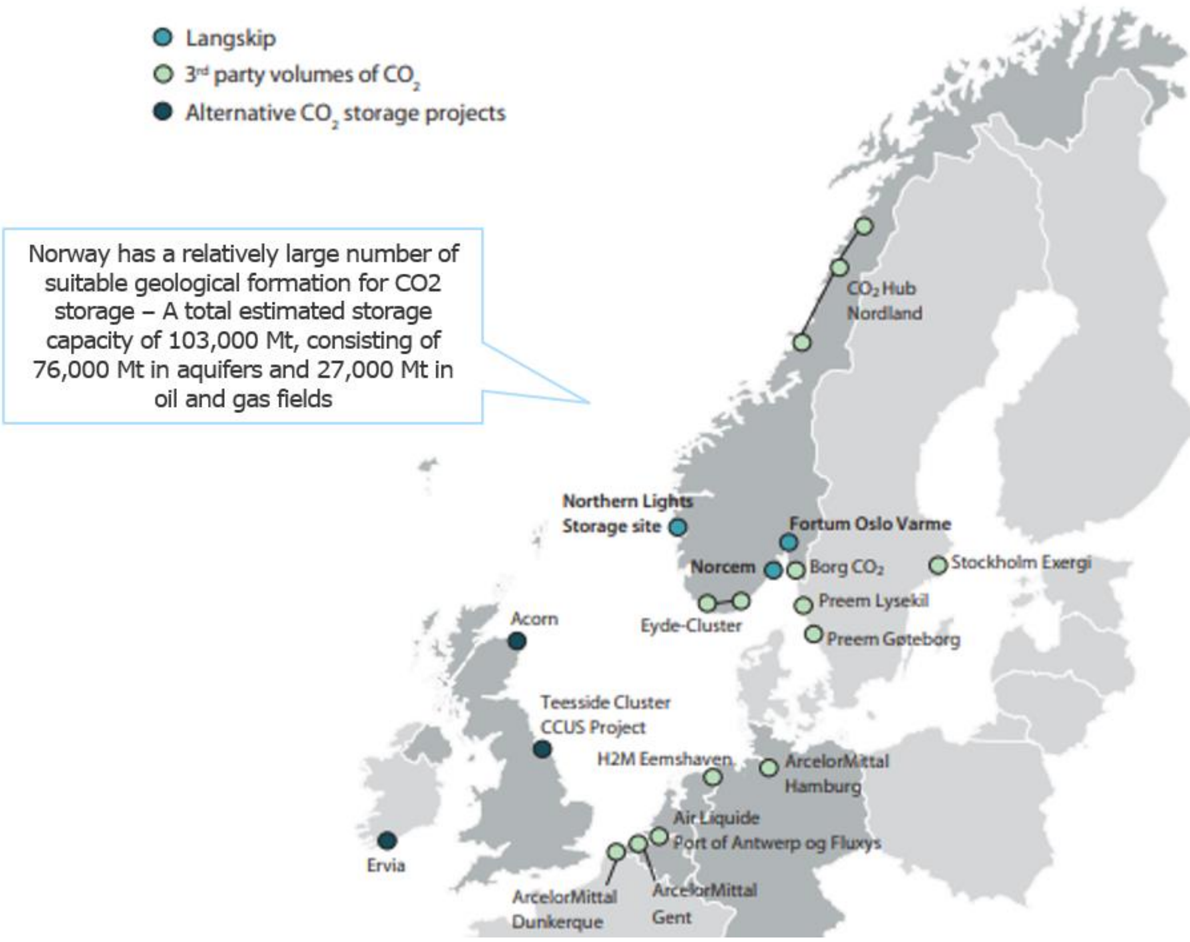
Carbon storage in oil and gas fields can be cheaper to develop than aquifer storage units as some of the offshore infrastructure is already in place[60].

Norwegian attitude and legislation are favourable towards CCS technology and offshore carbon storage, as described in section 4.2.3.2.

As a result, the carbon storage capacity of Norway is considered sufficient to cover all upcoming CSS activity and will be sufficient to store CO2 imports from other countries[61].

The figure below provides an overview of the CCS projects in Norway.

Figure 2: Overview of CCS facilities in Norway



Source: Norwegian Ministry of Petroleum and Energy, "Longship – Carbon capture and storage", Ramboll analysis

[58] Nordic CCS Competence Centre, "CO2 Storage potential in the Nordic region"
[59] EU GeoCapacity, "Assessing European capacity for Geological Storage of Carbon Dioxide"
[60] IOGP, "The potential for CCS and CCU in Europe"
[61] Ramboll Expert

4.2.4 Germany

4.2.4.1 Summary of CCS potential in Germany

Germany's emissions from large sources in 2017 were ~406 MtCO2. The energy sector is one of the largest single sources of CO2 emissions in Europe.

Germany aims to become climate neutral in 2050, and as Europe's largest emitter, CCS will most likely become a significant means of reaching this climate target. The role of CCS for reaching carbon neutrality has been noted in Germany's Climate Action programme as unavoidable and by former Chancellor Angela Merkel at the Petersburger Klimadialog to be necessary. However, currently, Germany has not set any CCS targets.

To support the deployment of CCS, Germany is preparing a subsidy programme aimed at the country's raw material industry for developing CCU and CCS technologies, with a budget at EUR 105 million for 2021 and, after that, an additional EUR 120 million per year until 2025.

CCS potential in Germany is estimated at 871 MtCO2 between 2022 and 2050 and on average 35 MtCO2/y between 2022 and 2040 and 49 MtCO2/y between 2041 and 2050, from close to 200 different large power and industrial processing facilities. The largest share of capturable CO2 is expected to be derived from the power & heat sector (natural gas-fired power plants and biomass-fired plants). Despite transforming to renewable energy sources within power supply, natural gas is expected to remain an important energy source by 2050. Germany's industrial sector plays a substantial role in Germany with high emission levels that are hard to abate (iron and steel, refining, chemicals/petrochemicals, cement).

Storage potential in Germany is estimated at 95,000 Mt, with 75,000 Mt of storage in depleted oil & gas fields and 20,000 Mt of storage in aquifers. 80% of aquifers are situated in states that have banned carbon storage. Germany is not actively pursuing CCS, and no facilities are currently planned or under construction. National storage is expected to be limited going forward, partly indicated due to public scrutiny of onshore storage.

The relevance for storage in Denmark is deemed potentially high. Given public opposition to onshore storage and the limitation of CO2 storage on national territory, the export of German CO2 for storage is considered likely.

Below is an overview of the CCS potential in Germany.

Table 17: Summary of CCS potential in Germany[62]

SUMMARY OF CCS POTENTIAL		
Category	**Indicator**	**Comments**
CO2 emissions 2017 (MtCO2) Plants >100 ktCO2	406.2	CO2 emissions from largest point sources; mainly from power and heat generation industry, followed by iron and steel, cement, chemical and mineral oil and gas refinery industries
Co2 reduction targets	✓	• 2030: -55% from 1990 levels (national target) and -38% from 2005 levels (non-EU ETS)[63] • 2050: Climate neutral
National CCS focus/Support	◐	As Germany is Europe's highest emitter, CCS will probably need to play a significant role in Germany. Given the public opposition and the limitation of CO2 storage on national territory, the export of German CO2 for storage is deemed likely.
CCS targets	✗	No specific targets have been set for the deployment of CCS in Germany.
Total CCS Potential (MtCO2) 2022-2050	871	The largest share of capturable CO2 is expected to be derived from the power & heat sector (natural gas-fired power plants and biomass-fired plants). Significant potential also assessed within the industry (mainly iron and steel, refining, chemicals/petrochemicals, and cement).

[62] Global CCS Institute, "Global Status of CCS 2020"

[63] Germany's Integrated National Energy and Climate Plan (NECP 2030)

Own storage capacity (Mt)	95,000	75,000 Mt of storage in depleted oil & gas fields; 20,000 Mt of storage in aquifers. 80% of aquifers are situated in states that have banned carbon storage[64].
Own storage potential/support		Germany is not actively pursuing CCS, and there are no CCS facilities in planning/construction. Additionally, public scrutiny of onshore storage indicates that national storage will be limited going forward.
Potential for DK storage	**High**	**Carbon storage outside of the country seems to likely, as the national storage of carbon is still controversial in Germany.**

4.2.4.2 CCS national targets and policies Germany

Germany is aiming to become climate neutral in 2050. As Germany is Europe's highest emitter, CCS will most likely need to play a significant role in Germany. While the German climate action programme highlights German initiatives that support CCS and CCU, it fails to substantiate a national commitment to technology uptake. Thus, the degree to which CCS will support the decarbonisation of industries has not been specified through CCS targets. However, the German integrated national energy and climate action plan explicitly gives room to the option of using carbon capture technology and notes that the majority of climate studies and scenarios confirm that CCS is indispensable for achieving net-zero emissions by 2050[65].

Until recently, Germany's had limited funding and support systems in place for the further development of CCS research and development projects. A CCS subsidy programme is currently being prepared, setting aside EUR 105 million for 2021 and, after that, EUR 120 million per year until 2025[66]. Aside from the programme under development, non-exclusive CCS programs have been in place, e.g., COORETEC focusing on coal-fired power with CCS, and Geotechnologien, which was a German R&D programme researching CO2 storage, which has now ended. The German NECP mentions the national "CO2-Win" and "CO2-Plus" programs as well as Germany's participation in the ERA-net EU Cofund ACT (Accelerating CCS Technologies) project as initiatives that will support research and the future application of CCU and CCS technologies, i.e. carbon separation, transport, storage and use[67]. In addition, Germany is currently preparing a subsidy programme aimed at supporting the country's raw material industry in developing technologies for CCU and CCS. The budget has been set at EUR 105 million for 2021 and, after that, an additional EUR 120 million per year until 2025[68].

Germany's regulatory framework related to CCS concerns the German CCS Act and the CO2 storage Act, both of which are integrated are based on the EU CCS directive in 2009. In 2012 the German CCS Act made onshore storage of CCS forbidden. The CCS Act halted all CCS projects except testing and demonstration pilots; no submissions were made. The storage Act restricts CO2 storage to only some parts of Germany, and the Federal States determine whether CO2 storage may take place based on several criteria. Additionally, storage activities are limited to those for which an application has been filed by December 2016 and to a maximum annual capacity of 1.3 MtCO2 per storage site. The total combined annual storage capacity for Germany is also limited to 4 MtCO2. However, the role of CCS in the future decarbonisation of the German economy became a point of discussion again after Chancellor Merkel stated in 2019 that CCS was necessary to achieve the ambitious climate targets.

Due to public acceptance issues and regulatory limits to onshore storage, tapping into the German onshore CO2 storage potential is most likely not politically feasible.

[64] European Commission, "On Implementation of Directive 2009/31/EX on the Geological Storage of Carbon Dioxide"
[65] Bundesministerium für Wirtshaft und Energie "Integrierter Nationaler Energie- und Klimaplan"
[66] Media Group: Germany Launches CCUS Support
[67] Bundesministerium für Wirtshaft und Energie "Integrierter Nationaler Energie- und Klimaplan"
[68] Media Group: Germany Launches CCUS Support

Table 18: CCS national targets and policies in Germany[69]

CCS NATIONAL TARGETS AND POLICIES		
Category	**Indicator**	**Comments**
Country CCS policy maturity/potential	◐	CCS recognised as a potentially important means of reaching climate targets. Yet, the lack of specific targets for CCS deployment and CCS restrictions in the legal framework creates a medium maturity level.
National CO2 reduction targets	✓	• 2030: -55% from 1990 levels (national target) and -38% from 2005 levels (non-EU ETS)[70] • 2050: Climate neutral
National CCS targets	✗	The Climate action programme names German initiatives supporting CCS and CCU but fails to substantiate a German commitment to the technology uptake.
CCS policies and legislations	—	The German CCS Act and the CO2 Storage Act are integrated and are based on the EU CCS directive in 2009. The Storage Act restricts CO2 storage to only some parts of Germany and sets limits to storage capacity. However, the role of CCS in the future decarbonisation of the German economy became a point of discussion again after former Chancellor Merkel stated in 2019 that CCS was necessary to achieve the ambitious climate targets.
CCS funding	—	A CCS subsidy programme is currently being prepared, setting aside EUR 105 million for 2021 and, after that, EUR 120 million per year until 2025[71]. However, until recently, support has been minimal, with a low level of R&D funding through non-exclusive CCS programs, e.g., COORETEC focusing on coal-fired power with CCS and Geotechnologien. The German NECP mentions the national "CO2-Win" and "CO2-Plus" programs as well as Germany's participation in the ERA-net EU project as initiatives that will support research and the future application of CCU technologies.
CCS storage-related policies	—	German CCS Act prohibits onshore storage of CCS. Due to public acceptance issues and regulatory limits to onshore storage, tapping into the German onshore CO2 storage potential is most likely not politically feasible.

4.2.4.3 CCS potential (capturable CO2 intended for storage) in Germany

Germany's energy sector remains one of the largest single sources of CO2 emissions in Europe. Emissions from large sources[72] are assessed at ~280 MtCO2 in 2017.

Today, energy in Germany is sourced predominantly by fossil fuels, followed by wind, nuclear power, solar, biomass (wood and biofuels) and hydro. As illustrated in Figure 3, supply is transforming towards heavier use of renewable energy sources in 2050; natural gas will remain an important energy source towards 2050.

Germany also has a substantial industrial sector with a high level of emissions (108.0 MtCO2 in 2017), including production and processing of iron and steel, refining, chemicals/petrochemicals, and cement.

The calculated capturable quantity of CO2 is estimated at on average 35 MtCO2/y between 2022 and 2040 and 49 MtCO2/y between 2041 and 2050, from close to 200 different large power and industrial processing facilities. The largest share of capturable CO2 is expected to be derived from the power & heat sector (natural gas-fired power plants and biomass-fired plants).

Within the industrial sector largest potential is assessed within the cement industry and refineries due to lacking alternatives to abate emissions, followed by other industries where CCS is relevant but only one option, i.e., chemical industry and iron & steel).

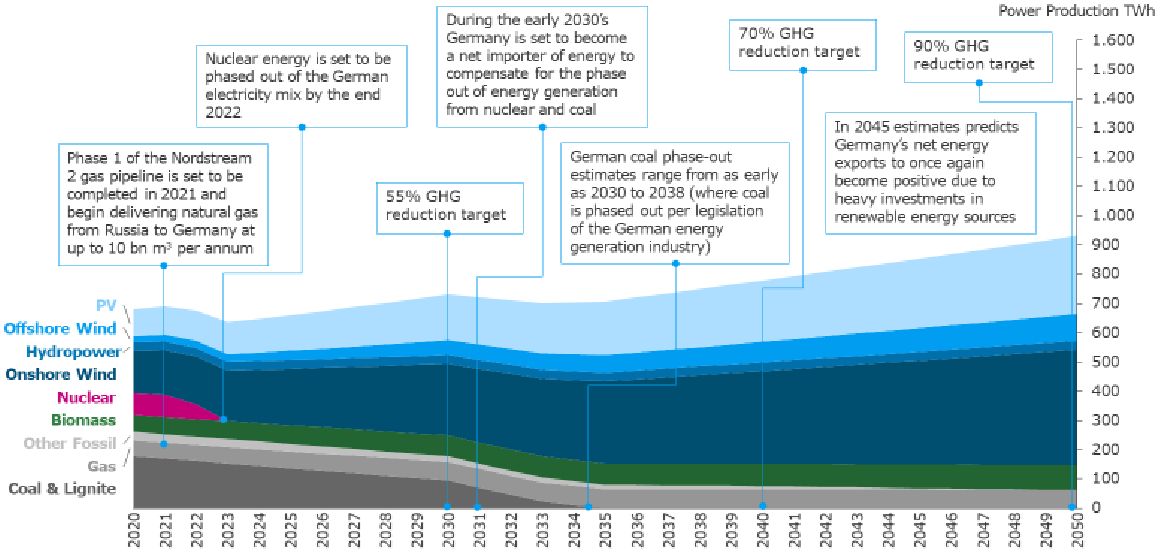
[69] Thema Consulting Group, "The role of carbon capture and storage in a carbon neutral Europe"; "Integrated National Energy and Climate Plan" of Germany; The European Commission, "Assessment of final national energy and climate plan of Germany"

[70] Germany's Integrated National Energy and Climate Plan (NECP 2030)

[71] Media Group: Germany Launches CCUS Support

[72] Plants with emissions exceeding 100,000 MtCO2/y

Figure 3: Germany’s potential energy mix towards 2050



Source: Ramboll Analysis; EWI Research, “The energy market in 2030 and 2050 – The contribution of gas and heat infrastructure to efficient carbon emission reductions.”

Table 19: CCS potential (intended for storage) in Germany

Sector	CO2 emissions 2017, MtCO2	Capturable quantity of CO2, MtCO2 (avg. MtCO2/y[73])		Comment
		2022-2040	2041-2050	
Power & Heat	**280.2**	**229** **(21)**	**339** **(34)**	• The overall significance of CCS within the German power & heat sector is low due to the focus on renewable power generation. However, the German government has expressed an interest in BECCS due to negative emissions compensating some industry and agricultural emissions hard to abate. Significance of CCS is also assessed to be high in case of non-recyclable and biogenic share of waste-to-energy and for emissions from natural gas-fired power plants • The capturable volume of CO2 intended for storage within the segment is estimated at up to ~36 MtCO2/y • The capturable quantities are evenly split between power plants fired on natural gas and those fired on biomass. However, the dynamics within these two segments are quite different. After an introduction around 2030, a capturable amount of CO2 from gas plants would quickly ramp up to comprise more than 50% of this industry by 2040. A further increase is expected towards 2050, as it is likely that only CCS-retrofitted plants will be allowed to operate. The overall share of capturable CO2 emissions from biomass-fired plants is expected to be much lower (~20%) but constant through the entire period (2030-2050) • CCS is not considered relevant for coal-driven plants since they will be phased out shortly after the CCS introduction

Industry	**108.0**	**154**
		(14)
			150
			(15)
				• Germany has a substantial industrial sector with a high level of emissions (108.0 MtCO2 in 2017), including production and processing of ferrous metals (28.6 Mt in 2017, mainly related to iron and steel), refining (21.1 MtCO2 in 2017), chemicals/ petrochemicals (24.6 Mt in 2017) and cement (25.0 MtCO2 in 2017)
				• The significance of CCS within the industrial sector varies across disciplines. It is assessed highest for cement processing and refining, where there are currently no other ways to reduce the process emissions significantly. Although switch of fossil fuels to biomass can reduce some emissions from cement processing, BECCS could still be an option to create negative emissions. Potential is also assessed within iron and steel, and chemicals. However, CCS is only one of several options on how to abate emissions (alternatives include electricity, green hydrogen and recycling). In general, the chemical industry is prioritizing CCU over CCS
				• According to Germany's Economy and Energy Ministry, around 30-40% of industrial emissions are process-linked and cannot be avoided using today's state of the art technology[74].
				• The total capturable volume intended for storage is estimated at up to ~18 MtCO2/y (peak between 2030 and 2040), and the highest potential is assessed within the mineral processing/cement industry. Ramp-up of the CCS within the industrial sector is expected to be relatively quick and reach the full potential already in 2035
				• CCS is also considered highly relevant for reducing CO2 emissions within:
				  ○ Chemical industry; Although the chemical industry is large in Germany, CCS is expected to be less prioritised than the alternative measures to abate emissions
				  ○ Iron and steel industry; Using hydrogen is an alternative (and high priority for the German government). Although the clear focus of the recently published Hydrogen Strategy is on green hydrogen production in- and outside of Germany (due to limited capacity/ability to produce enough green hydrogen, Germany is looking into collaborations with other countries), there are no provisions against the import and use of blue hydrogen[75]. Blue hydrogen is therefore expected to be a transitional solution, creating a need for CCS
				  ○ The gas refining industry; Given the long-term commitment to natural gas via the Nord Stream pipeline

Other	**18.8**	**-**	**-**	• No other significant potential areas have been assessed

[73] Average CO2 capturable amount is calculated for the time period 2030-2040

[74] The role of Carbon Capture and Storage in a Carbon Neutral Europe, Carbon Limits, 2020

[75] Federal Ministry of Economic Affairs and Energy – "Die Nationale Wasserstoffstrategie"

4.2.4.4 CO2 storage potential in Germany

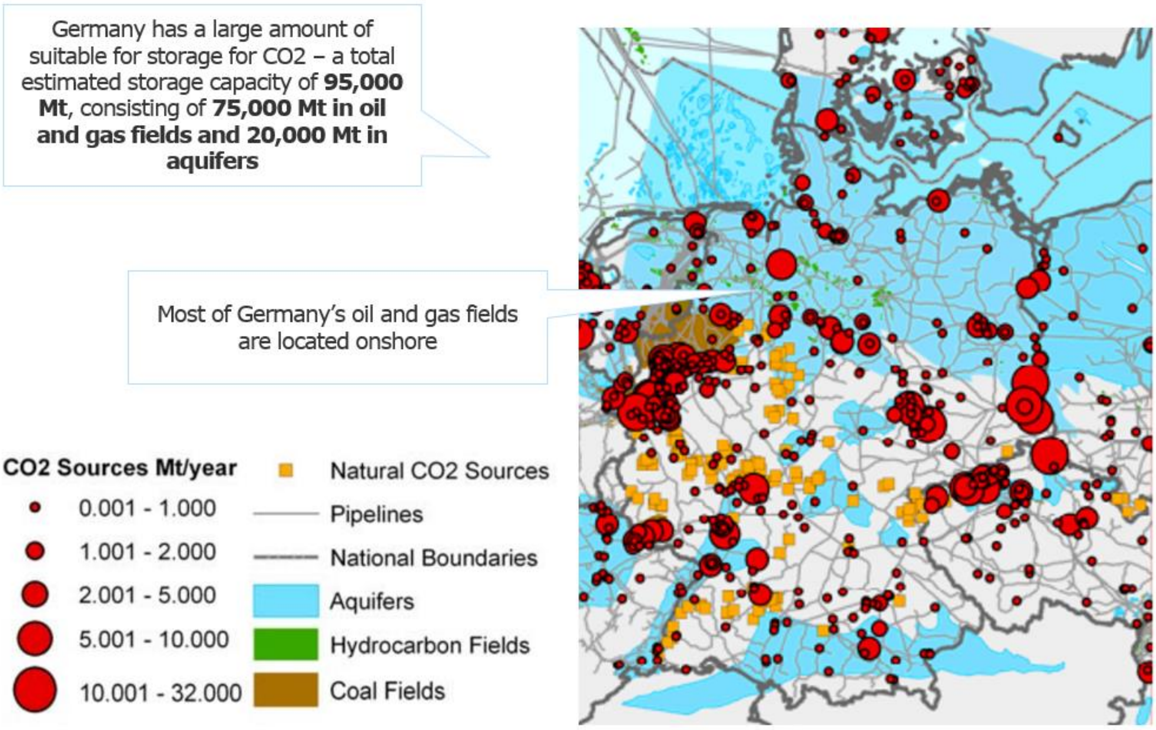
Germany's total CO2 storage capacity is 95,000 Mt, of which the majority – 75,000 Mt – is situated in oil and gas fields, and 20,000 Mt is situated in storage aquifers. Most of the German domestic carbon storage capacity is located onshore. The storage potential in the Baltic Sea is limited and virtually non-existent in the North Sea[76].

The German public has opposed onshore carbon storage, and as a result, only offshore carbon storage is currently legal, as described in section 4.2.4.2. No current or planned development projects of domestic carbon storage sites have been identified[77].

This means Germany does not have nor plan on developing domestic carbon storage capacity to cover upcoming CCS activity. However, due to the large amounts of captured carbon necessary to reach emissions reduction targets and the lack of plans for developing national storage, carbon export from Germany is deemed likely[78].

The picture below provides an overview of German storage site locations.

Figure 4: Overview of German carbon storage site locations



Source: Ramboll analysis, EU GeoCapacity, "Assessing European Capacity for Geological Storage of Carbon Dioxide"

[76] DEA/Ramboll, "Catalouge of Geological Storage of CO2 in Denmark"
[77] The Global CCS Institute, "Global status of CCS 2020"
[78] Ramboll Expert

4.2.5 United Kingdom

4.2.5.1 Summary of CCS potential in the United Kingdom

The UK's emission is among the largest emitters of the analysed countries, with emissions from large stationary plants in 2017 at ~146 MtCO2.

The UK has created favourable conditions for the development and use of CCS through strong policy and regulatory support and dedicated action plants for CCS. Targets and commitments to CCS deployment at scale starting from the 2030s have been made, estimating >10 MtCO2 to be captured per year by 2030. CCS is a key part of the decarbonisation strategy to achieve carbon neutrality in 2050 in the UK, subject to costs coming down sufficiently. CCS will be of particular need in hard-to-abate industry sectors and decarbonisation of home-heating (hydrogen with CCS).

To support CCS research and projects extensive funding has been granted in the UK, e.g., 100 million GBP via Clean Growth Strategy funding to CCUS, BECCS and transport and storage of CO2, an additional 123 million GBP to R&D/innovation via UK CCS Research Centre), and with plans for further 1 billion GBP funding and revenue mechanisms.

CCS potential in the UK is high in both power & heat and industry; 1,986 MtCO2 in total between 2022 and 2050, and on average 50 MtCO2/y between 2022 and 2040 and 119 MtCO2/y between 2041 and 2050 for both the power & heat sector and the industry sector. CCS potential in the power & heat sector will primarily be in connection with hydrogen, in which CCS will be central to support this. Within the industry, potential is in hard-to-abate industries, i.e., mineral oil & gas refineries, mineral production (cement, lime and plaster), iron and steel production, chemicals production, as well as food production.

The UK has significant storage capacity, estimated at 69,000 Mt of storage in aquifers and 9,000 Mt of storage in depleted oil & gas fields. Storage is permitted in the offshore area.

The relevance for storage in Denmark is deemed low, as the UK has already invested in CCS technology, initiated storage projects, developed CCS deployment timelines and expect CCS to be key to reaching net zero emissions.

Below is an overview of the CCS potential in the UK.

Table 20: Summary of CCS potential in United Kingdom

SUMMARY OF CCS POTENTIAL		
Category	**Indicator**	**Comments**
CO2 emissions 2017 (MtCO2) Plants >100 ktCO2	146.3	CO2 emissions from large point sources; primarily from the power and heat generation industry followed by refineries and chemical production facilities.
CO2 reduction targets	✓	• 2030: -68% from 1990 levels[79] (economy wide emissions) • 2050: Net zero emissions
National CCS focus/Support	◕	Strong policy and regulatory support, as well as dedicated actions plans for CCS, create favourable conditions for the development and use of CCS in the UK. An extensive national support system is in place, granting 100 million GBP via Clean Growth Strategy to CCUS, BECCS and transport and storage of CO2. Additional GBP 123 million to R&D via UK CCS Research Centre and plans for further GBP 1 billion funding and revenue mechanisms have been announced.
CCS targets	✓	The UK is committed to deploying CCS at scale during the 2030s, subject to costs coming down sufficiently. The UK's target is to capture >10 MtCO2/y by 2030, and capture and store ~0.32 tCO2 per capita. Between 2023-2032, the government estimates that driving the growth of low hydrogen could deliver savings of ~40 MtCO2e, equivalent to 9% of 2018 UK emissions.[80] By 2050, ~60% of the carbon captured in the

[79] https://www.gov.uk/government/news/uk-sets-ambitious-new-climate-target-ahead-of-un-summit

[80] HM Government "The Ten Point Plan for a Green Industrial Revolution"

		UK has been estimated to be in the greenhouse gas removals sector[81].
Total CCS Potential (MtCO2) 2022-2050	1,986	Both within power & heat sector (in connection with hydrogen) and industry (mineral oil & gas refineries, mineral production, iron and steel production, chemicals production, as well as food production)
Own storage capacity (Mt)	78,000[82]	69,000 Mt of storage in aquifers; 9,000 Mt of storage in depleted oil & gas fields
Own storage potential/support		The UK is actively developing and investing in offshore storage sites as a part of the climate strategy which has the support of the public[83]
Potential for DK storage	**Low**	**Low significance for DK; UK has significant storage capacity and already developed invested in CCS technology, initiated offshore storage projects, implemented CCS deployment timelines and believe CCS to be key for reaching net-zero.**

4.2.5.2 CCS national targets and policies in the United Kingdom

The UK aims to become carbon neutral in 2050 and emphasises CCS as a key decarbonisation strategy to achieve carbon neutrality. The UK's 'Clean Growth Strategy' of 2017 includes CCS as a specific approach to decarbonisation, setting forth an approach to enable the UK to become a global technology leader for CCUS and ensure that government has the option of deploying CCUS at scale during the 2030s[84]. CCS is recognised as an essential technology to reduce emissions from especially industry sectors and to decarbonise home-heating (hydrogen with CCS). However, the strategy notes that the cost of CCS will have to come down for it to be deployed at scale in the UK. In 2018, the UK Government's 'Carbon Capture Usage and Storage Deployment Pathway' set out further details on the steps it plans to take to deploy CCUS at scale during the 2030s, subject to the costs coming down sufficiently[85]. The Government's "10 Point Action Plan for a Green Industrial Revolution", announced in November 2020, also includes CCUS as a necessary point to decarbonise hard to abate sectors and reach negative emissions[86]. In December 2020, the UK's Climate Change Committee, acting as the government's climate advisers, have proposed a legally binding "carbon budget" that is in line with the national target of "net-zero" emissions by 2050, in which all pathways explored see the use of CCS as a critical and cost-effective means of meeting the UK's 2050 Net Zero target[87].

The UK has set a specific target for CCS deployment in 2030. The UK's CCS target is to capture >10 MtCO2/y by 2030[88]. The Climate Change Committee estimates that by 2030, CCS per capita will reduce UK emissions by 0.32 tCO2/person/year[89]. Further, the estimated savings between 2023-2032 from the deployment of low-carbon hydrogen are ~40 MtCO2e. By 2050, ~60% of the carbon captured in the UK has been estimated to be in the greenhouse gas removals sector, primarily through the combustion of biomass for electricity generation, with a further 20% used for the production of hydrogen and 10% used with gas in the power sector. Bioenergy with carbon capture and storage (BECCS) facilities have been estimated by the UK's Climate Change Committee to remove 22 MtCO2/y from the atmosphere by 2035 and 53 MtCO2/y by 2050[90]. The Committee estimates that Direct Air Capture of CO2 with storage (DACCS) starts to scale up from 2040 to reach 5 MtCO2/y by 2050.

The UK has an extensive national support system for CCS in place. CCS funding has been granted through the Clean Growth Strategy, allocating GBP 100m for CCUS applications in low-carbon hydrogen production, BECCS, as well as transport and storage of CO2. In addition, GBP 125m was allocated to an R&D and innovation program, which established UK CCS Research Centre. In

[81] Climate Change Committee "The Sixth Carbon Budget - The UK's plan to net zero"
[82] Department of Energy & Climate Change "CCS Roadmap Supporting deployment of Carbon Capture and Storage in the UK"
[83] Edie "Survey: Two-thirds of Brits support UK's green industrial revolution plans"
[84] HM Government "Clean Growth: The UK Carbon Capture Usage and Storage deployment pathway: An Action Plan"
[85] HM Government "The Clean Growth Strategy Leading the way to a low carbon future"
[86] HM Government "The Ten Point Plan for a Green Industrial Revolution"
[87] Climate Change Committee "The Sixth Carbon Budget - The UK's plan to net zero"
[88] HM Government "The Ten Point Plan for a Green Industrial Revolution"
[89] Climate Change Committee "The Sixth Carbon Budget - The UK's plan to net zero"
[90] Climate Change Committee "The Sixth Carbon Budget - The UK's plan to net zero"

2017, the Centre was awarded an additional GBP 6.1m to fund research work on CCS through 2022. In 2020, the government further committed to establishing a GBP 1 billion CCUS Infrastructure Fund, and in 2021, aims to introduce a revenue mechanism to bring through private sector investment in industrial carbon capture and hydrogen projects to provide the certainty investors require[91]. Further, the Scottish Government's strategy allocates GBP 60m to the Low Carbon Innovation Fund, as well as GBP 20m to the Energy Investment Fund. Additionally, the UK government has supported several frontend engineering, and design (FEED) studies for CCS in the UK (e.g., Peterhead and Longannet).

The UK is one of the leading nations in terms of policy support for CCS with a strong institutional framework and a range of climate change mitigation policies such as emission performance standards and a carbon price floor. The UK's comprehensive legal and regulatory CCS framework addresses the full chain of the CCS project life cycle. The Energy Act 2008 and its accompanying Carbon Dioxide Licensing Regulations 2010 transpose the requirements of the EU Storage Directive and establish the UK's framework for offshore CO2 storage activities. The regime applies to storage in the offshore area comprising both UK territorial sea and beyond designated as a gas importation and storage zone (GISZ) under section 1(5) of the Act. In addition, the UK has ratified the London Protocol that allows CO2 export to other states for storage purposes.

Table 21: CCS national targets and policies in the United Kingdom

CCS NATIONAL TARGETS AND POLICIES IN UNITED KINGDOM		
Category	**Indicator**	**Comments**
Country CCS policy maturity/potential	●	The policy maturity is considered high due to CCS strategies and targets, strong policy and legislative frameworks and financial support, creating favourable conditions for CCS.
National CO2 reduction targets	✓	• 2030: -68% from 1990 levels[92] (economy wide emissions) • 2050: Net zero emissions
National CCS targets	✓	The UK is committed to deploying CCS at scale during the 2030s, subject to costs coming down sufficiently. The UK's target is to capture >10 MtCO2/y by 2030 and capture and store ~0.32 tCO2 per capita.
CCS policies and legislations	✓	The UK is one of the leading nations in terms of policy support for CCS with a strong institutional framework in place and a range of climate change mitigation policies such as emission performance standards and a carbon price floor. CCS legislation comprises The Energy Act 2008 and its accompanying regulations which transpose the requirements of the EU Storage Directive and establish the UK's framework for offshore CO2 storage activities.
CCS funding	✓	Extensive funding dedicated to CCS research and projects has been granted in the UK.
CCS storage-related policies	✓	Storage permitted in the offshore area comprising both UK territorial sea and beyond designated as a gas importation and storage zone (GISZ) under section 1(5) of the Act.

4.2.5.3 CCS potential (capturable CO2 intended for storage) in the United Kingdom

The UK is one of the largest emitters of the countries, with emissions from large stationary plants estimated at ~146 MtCO2 in 2017, of which the power sector comprises 109.6 MtCO2 and the industry 33.2 MtCO2.

At present, energy is sourced from primary oil (crude oil and natural gas liquids), natural gas, primary electricity (consisting of nuclear, wind, solar and natural flow hydro), bioenergy and waste, and a very small amount of coal (1%)[93]. The UK power and heat sector have been transforming already from the 2020s towards increased supplies of low-carbon electricity

[91] HM Government "The Ten Point Plan for a Green Industrial Revolution"

[92] https://www.gov.uk/government/news/uk-sets-ambitious-new-climate-target-ahead-of-un-summit

(renewables and nuclear) and hydrogen, where CCS will be a central support vehicle to those supplies[94].

The industry comprises mineral oil & gas refineries, mineral production (cement, lime and plaster), iron and steel production, chemicals production, as well as food production, where high CCS potential is deemed due to CCS regarded as a key solution to decarbonise these hard to abate emissions.

All of the scenarios outlined by the CCC critically incorporate CCS since it is considered a cost-efficient means of meeting the UK's 2050 Net-zero target, and the deployment of CCS is already beginning from 2025[95]. The calculated capturable quantity of CO2 is estimated at on average 50 MtCO2/y between 2022 and 2040 and 119 MtCO2/y between 2041 and 2050 for both the power & heat sector and the industry sector.

[94] Committee on Climate Change (CCC), "Net Zero. The UK's contribution to stopping global warming"

[95] Gov.uk, "UK ENERGY IN BRIEF 2020"

Table 22: CCS potential (intended for storage) in the United Kingdom

Sector	CO2 emissions 2017, MtCO2	Capturable quantity of CO2, MtCO2 (avg. MtCO2/y[96])		Comment
		2022-2040	2041-2050	
Power & Heat	**109.6**	**518.4** **(32.4)**	**798.8** **(79.9)**	• The overall significance of CCS within the UK power sector is considered to be widespread due to the UK's energy sector transformation towards increased supplies of low-carbon electricity (renewables and nuclear) and hydrogen, where CCS will be a central support vehicle to those supplies[97] • Power and heat CO2 in the United Kingdom splits into thermal power and heat generation (99.7 MtCO2) and waste-to-energy plants (9.9 MtCO2) • The capturable volume of CO2 intended for storage within the segment is estimated at up to 90 MtCO2/y, including BECCS: - Based on scenario studies CCS from fossil power generation can range between 22-51 MtCO2 in 2050, and Ramboll estimates the median of the two in 2050, i.e. 36 MtCO2 - BECCS will play a significant role for new WtE plants and extensions where CCS should be built, and all energy-from-waste plants should fit CCS by 2050, starting from 2040. BECCS from the power industry as a whole is expected to range between 11-25 MtCO2/y in 2050, for which Ramboll also assumes the median; 18 MtCO2/y - Further, there is an important role for hydrogen produced from fossil gas with CCS in the medium term to enable hydrogen growth. Thus CCS from the production of hydrogen has potential and is estimated to range between 22-50 MtCO2/y in 2050, where Ramboll applies the median (36 MtCO2/y) • The introduction of CCS is expected from 2025, and the most rapid emissions reduction increases are estimated from 2025-2035, therefore the increase of CCS potential is the steepest between this period[98]. From 2035-2050 the CCS potential continues to rise but at a slower pace: Following the 2024 coal phase-out, gas-fired power without CCS should be phased out by 2035 and any gas plant built before 2030 should be made ready for a switch to CCS or hydrogen, which is why the deployment of CCS keeps increasing towards 2050
Industry	**33.2**	**278.8** **(17.4)**	**390.3** **(39.0)**	• The UK produces notable levels of emissions in the industry sector, including mineral oil & gas refineries, mineral production (cement, lime and plaster), iron and steel production, chemicals production, as well as food production • In the industry sector, CCS faces competition from hydrogen, electrification and CCU. However, CCS is considered to comprise the majority of engineered greenhouse gas removals in 2050. The significance of CCS is high within the industry sector since CCS is considered the key deep decarbonisation option for manufacturing, oil refineries, cement and steel production. • Total capturable volumes intended for CCS excluding BECCS are aligned with the CCC high case of about 24 MtCO2/y in 2050: - CCS is applied to the manufacturing sector at scale in the 2030s and continues to remove CO2 at similar levels out to 2050 - CCS is also applied to half of the UK's integrated steelwork capacity in the early 2030s - CCS will play a significant role in binging emissions down for cement, lime and other mineral sites - Oil refineries emissions are also abated through CCS, along with reduced oil demand and energy efficiency improvements. CCS is the main emissions reduction measure for the remaining emissions from oil refineries • BECCS from the industry sector is expected to range between 11-25 MtCO2/y in 2050, of which Ramboll estimates the median in 2050, i.e. 18 MtCO2/y

[96] Average CO2 capturable amount is calculated for the time period 2030-2040

[97] Committee on Climate Change (CCC), "Net Zero. The UK's contribution to stopping global warming"

[98] Climate change committee, "The Sixth Carbon Budget. The UK's path to Net Zero"

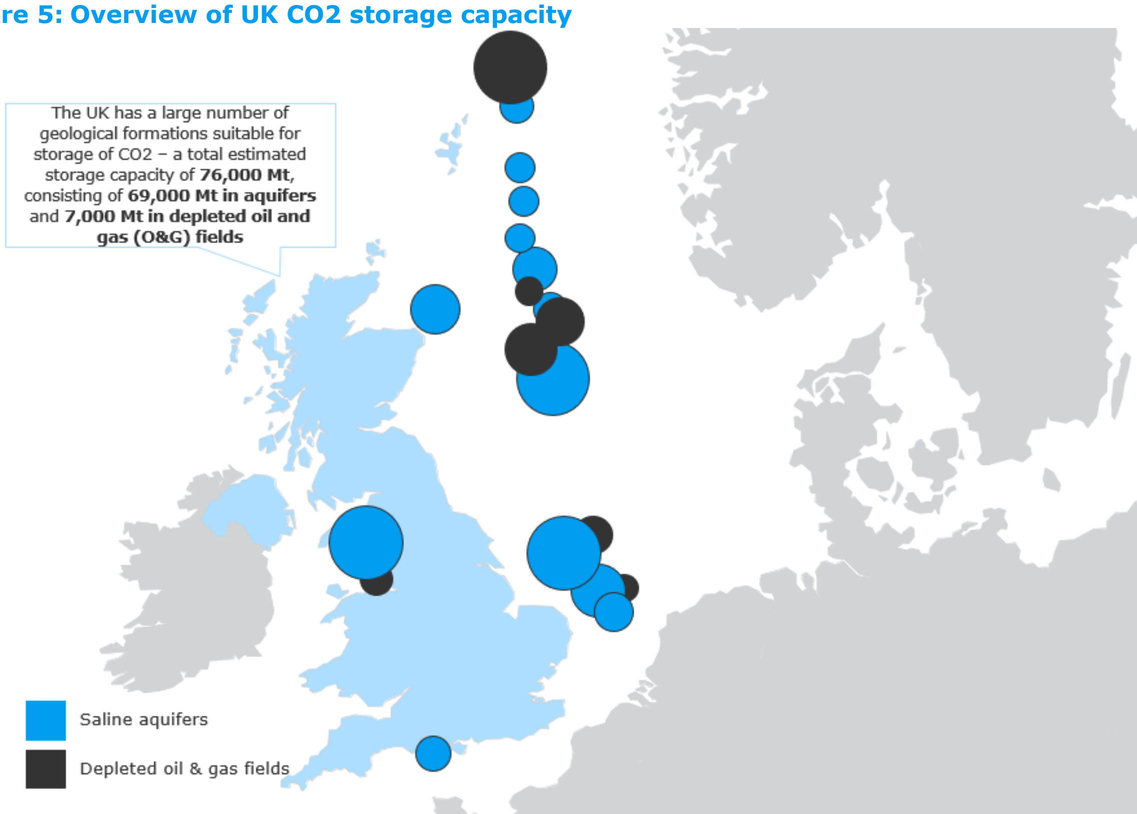
4.2.5.4 CO2 storage potential in the United Kingdom

The UK's total CO2 storage capacity is assessed at 78,000 Mt. The majority, 69,000 Mt, is situated in storage aquifers, and 9,000 Mt is situated in oil and gas fields units. Most of the aquifer storage capacity is located on the United Kingdom continental shelf relatively far offshore in the North Sea near the oil and gas fields. Oil and gas fields can be cheaper to develop than aquifer storage units as some of the offshore infrastructures is already in place[99].

The UK public has a positive attitude towards utilising domestic offshore carbon storage capacity[100]. UK's storage capacity is considered to be sufficient to cover all upcoming CCS activity.

The picture below provides an overview of UK storage site locations and their relative sizes.

Figure 5: Overview of UK CO2 storage capacity



Source: Ramboll analysis, EU Geocapacity, "Assessing European Capacity for Geological Storage of Carbon Dioxide"; Costain, Energy Technologies Institute, Pale Blue Dot, Axis Well Technology, "Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource: A summary of result from the strategic UK CO2 storage appraisal project

[99] IOGP, "The potential for CCS and CCU in Europe"

[100] Edie, "Two thirds of Brits support UK's green industrial revolution plans"

4.2.6 The Netherlands

4.2.6.1 Summary of CCS potential in the Netherlands

The Netherlands' CO2 emissions from large sources in 2017 were ~95 MtCO2. Most emissions relate to the power and heat sector (~65 MtCO2) and industrial production and processing (~30 MtCO2).

The Netherlands is aiming to reduce CO2 emissions by 95% from 1990 levels by 2050. CCS is acknowledged in the Netherlands for its important role in reaching the climate target, yet mostly as a transition solution until CCU and CCS linked with bioenergy can replace current CCS solutions for fossil fuel industries. A CCS target has been set to 7.2 MtCO2/y by 2030, which is about half of the country's industry CO2 emissions reduction target of 14.3 MtCO2/y. Thus, CCS plays a considerable role in the reduction of CO2 emissions from industry, yet it is controlled since subsidies for CCS is capped at 7.2 MtCO2/y and subsidised are made available only if no other cost-effective CO2-reduction alternatives are available, and finally, after 2035, no new subsidies are granted to fossil CCS projects. The latter limitation is to ensure that the fossil fuel industry does not continue in the future. According to national policies, CCS is initially limited to industry sectors (steel, refinery, hydrogen, fertilizer, waste incineration)[101]. Despite ambitious climate targets, the Netherlands is currently behind most other EU countries with respect to their renewable energy targets, i.e., the country's share of energy coming from renewable sources is the lowest in the EU.

National support for CCS has been granted through various R&D-related funding and going forward; subsidies will be granted to a broader set of technologies to avoid CO2 emissions, including CCS through The Sustainable Energy Transition Incentive Scheme (SDE++).

CCS potential in the Netherlands is estimated at 274 MtCO2 between 2022 and 2050 and on average 12 MtCO2/y between 2022 and 2040 and 15 MtCO2/y between 2041 and 2050, with the largest share from the power & heat sector. Gas is still expected to be part of the Dutch energy mix towards 2050, and CCS will play an important role to abate CO2 emissions from this source. Industrial sector emissions mainly relate to chemicals and refineries and will be highest in the short-medium run, as in the long run, the government is expected to prioritize CCU and CCS linked with bioenergy.

Storage potential in the Netherlands is estimated at 4,000 Mt, with 3,000 Mt of storage in depleted oil & gas fields and 1,000 Mt of storage in aquifers. Storage is only allowed offshore or in other countries.

The relevance for storage in Denmark is deemed medium. It is uncertain how much the Netherlands expects to store nationally. The Netherlands has identified the risk that CO2 transport demand might exceed the storage capacity in their CO2TransPorts industry cluster project[102]. Additionally, there could be opportunities for export of Dutch CO2 if their national CCS projects delay (the country has a history of delay with previous renewable energy projects), and finally, The Dutch government has acknowledged that it will be challenging for The Netherlands to achieve emissions reduction by scaling up renewables and thus, CCS could be a potential source to make up for this potential gap[103]. Therefore, it is possible that Netherlands will not be able to meet the CO2 demand with national storage capacity in time and will need to export CO2, at least in the short-medium term.

Below is an overview of the CCS potential in the Netherlands.

[101] The Dutch Ministry of Economic Affairs & Climate Policy: Clean Energy Solutions Center – "Carbon Capture, Utilization and Storage in The Netherlands (Webinar)"

[102] European Commission, "Candidate PCI projects in cross-border carbon dioxide transport networks"

[103] IEA – The Netherlands 2020 Energy Policy Review

Table 23: Summary of CCS potential in the Netherlands

SUMMARY OF CCS POTENTIAL		
Category	**Indicator**	**Comments**
CO2 emissions 2017 (MtCO2) Plants >100 ktCO2	95.0	CO2 emissions from largest point sources; mainly by from the power and heat generation industry, followed by the chemical production and mineral oil and gas refinery industries
CO2 reduction targets	✓	• 2030: -49% from 1990 levels (national target) and -36% from 2005 levels (non-EU ETS)[104] • 2050: -95% from 1990 levels (national target)
National CCS focus/Support	◕	The Netherlands recognizes the important role CCS will have in reaching CO2 reduction targets, yet mostly as a short-term solution until CCU and CCS linked with bioenergy can replace current CCS solutions.
CCS targets	✓	The Netherlands initially planned to capture and store 18 MtCO2/y by 2030, but the target has been adjusted to 7.2 MtCO2/y, as few believed the initial goal to be realistically achievable.[105] CCS is estimated to account for 20 mtCO2 reductions by 2030 from industrial sectors.[106]
Total CCS Potential (MtCO2) 2022-2050	274	Evenly split between power & heat (natural gas emissions) and industry (emissions from chemicals processing and refineries).
Own storage capacity (Mt)	4,000[107]	3,000 Mt of storage in depleted oil & gas fields; 1,000 Mt of storage in aquifers
Own storage potential/support	◑	Storage of CO2 is only allowed offshore or in other countries but supported by the government through several projects.[108]
Potential for DK storage	**Medium**	**Medium significance for DK storage due to ongoing national carbon storage site development. However, uncertainty remains regarding project delays and storage capacity, preventing NL from reaching GHG targets in the next 10-20 years, making carbon export a possibility in the future.**

4.2.6.2 CCS national targets and policies the Netherlands

The Netherlands is aiming to reduce CO2 emissions by 95% from 1990 levels by 2050. The Netherlands has a favourable policy- and regulatory environment for the uptake of CCS, as is seen by the government indicating CCS as a necessary instrument to reduce CO2 emissions in the short term.[109] However, in the long term, the government wants to move away from CCS of fossil fuel emissions towards CCU and CCS linked with bioenergy.[110]

The Netherlands has set CCS targets limited to the industry sector, initially planning to capture and store 18 MtCO2/y by 2030, but the target has been adjusted to 7.2 MtCO2/y, as few believed the initial target to be realistically achievable[111]. By 2030, CCS has been estimated to account for 20 mtCO2 reductions from industrial sectors[112].

Policy measures are in place to support the deployment of CCS in the Netherlands. The government is preparing to release a new Dutch CCS Roadmap that is expected to accelerate the deployment of CCS.[113] In 2019, the Dutch government decided, on top of the ETS system, to implement a carbon tax, which could provide additional incentive for large emitters to implement CCS.

[104] The Netherland's Integrated National Energy and Climate Plan (NECP 2030)
[105] CE Delft "Feasibility study into blue hydrogen – technical, economic and sustainability analysis", July 2018
[106] Global CCS Institute CO2RE database
[107] GEUS "Assessment of CO2 Storage Potential in Europe"
[108] International Energy Agency "The Netherlands 2020: Energy Policy Review"
[109] Klimaat-akkoord "Voorstel voor hoofdlijnen van het Klimaatakkoord"
[110] International Energy Agency "The Netherlands 2020: Energy Policy Review"
[111] CE Delft "Feasibility study into blue hydrogen – technical, economic and sustainability analysis", July 2018
[112] Global CCS Institute CO2RE database
[113] Global CCS Institute CO2RE database

In recent years, the Dutch Government has supported CCS R&D initiatives through CATO, which is a national CCS R&D program that involves collaboration and funding from both the government and industry.[114] The Sustainable Energy Transition Incentive Scheme (SDE++) of 2020 is a key funding source as it awards subsidies to a broader set of technologies to avoid CO2 emissions, including CCS. The government is expecting that a significant share of industrial emissions reductions will be realised through SDE++ support for CCS and low-carbon hydrogen.[115] The scheme sets a limit of 7.2 MtCO2/y for subsidising industrial CCS. A carbon storage project called Porthos is expected to be granted funding from the SDE++ scheme in 2022.

The Netherlands has developed an integrated and comprehensive legal framework for CCS activities, which draws upon wider national environmental and mining laws. The Dutch government has mainly implemented the requirements of the EU storage Directive through amendments to the national mining legislation, notably the Mining Decree and Mining Regulation. In addition, the Netherlands has ratified the London Protocol that allows CO2 export to other states for storage purposes.

Under the Dutch Mining Act, underground storage of CO2 is only allowed offshore or in other countries.[116] To unlock storage potential, regulatory changes on the transfer of ownership and decommissioning of the gas field after they have been depleted are necessary. These regulatory aspects have been identified as potential barriers to the development of CCS projects in the Netherlands.

Table 24: CCS national targets and policies in the Netherlands

CCS NATIONAL TARGETS AND POLICIES		
Category	**Indicator**	**Comments**
Country CCS policy maturity/potential	◕ (three-quarter filled circle)	Strong policy and regulatory framework to support CCS and specific targets for CCS deployment create favourable policy conditions for CCS in the Netherlands, yet mostly in the short-term.
National CO2 reduction targets	✓	• 2030: -49% from 1990 levels (national target) and -36% from 2005 levels (non-EU ETS)[117] • 2050: -95% from 1990 levels (national target)
National CCS targets	✓	The Netherlands initially targeted to capture and store 18 MtCO2/y by 2030, but the target has been adjusted to 7.2 MtCO2/y from the industrial sector.[118] By 2030, CCS is estimated to account for 20 MtCO2 reductions from industrial sectors.[119]
CCS policies and legislations	✓	CCS is regarded as a necessary instrument to reduce CO2 emissions in the short term[120], but in the long term, the government wants to move away from CCS of fossil fuel emissions towards CCU and BECCS.[121] The Netherlands has developed an integrated and comprehensive legal framework for CCS activities, which draws upon wider national environmental and mining laws.
CCS funding	✓	Support systems and funding for CCS research and projects are in place in the Netherlands, most notably through the national CCS R&D programme CATO. The more recent funding source available for CCS is the SDE++, which is a pivotal funding source for CCS in the Netherlands. A carbon storage project called Porthos is expected to be granted funding for the SDE++ scheme in 2022.
CCS storage-related policies	—	Underground storage of CO2 is only allowed offshore or in other countries.[122] To unlock storage potential and prevent the development of CCS projects in the Netherlands, regulatory

[114] Global CCS Institute CO2RE database
[115] International Energy Agency "The Netherlands 2020: Energy Policy Review"
[116] International Energy Agency "The Netherlands 2020: Energy Policy Review"
[117] The Netherland's Integrated National Energy and Climate Plan (NECP 2030)
[118] CE Delft "Feasibility study into blue hydrogen – technical, economic and sustainability analysis", July 2018
[119] Global CCS Institute CO2RE database
[120] Klimaat-akkoord "Voorstel voor hoofdlijnen van het Klimaatakkoord"
[121] International Energy Agency "The Netherlands 2020: Energy Policy Review"
[122] International Energy Agency "The Netherlands 2020: Energy Policy Review"

		changes on the transfer of ownership and decommissioning of the gas field after they have been depleted are necessary.

4.2.6.3 CCS potential (capturable CO2 intended for storage) in the Netherlands

Total CO2 emissions from large sources[123] in the Netherlands were ~95 MtCO2 in 2017, of which ~65 MtCO2 were related to the power & heat sector and ~30 MtCO2 to the industrial production and processing.

The overall significance of CCS within the Dutch power & heat sector is considered medium.

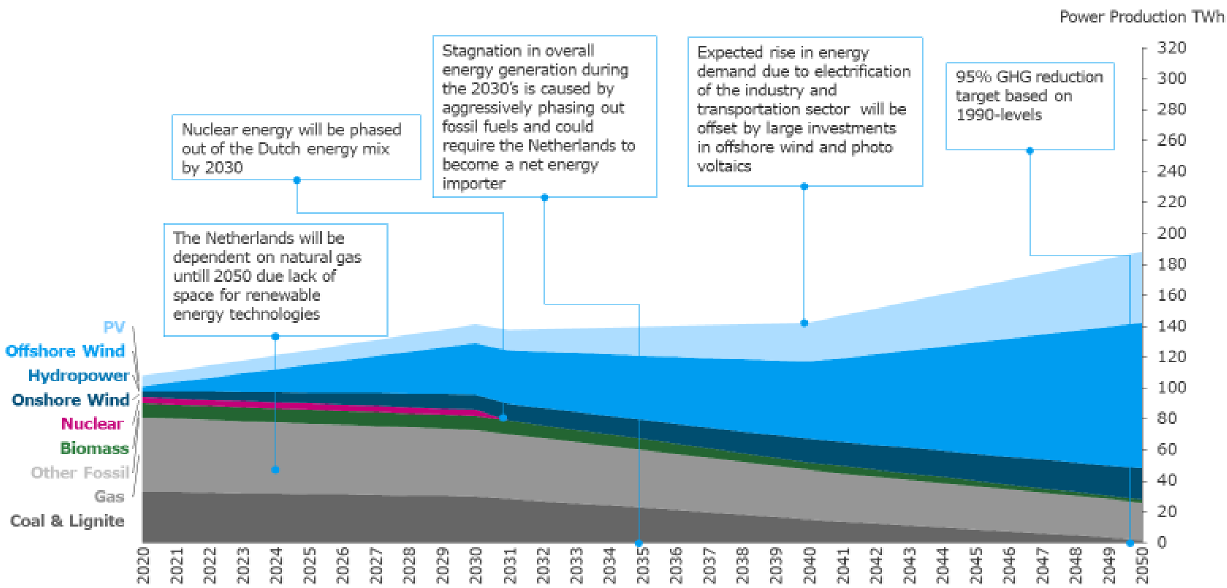
Despite the very ambitious targets for climate-change mitigation, the Netherlands today is currently furthest behind other EU countries in the production of energy from renewable sources, e.g., they fell short of their onshore wind target of 6 GW in 2020 due to public acceptance, grid constraints (require a confirmation from relevant network operators) and land fees, whereas large-scale PV projects were delayed since the supporting grid infrastructure was not delivered in time for when the PV construct was finished. Renewable energy in the Netherlands comes mainly from biofuels, waste, and wind, while geothermal, solar and hydro energy play only a minor role in the country.

Despite plants phasing out production at Groningen, Europe's largest onshore natural gas field, by 2022, it is expected that the gas will still be part of the Dutch energy mix towards 2050.

Emissions for the industrial sectors have mainly concentrated around chemicals and refineries. While significant potential is assessed with regards to refineries, the chemicals sector is expected to prioritise other alternatives, including CCU, in the long run.

The calculated capturable quantity of CO2 is estimated at on average 12 MtCO2/y between 2022 and 2040 and 15 MtCO2/y between 2041 and 2050.

Figure 6: The Netherland's potential energy mix towards 2050



Source: Ramboll Analysis; Alliander, ECN, "The supply of flexibility for the power system in the Netherlands, 2015-2050"

Table 25: CCS potential (intended for storage) in the Netherlands

Sector	CO2 emissions 2017, MtCO2	Capturable quantity of CO2, MtCO2 (avg. MtCO2/y[124])		Comment
		2022-2040	2041-2050	
Power & Heat	**64.6**	**75** **(5)**	**95** **(9)**	• The overall significance of CCS within the Dutch power & heat sector is considered medium, as the Netherlands is challenged to convert all its energy production to renewable sources • The capturable volume of CO2 intended for storage within the segment is estimated at up to ~9 MtCO2/y, and mainly related to the gas-fired plants • CCS is not considered relevant for coal-driven plants since they will be phased out shortly after the CCS introduction
Industry	**29.9**	**79** **(5)**	**51** **(5)**	• Emission from the industrial sector was 29.9 MtCO2 in 2017, including production and processing of chemicals/ petrochemicals (16.9 Mt in 2017) and refineries (10.6 MtCO2 in 2017) • The significance of CCS within the industrial sector varies across disciplines. It is high for refineries but much lower for the chemicals industry, where there are several options to abate emissions. In general, the chemical industry is prioritizing CCU over CCS • The total capturable volume intended for storage is estimated at up to ~5 MtCO2/y; The Netherlands has indicated CCS as a necessary instrument to reduce CO2 emissions in the short term. In the long term, the government wants to move away from CCS of fossil fuel emissions towards CCU and CCS linked with bioenergy. Consequently, CCS within the industrial sector is expected to peak between 2030 and 2045 and slightly decrease thereafter.
Other	**0.5**	**-**	**-**	• No other significant potential areas have been assessed

[124] Average CO2 capturable amount is calculated for the time period 2030-2040

4.2.6.4 CO2 storage potential in the Netherlands

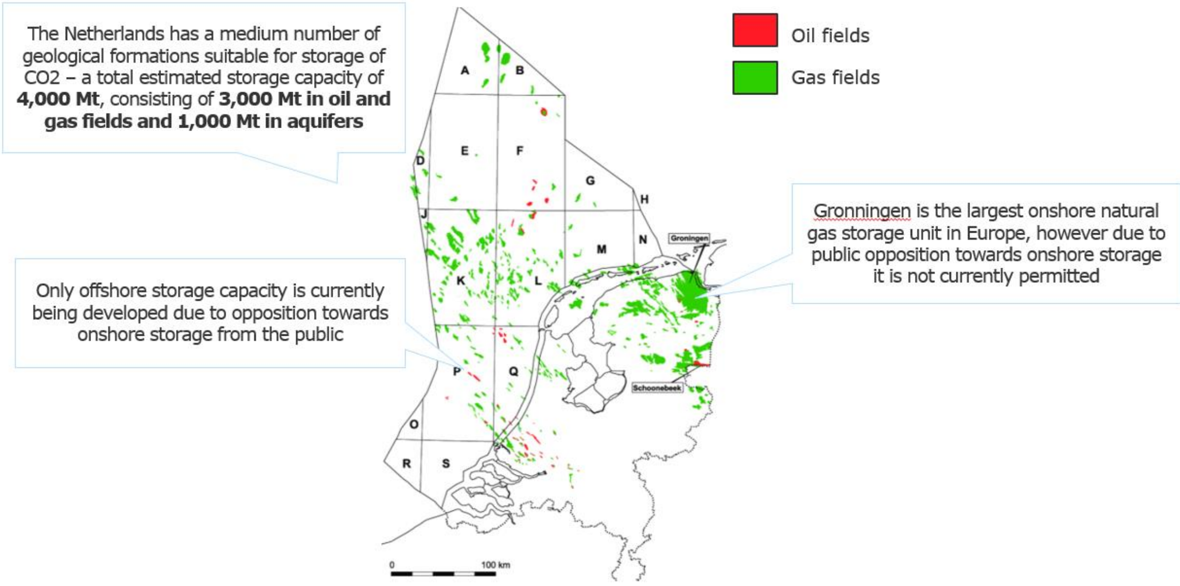
The Netherlands has a total of 4,000 Mt of storage capacity – 3,000 Mt – in oil and gas fields and 1,000 Mt in aquifers[125]. As described in section 4.2.6.2, carbon storage is only allowed offshore, which corresponds to 1,000 Mt of storage capacity in oil and gas fields and 700 Mt in offshore aquifer storage capacity[126].

While the Netherlands is developing projects to store carbon domestically, industry cluster projects acknowledge that the demand for storing CO2 might exceed the storage capacity and especially if the CCS project deliveries are faced with delays[127]. This means that the export of captured carbon to international carbon storage sites could be necessary for the short-to-medium term.

Despite Government support for CCS and their continued efforts to support CCS and set targets, CCS was a controversial topic during the 2019 climate agreement negotiations; It was opposed by several NGOs and some political parties[128]. Nevertheless, a study of public opination towards CCS showed the Dutch public a neutral attitude towards offshore CCS[129].

The picture below provides an overview of possible carbon storage sites in the Netherlands.

Figure 7: Overview of CCS facilities in Netherlands



Source: Ramboll analysis, Vrije Universiteit Amsterdam, Jan de Jager, "Petroleum Geology of the Netherlands"

[125] GEUS, "Assessment of CO2 Storage Potential in Europe"

[126] Noordzeeloket, "CO2-storage"

[127] European Commission, "Candidate PCI projects in cross-border carbon dioxide transport networks"

[128] The Dutch Ministry of Economic Affairs & Climate Policy: Clean Energy Solutions Center – "Carbon Capture, Utilization and Storage in The Netherlands (Webinar)"

[129] Centre for Energy and Environmental Studies, Dept. of Psychology, Leiden University, "Informed public opinion in the Netherlands: Evaluation of CO2 capture and storage technologies in comparison with other CO2 mitigation options"

4.2.7 Poland

4.2.7.1 Summary of CCS potential in Poland

Poland's emissions from large sources in 2017 were ~167 MtCO2. Most emissions relate to the power & heat sector (121 MtCO2), and the remaining to industrial production and processing (22 MtCO2) and other activities (23 MtCO2), including coal mining, landfill etc.

Poland is the only country where the Government has not yet committed to becoming carbon neutral of all the ten countries and the EU countries. However, the climate ministry presented an update of the country's 2040 energy roadmap at the end of 2020, where the country formally endorses the EU 2050 climate neutrality goal. Poland does not actively pursue CCS at present. However, the outlook for its coal expansion plans provide opportunities for carbon removal for Poland to reach the EU commitments.

CCS potential in Poland is estimated at 591 MtCO2 between 2022 and 2050 and on average 19 MtCO2/y between 2022 and 2040 and 34 MtCO2/y between 2041 and 2050, with the largest share coming from the power & heat sector. To decarbonise the Polish power & heat sector, CCS and BECCS are expected to be necessary. Although most of the existing plants are old, CCS will be relevant for some of the newer current power & heat plants (coal and biomass CHP) and upcoming natural gas (to be built by 2035). Further, CCS is expected to play a role in the decarbonising industrial sector, specifically, iron and steel (in connection with the use of blue hydrogen) and mineral/cement industry, where CCS is currently the only relevant option for emissions abatement.

Storage potential in Poland is estimated to be 78,000 Mt, mainly in aquifers. Only offshore storage can currently be developed (CO2 storage is banned until 2024 except for offshore demonstration projects). However, no development projects have been registered, and Poland has shown limited interest in national storage. While Poland's domestic storage capacity can cover all upcoming CCS activity needs until 2050, it is expected that only some of the upcoming CCS activity will be covered by domestic storage capacity. Nonetheless, with potential EU funding Poland may become interested in national storage, especially since the high cost of exporting CO2 might be high.

The relevance for storage in Denmark is deemed medium, as limited interest in national storage and large CCS potential could make CO2 export relevant.

Below is a summary table of the CCS potential in Poland.

Table 26: Summary of CCS potential in Poland

SUMMARY OF CCS POTENTIAL		
Category	**Indicator**	**Comments**
CO2 emissions 2017 (MtCO2) Plants >100 ktCO2	166.7	CO2 emissions from the largest point sources; mainly from the power and heat generation industry powered by old coal plants, followed by the cement, iron and steel industries
Co2 reduction targets	✓	• 2030: -21% in EU ETS sectors and -7% from 2005 levels (non-EU ETS) (-30% from 1990 levels)[130] 2050: -85-90% from 1990 levels
National CCS focus/Support	◔	Poland does not actively pursue CCS at present. However, the outlook for its coal expansion plans provide opportunities for carbon removal for Poland to reach the EU commitments.
CCS targets	✗	No specific targets have been set for the deployment of CCS in Poland.
Total CCS Potential (MtCO2) 2022-2050	591	The largest share of capturable CO2 is expected to be derived from the power & heat sector (natural gas-fired power plants and biomass-fired plants). Significant potential also assessed within the industry (mainly iron and steel, and cement).
Own storage capacity (Mt)	78,000[131]	77,000 Mt of storage in aquifers – however, estimates are debatable and vary widely; 1,000 Mt of storage in depleted oil & gas fields

[130] PEP2040 – Poland's energy policy until 2040

[131] Mineral and Energy, Economy Research Institute of Polish Academy Sciences, "CO2 storage capacity of deep aquifers and hydrocarbon fields in Poland – EU GeoCapacity project results"

Own storage potential/support	TBD	CO2 storage is banned in Poland until 2024 (except for offshore demonstration projects). This could indicate that the country has no particular interest in storage at present. However, CCS is expected to become a highly relevant measure to offset emissions from the continued use of natural gas. Given that CO2 export can be more expensive than domestic storage, Poland is therefore expected to explore its own storage options (especially if the EU funding will be available)
Potential for DK storage	**MEDIUM**	Poland's domestic storage capacity can cover all upcoming CCS activity needs until 2050. However, only some of the upcoming CCS activity is expected to be covered by domestic storage capacity.

4.2.7.2 CCS national targets and policies Poland

Poland is aiming to reduce CO2 emissions by 85-90% from 1990 levels by 2050. However, the climate ministry presented an update of the country's 2040 energy roadmap at the end of 2020, where the country formally endorses the EU 2050 climate neutrality goal. Poland does not actively pursue CCS at present as a means of decarbonisation and has not set targets for CCS deployment. However, the Polish energy policy notes that there is institutional interest in CO2 capture projects, and the possibility of implementing them with the option to transport it outside Poland is not ruled out (e.g., in the North Sea region). Furthermore, in light of the planned expansion of Poland's coal industry, CCS can be expected to be necessary for Poland to reach its climate targets and EU commitments.

Currently, no national support system for CCS deployment is in place in Poland. Previously, through its R&D program "New Technologies for Energy Generation", Poland supported two CCS pilot facilities that tested varying capture approaches in Lagisza and Jaworno power plants from 2010-2015. Both projects were cancelled due to the high cost of the CCS technology as well as the influence of the social resistance coming from the rest of the EU of storing CO2 on geological formations. Further, a demo CO2 post-capture project was performed at Belchatow (on the new 858 MW lignite-fired unit), which was also abandoned at the stage of a CCS ready investment due to high cost and lack of sufficient (national) financial support[132]. However, the institutional interest in CCS remains, and the option of capturing CO2 and transporting it outside Poland is specifically noted in Poland's energy policy as a consideration.

Poland has basic legal and regulatory frameworks in place related to CCS. Poland has implemented the EU's CCS Directive by amending the Polish Geological and Mining Law. However, CO2 storage is banned in Poland until 2024, except for offshore demonstration projects. Under the amendments, Poland thus prohibits onshore storage and identifies only one storage site for commercial CO2 storage – in the Baltic Sea, which is located far from the biggest sources of CO2 emissions.[133]

Table 27: CCS national targets and policies in Poland

CCS NATIONAL TARGETS AND POLICIES		
Category	**Indicator**	**Comments**
Country CCS policy maturity/potential	◔	Poland does not actively pursue CCS at present.
National CO2 reduction targets	✓	• 2030: -21% in EU ETS sectors and -7% from 2005 levels (non-EU ETS) (-30% from 1990 levels)[134] • 2050: -85-90% from 1990 levels
National CCS targets	✗	Poland has no CCS targets.
CCS policies and legislations	–	Poland has basic regulatory and policy frameworks to enable CCS deployment in the country due to its EU membership. The energy policy of Poland mentions the so-called "CCS ready" requirements, and the decision to employ CCS will need to fulfil these requirements and be economically efficient.

[132] CCS – Polish Point of View, Basrec conference Warsawa
[133] Carbon neutral Baltic states: "Do we have CCUS among accepted options"
[134] PEP2040 – Poland's energy policy until 2040

CCS funding	❌	No national support systems in place.
CCS storage-related policies	❌	CO2 storage is banned in Poland until 2024, except for offshore demonstration projects. CO2 use for EOR and EGR and associated CO2 storage onshore and offshore are allowed.

4.2.7.3 CCS potential (capturable CO2 intended for storage) in Poland

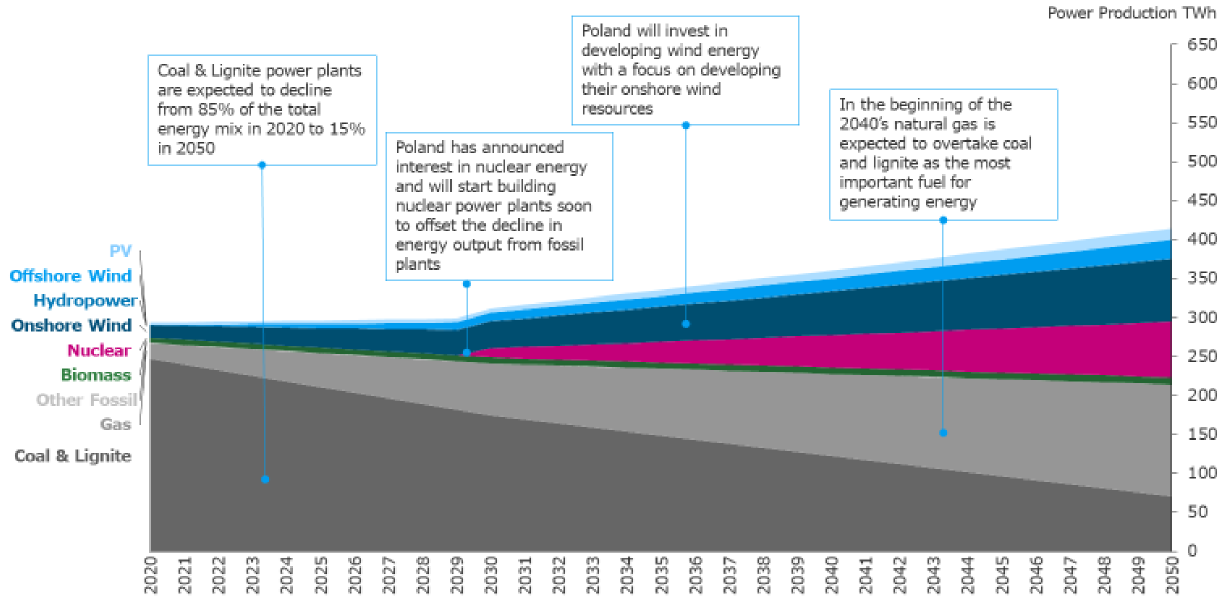
Total CO2 emissions from large sources[135] in Poland were ~167 MtCO2 in 2017, of which 121 MtCO2 were related to the power & heat sector, 22 MtCO2 to the industrial production and processing and the remaining 23 MtCO2 to other activities, including coal mining, landfill etc.

The overall significance of CCS within the power & heat sector in Poland is considered low, as renewables and nuclear energy are expected to lead the decarbonisation of the power sector. However, Poland's reliance on natural gas is expected to increase and be high at least until 2040. Furthermore, there are up to date no announced plans to completely discontinue the four newly build coal-driven power plants. Consequently, CCS is seen as necessary in order to abate the remaining CO2 emissions within the sector. Poland also has carbon sink potential due to large surface areas and large forest areas. However, forests are becoming mature, resulting in the decrease of the carbon sink potential. Other options in terms of agricultural fields/soil and wetlands are possible but would require significant investments. The total carbon sink is expected to be approximately 10 MtCO2e/y in 2050[136].

Poland's industry's decarbonization pathway will likely require the development of alternative fuels (hydrogen, biomass, and electricity), and CSS is seen as a last-resort option at scale. Decarbonisation of Poland's industry sector is also expected later on compared to the power & heat sector.

The calculated capturable quantity of CO2 is estimated at on average 19 MtCO2/y between 2022 and 2040 and 34 MtCO2/y between 2041 and 2050, with the largest share coming from the power & heat sector.

Figure 8: Poland's potential energy mix towards 2050



Source: Ramboll Analysis; Forum Energii, "Polish energy sector 2050"

[135] Plants with emissions exceeding 100,000 MtCO2/y

[136] Carbon-neutral Poland 2050: Turning a challenge into an opportunity, McKinsey & Company 2020

Table 28: CCS potential (intended for storage) in Poland

Sector	CO2 emissions 2017, MtCO2	Capturable quantity of CO2, MtCO2 (avg. MtCO2/y[137])		Comment
		2022-2040	2041-2050	
Power & Heat	**121.2**	**217** (**17**)	**310** (**31**)	• The overall significance of CCS within the power & heat sector in Poland is considered low, as renewables and nuclear energy are preferred options for decarbonisation of the power sector • However, switching power-generation technology from fossil fuels to renewable energy is expected to be a major challenge for Poland, and not all fossil sources will be decommissioned by 2050. Consequently, CCS is seen as a necessary measure in order to abate the remaining CO2 emissions within the sector • Although the overall decarbonisation of Poland's power & heat sector will be to a large degree driven by electrification, Poland has recently invested in a number of large power plants relevant for CCS (4 newer coal-fired plants and seven biomass-fired CHP plants) and five natural gas plants are planned to be delivered the mid-2020s. All of these plants are expected to operate towards 2050. The majority of the remaining installed coal capacity is older than 30 years and will most probably need to be decommissioned before 2050 • Total capturable CO2 volume from these plants is estimated at up to ~33 MtCO2/y
Industry	**22.4**	**32** (**3**)	**31** (**3**)	• CO2 emissions from the industrial sector were at 22 MtCO2 in 2017, primarily concentrated in iron and steel (7.1 MtCO2 in 2017) and cement (6.8 MtCO2 in 2017). Additional smaller amounts are assessed within refineries, non-ferrous metals and chemicals. • CCS would be an important measure to reduce emission within this sector, along with the development of alternative fuels (hydrogen, biomass, and electricity). However, CCS is still considered a last-resort option at scale in Poland. • Total capturable volume intended for storage is estimated at up to ~3 MtCO2/y, and the highest potential is assessed within the mineral processing/cement industry, where CCS is assessed to be the most effective way to significantly reduce emissions. Ramp-up of the CCS within the industrial sector is expected to be moderate, starting from 2030 and reach the full potential around 2040 • CCS is also considered highly relevant for reducing CO2 emissions within the iron and steel industry. Hydrogen is currently considered to be a preferred option to abate CO2 emissions within this industry. However, there are no provisions against the import and use of blue hydrogen. Blue hydrogen is therefore expected to be the transitional solution, creating the need for CCS • Some minor potentials are also assessed within the refining industry and chemical industry. However, in general, the chemical industry is prioritizing CCU over CCS
Other	**23.1**	**-**	**-**	• Other comprises coal mining, landfill and waste management. None of these are considered relevant for CCS in Poland

[137] Average CO2 capturable amount is calculated for the time period 2028-2040

4.2.7.4 CO2 storage potential in Poland

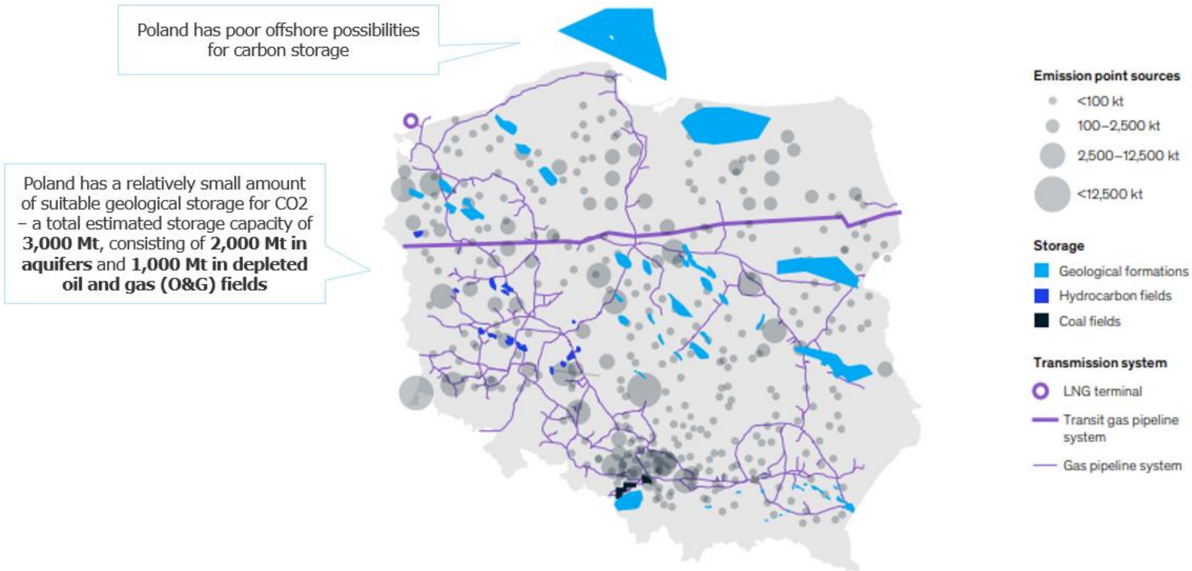
Poland has an estimated 78,000 Mt of storage capacity, of which the majority – 77,000 Mt – is situated in storage aquifers, and 1,000 Mt is situated in oil and gas fields[138]. Aquifer units are mostly located onshore, while oil and gas fields are located offshore and onshore. Only offshore storage can currently be developed; however, no development projects have been registered[139].

The storage capacity of oil and gas fields are mapped more accurately[140] and can theoretically cover Poland's CCS activity needs. The storage capacity could be too expensive to develop and operate due to the relatively small scale of the storage units and a lack of government will and incentives. The current situation suggests that Poland is not currently interested in developing storage. However, CCS is expected to become highly relevant as an emission offset measure for the continued use of natural gas. Given CO2 export can be more expensive than storage, Poland is expected to explore domestic storage opportunities, especially if EU finance is available[141].

The Polish public recognizes CCUS as an effective climate change technology[142]. However, currently little governmental support for the development of storage sites is provided, as described in section 4.2.7.2. This means that, while Poland's domestic storage capacity can cover all upcoming CCS activity needs until 2050, it is expected that only some of the upcoming CCS activity will be covered by domestic storage capacity.

The picture below details the location and relative size of the storage locations in Poland.

Figure 9: Overview of Carbon Storage in Poland



Source: McKinsey & Co., "Carbon-neutral Poland 2050: Turning a challenge into an opportunity"

4.2.8 Estonia

4.2.8.1 Summary of CCS potential in Estonia

Estonia's emissions from large stationary plants in 2017 were ~25 MtCO2, yet due to the closure of five oil shale plants from 2017-2020, emissions have been adjusted to ~12 MtCO2. Of the updated emissions, power and heat comprise 8.5 MtCO2, the industry comprises 2.6 MtCO2, whereas waste management comprises the remaining 1.4 MtCO2.

[138]Mineal and Energy, Economy Research Institute of Polish Academy of Sciences, "CO2 storage capacity of deep aquifers and hydrocarbon field in Poland- EU Geocapacity Results

[139] The Global CCS Institute, "Global Status of CCS 2020"

[140] Mineral and Energy, Economy Research Institute of Polish Academy of Sciences, "CO2 storage capacity of deep aquifers and hydrocarbon fields in Poland – EU GeoCapacity Project Results"

[141] Ramboll Expert

[142] Eurobarometer, "Public Awareness and Acceptance of CO2 capture and storage"

Estonia aims to become carbon neutral in 2050, but the country does not have any CCS specified targets. Nevertheless, the country's oil shale industry could suggest the potential for the implementation of CCS.

CCS potential in Estonia is estimated at 9.0 MtCO2 between 2022 and 2050, and on average 0.4 MtCO2/y between 2022 and 2040 and 0.5 MtCO2/y between 2041 and 2050, split fairly evenly between power & heat and industry. CCS potential is mainly related to power & heat (due to planned blue hydrogen production) and cement production (where CCS is the only option currently relevant for CO2 abatement). Within the industry sector, decarbonisation, cement is identified as a hard to abate emissions source. Thus CCS will likely play a role.

Storage potential in Estonia is low, as geological conditions are unfavourable for CO2 storage. National storage is therefore not viable, and CO2 would need to be exported to other countries.

Additionally, CO2 utilisation is also currently very limited and require high-quality CO2. A study from the University of Tallinn explored the options for using CCUS in Estonian oil shale-based energetics. Preliminary results showed that it is technologically possible but very costly[143]; thus, this strengthens further the case for CO2 export.

The relevance for storage in Denmark is deemed low, as the estimated volumes are too insignificant.

Below is an overview of the CCS potential in Estonia.

Table 29: Summary of CCS potential in Estonia

SUMMARY OF CCS POTENTIAL		
Category	**Indicator**	**Comments**
CO2 emissions 2017 (MtCO2) Plants >100 ktCO2	24.7	CO2 emissions from the largest point sources; mainly from heat and power industry powered oil shale, followed by the waste management and cement industry
Co2 reduction targets	✓	• 2030: -70% compared to 1990 (national target), and -13% compared to 2005 (non-EU ETS)[144] • 2050: climate neutral[145]
National CCS focus/Support	◔	Estonia's policies, regulations and climate plans do not actively pursue CCS development in the country today. However, as the country has recently committed to carbon neutrality and in an analysis which the Government commissioned, CCS/CCSU is mentioned as a prerequisite to reduce emissions to zero.
CCS targets	✗	No specific targets have been set for the deployment of CCS in Estonia.
Total CCS Potential (MtCO2) 2022-2050	6	Primary CCS potential comes from its oil shale production as well as the cement industry.
Own storage capacity (Mt)	0[146]	CO2 storage is not possible on Estonian territory as there are no suitable geological formations.
Own storage potential/support	○	Due to shallow setting, geological conditions in Estonia are unfavourable for CO2 storage. Therefore, Estonia would need to turn to the option of exporting CO2.
Potential for DK storage	Low	**Carbon storage outside the country seems likely, however, the estimated CCS volumes are deemed insignificant**

4.2.8.2 CCS national targets and policies Estonia

Estonia has committed to carbon neutrality by 2050. The country has no stated CCS targets. However, it would need to turn to CCS to reach climate targets if oil shale (local fossil fuel) based

[143] Interview with Tallinn University of Technology

[144] Estonia's 2030 National Energy and Climate Plan (NECP 2030)

[145] Stockholm Environment institute – "Reaching climate neutrality in Estonia"

[146] GEUS "EU GeoCapacity Assessing European Capacity for Geological Storage of Carbon Dioxide"

electricity and oil production continues. Government has a plan to stop producing oil shale[147] power by 2035[148]. To address this, Estonia, together with Latvia and Lithuania, will synchronise through Poland with a reliable and unified power system of continental Europe by 2025 to be able to increase the amount of renewable energy sources employed. However, the Estonian environment minister stated that the country could not drop oil shale until the power supply has been secured. Therefore, within the next decade, Estonia will need to decrease its dependency on oil shale, but the acceleration of this is uncertain, and thus, CO2 storage could be an additional mechanism for renewables to achieve its climate targets. Further, Estonia plans to produce blue hydrogen in the future. Producing Hydrogen with CCS could be one of the future options, and Bio-CCS may also help to reach carbon neutrality by 2050.

National financial support for research is targeted now for CO2 capture and use[149]. Based on the Estonian Government-commissioned study on a climate-neutrality scenario in 2050, total hard-to-abate emissions are estimated to be 2.1 MtCO2e (excluding Transport), with the energy sector contributing to close to zero emissions.

In 2019-2021, Tallinn University of Technology will carry out the project "Climate change mitigation through CCS and CCU technologies" to assess the suitability and work of different carbon capture technologies developed scenarios for the application of these technologies in the Estonian oil shale industry[150].

The absence of storage capacity in Estonia has meant that permanent storage of CO2 has been prohibited.

Estonia has ratified the London Protocol that allows CO2 export to other states for storage purposes.

Table 30: CCS national targets and policies in Estonia

CCS NATIONAL TARGETS AND POLICIES		
Category	**Indicator**	**Comments**
Country CCS policy maturity/potential	◔	CCS identified in the national climate strategy as potentially relevant, yet lack of supportive policy measures and regulatory restrictions create less favourable conditions for CCS.
National CO2 reduction targets	✓	• 2030: -70% compared to 1990 (national target), and -13% compared to 2005 (non-EU ETS)[151] • 2050: climate neutral[152]
National CCS targets	✗	Estonia does not actively pursue CCS and has no CCS facilities in operation/construction.
CCS policies and legislations	–	The NECP does not mention the strategic energy technology (SET) plan, even though Estonia is actively participating in three implementation working groups on photovoltaics, offshore wind and carbon capture utilisation and storage.[153] The applicable legislation mainly deals with the transportation and capture of CO2 rather than key aspects of CCS, such as monitoring and verification requirements, surface access and reclamation activities or closure regimes.[154]
CCS funding	✗	At the end of 2018, at the initiative of Norway, the Nordic Cooperation Group on Carbon Capture, Use and Storage (CCUS) and GHG Reduction (NGCCUS) were established, which could be a source of CCS funding. However, the Estonian development plan for research, development, innovation and entrepreneurship 2021-2035 is currently being developed, and thus more detailed funding and timeframes remain unclear.

[147] CO2 emission from oil shale combustion is significantly higher in comparison with other fossil fuels as energy sources. This is why CO2 emission per capita in Estonia is about two times higher than the average value in Europe.

[148] EER News, "Environment minister: Estonia cannot drop oil shale until supply is secured"

[149] Tallinn University of Technology – "Carbon neutral Baltic States: Do we have CCUS among accepted options?"

[150] Stockholm Environment Institute – "Raising Estonia's climate ambition analysis of possibilities"

[151] Estonia's 2030 National Energy and Climate Plan (NECP 2030)

[152] Stockholm Environment institute – "Reaching climate neutrality in Estonia"

[153] European Commission "Assessment of the final national energy and climate plan of Estonia"

[154] Global CCS Institute CO2RE database

CCS storage related policies	❌	The absence of storage capacity in Estonia has meant that the permanent storage of CO2 has been prohibited (with a limited exception for research purposes). Specifically, geological storage of carbon dioxide is prohibited in Estonia and under the continental shelf in accordance with the Earth's Crust Act, as well as within Estonia's maritime boundaries in accordance with the Water Act.[155]

4.2.8.3 CCS potential (capturable CO2 intended for storage) in Estonia

Total CO2 emissions from large stationary plants in Estonia were at ~25 MtCO2 in 2017. However, from 2017-2020, five oil shale plants have closed, and therefore the emissions have been adjusted to about ~12 MtCO2[156]. Of the updated amounts, power and heat comprise 8.5 MtCO2, the industry comprises 2.6 MtCO2, whereas waste management comprises the remaining 1.4 MtCO2.

The overall significance of CCS within the power & heat sector in Estonia is considered low, as renewables and nuclear energy are expected to lead the decarbonisation of the power sector. However, Estonia's reliance on oil shale mixed with biomass (maximum 20% of the mix) is expected to remain, although Estonia has introduced a target to phase out oil shale plants by 2035 due to the country's worry of energy supply security.

With regards to the industry, cement has been identified in Estonia's decarbonization pathway as a hard to abate emissions source, where CCS will likely play a role.[157]

The calculated capturable quantity of CO2 is estimated at on average 0.4 MtCO2/y between 2030 and 2040 and 0.5 MtCO2/y between 2041 and 2050, split fairly evenly between power & heat and industry.

[155] Global CCS Institute CO2RE database

[156] Tallinn University of Technology, "Carbon neutral Baltic states: do we have CCUS among accepted options?"

[157] Stockholm Environment Institute – "Raising Estonia's climate ambition analysis of possibilities"

Table 31: CCS potential (intended for storage) in Estonia

Sector	CO2 emissions 2017, MtCO2	Capturable quantity of CO2, MtCO2 (avg. MtCO2/y[158])		Comment
		2022-2040	2041-2050	
Power & Heat	**8.5**	**1.2** (**0.1**)	**0.5** (**0.05**)	• The overall significance of CCS within the Estonia power & heat sector is low due to the Government's focus on renewable power generation and nuclear. However, Estonia has expressed the need for energy supply security through domestic measures after having rapidly closed five oil shale production plants in recent years; thus, this might pose a deployment of CCS at the currently existing fossil fuel-driven power plants starting from 2030. Nevertheless, the Government has announced a target of phasing out all oil shale plants by 2035. Therefore it is expected that 50% of currently operating plants will be closed by 2035. From 2035-2050 it is estimated that 50% of energy will be produced by renewable energy and nuclear, whereas the other 50% will be produced from other fuels mixed with biomass (the maximum share of biomass mix is 20%). Based on these trends and assumptions, CCS is assumed to be utilised for 20% of the emissions from the early 2030s • The capturable volume of CO2 intended for storage within the segment is estimated at up to 0.2 MtCO2/y (peak between 2030 and 2040)
Industry	**2.6**	**1.4** (**0.1**)	**3.3** (**0.2**)	• Estonia has a small industrial sector with an emission of 2.6 MtCO2 in 2017, including cement production and other wood processing. The emissions relevant for CCS come solely from cement (0.6 MtCO2), which are hard to abate emissions in 2050 • CCU is a competitor to CCS and is preferred compared to CCS. Therefore CCS of the cement emissions are estimated from 30-40% between early 2030 to 2050 • The capturable volume of CO2 intended for storage within the segment is estimated at up to 0.5 MtCO2/y in 2050
Other	**1.4**	**-**	**-**	• No other significant potential areas have been assessed

4.2.8.4 CO2 storage potential in Estonia

Carbon storage in Estonia is unfavourable due to unsuitable geological conditions[159]. Any domestic storage of Carbon is prohibited by law, as described in section 4.2.8.2.

Estonian attitude towards CCS technology is favourable in the shape of national financial support for research projects while also allowing the export of carbon for storage[160]. However, Estonia does not currently have CCS facilities in operation or construction[161].

As a result, Estonia does not have the storage capacity to cover upcoming CCS activity and will be looking to export captured carbon.

[158] Average CO2 capturable amount is calculated for the time period 2030-2040

[159] Institute of Geology, Tallinn University of Technology, "Possibilities for geological storage and mineral trapping of industrial CO2 emissions in the Baltic Sea"

[160] Tallinn University of Technology, "Carbon Neutral Baltic States: Do we have CCUS among accepted options"

[161] The Global CCS Institute, "Global Status of CCS 2020"

4.2.9 Lithuania

4.2.9.1 Summary of CCS potential in Lithuania

Lithuania's emissions from large stationary plants in 2017 were ~5 MtCO2, of which only 0.1 MtCO2 were related to the power & heat sector. Most emissions relate to waste-to-energy plants and the remaining industry, including oil & gas refineries, chemical production and cement production.

Lithuania is aiming to become carbon neutral by 2050. Lithuania's strong focus on renewable energy is reflected in the 45% renewable energy share in final energy consumption in 2030. While the Lithuanian government states that CCSU technologies are required to reduce the cost of renewable energy, no specified CCS targets are mentioned in the Government's National energy and climate strategies.

CCS potential in Lithuania is estimated at 7.4 MtCO2 between 2022 and 2050 and on average 0.4 MtCO2/y between 2022 and 2040 and 0.3 MtCO2/y between 2040 and 2050. In general, very small potential is assessed for CCS by 2050, as oil and gas have been phased out, and other alternatives such as CCU are prioritized in the rest of the industry.

Storage potential in Lithuania is estimated to be 2.2 Mt. However, both onshore and offshore CO2 storage was recently banned in Lithuania (July 2020).

The relevance for storage in Denmark is deemed low, as the estimated volumes are too insignificant.

Below is an overview of the CCS potential in Lithuania.

Table 32: Summary of CCS potential in Lithuania

SUMMARY OF CCS POTENTIAL		
Category	**Indicator**	**Comments**
CO2 emissions 2017 (MtCO2) Plants >100 ktCO2	5.19	CO2 emissions from largest point sources; mainly chemicals production industry focusing on the production of fertiliser and ammonia, followed by the mineral oil and gas industries
Co2 reduction targets	✓	• 2030: -43% from 2005 levels (EU ETS) and -9% from 2005 levels (non-EU ETS)[162] • 2040: -70% from 1990 levels (all sectors) 2050: Carbon neutral: -80% from 1990 levels (all sectors) and -20% absorbed by LULUCF carbon sink
National CCS focus/Support		Lithuania's policies, regulations and climate plans do not actively pursue CCS development in the country today. However, the country has recently committed to carbon neutrality, and CCS is mentioned as potentially relevant to achieve climate neutrality.
CCS targets	✗	No specific targets have been set for the deployment of CCS in Lithuania.
Total CCS Potential (MtCO2) 2030-2050	7	The potential is deemed from oil and gas refineries primarily, who are the main advocates for CCS, however, will be phased out by 2045.
Own storage capacity (Mt)	2,286[163]	2,280 Mt of storage in aquifers and 6 Mt of storage in oil and gas fields
Own storage potential/support		Lithuania recently banned CO2 injection, and thus, CO2 storage is not permitted onshore or offshore[164].
Potential for DK storage	**Low**	**Carbon storage outside the country seems likely, however, the estimated CCS volumes are deemed insignificant**

[162] Lithuania's Integrated National Energy and Climate Plan (NECP 2030)

[163] GEUS "Assessment of CO2 Storage Potential in Europe"

[164] Lithuanian Parliament, LRT news

4.2.9.2 CCS national targets and policies Lithuania

Lithuania aims to become carbon neutral by 2050, allowing 20% of CO2 reductions to be absorbed by the LULUCF carbon sink. While the Lithuanian government states that CCSU technologies are required to reduce the cost of renewable energy and that further developing CCUS technologies and analysing their applications in Lithuania is necessary, **no specified CCS targets** have been set in Lithuania. Lithuania's strong focus on renewable energy is reflected in the 45% renewable energy share in final energy consumption in 2030.

Latvia does not have national support systems in place for CCS funding. According to the country's NECP, 2% in its SET-plan will be allocated to CCS of the share of total R&I investments from 2021-2027 in the field of energy[165]. However, despite these developments, CCS is not considered a priority in Latvia today.

Lithuania's legal and regulatory framework related to CCS activities has been developed to address multiple elements of the project lifecycle. The framework transposes the requirements of the EU storage Directive into national law. The licensing regime adopted is similar to other models governing the country's oil, gas, and mining operations. While several elements of the resulting framework are well characterised, some aspects of the CCS project lifecycle have yet to be fully addressed. In addition, Lithuania has recently banned CO2 injections, thereby permitting neither onshore nor offshore storage[166].

Table 33: CCS national targets and policies in Lithuania

CCS NATIONAL TARGETS AND POLICIES		
Category	**Indicator**	**Comments**
Country CCS policy maturity/potential	◔	CCS identified in the national climate strategy as potentially relevant, yet lack of supportive policy measures and regulatory restrictions create less favourable conditions for CCS.
National CO2 reduction targets	✓	• 2030: -43% from 2005 levels (EU ETS) and -9% from 2005 levels (non-EU ETS)[167] • 2040: -70% from 1990 levels (all sectors) • 2050: Carbon neutral: -80% from 1990 levels (all sectors) and -20% absorbed by LULUCF carbon sink
National CCS targets	✗	The country has no CCS targets. However, the National energy and climate action plan from 2021-2030 outlines that technology will play a central role in achieving its energy policy goals, one such technology mentioned is CCS.[168]
CCS policies and legislations	–	The country has developed a legal and regulatory model for CCS activities, which addresses multiple elements of the project lifecycle and transposes the requirements of the EU storage Directive into national law.
CCS funding	✗	Latvia will allocate 2% in its SET-plan priorities to CCS of the share of total R&I investments from 2021-2027 in the field of energy[169]. However, CCS is not considered a priority.
CCS storage-related policies	✗	Lithuania recently banned CO2 injection, and thus, CO2 storage is not permitted onshore or offshore[170].

[165] Latvia's national energy and climate plan, 2021-2030
[166] Lithuanian Parliament, LRT news
[167] Lithuania's Integrated National Energy and Climate Plan (NECP 2030)
[168] National energy and climate action plan of the republic of Lithuania for 2021-2030
[169] Latvia's national energy and climate plan, 2021-2030
[170] Lithuanian Parliament, LRT news

4.2.9.3 CCS potential (capturable CO2 intended for storage) in Lithuania

Total CO2 emissions from large stationary plants in Lithuania were at ~5 MtCO2 in 2017. Only 0.1 MtCO2 were related to the power & heat sector; From waste-to-energy plants, and the rest from industry, including oil & gas refineries, chemical production and cement production.

Lithuania is mainly focused on renewable energy, so the emissions are already to date minimal in the power and heat sector.

Lithuania's climate plan notes that the country will make maximum use of natural carbon sinks and prefers CCU above CCS; only environmentally safe CCS technologies will be used to ensure a 100% reduction in the industry segment[171]. There is reportedly one oil company that is advocating the use of CCS[172]. Further, the fossil fuel industry will be fully abandoned by 2045 and will be replaced by green hydrogen.

The calculated capturable quantity of CO2 is estimated at on average 0.4 MtCO2/y between 2022 and 2040 and 0.3 MtCO2/y between 2041 and 2050.

Table 34: CCS potential (intended for storage) in Lithuania

Sector	CO2 emissions 2017, MtCO2	Capturable quantity of CO2, MtCO2 (avg. MtCO2/y[173])		Comment
		2022-2040	2041-2050	
Power & Heat	**0.1**	**0.2** (**0.02**)	**0.2** (**0.02**)	• The overall significance of CCS within the Lithuanian power & heat sector is insignificant due to the lack of emissions in this sector as renewables have been employed at large-scale already • The capturable volume of CO2 within the segment is estimated below ~0.1 MtCO2/y in 2050
Industry	**5.1**	**4.4** (**0.4**)	**2.6** (**0.3**)	• The significance of CCS in the industry is low since other carbon removal means are prioritised, such as CCU • CCS will be mainly relevant for the oil & gas industry, which only comprise 1.7 MtCO2 in 2017 since CCU is preferred for the other industry sectors (cement and chemical production) • CCS is estimated to rise up to comprise about 20% of emissions reduction for industry from 2035 to 2045 • Since the fossil fuel industry will be phased out by 2045, the CCS potential from the oil & gas sector is removed, and Ramboll estimates the capture potential to be only 10% of emissions • The capturable volume of CO2 intended for storage within the segment is estimated to peak from 2035-2045 at 0.6 MtCO2/y and will decrease with the closure of oil & gas refineries (largest advocate of CCS) by 2045 to below 0.1 MtCO2/y towards 2050
Other	-	-	-	• No other significant potential areas have been assessed

[171] Latvia's national energy and climate plan, 2021-2030

[172] Expert interview with Baltics representative from Tallinn University of Technology

[173] Average CO2 capturable amount is calculated for the time period 2030-2040

4.2.9.4 CO2 storage potential in Lithuania

Lithuania's total carbon storage capacity is 2,280 Mt, situated almost exclusively in aquifer storage units with 5.8 Mt of storage capacity located in oil and gas fields[174]. However, the aquifer storage units are located close to the surface and have not been tested for any leakages, which is a long and expensive process.

As described in section 4.2.9.2, any carbon storage is prohibited in Lithuania, but that could change in the short term as new politicians are elected. The attitude towards CCS technologies in Lithuania is considered favourable[175] as several carbon capture facilities have been planned with the intention of exporting the captured carbon[176].

As a result, Lithuania has adequate domestic storage to cover upcoming CCS activities but does not plan to develop the storage sites. This means that any carbon captured from upcoming CCS activities will have to be exported for storage.

4.2.10 Latvia

4.2.10.1 Summary of CCS potential in Latvia

Latvia's emissions from large stationary plants in 2017 were ~1 MtCO2. Thermal power and heat comprise the total amount of these emissions. Latvia (and Lithuania) has significantly lower emissions than Estonia due to the utilisation of other main energy sources (nuclear and hydro-energy) than oil shale.

Latvia is aiming to become carbon neutral in 2050. As energy and transport sectors comprise ~64% of total GHG emissions in 2017, these sectors are expected to play a significant role in achieving the goal. Latvia's carbon neutrality strategy states that CCS could be relevant for industrial sectors, yet not in the significant energy and transport sectors. The potential for CCS in Latvia is low as the country has no industrial plants >100 ktCO2.

Latvia's CCS potential is estimated at 2.2 MtCO2 between 2022 and 2050, and on average 0.1 MtCO2/y between 2022 and 2040 and 0.1 MtCO2/y between 2040 and 2050, and the potential is mainly related to the power & heat sector. Latvia does not have industrial plants above 100 ktCO2 (where CCS could be applied), and therefore, the potential for CCS in Latvia is considered low.

Storage potential in Latvia is estimated to be 3,400 Mt in aquifers. The relevance for storage in Denmark is deemed low, as the estimated volumes are so insignificant.

Below is an overview of the CCS potential in Latvia.

Table 35: Summary of CCS potential in Latvia

SUMMARY OF CCS POTENTIAL		
Category	**Indicator**	**Comments**
CO2 emissions 2017 (MtCO2) Plants >100 ktCO2	1.0	CO2 emissions from the largest point sources; mainly from the power and heat generation industry
Co2 reduction targets	✓	• 2030: -65% from 1990 (national target) and -6% from 2005 (non-EU ETS)[177] 2050: Carbon neutral
National CCS focus/Support	◔	Latvia's policies, regulations and climate plans do not actively pursue CCS development in the country today. However, the country has recently committed to carbon neutrality, and CCS is mentioned as potentially relevant to achieve climate neutrality.
CCS targets	✗	No specific targets have been set for the deployment of CCS in Latvia.

[174] GEUS, "Assessment of CO2 storage potential in Europe"

[175] IOGP, "the potential for CCS and CCU in Europe"

[176] Tallinn University of Technology, "Carbon Neutral Baltic States: Do we have CCUS among accepted options?"

[177] Latvia's Integrated National Energy and Climate Plan (NECP 2030)

Total CCS Potential (MtCO2) 2022-2050	2	Mainly related to the power & heat sector
Own storage capacity (Mt)	3,400[178]	3,400 Mt of storage in aquifers
Own storage potential/support	◔	Domestic CO2 storage is not currently permitted in Latvia and as no experiments have been conducted to ensure geological suitability for carbon storage, developing these sites would be difficult and could take several years[179]
Potential for DK storage	**Low**	**Carbon storage outside the country seems likely, however, the estimated CCS volumes are deemed insignificant**

4.2.10.2 CCS national targets and policies Latvia

Latvia aims to become carbon neutral by 2050 but does not actively pursue CCS as a means to achieve this climate target and currently has no CCS facilities in planning/construction. Thus, **no specific targets related to CCS** have been set either. However, Latvia's carbon neutrality strategy states that CCS could be relevant for energy and industrial sectors[180], indicating that the policy support for CCS is slightly maturing.

Latvia has not previously provided funding or support to CCS research or projects. However, the NECP indicates that Latvia will spend 2% of investments in total R&I investments in the field of energy on CCS between 2021-2027[181]. However, the funds allocated to energy research are not described, making it difficult to assess the degree to which the 2% to CCS is sufficient.

Latvia's regulatory framework related to CCS has transposed the requirements of the EU storage Directive into national law. However, it has also prohibited CO2 storage in the country. Latvia's legal and regulatory framework considers some parts of the CCS project cycle, including the operator's responsibilities, carbon dioxide purity criteria and dispute resolution procedures, yet key aspects of the CCS process such as storage and closure are not addressed due to the prohibition and storage of CO2[182].

Table 36: CCS national targets and policies in Latvia

CCS NATIONAL TARGETS AND POLICIES		
Category	**Indicator**	**Comments**
Country CCS policy maturity/potential	◔	CCS identified in the national climate strategy as potentially relevant, yet lack of supportive policy measures and regulatory restrictions create less favourable conditions for CCS.
National CO2 reduction targets	✓	• 2030: -65% from 1990 (national target) and -6% from 2005 (non-EU ETS)[183] • 2050: Carbon neutral
National CCS targets	✗	No specific targets have been set for the deployment of CCS in Latvia.
CCS policies and legislations	✗	Latvia's regulatory framework has transposed the EU storage Directive into national law. However, the framework prohibits CO2 storage in the country.
CCS funding	✗	No national support system for the deployment of CCS in place, yet Latvia's NECP indicates that funds will be allocated to R&I in the field of energy on CCS between 2021-2027[184], although it is unclear if the funds will suffice for the deployment of CCS.
CCS storage-related policies	✗	According to Section 82 of the Law On Pollution, storage of carbon dioxide in geological formations and the water column is prohibited in the territory of Latvia, the exclusive economic zone and continental shelf thereof.[185]

[178] GEUS "Assessment of CO2 Storage Potential in Europe"
[179] Ramboll Expert
[180] Strategy of Latvia for the Achievement of Climate Neutrality by 2050
[181] Latvia's Integrated National Energy and Climate Plan (NECP 2030)
[182] Global CCS Institute CO2RE database
[183] Latvia's Integrated National Energy and Climate Plan (NECP 2030)
[184] Latvia's Integrated National Energy and Climate Plan (NECP 2030)
[185] Ecolex - Latvia, Law on pollution

4.2.10.3 CCS potential (capturable CO2 intended for storage) in Latvia

Total CO2 emissions from large stationary plants in Latvia were ~1 MtCO2 in 2017, of which all amounts come from thermal power and heat.

The overall significance of CCS within the thermal power and heat is considered low, as renewables are expected to lead the decarbonisation of the power sector. However, in its strategy towards carbon neutrality in 2050, Latvia mentions with regards to the energy sector that the assessment of the introduction of new technologies in relation to carbon capture and storage should be taken into consideration.

The calculated capturable quantity of CO2 is estimated at on average 0.1 MtCO2/y between 2022 and 2040 and 0.1 MtCO2/y between 2040 and 2050.

Table 37: CCS potential (intended for storage) in Latvia

Sector	CO2 emissions 2017, MtCO2	Capturable quantity of CO2, MtCO2 (avg. MtCO2/y[186])		Comment
		2022-2040	2041-2050	
Power & Heat	**1**	**1.2** (0.1)	**1.0** (0.1)	• The potential for the power and heat sector is low since the Latvian Government has plans to reduce its emissions with renewable energy. However, in its strategy towards carbon neutrality in 2050, Latvia mentions with regards to the energy sector that the assessment of the introduction of new technologies in relation to carbon capture and storage should be taken into consideration[187] • Ramboll assesses that CCS could capture up to 20% of power and heat emissions towards 2050 since there are potential competing alternatives that could be preferred, such as CCU[188] • The CCS potential is about 0.1 MtCO2/y in 2050
Industry	**-**	**-**	**-**	They have mentioned plans to employ CCUS within the industry sector, however, their industry sectors do not have large stationary plants (above 100 ktCO2/y), which is why CCS potential is not considered.
Other	**-**	**-**	**-**	• No other significant potential areas have been assessed

[186] Average CO2 capturable amount is calculated for the time period 2030-2040
[187] Strategy of Latvia for the Achievement of Climate Neutrality by 2050
[188] Interview with CCUS expert in Baltics

4.2.10.4 CO2 storage potential in Latvia

Latvia has a carbon storage capacity of 3,400 Mt, of which the majority, 3,000 Mt, is situated in aquifers, and 400 Mt is situated in oil and gas fields[189]. Some capacity in the oil and gas fields is currently being used for the storage of natural gas[190]. However, experiments testing the geological suitability for carbon storage have not been initiated and could take years to complete adding to the cost of developing domestic storage capacity[191].

As described in section 4.2.10.2, any storage of carbon is currently prohibited domestically in Latvia. However, this could change in the short term, as governmental opinion changes following election cycles. Latvian attitude towards CCS is regarded as neutral[192] due to small CCS incentives and lack of recognition of CCS in the national 2050 climate strategy[193]. Moreover, Latvia has not yet allowed the export of carbon for storage but has been urged to by experts[194].

As a result, Latvia does not have the carbon storage capacity to cover all upcoming CCS activity.

[189] GEUS, “Assessment of CO2 storage potential in Europe”

[190] Ramboll/DEA, “Cata

[191] Ramboll Expert

[192] IOGP, “The potential for CCS and CCU in Europe”

[193] INFORSE-Europe, “Sustainable Energy Strategy for Latvia’s: Vision 2050”

[194] Tallinn University of Technology, “Carbon Neutral Baltic States: Do we have CCUS among accepted options?”

4.3 ASSUMPTIONS UNDERLYING ESTIMATION OF CAPTURABLE CO2

Data basis for CO2-emissions

The analysis presented in this report is based on emissions data retrieved from the E-PRTR emissions data from the year 2017. The year 2017 was chosen as it comprises the most complete data set, where all countries had had the opportunity to re-report and confirm emission numbers. Moreover, the E-PRTR database includes emissions from biogenic sources, which are relevant from a CCS perspective.

Due to the incompleteness of the E-PRTR emissions data set in years after 2017, it is not possible to compare emissions from that database to identify trends or outliers that can impact the estimates presented in the report. As a result, emissions data from the EU-ETS database from 2017 and 2019 was used. Specifically, the industrial 'Combustion of fuels' emissions was used. This covers the emissions released as a direct result of the combustion of fuels used for heating in plants emitting more than 100 ktCO2/year. These emissions were compared to identify trends and outliers.

Box 1 - A note on emissions comparison

Emissions compared below are based on values from the EU-ETS emissions database from the years 2017 and 2019 respectively. The emissions are the confirmed unadjusted values. have been used as a tool to identify potential countries with severe reductions in emissions and thus potentially need to have emissions values adjusted to reflect the countries' current emission-level. The E-PRTR database does not fully cover both 2017 and 2019 for all countries that have been analyzed. As a result, the EU-ETS emissions database has been used instead. The datasets included in this database have all been confirmed and the database covers all countries that have been analyzed in this report.

Table 38: EU-ETS emissions comparison

EU-ETS 'Combustion of Fuels' emissions comparison										
	FI	SE	NO	DE	UK	NL	PL	EE	LT	LV
EU-ETS emissions, 2017 [MtCO2]	12.4	8.1	14.2	313.4	98.1	61.3	162.8	12.5	0.9	1.3
EU-ETS emissions, 2019 [MtCO2]	11.3	7.2	13.7	245.4	81.5	53.9	144.8	6.2	0.6	1.6
%-change	-9%	-11%	-3.5%	-22%	-17%	-12%	-11%	-50%	-33%	23%
Comments				The decline in emissions between 2017 and 2019 in Germany was caused by the decrease in coal usage at power plants[195].	The UK experienced a rapid decline in CO2 emissions between 2017 and 2019 as the heat & power sector cut emissions by 60%[196].			Estonia has phased out several plants between 2017 and 2019[197].	Lithuania decreased emissions by 1/3 between 2017 and 2019 due to large decrease in the use of natural gas and by the heat & power sector[198].	Latvia has seen an increase in emissions due to the national energy strategy focusing on independent energy supply[199].

[195] Clean Energy Wire, "Germany's CO2 emissions set to fall markedly in 2019 as energy use declines"

[196] IEA Emissions Database

[197] Interview with Tallinn University CCS professor

[198] IEA Emissions Database

[199] National Energy and Climate Plan of Latvia

The general trend among all countries included in the analysis is a decline in emissions which is expected due to the global focus on reducing GHG emissions. Events or actions causing substantial drops in emissions have all been addressed in our calculated estimates.

In Germany, 70% of the emissions are caused by the heat & power sector, which is currently going through a transition away from coal and oil towards natural gas and zero-emission technologies. This has been accounted for in the estimates for CCS potential as CCS on coal and oil power plants have been assumed to be zero due to the phase-out of coal and oil in Germany by as early as 2030 and 2038 at the latest. The United Kingdom, Poland, Estonia, and Lithuania all have power sectors going through similar transitions, which have also had certain power generation technologies excluded due to expected decommission before CCS reaches maturity. This is done because retrofitting CCS technology to plants scheduled for decommissioning would be ineffective as only insignificant amounts of CO2 emissions would end up being captured by the CCS system. Fitting CCS technology to a newer plant which is expected to run for a long time, would yield larger amounts of captured carbon and make more sense as an investment as a result.

Latvia is the only country that has had its emissions increased. This is due to the country’s national energy strategy, which is currently focusing on achieving a larger share of energy independence. Currently, Latvia imports approximately 70% of the country’s electricity mostly from Sweden and any domestic production of electricity would as a result increase the emissions of Latvia. Moreover, Latvia’s emissions are insignificant compared to, e.g. Germany and Poland and has, as a result, had a low impact on the overall CCS potential estimates.

Technical assumptions for CCS potential

Estimation of CCS potential within each country is based on CO2 emissions from large sources, multiplied by technically capturable share (country-based adjustments have been applied where necessary based on Ramboll’s technical insights), and again multiplied by the expected share of CO2 that will be stored (estimated CCS share).

In the definition of the technical capture potential, this report applied some general assumptions for technically capturable volumes connected with the power & heat plants and plants within the energy-intensive industries in Europe.

Table 39: Assumptions underlying technically capturable volume (technical capture potential) across the analysed countries

Sector	Industry	Significance of CCS	CCS application[200]	Technical capture potential %[201]
Power and heat generation	Power and heat plants, including fossil, biomass-fired plants etc.	In general, LOW for fossil-fired plants, as the focus is typically on renewable power generation. However, for some European countries currently heavily relying on coal power generation, CCS on coal power plants could be an attractive option. MEDIUM/HIGH for biomass plants (incl. incineration plants) due to interest for BECCS that can provide	CCS can be used in thermal power and heat plants regardless of the fuel used during combustion is fossil or renewable. The technology can be retrofitted to existing plants or applied to newly constructed plants by collecting and ‘cleaning’ the flue gasses from the stacks.	Up to ~90%

[200] Based on Ramboll’s technical insights and external research (mainly *The role of Carbon Capture and Storage in a Carbon Neutral Europe, Carbon Limits, 2020)*

[201] Share of volumes that are technically feasible to capture; Input based on Ramboll’s technical insights and external research (mainly *The role of Carbon Capture and Storage in a Carbon Neutral Europe, Carbon Limits, 2020)*

		negative emissions compensating some industry and agricultural emissions hard to abate.		
Energy-intensive industry	Iron and steel (incl. other ferrous metals)	MEDIUM; Both CCS and hydrogen can be applied. Hydrogen replacing fossil fuels is expected to be the preferred option. However, if hydrogen from natural gas (blue hydrogen) is applied, then CCS is key.	CCS can be applied to current blast furnaces in the steel-making process responsible for most of the CO2 emissions in the iron and steel industry, enabling up to 50% reduction of emissions. Alternatively, direct smelting technology could be used to concentrate CO2 generation further, enabling higher amounts of emissions reduction.	Up to ~60%
	Refineries	HIGH as emissions from refining and mineral oil and gas are hard to abate.	CO2 production from refineries is spread over multiple stacks with varying CO2 emission amounts making it infeasible to capture CO2 from all sources.	Up to ~50%
	Mineral production (mainly cement, but also glass ceramics etc.)	HIGH, CCS is key in the cement sector as there are no other ways to reduce the process emissions significantly. While the use of biomass instead of fossil fuels can reduce some emissions, BECCS would still be relevant to provide negative emissions).	In the cement sector, 60-65% of CO2 is generated during the heating process due to the combustion of fuels providing heat and because of a reaction within the cement during the heating process.	Up to ~50%
	Chemicals	MEDIUM; Mostly transitional solution as renewable energy sources can be applied; In general, the chemical industry is prioritising CCU over CCS.	CCS can be applied to process emissions as well as emissions from fuel combustion. Application varies due to high diversity of the sector. Ammonia and blue hydrogen production produce a relatively pure CO2 stream, potentially allowing for very high capture rates.	Up to ~50%
	Pulp & paper	HIGH; Pulp and paper industry in most cases utilise production residuals/biomass as energy input in processing; BECCS here would be key here to compensate for emissions from other industries where they are harder to abate. Pulp and paper plants are often located close to coastline and rivers (as they need water in production), and this makes it potentially easier to transport CO2	During the chemical pulping process, woodchips are cooked by burning by-products from the paper-making process. Installing CCS technology can be applied to capture carbon from flue gasses.	Up to ~90%

Estimated CCS share reflects what is actually expected for CCS given alternatives (CCU, renewable energy, heat pumps etc), and is based on high-level qualitative and country-specific analysis (interviews and available research).

Box 2 – Estimated CCS share

Note that table below presents the maximum estimated capturable share, i.e. peak share expected after years of gradual ramp-up.

Overview of assumptions for CO2 emissions from large sources, technical potential and estimated CCS share per country are presented in the table below. See appendix for more information on estimated CCS share.

Table 40: Overview of assumptions for CO2 emissions, technical potential, and estimated CCS share (peak estimates) potential per country

Industry	Sub-industry	FI			SE			NO			DE			UK		
		CO2 emissions 2017	Tech. potential	Est. CCS share	CO2 emissions 2017	Tech. potential	Est. CCS share	CO2 emissions 2017	Tech. potential	Est. CCS share	CO2 emissions 2017	Tech. potential	Est. CCS share	CO2 emissions 2017	Tech. potential	Est. CCS share
Power and heat	Thermal power and heat generation	16,9	90%	N/A	11,7	90%	N/A	14,2	90%	50%	263,8	90%	5%	99,7	90%	10%
	WtE plants	0,2	90%	90%	4,8	90%	90%	0,0	90%	N/A	16,4	90%	50%	9,9	90%	80%
	Steel & iron production/ferrous metals	1,5	60%	60%	4,1	60%	0%	2,5	60%	50%	28,6	60%	20%	6,7	60%	50%
	Non-ferrous metals (aluminium, copper and zinc etc)	0,0	N/A	N/A	0,7	N/A	N/A	2,7	N/A	N/A	1,7	N/A	N/A	0,0	N/A	N/A
	Mineral oil and gas refineries	3,1	50%	50%	2,7	50%	50%	2,6	50%	75%	21,1	50%	30%	10,8	50%	25%
Industrial plants	Chemicals production	0,7	50%	50%	1,0	50%	25%	1,5	50%	25%	24,6	50%	30%	4,8	50%	25%
	Chemicals production (fertiliser/ammonia production)	0,0	50%	N/A	0,0	50%	N/A	0,0	50%	N/A	0,0	50%	0%	0,6	50%	25%
	Pulp & paper	20,3	80%	80%	22,8	80%	80%	0,2	80%	50%	0,0	80%	N/A	0,0	80%	N/A
	Mineral production (cement)	1,3	90%	90%	2,8	90%	90%	1,2	90%	90%	25,0	90%	50%	7,2	90%	90%
	Mineral production (lime, plaster, ceramics, glass etc)	0,0	90%	N/A	0,0	90%	N/A	0,5	90%	90%	0,9	90%	N/A	1,0	90%	90%
	Food processing	0,0	90%	N/A	0,0	90%	N/A	0,0	90%	N/A	0,8	90%	N/A	1,2	90%	50%
Other	Other	2,9	N/A	N/A	0,7	N/A	N/A	0,0	N/A	N/A	23,3	N/A	N/A	4,4	N/A	N/A
Total		**46,8**			**51,3**			**25,4**			**406,2**			**146,3**		

Industry	Sub-industry	NL			PL			EE			LT			LV		
		CO2 emissions 2017	Tech. potential	Est. CCS share	CO2 emissions 2017	Tech. potential	Est. CCS share	CO2 emissions 2017	Tech. potential	Est. CCS share	CO2 emissions 2017	Tech. potential	Est. CCS share	CO2 emissions 2017	Tech. potential	Est. CCS share
Power and heat	Thermal power and heat generation	55,7	90%	5%	121,2	90%	30%	7,9	90%	5%	0,0	90%	N/A	1,0	90%	20%
	WtE plants	8,9	90%	90%	0,0	90%	N/A	0,0	90%	N/A	0,1	90%	20%	0,0	90%	N/A
	Steel & iron production/ferrous metals	0,0	60%	N/A	7,1	60%	30%	0,0	60%	N/A	0,0	60%	N/A	0,0	60%	N/A
	Non-ferrous metals (aluminium, copper and zinc etc)	0,0	N/A	N/A	1,2	N/A	N/A	0,0	N/A	N/A	0,0	N/A	N/A	0,0	N/A	N/A
	Mineral oil and gas refineries	10,6	50%	90%	1,7	50%	50%	0,0	50%	N/A	1,7	50%	0%	0,0	50%	N/A
Industrial plants	Chemicals production	16,9	50%	75%	1,0	50%	10%	0,0	50%	N/A	0,0	50%	N/A	0,0	50%	N/A
	Chemicals production (fertiliser/ammonia production)	0,0	50%	75%	1,7	50%	10%	0,0	50%	N/A	2,6	50%	30%	0,0	50%	N/A
	Pulp & paper	0,0	80%	N/A	0,0	80%	N/A	0,0	80%	N/A	0,0	80%	N/A	0,0	80%	N/A
	Mineral production (cement)	0,5	90%	90%	6,8	90%	50%	0,6	90%	90%	0,7	90%	90%	0,0	90%	N/A
	Mineral production (lime, plaster, ceramics, glass etc)	0,1	90%	N/A	2,1	90%	40%	0,0	90%	N/A	0,0	90%	N/A	0,0	90%	N/A
	Food processing	0,9	90%	N/A	0,0	90%	N/A	0,0	90%	N/A	0,0	90%	N/A	0,0	90%	N/A
Other	Other	1,4	N/A	N/A				3,4	N/A	N/A	0,0	N/A	N/A	0,0	N/A	N/A
		95,0			**166,7**			**11,9***			**5,2**			**1,0**		

*Note: * CO" emissions in Estonia (EE), have been adjusted in relation to the source (E-PRTR), as the CO2 emission from power and heat sector (20.7 Mt in 2017 according to E-PRTR) is outdated since several fossils fuel-driven plants were close in the past couple of years. Therefore, a more representative number is 7.9 Mt.*

5. OVERVIEW AND EVALUATION OF POTENTIAL SET-UPS FOR TRANSPORT AND STORAGE OF CO2 IN DENMARK

This chapter aims to identify relevant market-based business models that ensure the lowest possible price of Danish CO2 storage and provide an assessment of the competitiveness of the Danish storage sites.

The following sections will go into depth with identifying the North European CO2 streams relevant for Danish storage, possible set-ups for transport and storage of CO2 in Denmark, the competitiveness of the Danish CO2 storage and institutional considerations.

The conclusions from this chapter will create the basis for evaluation of various business models for CO2 storage in Denmark, which will be examined in the next chapter.

5.1 KEY CONCLUSIONS ON THE POTENTIAL SET-UPS FOR TRANSPORT AND STORAGE OF CO2 IN DENMARK

The total volume of up to ~45 MtCO2/y is potentially eligible for import from several North European countries. Denmark has several sites with CO2 storage structures that can be paired with different types of CO2 transportation options to provide various solutions for CO2 storage. Some of these sites and transport set-ups can be combined to increase scale, enhance convenience, or decrease costs. The most cost-efficient set-ups are onshore or nearshore, especially if they are combined with CO2 transport pipelines from regions with large clusters of CO2 emission sources (e.g. Hamburg, DE). Using transport pipelines from such regions enables an opportunity to offer flexible low-priced transport solutions, which enhance the competitiveness of Danish storage solutions. None of the solutions, however, can work by themselves, meaning there is a need for involvement from the state.

When other aspects than costs are considered, both onshore and offshore solutions and both transportation option (pipeline vs sea transportation) have advantages and disadvantages. The onshore solution (especially Havnsø) is located close to the largest domestic CO2 source and can allow flexibility if a gradual build-up is preferred (which is less meaningful in the case of offshores that work best with transport pipeline). On the other hand, the offshore solution can prove to be faster to implement due to a potentially shorter permitting process and the ability to reuse some of the existing infrastructure.

The table below summarises the key conclusions on the potential set-ups for the transport and storage of CO2 in Denmark.

Table 41: Key Conclusions on the overview and evaluation of the potential set-ups for transport and storage of co2 in Denmark

Topic	Key Conclusions
North European CO2 streams relevant for danish storage	The indicative CO2 volumes relevant for Denmark (including domestic CO2 volumes) are estimated at up to ~45 MtCO2/y. The foreign storages that could potentially compete with Danish CO2 storages are mainly the UK and Norway. The import of CO2 is mainly relevant from DE, SE and FI. There is some potential for CO2 import from PL and NL, while no or insignificant import is expected from the Baltics, NO or UK (the latter two have well developed domestic storage projects).
Possible set-ups for transport and storage of CO2 in Denmark	Available options for storage are Gassum (onshore), Havnsø (onshore), Hanstholm (nearshore) and the Northern oil and gas fields in the North Sea (offshore). Available options for transport are shuttle tankers, vessels, and pipelines. Nine possible set-ups for transport and storage og CO2 in Denmark have been identified: Two onshore, two near shore and five offshore. They include different combinations of transport and storage options, meaning that some set-ups will require ports and intermediate storage. In general, the cost comparison shows that onshore storage is the most cost-effective solution (both when pipeline and sea transport is applied), followed by nearshore storage and with offshore storage as the most expensive solution. On the other hand, pipelines provide scale advantage and are thus the most effective transport solution at large-scale.

	In addition to being the least expensive option, the onshore storage has the advantage of being located close to the large domestic CO2 emission sources (Copenhagen area). However, uncertainty whether the site can be used (and thus need for seismic tests and drilling) and the general risk of public opposition can lead to a longer permitting process than in the case of the offshore site. Although the most expensive option, offshore storage offers several advantages, especially in the form of known feasibility and demonstrated tightness. It can be potentially easier to obtain necessary permits (especially compared to onshore sites). Furthermore, some of the existing equipment (platforms and support systems) can be potentially reused, meaning that the offshore solution can be potentially even quicker implementer than the onshore or nearshore solution. Solutions with a pipeline from Germany would provide a more certain CO2 stream from abroad, making it potentially easier (and cheaper) to find investors. On the other hand, this type of solution is only meaningful when the full-scale operations are planned for construction from the beginning, while sea transportation enables small-scale start with gradual build-up. Note that a more gradual start is also possible in the case of the onshore storage, where pipelines from source and other connecting infrastructure can be added afterwards.
Competitiveness of Danish CO2 storage	The competitiveness of CO2 storage is defined by meeting the following criteria: a low-cost solution, with low marginal cost, and the ability to create a solution that allows flexibility Based on the above, it is Ramboll's assessment that Denmark can offer highly competitive solutions that are cost-effective, flexible and a convenient option for the target countries (mainly Germany, Sweden, Finland and potentially Poland). The most cost-competitive solutions include set-ups where large CO2 amounts are contracted via pipeline and those that comprise or combine onshore and nearshore storage sites.
Institutional considerations	It is important to consider varying institutional set-ups of CCS since although CCS is technically feasible and can remove CO2 emissions on a large scale, the business case does not exist without state and Government involvement. To understand the need for state involvement as well as the interplay between different actors and institutional set-ups, several case studies have been studied: the Norwegian full-scale carbon capture, transport and storage demonstration project "Longship", three large CCUS developments in "the UK and the Government's CCS business model considerations" as well as the Porthos CCS project in the Netherlands. See 5.4.2. for the conclusions based on the case studies mentioned above.

5.2 MAPPING OF NORTH EUROPEAN CO2 STREAMS RELEVANT FOR DANISH STORAGE

As assessed in chapter 4, many of the North European countries are expected to apply CCS as a measure to achieve 2030 and 2050 decarbonisation targets. However, not all of these countries have sufficient storage capacity (or an intention to store CO2 domestically) and will therefore need to seek foreign storage.

Based on insights from the previous chapter, this section will provide a mapping of possible CO2 flows between Denmark and Northern Europe, considering potential competing storages, geographical conditions, clusters etc.

The foreign storages that could compete with Danish CO2 storages are mainly the UK and Norway with storages situated offshore in the North Sea. They could potentially compete with a large share of the CO2 export coming from the countries deemed relevant to export CO2 to Denmark (i.e. Germany, Sweden, Finland, The Netherlands but perhaps less likely Poland). Poland could also pose a potential competitive threat and compete with possible CO2 export streams from Finland and Sweden. Of course, this is if they decide to pursue CO2 storage in the future (as mentioned previously, geological storage of CO2 is prohibited until at least 2024 in the country). Competition from the Baltics of CO2 exports is not expected since geological storage is not possible in Estonia, while in Latvia and Lithuania, CO2 storage is currently prohibited. Additionally, in Latvia and Lithuania, the CO2 CCS potential is very limited as policies and climate strategies in these countries are not prioritising CCS and have a preference for CCU if they turn to greenhouse gas removal technologies.[202]

CO2 exports from the following countries are expected to be most relevant:

[202] Ramboll analysis

- Germany: Large volumes of captured CO2 volumes intended for storage in foreign countries are expected, as the country has clearly announced it will not utilise CO2 storage capacities on its own territory. The CO2 volumes are concentrated around the Hamburg area and Northern Germany, where there are numerous power plants and large iron and steel plants. Transport of CO2 from Germany to Denmark by ship and through a pipeline are both feasible possibilities.
- Sweden and Finland: Although there is not a heightened focus on CCS in the countries' climate strategies, compared to the focus on renewable energy and green hydrogen, the pulp and paper industries in these countries are the two largest in Europe. BECCS could therefore become highly relevant for both of these countries so they can close the CO2 emissions mitigation gap to reach their climate neutrality targets. Geological storage is not possible in Finland, and although Sweden has some storage capacities, the country has expressed a preference to export CO2. Moreover, many of the pulp and paper plants are situated close to the coast or rivers (since they use a lot of water resources in their production). It would be potentially effortless to export the CO2 from plants situated close to the coasts with shuttle tankers.

CO2 exports might potentially also come from the Netherlands and Poland:

- The Netherlands: The country has expressed that CCS is a temporary solution to emission removal until CCU and renewables become available at full scale. However, natural gas production is not expected to be phased out in the Netherlands, at least in the short- and medium-term; thus CCS has a large potential to be a key source to mitigate emissions at these plants. The Netherlands has CO2 storage capacities and is planning CCS projects, e.g. the Porthos project is the most known large-scale project. However, other projects are also being planned: Athos in Amsterdam and the Carbon Connect Delta project[203]. Depending on how the Dutch CCS projects progress, there might be some potential for CO2 exports in the short term, industry cluster projects acknowledge that the demand for storing CO2 might exceed the storage capacity and especially if the CCS project deliveries are faced with delays[204]. This means that the export of captured carbon to international carbon storage sites could be necessary for the short-to-medium term. Additionally, the Netherlands have ambitious renewable energy targets, however, they are the country furthest away in the EU from achieving their announced renewable energy targets[205]. To make up for this gap due to the delay of renewables deployment, CCS could be a potential solution to mitigate emissions. Therefore, CO2 emissions from both industry and the power & heat (mainly in the long-term since CCS is limited to industry sectors, to begin with) sector could pose some opportunities to utilise CCS, and some amounts could be exported. It is uncertain to which countries (or how the share of exported CO2 emissions would be split between countries) potential Dutch CO2 export volumes will be transported to. Norway, UK or Denmark could all be potential candidates, and therefore this is also limiting the forecasted CCS volumes from The Netherlands to Denmark. Therefore, Ramboll estimates that there is some potential of storing CO2 from the Netherlands in Denmark, yet the potential is smaller than the CO2 streams coming from Germany, Finland, and Sweden.
- Poland: The country has CO2 storage capacities, which could become relevant in the future and potentially also be cheaper than exporting CO2 to other countries. However, they have not announced interest in utilising their own CO2 capacities, and this is prohibited until 2024. And thus, there is some potential for CO2 exports from Poland, but this is highly dependent on political decisions, and the unfolding of these are highly uncertain.

Norway and UK storages could potentially compete for all the CO2 volumes described above.

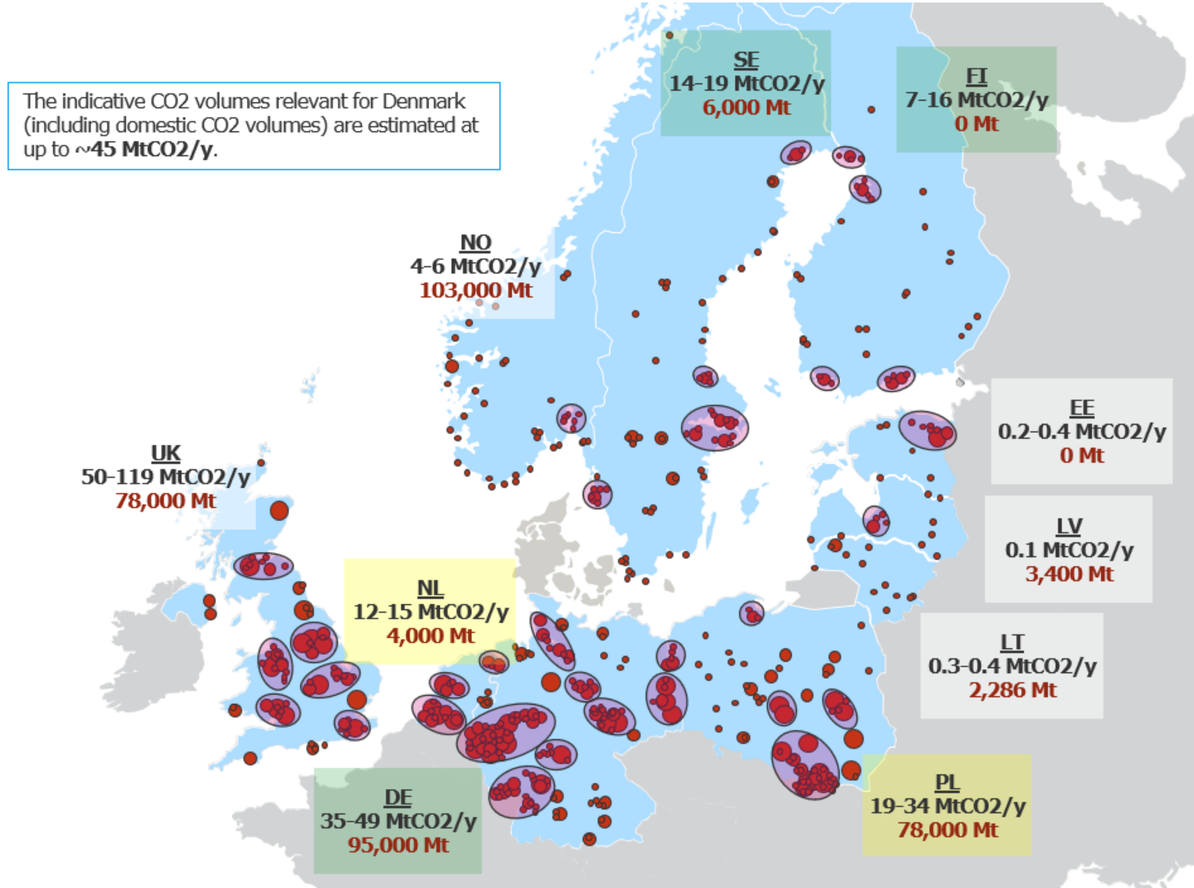
The potential of CO2 exports from the Baltic countries is limited or even deemed insignificant. As mentioned, the country's policies are not focusing or prioritising CCS, and the CCS potential of CO2 for CCS are limited. Nevertheless, the governing party in power changes often in these countries and especially the Latvian and Lithuanian Government (depending on the ruling political party) have shifted between allowing CO2 storage and prohibiting it, which poses uncertainty with

[204] European Commission, "Candidate PCI projects in cross-border carbon dioxide transport networks"

[205] Eurostat – "Renewable energy statistics"

regards to the countries' positioning towards CCS. Nevertheless, CCU is preferred above CCS in all of the Baltic countries.[206]

Figure 10: Overview of North European CO2 streams relevant for Danish storage



Source: Ramboll analysis, E-PRTR database

The indicative CO2 volumes relevant for Denmark (including domestic CO2 volumes) are estimated at up to ~45 MtCO2/y. Note that the volumes presented below are not final and only potential volume estimates subject to change since they depend on future policy decisions and climate strategies in different countries. This poses uncertainties since the political landscape and policies change, making it difficult to forecast the CO2 CCS potential. Additionally, the imported CO2 volumes are also dependent on the development of CO2 prices, competition from foreign CO2 storages and Denmark's own CO2 storage capacity developments.

Table 42: Estimated CO2 volume that can be potentially imported to DK (MtCO2/y)

Country	Total CO2 intended for CCS (MtCO2/y)[207]	Comment	Potential import to DK (MtCO2/y)
Germany	42	~20% of all emissions are from clusters in Northern Germany; Since capturable amount only includes large CO2 sources, an even higher share is expected from these clusters. Consequently, Ramboll estimates that up to 35% of emissions are within clusters; Additional CO2 can be imported via shuttle tanker transport. Due to general constraints, i.e. that some CO2 can be difficult to access or not feasible for dispersed sources or sent to other competing countries, Ramboll makes the assumption that up to ~50% of the estimated CO2 volumes can be potentially transported to Denmark.	~21

[206] Expert interview; Tallinn University of Technology

[207] Calculated as an average annual value for the years from the start point (e.g. 2025 for UK and 2030 for some other countries) and up to 2050

Finland	12	The majority of capturable emissions comes from the pulp & paper industry, which are often located close to coastline or rivers, and thus easily accessible. For financial estimates in this chapter, we assume that up to ~75% of CO2 volumes intended for CCS will be transported to foreign storages, including Denmark, of which half of the 75% can potentially be exported to Denmark. Only shuttle tanker transport applies.	~5
Sweden	17		~6
The Netherlands	14	Although the Netherlands have their own storage capacities, there might be potential for CO2 export. The majority of emission sources are close to coastline or rivers (and thus accessible), which makes them somewhat feasible for CO2 export. However, both Norway and the UK, in addition to Denmark, could compete for these exported CO2 volumes. Based on these conditions, Ramboll estimates that 20% of estimated CCS volume will be imported to Denmark; Shuttle tanker transport applies for onshore and nearshores storage solutions, while either shuttle tanker or pipeline applies for the offshore solution.	~3
Poland	27	In Poland, there are some large energy clusters in the central and southern part of the country. However, a large share of the plants in the south are coal-driven and thus not relevant since the large majority will be phased out. Although CO2 could potentially be transported from the central part of the country (inland locations) via rivers, there is a high probability that some of the CO2 is too difficult to access or not feasible for dispersed sources. Existing and planned natural gas plants are considered most relevant – these are relatively spread all over the country. Further, emissions from industry are highest in the south and south-eastern parts of the country. Consequently, for financial estimates, we make a conservative assumption that ~25% of the estimated impact will be transported to Denmark. Only shuttle tanker transport applies since CO2 transported by a pipeline is deemed too risky to construct if Poland starts to invest in their own storages.	~7
Total CO2 that can be imported to DK (MtCO2/y)			**~40**

In terms of domestic CO2 sources in Denmark, we have estimated them to be at about ~5 MtCO2/y (~3 MtCO2/y from the Copenhagen area and ~2 MtCO2/y from the Aalborg area)[208]:

- CO2 clusters are present in the Copenhagen area since it is an urban area with CO2 volumes coming from, e.g., Amager Bakke, Amagerværket, HC Ørsted power plant, Avedøre power plant, Roskilde waste incineration plant and others
- In Aalborg, situated in Northern Denmark, there are also CO2 sources from Aalborg Portland, a cement plant and Nordjyllandsværket power plant
- Other potential CO2 sources could be captured in the Aarhus area, which is also urbanized.

5.3 POSSIBLE SET-UPS FOR TRANSPORT AND STORAGE OF CO2 IN DENMARK

The full CCS chain consists of several elements:

- Capture at source
- Compression/liquefaction
- Intermediate storages at export – option at capture site and/or at a storage site
- Transportation: pipeline transportation or ship (shuttle tanker of the vessel)
- Intermediate storages close to storage - option
- Geological storage

This section will map available options for transport and storage of CO2 in Denmark (last three of the above-listed bullets), i.e. part of the CCS value chain within Denmark's scope. Different options will then be compiled into different possible set-ups, paired with estimated costs and compared to identify the most cost-effective solutions.

Options for transport and storage in Denmark, as well as cost estimates, are based on Catalogue of Geological Storage of CO2 in Denmark by Danish Energy Agency and Ramboll (2021) and Catalogue on Technology Data for Energy Transport published by the Danish Energy Agency and Energinet (2017, updated in 2020), supplied with Ramboll's technical and commercial insights (e.g. in relation to scaling up of costs for large-scale scenarios).

[208] Danish Energy Agency/Ramboll - Catalogue of geological storage of co2 in Denmark

Estimates such as costs, capacity etc., can only be clearly defined after design and data collection has been performed and should therefore be treated as indicative and with some uncertainty.

Box 3 – A note on set-ups

All storage and transport set-ups presented in this chapter are potential illustrative scenarios only. This also pertains to the suggested storage and pipeline locations as well as the shipping routes. Thus, the set-ups are not to be regarded as definitive rather as potential suggestions for feasible scenarios. The set-ups take a point of departure in the Catalogue of Geological Storage of CO2 in Denmark by Danish Energy Agency and Ramboll (2021).

5.3.1 Available options for transport and storage of CO2 in Denmark

5.3.1.1 Suitable storage sites in DK

Based on Ramboll's previous analyses[209], and mapping by GEUS, three different generic scenarios are assessed for suitable storage sites in DK: onshore saline aquifers, near shore saline aquifers and offshore depleted oil/gas fields.

Ramboll finds all geological storage scenarios analysed in this study to be feasible and realistic[210]. However, the present report should not be used for decision making for the development of concrete storage projects.

Onshore and nearshore saline aquifers: An aquifer is a porous sandstone with water naturally present in the pores in the sand. Consequently, injected carbon dioxide can behave the same way water does (occupy the pores) or potentially be dissolved into the water over a longer time. The system consists of an injection well, injection pump for additional compression, monitoring in the well cellar and different monitoring systems spread out on the surface of the anticipated delineation of the CO_2 plume[211]. The below geological structures are considered to be realistic options for onshore CO_2 storage in Denmark[212]:

Onshore structures:

- *North Jylland:* Vedsted structure (storage capacity as published by GEUS: 162 Mt); The structure is mature for further development.
- *East Jylland*: Gassum structure (630 Mt), Voldum structure (288 Mt) and Paarup structure (91 Mt); All these three structures could be developed as storage options.
- *Sjælland:* Havnsø structure (927 Mt); A large and promising structure, that has not been drilled.

Near shore structures:

- Hanstholm structure (2,753 Mt); The expected injection site is located some 30-50 km offshore from the Port of Hanstholm. A similar but very immature type of near shore storage option may exist in the southern part of the North Sea (off the coast of Esbjerg), with the geological structure located some 100 km offshore.
- Røsnæs structure (227 Mt); Located under the Great Belt with a smaller part below the tip of Røsnæs. This means that wells potentially could be drilled from land.

Offshore depleted oil/gas fields[213]: Oil & gas has been produced from the Danish North Sea since the early 1970s, and some of the fields are approaching the end of field life. The depleted northern sandstone fields in the Central Graben are at this point in time considered most suitable for the timely development of geological CO2 storage. Chalk fields may be relevant later: requires re-use of long horizontal wells and wellhead platforms,

The different storage options are presented in the figure below:

[209] Catalogue of geological storage of CO2 in Denmark, Ramboll/DEA, 2021 and CCUS Technology Catalogue, Ramboll, 2020

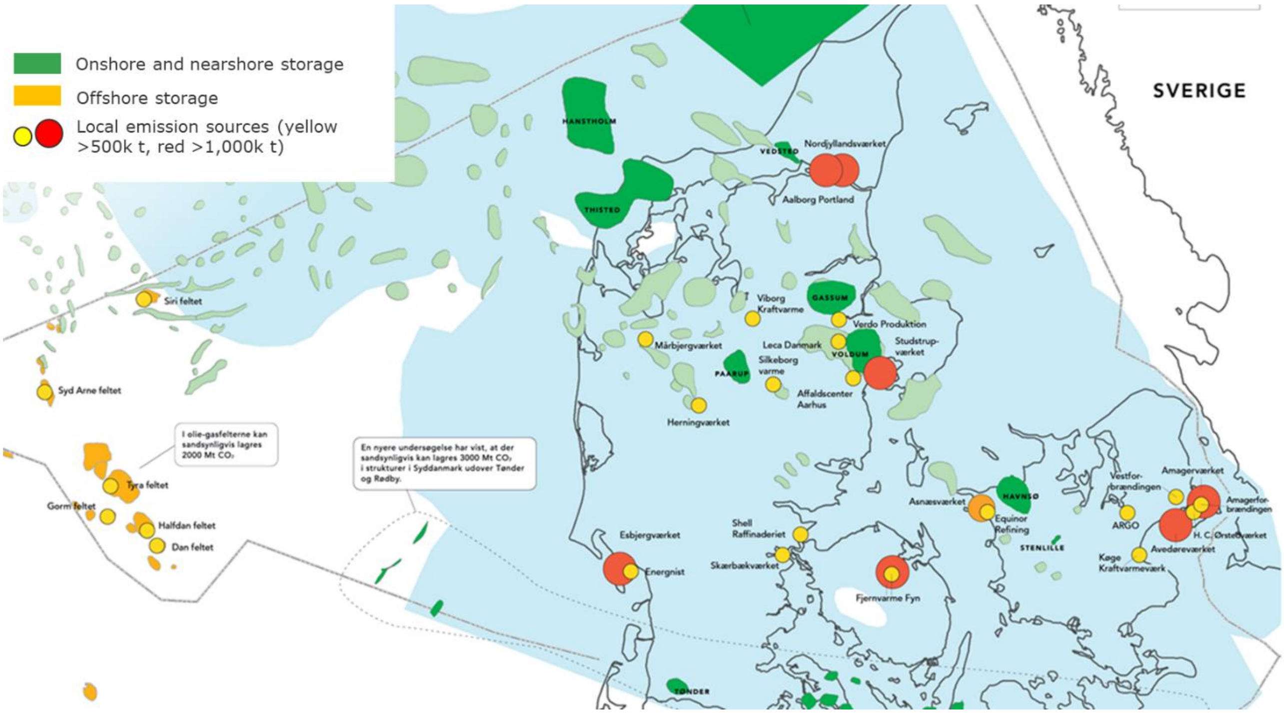
[210] Catalogue of geological storage of CO2 in Denmark, Ramboll/DEA, 2021

[211] S. M. Thomsen and J. Flørning, 'CO2 neutral energy system utilizing the subsurface', Copenhagen, 2019

[212] Catalogue of geological storage of CO2 in Denmark, Ramboll/DEA, 2021

[213] Catalogue of geological storage of CO2 in Denmark, Ramboll/DEA, 2021

Figure 11: Overview of potential CO2 storage options in Denmark



Source: GEUS

5.3.1.2 Available options for the transport of CO2 to the storage site[214]

CO2 emission sources and suitable geological storage sites are likely to be geographically separated. Consequently, the realisation of carbon capture storage will nearly always involve the transportation of CO_2. The main technologies deemed suitable for the transport of CO2 are:

- Pipeline transport
- Ship transport (shuttle tanker transport combined with intermediate storage or transport by vessels equipped with storage facilities)
- Road transport

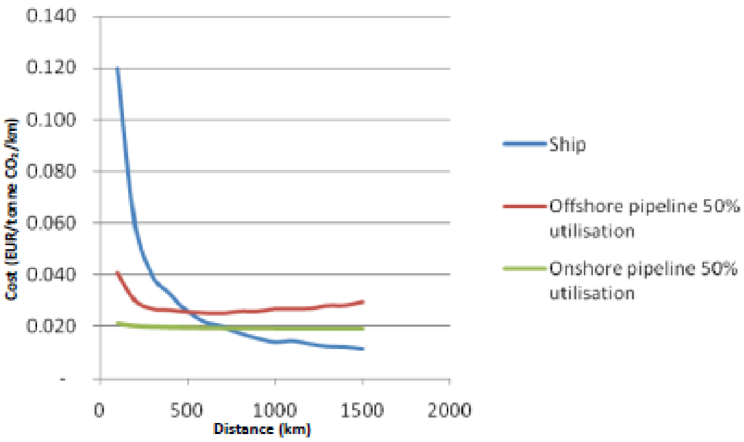
The different modes of transportation have varying advantages and disadvantages. Take CO2 transport by a shuttle tanker; this provides more flexibility than pipeline solutions since the routes of transport can be easily adjusted. This is particularly beneficial because transportation is needed for a new CO2 source location or storage site location. Further, the transport capacity can also be adjusted depending on demand. Standard carrier shuttle tankers can also be used for other transport of goods /e.g. LNG), if the need for transporting CO2 decreases.

On the other hand, shuttle tanker transport of CO2 is more expensive than pipeline transport for short to medium distances and costly CO2 terminals and intermediate storage facilities are also required for this mode of transportation. Thus, both the shuttle tanker's capital expenditure and the terminal fees are fixed regardless of the distances. If large volumes of CO2 (providing economies of scale) are transported or if CO2 point sources are located inland, then a pipeline solution will be the most cost-efficient option. As shown in the graph below conducted by ZEP[215], pipeline transport is estimated to be more cost-efficient for transport distances of 500-700 km, after which shuttle tanker becomes economically more feasible.

[214] Catalogue on Technology Data for Energy Transport published by the Danish Energy Agency and Energinet (2017, updated in 2020)

[215] The Cost of CO_2 Transport – Post-demonstration CCS in the EU. ZEP report 2010.

Figure 12: Cost of CO_2 transport (EUR/tonne/km, 2010 cost level) by pipeline at 50% capacity and by ship at 100% capacity (including terminal) for 10 MtCO2/y



Note: In the research below, transport of 10 MtCO2/y was compared between ships (shuttle tanker) and pipeline. Further, the study underlies the assumption that pipeline utilisation is 50%. Different assumptions change the intersection point of when which transport mode becomes more cost-efficient. Source: ZEP, Catalogue on Technology Data for Energy Transport published by the Danish Energy Agency and Energinet (2017, updated in 2020).

When CO2 sources are concentrated (e.g. in the form of an industry cluster), the most uncomplicated composition would be a capture, compression, pipeline transportation and storage. Suppose several sources are combined and cannot be connected to a pipeline. In that case, there will be a need for intermediate storage above the ground, which is connected to the permanent storage by a pipeline for onshore/nearshore activities or shuttle tankers for offshore activities.

5.3.2 Mapping of possible set-ups for transport and storage of CO2 in Denmark

Possible set-ups for CO2 transport and storage are presented in this section. They have been created based on Ramboll's expertise within CCS and with inspiration from ongoing CCS projects in Norway, the Netherlands, and Great Britain. Additionally, experience from the oil and gas industry and knowledge from the district heating industry have been used to qualify the set-ups presented below. This includes but is not limited to the know-how of large volume transport of gas and liquids using pipelines, ships and trucks.

In the table below, nine set-ups in total are presented: Two onshore, two near shore and five offshore (presented in Table 43 below, and also visualised in Figure 13). They include different combinations of transport and storage possibilities, meaning some set-ups will require ports and intermediate storage (e.g. set-up #3). In contrast, other set-ups are based exclusively at sea (e.g. set-up #7).

Set-ups including pipelines from Northern Germany or the Netherlands are still open to shuttle tanker transport from these countries. This means that CO2 transportation via shuttle tankers from these countries is expected to continue but decrease to some extent to take advantage of the decrease in marginal cost enabled by a pipeline.

Table 43: Overview of potentially relevant set-ups for transport and storage of CO2 to Denmark

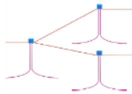
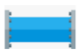
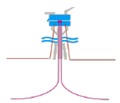
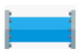
Storage type	Potential site name (and capacity)	Assumed max. injection capacity per year	Set-up #	CO2 Transport from source	Intermediate storage and preparation facilities	Transport from intermediate storage to well	Injection site	Description
Onshore	Gassum (630 Mt) Or Havnsø (927 Mt)	**10 MtCO2** (Gassum)	**1**					- Shuttle tankers transport CO2 from ports near emissions sources to a port near the storage site. The CO2 is transported from the port to the injection site via pipeline, where it is injected into the onshore storage site
			2	  From DK/CPH				- Shuttle tankers transport CO2 from ports near emissions sources to a port near the storage site. - Additionally, CO2 from CPH is transported via pipeline to the port - The CO2 is transported from the port to the injection site via pipeline, where it is injected into the onshore storage site - Assumption: 40%-80% (4MtCO2/y) will come from DK/CPH through the pipeline, and the remaining CO2 via sea from other sources
Nearshore	Røsnæs (227 Mt) or Hanstholm (2,753 Mt)	**10 MtCO2** (Hanstholm)	**3**					- Shuttle tankers transport CO2 from ports near emissions sources to a port near the storage site - The CO2 is transported from the port to the injection site via pipeline, where it is injected into the nearshore storage site
			4	  From DK/CPH				- Shuttle tankers transport CO2 from ports near emissions sources to a port near the storage site - Additionally, CO2 from CPH is transported via pipeline to the port - The CO2 is transported from the port to the injection site via pipeline, where it is injected into the nearshore storage site - Assumption: 40%-80% (4MtCO2/y) will come from DK/CPH through the pipeline, and the remaining CO2 via sea from other sources

Figure continues on the next page

Storage type	Potential site name (and capacity)	Assumed max. injection capacity per year	Set-up #	CO2 Transport from source	Intermediate storage and preparation facilities	Transport from intermediate storage to well	Injection site	Description
Offshore	Depleted oil and gas field in the North Sea (estimated ~2,000 Mt)	**10 MtCO2**	**5**					- Shuttle tankers transport CO2 from ports near emissions sources to a port near the storage site - CO2 is transported from the port to the injection site via pipeline, where it is injected into the offshore storage site
			6					- Vessels transport CO2 from ports near emissions sources to injection sites - The CO2 is transferred directly to the offshore storage site, where it is injected
			7					- Shuttle tankers transport CO2 from ports near emission sources to a permanently moored FSU near the storage site - The CO2 is directly transferred from the FSU to the injected site, where it is injected into an offshore storage site
			8	From DE				- Shuttle tankers transport CO2 from ports near emissions sources to a port near the storage site - Additionally, CO2 from Northern Germany is transported to the port via an onshore pipeline - CO2 is transported from the port to the injection site via pipeline, where it is injected into the offshore storage site - Assumption: 4-5 MtCO2/y will come from DE through a pipeline, and the remaining CO2 via sea from other sources
			9	From SE, FI, PL & DK (rest) From DE From NL				- Shuttle tankers transport CO2 from ports near emission sources in DK, SE, FI & PL to a port near the storage site. From the port, CO2 goes to the injection site via pipeline - Additionally, pipelines from Northern Germany and the NL transport CO2 from nearby CO2 emissions clusters to the injection site via pipelines. From the injection site, the CO2 is injected into the offshore storage site - Assumption: 4-6 MtCO2/y will come from DE+NL via pipeline, and the remaining CO2 via sea from other sources

Note: Shuttle tankers are considered pure transport vehicles, meaning they do not have cooling equipment and storage preparation equipment needed to connect directly to an injection site. As a result, shuttle tankers need to unload CO2 into intermediate storage near refrigeration and storage preparation equipment before it can be transferred to an injection site; Vessels can be used for transport and carry cooling and storage preparation equipment. This means they can connect directly to injection sites; Permanently moored FSU stations are considered stationary and cannot be moved. Shuttle tankers will transport CO2 to the station, which will prepare the CO2 for storage before sending it to the injection site; Well pad: An area that is cleared or prepared for the drilling of wells, the area is a fenced-off area with drainage and other facilities to allow safe and environmentally friendly drilling of wells; Wellhead platform: An offshore steel structure for the support of production and/or injection wells and associated support systems; Injection well: A well for injection of CO2 into a subsurface reservoir; Intermediate CO2 storage: A site with pressurised and cooled tanks for storage of liquified CO2; Permanently moored vessel: A so-called floating storage unit (FSU) equipped with the injection facilities; **Source:** Ramboll analysis

Figure 13: Illustration of different set-ups for ups for transport and storage of CO2 to Denmark (see appendix for illustration of each set-up separately)

Note: Ports (especially foreign) are only illustrative suggestions for where CO2 could depart by ship transport.
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark."

It is Ramboll's assessment that no single storage site in Denmark is capable of handling 45 MtCO2/y alone. Meaning, that if a capacity of up to 45 MtCO2/y is desired, a combination of the set-ups presented below must be used. The offshore storage sites do theoretically have adequate storage capacity. However, even though they have the theoretical capacity to store the 45 MtCO2/y over a period of 30 years (1350 Mt in total), the maximum injection rate of the sites is rated at 10 MtCO2/y. This is due to a large amount of the capacity being situated in depleted oil and gas field that are in chalk reservoirs not suited for CO2 injection. Injection of CO2 into these fields would require a large number of wells raising the price of CO2 injection to higher levels[216]. Alternatively, large offshore aquifers could be utilised, however, they remain largely unmapped, meaning there is a large amount of uncertainty regarding their storage capacity and possible injection rates. As a result, offshore aquifers have not been considered in this report.

Note that shuttle tankers are currently not large enough to handle the estimated amounts of CO2 without deploying a large number of shuttle tankers. Set-ups below assume that larger shuttle tankers (20,000 net tonnages or even above) will be available at the time storage is operationalised. Larger shuttle tankers would require larger ports, which means that shuttle tanker sizes will also vary depending on the size of the port near emissions sources. However, some ports will remain small, which means large intermediate ports could be established where smaller shuttle tankers from smaller ports could transport and unload CO2. Larger shuttle tankers could then transport the aggregated CO2 from the intermediate port to the final port.

Furthermore, the set-ups are built upon the assumption that all pipeline, intermediate storage, and injection site infrastructure will have to be constructed. Some infrastructure can theoretically be re-used; however, given the large CO2 volumes assumed in this report, this is deemed a less efficient and a more complex solution and will therefore not be considered.

More scenarios were considered, however, they were deemed technically, economically, or politically infeasible for the time being. Particularly pipelines from Northern Germany and the Netherlands were not included in the onshore and nearshore set-ups as the pipelines would have to extend further, which was deemed too expensive.

[216] Ramboll expert

5.3.3 Overview costs for transport and storage of CO2 in Denmark per set-up

To assess which solution(s) are the most cost-effective, each of the set-ups described in 5.3.2 has been matched with respective costs for transportation and storage of CO2 in Denmark.

Cost estimates include relevant considerations, such as type of storage and transportation technology applied, quantities of CO2 expected through pipelines and sea, respectively, and distance from the source. Cost estimates in this report are based on assumptions from Catalogue of Geological Storage of CO2 in Denmark by the Danish Energy Agency and Ramboll (2021) and the Catalogue on Technology Data for Energy Transport published by the Danish Energy Agency and Energinet (2017, updated in 2020).

Costs have been compiled for two scenarios: 5 MtCO2/y and 10 MtCO2/y. In order to secure full comparability across presented set-ups, the cost comparison is only performed for the scenario with 5 MtCO2/y, as assumptions underlying the 10MtCO2/y scenario are more set-up specific. For example, the amount of CO2 transported via pipeline in set-up 2 (pipeline from Copenhagen to onshore storage and remaining share transported from other sources by sea) is constant in both scenarios, i.e. it amounts to 80% at 5 MtCO2/y and only 40% at 10 MtCO2/y. While set-up 1 is 100% sea transport in both scenarios (5 MtCO2/y and 10 MtCO2/y). However, it is our opinion that conclusions drawn from the cost benchmark at 5 MtCO2/y will also be applicable for larger scenarios. Overview of cost estimates for 10 MtCO2/y is provided in the appendix.

The cost comparison shows that onshore storage is the most cost-effective solution (both when pipeline and sea transport is applied). On the other hand, a pipeline provides a scale advantage and is thus the most effective transport solution at large-scale (i.e., e.g. 5 MtCO2/y). More specifically, the following conclusions can be drawn:

- Set-up 2 (focus on pipeline transport from Copenhagen to onshore storage) is the least expensive
- Set-up 4 (focus on pipeline transport from Copenhagen to nearshore storage) is the least expensive nearshore option but more expensive than onshore storage
- Set-ups comprising offshore storage are more expensive than those with both onshore and nearshore solutions
- Set-up 8 (focus on pipeline transport from DE) is the least expensive of all offshore storage options

Storage cost comprises cost to establish the storage (e.g., pre-FID studies, the pipeline from port to storage, injection equipment, monitoring equipment etc.) and operations (incl. organisation, power etc.). In the calculation for onshore storage, it is assumed that the Havnsø storage site, accessed through Kalundborg harbour, will be used due to the estimated size, proximity to Amager Forbrænding and the current momentum of the site. For nearshore storage, it is assumed that the Hanstholm storage site, accessed through Hanstholm harbour, will be used due to the size of the estimated storage capacity. Offshore storage will be assumed to be in the Northern part of the North Sea oil and gas fields, accessed through Esbjerg harbour, due to the sites' geological nature, meaning fewer wells are needed for the same flow rate.

Transport cost covers the cost of transporting CO2 from ports near emission sources in five Northern European countries and domestically in Denmark, to a Danish intermediate storage facility near a storage site, either through the pipeline or by sea. Pipeline transportation includes CAPEX (for both pipeline and power stations), maintenance, monitoring and power costs. Sea transportation includes CAPEX (for ships and intermediate storage at export ports), maintenance and fuel. Note that the cost for transport by the sea does not include harbour fees or the cost for liquefaction (which is typically included at the CO2 capture plant).

CO2 transport costs from shuttle tankers are included in the business cases in chapter 6, although this could potentially be paid by the emitter or split between the emitter and the CO2 storage provider. In the case that Denmark pays for the export countries' transport of CO2, the export countries will receive favourable conditions – especially in the less expensive onshore storage solution option. The cost of covering export countries' transport might be transferred to Danish emitters, making it more expensive for them, and Danish emitter might choose storage solutions in competing countries. If CO2 is imported at a large-scale, it could be more feasible to cover the export countries' transport costs since the price could come down with economies of scale.

Note that there is still a lot of uncertainty about costs and performance, as only a few carbon storage projects have been implemented in Europe, and mostly in association with oil and gas production. In addition to the general cost levels, there is also uncertainty with respect to the delimitation of the operator's responsibility after closing of the storage (and costs for e.g. monitoring) and to the technical development (e.g. injection rates in different types of reservoirs as well as the choice of steel material, e.g. wells), which can both impact costs. Initially, we assume that a conservative approach will be used, which may increase the cost for the first large-scale projects. In line with operational experience, there may be a decline in cost due to a more optimized design. The actual capacity may prove to be larger than the nameplate capacity.

Box 4 – A note on costs

All individual costs inputs i.e. transportation and storage costs presented in this chapter and utilised in the business cases in chapter 6 are not levelized costs.

Details regarding assumptions used for cost estimation in each set-up are described in Appendix.

Table 44: Cost for the different set-ups for transport and storage of CO2 in Denmark

		Set-up # 1 **Onshore**; Shuttle tankers -> port -> storage site via pipeline	Set-up # 2 **Onshore**; shuttle tankers & pipeline (from CPH) -> port -> storage site via pipeline	Set-up # 3 **Nearshore**; Shuttle tankers -> port -> storage site via pipeline	Set-up # 4 **Nearshore**; Shuttle tankers & pipeline (CPH) -> port -> storage site via pipeline	Set-up # 5 **Offshore**; Shuttle tankers -> port -> storage site via pipeline	Set-up # 6 **Offshore**; Vessels -> injection site	Set-up # 7 **Offshore**; Shuttle tankers -> permanently moored FSU -> injection site	Set-up # 8 **Offshore**; Shuttle tankers & pipeline (from DE) -> port -> storage site via pipeline	Set-up # 9 **Offshore**; Shuttle tankers (SE, FI, PL & DK) -> port -> storage via pipeline; Pipeline from DE & NL -> storage
		MDKK 5 MtCO2/y	MDKK 5 MtCO2/y	MDKK 5 MtCO2/y	MDKK 5 MtCO2/y	MDKK 5 MtCO2/y	MDKK 5 MtCO2/y	MDKK 5 MtCO2/y	MDKK 5 MtCO2/y	MDKK 5 MtCO2/y
STORAGE	**Pre-FID Cost**	**195**	**195**	**370**	**370**	**120**	**300**	**120**	**120**	**120**
	2D Seismic	90	90	90	90	70	150	70	70	70
	Basline studies	20	20	20	20	20	60	20	20	20
	Appraisal well	55	55	230	230	n/a	n/a	n/a	n/a	n/a
	FEED Studies	10	10	10	10	10	30	10	10	10
	Approvals	20	20	20	20	20	60	20	20	20
	CAPEX	**2.315**	**2.315**	**4.065**	**4.065**	**4.770**	**2.980**	**3.855**	**4.770**	**4.770**
	Intermediate storage	180	180	180	180	180	n/a	n/a	180	180
	Injection plant	420	420	420	420	390	340	390	390	390
	Pipeline	140	140	350	350	1.750	n/a	n/a	1.750	1.750
	Injection wells	1.575	1.575	2.835	2.835	1.925	1.960	1.925	1.925	1.925
	Wellhead platform	n/a	n/a	280	280	525	275	525	525	525
	Mooring and loading system	n/a	n/a	n/a	n/a	n/a	405	375	n/a	n/a
	Purpose built CO2 carrier/FSU	n/a	n/a	n/a	n/a	n/a	n/a	640	n/a	n/a
	Accumulated OPEX	**2.938**	**2.938**	**4.512**	**4.512**	**9.101**	**13.242**	**11.443**	**9.101**	**9.101**
	Base organisation	175	175	350	350	525	525	525	525	525
	Intermediate storage	223	223	223	223	223	n/a	n/a	223	223
	Injection plant	521	521	521	521	967	844	967	967	967
	Pipeline	38	38	95	95	473	n/a	n/a	473	473
	Injection wells	427	427	825	825	527	608	527	527	527
	Monitoring	670	670	920	920	920	920	920	920	920
	Power	884	884	884	884	3.036	3.450	3.036	3.036	3.036
	Wellhead platform	n/a	n/a	694	694	2.430	4.650	2.430	2.430	2.430
	Standby vessel	n/a	n/a	n/a	n/a	n/a	1.240	620	n/a	n/a
	Mooring and loading system	n/a	n/a	n/a	n/a	n/a	1.005	831	n/a	n/a
	Purpose built CO2 carrier/FSU	n/a	n/a	n/a	n/a	n/a	n/a	1.587	n/a	n/a
	Closure costs	**805**	**805**	**1.311**	**1.311**	**1.435**	**1.122**	**1.275**	**1.435**	**1.435**
	Abandonment cost (ABEX)	405	405	711	711	835	522	675	835	835
	Post-Closure Cost/Monitoring	400	400	600	600	600	600	600	600	600
TRANSPORT – SHUTTLE TANKER/ VESSEL	**CAPEX**	**3.669**	**2.723**	**3.669**	**2.348**	**3.669**	**4.542**	**3.669**	**2.723**	**2.723**
	Transport shuttle	1.419	473	1.419	473	1.419	n/a	1.419	473	473
	Vessel	n/a	n/a	n/a	n/a	n/a	2.292	n/a	n/a	n/a
	Export intermediate storage	2.250	2.250	2.250	1.875	2.250	2.250	2.250	2.250	2.250
	Accumulated OPEX	**4.412**	**2.607**	**4.499**	**2.316**	**4.587**	**5.759**	**4.575**	**2.659**	**2.668**
	Transport ships fixed O&M	3.738	2.461	3.738	2.157	3.738	n/a	3.738	2.461	2.461
	Vessels fixed O&M	n/a	n/a	n/a	n/a	n/a	4.917	n/a	n/a	n/a
	Fuel costs	673	146	761	159	848	843	837	198	207
TRANSPORT – PIPELINE (from port or from emission source)	**CAPEX**	**-**	**467**	**-**	**2.100**	**-**	**-**	**-**	**1.108**	**6.417**
	Onshore pipeline	n/a	350	n/a	1.050	n/a	n/a	n/a	875	n/a
	Offshore pipeline	n/a	n/a	n/a	700	n/a	n/a	n/a	n/a	5.950
	Pumping station	n/a	117	n/a	350	n/a	n/a	n/a	233	467
	Accumulated OPEX	**-**	**203**	**-**	**905**	**-**	**-**	**-**	**506**	**2.627**
	Onshore pipeline fixed O&M	n/a	95	n/a	284	n/a	n/a	n/a	236	n/a
	Offshore pipeline fixed O&M	n/a	n/a	n/a	189	n/a	n/a	n/a	n/a	1.607
	Power cost	n/a	108	n/a	432	n/a	n/a	n/a	270	1.020
Total cost per ton, DKK/ton		106	91	136	133	175	207	185	166	221
*hereof storage		46	46	76	76	114	131	124	114	114
*hereof transport		60	44	61	57	61	76	61	52	107

Source: Catalogue of Geological Storage of CO2 in Denmark by Danish Energy Agency and Ramboll (2021) and Catalogue on Technology Data for Energy Transport published by the Danish Energy Agency and Energinet (2017, updated in 2020), supplied with Ramboll's technical and commercial insights (e.g. in relation to scaling up of costs for large-scale scenarios)

5.3.4 Other advantages and disadvantages of the different set-ups

In the previous sections, the different set-ups were evaluated based exclusively on costs. This section aims to provide an overview of other aspects of the identified aspects, both those in favour and disadvantages.

In addition to being the least expensive option (as described in the previous section), the onshore storage has the advantage of being located close to the large domestic CO2 emission sources (Copenhagen area). However, uncertainty whether the site can be used (and thus need for seismic tests and drilling) and the general risk of public opposition can lead to a longer permitting process than in the case of the offshore site.

Although the most expensive option, offshore storage offers several advantages, especially in known feasibility and demonstrated tightness. It can be potentially easier to obtain necessary permits (especially for the onshore site). Furthermore, some existing equipment (platforms and support systems) can potentially be reused, meaning that the offshore solution can be implemented even faster than the onshore or nearshore solution.

Solutions with a pipeline from Germany would provide a more certain CO2 stream from abroad, making it potentially easier (and cheaper) to find investors. On the other hand, this type of solution is only meaningful when the full-scale operations are planned for construction from the beginning, while sea transportation enables small-scale start with gradual build-up. Note that a more gradual start is also possible in the case of the onshore storage, where pipelines from source and other connecting infrastructure can be added afterwards.

The table below provides a detailed overview of the advantages and disadvantages of each set-up for transport and storage of CO2 in Denmark.

Table 45: Overview of other (non-cost based) advantages and disadvantages of the different set-ups

Set-up		Advantages	Disadvantages
Onshore	**#1, #2**	- Havnsø is an attractive location for storage due to its close proximity to large emission sources in the Copenhagen area. Furthermore, it is close to a deep-water port, making it feasible for transport with large shuttle tankers (assumption for this project)	- Since the site has not yet been drilled, it is not 100% certain that the site can be used for CO2 storage. It is, therefore, necessary to carry out seismic surveys as well as appraisal drilling, which can extend the timeline (and also meet public opposition due to the onshore testing equipment) - Due to the onshore location and possible public opposition, permitting process can be longer (and more uncertain) than for the offshore storage
Nearshore	**#3, #4**	- Pumping equipment can be located onshore, making this solution less expensive than the offshore solution (as the power connection can be done onshore and does not need to be solved offshore) - Similar to Havnsø, Hanstholm is located close to a deep-water port that can receive large shuttle tankers	- Nearshore reservoirs have not yet been drilled, and it is not 100% certain that they can be used for CO2 storage. However, the seismic equipment can be placed offshore, meaning it is easier and can meet less public opposition than onshore - Although CO2 can be sourced from the Aalborg area, the distance to the largest source of domestic emissions (Copenhagen area) is much longer than for the onshore storage, making it more expensive to transport
Offshore	**All offshore-based set-ups**	- Tightness (and thus feasibility) of the geological system has been already demonstrated, e.g. in connection with EOR (Enhanced Oil Recovery) in North America. Seismic studies still need to be carried out; however, this process is expected to be shorter than is the case for onshore or offshore storage sites. - Furthermore, some of the existing equipment can be reused (e.g. wells, platforms, parts of the topside facilities, support systems). Together with the above, this means that offshore storage can potentially be	- Although CO2 can be sourced from the Aalborg area, the distance to the largest source of domestic emissions (Copenhagen area) is much longer than for the onshore storage, making it more expensive to transport

		deployed faster/earlier than the onshore and nearshore solutions. - Due to long-distance to shore and lower environmental impact, less public opposition is expected and potentially easier to obtain necessary permits.	
	#6, #7	- Injection directly from vessels or FSU requires simpler infrastructure and allows to start with a smaller solution and then potentially gradually scale-up - A set-up without the need for construction of pipeline means that potentially fewer stakeholders need to be involved	- Solutions with vessels (set-up #6) and with FSU (set-up #7) are more expensive than with a pipeline from the port (set-up #8)
	# 8, #9	- Pipeline from source binds emitters, lowering competition for CO2 and providing more security (thus potentially making it easier and less expensive to find investors, especially if the pipeline entails certain CO2 sources like iron & steel industry in the Hamburg area) - Potential synergies with a planned P-t-X plant close to Esbjerg port, i.e. if the plant will need to use carbon, it could be possible to share the pipeline from emission sources and also costs	- To be fully efficient, solutions with pipeline transport from mission source require that the full-scale infrastructure is constructed from the start (i.e. it is not meant to start small and then expand/add-on later on) - Solution with pipeline form source (e.g. DE) require pre-work, i.e. collaboration and agreements with German companies and potentially state

5.4 ASSESSMENT OF DANISH COMPETITIVENESS FOR CO2 STORAGE

To assess the competitiveness of the Danish CO2 storage, criteria for competitiveness need to be defined. In this case, the following **criteria** are considered suitable **to assess the competitiveness of a CO2 storage solution**:

1. A low-cost solution: Although this report has not compared the cost of CO2 storage in different countries, it was assessed that onshore storage is the least expensive solution for CO2 storage, followed by near-shore storage and offshore storage as the most expensive option. Similarly, when large CO2 volumes are concentrated, pipeline proves to be the most cost-effective transport solution for distances of up to ~700 km. Combining offshore solution with an onshore transport pipeline (from source) can thus potentially provide a more cost-effective solution than a combination of offshore storage and CO2 transport by sea
2. Offers low marginal cost: Ability to create a solution that allows flexibility – i.e. it is possible to add or reduce volumes at a low additional cost
3. Provides high solution convenience (for other countries): A solution that is convenient for the CO2 producer; This could be geographical proximity or an easy and/or a low-cost way to push over large amounts of CO2, i.e. without investing in multiple storage facilities and complex logistics set-ups

Based on the analysis of the different **set-ups for transport and storage of CO2 in Denmark**, the following **factors** are identified in **providing Denmark with a competitive advantage**:

- Denmark can establish varying set-ups and even combine them if needed. Possible storage solutions include onshore, nearshore and offshore sites and the possibility of establishing varying transport solutions (e.g., pipelines, shuttle tanker, vessels, etc.). All storages can be potentially combined through a network of pipelines, allowing for a huge storage capacity (e.g., ~40 MtCO2/y), high input flexibility and a low total cost per tonne of CO2 (as a result of combining the least costly solutions for both storage and transport); Different solutions can also be added/expanded over time
- Denmark is strategically located close to Northern Germany, which has one of the largest CO2 sources in Europe. Close geographic proximity, combined with a possibility to build a pipeline from a cluster in Northern Germany, can provide a very cost-effective and overall convenient solution for Germany
- Likewise, Denmark is favourably located regarding CO2 transport by sea from target countries, Sweden, Finland, and Poland. Although, e.g., SE has formally announced that they are interested in collaboration with Norway for storage of CO2, many of the CO2 in both Sweden and Finland comes from the pulp and paper plants that are spread along the

coasts. As the CO_2 can be stored on the eastern side of Denmark (e.g., in Havnsø), or loaded off for pipeline transport to other storage sites in Denmark, this could potentially provide a cost-competitive solution that is also highly convenient (as large amounts of CO_2 will only need to be shipped halfway compared to storages in, e.g., UK or Norway).

Based on the above, Ramboll assesses that Denmark can offer a highly competitive solution that is cost-effective, flexible, and a convenient option for the target countries (especially Germany, Sweden, Finland and potentially Poland). The most cost-competitive solutions include set-ups where large CO_2 amounts are contracted via pipeline and those that comprise or combine onshore and nearshore storage sites.

5.5 INSTITUTIONAL CONSIDERATIONS

It is important to consider varying institutional set-ups of CCS since although CCS is technically feasible and can remove CO_2 emission on a large scale, the business case for it does not exist. Market failures prevent actors from developing CCS on their own. There are two principle market failures at work:

- The price of emitting CO_2 is lower than the socioeconomic cost of emitting CO_2. This incentivises businesses to emit CO_2 since, from a financial perspective, this is more profitable than what is logical from a socioeconomic perspective (negative externality)
- CCS technology has the characteristics of a public good, i.e., it is useful to the public/others and not only to the technology developer. The developer will thus carry the costs while the benefits are shared by the public (positive externality)

Additionally, there are investment barriers such as establishing a storage facility that comes with a high up-front cost. In contrast, the costs become lower for any new actors entering to utilise the existent set-up. They benefit from the experience and knowledge from the first developments, which will lower costs for subsequent actors who enter. Thus, from a business perspective, it can therefore be profitable to wait until the first movers have incurred the cost of early development. Finally, there is a need for many actors since the whole chain involves activities from capture, to transport and storage. This creates a risk in terms of the development and dependency of other actors; A risk that is difficult for one industry actor to take.[217]

The above highlights the inevitable need for state involvement since without it, there will be no incentives with current conditions for market actors to embark on CCS deployment alone. Further, it also stresses the importance of considering institutional set-ups. The interfaces that arise from the transition between the different CCS value chain segments leads to uncertainties and possibly complex institutional set-ups, which shall be addressed. However, suppose the institutional set-up is robust and carefully planned. In that case, CCS can be deployed at scale, and the CCS abatement cost might come down and be more favourable compared to other CO_2-reduction solutions.

To understand the need for state involvement and the interplay between different actors and institutional set-ups, it is useful to outline cases in other countries with CCS projects. Following case studies will be described below: the Norwegian full-scale carbon capture, transport and storage demonstration project "Longship", three large CCUS developments in the UK and the Government's CCS business model considerations, and the Porthos CCS project in the Netherlands. Main takeaways from the cases (regarding institutional set-ups) are presented at the end of this section.

Box 5 – A note on business case set-ups vs. business models

A pivotal distinction is made between business case set-ups and business models. Business case set-ups bring forth the most relevant market-based cases for which the profitability and break-even is calculated, whereas business models incorporate the organisational aspects; In this case, pivotal institutional considerations necessary to develop transport and storage infrastructure and operate it, which are discussed below.

[217] Natalia Romasheva and Alina Ilinova - "CCS Projects: How Regulatory Framework Influences Their Deployment"; Norwegian Ministry of Petroleum and Energy, Longship – Carbon capture and storage

5.5.1 Case studies from Norway, UK and the NL

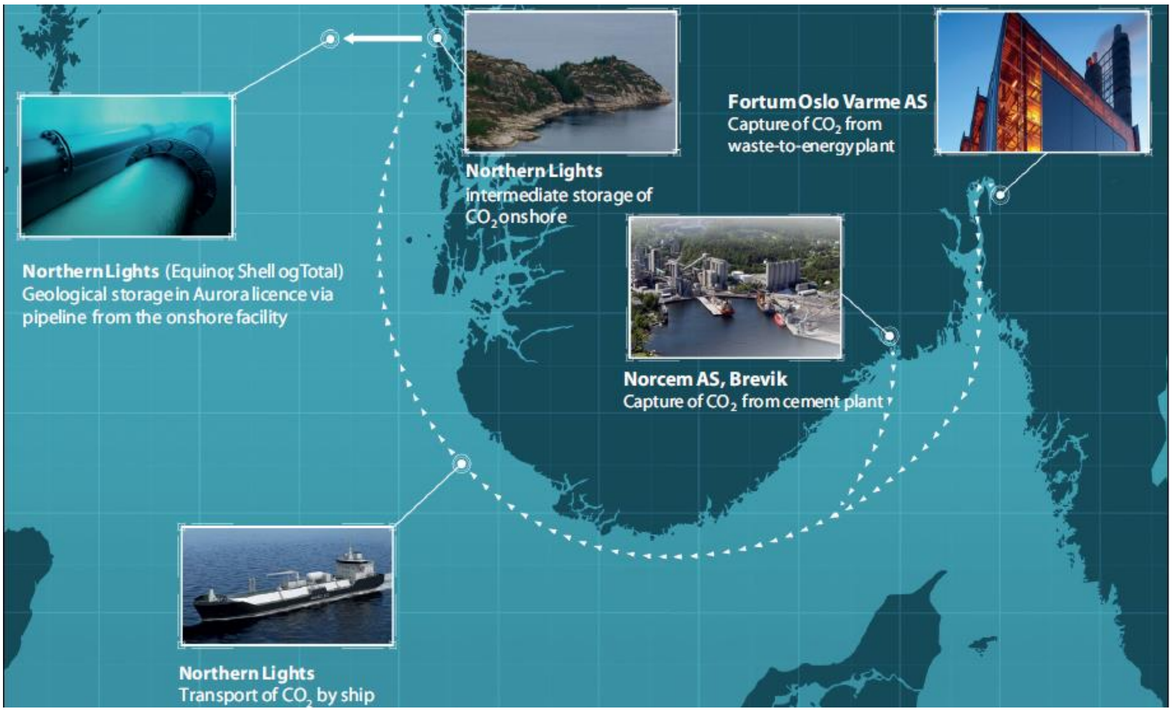
5.5.1.1 Norway: The Longship carbon capture and storage project

The Norwegian Government proposed to the Norwegian Parliament that funding be provided to establish a full-scale CCS project named "Longship". The objective of the Longship project is to demonstrate that CCS is feasible and secure and to facilitate learning and cost reductions in subsequent projects. Further, according to the white paper to the Norwegian Parliament from the Norwegian Ministry of Petroleum and Energy, *"Infrastructure will be developed with additional capacity that other projects can utilise. Hence, the threshold for establishing new carbon capture projects will be lowered. Longship can also facilitate business development through harnessing, transforming, and developing new industries in Norway"*[218].

The Longship project set-up was based on a pre-feasibility study conducted by Gassnova in 2015, which recommended that a transport and storage actor was needed to provide services to other industry actors who did not possess expertise in CO2 transport and storage. Further, the study suggested dividing the value chain into parts where each actor has responsibility for the undertaking within their activities. Meanwhile, the state would minimise the risk of these actors by acting as the intermediary between the interfaces of the value chain parts, which requires the state to ensure the value chain functions throughout the design phase to the realisation and operational phases, concerning the interfaces, schedules and operational risks.

The Longship project's key operating parties are shown in the picture below. They include the Northern Lights Consortium, which is a collaboration between Equinor, Norske Shell and Total E&P who has the role of intermediate storage onshore, transport and geological storage. Equinor has the lead responsibility of CCS studies performed by the Northern Lights. The Longship project also includes industry companies capturing CO2 at their plants, hereunder, the cement company Norcem AS (part of the HeidelbergCement Group) as well as the waste-to-energy incineration plant Fortum Oslo Varme AS**.**

Figure 14: Overview of Longship project

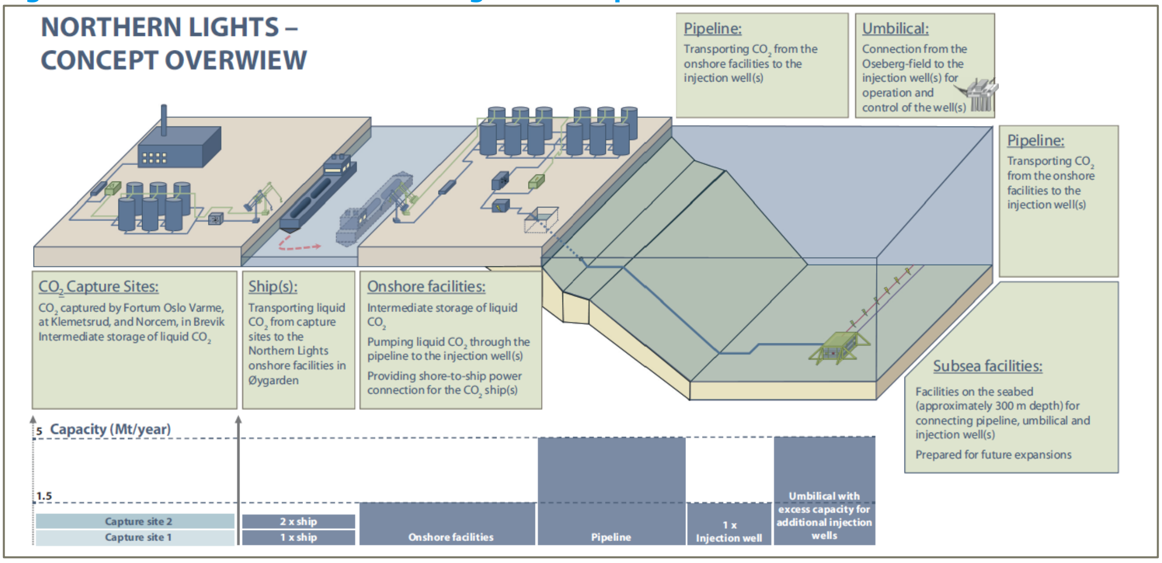


Source: Norwegian Ministry of Petroleum and Energy, Longship – Carbon capture and storage

The Northern Lights Consortium's concept is shown in the below picture and is an integrated part of the Longship project.

[218] Norwegian Ministry of Petroleum and Energy, Longship – Carbon capture and storage, p. 7

Figure 15: Overview of Northern Lights concept



Source: Norwegian Ministry of Petroleum and Energy, Longship – Carbon capture and storage

In addition to the key stakeholders involved in the operation of the Longship CCS project, the institutional set-up of the project importantly also includes the Norwegian Government, the Norwegian state and Gassnova, who is the state enterprise for CCS made up of members from Gassnova and the Norwegian Ministry of Energy and Petroleum. The role of all the parties in the institutional setup is described below.

- The Norwegian Government brought forth to the Norwegian Parliament that funding should be allocated for the implementation of the Longship project. The Government continues to foster international cooperation on technology development and emission reduction, which are key to Longship. They also have the role to follow up on the Longship project and the benefit realisation work in close collaboration with the industrial companies and share the learnings of CCS in Europe and the world.
- The Norwegian state acts as the intermediary between Norcem, Fortum Oslo Varme (if applicable) and Northern Lights. The state carries risks related to the interfaces between the different parts of the project, as well as the risk associated with project scheduling and costs. The state will need to balance the risks with the costs since costs will need to be kept at a minimum to demonstrate the project feasibility and a successful effect of the project. The state is expected to cover about two thirds (NOK 16.8 billion of 25.1 billion) of the project costs. However, the state's eventual costs will depend on the actual costs of the project. The costs are high, and the state carries risk through funding agreements with the industrial companies. The state will not engage in negotiations of state aid with individual stakeholders. Uncertainty also prevails beyond the state's control that affects the project success, such as other countries' climate policy development and the number of subsequent projects implemented
- Gassnova leads the overall planning of Longship; Follows up on the actors' project management through agreed reporting on behalf of the state, and manages the study contracts with the industry partners. Gassnova evaluated the FEED studies and subsequently provided project recommendations to the Government[219]. Gassnova also coordinates the work on benefit realisation and facilitates the sharing of relevant experience with other projects and stakeholders to ensure the overall project goals are met.
- Equinor – the majority of which is state-owned –formed a consortium with Norske Shell and Total E&P, named Northern Lights**.** Equinor also has the lead responsibility of carrying studies of CO2 transport in connection to the Longship project. They are jointly responsible for the CO2 transport and storage part of the project. Knowledge and

[219] In the Fall of 2016, Gassnova announced two competitions for state aid to carry out concept selection and front-end engineering design (FEED) studies; one for CO2 capture on industrial sites and one for geological storage of CO2. After the studies were completed the Storting pledged funding to initiate the FEED studies at Norcem and Fortum Oslo Varme.

experience from the Petroleum industry have been and are vital to the CCS development in Norway. The companies will own and develop the project, which comprises shuttle tankers for transport of liquid CO2, a reception terminal in Øygarden municipality located in Vestland county on the south-west coast of Norway, and pipeline to a well where CO2 will be injected into a storage formation beneath the seabed. The state aid agreement for the transport and storage part of the project has been designed to regulate the cost and the risk distribution of the project, including incentives to keep costs low and bring in new projects. All of the Northern Lights' revenues will stem from CO2 storage from recent projects. Thus, Northern Lights has a solid incentive to develop the market for CO2 storage. Further, the Ministry of Petroleum and Energy considers it pivotal that Northern Lights' capacity is utilised by industry actors not financed directly by the Norwegian state. The success of this will provide evident proof that the project has the desired effect. Northern Lights has also contributed to the benefit realisation work during the FEED phase. Northern Lights comprises a two-phase development plan: The first phase includes an estimated capacity of 1.5 MtCO2/y (completed mid-2024) over 25 years. A subsequent and potential second phase is estimated with a capacity of 5 MtCO2/y.

- Norcem is a Norwegian cement manufacturer part of the Heidelberg Cement Group, where carbon capture from its activities at its factory in Brevik is performed. The company conducted FEED studies and has also verified their selected carbon capture technologies, optimised integration, prepared contracts with key suppliers and prepared benefit realisation plans. The Norcem capture development has a large state grant (NOK 3.8 billion)
- Fortum Oslo Varme is a waste incineration plant, and carbon capture from its activities at the waste incineration facility at Klemetsrud, Oslo is performed. The company conducted FEED studies and has also verified their selected carbon capture technologies, optimised integration, prepared contracts with key suppliers and prepared benefit realisation plans. However, the Ministry of Petroleum and Energy ranks Norcem significantly higher than Fortum Oslo Varme since the state's costs and risks are lower for Norcem's project than Fortum Oslo Varme's project. The state aid is limited to NOK 2 billion in investments and NOK 1 billion in operating expenses and the rest of the costs Fortum will need to apply for external funding. Thus, the Fortum Oslo Varme project is dependent on external funding for it to become operational and has therefore applied for a large grant via the EU innovation fund

The Longship project highlights the importance of state involvement to a large extent, since not only is the state itself involved combined with Government support, but Gassnova and Equinor are both state-owned organisations. Gassnova ensures that the state's interests are incorporated throughout the project, whereas any substantial revenue gains made by Equinor is state-owned and thus also controlled.

5.5.1.2 UK: CCUS developments and the Government's CCS business model propositions

The UK Government has recently funded three large developments that will jointly deliver CCUS applications to approximately 50% of the industrial emissions generated in the UK: Teesside (NZT) and Humber projects (ZCH) which will be connected by the Northern Endurance Partnership (NEP).[220]These developments are a consequence of the UK's Ten Point Plan, which outlines the need and ambition to develop a CCUS industry.[221]

The below picture shows the connection between the three developments in the UK.

[220] Business Live – "Huge North Sea carbon storage solution backed alongside the regional projects set to feed it"

[221] HM Government – "The Ten Point Plan for a Green Industrial Revolution"

Figure 16: Overview of the three large development projects delivering CCUS solutions in the UK

Source: Oil and gas climate initiative

The NZT is a full chain CCUS project led by oil and gas majors **B**P, Eni, Equinor, Shell, and Total, with BP as the main operator. From 2025, the project aims to capture up to 10 mtCO2 emissions per year.

The ZCH is a partnership that will build a net-zero industrial cluster and has the ambition to decarbonise the North of England, including solutions such as low carbon hydrogen production, CCUS and shared onshore and offshore infrastructure and greenhouse gas removal technology. It comprises 12 formal partners**:**

- Associated British Ports (UK's leading port operator),
- British Steel (steel producer),
- Centrica Storage (Gas facilities),
- Drax (UK's third-largest electricity generator),
- Equinor (Oil and gas),
- Mitsubishi power (power generation equipment),
- National Grid Ventures (developing and operating energy infrastructure),
- PX Group (manages, operates, and maintains industrial facilities),
- SSE Thermal (developer, owner and operator of electricity generation and energy storage assets),
- Triton Power (power generation),
- Uniper (energy company) and
- The University of Sheffield AMRC (network of world-leading research and innovation centres working with manufacturing companies)

By 2026, ZCH expects to capture at least 17 MtCO2/y from projects across the Humber 2035.

The NEP will develop the offshore infrastructure to transport and store millions of tonnes of CO2 in the UK North Sea. BP, Eni, Equinor, National Grid, Shell and Total formed the NEP Partnership, with BP as the operator.

All three developments have secured funding from the Industrial Strategy Challenge Fund, which the UK Government sets up to address the most significant industrial and societal challenges using research and development based in the UK. Jointly the three developments have received GBP 229 million in public and private funding. Thus, as was the case with the Norwegian Longship project state funding, is once again proven to be key to mobilise CCUS projects and further unlock private investments.

Further, the UK Government has published a whitepaper on potential business models for CCUS in which the Government indicates which ones they find most promising:

- CO2 transport and storage: a regulated T&S network where financing follows a RAB business model[222], in which there is an economic and market regulator, and the risks are allocated to those who are best able to manage them.
- Power CCUS: a payment model with payment availability of low carbon generation capacity (providing a known return of investment payment for investors)[223], and a variable payment (to account for a power CCUS plant's added costs, relative to those of an equivalent unabated plant). This payment combination could allow a plant to operate flexibly, provide value to a low carbon electricity system with increasing renewable capacity, and yet provide certainty to investors.
- Industrial CCUS: a hybrid model comprising three phases. Phase one entails an industrial contract for difference (CfD) with upfront capital support to assist with revenue support for a set duration, and CfD payments would cover the operating cost of capture, recovery of the CAPEX investment made by the owner of the plant, and costs for accessing the CO2 T&S infrastructure. Phase two entails a transition to competitively allocated CfD after the risks and costs are reduced in phase one, whilst upfront investment funding from the Government is phased out. Phase 3 is a market-based approach, where CCUS is sustained by the CO2 price alone, based on the assumption that as the market matures, costs of CCUS technologies will come down, and pass-through costs will increase with a more developed market for low-carbon industrial products along with policies allowing efficient competition.

Together with the CCS Infrastructure Fund, the business models shall incentivise decarbonisation and cost reductions while minimising the risk of market distortions. The Government recognises the inherent market failures and emphasises the need for their involvement, primarily to support the value chain interfaces and fund the initial clusters to help unlock capital investments. However, it is important the financing model reflects the large upfront capital investments and that the operational costs are expected to be lower, and thus supports investment and returns across the asset's lifetime.

The UK Government's preferred model for CO2 transport and storage is further elaborated upon below to highlight the importance of state involvement both in terms of funding but also in terms of financial regulatory oversight and the need for risk allocation in order for the CCS market to function efficiently. The CO2 transport and storage model shall incorporate the following pivotal aspects:

- The Government supports and incentivises the investment in CO2 infrastructure, especially for the first developments
- CO2 transport and storage regulated by an independent body to oversee the industry and deploy Government policies to address natural monopolies issues linked to regional T&S networks
- Finance and funding through a RAB model[222] consisting of regulated revenue streams determined by a building block approach (representing a category of costs incurred by the project company, which are scrutinised by the economic regulator to ensure costs are efficient) paid by the users of the T&S network determined by an economic regulator to mimic the incentives similar in a competitive market. The economic regulator and market regulator would oversee the interface of capture plants to the T&S network, similar to the Oil & Gas Authority's role in awarding CO2 storage licenses offshore. This role could be performed by a single entity
- T&S risk shall be allocated to the party that is best able to manage them, however, no risk model has been developed. The Government will work with the CCUS T&S Expert Group to develop an understanding of the risks[224]

[222] RAB is short for Regulated Asset Base: "The T&S company would receive a licence from an economic regulator, which grants it the right to charge a regulated price to users in exchange for delivering and operating the T&S network. To prevent monopolistic disadvantages, the charge is set by an independent regulator who considers allowable expenses, over a set period of time, to ensure costs are necessary and reasonable. Model variants could include the provision of financial support to decrease the upfront capital expenditure.", p 21. Source: UK, Department for Business, Energy & Industrial Strategy – "A Government Response on potential business models for Carbon Capture, Usage and Storage"

[223] The availability payment could be a stable ongoing payment from a counterparty to the generator. This could be paid based on the availability of low carbon generation plant, could be set relative to the cost of the generation and capture plant, taking into account capture rate availability, and could be indexed to inflation.

[224] UK, Department for Business, Energy & Industrial Strategy – "A Government Response on potential business models for Carbon Capture, Usage and Storage"

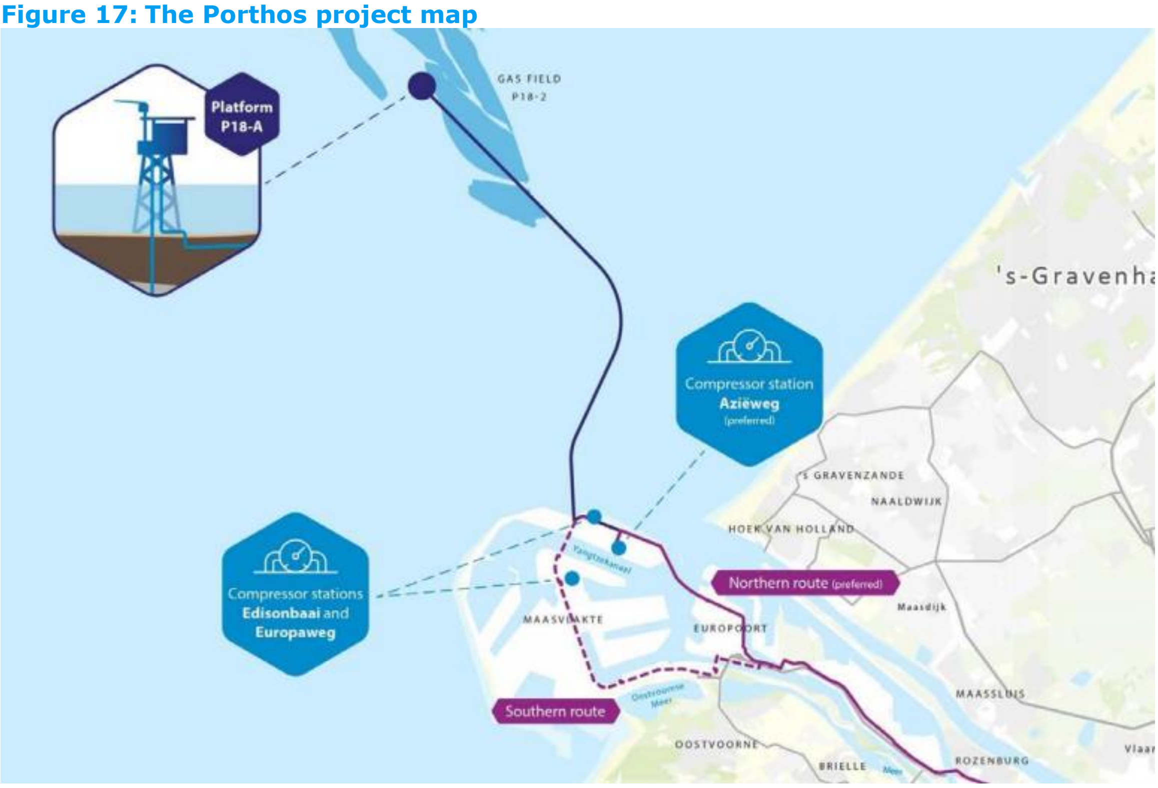
The UK Government's whitepaper on CCUS business models illustrates not only the need for state funding. Still, it emphasises the need for the Government to propose and establish business models and act as the intermediary as with the Longship case.

5.5.1.3 The Netherlands: The Porthos project

Porthos[225] CCS project is developed in the Netherlands to transport CO2 from industrial activities in the Port of Rotterdam and store the emissions in empty gas fields (P18-2, P18-4 and P18-6) below the North Sea. Over 15% of the Netherland's CO2 emissions are emitted in the Rotterdam Port area. Various industry companies will capture the CO2, and they will supply it to an existing pipeline that runs through the Rotterdam port area and is approximately 30 km. The CO2 will then be transported through a 19 km-long offshore pipeline to a platform laid beneath the North Sea, approximately 20-25 km off the coast. The project infrastructure is proposed to be developed as "open access" to capture, transport and store CO2 from industry companies in the Port of Rotterdam, such as refineries, chemical producers, and hydrogen plants. Companies will be subject to pay a fee for having their carbon emissions transported and stored by the Porthos. It is expected that the project will be operational from 2024, and during the first years, it is estimated that 2.5 MtCO2 can be stored per year[226].

The Porthos project is mapped below.

Figure 17: The Porthos project map



Source: Porthos CO2 transport and storage website

The key stakeholders in the project are the following three main parties:

- The joint venture amongst the Port of Rotterdam Authority, Gasunie and EBN, who are all state-owned and will be responsible for the transport and storage of CO2. The Port of Rotterdam Authority contributes to the project with its experience and expertise in the local situation and market, Gasuine has experience and knowledge within gas infrastructure and transport, and EBN contributes with its expertise within offshore infrastructure and has expertise within the field of deeper soil layers
- parties contribute the following
- The Dutch government who provides funding and mandate

[225] Porthos stands for Port of Rotterdam CO_2 Transport Hub and Offshore Storage.

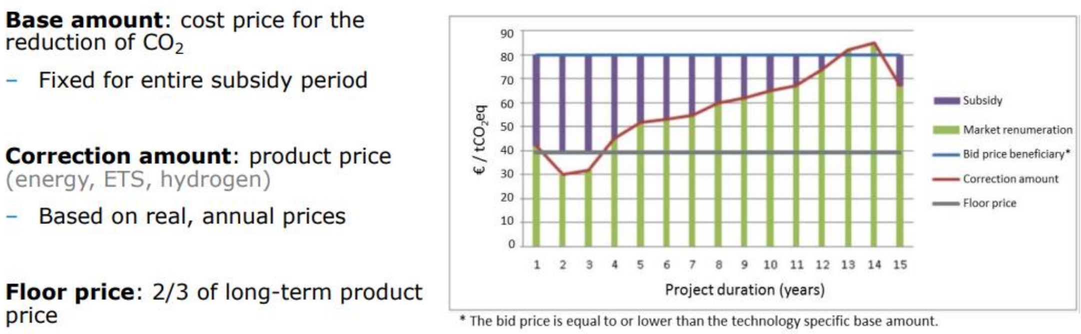
[226] Porthos CO2 transport and storage website

- Private companies that will supply CO2 invest in carbon capture and pay for storage.:

The joint venture wanted to build the infrastructure, and to build it, they needed private companies to commit as clients, however, while the clients also wanted the infrastructure, they needed funding for capture infrastructure and storage fees. Meanwhile, the Dutch Government wanted to ensure the infrastructure before providing funding to the private companies[227]. The solution to this was to establish agreements with both the Government and companies supplying CO2. Thus, so-called Joint Development Agreements (JDAs) has been signed between Porthos and four companies: Air Liquide, Air Products, ExxonMobil and Shell, although the agreements are not binding. The JDAs underlie that Porthos and the companies collectively work towards definite transport and storage contracts[228].

An important development to enable these companies and others to make investments within decarbonisation has been the Dutch sustainable energy transition subsidy scheme (SDE++), which was updated in 2020 from SDE+ to SDE++ to broaden the scope and provide funding for CCS projects and other decarbonisation technologies. In 2021, the four private companies: Air Liquide, Air Products, ExxonMobil and Shell, applied for EUR 2 billion from SDE++, which is expected to be granted in the spring of 2022.[229] The SDE++ also provides funding for transport and storage infrastructure. The subsidy scheme builds on a CO2 premium, which is based on the cost (CAPEX and OPEX over a 15-year period) and revenues, as per the existent ETS scheme. The SDE++ only provides a subsidy for the profitable part of the project (see the illustrative graph of this), and the subsidy is adjusted on a yearly basis based on the ETS price. Since CCS is viewed as a relatively complex technology, the subsidy rounds are conducted on an open book basis. Receivers of the subsidy must report the costs incurred to avoid over subsidy. They are also subject to completing feasibility studies, and the projects must be realised within a 5-year period. The SDE++ funds the most competitive technologies, and the estimated costs of applications are calculated by the Dutch Environment Agency, which provides a maximum subsidy. For CCS, the maximum is EUR 62 per tCO2, but it can exceed EUR 100 per tCO2 depending on the project (e.g., considering capture methods for hydrogen production in terms of methane).[230]

Figure 18: The SDE++ provides subsidy only for the profitable part of the project



Source: Porthos CO2 transport and storage website

Funding for Porthos has also been collected from several other sources; for the feasibility studies, Porthos was granted EUR 1.2 million from RVO (Netherlands Enterprise Agency) in 2018 and EUR 6.5 million from the European Commission in 2019, as well as a subsidy of EUR 102 million from Brussels for the construction of the infrastructure in 2021. In 2020, Porthos was deemed a "Project of Common Interest (PCI)" by the EU, which are cross border infrastructure projects deemed pivotal and they link energy systems of EU countries.

The final investment decision is expected in 2022. It is dependent on technical development infrastructure, Environmental Impact Assessment and permits, the securing of agreements with

[227] The Dutch Ministry of Economic Affairs & Climate Policy: Clean Energy Solutions Center – "Carbon Capture, Utilization and Storage in The Netherlands (Webinar)"

[228] Porthos CO2 transport and storage website

[229] Offshore Energy website –" Porthos CCS project: Industry targets €2 billion in Dutch subsidies"

[230] The Dutch Ministry of Economic Affairs & Climate Policy: Clean Energy Solutions Center – "Carbon Capture, Utilization and Storage in The Netherlands (Webinar)"

companies to supply CO2, as well as the Dutch government's continued support to enable CCUS. After the final investment decision, the construction of the project can be initiated.[226]

The Porthos case outlines once again strong representation from state-owned entities, Government intervention, especially to get the project started and to incentivise and enable the private companies to commit to CCS ventures. Further, this case also importantly portrays European funding to support site preparations.

5.5.2 Lessons learnt

There are three main takeaways from the cases presented above regarding institutional set-ups:

1. The necessity of state involvement in terms of funding (upfront capital expenditure), risk management and supporting the initiatives
2. The need for a body that acts on behalf of the state and administers and maintains the strategic overview of the project progress and follow-up
3. The need for parties who possess operational and technical expertise

All three country cases highlight the importance of state involvement since other actors do not have the capacity or economic incentive at present to drive the development for CCS on their own. Thus, there is most likely a need for state-aid and state involvement in Denmark as well, and the Danish Government will probably need to take a supportive role in the CCS initiative.

Further, the cases illustrate the need for an organisation to take the overall lead and oversight role; One that will act on behalf of the state to ensure the project is progressing accordingly and that the incentive structures that are in place are working efficiently to demonstrate market-based success, e.g., in the Longship case this role is held by Gassnova. To this, a possible existent candidate could be the Danish North Sea Fund ("Nordsøfonden"), Energinet or its subsidiary Gas storage Denmark to take on this lead administrative and oversight role of CCS in a Danish context. Another candidate to take on this role is the Danish Energy Agency. Alternatively, a new entity might need to be established. It is also important to consider that the candidate covering this role has the necessary expertise in the varying set-ups between onshore, nearshore, offshore or a combination of these.

Additionally, an entity or a group of entities representing the state to some extent in the operational role of CO2 transport and storage has also been identified in all cases. In Longship, Equinor (state-owned) has the lead role of operating and overseeing the transportation and storage of CO2, whereas, in Porthos, this role is held by three companies in a joint venture who are all state-owned. Similarly, the regulated T&S network business model that the UK Government is favouring is also comprising a state-economic regulatory body that can oversee transport and storage interfaces of CO2. In Denmark, there is a limited number of companies that are state-owned and would be suitable for this role. However, one candidate could be Energinet or its subsidiary Gas storage Denmark might be candidates to take this responsibility. However, these entities do not encompass offshore geological knowledge, so they would be more suitable in a business model set-up comprising an onshore and possibly nearshore solution. In an offshore set-up, this transport and storage operating role could also be a constellation comprising oil and gas companies (e.g., Ineos, Total) underlying a model where there is a competition to ensure costs are kept efficient, and revenues are allocated.

The cases also portray the importance of involving parties with technical knowledge about geological storage, capture technology etc. Additionally, as EBN in the Porthos case possesses knowledge about deeper soil levels, it can be necessary to involve this type of organisation in the institutional set-up in Denmark (e.g. GEUS that has geological expertise).

It is essential to consider an appropriate institutional setup to incentivise the deployment of CCS projects and to plan a constellation of value chain partners who can work seamlessly between the interfaces of the value chain segments. It is also pivotal to tailor the institutional set-up so it fits the chosen project location and infrastructure set-up (e.g., offshore, onshore, nearshore or a hybrid of these) since the entities will need to possess expertise suitable to this.

6. PROFITABILITY ASSESSMENT OF CO2 STORAGE IN DENMARK

6.1 INTRODUCTION TO BUSINESS CASES

The business cases in this chapter are developed to assess the return on investment of different feasible set-ups for the transport and storage of CO2 in Denmark. An important distinction is made between the business case set-ups and the business models. Business case set-ups bring forth the most relevant market-based cases for which the profitability and break-even are calculated, whereas business models incorporate the organisational aspects; In this case, pivotal institutional considerations necessary to develop CCS infrastructure and operate it. This chapter outlines the selected business case set-ups.

Box 6 – A note on the business cases' profitability and underlying revenue

It is important to clearly state that all business cases assume state-aid in order to become profitable. The reference price applied underlies state-aid, i.e. the price will be a combination of e.g., CO2 prices, CO2 taxes, grants etc. Without these support mechanisms the CCS business cases will neither result in the net present values (NPV) nor the payback periods presented.

It is difficult to estimate a precise price for CO2 transport and storage since the market is immature and there exists no defined market price at present. CO2 prices and subsidies are potential ways to construct the price, however, it is highly uncertain to what extent, who and how these will be allocated in the future (e.g., income from CO2 pricing will also cover other technologies than CCS). Thus, we have instead developed an alternative reference price, which is based on a feasible competing set-up in the countries that are the main competitors to Denmark: UK and Norway.

Based on the assessment of Denmark's competitive traits in section 1 three overarching business cases are presented:

Case 1): Small-scale - Denmark to become a domestic CO2 storage provider purely with sea transportation only

This case is purely focused on the national market of CO2 transport and storage. Denmark will store 5 MtCO2 from domestically sourced CO2 volumes at an offshore storage site in the Northern fields, to which 3 Mt will be shipped with vessels from Copenhagen and 2 Mt from Aalborg. In practice, CO2 can be picked up by vessels from any location, also from abroad and also depending on market supply. However, this case assumed only Danish CO2 for the business case calculations.

This case is appropriate if the intention is to have more flexibility and establish a starting point for CO2 transport and storage in Denmark. This case can offer more flexibility in that it provides a platform to get started with CO2 transport and storage while it does not necessarily limit the option to expand the infrastructure later. However, it could limit Denmark's unique opportunity to offer CO2 storage internationally and take on a leading CO2 storage provider role, which might be difficult to claim later when competing countries have developed their infrastructure. Moreover, since this case takes a point of departure in vessel transport as well as offshore storage, it is the most expensive case in terms of cost per ton of CO2 (particularly demonstrated by the need for higher operational expenditures due to a higher number of wellhead platforms, standby vessels as well as mooring and loading systems required).

Note that small-scale cases could also be developed for onshore and nearshore storage, and these solutions could potentially have similar advantages and lower costs than the offshore solution in case 1. However, the scope of this report only comprises the offshore storage for the small-scale solution.

Case 2): Medium-scale - Denmark to become a domestic CO2 storage provider primarily while serving the international market to some extent

In this case, Denmark is storing CO2 for 10 MtCO2/y and will still focus primarily on storing domestic CO2 volumes; 5 MtCO2/y will be reserved for Danish CO2 volumes (3 MtCO2/y from Copenhagen and 2 MtCO2/y from Aalborg), while also providing 5 Mt storage capacity for CO2 volumes coming from Germany, Sweden, Finland, Poland and/or the Netherlands. As such, the primary focus will be to serve the national market while also entering the international market at some scale.

This provides a starting point for becoming an internationally claimed player within CO2 transport and storage in Northern Europe. This case is suitable if the intention is to enter the international market from the beginning and take on less risk and limit the up-front capital investments than comparing to case 3 (large-scale international CCS solution). All of the options, in this case, have a lower cost per ton of CO2 than case 1 while being higher than case 3. Further, the options, in this case, provides the opportunity to expand the CO2 transport and storage later. However, as with case 1, these options limit Denmark's possibilities to offer CO2 storage internationally on a large scale and take on a leading CO2 storage provider role, which might be challenging to claim later when competing countries have developed their infrastructure. Additionally, while the solutions in case 2 require less complexity and investments in CCS infrastructure than case 3, they will also result in a smaller number of market players. Thus, there is less competition and potential for the case to become more market-oriented.

There are three different storage placement options for this case:

2A) Onshore CO2 storage,
2B) Nearshore CO2 storage, and
2C) Offshore CO2 storage

The onshore CO2 storage scenario includes a planned 10 MtCO2/y storage in Havnsø with a pipeline from Copenhagen to Kalundborg and shuttle tanker transport to Havnsø harbour from international countries. As previously demonstrated, the onshore possibility is the most affordable option, and thus, Denmark can provide a cost-effective solution for potential export countries. However, there might be some public opposition since there are housing areas onshore (and the general opposition against onshore storage observed in some other countries).

The nearshore option includes a planned 10 MtCO2/y storage in Hanstholm about 50 km from shore, a pipeline from Copenhagen to Hanstholm (partly onshore and partly offshore, via Fredericia), one onshore pipeline from Aalborg to Hanstholm and one shorter, offshore pipeline from Hanstholm port to the storage site. Furthermore, shuttle tanker transport is assumed to Hanstholm harbour from international countries. This scenario is more expensive than the onshore scenario yet less expensive than the offshore scenario.

The offshore scenario includes a CO2 storage site in the North Sea fields with a planned capacity of 10 MtCO2/y, a pipeline from Copenhagen to Esbjerg (partly onshore and partly offshore, via Fredericia), as well as shuttle tanker transport to Esbjerg harbour from international countries. CO2 is then transported from Esbjerg to the offshore site via an offshore pipeline (the case assumes reuse of the existing gas pipeline). This scenario is more expensive than 2A and 2B. Furthermore, for many of the source countries, the distance to this storage by ship is not significantly different from the offshore storage possibilities that UK or Norway is providing. Thus, there will be a potentially lower incentive for export countries to opt for storing their CO2 in Danish offshore storage comparing to Norwegian storages or even CO2 storages provided by the UK, compared to the onshore and nearshore solutions.

Case 3): Large-scale - Denmark to become an established large-scale international CO2 storage provider while serving the domestic market simultaneously

In this case, Denmark is a large-scale CO2 storage provider for international markets. Denmark has a competitive advantage in terms of its location, as Denmark is strategically located in close proximity to Germany – the largest CO2 emitter in Europe and Sweden, Finland, Poland, and The Netherlands. Denmark can provide an attractive and cost-effective pipeline solution for German CO2 volumes, a pipeline spanning from Northern Germany to Esbjerg serving 20 MtCO2/y. In total, Denmark will store 40 MtCO2/y; 20 MtCO2/y from Germany; 15 MtCO2/y in total from Sweden, Finland and Poland, as well as 5 MtCO2/y domestically from Denmark. In this case, the Netherlands is not accounted for since the case will mainly focus on serving pipeline and shipping solutions for Germany and the countries located East of Denmark. However, this option does not exclude any potential CO2 volumes coming from the Netherlands, e.g. by ships, and these volumes would be considered as an additional upside.

This case includes storages in Havnsø (10 MtCO2/y), Hanstholm (10 MtCO2/y) and two offshore storages in the Northern fields (20 MtCO2/y in total). It would also include a pipeline from

Copenhagen to Esbjerg (partly onshore and partly offshore, via Fredericia), Hamburg to Esbjerg, Esbjerg to Hanstholm, and from Hanstholm to Aalborg, one shorter offshore pipeline from Hanstholm port to the Hanstholm site and two offshore pipelines from Esbjerg to the offshore sites (the case assumes reuse of the existing gas pipeline in one case).

The advantage of this case is that Denmark will take on a leading CO2 storage provider role in Europe by providing a unique CCS solution, which the other countries do not have the capacity or possibility to offer. It will also commit Germany to store its CO2 volumes in Denmark through a convenient and cost-efficient pipeline solution. Further, Denmark will make it favourable for Sweden and Finland to store their CO2 in Denmark – by providing a pipeline connection from Kalundborg to a mix of onshore, nearshore and offshore CO2 storage sites. This would make it considerably more convenient for these countries to store CO2 in Denmark instead of shipping it to the UK or Norway.

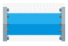
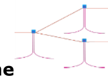
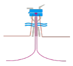
This case will also entail that various public and private bodies are involved and are responsible for different parts of the value chain. Since there are so many transport infrastructures laid out, it might involve more competition between players, and as such, CCS might become more market-oriented.

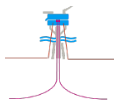
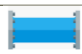
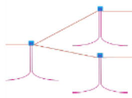
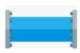
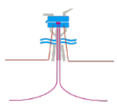
The potential disadvantages are that this solution will require extensive state involvement and investments in widespread CCS infrastructure. It will also require the EU to cooperate to support and pass policies that will aid the CCS market.

6.2 OVERVIEW OF ANALYSED BUSINESS MODELS

The scope of the business cases comprises the nationally focused business case 1 and the overarching nationally and partly internationally focused business cases 2A, 2B, 2C and the internationally-focused business case 3:

Table 46: Overview of business cases 1, 2A, 2B, 2C and 3

 **Shuttle tanker**  **Port**  **Pipeline**  **Well pad**  **Well head platform**  **Vessel**

Case	Storage type	Potential site name (and capacity)	Assumed max. injection capacity/ year	CO2 Transport from source	Intermediate storage and preparation facilities	Transport from intermediate storage to well	Injection site
1	**Offshore**	Depleted oil and gas field in the North Sea (estimated ~2,000 Mt)	**10 MtCO2**				
2A	**Onshore**	Havnsø (927 Mt)	**10 MtCO2**	  From DK/CPH			
2B	**Nearshore**	Hanstholm (2,753 Mt)	**10 MtCO2**	  From DK/CPH			
2C	**Offshore**	Depleted oil and gas field in the North	**10 MtCO2**				

		Sea (estimated ~2,000 Mt)		From DK/CPH			
3	**Onshore**	Havnsø (927 Mt)	**10 MtCO2**	From DK/CPH	(Kalundborg)		
	Offshore	Depleted oil and gas field in the North Sea (estimated ~2,000 Mt)	**10 MtCO2**	From DK/ Kalundborg From DE/ Hamburg	(Esbjerg)		
	Nearshore	Hanstholm (2,753 Mt)	**10 MtCO2**	From DK/Esbjerg	(Hanstholm)		
	Onshore	Gassum (630 Mt)	**5 MtCO2**	From DK/Esbjerg	(Aalborg)		

Note: Shuttle tankers are considered pure transport vehicles, meaning they do not have cooling equipment and storage preparation equipment needed to connect directly to an injection site. As a result, shuttle tankers need to unload CO2 into intermediate storage near refrigeration and storage preparation equipment before it can be transferred to an injection site; Vessels can be used for transport and carry cooling and storage preparation equipment. This means they can connect directly to injection sites; Permanently moored FSU stations are considered stationary and cannot be moved. Shuttle tankers will transport CO2 to the station, which will prepare the CO2 for storage before sending it to the injection site;
Source: Ramboll analysis

Box 7 – A note on specific storage locations

All storage and transport set-ups presented in this chapter are potential illustrative scenarios only. This also pertains to the suggested storage and pipeline locations as well as the shipping routes. Thus, the business cases are not to be regarded as definitive rather as potential suggestions for feasible scenarios.

6.3 BUSINESS CASE ASSUMPTIONS

The below table summarises the assumptions applied in all four business cases. It is important to note that all individual costs inputs, i.e. transportation and storage costs presented in this chapter and utilised in the business cases, are not levelized costs.

Table 47: Input assumptions[231]

Data input	Description	Assumptions comments
Alternative reference price	Revenue	It is difficult to estimate a precise price for CO2 transport and storage since the market is immature, and there exists no defined market price at present. CO2 prices and subsidies are potential ways to construct the price, however, it is highly uncertain to what extent, who and how these will be allocated in the future (e.g. income from CO2 pricing will also cover other technologies than CCS). Thus, we have instead developed an alternative reference price based on a feasible competing set-up in the countries that are the main competitors to Denmark: UK and Norway. Nevertheless, the alternative reference price underlies state-aid, e.g., CO2 prices, CO2-taxes, grants etc., the constellation of them is not known in developing the alternative reference price. Both UK and Norway are developing CCS offshore storage sites solely, so a reference price reflecting this type of storage is appropriate. Further, applying a transport cost for a shipping distance to a location in these countries would also reflect a ballpark estimate of the transportation costs. The below explains the price in more detail.

[231] Ramboll experts

		The reference price used in this case has been based on the average cost of the Danish offshore storage site since the competing alternatives in both the UK and Norway are offshore options and, thus, considered direct competitors and alternatives to the Danish storages. Further, Edinburgh (Scotland) has been chosen as a reference storage location since it is considered a feasible direct alternative for countries exporting CO2 in Europe. Thus, the reference price also includes the shipping cost of transporting CO2 from the emitting countries (Germany, Sweden, Finland, Poland, Denmark and the Netherlands) to Edinburgh; The distances and volumes from each country are adjusted accordingly, and a weighted average of these is calculated. The price has also been discounted according to the 30-year technical lifetime. The price estimate applied is subject to uncertainty, as the CCS market is in its early stages, and the cost of CCS infrastructure is subject to technology developments and a learning curve. However, the chosen methodology is deemed most reliable for the reasons stated above, compared to alternative methods.
CO2 volume	Revenue	The volumes for each business case are based on the expected volumes coming from both domestic CO2 streams and international CO2 streams in each business case. Case 1 assumes 5 MtCO2/y, and cases 2A, 2B and 2C, as demonstrated previously, all assume 10 MtCO2/y, whereas case 3 assumes 40 MtCO2/y.
Storage	CAPEX	Storage CAPEX is based on 5 MtCO2/y for case 1, while this is 10 MtCO2/y capacity for business cases 2A, 2B and 2C. For business case 3, this is assumed to be 40 MtCO2/y, in which costs for business model set-up 2, 4 and 5 have been combined. The storage CAPEX comprises storage pre-FID costs (final investment decision), Storage instalment costs[232] and in the final year of the storage plant's lifetime (year 30), storage abandonment costs (ABEX) and storage post-closure costs are applied. ABEX is assumed to be 17.5% of total storage instalment costs.
	OPEX	The operational expenditures for case 1 storage comprise the base organisation, injection plant, injection wells, monitoring, power, wellhead platform, standby vessel as well as mooring and loading system for storage capacity of 5 Mt. Business case 2A has the same OPEX storage costs as set-up 2 for 10 Mt storage capacity (see chapter 5); Base organisation, intermediate storage, injection plant, injection wells as well as monitoring and power. Business case 2B has similar OPEX storage costs as set-up 4; Base organisation, intermediate storage, injection plant, injection wells, monitoring, power and wellhead platform. While business case 2C has the same OPEX storage as set-up 8; Base organisation, intermediate storage, injection plant, injection wells, monitoring, power and wellhead platform. Business case 3 storage OPEX is calculated based on costs combined from set-up 2 (one for storage capacity of 5 Mt and one for storage capacity of 10 Mt), set-up 4 and set-up 5.
Pipeline	CAPEX	Pipeline CAPEX comprises the cost of constructing pipelines and the number of pumping stations needed to transport the CO2 volumes. Pipeline cost varies depending on the length and rated capacity. Pumping stations are placed every 200 km for onshore pipelines and at both ends of offshore pipelines, independent of length. Regarding case 1, 2C and case 3, we are reusing the existent gas pipeline, and thus, costs for these are assessed to be zero. However, since the pipeline starts in Nybro (a short distance from Esbjerg), a new short, onshore pipeline will transport the aggregated CO2 from Esbjerg port to Nybro.
	OPEX	Pipeline OPEX comprises power, fixed O&M from transport pipeline as well as a pipeline from port to storage site. Fixed O&M calculations are based 1% of CAPEX pertaining to each business case and the technical lifetime value.
Shuttle tanker/ vessel	CAPEX	Shuttle tanker/vessels CAPEX comprises acquisition price and export intermediate storage costs. For case 1, the acquisition price is based on a vessel of 20,000 t capacity in which 3 vessels are required. For the other cases, shuttle tankers of 20,000 t capacity are assumed. For business case 2B 3 shuttle tankers are needed. For 2A and 2C 4 shuttle tankers are required, while business case 3 requires 10 shuttle tankers. The additional capital expenditures attributed to the injection systems and intermediate storage onboard the vessels are covered in the storage CAPEX.
	OPEX	Shuttle tanker/vessels OPEX comprise fixed operations, maintenance, and fuel costs. The fixed O&M costs are based on 5% of shuttle tanker/vessel CAPEX pertaining to each business case and EUR 75/tCO2 export intermediate storage capacity. Fuel costs are based on the number of loading/unloading cycles, days per cycle, fuel consumption per day, cost of fuel and technical lifetime values. The additional operational expenditures attributed to the injection systems and intermediate storage onboard vessels are covered in storage OPEX.
Operations time period	Years of operation	It is assumed that the CO2 transport and storage projects have an operational lifetime of 30 years[233].
Operation start year	Year	2030 is the assumed start year of operation. CAPEX occurs in year 0, i.e. 2030, and in year 1, i.e. 2031, OPEX and revenues are applied.

232 For case 1 storage instalment CAPEX comprise: Intermediate storage, Injection plant, Injection wells, Wellhead platform as well as Mooring and loading system. For case 2A this includes: Intermediate storage, Injection plant and Injection wells. For case 2B and 2C: Intermediate storage, Injection plant, Injection wells and Wellhead platform. For case 3: Intermediate storage, Injection plant, Injection wells as well as wellhead platform for nearshore and offshore storages.

233 Ramboll expert

WACC	Financial costs	The WACC applied in all business cases are based on the European Commission's guide to cost-benefit analysis indicative benchmark value of investment projects, which is 4%.[234]

CO2 transport costs from shuttle tankers, vessels and pipelines are included in business cases 1, 2 and 3, although this could potentially be paid by the emitter or split between the emitter and the CO2 storage solution provider. If Denmark pays for the export countries' transport of CO2, the export countries will receive favourable conditions – especially in the less expensive onshore storage solution option. The cost of covering export countries' transport might be transferred to Danish emitters, which makes it more expensive for them, and Danish emitter might end up choosing storage solutions in competing countries. If CO2 is imported at a large scale it could be more feasible to cover the export countries' transport costs, since, with economies of scale, the price could come down.

Additionally, no liquefaction is assumed in any of the calculations of the cost of sea transportation. Liquefaction is a high cost, but if it is excluded in both our cost calculation and the references price (i.e. the applied revenue), then it matters not so much. Also, the cost for transportation by the sea does not include harbour fees. Liquefaction and harbour fees are typically included at the CO_2 capture plant. However, as both liquefaction and harbour fees are particular to sea transport, this could potentially enhance the business case for using pipeline transport.

6.4 KEY CONCLUSIONS ON THE PROFITABILITY OF THE CO2 STORAGE IN DENMARK

Four out of five cases result in positive NPV values within a 30-year lifetime and range from a payback period between 8-25 years. However, it is **pivotal to note that the assessed business cases take a point of departure in the assumption that there will be a business case for CO2 storage providers and the price will be a combination of, e.g., CO2 prices, CO2 taxes, grants etc**. However, the way in which the price is subsidised is not deemed necessary to assess the profitability and break-even of the business cases. Rather, it is important to forecast a price that is representative of a feasible market-based (i.e. competitive) scenario, and thus, we have developed a reference price for transport and storage, which is based on what it would cost for the export countries to export their CO2 to an offshore UK storage, which is deemed a representative, competitive and feasible alternative to Danish CO2 storage solutions. The reference price is based on an average of the various Danish offshore storage alternatives presented in the set-ups (Chapter 5.3), which is based on what it would cost for the export countries to export their CO2 to an offshore UK storage, which is deemed a representative, competitive and feasible alternative to Danish CO2 storage solutions. Further, utilising a reference price is seen as the most representative methodology, since forecasting the CO2 price and subsidy mechanisms includes high uncertainty and an array of the possible pathway (e.g., uncertainty around how income from CO2 prices, taxes and grants are allocated, since they are not solely allocated to CCS).

(large-scale international CCS solution), mainly due to the high revenue volumes per year (40 MtCO2/y), economies of scale from large-scale operations and from combining solutions, e.g., pipelines utilised for different types of storages. Furthermore, this case includes all types of storages, meaning that CAPEX is lower than if only offshore storage was applied. Although case 3 has a significantly higher total cost than the domestic cases, the investment payback (**payback period is 11 years**) is expected sooner than for case 1, 2B and 2C, again due to expected large CO2 volumes combined with economies of scale/ use of price-effective storage and transport solutions.

Although providing a clear advantage in the form of flexibility, Case 1 (small-scale, domestically focused case with sea transportation only) **results in a negative NPV (DKK ~ (2.0) billion)** and the **longest payback period (25 years)**. The main reason is that this case has a considerable higher OPEX than the rest of the domestically focused cases, and the highest cost per ton CO2 among all cases. However, it is important to note that the case is built on the assumption that only vessels will be used for the transportation of CO2 (which is the most expensive transportation solution) during the 30-year business case period. If the transportation is optimised during the ramp-up, by e.g. adding a pipeline of permanently moored FSU, the business case could potentially improve. At the same time, the revenue applied in the model is

[234] European Commission - Guide to cost-benefit analysis of investment projects

difficult to determine, and there is therefore associated uncertainty with regards to business case results – i.e. business case would improve at higher revenue.

Case 2C (medium-scale, domestically focused case, with offshore storage) – also an offshore option in case 2 - **posts an NPV of DKK ~2.1 billion** and a **payback period of 15 years**. While this is a positive NPV, it is more expensive than 2A, and 2C since offshore storage sites are more expensive than onshore and nearshore solutions.

Case 2A (medium-scale, domestically focused case, with onshore storage) **results in the second-highest NPV of DKK ~11.5 billion** and has the **shortest payback period (8 years)**. **Case 2B** (medium-scale, domestically focused case, with nearshore storage) has an **NPV of DKK ~5.5 billion and a payback period of 13 years**. This case has the highest CAPEX of all medium-size cases (i.e. 2A, 2B, 2C), however, OPEX is the second-lowest.

The results above are **based on a number of prerequisites**, including expected CO2 volumes, strong project management and identification of qualified, responsible parties, financial support (both nationally and in case 3 also internationally), that necessary permits are obtained without major delays, technological enhancement and ability to start the operations no later than 2030 (or at least in line with the volume uptake). Furthermore, some case-specific prerequisites apply, e.g. that the reservoirs (especially the less known onshore and nearshore storages) can be used for storage of CO2 and availability of the existing offshore pipeline infrastructure in time for the start of constructions works (and that it is possible to fully retrofit it to handle the large CO2 volumes) and that necessary international agreement, e.g. with German companies and state are secured up-front before the pipeline is constructed. For case 1 (small-scale and domestically focused case), one important prerequisite is that oil and gas companies possessing the concession rights are willing to switch from oil & gas activities to CO2 storage.

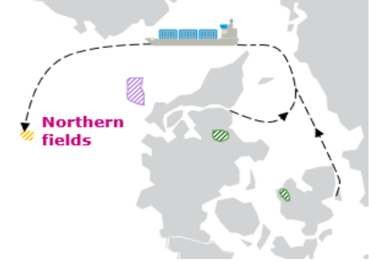
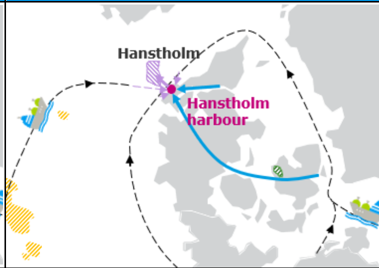
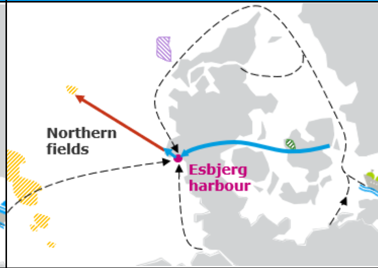
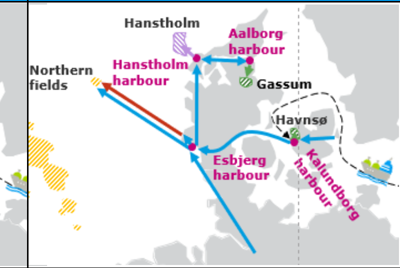
Furthermore, **pro’s and con’s have been compiled** for both domestically focused cases (case 1 and 2) and the case with international solution (case 3). It is important to highlight that the domestic-oriented solutions are less complex and more affordable options (especially case 2A, which offers a highly price competitive option, with the highest IRR and with the shortest pay-back period). However, when starting at a smaller scale, it can, in many cases, be more challenging to move towards large-scale and international market solutions than starting at a large scale from the beginning. On the other hand, the small-scale domestic case with vessel transportation (case 1) is the one providing the highest degree of flexibility, as it can be ramped up to the medium-size solution (or even large-scale, although choosing this way around can lead to lost opportunities), and modified into other solutions stepwise. Consequently, this case gives the possibility to explore the market before making the final decision on the strategic direction. However, this case has also the highest total cost per ton of CO2.

The internationally oriented solution (case 3) enables full utilisation of the market potential (and Denmark’s strategic location, with close proximity to DE, SE, FI and PL) by offering a price competitive, convenient, and potentially binding solution. This solution can also play into the EU’s plan to reach ambitious CO2 reduction targets and thus secure international financing and cost/risk-sharing. On the other hand, this solution is significantly more complex (however not unrealistic, as proven by the recent Baltic Pipe project), would imply a need for extensive state involvement and investments in widespread CCS infrastructure, and also require EU to cooperate in continuing to support and pass policies that will aid the CCS market. Furthermore, this solution is the most meaningful if planned at a large scale from the beginning - adding storages or infrastructure at a later time can impair this system's competitiveness and expected CO2 volumes.

The detailed cash flow results for each business case scenario are shown in the figures and tables in the following sub-sections, with a corresponding summary description of the results.

Table 48: Overview of the results from the assessment of the different business cases

Nearshore storage site | Onshore storage site | Offshore storage site | CO2 Pipelines | Repurposed pipelines | CO2 Shipping routes | Harbour

Category	**Case 1:** Small-scale domestically focused case with sea transportation	**Case 2A:** Medium-scale, domestically focused case, with onshore storage	**Case 2B:** Medium-scale, domestically focused case, with nearshore storage	**Case 2C:** Medium-scale, domestically focused case, with offshore storage	**Case 3:** Large-scale international CCS solution
Illustration of business case (see appendix for full size)					
NPV (DKK) and IRR	**NPV: ~ (2.0) bn** **IRR: ~0.2%**	**NPV: ~11.5 bn** **IRR: ~12%**	**NPV: ~5.5 bn** **IRR: ~7%**	**NPV: ~2.1 bn** **IRR: ~5%**	**NPV: ~26.6 bn** **IRR: ~9%**
DKK/ton	172	82	109	132	101
Break-even year	2055	2038	2043	2045	2041
Pre-requisites	• The source countries will capture CO2 with the intention for storage and choose Denmark as the storage destination • It is possible to identify and appoint parties with operational and technical CCS expertise to represent the state in order to secure fair competition (i.e. to avoid monopolisation of the market) • Likewise, all of the cases will require financial aid in order to be operational, as none of the solutions can operate without subsidies and grants • All necessary permits can be obtained without major delays • Required technology developments are achieved. For both cases, it is, e.g. assumed that shuttle tankers up to at least 20,000 tonnes will become available in the future • Operations start in 2030. The payback period assumes that the CCS systems (both storages and transport infrastructure) can be built in time to start operations no later than 2030, or at least in line with the volume uptake				
	• Interest and willingness from the oil & gas companies with concession rights to switch from gas/oil to CO2 operations • Pumping technology on vessels are is proven to work efficiently and commercialised • Existing injection wells can be reused (other cases assume that new wells will be built) • This case assumes focus on domestic activities only and CO2 import from abroad is not comprised; In practice, once on vessels, CO2 can be transported	• Especially for case 2A, there is a prerequisite that all necessary permits can be obtained without major delays. Due to the onshore location of the site, there is a risk of public opposition and difficulty obtaining necessary permits. • Both for case 2A and 2B, it is a prerequisite that the reservoirs can be used for the storage of CO2. None of these sites has been drilled yet, and it will therefore be necessary to carry out seismic surveys as well as appraisal drilling		• The existent gas pipeline can be reused for CCS purposes	• The existent gas pipeline can be reused for CCS purposes • EU and/or individual collaboration countries will provide support for the development of a CCS system • Agreements with German companies and state are secured upfront before the pipeline is constructed

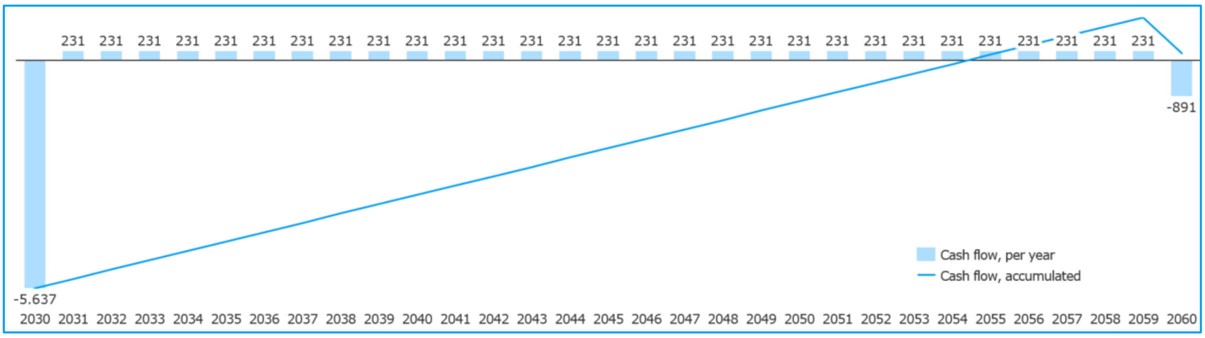
	from different locations (both domestically and internationally)			
Pro's	• This model gives a high degree of flexibility, as it can be re-evaluated and potentially changed/adjusted underway to match changing conditions and market needs. E.g. it is possible to switch to or add-on other solutions (e.g. a permanently moored FSU or pipeline that can optimise costs but also reduce flexibility) over time, when the market has been tested. It is also possible to add international markets any time, as the vessels can pick-up CO2 from various sources, also abroad • Relatively short construction time (~ 5 years) allows starting some operations already in 2026 (given that construction works start no later than in 2022) • Abandonment costs for existing oil & gas infrastructure can be postponed if it is reused for CO2 operations	• Less complex and affordable option: Especially case 2A offers a highly price competitive option, with the highest IRR and the shortest pay-back period • The domestically oriented solutions are more flexible with regards to a gradual build-up than the international case (as long as the focus remains on the domestic CO2 volumes). I.e. it is possible for this solution to start at a smaller scale and then add capacity as needed • CO2 transported via pipelines does not need to be liquefied. Although liquefaction is not included in this report (as it is considered to be part of carbon capture systems at source), it can be significant and result in additional costs for emitters		• Case with the highest NPV • Full utilisation of the market potential (and DK's strategic location, with close proximity to DE, SE, FI and PL) by offering a price competitive, convenient, and potentially binding solution • Ambitious EU targets for decarbonisation will most probably require CSS to close any potential gap in CO2 reductions, meaning that the project can receive financial support from EU and/or collaboration countries • A complex solution might imply more competition between players, and as such, the CCS might become more market-oriented • CO2 transported via pipelines does not need to be liquefied. Although liquefaction for sea transport is not included in this report (as it is considered to be part of carbon capture systems at source), it can be significant and result in higher costs for emitters
Con's	• Case 1 has the highest cost per ton among all cases, although it can be potentially improved over time if it is expanded to include more cost-efficient solutions • Likewise, in case 1, CO2 emitters/sources are not committed to Denmark (which would be the case with pipeline), implying a potentially higher risk of losing these customers to competition (especially given relatively high costs, which will presumably impact the price on CO2 transport and storage as well) • Vessels in case 1 are built for the purpose and can potentially become sunk cost if this solution is dropped or changed over time (i.e. are more difficult to retrofit to other purposes, than, e.g. shuttle tankers)	• Particularly onshore and nearshore solution can be difficult and potentially unprofitable to expand to the international scale later in time • Risk for public opposition against the onshore storage		• High project complexity meaning the risk to the timeline. However, the recent project experiences within the gas industry (Baltic Pipe) prove such complex solutions realistic • Need for extensive state involvement and investments in widespread CCS infrastructure. It will also require EU to cooperate in continuing to support and pass policies that will aid the CCS market • Only meaningful if the full infrastructure is planned from the beginning. Adding storages or infrastructure afterwards can impair the competitiveness of this system and also expected CO2 volumes

6.5 BUSINESS CASE DEEP-DIVES

6.5.1 Case 1 – Small-scale, domestically focused case, with offshore CO2 storage, but sea transportation only (no pipeline or ports assumed)

Case 1 posts a negative **NPV of DKK ~ (2.0) billion** and a **payback time of 25 years**. Thus, this case has the lowest NPV of all cases and the longest payback period due to the high OPEX, although this case does not have costs related to pipeline transport. The operational expenditure for vessels and storage (most significant contributors to this are the OPEX of wellhead platforms, standby vessels, and mooring and loading systems) are higher than the rest of case 2 options. The IRR is positive at **~ 0.2%**.

Figure 19: Cash flow case 1



Source: Ramboll analysis

Figure 20: Business case overview 1

YEAR	Unit	0	1	2	3	24	25	26	27	28	29	30
Year		**2030**	**2031**	**2032**	**2033**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**
Revenue												
Reference price	DKK	169 kr.	169 kr.	169 kr.	169 kr.	169 kr.	169 kr.	169 kr.	169 kr.	169 kr.	169 kr.	169 kr.
CO2 volume		5	5	5	5	5	5	5	5	5	5	5
Total revenue	**mDKK**	**843 kr.**	**843 kr.**	**843 kr.**	**843 kr.**	**843 kr.**	**843 kr.**	**843 kr.**	**843 kr.**	**843 kr.**	**843 kr.**	**843 kr.**
OPEX												
Storage	mDKK		490 kr.	490 kr.	490 kr.	490 kr.	490 kr.	490 kr.	490 kr.	490 kr.	490 kr.	490 kr.
Vessels	mDKK		122 kr.	122 kr.	122 kr.	122 kr.	122 kr.	122 kr.	122 kr.	122 kr.	122 kr.	122 kr.
Pipeline	mDKK		0 kr.	0 kr.	0 kr.	0 kr.	0 kr.	0 kr.	0 kr.	0 kr.	0 kr.	0 kr.
Total operating expenditures	**mDKK**		**612 kr.**	**612 kr.**	**612 kr.**	**612 kr.**	**612 kr.**	**612 kr.**	**612 kr.**	**612 kr.**	**612 kr.**	**612 kr.**
EBITDA	**mDKK**		**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**
CAPEX												
Storage, Pre-FID cost (one-time cost)	mDKK	300 kr.										
Storage, Instalment costs	mDKK	2.980 kr.										
Storage, Abandonment cost (ABEX)	mDKK											522 kr.
Storage, Post-Closure Cost/Monitoring	mDKK											600 kr.
Vessels, acquisition cost	mDKK	1.419 kr.										
Export intermediate storage	mDKK	938 kr.										
Pipeline, Instalment costs	mDKK	0 kr.										
Total capital expenditures	**mDKK**	**5.637 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**1.122 kr.**
Depreciations												
	mDKK		188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	1.309 kr.
EBIT	**mDKK**	**0 kr.**	**43 kr.**	**43 kr.**	**43 kr.**	**43 kr.**	**43 kr.**	**43 kr.**	**43 kr.**	**43 kr.**	**43 kr.**	**-1.078 kr.**
Cash flow	**mDKK**	**-5.637 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**231 kr.**	**-891 kr.**
Discounted cash flow	**mDKK**	**-5.637 kr.**	**222 kr.**	**213 kr.**	**205 kr.**	**90 kr.**	**87 kr.**	**83 kr.**	**80 kr.**	**77 kr.**	**74 kr.**	**-275 kr.**
Accumulated cash flow	**mDKK**	**-5.637 kr.**	**-5.406 kr.**	**-5.175 kr.**	**-4.944 kr.**	**-95 kr.**	**136 kr.**	**367 kr.**	**598 kr.**	**829 kr.**	**1.060 kr.**	**169 kr.**

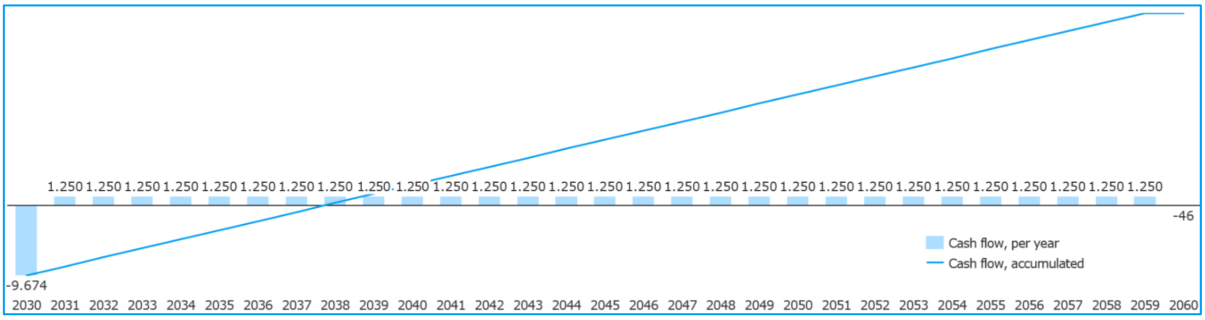
Present value (PV), mDKK	**DKK**	**3.647**
Net present value (NPV), mDKK	**DKK**	**(1.989)**
IRR		**0,2%**
WACC		**4%**

Source: Ramboll analysis

6.5.2 Case 2A – Medium-scale, domestically focused case, with onshore storage

Case 2A has an **NPV of DKK ~11.5 billion** and a **payback time of 8 years** in **2038**. The NPV is the highest of all business cases in the medium-scale option, whereas the payback period is the lowest of all business cases and is mainly due to OPEX and CAPEX for the onshore option being the lowest and the reference price applied is the same for all cases (except the price for case 3, which is slightly lower). The IRR also reflects these results and posts **~12%.**

Figure 21: Cash flow 2A



Source: Ramboll analysis

Figure 22: Business case overview 2A

YEAR	Unit	0	1	2	3	4	5	6	7	8	28	29	30
Year		**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2058**	**2059**	**2060**
Revenue													
Reference price	DKK	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.
CO2 volume		10	10	10	10	10	10	10	10	10	10	10	10
Total revenue	**mDKK**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**
OPEX													
Storage	mDKK		188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	188 kr.	188 kr.
Shuttle tanker/vessels	mDKK		209 kr.	209 kr.	209 kr.	209 kr.	209 kr.	209 kr.	209 kr.	209 kr.	209 kr.	209 kr.	209 kr.
Pipeline	mDKK		16 kr.	16 kr.	16 kr.	16 kr.	16 kr.	16 kr.	16 kr.	16 kr.	16 kr.	16 kr.	16 kr.
Total operating expenditures	**mDKK**		**413 kr.**	**413 kr.**	**413 kr.**	**413 kr.**	**413 kr.**	**413 kr.**	**413 kr.**	**413 kr.**	**413 kr.**	**413 kr.**	**413 kr.**
EBITDA	**mDKK**		**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**
CAPEX													
Storage, Pre-FID cost (one-time cost)	mDKK	308 kr.											
Storage, Instalment costs	mDKK	4.170 kr.											
Storage, Abandonment cost (ABEX)	mDKK												730 kr.
Storage, Post-Closure Cost/Monitoring	mDKK												566 kr.
Shuttle tankers, acquisition cost	mDKK	1.892 kr.											
Export intermediate storage	mDKK	2.625 kr.											
Pipeline, Instalment costs	mDKK	679 kr.											
Total capital expenditures	**mDKK**	**9.674 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**1.295 kr.**
Depreciations													
	mDKK		322 kr.	322 kr.	322 kr.	322 kr.	322 kr.	322 kr.	322 kr.	322 kr.	322 kr.	322 kr.	1.618 kr.
EBIT	**mDKK**	**0 kr.**	**927 kr.**	**927 kr.**	**927 kr.**	**927 kr.**	**927 kr.**	**927 kr.**	**927 kr.**	**927 kr.**	**927 kr.**	**927 kr.**	**-368 kr.**
Cash flow	**mDKK**	**-9.674 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**1.250 kr.**	**-46 kr.**
Discounted cash flow	**mDKK**	**-9.674 kr.**	**1.202 kr.**	**1.156 kr.**	**1.111 kr.**	**1.068 kr.**	**1.027 kr.**	**988 kr.**	**950 kr.**	**913 kr.**	**417 kr.**	**401 kr.**	**-14 kr.**
Accumulated cash flow	**mDKK**	**-9.674 kr.**	**-8.424 kr.**	**-7.174 kr.**	**-5.924 kr.**	**-4.674 kr.**	**-3.424 kr.**	**-2.174 kr.**	**-925 kr.**	**325 kr.**	**25.323 kr.**	**26.572 kr.**	**26.527 kr.**

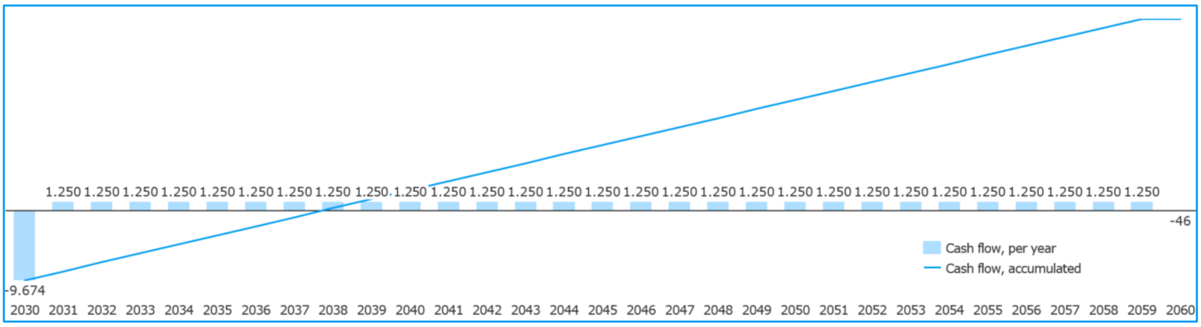
Present value (PV), mDKK	**DKK 21.213**
Net present value (NPV), mDKK	**DKK 11.540**
IRR	**12,49%**
WACC	**4,0%**

Source: Ramboll analysis

6.5.3 Case 2B – Medium-scale, domestically focused case, with nearshore storage

Case 2B has an **NPV of DKK ~5.5 billion** and a **payback time of 13 years** in **2043**. Thus, this case has a lower NPV and longer payback period than case 2A since the nearshore solution is more expensive than an onshore solution. This case has the second-highest total CAPEX of all options in case 2, however, OPEX is the second-lowest of all cases. The IRR is at **~7%.**

Figure 23: Cash flow 2B



Source: Ramboll analysis

Figure 24: Business case overview

YEAR	Unit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	30
Year		**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2060**
Revenue																
Reference price	DKK	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.
CO2 volume		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Total revenue	**mDKK**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**
OPEX																
Storage	mDKK		276 kr.	276 kr.	276 kr.	276 kr.	276 kr.	276 kr.	276 kr.	276 kr.	276 kr.	276 kr.	276 kr.	276 kr.	276 kr.	276 kr.
Shuttle tanker/vessels	mDKK		164 kr.	164 kr.	164 kr.	164 kr.	164 kr.	164 kr.	164 kr.	164 kr.	164 kr.	164 kr.	164 kr.	164 kr.	164 kr.	164 kr.
Pipeline	mDKK		48 kr.	48 kr.	48 kr.	48 kr.	48 kr.	48 kr.	48 kr.	48 kr.	48 kr.	48 kr.	48 kr.	48 kr.	48 kr.	48 kr.
Total operating expenditures	**mDKK**	**0 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**	**488 kr.**
EBITDA	**mDKK**	**1.663 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**
CAPEX																
Storage, Pre-FID cost (one-time cost)	mDKK	658 kr.														
Storage, Instalment costs	mDKK	7.086 kr.														
Storage, Abandonment cost (ABEX)	mDKK															1.240 kr.
Storage, Post-Closure Cost/Monitoring	mDKK															849 kr.
Shuttle tankers, acquisition cost	mDKK	1.419 kr.														
Export intermediate storage	mDKK	2.063 kr.														
Pipeline, Instalment costs	mDKK	2.950 kr.														
Total capital expenditures	**mDKK**	**14.175 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**2.089 kr.**
Depreciations																
	mDKK		473 kr.	473 kr.	473 kr.	473 kr.	473 kr.	473 kr.	473 kr.	473 kr.	473 kr.	473 kr.	473 kr.	473 kr.	473 kr.	2.561 kr.
EBIT	**mDKK**	**1.663 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**703 kr.**	**-1.386 kr.**
Cash flow	**mDKK**	**-14.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**1.175 kr.**	**-913 kr.**
Discounted cash flow	**mDKK**	**-14.175 kr.**	**1.130 kr.**	**1.087 kr.**	**1.045 kr.**	**1.005 kr.**	**966 kr.**	**929 kr.**	**893 kr.**	**859 kr.**	**826 kr.**	**794 kr.**	**763 kr.**	**734 kr.**	**706 kr.**	**-282 kr.**
Accumulated cash flow	**mDKK**	**-14.175 kr.**	**-13.000 kr.**	**-11.825 kr.**	**-10.650 kr.**	**-9.475 kr.**	**-8.299 kr.**	**-7.124 kr.**	**-5.949 kr.**	**-4.774 kr.**	**-3.599 kr.**	**-2.424 kr.**	**-1.248 kr.**	**-73 kr.**	**1.102 kr.**	**18.992 kr.**

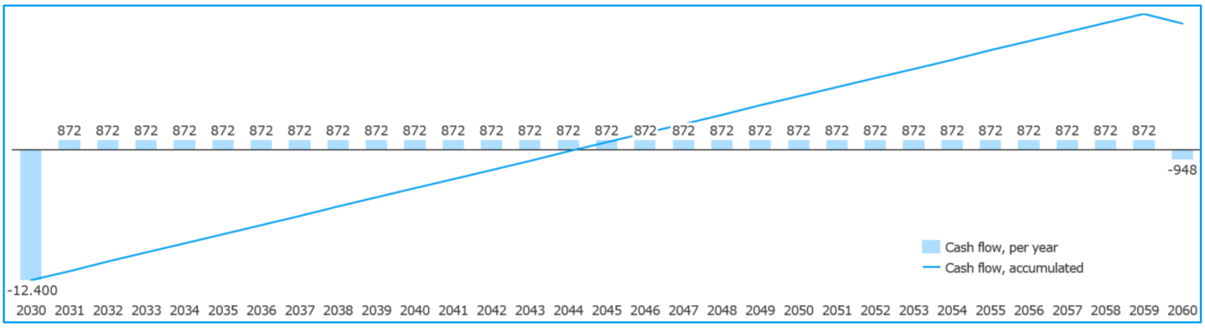
Present value (PV), mDKK	**DKK 19.678**
Net present value (NPV), mDKK	**DKK 5.502**
IRR	**7,1%**
WACC	**4,0%**

Source: Ramboll analysis

6.5.4 Case 2C – Medium-scale, domestically focused case, with offshore storage

Case 2C has an **NPV of DKK ~2.1 billion** and a **payback time of 15 years** in **2045**. Thus, this case has a lower NPV and longer payback period than case 2A and case 2B. This case has the second-highest total CAPEX of all options in case 2, however, OPEX is the second-lowest of all cases. The IRR is at **~6%**.

Figure 25: Cash flow 2C



Source: Ramboll analysis

Figure 26: Business case overview 2C

YEAR	Unit	0	1	2	3	10	11	12	13	14	15	30
Year		**2030**	**2031**	**2032**	**2033**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2060**
Revenue												
Reference price	DKK	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.	166 kr.
CO2 volume		10	10	10	10	10	10	10	10	10	10	10
Total revenue	**mDKK**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**	**1.663 kr.**
OPEX												
Storage	mDKK		547 kr.	547 kr.	547 kr.	547 kr.	547 kr.	547 kr.	547 kr.	547 kr.	547 kr.	547 kr.
Shuttle tanker/vessels	mDKK		210 kr.	210 kr.	210 kr.	210 kr.	210 kr.	210 kr.	210 kr.	210 kr.	210 kr.	210 kr.
Pipeline	mDKK		34 kr.	34 kr.	34 kr.	34 kr.	34 kr.	34 kr.	34 kr.	34 kr.	34 kr.	34 kr.
Total operating expenditures	**mDKK**		**791 kr.**	**791 kr.**	**791 kr.**	**791 kr.**	**791 kr.**	**791 kr.**	**791 kr.**	**791 kr.**	**791 kr.**	**791 kr.**
EBITDA	**mDKK**		**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**
CAPEX												
Storage, Pre-FID cost (one-time cost)	mDKK	170 kr.										
Storage, Instalment costs	mDKK	5.552 kr.										
Storage, Abandonment cost (ABEX)	mDKK											972 kr.
Storage, Post-Closure Cost/Monitoring	mDKK											849 kr.
Shuttle tankers, acquisition cost	mDKK	1.892 kr.										
Export intermediate storage	mDKK	2.625 kr.										
Pipeline, Instalment costs	mDKK	2.160 kr.										
Total capital expenditures	**mDKK**	**12.400 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**1.820 kr.**
Depreciations												
	mDKK		413 kr.	413 kr.	413 kr.	413 kr.	413 kr.	413 kr.	413 kr.	413 kr.	413 kr.	2.234 kr.
EBIT	**mDKK**	**0 kr.**	**458 kr.**	**458 kr.**	**458 kr.**	**458 kr.**	**458 kr.**	**458 kr.**	**458 kr.**	**458 kr.**	**458 kr.**	**-1.362 kr.**
Cash flow	**mDKK**	**-12.400 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**872 kr.**	**-948 kr.**
Discounted cash flow	**mDKK**	**-12.400 kr.**	**838 kr.**	**806 kr.**	**775 kr.**	**589 kr.**	**566 kr.**	**545 kr.**	**524 kr.**	**503 kr.**	**484 kr.**	**-292 kr.**
Accumulated cash flow	**mDKK**	**-12.400 kr.**	**-11.528 kr.**	**-10.656 kr.**	**-9.784 kr.**	**-3.681 kr.**	**-2.810 kr.**	**-1.938 kr.**	**-1.066 kr.**	**-194 kr.**	**678 kr.**	**11.935 kr.**

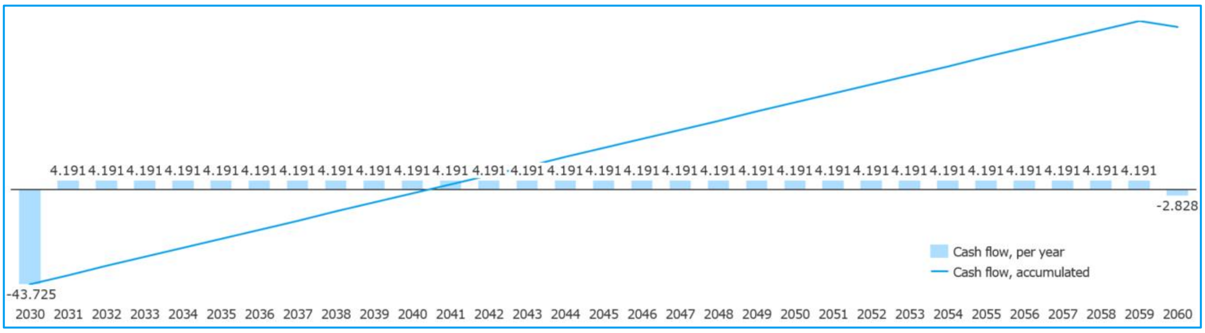
Present value (PV), mDKK	**DKK 14.514**
Net present value (NPV), mDKK	**DKK 2.115**
IRR	**5,4%**
WACC	**4%**

Source: Ramboll analysis

6.5.5 Case 3 – Large-scale international CCS solution

Case 2 has an **NPV of DKK ~26.6 billion** and a **payback time of 11 years** in **2041**. Thus, this case has the highest NPV of all cases, while the payback period is the second shortest (after case 2A). Naturally, this case it the most expensive in terms of both CAPEX and OPEX, however, the volumes are four times higher (40 MtCO2/y) than the options in case 2 and eight times higher than case 1 (although the reference price is just slightly lower than the other cases), which results in the case having the highest NPV. Further, this solution combines onshore, nearshore and offshore storages, as well as pipeline (including the assumption that existing gas pipelines can be utilised) and shuttle tanker transportation and this, results in a combination of solutions that provides economies of scale as well as synergies (e.g., the same pipeline can be used for more than one storage solution). The IRR is at **~9%**.

Figure 27: Cash flow 3



Source: Ramboll analysis

Figure 28: Business case overview 3

YEAR	Unit	0	1	2	3	4	5	6	7	8	9	10	11	30
Year		**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2060**
Revenue														
Reference price	DKK	159 kr.	159 kr.	159 kr.	159 kr.	159 kr.	159 kr.	159 kr.	159 kr.	159 kr.	159 kr.	159 kr.	159 kr.	159 kr.
CO2 volume		40	40	40	40	40	40	40	40	40	40	40	40	40
Total revenue	**mDKK**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**	**6.367 kr.**
OPEX														
Storage	mDKK		1.518 kr.	1.518 kr.	1.518 kr.	1.518 kr.	1.518 kr.	1.518 kr.	1.518 kr.	1.518 kr.	1.518 kr.	1.518 kr.	1.518 kr.	1.518 kr.
Shuttle tanker/vessels	mDKK		437 kr.	437 kr.	437 kr.	437 kr.	437 kr.	437 kr.	437 kr.	437 kr.	437 kr.	437 kr.	437 kr.	437 kr.
Pipeline	mDKK		222 kr.	222 kr.	222 kr.	222 kr.	222 kr.	222 kr.	222 kr.	222 kr.	222 kr.	222 kr.	222 kr.	222 kr.
Total operating expenditures	**mDKK**		**2.176 kr.**	**2.176 kr.**	**2.176 kr.**	**2.176 kr.**	**2.176 kr.**	**2.176 kr.**	**2.176 kr.**	**2.176 kr.**	**2.176 kr.**	**2.176 kr.**	**2.176 kr.**	**2.176 kr.**
EBITDA	**mDKK**		**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**
CAPEX														
Storage, Pre-FID cost (one-time cost	mDKK	1.500 kr.												
Storage, Instalment costs	mDKK	22.882 kr.												
Storage, Abandonment cost (ABEX)	mDKK													4.004 kr.
Storage, Post-Closure Cost/Monitorin	mDKK													3.014 kr.
Shuttle tankers, acquisition cost	mDKK	4.730 kr.												
Export intermediate storage	mDKK	2.813 kr.												
Pipeline, Instalment costs	mDKK	11.799 kr.												
Total capital expenditures	**mDKK**	**43.725 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**0 kr.**	**7.019 kr.**
Depreciations														
	mDKK		1.457 kr.	1.457 kr.	1.457 kr.	1.457 kr.	1.457 kr.	1.457 kr.	1.457 kr.	1.457 kr.	1.457 kr.	1.457 kr.	1.457 kr.	8.476 kr.
EBIT	**mDKK**	**0 kr.**	**2.733 kr.**	**2.733 kr.**	**2.733 kr.**	**2.733 kr.**	**2.733 kr.**	**2.733 kr.**	**2.733 kr.**	**2.733 kr.**	**2.733 kr.**	**2.733 kr.**	**2.733 kr.**	**-4.285 kr.**
Cash flow	**mDKK**	**-43.725 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**4.191 kr.**	**-2.828 kr.**
Discounted cash flow	**mDKK**	**-43.725 kr.**	**4.030 kr.**	**3.875 kr.**	**3.726 kr.**	**3.582 kr.**	**3.444 kr.**	**3.312 kr.**	**3.185 kr.**	**3.062 kr.**	**2.944 kr.**	**2.831 kr.**	**2.722 kr.**	**-872 kr.**
Accumulated cash flow	**mDKK**	**-43.725 kr.**	**-39.534 kr.**	**-35.343 kr.**	**-31.152 kr.**	**-26.962 kr.**	**-22.771 kr.**	**-18.580 kr.**	**-14.390 kr.**	**-10.199 kr.**	**-6.008 kr.**	**-1.818 kr.**	**2.373 kr.**	**74.978 kr.**

Net present value (NPV), mDKK	**DKK 26.577**
IRR	**8,7%**
WACC	**4%**

Source: Ramboll analysis

6.6 BUSINESS CASE PREREQUISITES

All business cases presented in this chapter build on a number of prerequisites. Following prerequisites pertain to **all cases**:

- The source countries will capture CO2 with the intention for storage and choose Denmark as the storage destination
    - Particularly in Poland, there is a risk that the country might start storing CO2 on national territories in the future instead of exporting abroad
    - Additionally, it also requires all countries to choose CCS as the technology to remove these estimated capturable volumes instead of, e.g. CCU. Although the capturable volumes consider only the volumes intended for CCS, this is based on the current market, which can change over the years (due to technology development in other areas, political focus changes, etc.).
    - Furthermore, there is a general risk that the countries will fully or partly abandon the decarbonisation targets or incur serious delays in technology deployment due to possible unforeseen events
    - Another important risk related to potential CO2 volumes is that the biogenic emission will not be subject to carbon taxation, decreasing the incentives for carbon capture of these emissions
- It is possible to identify and appoint parties with operational and technical CCS expertise to represent the state in order to secure fair competition (i.e. to avoid monopolisation of the market). As mentioned in the chapter concerning institutional considerations, all cases will most likely require state involvement, a state-run body that upholds the strategic and administrative oversight of the project and parties (which to some degree represent the state/state-owned) with operational and technical expertise within CCS. Particularly case 2, which combines onshore, nearshore and offshore storage solutions, require increased governmental involvement
- Likewise, all of the cases will require financial aid in order to be operational, as none of the solutions can operate without subsidies and grants. In case of the large, internationally oriented solution (case 2), it is expected that EU and/or individual collaboration countries will provide support for the development of a CCS system, especially in a case, where a potential emission gap will be needed to be closed in order to reach the ambitious decarbonisation target set by EU for 2030 (reduction of the greenhouse gas emissions to at least 55% below 1990 levels by 2030). Furthermore, all cases outlined in this report comprise costs for the full infrastructure (i.e. both storage and transport of CO2 from source countries). Here it is also possible that transportation costs can be potentially shared with the emitters (e.g. cost for the pipeline from Germany or construction/acquisition of shuttle tankers). With reference to the bullet above, securing of the financing and potential cost-sharing requires proper and professional project management
- The offshore cases (2C and 3) underlie that an existent gas pipeline can be reused for CCS purposes. This means that the offshore pipeline infrastructure is available at the time constructions works to start and that retrofitting to handle the large CO2 volumes is possible
- Required technology developments are achieved. For both cases, it is, e.g. assumed that shuttle tankers up to at least 20,000 tonnes would become available in the future
- All necessary permits can be obtained without major delays. Especially the onshore storage can meet public opposition, resulting in the extended and potentially more uncertain permitting process than for the offshore storage
- Operations start no later than in 2030. The payback period assumes that the CCS systems (both storages and transport infrastructure) can be built in time to start operations no later than 2030, or at least in line with the volume uptake. In case of large delays, the risk is not only that the payback period will be longer, but also that volumes can be lost to competing storages. In practice, the full uptake of the CO2 volumes is not expected from year 1, and smaller delays or that only a share of operations can be carried during the first couple of years will not necessarily imply significant complications. Furthermore,

based on recent experience with the Baltic Pipe project, it is possible that all of the systems can be finalised even before 2030 (given that construction works can start already in 2022, the onshore and nearshore solutions could be completed in 2027 (expected timeline of ~6 years) and the offshore solution in 2026 (expected timeline of ~5 years; the shorter timeline is due to the possibility to reuse of some equipment and the geological structures being already known).

Other, **case-specific** prerequisites:

Case 1:

- Oil & gas companies with concession rights need to have interest and be willing to switch from gas/oil to CO2 operations. A potential challenge could arise if oil and gas prices increase significantly, which can impact the willingness of these companies to stop exploiting before the governmentally set deadline. This could potentially require an incentive system
- By the time operations start, the onboard pumping technology has been fully developed and tested (and proven to work efficiently) and has been commercialised.

Case 2:

- Both for case 2A and 2B, it is a prerequisite that the reservoirs can be used for the storage of CO2. None of these sites has been drilled yet, and it will therefore be necessary to carry out seismic surveys as well as appraisal drilling

Case 3:

- In order to be fully efficient, the solution outlined in case 3 requires that the full-scale infrastructure is constructed from the start (i.e. it is not meaningful to start small and expand later on). If a more gradual start is needed for this solution, then it is recommended to start with the offshore site, as it can be built fastest, and to avoid that price offered to customers increase significantly. Offshore solutions are assessed to be more expensive than onshore and nearshore solutions and will thus probably result in higher prices. High prices are expected to be more acceptable in the early stages of CCS, and the price is expected to become more competitive over time (which can be obtained by expanding with more price-competitive solutions).
- Collaboration and agreements with German companies and potentially state can be secured up front before the pipeline is constructed, i.e. the pipeline form source (e.g. Germany) will require some pre-work

6.7 PRO'S AND CON'S FOR THE ASSESSED BUSINESS CASES

The table below summarizes the key pro's and con's for case 1, 2 and 3, based on the insights gained in this chapter.

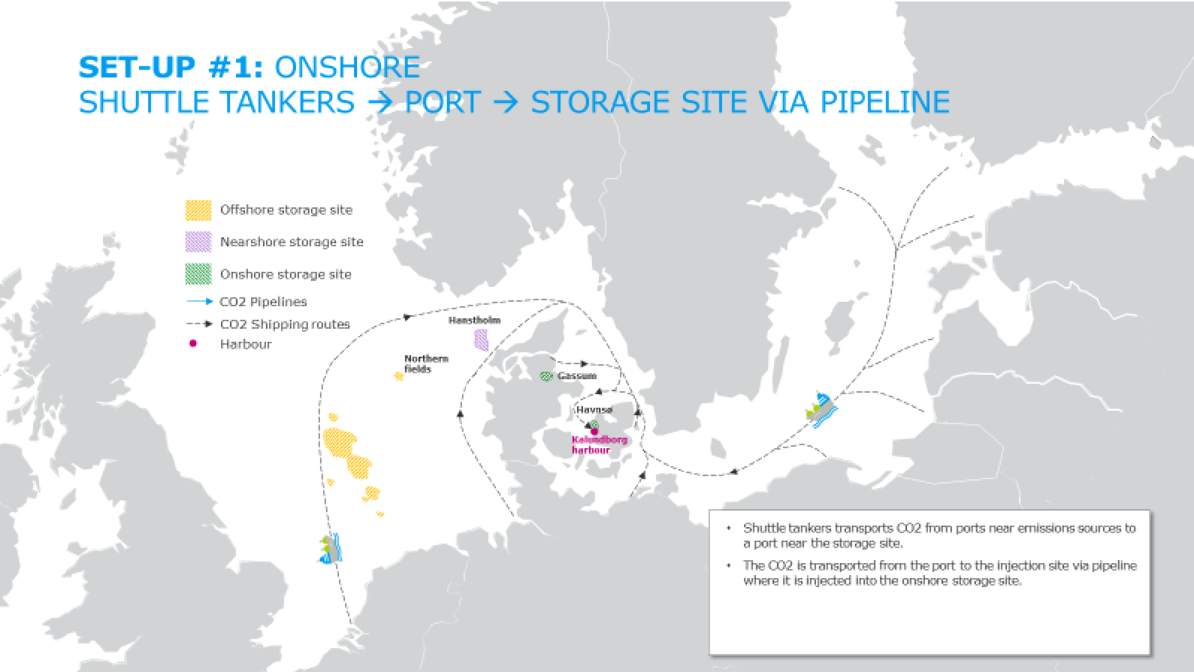
Table 49: Overview of pro's and con's for the assessed business cases

	Case 1 & 2 (A, B & C)	Case 3
Pro's	• Less complex and affordable option: Especially case 2A offers a highly price competitive option, and with the shortest pay-back period • All of the domestically oriented solutions are more flexible with regards to a gradual build-up than the international case (as long as the focus remains on the domestic CO2 volumes). I.e. it is possible for this solution to start at a smaller scale and then add capacity as needed in line with the market development • Especially case 1 gives a high degree of flexibility, as it can be re-evaluated and potentially changed/adjusted underway to match changing conditions and market needs. E.g. it is possible to switch to or add-on other solutions (e.g. a permanently moored FSU or pipeline that can optimise costs but also reduce flexibility) over time, when the market has been tested. It is also possible to add international markets any time, as the vessels can pick-up CO2 from various sources. • Relatively short construction time (~ 5 years) allows starting some operations already in 2026 (given that construction works start no later than in 2022) • Abandonment costs for existing oil & gas infrastructure can be postponed if it is reused for CO2 operations	• Case with the highest NPV • Denmark has a competitive advantage in terms of its location, being strategically located in close proximity to Germany, Sweden, Finland and Poland, to which it can offer both a convenient and price competitive solution, and thus secure CO2 volumes (especially from Germany via a pipeline) • Denmark is beside the NL, the only EU country which has shown willingness to develop storage capacity to store CO2 from other EU countries. The ambitious EU targets for decarbonisation will most probably require CSS to close any potential gap in CO2 reductions, meaning that the project can receive financial support from EU and/or collaboration countries • This case will entail that various player from both public and private bodies are involved and are responsible for different parts of the value chain. Since there are so many transport infrastructures laid out, it might involve more competition between players, and as such, CCS might become more market-oriented • CO2 transported via pipelines does not need to be liquefied. Although liquefaction is not included for sea transport in this report (as it is considered to be part of carbon capture systems at source), it can be significant and result in additional costs for emitters; Note that this advantage also applies to some degree for case 2
Con's	• Medium-scale solution (case 2, particularly 2A, onshore and 2B, nearshore) can be difficult and potentially unprofitable to expand to the international scale afterwards, as moving towards more expensive solutions can impair the competitiveness of the system (especially given that the market will move the opposite way, i.e. towards more price efficient solutions) • Risk for public opposition against onshore storage • In the case of 2C (offshore solution), the distance to the storage by ship is not significantly different from the offshore storage possibilities that UK or Norway is providing. Thus, there will be a potentially lower incentive for export countries to opt for storing their CO2 in Denmark. • Case 1 has the highest cost per ton among all cases, although it can be potentially improved over time if it is expanded to include more cost-efficient solutions • Likewise, in case 1, CO2 emitters/sources are not committed to Denmark (which would be the case with pipeline), implying a potentially higher risk of losing these customers to competition (especially given relatively high costs, which will presumably impact the price of CO2 transport and storage as well) • Vessels in case 1 are built for the purpose and can potentially become sunk cost if this solution is dropped or changed over time (i.e. are more difficult to retrofit to other purposes, than, e.g. shuttle tankers)	• High project complexity meaning risk to the timeline. However, the recent project experiences within gas industry (Baltic Pipe) provide a steppingstone for the development of such complex solutions. The Baltic pipe is expected to be completed in 2022, and thus only after a 5-year process, showcasing that timely completion of such projects is realistic • It will potentially require extensive state involvement and investments in widespread CCS infrastructure. It will also require the EU to cooperate in continuing to support and pass policies that will aid the CCS market • The international solution will be meaningful only in case when the full infrastructure is planned from the beginning. Adding storages or infrastructure afterwards can impair competitiveness of this system and the expected CO2 volumes

7. APPENDIX

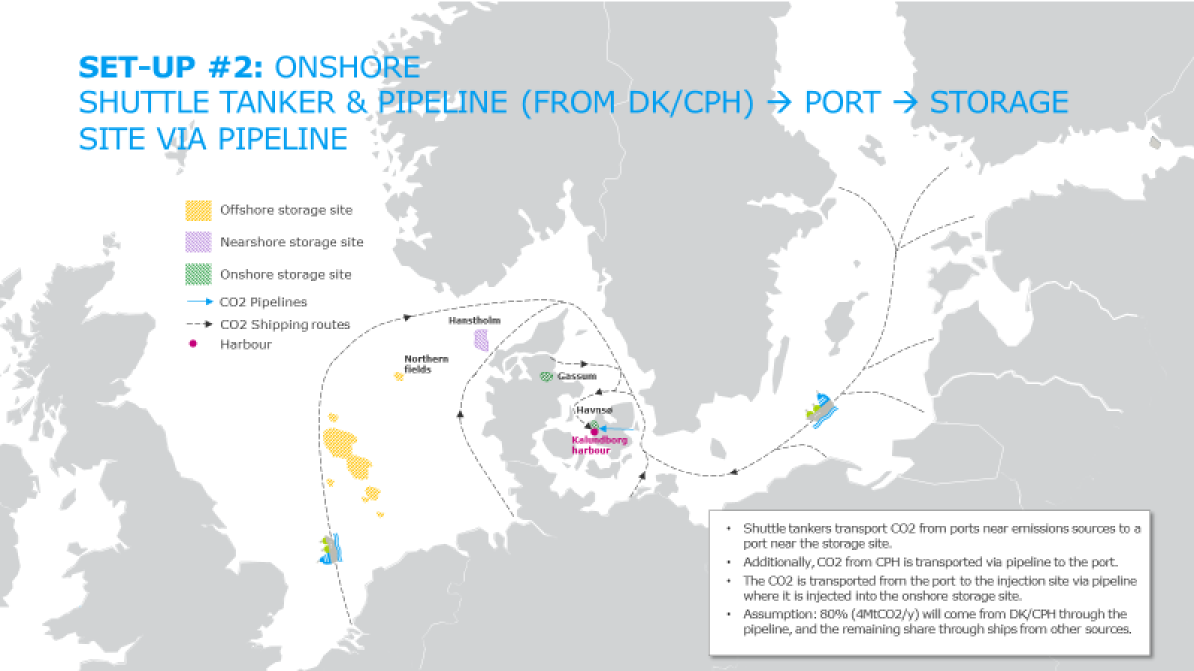
7.1 GRAPHICAL OVERVIEW OF BUSINESS MODEL SET-UPS

Figure 29: Set-up #1



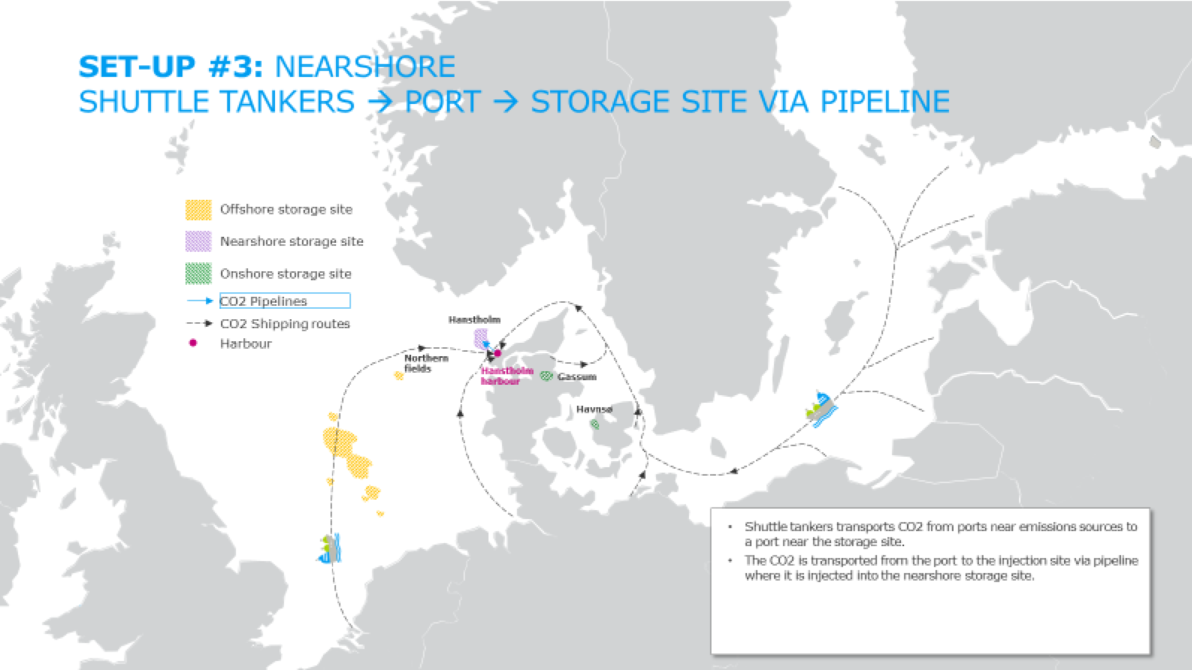
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 30: Set-up #2



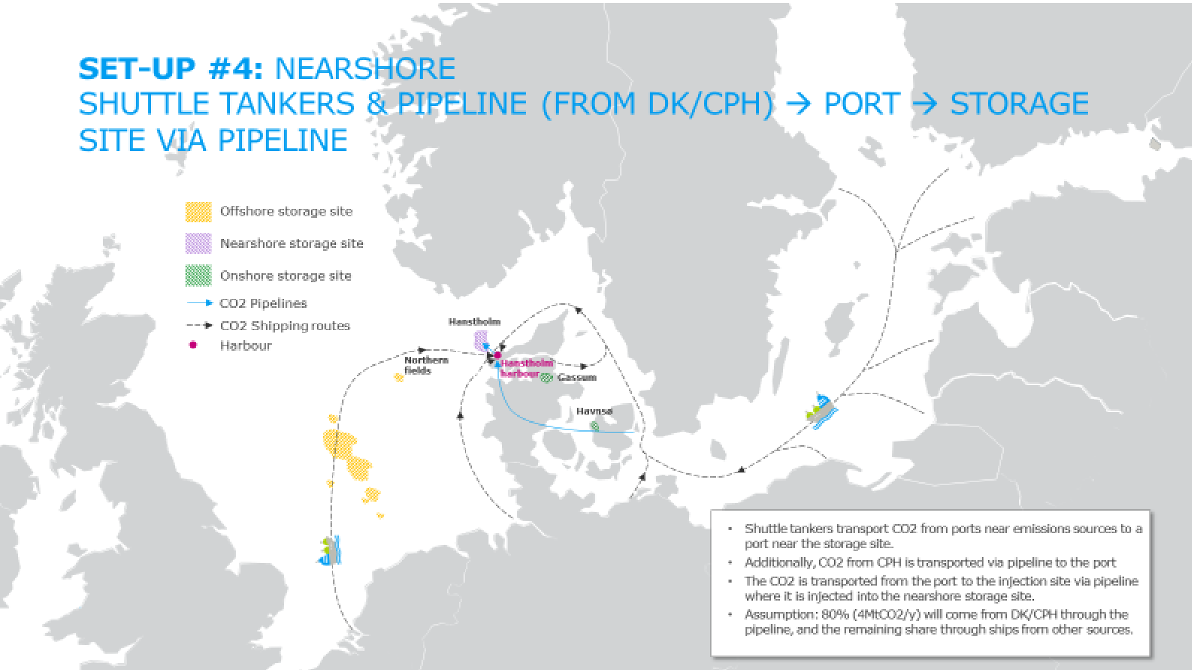
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 31: Set-up #3



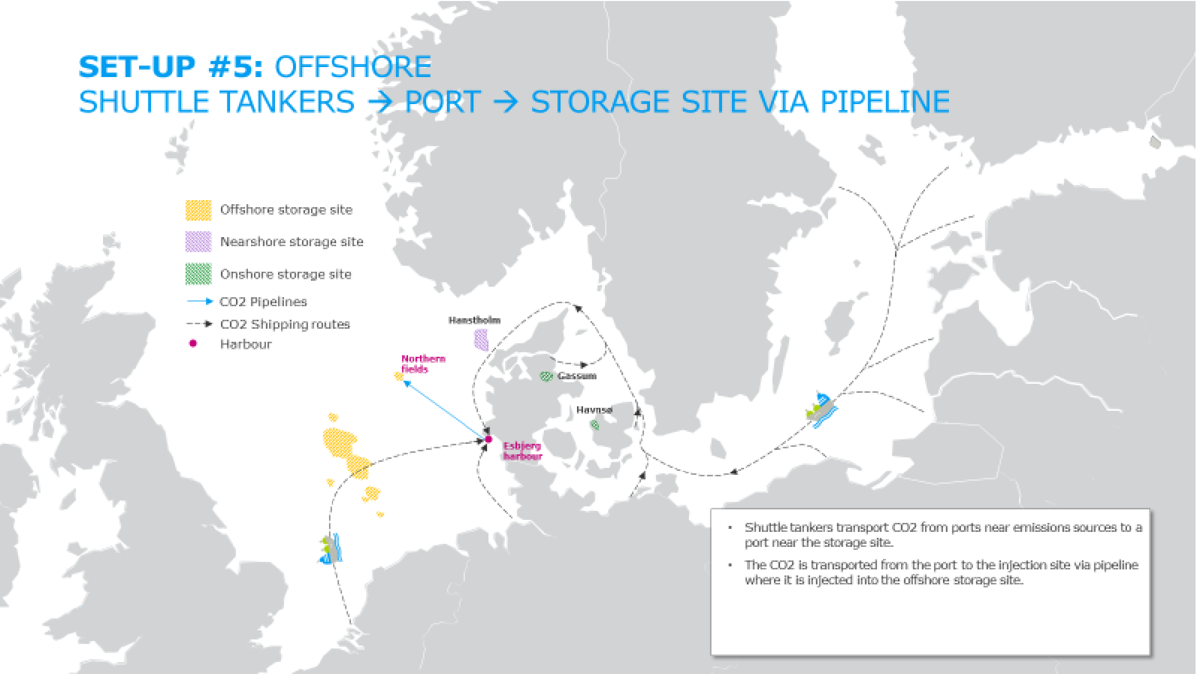
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 32: Set-up #4



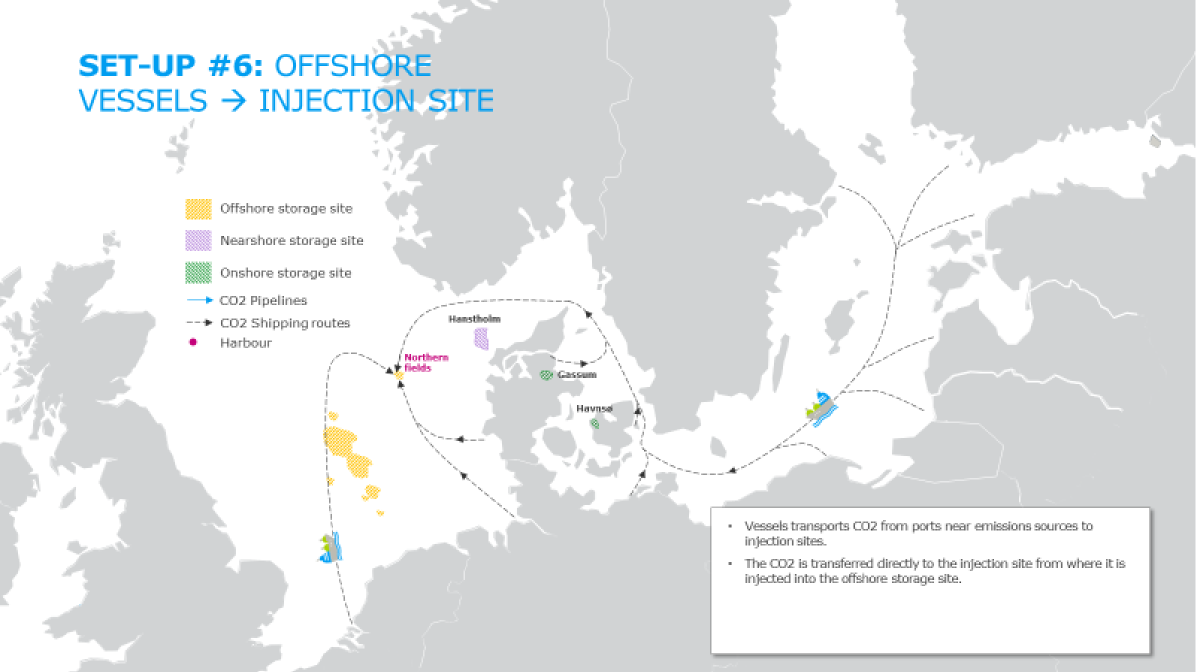
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 33: Set-up #5



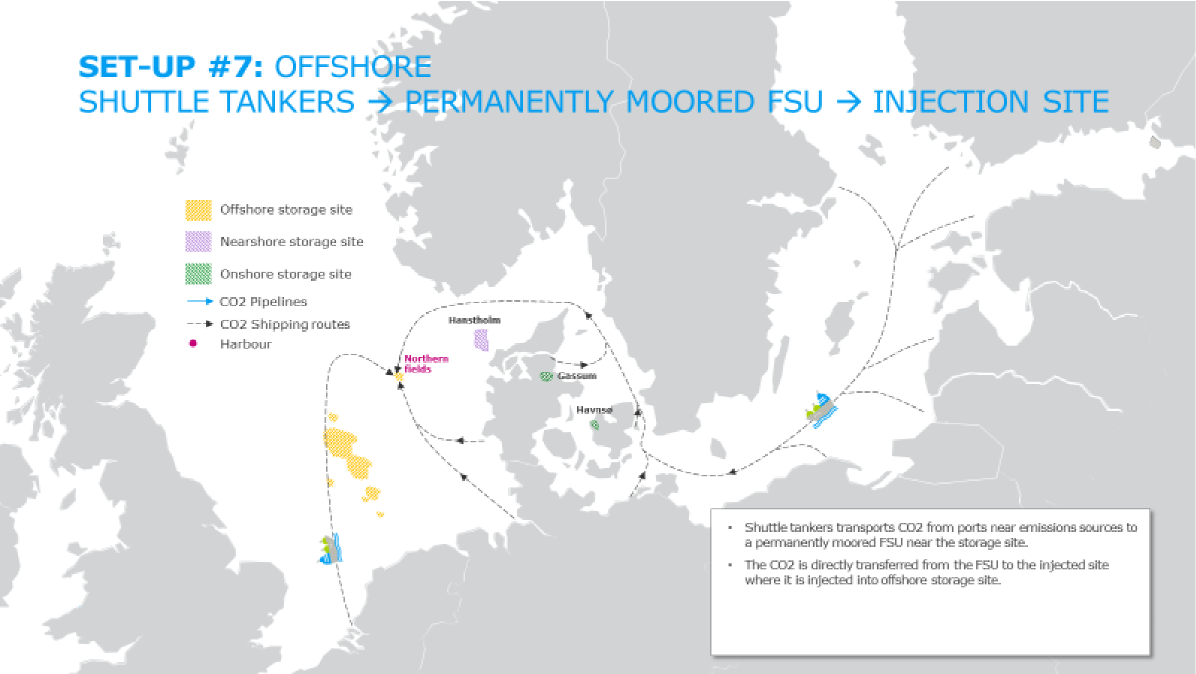
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 34: Set-up #6



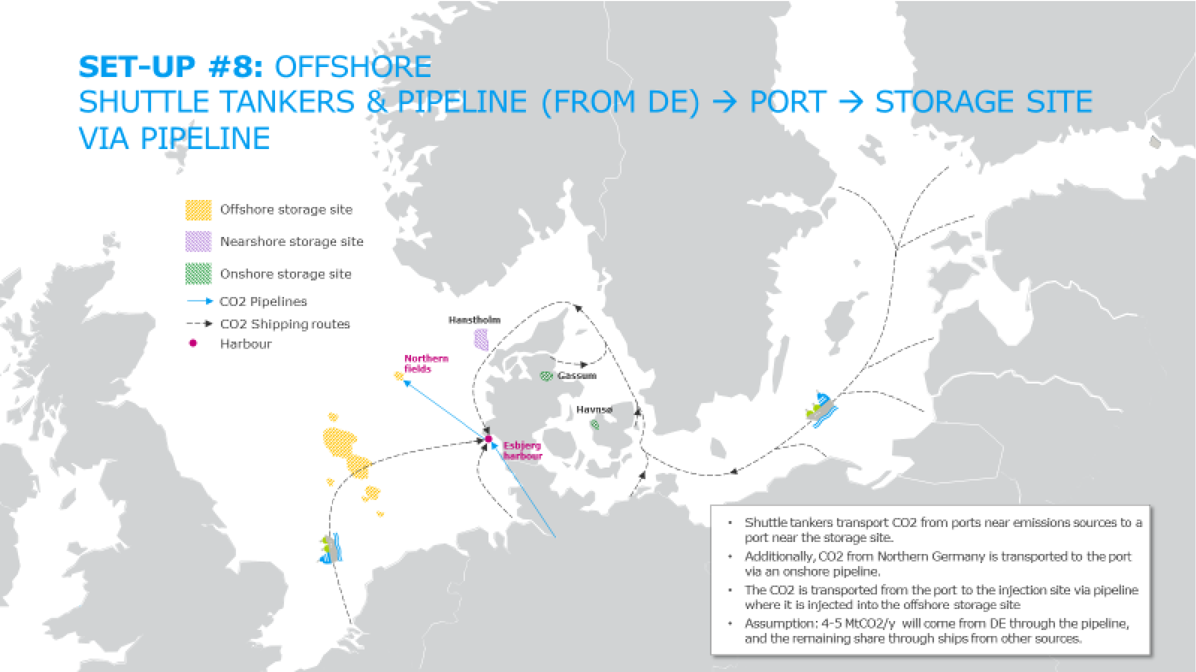
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 35: Set-up #7



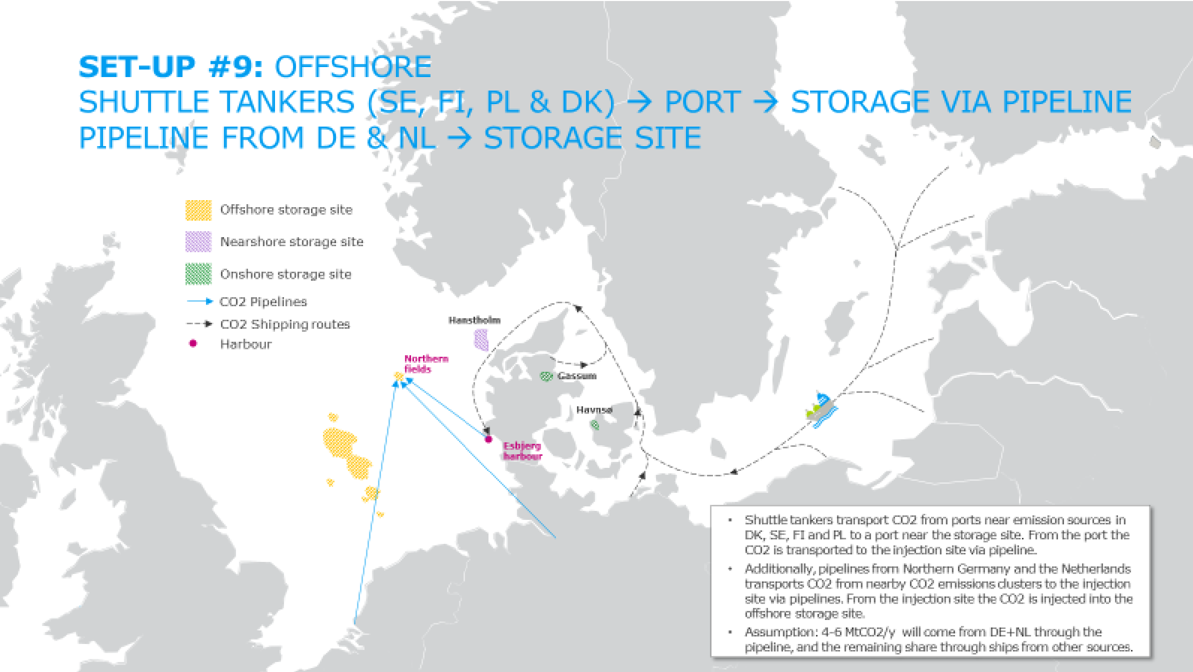
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 36: Set-up #8



Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

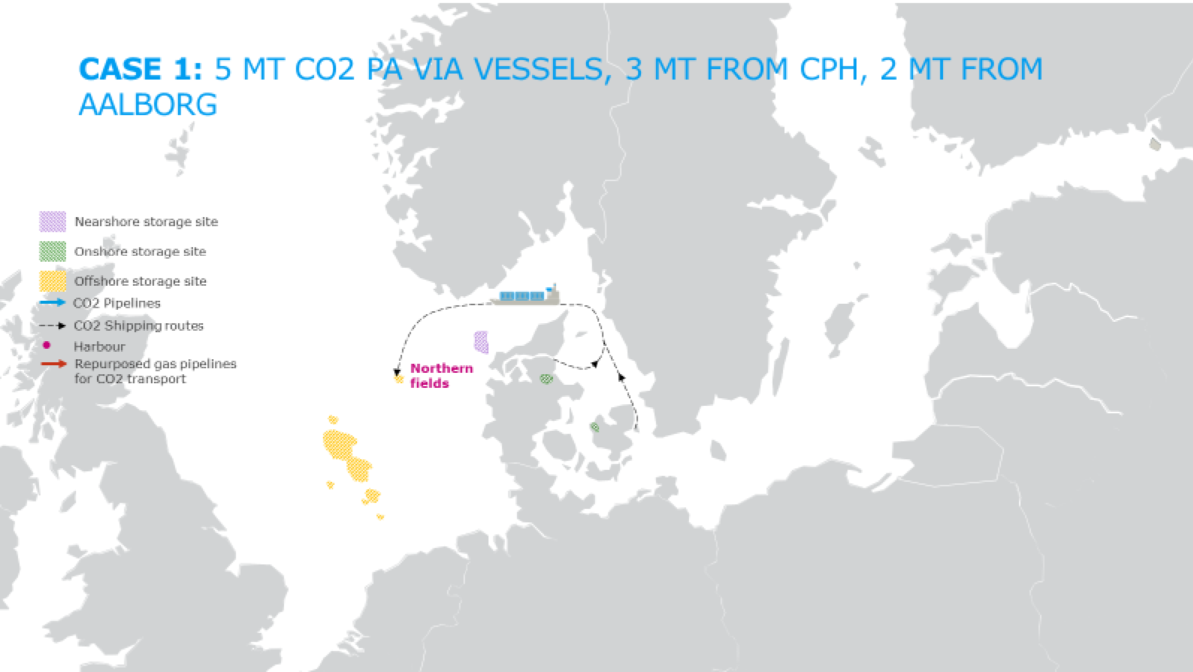
Figure 37: Set-up #9



Source: Ramboll analysis; Ramboll & the Danish Energy Agency

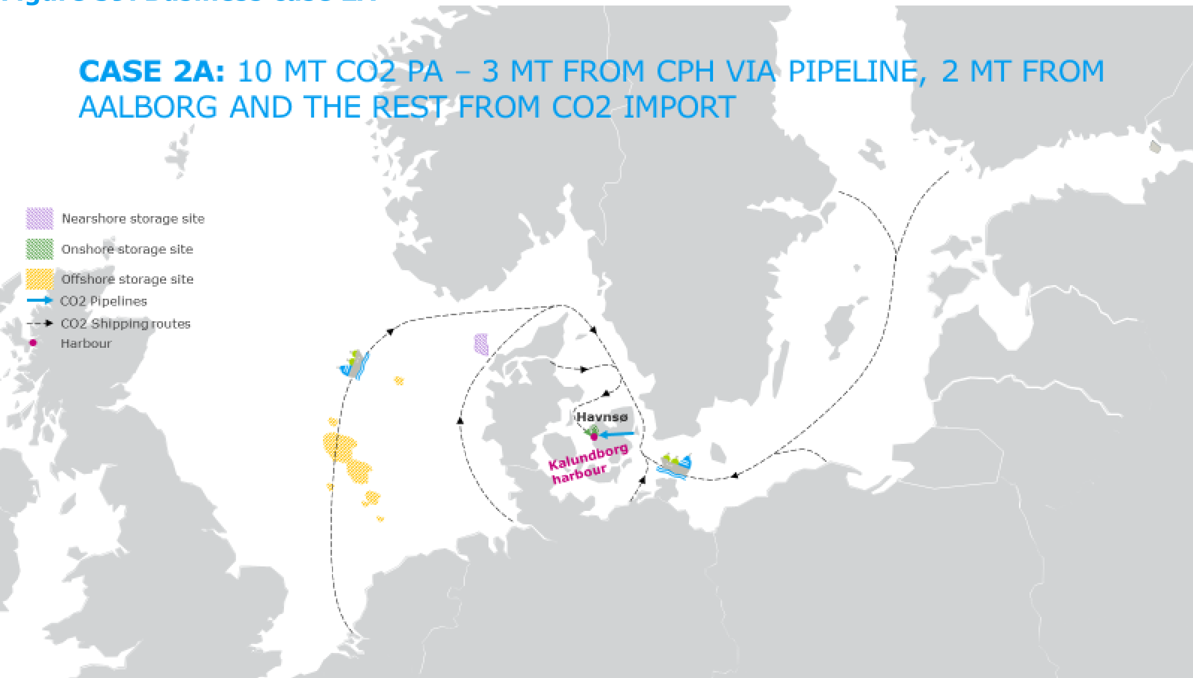
7.2 GRAPHICAL OVERVIEW OF BUSINESS CASES

Figure 38: Business case 1



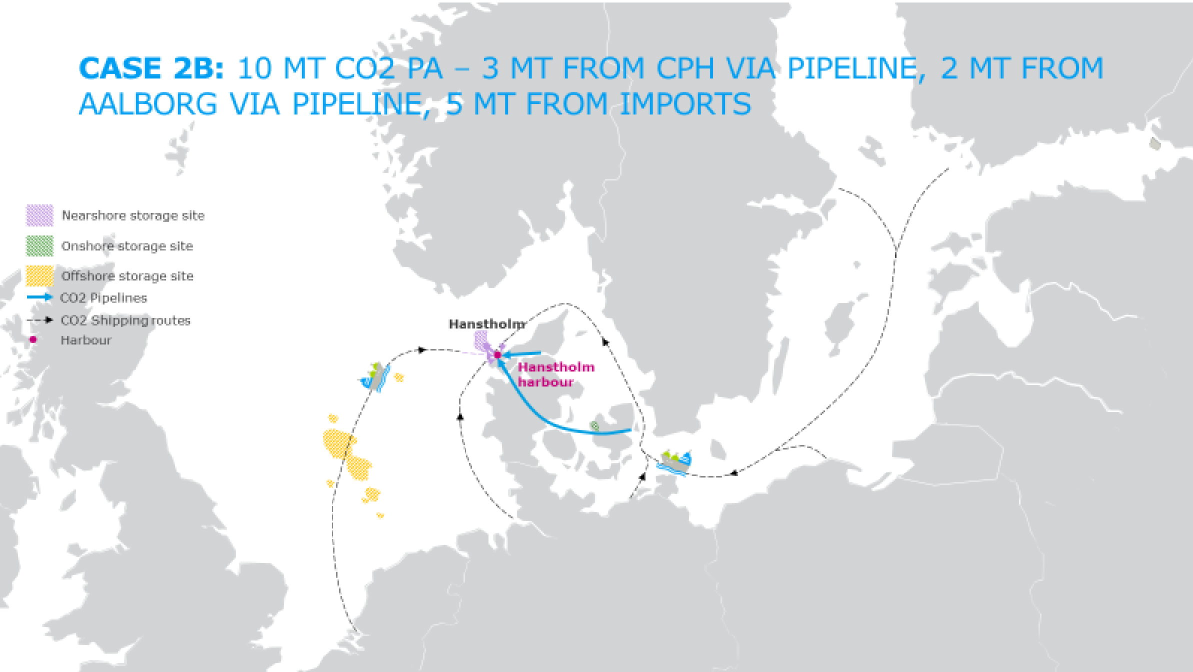
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 39: Business case 2A



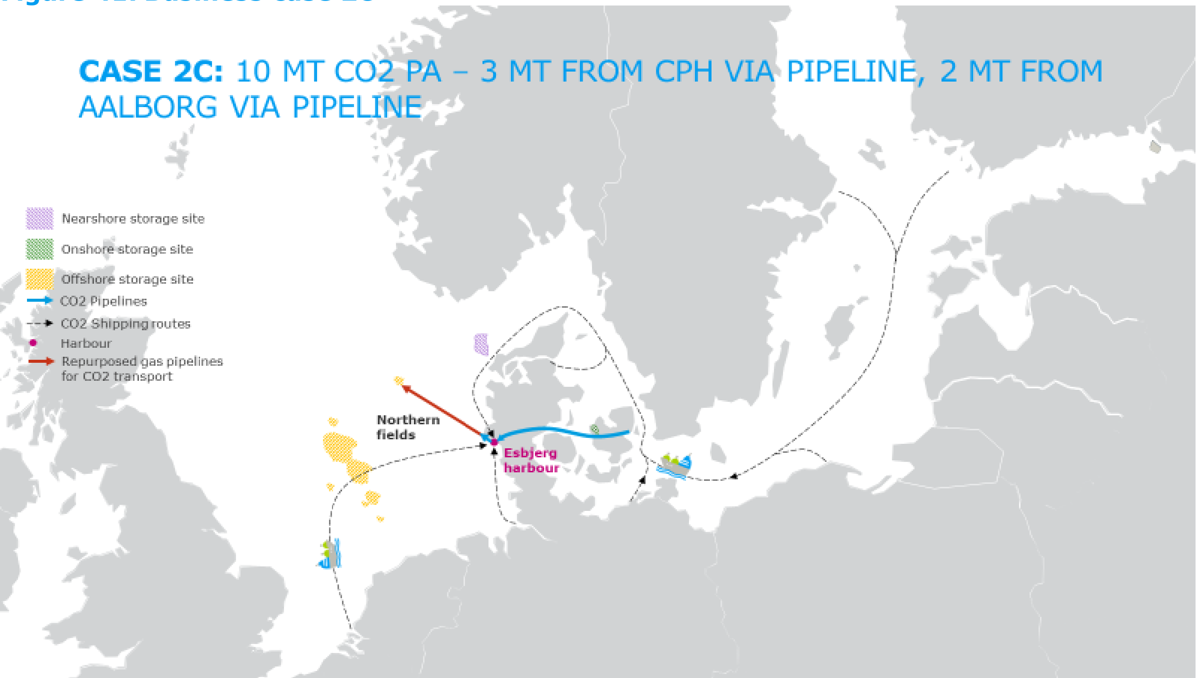
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 40: Business case 2B



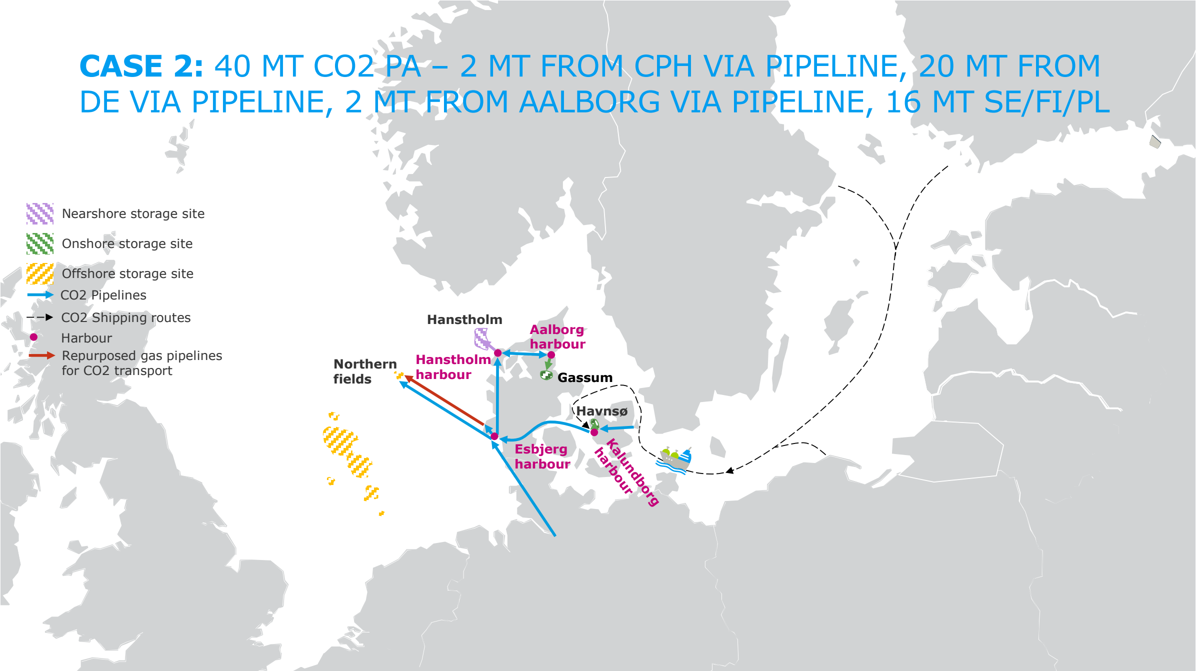
Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 41: Business case 2C



Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

Figure 42: Business case 3



Source: Ramboll analysis; Ramboll & the Danish Energy Agency, "Catalogue of Geological CO2 Storage in Denmark"

7.3 OVERVIEW OF COSTS AND ASSUMPTIONS PER BUSINESS MODEL SET-UP

This appendix section provides an overview of the cost for establishing and operating nine different CO2 transportation and storage set-ups based in Denmark.

Storage cost covers the cost of establishing, maintaining, and monitoring CO2 injection facilities and CO2 storage sites.

Transport cost covers the cost of transporting CO2 from ports near emission sources in five Northern European countries and domestically in Denmark to a Danish intermediate storage facility near a storage site. The costs are provided for the nine proposed setups identified in chapter 5.

Mapping of available options for transport and storage in Denmark, as well as cost estimates, is based on Catalogue of Geological Storage of CO2 in Denmark (to be published by Danish Energy Agency and Ramboll in 2021) and Catalogue on Technology Data for Energy Transport published by the Danish Energy Agency and Energinet (2017). Cost estimates from these sources have been supplemented by Ramboll's technical and commercial insights in connection with applying the costs to specific set-ups and scaling up.

The cost estimates follow the general assumptions outlined below:

- **The technical project lifetime** is assumed to be 30 years. While some equipment may have shorter lifetimes and some may have longer lifetimes, the average lifetime of equipment is expected to be 30 years. As a result, the accumulated OPEX of the project should supposedly cover 30 years of full operational expenditures. However, since ramping of injection rates to the assumed capacities is expected to take some years, the lifetime of the project at full operational capacity is expected to be effectively 27 years. As the operational expenditures are expected to ramp with the injection rate, the accumulated OPEX for the project will be reduced from covering 30 years to covering 27 years of full operational expenditures
- **Upgrading or retrofitting existing facilities** have not been included in the cost estimates of the set-ups, meaning all infrastructure associated with the project must be built from new
- **OPEX**
  - **Storage**: Covers storage facilities, injection facilities, wellhead platforms, wells, pipelines, mooring/loading systems, and FSUs which are based on offshore oil and gas industry norms, effectively percentages of CAPEX. This also includes monitoring, energy, standby vessels, base organisation, and staff
  - **Transport:** Covers fixed O&M for shuttle tankers, vessels, intermediate storage at export sites, onshore and offshore pipelines. It also includes fuel used during transportation
- **CAPEX**
  - **Storage:** Covers storage facilities, wellhead platforms, wells, pipelines, mooring/loading systems, and FSUs which are based on standards from the oil and gas industry and the size of the main components. This also covers any support systems for the facilities
  - **Transport:** Covers shuttle tankers, vessels, onshore and offshore pipeline, and any pumping stations associated with the pipelines
- **Pre-FID cost for storage** are incurred prior to final investment decision and are required to ensure the geological structures can store CO2 and to obtain the necessary approvals for establishing CO2 storage sites

- **Intermediate storage** is used at the port receiving the CO_2 as a buffer for delays. A capacity of 50,000 t of intermediate storage was adequate for a 5 $MtCO_2/y$ scenario, which, assuming the logistics are well optimised, will also be adequate for the 10 $MtCO_2/y$ scenarios presented below. Capacity is considered to cost 2,500 EUR/t.
- **Ships (shuttle tankers and vessel)** for CO_2 transport of the proposed size (20,000 t net capacity) have not yet been developed but is widely expected to be, and as a result, costs have been extrapolated using the cost of smaller ships as a basis
  - **Shuttle tankers** carry equipment for loading and unloading to and from intermediate storage facilities
  - **Vessels** carry injection and intermediate storage capabilities
- **A floating storage unit (FSU)** is a permanently moored vessel with injection and intermediate storage facilities where costs have been benchmarked against similar LNG FSUs. It only applies to offshore storage
- **Energy consumption** at onshore injection facilities is expected to be covered by electricity from the grid, where the cost of connection is included in the CAPEX of storage, pipeline, and injection facilities. Nearshore injection facilities are assumed to be connected by an AC electricity cable to the onshore grid, which will cover energy consumption. The cost of the AC cable is included in the CAPEX cost of the nearshore pipeline. Offshore operations (injection and intermediate storage) are assumed to connect to existing energy providing infrastructure in the North Sea. This means the cost of constructing the infrastructure that provides energy to the offshore operations is not included
- **Distances from exporting countries** are estimated based on the positions of ports near the largest emission clusters in a given country
- **Abatement expenditures ABEX** includes the port-to-storage pipelines, but not the transport pipelines, which are assumed can be repurposed after end-of-service, similarly to current oil and gas pipelines
- **Cost estimates do not consider** compensation to the local community for the loss of property value in the vicinity of the CO_2 storage site or facilities. Furthermore, costs related to upgrading of port facilities (jetty, quayside, etc.), liquefaction of CO_2 at export ports and any harbour fees related to docking have not been included

Table 50: Specific assumptions table

Overview of specific assumptions			
Name	**Unit**	**Value**	**Comments**
CO2 pipeline flow power	kW/km/(t CO2/h)	0.02	The amount of power it takes to pump a certain mass of CO2 a certain flow rate
Cost, heavy fuel oil (HFO)	EUR/ton	270	Assumed average price of HFO
Cost, intermediate storage capacity	EUR/t	2500	CAPEX cost of establishing intermediate storage capacity
Cost, shuttle tanker/vessel	MDKK	473	Cost of acquiring a CO2 shuttle tanker/vessel with 20,000 t net capacity
Energy consumption, shuttle tankers/vessels	MWh/day	256	The assumed energy consumption of a ship transporting 20,000 net ton of CO2 when at sea
Loading/unloading time per cycle, shuttle tanker	Days	1	The accumulated time it takes to load and unload a shuttle tanker per cycle
Loading/unloading time per cycle, vessel	Days	2	The accumulated time it takes to load and unload a vessel per cycle

Lower calorific value, heavy fuel oil (HFO)	MJ/kg	39.0	Amount of energy assumed to be extracted from HFO in a marine ICE engine
Pipeline, onshore, 3 MtCO2/y	MDKK/km	2.9	Assumed cost of onshore pipeline with 3 MtCO2/y capacity, based on oil and gas industry standards
Pipeline, onshore, 5 MtCO2/y	MDKK/km	3.5	Assumed cost of onshore pipeline with 5 MtCO2/y capacity, based on oil and gas industry standards
Pipeline, onshore, 10 MtCO2/y	MDKK/km	5.3	Assumed cost of onshore pipeline with 10 MtCO2/y capacity, based on oil and gas industry standards
Pipeline, onshore, 20 MtCO2/y	MDKK/km	7.0	Assumed cost of onshore pipeline with 20 MtCO2/y capacity, based on oil and gas industry standards
Pipeline, offshore, long 5 MtCO2/y	MDKK/km	7.0	Assumed cost of an offshore pipeline with 5 MtCO2/y capacity and no electricity cable, based on oil and gas industry standards
Pipeline, offshore, long 10 MtCO2/y	MDKK/km	11.0	Assumed cost of an offshore pipeline with 10 MtCO2/y capacity and no electricity cable, based on oil and gas industry standards
Pipeline, offshore, short 5 MtCO2/y	MDKK/km	7.0	Assumed cost of an offshore pipeline with 5 MtCO2/y capacity laid nearshore with an AC electricity cable, based on oil and gas industry standards
Pipeline, offshore, short 10 MtCO2/y	MDKK/km	11.0	Assumed cost of an offshore pipeline with 5 MtCO2/y capacity laid nearshore with an AC electricity cable, based on oil and gas industry standards
Pumping station, 3 MtCO2/y	MDKK	70	The pumping stations are placed every 200 km onshore transport pipelines or at each end of offshore transport pipelines
Pumping station, 5 MtCO2/y	MDKK	117	Pumping stations are placed every 200 km onshore transport pipelines or at each end of offshore transport pipelines
Pumping station, 10 MtCO2/y	MDKK	233	Pumping stations are placed every 200 km onshore transport pipelines or at each end of offshore transport pipelines
Pumping station, 20 MtCO2/y	MDKK	467	Pumping stations are placed every 200 km onshore transport pipelines or at each end of offshore transport pipelines
Utilisation rate, shuttle tankers	%	95	Expected rate of utilisation of the shuttle tankers, due to maintenance and routine inspections
Utilisation rate, vessel	%	90	Expected rate of utilisation of the vessels, due to maintenance and routine inspections

More details regarding specific assumptions and methodology for cost estimation are available in the Catalogue of Geological Storage of CO2 in Denmark published by the Danish Energy Agency and Ramboll in 2021 and the Catalogue on Technology Data for Energy Transport published by the Danish Energy Agency and Energinet (2017).

Estimated costs for each set-up are presented below. N**ote that the numbers do not include levelized cost of storage.**

OPTION #1: Onshore, shuttle tanker to Kalundborg harbour, then to Havnsø via pipeline

Table 51: Overview option #1

	Cost category	Unit	5 MtCO2/y	10 MtCO2/y	Comment
STORAGE	**Pre-FID**				
	2D seismic	MDKK	*90*	*127*	Based on the size of the area to be assessed
	Baseline studies	MDKK	*20*	*28*	Surveys all relevant pre-injection data
	Appraisal well	MDKK	*55*	*110*	The number of appraisal wells increases linearly with the size of the area to be appraised
	FEED studies	MDKK	*10*	*14*	Front end engineering design
	Approvals	MDKK	*20*	*28*	Regulatory approvals for establishing CO2 storage sites
	Total pre-FID costs	**MDKK**	**195**	**308**	
	CAPEX				
	Intermediate storage	MDKK	*180*	*180*	Assumed storage size of 50,000 t
	Injection plant	MDKK	*420*	*840*	Includes booster pumps, heat exchangers and boiler system
	Pipeline	MDKK	*140*	*212*	The pipeline between storage and injection site; cost is based on the length and industry-standard per km cost
	Injection wells	MDKK	*1,575*	*3,150*	The number of injection wells scales linearly to accommodate natural injection rate limitations of the storage site
	Wellhead platform	MDKK	*n/a*	*n/a*	The offshore structure that supports injection wells and associated support systems
	Mooring/loading system	MDKK	*n/a*	*n/a*	System for mooring and/or unloading CO2 offshore
	Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Permanently moored FSUs near offshore storage site have intermediate storage and injection capabilities
	Total CAPEX	**MDKK**	**2,315**	**4,382**	
	Acc. OPEX				
	Base organisation	MDKK	*175*	*247*	Covers day-to-day operations of the organisation
	Intermediate storage	MDKK	*223*	*223*	Facility size remains constant as additional buffer size does not provide value
	Injection plant	MDKK	*521*	*1,042*	The accumulated variable cost for operating the injection plant systems
	Pipeline	MDKK	*38*	*57*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime period
	Injection wells	MDKK	*427*	*854*	The accumulated variable cost of operating wells for injection of CO2 into subsurface reservoirs

		Monitoring	MDKK	*670*	*948*	Post-injection monitoring is only evaluated over a 20-year period
		Power	MDKK	*884*	*1,768*	Power scales linearly with the project size and is based on 0.5 DKK/KWh pricing
		Wellhead platform	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the wellhead platform
		Standby vessel	MDKK	*n/a*	*n/a*	Scales linearly with the number of vessels expected to be near the storage site
		Mooring/loading system	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the mooring/loading system offshore
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the FSU offshore
		Total acc. OPEX	**MDKK**	**2,938**	**5,139**	
		Closure costs				
		Abandonment cost	MDKK	*405*	*767*	Evaluated as 17,5% of total storage CAPEX
		Post-Closure cost	MDKK	*400*	*566*	Cost of monitoring the storage site post-closure
		Total closure costs	**MDKK**	**805**	**1,333**	
CO2 TRANSPORT	**Shuttle tanker/ Vessel**	**CAPEX**				
		Transport shuttle	MDKK	*1,419*	*2,365*	Import via shuttle tankers is assumed to be 100% of the import volume
		Vessel	MDKK	*n/a*	*n/a*	The additional cost of equipment for the vessels is included in the CAPEX and OPEX for storage
		Export intermediate storage	MDKK	*2,250*	*2,625*	Total export intermediate storage is 120,000 t and 140,000 t for each scenario, respectively, split between the exporting countries relative to their expected export volume
		Total CAPEX	**MDKK**	**3,669**	**4,990**	
		Acc. OPEX	MDKK			
		Transport shuttle fixed O&M	MDKK	*3,738*	*5,319*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Vessels fixed O&M	MDKK	*n/a*	*n/a*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Fuel	MDKK	*673*	*1,347*	Shuttle tankers during transport are assumed to consume 256 MWh per day, which drives fuel costs
		Total acc. OPEX	**MDKK**	**4,412**	**6,666**	

	Pipeline	**CAPEX**				
		Onshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Offshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Pumping station	MDKK	*n/a*	*n/a*	One pumping stations is added for every 200 km of pipeline commenced and one at each end of the offshore pipeline
		Total CAPEX	**MDKK**	**n/a**	**n/a**	
		Acc. OPEX				
		Onshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Offshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Power	MDKK	*n/a*	*n/a*	Based on 0.5 DKK/KWh pricing
		Total acc. OPEX	**MDKK**	***n/a***	***n/a***	
Total cost/t			**DKK/t**	**106**	**85**	
*****_hereof storage_			**DKK/t**	**46**	**41**	
**hereof transport*			**DKK/t**	**60**	**43**	

Other case-specific assumptions:

- Transport pipelines are not included in this set-up
- 50% of German CO2 exports are assumed to come from Rostock (East of Jutland), and the remaining 50% is assumed to come from Hamburg (West of Jutland)
- 100% of exports from NL is assumed to come from Rotterdam harbour

OPTION #2: Onshore, shuttle tanker to Kalundborg harbour and pipeline from Copenhagen to Kalundborg harbour, then to Havnsø via pipeline

Table 52: Overview option #2

	Cost category	Unit	5 MtCO2/y	10 MtCO2/y	Comment
STORAGE	**Pre-Fid**				
	2D seismic	MDKK	*90*	*127*	Based on the size of the area to be assessed
	Baseline studies	MDKK	*20*	*28*	Surveys all relevant pre-injection data
	Appraisal well	MDKK	*55*	*110*	The number of appraisal wells increases linearly with the size of the area to be appraised
	FEED studies	MDKK	*10*	*14*	Front end engineering design
	Approvals	MDKK	*20*	*28*	Regulatory approvals for establishing CO2 storage sites
	Total pre-FID costs	MDKK	**195**	**308**	
	CAPEX				
	Intermediate storage	MDKK	*180*	*180*	Assumed storage size of 50,000 t
	Injection plant	MDKK	*420*	*840*	Includes booster pumps, heat exchangers and boiler system
	Pipeline	MDKK	*140*	*212*	The pipeline between storage and injection site; cost is based on the length and industry-standard per km cost
	Injection wells	MDKK	*1,575*	*3,150*	The number of injection wells scales linearly to accommodate natural injection rate limitations of the storage site
	Wellhead platform	MDKK	*n/a*	*n/a*	The offshore structure that supports injection wells and associated support systems
	Mooring/loading system	MDKK	*n/a*	*n/a*	System for mooring and/or unloading CO2 offshore
	Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Permanently moored FSUs near offshore storage site have intermediate storage and injection capabilities
	Total CAPEX	**MDKK**	**2,315**	**4,382**	
	Acc. OPEX				
	Base organisation	MDKK	*175*	*247*	Covers day-to-day operations of the organisation
	Intermediate storage	MDKK	*223*	*223*	Facility size remains constant as additional buffer size does not provide value
	Injection plant	MDKK	*521*	*1,042*	Accumulated variable cost for operating the injection plant systems
	Pipeline	MDKK	*38*	*57*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime period

		Injection wells	MDKK	*427*	*854*	Accumulated variable cost of operating wells for injection of CO2 into subsurface reservoirs
		Monitoring	MDKK	*670*	*948*	Post-injection monitoring is only evaluated over a 20-year period
		Power	MDKK	*884*	*1,768*	Power scales linearly with the project size and is based on 0.5 DKK/KWh pricing
		Wellhead platform	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the wellhead platform
		Standby vessel	MDKK	*n/a*	*n/a*	Scales linearly with the number of vessels expected to be near the storage site
		Mooring/loading system	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the mooring/loading system offshore
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the FSU offshore
		Total acc. OPEX	**MDKK**	**2,938**	**5,139**	
		Closure costs				
		Abandonment cost	MDKK	*405*	*767*	Evaluated as 17,5% of total storage CAPEX
		Post-Closure cost	MDKK	*400*	*566*	Cost of monitoring the storage site post-closure
		Total closure costs	**MDKK**	**805**	**1,333**	
CO2 TRANSPORT	**Shuttle tanker/ Vessel**	**CAPEX**				
		Transport shuttle	MDKK	*473*	*1,419*	Import via shuttle tankers is assumed to increase from 20% of the import volume to 60% between the 5 and 10 MtCO2/y scenarios
		Vessel	MDKK	*n/a*	*n/a*	Additional cost of equipment for the vessels is included in the CAPEX and OPEX for storage
		Export intermediate storage	MDKK	*2,250*	*2,625*	Total export intermediate storage is 120,000 t and 140,000 t for each scenario, respectively, split between the exporting countries relative to their expected export volume
		Total CAPEX	**MDKK**	**2,723**	**4,044**	
		Acc. OPEX				
		Transport shuttle fixed O&M	MDKK	*2,461*	*4,042*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Vessels fixed O&M	MDKK	*n/a*	*n/a*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Fuel	MDKK	*146*	*875*	Shuttle tankers during transport have been assumed to consume 256 MWh per day, which drives fuel costs
		Total acc. OPEX	**MDKK**	**2,607**	**4,917**	

	Pipeline	**CAPEX**				
		Onshore pipeline	MDKK	*350*	*350*	Normally cost would be 5,3 MDKK/km for 10MT/y, but this is adjusted as the same amount goes through the pipeline from CPH-Kalundborg as in 5Mt/y scenario
		Offshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Pumping station	MDKK	*117*	*117*	One pumping stations is added for every 200 km of pipeline commenced and one at each end of an offshore pipeline
		Total CAPEX	**MDKK**	**467**	**467**	
		Acc. OPEX				
		Onshore pipeline fixed O&M	MDKK	*95*	*95*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Offshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Power	MDKK	*108*	*108*	Based on 0.5 DKK/KWh pricing
		Total acc. OPEX	**MDKK**	**203**	**203**	
Total cost/t			**DKK/t**	**91**	**77**	
***hereof storage**			**DKK/t**	**46**	**41**	
**hereof transport*			**DKK/t**	**44**	**36**	

Other case-specific assumptions:

- A 100 km CO2 transport pipeline from CPH to Kalundborg harbour is included in this set-up carrying 4 MtCO2/y
- Additional import volume between the 5 and 10 MtCO2/y cases is assumed to be transported using only shuttle tankers
- 50% of German CO2 exports are assumed to come from Rostock (East of Jutland), and the remaining 50% is assumed to come from Hamburg (West of Jutland)
- 100% of exports from NL is assumed to come from Rotterdam harbour

OPTION #3: Nearshore, shuttle tanker to Hanstholm harbour, then to Hanstholm storage site via pipeline

Table 53: Overview option #3

	Cost category	Unit	5 MtCO2/y	10 MtCO2/y	Comment
STORAGE	**Pre-Fid**				
	3D seismic	MDKK	*90*	*127*	Based on the size of the area to be assessed
	Baseline studies	MDKK	*20*	*28*	Surveys all relevant pre-injection data
	Appraisal well	MDKK	*230*	*460*	The number of appraisal wells increases linearly with the size of the area to be appraised
	FEED studies	MDKK	*10*	*14*	Front end engineering design
	Approvals	MDKK	*20*	*28*	Regulatory approvals for establishing CO2 storage sites
	Total pre-FID costs	**MDKK**	**370**	**658**	
	CAPEX				
	Intermediate storage	MDKK	*180*	*180*	Assumed storage size of 50,000 t
	Injection plant	MDKK	*420*	*840*	Includes booster pumps, heat exchangers and boiler system
	Pipeline and power cable	MDKK	*350*	*550*	The pipeline between storage and injection site; cost is based on the length and industry-standard per km cost; includes an AC cable providing power to injection operations
	Injection wells	MDKK	*2,835*	*5,670*	The number of injection wells scales linearly to accommodate natural injection rate limitations
	Wellhead platform	MDKK	*280*	*396*	The offshore structure that supports injection wells and associated support systems
	Mooring/loading system	MDKK	*n/a*	*n/a*	System for mooring and/or unloading CO2 offshore
	Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Permanently moored FSUs near offshore storage site have intermediate storage and injection capabilities
	Total CAPEX	**MDKK**	**4,065**	**7,636**	
	Acc. OPEX				
	Base organisation	MDKK	*350*	*495*	Covers day-to-day operations of the organisation
	Intermediate storage	MDKK	*223*	*223*	Facility size remains constant as additional buffer size does not provide value
	Injection plant	MDKK	*521*	*1,042*	Accumulated variable cost for operating the injection plant systems
	Pipeline and power cable	MDKK	95	149	Costs are evaluated as a 1% of CAPEX per year for the full technical lifetime period
	Injection wells	MDKK	*825*	*1,650*	Accumulated variable cost of operating wells for injection of CO2 into subsurface reservoirs

		Monitoring	MDKK	*920*	*1,301*	Post-injection monitoring is only evaluated over 20 years
		Power	MDKK	*884*	*1,768*	Power scales linearly with the project size and is based on 0.5 DKK/KWh pricing
		Wellhead platform	MDKK	*694*	*981*	Accumulated variable cost for operating the wellhead platform
		Standby vessel	MDKK	*n/a*	*n/a*	Scales linearly with the number of vessels expected to be near the storage site
		Mooring/loading system	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the mooring/loading system offshore
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the FSU offshore
		Total acc. OPEX	**MDKK**	**4,512**	**7,609**	
		Closure costs				
		Abandonment cost	MDKK	*711*	*1,336*	Evaluated as 17,5% of total storage CAPEX
		Post-Closure cost	MDKK	*600*	*849*	Cost of monitoring the storage site post-closure
		Total closure costs	**MDKK**	**1,311**	**2,185**	
CO2 TRANSPORT	**Shuttle tanker/ Vessel**	**CAPEX**				
		Transport shuttle	MDKK	*1,419*	*2,838*	Import via shuttle tankers is assumed to be 100% of the import volume
		Vessel	MDKK	*n/a*	*n/a*	Additional cost of equipment for the vessels is included in the CAPEX and OPEX for storage
		Export intermediate storage	MDKK	*2,250*	*2,625*	Total export intermediate storage is 120,000 t and 140,000 t for each scenario, respectively, split between the exporting countries relative to their expected export volume
		Total CAPEX	**MDKK**	**3,669**	**5,463**	
		Acc. OPEX				
		Transport shuttle fixed O&M	MDKK	*3,738*	*5,958*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Vessels fixed O&M	MDKK	*n/a*	*n/a*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Fuel	MDKK	*761*	*1,522*	Shuttle tankers during transport have been assumed to consume 256 MWh per day, which drives fuel costs
		Total acc. OPEX	**MDKK**	**4,499**	**7,480**	
	Pipeline	**CAPEX**				
		Onshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity

		Offshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Pumping station	MDKK	*n/a*	*n/a*	Shuttle tankers during transport are assumed to consume 256 MWh per day, which drives fuel costs
		Total CAPEX	**MDKK**	**n/a**	**n/a**	
		Acc. OPEX				
		Onshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Offshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Power	MDKK	*n/a*	*n/a*	Based on 0.5 DKK/KWh pricing
		Total acc. OPEX	**MDKK**	**n/a**	**n/a**	
Total cost/t			**DKK/t**	**136**	**115**	
hereof storage			**DKK/t**	**76**	**67**	
**hereof transport*			**DKK/t**	**61**	**48**	

Other case-specific assumptions:

- Transport pipelines are not included in this set-up
- 50% of German CO2 exports is expected to come from Rostock (East of Jutland), and the remaining 50% is expected to come from Hamburg (West of Jutland)
- 100% of exports from NL is assumed to come from Rotterdam harbour
- Energy is provided to the injection site via an AC electricity cable from the onshore grid to the nearshore injection operations

OPTION #4: Nearshore, shuttle tanker to Hanstholm harbour and pipeline from Copenhagen to Hanstholm harbour, then to Hanstholm storage site via pipeline

Table 54: Overview option #4

	Cost category	Unit	5 MtCO2/y	10 MtCO2/y	Comment
STORAGE	**Pre-Fid**				
	3D seismic	MDKK	*90*	*127*	Based on the size of the area to be assessed
	Baseline studies	MDKK	*20*	*28*	Surveys all relevant pre-injection data
	Appraisal well	MDKK	*230*	*460*	The number of appraisal wells increase linearly with the size of the area to be appraised
	FEED studies	MDKK	*10*	*14*	Front end engineering design
	Approvals	MDKK	*20*	*28*	Regulatory approvals for establishing CO2 storage sites
	Total pre-FID costs	**MDKK**	**370**	**658**	
	CAPEX				
	Intermediate storage	MDKK	*180*	*180*	Assumed storage size of 50,000 t
	Injection plant	MDKK	*420*	*840*	Includes booster pumps, heat exchangers and boiler system
	Pipeline and power cable	MDKK	*350*	*550*	The pipeline between storage and injection site; cost is based on the length and industry-standard per km cost; includes an AC cable providing power to injection operations
	Injection wells	MDKK	*2,835*	*5,670*	The number of injection wells scales linearly to accommodate natural injection rate limitations
	Wellhead platform	MDKK	*280*	*396*	The offshore structure that supports injection wells and associated support systems
	Mooring/loading system	MDKK	*n/a*	*n/a*	System for mooring and/or unloading CO2 offshore
	Purpose built CO2 carrier / FSU	MDKK	*180*	*180*	Permanently moored FSUs near offshore storage site have intermediate storage and injection capabilities
	Total CAPEX	**MDKK**	**4,065**	**7,636**	
	Acc. OPEX				
	Base organisation	MDKK	*350*	*495*	Covers day-to-day operations of the organisation
	Intermediate storage	MDKK	*223*	*223*	Facility size remains constant as additional buffer size does not provide value
	Injection plant	MDKK	*521*	*1,042*	Accumulated variable cost for operating the injection plant systems
	Pipeline and power cable	MDKK	*95*	*149*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime period
	Injection wells	MDKK	*825*	*1,650*	Accumulated variable cost of operating wells for injection of CO2 into subsurface reservoirs

		Monitoring	MDKK	*920*	*1,301*	Post-injection monitoring is only evaluated over a 20-year period
		Power	MDKK	*884*	*1,768*	Power scales linearly with the project size and is based on 0.5 DKK/KWh pricing
		Wellhead platform	MDKK	*694*	*981*	Accumulated variable cost for operating the wellhead platform
		Standby vessel	MDKK	*n/a*	*n/a*	Scales linearly with the number of vessels expected to be near the storage site
		Mooring/loading system	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the mooring/loading system offshore
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the FSU offshore
		Total CAPEX	**MDKK**	**4,512**	**7,609**	
		Closure costs				
		Abandonment cost	MDKK	*711*	*1,336*	Evaluated as 17,5% of total storage CAPEX
		Post-Closure cost	MDKK	*600*	*849*	Cost of monitoring the storage site post-closure
		Total closure costs	**MDKK**	**1,311**	**2,185**	
CO2 TRANSPORT	**Shuttle tanker/ Vessel**	**CAPEX**				
		Transport shuttle	MDKK	*473*	*1,892*	Import via shuttle tankers is assumed to increase from 20% of the import volume to 60% between the 5 and 10 MtCO2/y scenarios
		Vessel	MDKK	*n/a*	*n/a*	The additional cost of equipment for the vessels is included in the CAPEX and OPEX for storage
		Export intermediate storage	MDKK	*1,875*	*2,063*	Total export intermediate storage is 100,000 t and 110,000 t for each scenario, respectively, split between the exporting countries relative to their expected export volume
		Total CAPEX	**MDKK**	**2,348**	**3,955**	
		Acc. OPEX	MDKK			
		Transport shuttle fixed O&M	MDKK	*2,157*	*4,225*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Vessels fixed O&M	MDKK	*n/a*	*n/a*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Fuel	MDKK	*159*	*952*	Shuttle tankers during transport have been assumed to consume 256 MWh per day, which drives fuel costs
		Total acc. OPEX	**MDKK**	**2,316**	**5,177**	

	Pipeline	**CAPEX**				
		Onshore pipeline	MDKK	*1,050*	*1,050*	Cost of pipeline from CPH to Hanstholm is split into two parts, onshore part and offshore part; throughput of 4 MtCO2/y is assumed the same for both scenarios meaning no change in price
		Offshore pipeline	MDKK	*700*	*700*	
		Pumping station	MDKK	*350*	*350*	One pumping stations is added for every 200 km of pipeline commenced and one at each end of an offshore pipeline
		Total CAPEX	**MDKK**	**2,100**	**2,100**	
		Acc. OPEX				
		Onshore pipeline fixed O&M	MDKK	*284*	*284*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Offshore pipeline fixed O&M	MDKK	*189*	*297*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Power	MDKK	*432*	*432*	Based on 0.5 DKK/KWh pricing
		Total acc. OPEX	**MDKK**	**905**	**1,013**	
Total cost/t			**DKK/t**	**133**	**112**	
***hereof storage**			**DKK/t**	**76**	**67**	
***hereof transport**			**DKK/t**	**57**	**45**	

Other case-specific assumptions:

- A 400 km CO2 transport pipeline from CPH to Hanstholm harbour is included in this set-up, consisting of 300 km onshore pipeline and 100 km offshore pipeline, assumed to transport 4 MtCO2/y for both the 5 and 10 MtCO2/y scenarios. Additional import volume for the 5 and 10 MtCO2/y scenarios is assumed to be transported from emission sources to Hanstholm harbour using shuttle tankers
- 50% of German CO2 exports are assumed to come from Rostock (East of Jutland), and the remaining 50% is assumed to come from Hamburg (West of Jutland)
- 100% of exports from NL is assumed to come from Rotterdam harbour
- Energy is provided to the injection site via an AC electricity cable from the onshore grid to the nearshore injection operations

OPTION #5: Offshore, shuttle tanker to Esbjerg harbour, then to the North Sea offshore storage site via pipeline

Table 55: Overview option #5

		Cost category	Unit	5 MtCO2/y	10 MtCO2/y	Comment
STORAGE		**Pre-Fid**				
		3D seismic	MDKK	*70*	*99*	Based on the size of the area to be assessed
		Baseline studies	MDKK	*20*	*28*	Surveys all relevant pre-injection data
		Appraisal well	MDKK	*n/a*	*n/a*	Appraisal wells are not included as the geological structures of the offshore storage sites are assumed to be well known due to prior mapping by the oil and gas industry
		FEED studies	MDKK	*10*	*14*	Front end engineering design
		Approvals	MDKK	*20*	*28*	Regulatory approvals for establishing CO2 storage sites
		Total pre-FID costs	**MDKK**	**120**	**170**	
		CAPEX				
		Intermediate storage	MDKK	*180*	*180*	Assumed storage size of 50,000 t
		Injection plant	MDKK	*390*	*780*	Includes booster pumps, heat exchangers and boiler system
		Pipeline	MDKK	*1,750*	*2,750*	The pipeline between storage and injection site; does not include the cost of electricity cable; cost is based on the length and industry-standard per km cost
		Injection wells	MDKK	*1,925*	*3,850*	The number of injection wells scales linearly to accommodate natural injection rate limitations
		Wellhead platform	MDKK	*525*	*742*	The offshore structure that supports injection wells and associated support systems
		Mooring/loading system	MDKK	*n/a*	*n/a*	System for mooring and/or unloading CO2 offshore
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Permanently moored FSUs near offshore storage site have intermediate storage and injection capabilities
		Total CAPEX	**MDKK**	**4,770**	**8,302**	
		Acc. OPEX				
		Base organisation	MDKK	*525*	*742*	Covers day-to-day operations of the organisation
		Intermediate storage	MDKK	*223*	*223*	Facility size remains constant as additional buffer size does not provide value
		Injection plant	MDKK	*967*	*1,934*	Accumulated variable cost for operating the injection plant systems
		Pipeline	MDKK	*473*	*743*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime period

		Injection wells	MDKK	*527*	*1,054*	Accumulated variable cost of operating wells for injection of CO2 into subsurface reservoirs
		Monitoring	MDKK	*920*	*1,301*	Post-injection monitoring is only evaluated over 20 years
		Power	MDKK	*3,036*	*6,072*	Power scales linearly with the project size and is based on 0.5 DKK/KWh pricing
		Wellhead platform	MDKK	*2,430*	*3,437*	Accumulated variable cost for operating the wellhead platform
		Standby vessel	MDKK	*n/a*	*n/a*	Scales linearly with the number of vessels expected to be near the storage site
		Mooring/loading system	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the mooring/loading system offshore
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the FSU offshore
		Total CAPEX	**MDKK**	**9,101**	**15,506**	
		Closure costs				
		Abandonment cost	MDKK	*835*	*1,453*	Evaluated as 17,5% of total storage CAPEX
		Post-Closure cost	MDKK	*600*	*849*	Cost of monitoring the storage site post-closure
		Total closure costs	**MDKK**	**1,435**	**2,301**	
CO2 TRANSPORT	**Shuttle tanker/ Vessel**	**CAPEX**				
		Transport shuttle	MDKK	*1,419*	*2,838*	Import via shuttle tankers is assumed to be 100% of the import volume
		Vessel	MDKK	*n/a*	*n/a*	Additional cost of equipment for the vessels is included in the CAPEX and OPEX for storage
		Export intermediate storage	MDKK	*2,250*	*2,625*	Total export intermediate storage is 120,000 t and 140,000 t for each scenario, respectively, split between the exporting countries relative to their expected export volume
		Total CAPEX	**MDKK**	**3,669**	**5,463**	
		Acc. OPEX	MDKK			
		Transport shuttle fixed O&M	MDKK	*3,738*	*5,958*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Vessels fixed O&M	MDKK	*n/a*	*n/a*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Fuel	MDKK	*848*	*1,697*	Shuttle tankers during transport are assumed to consume 256 MWh per day, which drives fuel costs
		Total acc. OPEX	**MDKK**	**4,587**	**7,655**	

	Pipeline	**CAPEX**				
		Onshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Offshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Pumping station	MDKK	*n/a*	*n/a*	One pumping stations is added for every 200 km of pipeline commenced and 1 at each end of the offshore pipeline
		Total CAPEX	**MDKK**	**n/a**	**n/a**	
		Acc. OPEX				
		Onshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Offshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Power	MDKK	*n/a*	*n/a*	Based on 0.5 DKK/KWh pricing
		Total acc. OPEX	**MDKK**	**n/a**	**n/a**	
Total cost/t			**DKK/t**	**175**	**146**	
hereof storage			**DKK/t**	**114**	**97**	
**hereof transport*			**DKK/t**	**61**	**49**	

Other case-specific assumptions:

- Transport pipelines are not included in this set-up
- 50% of German CO2 exports are assumed to come from Rostock (East of Jutland), and the remaining 50% is assumed to come from Hamburg (West of Jutland)
- 100% of exports from NL is assumed to come from Rotterdam harbour
- Infrastructure for providing energy offshore is assumed to already be installed and has not been included in the above estimates
- Injection wells are placed in the Northern part of the North Sea oil and gas fields as the geological structure of these sites means fewer wells are needed for the same injection rate compared to the remaining Danish oil and gas fields

OPTION #6: Offshore, vessel to North Sea offshore storage site, then direct injection of CO2 into storage site using onboard equipment

Table 56: Overview option #6

		Cost category	Unit	5 MtCO2/y	10 MtCO2/y	Comment
STORAGE		**Pre-Fid**				
		3D seismic	MDKK	*150*	*250*	Based on the size of the area to be assessed
		Baseline studies	MDKK	*60*	*100*	Surveys all relevant pre-injection data
		Appraisal well	MDKK	*n/a*	*n/a*	Appraisal wells are not included as the geological structures of the offshore storage sites are assumed to be well known due to prior mapping by the oil and gas industry
		FEED studies	MDKK	*30*	*50*	Front end engineering design
		Approvals	MDKK	*60*	*100*	Regulatory approvals for establishing CO2 storage sites
		Total pre-FID costs	**MDKK**	**300**	**500**	
		CAPEX				
		Intermediate storage	MDKK	*n/a*	*n/a*	Intermediate storage is included in the cost of the vessel
		Injection plant	MDKK	*340*	*680*	Includes booster pumps, heat exchangers and boiler system
		Pipeline	MDKK	*n/a*	*n/a*	Pipeline between storage and injection site; does not include cost of electricity cable; cost is based on length and industry-standard per km cost
		Injection wells	MDKK	*1,960*	*3,920*	Number of injection wells scale linearly to accommodate natural injection rate limitations
		Wellhead platform	MDKK	*275*	*550*	The offshore structure that supports injection wells and associated support systems
		Mooring/loading system	MDKK	*405*	*675*	Includes a SAL system allowing vessels to attach themselves to wells and start injection of the transported CO2
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Permanently moored FSUs near offshore storage site have intermediate storage and injection capabilities
		Total CAPEX	**MDKK**	**2,980**	**5,825**	
		Acc. OPEX				
		Base organisation	MDKK	*525*	*525*	Covers day-to-day operations of the organisation
		Intermediate storage	MDKK	*n/a*	*n/a*	Facility size remains constant as additional buffer size does not provide value
		Injection plant	MDKK	*844*	*1.688*	Accumulated variable cost for operating the injection plant systems

		Pipeline	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime period
		Injection wells	MDKK	*608*	*1.216*	Accumulated variable cost of operating wells for injection of CO2 into subsurface reservoirs
		Monitoring	MDKK	*920*	*1.840*	Post-injection monitoring is only evaluated over 20 years
		Power	MDKK	*3,450*	*6,900*	Power scales linearly with the project size and is based on 0.5 DKK/KWh pricing
		Wellhead platform	MDKK	*4,650*	*9,300*	Accumulated variable cost for operating the wellhead platform
		Standby vessel	MDKK	*1,240*	*2,480*	Scales linearly with the number of vessels expected to be near the storage site
		Mooring/loading system	MDKK	*1,005*	*1,675*	Accumulated variable cost for operating the mooring/loading system offshore
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the FSU offshore
		Total CAPEX	**MDKK**	**13,242**	**25,624**	
		Closure costs				
		Abandonment cost	MDKK	*522*	*1,019*	Evaluated as 17,5% of total storage CAPEX
		Post-Closure cost	MDKK	*600*	*849*	Cost of monitoring the storage site post-closure
		Total closure costs	**MDKK**	**1,122**	**1,868**	
CO2 TRANSPORT	**Shuttle tanker/ Vessel**	**CAPEX**				
		Transport shuttle	MDKK	*n/a*	*n/a*	Import via shuttle tankers is assumed to be 0% of the import volume
		Vessel	MDKK	*2,292*	*4,584*	Import via vessels is assumed to be 100% of the import volume; the additional cost of equipment for the vessels is included in the CAPEX and OPEX for storage
		Export intermediate storage	MDKK	*2,250*	*2,625*	Total export intermediate storage is 120,000 t and 140,000 t for each scenario, respectively, split between the exporting countries relative to their expected export volume
		Total CAPEX	**MDKK**	**4,542**	**7,209**	
		Acc. OPEX	MDKK			
		Transport shuttle fixed O&M	MDKK	*n/a*	*n/a*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Vessels fixed O&M	MDKK	*4,917*	*8,315*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Fuel	MDKK	*843*	*1,686*	Shuttle tankers during transport are assumed to consume 256

						MWh per day, which drives fuel costs
		Total acc. OPEX	**MDKK**	**5,759**	**10,000**	
	Pipeline	**CAPEX**				
		Onshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Offshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Pumping station	MDKK	*n/a*	*n/a*	One pumping stations is added for every 200 km of pipeline commenced and one at each end of the offshore pipeline
		Total CAPEX	**MDKK**	**n/a**	**n/a**	
		Acc. OPEX				
		Onshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Offshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Power	MDKK	*n/a*	*n/a*	Based on 0.5 DKK/KWh pricing
		Total acc. OPEX	**MDKK**	**n/a**	**n/a**	
Total cost/t			**DKK/t**	**207**	**189**	
***hereof storage**			**DKK/t**	**131**	**125**	
**hereof transport*			**DKK/t**	**76**	**64**	

Other case-specific assumptions:

- Transport pipelines are not included in this set-up
- All transport of CO2 happens via vessels with onboard intermediate storage and injection capabilities, meaning no intermediate storage near the storage site is needed for the set-up
- 50% of German CO2 exports are assumed to come from Rostock (East of Jutland), and the remaining 50% is assumed to come from Hamburg (West of Jutland)
- 100% of exports from NL is assumed to come from Rotterdam harbour
- Appraisal wells are not included as the geological structures of the offshore storage sites are assumed to be well known due to prior mapping by the oil and gas industry
- Infrastructure for providing energy offshore is assumed to be already installed and has not been included in the above estimates
- Injection wells are placed at five different injection clusters with two platforms at each cluster. The clusters will be found in the Northern part of the North Sea oil and gas fields as the geological structure of these sites means fewer wells are needed for the same injection rate compared to the remaining Danish oil and gas fields
- The cost of pipelines between the clusters has not been included as no pre-existing cost estimates have been found. Construction of these pipelines might be necessary if this set-up structure will be used as the.
- This set-up is the most expensive due to increased cost for Wellhead platform, standby vessels, mooring/loading system, CAPEX and OPEX for vessels, which is caused by a decrease in utilisation rate and increase in loading/unloading time per cycle

OPTION #7: Offshore, shuttle tanker to offshore FSU near North Sea storage site, then to North Sea storage site using FSU onboard injection equipment

Table 57: Overview option #7

		Cost category	Unit	5 MtCO2/y	10 MtCO2/y	Comment
STORAGE		**Pre-Fid**				
		3D seismic	MDKK	*70*	*99*	Based on the size of the area to be assessed
		Baseline studies	MDKK	*20*	*28*	Surveys all relevant pre-injection data
		Appraisal well	MDKK	*n/a*	*n/a*	Appraisal wells are not included as the geological structures of the offshore storage sites are assumed to be well known due to prior mapping by the oil and gas industry
		FEED studies	MDKK	*10*	*14*	Front end engineering design
		Approvals	MDKK	*20*	*28*	Regulatory approvals for establishing CO2 storage sites
		Total pre-FID costs	**MDKK**	**120**	**170**	
		CAPEX				
		Intermediate storage	MDKK	*n/a*	*n/a*	Intermediate storage is included in the cost of the FSU
		Injection plant	MDKK	*390*	*780*	Includes booster pumps, heat exchangers and boiler system
		Pipeline	MDKK	*n/a*	*n/a*	Pipeline between storage and injection site; does not include cost of electricity cable; cost is based on length and industry-standard per km cost
		Injection wells	MDKK	*1,925*	*3,850*	Number of injection wells scale linearly to accommodate natural injection rate limitations
		Wellhead platform	MDKK	*525*	*742*	Offshore structure that supports injection wells and associated support systems
		Mooring/loading system	MDKK	*375*	*530*	The estimated cost is based on industry standards from the oil and gas industry
		Purpose built CO2 carrier / FSU	MDKK	*640*	*905*	Permanently moored FSUs near offshore storage site have intermediate storage and injection capabilities
		Total CAPEX	**MDKK**	**3,855**	**6,808**	
		Acc. OPEX				
		Base organisation	MDKK	*525*	*742*	Covers day-to-day operations of the organisation
		Intermediate storage	MDKK	*n/a*	*n/a*	Facility size remains constant as additional buffer size does not provide value
		Injection plant	MDKK	*967*	*1,934*	Accumulated variable cost for operating the injection plant systems

		Pipeline	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime period
		Injection wells	MDKK	*527*	*1,054*	Accumulated variable cost of operating wells for injection of CO2 into subsurface reservoirs
		Monitoring	MDKK	*920*	*1,301*	Post-injection monitoring is only evaluated over 20 years
		Power	MDKK	*3,036*	*6,072*	Power scales linearly with the project size and is based on 0.5 DKK/KWh pricing
		Wellhead platform	MDKK	*2,430*	*3,437*	Accumulated variable cost for operating the wellhead platform
		Standby vessel	MDKK	*620*	*1,240*	Scales linearly with the number of vessels expected to be near the storage site
		Mooring/loading system	MDKK	*831*	*1,662*	Accumulated variable cost for operating the mooring/loading system offshore
		Purpose built CO2 carrier / FSU	MDKK	*1,587*	*2,244*	Accumulated variable cost for operating the FSU offshore
		Total CAPEX	**MDKK**	**11,443**	**19,686**	
		Closure costs				
		Abandonment cost	MDKK	*675*	*1,191*	Evaluated as 17,5% of total storage CAPEX
		Post-Closure cost	MDKK	*600*	*849*	Cost of monitoring the storage site post-closure
		Total closure costs	**MDKK**	**1,275**	**2,040**	
CO2 TRANSPORT	**Shuttle tanker/ Vessel**	**CAPEX**				
		Transport shuttle	MDKK	*1,419*	*2,838*	Import via shuttle tankers is assumed to be 100% of the import volume unloading at an FSU near the storage site
		Vessel	MDKK	*n/a*	*n/a*	The additional cost of equipment for the vessels is included in the CAPEX and OPEX for storage
		Export intermediate storage	MDKK	*2,250*	*2,625*	Total export intermediate storage is 120,000 t and 140,000 t for each scenario, respectively, split between the exporting countries relative to their expected export volume
		Total CAPEX	**MDKK**	**3,669**	**5,463**	
		Acc. OPEX				
		Transport shuttle fixed O&M	MDKK	*3,738*	*5,958*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Vessels fixed O&M	MDKK	*n/a*	*n/a*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Fuel	MDKK	*837*	*1,675*	Shuttle tankers during transport are assumed to consume 256 MWh per day, which drives fuel costs

		Total acc. OPEX	**MDKK**	**4,575**	**7,632**	
	Pipeline	**CAPEX**				
		Onshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Offshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Pumping station	MDKK	*n/a*	*n/a*	One pumping stations is added for every 200 km of pipeline commenced and one at each end of the offshore pipeline
		Total CAPEX	**MDKK**	**n/a**	**n/a**	
		Acc. OPEX				
		Onshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Offshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Power	MDKK	*n/a*	*n/a*	Based on 0.5 DKK/KWh pricing
		Total acc. OPEX	**MDKK**	**n/a**	**n/a**	
Total cost/t			**DKK/t**	**185**	**155**	
***hereof storage**			**DKK/t**	**124**	**106**	
**hereof transport*			**DKK/t**	**61**	**49**	

- Transport pipelines are not included in this set-up
- All transport of CO2 happens via transport shuttles which unload to a permanent floating storage unit (FSU) with intermediate storage and injection capabilities near offshore storage sites
- 50% of German CO2 exports are assumed to come from Rostock (East of Jutland), and the remaining 50% is assumed to come from Hamburg (West of Jutland)
- 100% of exports from NL is assumed to come from Rotterdam harbour
- Appraisal wells are not included as the geological structures of the offshore storage sites are assumed to be well known due to prior mapping by the oil and gas industry
- Infrastructure for providing energy offshore is assumed to already be installed and has not been included in the above estimates
- Injection wells are placed in the Northern part of the North Sea oil and gas fields as the geological structure of these sites means fewer wells are needed for the same injection rate compared to the remaining Danish oil and gas fields

OPTION #8: Offshore, shuttle tanker to Esbjerg harbour and pipeline from Hamburg to Esbjerg harbour, then to the storage site via pipeline

Table 58: Overview option #8

		Cost category	Unit	5 MtCO2/y	10 MtCO2/y	Comment
STORAGE		**Pre-Fid**				
		3D seismic	MDKK	*70*	*99*	Based on the size of the area to be assessed
		Baseline studies	MDKK	*20*	*28*	Surveys all relevant pre-injection data
		Appraisal well	MDKK	*n/a*	*n/a*	Appraisal wells are not included as the geological structures of the offshore storage sites are assumed to be well known due to prior mapping by the oil and gas industry
		FEED studies	MDKK	*10*	*14*	Front end engineering design
		Approvals	MDKK	*20*	*28*	Regulatory approvals for establishing CO2 storage sites
		Total pre-FID costs	**MDKK**	**120**	**170**	
		CAPEX				
		Intermediate storage	MDKK	*180*	*180*	Assumed storage size of 50,000 t
		Injection plant	MDKK	*390*	*780*	Includes booster pumps, heat exchangers and boiler system
		Pipeline	MDKK	*1,750*	*2,750*	Pipeline between storage and injection site; does not include the cost of electricity cable; cost is based on length and industry-standard per km cost
		Injection wells	MDKK	*1,925*	*3,850*	Number of injection wells scale linearly to accommodate natural injection rate limitations
		Wellhead platform	MDKK	*525*	*742*	The offshore structure that supports injection wells and associated support systems
		Mooring/loading system	MDKK	*n/a*	*n/a*	The estimated cost is based on industry standards from the oil and gas industry
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Permanently moored FSUs near offshore storage site have intermediate storage and injection capabilities
		Total CAPEX	**MDKK**	**4,770**	**8,302**	
		Acc. OPEX				
		Base organisation	MDKK	*525*	*742*	Covers day-to-day operations of the organisation
		Intermediate storage	MDKK	*223*	*223*	Facility size remains constant as additional buffer size does not provide value
		Injection plant	MDKK	*967*	*1,934*	Accumulated variable cost for operating the injection plant systems
		Pipeline	MDKK	*473*	*743*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime period

		Injection wells	MDKK	*527*	*1,054*	Accumulated variable cost of operating wells for injection of CO2 into subsurface reservoirs
		Monitoring	MDKK	*920*	*1,301*	Post-injection monitoring is only evaluated over 20 years
		Power	MDKK	*3,036*	*6,072*	Power scales linearly with the project size and is based on 0.5 DKK/KWh pricing
		Wellhead platform	MDKK	*2,430*	*3,437*	Accumulated variable cost for operating the wellhead platform
		Standby vessel	MDKK	*n/a*	*n/a*	Scales linearly with the number of vessels expected to be near the storage site
		Mooring/loading system	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the mooring/loading system offshore
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the FSU offshore
		Total CAPEX	**MDKK**	**9,101**	**15,506**	
		Closure costs				
		Abandonment cost	MDKK	*835*	*1,453*	Evaluated as 17,5% of total storage CAPEX
		Post-Closure cost	MDKK	*600*	*849*	Cost of monitoring the storage site post-closure
		Total closure costs	**MDKK**	**1,435**	**2,301**	
CO2 TRANSPORT	**Shuttle tanker/ Vessel**	**CAPEX**				
		Transport shuttle	MDKK	*473*	*1,419*	Import via shuttle tankers is assumed to increase from 20% of the import volume to 50% between the 5 and 10 MtCO2/y scenarios
		Vessel	MDKK	*n/a*	*n/a*	The additional cost of equipment for the vessels is included in the CAPEX and OPEX for storage
		Export intermediate storage	MDKK	*2,250*	*2,625*	Total export intermediate storage is 120,000 t and 140,000 t for each scenario, respectively, split between the exporting countries relative to their expected export volume
		Total CAPEX	**MDKK**	**2,723**	**4,517**	
		Acc. OPEX	MDKK			
		Transport shuttle fixed O&M	MDKK	*2,461*	*4,680*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Vessels fixed O&M	MDKK	*n/a*	*n/a*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Fuel	MDKK	*198*	*991*	Shuttle tankers during transport are assumed to consume 256 MWh per day, which drives fuel costs
		Total acc. OPEX	**MDKK**	**2,659**	**5,672**	

	Pipeline	**CAPEX**				
		Onshore pipeline	MDKK	*875*	*1,325*	Based on industry-standard price per km for pipelines of the assumed capacity
		Offshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Pumping station	MDKK	*233*	*233*	One pumping stations is added for every 200 km of pipeline commenced and one at each end of the offshore pipeline
		Total CAPEX	**MDKK**	**506**	**695**	
		Acc. OPEX				
		Onshore pipeline fixed O&M	MDKK	*236*	*358*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Offshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Power	MDKK	*270*	*338*	Based on 0.5 DKK/KWh pricing
		Total acc. OPEX	**MDKK**	**506**	**695**	
Total cost/t			**DKK/t**	**166**	**139**	
***hereof storage**			**DKK/t**	**114**	**97**	
**hereof transport*			**DKK/t**	**52**	**42**	

Other case-specific assumptions:

- A 250 km CO2 transport pipeline from Hamburg to Esbjerg harbour is included in this set-up carrying 4 MtCO2/y in the 5 MtCO2/y scenarios and 5 MtCO2/y in the 10 MtCO2/y scenarios. Additional imported CO2 volume between the 5 and 10 MtCO2/y scenarios is assumed to be transported from the emission source to Esbjerg harbour using shuttle tankers
- 50% of German CO2 exports is expected to come from Rostock (East of Jutland), and the remaining 50% is expected to come from Hamburg (West of Jutland)
- 100% of exports from NL is assumed to come from Rotterdam harbour
- Appraisal wells are not included as the geological structures of the offshore storage sites are assumed to be well known due to prior mapping by the oil and gas industry
- Infrastructure for providing energy offshore is assumed to already be installed and has not been included in the above estimates
- Injection wells are placed in the Northern part of the North Sea oil and gas fields as the geological structure of these sites means fewer wells are needed for the same injection rate compared to the remaining Danish oil and gas fields

OPTION #9: Offshore, shuttle tanker to Esbjerg harbour, then to the storage site via pipeline and two separate pipelines from Hamburg and Rotterdam to North Sea storage site

Table 59: Overview option #9

		Cost category	Unit	5 MtCO2/y	10 MtCO2/y	Comment
STORAGE		**Pre-Fid**				
		3D seismic	MDKK	*70*	*99*	Based on the size of the area to be assessed
		Baseline studies	MDKK	*20*	*28*	Surveys all relevant pre-injection data
		Appraisal well	MDKK	*n/a*	*n/a*	Appraisal wells are not included as the geological structures of the offshore storage sites are assumed to be well known due to prior mapping by the oil and gas industry
		FEED studies	MDKK	*10*	*14*	Front end engineering design
		Approvals	MDKK	*20*	*28*	Regulatory approvals for establishing CO2 storage sites
		Total pre-FID costs	**MDKK**	**120**	**170**	
		CAPEX				
		Intermediate storage	MDKK	*180*	*180*	Assumed storage size of 50,000 t
		Injection plant	MDKK	*390*	*780*	Includes booster pumps, heat exchangers and boiler system
		Pipeline	MDKK	*1,750*	*2,750*	Pipeline between storage and injection site; does not include cost of electricity cable; cost is based on length and industry-standard per km cost
		Injection wells	MDKK	*1,925*	*3,850*	Number of injection wells scales linearly to accommodate natural injection rate limitations
		Wellhead platform	MDKK	*525*	*742*	Offshore structure that supports injection wells and associated support systems
		Mooring/loading system	MDKK	*n/a*	*n/a*	The estimated cost is based on industry standards from the oil and gas industry
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Permanently moored FSUs near offshore storage site have intermediate storage and injection capabilities
		Total CAPEX	**MDKK**	**4,770**	**8,302**	
		Acc. OPEX				
		Base organisation	MDKK	*525*	*742*	Covers day-to-day operations of the organisation
		Intermediate storage	MDKK	*223*	*223*	Facility size remains constant as additional buffer size does not provide value
		Injection plant	MDKK	*967*	*1,934*	Accumulated variable cost for operating the injection plant systems

		Pipeline	MDKK	*473*	*743*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime period
		Injection wells	MDKK	*527*	*1,054*	Accumulated variable cost of operating wells for injection of CO2 into subsurface reservoirs
		Monitoring	MDKK	*920*	*1,301*	Post-injection monitoring is only evaluated over 20 years
		Power	MDKK	*3,036*	*6,072*	Power scales linearly with the project size and is based on 0.5 DKK/KWh pricing
		Wellhead platform	MDKK	*2,430*	*3,437*	Accumulated variable cost for operating the wellhead platform
		Standby vessel	MDKK	*n/a*	*n/a*	Scales linearly with the number of vessels expected to be near the storage site
		Mooring/loading system	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the mooring/loading system offshore
		Purpose built CO2 carrier / FSU	MDKK	*n/a*	*n/a*	Accumulated variable cost for operating the FSU offshore
		Total CAPEX	**MDKK**	**9,101**	**15,506**	
		Closure costs				
		Abandonment cost	MDKK	*835*	*1,453*	Evaluated as 17,5% of total storage CAPEX
		Post-Closure cost	MDKK	*600*	*849*	Cost of monitoring the storage site post-closure
		Total closure costs	**MDKK**	**1,435**	**2,301**	
CO2 TRANSPORT	**Shuttle tanker/ Vessel**	**CAPEX**				
		Transport shuttle	MDKK	*473*	*1,419*	Import via shuttle tankers is assumed to decrease from 80% of the import volume to 60% between the 5 and 10 MtCO2/y scenarios
		Vessel	MDKK	*n/a*	*n/a*	Additional cost of equipment for the vessels is included in the CAPEX and OPEX for storage
		Export intermediate storage	MDKK	*2,250*	*2,625*	Total export intermediate storage is 120,000 t and 140,000 t for each scenario, respectively, split between the exporting countries relative to their expected export volume
		Total CAPEX	**MDKK**	**2,723**	**4,044**	
		Acc. OPEX	MDKK			
		Transport shuttle fixed O&M	MDKK	*2,461*	*4,042*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Vessels fixed O&M	MDKK	*n/a*	*n/a*	5% of CAPEX + 75 EUR/ton export intermediate storage per year over the full technical project lifetime
		Fuel	MDKK	*207*	*827*	Shuttle tankers during transport are assumed to consume 256 MWh per day, which drives fuel costs

		Total acc. OPEX	**MDKK**	**2,668**	**4,869**	
	Pipeline	**CAPEX**				
		Onshore pipeline	MDKK	*n/a*	*n/a*	Based on industry-standard price per km for pipelines of the assumed capacity
		Offshore pipeline	MDKK	*5,950*	*5,950*	The offshore pipeline is a combination of the Hamburg and Rotterdam pipelines, both transporting CO2 directly to the North Sea storage sites; does not include electricity cable cost; pipelines with the same capacity is assumed to be used in both scenarios causing cost to stay the same
		Pumping station	MDKK	*467*	*467*	One pumping stations is added for every 200 km of pipeline commenced and one at each end of the offshore pipelines; it does not include electricity cable cost
		Total CAPEX	**MDKK**	**6,417**	**6,417**	
		Acc. OPEX				
		Onshore pipeline fixed O&M	MDKK	*n/a*	*n/a*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Offshore pipeline fixed O&M	MDKK	*1,607*	*1,607*	Costs are evaluated as 1% of CAPEX per year for the full technical lifetime
		Power	MDKK	*1,020*	*1,530*	Based on 0.5 DKK/KWh pricing
		Total acc. OPEX	**MDKK**	**2,627**	**3,137**	
Total cost/t			**DKK/t**	**221**	**166**	
***hereof storage**			**DKK/t**	**114**	**97**	
**hereof transport*			**DKK/t**	**107**	**68**	

Other case-specific assumptions:

- A 400 km CO2 offshore transport pipeline from Hamburg to the North Sea storage sites is included in this set-up carrying 2 MtCO2/y in the 5 MtCO2/y scenario and 3 MtCO2/y in the 10 MtCO2/y scenario
- A 450 km CO2 offshore transport pipeline from Rotterdam to the North Sea storage sites is included in this set-up carrying 2 MtCO2/y in the 5 MtCO2/y scenario and 3 MtCO2/y in the 10 MtCO2/y scenario
- The remaining increase in import volume between the 5 and 10 MtCO2/y cases is assumed to be transported using shuttle tankers to Esbjerg harbour and transported via pipeline to the North Sea storage site
- German CO2 exports not included in the pipeline is assumed to come from Rostock (East of Jutland)
- No CO2 export other than export via pipeline is expected from the Netherlands
- Appraisal wells are not included as the geological structures of the offshore storage sites are assumed to be well known due to prior mapping by the oil and gas industry
- Infrastructure for providing energy offshore is assumed to already be installed and has not been included in the above estimates

- Injection wells are placed in the Northern part of the North Sea oil and gas fields as the geological structure of these sites means fewer wells are needed for the same injection rate compared to the remaining Danish oil and gas fields

7.4 OVERVIEW OF ESTIMATED CCS SHARE BY COUNTRY

Table 60: Estimated CCS share; Finland

Industry	Sub-industry	CO2 Emissions (2017) [Mt]	Technically capturable share	Estimated CCS share (what is actually expected for CCS given alternatives etc)	Comments on estimated CCS share (if relevant)
Power and heat generation	**Thermal power and heat generation**	16,9	90%	N/A	Thermal power and heat generation are not considered relevant, since Finland will employ electrification and other initatives to make up for emissions.
	WtE plants	0,2	90%	90%	Finland has one large WtE facility that is considered relevant if Finland chooses to deploy BECCS, which the country has indicated in its Government strategies that it might.
Industrial plants	**Steel & iron production/ferrous metals**	1,5	60%	60%	Finland has two large iron and steel facilities, which have potential for carbon capture.
	Non-ferrous metals (aluminium, copper and zinc etc)	-	N/A	N/A	N/A
	Mineral oil and gas refineries	3,1	50%	50%	CO2 prduction from refineries using fossil fuels have a potential to utilise CCS.
	Chemicals production	0,7	50%	50%	One petrochemical plant in operation, however, reduction of CO2 emission can also be achieved by easier mesasures (widely available in Finland), i.e., recycling of chemicals and electrification.
	Chemicals production (fertiliser/ammonia production)	-	50%	N/A	N/A
	Pulp & paper	20,3	80%	80%	If Finland chooses to implement BECCS into their climate strategy, the pulp & paper industry is highly suitable; Large volumes of CO2 from biomass in pulp & paper production facilities could be counted as negative emissions if captured and stored, the large factories are often located near rivers,
	Mineral production (cement)	1,3	90%	90%	Two cement plants in operations; use of biofuels can reduce some emissions, however CCS would be highly relvant to achieve carbon neutrality.
	Mineral production (lime and plaster, ceramics, glass and mineral fibers etc)	-	90%	N/A	N/A
	Food processing	-	90%	N/A	N/A
Other	**Other**	2,9	N/A	N/A	N/A
Total		**46,8**			

Table 61: Estimated CCS share; Sweden

Industry	Sub-industry	CO2 Emissions (2017) [Mt]	Technically capturable share	Estimated CCS share (what is actually expected for CCS given alternatives etc)	Comments on estimated CCS share (if relevant)
Power and heat generation	**Thermal power and heat generation**	11,7	90%	N/A	The majority of fossil plants are expected to be phased out by 2050, making any CCS retrofit a less attractive option compared to alternatives such as electrification.
	WtE plants	4,8	90%	90%	WtE plants in Sweden is considered relevant as Sweden has openly cpmmunicated a strategy to deploy BECCS.
Industrial plants	**Steel & iron production/ferrous metals**	4,1	60%	0%	Fossil free production using green hydrogen expected by 2035.
	Non-ferrous metals (aluminium, copper and zinc etc)	0,7	N/A	N/A	N/A
	Mineral oil and gas refineries	2,7	50%	50%	To minimise CO2 emissions, Sweden is expected to retrofit any refinery with carbon capture technologies if the economic return is positive.
	Chemicals production	1,0	50%	25%	The chemical industry is expected to rely roughly 50% on CCS, and 50% on CCU.
	Chemicals production (fertiliser/ammonia production)	-	50%	N/A	
	Pulp & paper	22,8	80%	80%	Large volumes of CO2 from biomass could be captured in the pulp & paper production facilities and counted as negative emissions if stored, the large factories are often located near rivers, making transport of CO2 away from the facilities cheaper and more convenient.
	Mineral production (cement)	2,8	90%	90%	To minimise CO2 emissions, Sweden is expected to retrofit most cement plants with carbon capture technologies if it economically viable.
	Mineral production (lime and plaster, ceramics, glass and mineral fibers etc)	-	90%	N/A	N/A
	Food processing	-	90%	N/A	N/A
Other	**Other**	0,7	N/A	N/A	N/A
Total		**51,3**			

Table 62: Estimated CCS share; Norway

Industry	Sub-industry	CO2 Emissions (2017) [Mt] (From EU-ETS)	Technically capturable share	Estimated CCS share (what is actually expected for CCS given alternatives etc)	Comments on estimated CCS share (if relevant)
Power and heat generation	**Thermal power and heat generation**	14,2	90%	50%	Presumably mainly related to oil & gas activities, energy majors are expected to prioritise CCS due to governmental focus on decarbonisation.
	WtE plants	-	90%	N/A	N/A
Industrial plants	**Steel & iron production/ferrous metals**	2,5	60%	50%	Fossil-reliant industries, such as steel, could choose to use CCS rather than invest in options like hydrogen.
	Non-ferrous metals (aluminium, copper and zinc etc)	2,7	N/A	N/A	N/A
	Mineral oil and gas refineries	2,6	50%	75%	Energy majors see CCS as a way of protecting a chunk of their existing extraction and refining business, because if the technology is proven to work at scale it can potentially offset the CO2 emissions from their operations.
	Chemicals production	1,5	50%	25%	The chemical industry is expected to rely roughly 50% on CCS and 50% on CCU.
	Chemicals production (fertiliser/ammonia production)	-	50%	N/A	N/A
	Pulp & paper	0,2	80%	50%	The pulp & paper industry in Norway is estimated to implement some CCS to achieve negative emissions.
	Mineral production (cement)	1,2	90%	90%	To minimise CO2 emissions, Norway is expected to retrofit most cement plants with carbon capture technologies if it is technologically possible.
	Mineral production (lime and plaster, ceramics, glass and mineral fibers etc)	0,5	90%	90%	Due to the large support towards CCS from the government, carbon capture technologies are expected to be widely installed in any industry where economically viable.
	Food processing	-	90%	N/A	N/A
Other	**Other**	-	N/A	N/A	N/A
Total		**25,4**			

Table 63: Estimated CCS share; UK

Industry	Sub-industry	CO2 Emissions (2017) [Mt]	Technically capturable share	Estimated CCS share (what is actually expected for CCS given alternatives etc)	Comments on estimated CCS share (if relevant)
Power and heat generation	**Thermal power and heat generation**	99,7	90%	10%	The UK plans to develop a hydrogen economy to supply industrial processes, long-distance HGVs and ships, and for electricity and heating. For heating, by 2035, existing homes should replace their heating systems for it to be low-carbon or ready for hydrogen, so that the share of low-carbon heating increases from 4.5% today to 90% in 2050. The hydrogen used in the CCC scenarios are assumed to come mainly from steam methane reforming with CCS in the UK.
	WtE plants	9,9	90%	80%	Expected to be prioritised highly and that any WtE plant built, after 2040, will have the technology deployed from the beginning.
Industrial plants	**Steel & iron production/ferrous metals**	6,7	60%	50%	Carbon capture is the only current technology that abates carbon emissions at scale for the steel & iron industry, and CCS is expected to be highly prioritised compared to CCU within the industry.
	Non-ferrous metals (aluminium, copper and zinc etc)	-	N/A	N/A	N/A
	Mineral oil and gas refineries	10,8	50%	25%	CCS faces competiton in this industry from electrification, and hydrogen and thus, a 50% allocation towards CCS is expected.
	Chemicals production	4,8	50%	25%	CCS faces competiton in this industry from electrification, hydrogen and CCU, a 50% allocation towards CCS is expected.
	Chemicals production (fertiliser/ammonia production)	0,6	50%	25%	
	Pulp & paper	-	80%	N/A	N/A
	Mineral production (cement)	7,2	90%	90%	Carbon capture is the only current technology that can abate carbon emissions at scale for the cement industry, and thus, CCS is expected to be highly prioritised.
	Mineral production (lime and plaster, ceramics, glass and mineral fibers etc)	1,0	90%	90%	Carbon capture is the only current technology that abates carbon emissions at scale for the mineral industry, and CCS is expected to be highly prioritised compared to CCU and other abatement technolgies within the industry.
	Food processing	1,2	90%	50%	Carbon capture is the only current technology that abates carbon emissions at scale for the food processing industry, however CCS is expected to be prioritised equally with other developing abatement technolgies like
Other	**Other**	4,4	N/A	N/A	N/A
Total		**146,3**			

Table 64: Estimated CCS share; Germany

Industry	Sub-industry	CO2 Emissions (2017) [Mt]	Technically capturable share	Estimated CCS share (what is actually expected for CCS given alternatives etc)	Comments on estimated CCS share (if relevant)
Power and heat generation	**Thermal power and heat generation**	263,8	90%	5%	Germany has a cliamte neutrality target in 2050 and aims to reduce emissions by 95% and the last 5% will need to be removed with technology such as CCS.
	WtE plants	16,4	90%	50%	BECCS is listed by the goverment as one of the CCS focus areas, and WtE is possibly the largest BECCS applications.
Industrial plants	**Steel & iron production/ferrous metals**	28,6	60%	20%	Green hydrogen is prioritised, however, Germany cannot produce all the green hydrogen they need by itself, and is, therfore, expected to collaborate with other countries. However, blue hydrogen is expected to be a transitional solution.
	Non-ferrous metals (aluminium, copper and zinc etc)	1,7	N/A	N/A	N/A
	Mineral oil and gas refineries	21,1	50%	30%	High priority due to the long-term commitment made to natural gas via the Nord Stream pipeline.
	Chemicals production	24,6	50%	30%	CCS is not expected to be prioritised as highly as in other industries due to a focus on CCU.
	Chemicals production (fertiliser/ammonia production)	-	50%	0%	Expected to be replaced entirely with zero-carbon technologies.
	Pulp & paper	-	80%	N/A	N/A
	Mineral production (cement)	25,0	90%	50%	Most new cement plants are expected to implement carbon capture technologies for the purpose of storage, however as there are currently a lot of cement factories in DE which are either old or small, only around 50% of the total emissions from the cement industry is expected to be captured and stored.
	Mineral production (lime and plaster, ceramics, glass and mineral fibers etc)	0,9	90%	N/A	N/A
	Food processing	0,8	90%	N/A	N/A
Other	**Other**	23,3	N/A	N/A	N/A
Total		**406,2**			

Table 65: Estimated CCS share; The Netherlands

Industry	Sub-industry	CO2 Emissions (2017) [Mt]	Technically capturable share	Estimated CCS share (what is actually expected for CCS given alternatives etc)	Comments on estimated CCS share (if relevant)
Power and heat generation	**Thermal power and heat generation**	55,7	90%	5%	Small part of the energy mix is renewable, which is expected, due to the high population density and thus low room for renewable energy generation technology. NL had problems reaching their 2020 goals and is expected to continue using gas fired power plants for some time.
	WtE plants	8,9	90%	90%	WtE plants are expected to be used long-term and thus, makes for an obvious choice to retrofit carbon capture equipment and reach negative emissions by storing it afterwards.
Industrial plants	**Steel & iron production/ferrous metals**	-	60%	N/A	N/A
	Non-ferrous metals (aluminium, copper and zinc etc)	-	N/A	N/A	N/A
	Mineral oil and gas refineries	10,6	50%	90%	CCS will be prioritised highly as it is the only current technology that can abate emissions at the expected scale of the mineral oil and gas refinery industry in the Netherlands.
	Chemicals production	16,9	50%	75%	In general, in the chemical industry in the NL CCS is expected to be prioritised over CCU or other emission abatement technologies
	Chemicals production (fertiliser/ammonia production)	-	50%	75%	
	Pulp & paper	-	80%	N/A	N/A
	Mineral production (cement)	0,5	90%	90%	High priority as current emissions from the cement production process are hard to abate with any other current technology.
	Mineral production (lime and plaster, ceramics, glass and mineral fibers etc)	0,1	90%	N/A	N/A
	Food processing	0,9	90%	N/A	N/A
Other	**Other**	1,4	N/A	N/A	N/A
Total		**95,0**			

Table 66: Estimated CCS share; Poland

Industry	Sub-industry	CO2 Emissions (2017) [Mt]	Technically capturable share	Estimated CCS share (what is actually expected for CCS given alternatives etc)	Comments on estimated CCS share (if relevant)
Power and heat generation	**Thermal power and heat generation**	121,2	90%	30%	Decarbonisation of the Polish power & heat generation sector will be driven by electrification, but some newer coal plants, upcoming natural gas plants and CPH plants will be relevant for CCS. There are currently 4 coal plants, 7 MSW/CPH plants and 2 natural gas plants that are newer and relevant: Total emissions at 28Mt/y. Furthermore, 5 natural gas plants are planned (all planned at around 2025) with total emissions at 6Mt/y. Therefore, total emissions at these plants are ~30Mt/y, of which 10Mt/y (30%) estimated to have CCS potential.
	WtE plants	-	90%	N/A	N/A
Industrial plants	**Steel & iron production/ferrous metals**	7,1	60%	30%	Due to fossil industry dominance, blue hydrogen is expected to play key role as a transitional technology, therfore a high CCS potential is expected.
	Non-ferrous metals (aluminium, copper and zinc etc)	1,2	N/A	N/A	N/A
	Mineral oil and gas refineries	1,7	50%	50%	CCS is a last resort technology at scale in Poland, however, there is a potential for blue hydrogen to become a transitional fuel in Poland, making CCS necessary.
	Chemicals production	1,0	50%	10%	CCU expected to be prioritised over CCS in Poland.
	Chemicals production (fertiliser/ammonia production)	1,7	50%	10%	
	Pulp & paper	-	80%	N/A	N/A
	Mineral production (cement)	6,8	90%	50%	CCS considered a relevant option. Some of the industry is looking intro RDF (Refused-derived fuel) instead of fossil fuels, however, also here BECCS could be relevant to obtain negative emissions and compensate for other industries that are hard to abate.
	Mineral production (lime and plaster, ceramics, glass and mineral fibers etc)	2,1	90%	40%	CCS is a last resort technology for emissions abatement at scale in Poland, so other technologies like CCU and electrification will be explored first.
	Food processing	-	90%	N/A	N/A
Other	**Other**	23,8	N/A	N/A	N/A
Total		**166,7**			

Table 67: Estimated CCS share; Estonia

Industry	Sub-industry	CO2 Emissions (2017) [Mt]	Technically capturable share	Estimated CCS share (what is actually expected for CCS given alternatives etc)	Comments on estimated CCS share (if relevant)
Power and heat generation	**Thermal power and heat generation**	7,9 (20,7)	90%	5%	The number (20.7 Mt in 2017) is outdated since a number of fossil fuel driven plants were close in the past couple of years. Therefore a more represenative number is 7.9 Mt than as provided by the E-PRTR in 2017. Since Estonia closed down oil-shale driven plants quite rapidly in the past couple of years, the country's energy supply security has been at risk. For this reason, the existent oil-shale plants will need to keep running until at least 2035 to secure the country's energy supply, which is why 5% is assumed to be potential for CCS in these fossil fuel driven plants. The oil-shale plants will be phased-out after 2035 according to strategy plans.
	WtE plants	-	90%	N/A	N/A
Industrial plants	**Steel & iron production/ferrous metals**	-	60%	N/A	N/A
	Non-ferrous metals (aluminium, copper and zinc etc)	-	N/A	N/A	N/A
	Mineral oil and gas refineries	-	50%	N/A	N/A
	Chemicals production	-	50%	N/A	N/A
	Chemicals production (fertiliser/ammonia production)	-	50%	N/A	N/A
	Pulp & paper	-	80%	N/A	N/A
	Mineral production (cement)	0,6	90%	90%	High priority as current emissions from the cement production process are hard to abate with any other current technology.
	Mineral production (lime and plaster, ceramics, glass and mineral fibers etc)	-	90%	N/A	N/A
	Food processing	-	90%	N/A	N/A
Other	**Other**	3,4	N/A	N/A	N/A
Total		**11,9**			

Table 68: Estimated CCS share; Lithuania

Industry	Sub-industry	CO2 Emissions (2017) [Mt]	Technically capturable share	Estimated CCS share (what is actually expected for CCS given alternatives etc)	Comments on estimated CCS share (if relevant)
Power and heat generation	**Thermal power and heat generation**	-	90%	N/A	N/A
	WtE plants	0,1	90%	20%	WtE plants considered relevant for CCS in general, however, Lithuania has not communicated any strategy to deploy BECCS in this sector.
Industrial plants	**Steel & iron production/ferrous metals**	-	60%	N/A	N/A
	Non-ferrous metals (aluminium, copper and zinc etc)	-	N/A	N/A	N/A
	Mineral oil and gas refineries	1,7	50%	0%	Expected to be replaced entirely with green hydrogen
	Chemicals production	-	50%	N/A	N/A
	Chemicals production (fertiliser/ammonia production)	2,6	50%	30%	CCU is preferred over CCS; however it is still unproven at scale compared with CCS. CCS expected to me a medium-term solution at best.
	Pulp & paper	-	80%	N/A	N/A
	Mineral production (cement)	0,7	90%	90%	CCS is expected to take the majority share in the cement industry in Lithuania as it is expected to be the cheapest abatement option.
	Mineral production (lime and plaster, ceramics, glass and mineral fibers etc)	-	90%	N/A	N/A
	Food processing	-	90%	N/A	N/A
Other	**Other**	-	N/A	N/A	N/A
Total		**5,2**			

Table 69: Estimated CCS share; Latvia

Industry	Sub-industry	CO2 Emissions (2017) [Mt]	Technically capturable share	Estimated CCS share (what is actually expected for CCS given alternatives etc)	Comments on estimated CCS share (if relevant)
Power and heat generation	**Thermal power and heat generation**	1,0	90%	20%	Low potential as the Latvian Government will phase out emissions in this sector and has promoted the potential for CCS in industrial activities and not power and heat. However, no industiral installations currently produce more than 100 ktCO2/y.
	WtE plants	-	90%	N/A	N/A
Industrial plants	**Steel & iron production/ferrous metals**	-	60%	N/A	N/A
	Non-ferrous metals (aluminium, copper and zinc etc)	-	N/A	N/A	N/A
	Mineral oil and gas refineries	-	50%	N/A	N/A
	Chemicals production	-	50%	N/A	N/A
	Chemicals production (fertiliser/ammonia production)	-	50%	N/A	N/A
	Pulp & paper	-	80%	N/A	N/A
	Mineral production (cement)	-	90%	N/A	N/A
	Mineral production (lime and plaster, ceramics, glass and mineral fibers etc)	-	90%	N/A	N/A
	Food processing	-	90%	N/A	N/A
Other	**Other**	-	N/A	N/A	N/A
Total		**1,0**			