CCS MULIGHETSSTUDIE | STATUSRAPPORT | NC00-2012-RE-00034

Mulighetsområdet for realisering av fullskala CO_2-håndtering i Norge

GASSNOVA

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CCS Mulighetsstudie

Statusrapport

Tittel:

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Mulighetsområdet for realisering av fullskala CO_2-håndtering i Norge

Prosjekt nr: NCCS 10061

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Forord

Rapporten gir status for Gassnovas utredningsarbeid vedrørende en bred og oppdatert kartlegging av mulighetsområdet for realisering av fullskala CO_2-håndtering utover Mongstad. Så langt i arbeidet er alle landbaserte CO_2-utslippskilder i Norge over en gitt størrelse kartlagt. Basert på vurdering av disse, er det etablert en liste over CO_2-utslippskilder som anses formålstjenlige for videre studier av hele CO_2-håndteringskjeder.

Gassnova har, i samarbeid med Mott MacDonald, utviklet evalueringsmetoden for mulighetsstudien. Evalueringsmetoden er basert innhentet relevant internasjonal erfaring, Gassnovas egne erfaringer fra CO_2-håndteringsprosjektene på Mongstad og Kårstø, samt Mott MacDonalds kompetanse og erfaring med utredning av CO_2-håndteringskjeder internasjonalt. Evalueringsmetoden som er valgt, sikrer at alle konklusjoner som fremkommer i rapporten, er forankret med utslippseierne. Utslippseiernes rolle har vært å fremlegge relevant informasjon om utslippskilden og evaluere denne, basert på utviklet metode. Gassnova retter en takk til alle utslippseierne for deres bidrag.

Ole Rønning med assistanse fra Julia Lindland har ledet arbeidet med studiet og status rapporten. Ståle Aakenes, Henrik Dannstrøm og Kjetil Emhjellen har hatt ansvar for ulike områder og er medforfattere til rapporten.

Ved ferdigstillelse av mulighetsstudien, planlagt i 2014, vil det bli presentert en sluttrapport med en bred og oppdatert kartlegging av mulighetsområdet for realisering av fullskala CO_2-håndtering i Norge, det vil si hele kjeder med fangst, transport og lagring av CO_2.

Innholdsfortegnelse

OPPSUMMERING

Med bakgrunn i Meld. St.9 (2010-2011) *Fullskala CO_2-håndtering* fikk Gassnova våren 2011 i oppdrag av OED å gjennomføre et utredningsarbeid hvor hensikten er å bidra til en bred og oppdatert kartlegging av mulighetsområdet for realisering av fullskala CO_2-håndtering utover prosjektet på Mongstad. Høsten 2012 ble mandatet utvidet til å omfatte vurdering av mulighetene for CO_2-håndtering på et eventuelt, nytt kullkraftverk i Longyearbyen. Mandatet kan finnes i sin helhet i vedlegg 1.

Utredningsarbeidet har til hensikt å kartlegge, evaluere og deretter rangere de mest formålstjenlige fangst-, transport- og lagringskjedene i Norge utover Mongstad og består av mulighetsstudier til industrielt definert modenhetsnivå (DG1 +/- 40 % som beskrevet i vedlegg 2). Sluttleveransen i mulighetsstudien vil inneholde evaluering av tekniske, finansielle og kommersielle forhold samt gjennomførbarhet av den/de mest formålstjenlige CO_2-håndteringsprosjektene utover Mongstad. Sluttrapport skal leveres i 2014.

Hensikten med denne statusrapporten er å gi en oppdatering av arbeidet som er gjort så langt. Med utgangspunkt i at det ikke kan defineres en CO_2-håndteringskjede uten en utslippskilde, er det gjennomført en kartlegging av alle landbaserte utslippskilder utover Mongstad med årlige CO_2-utslipp over 100.000 tonn. Videre er både eksisterende og kjente potensielle utslippskilder over 400.000 tonn CO_2 per år evaluert i henhold til metoden som er utarbeidet.

"CO_2-håndtering" innebærer en kjede som omfatter utslipp, fangst, transport, lagring/og eller utnyttelse av fanget CO_2. Dette kan være et relevant tiltak for industrien for å redusere egne CO_2-utslipp, men vil innebære betydelige tekniske, kommersielle og finansielle konsekvenser for bedriften. CO_2-håndtering kan enten besluttes på bakgrunn av at det foreligger krav fra myndighetene eller at det finnes drivere slik at industrien ser kommersielle muligheter som oppveier ulempene ved et slikt tiltak. "Realisering" av fullskala CO_2-håndtering ved nye og eksisterende kilder som ikke har slikt pålegg, betinger derfor at utslippseierne vil kunne oppnå gevinster som kompenserer for ulempene ved tiltaket, og at aktøren har tilstrekkelig evne og vilje til å ta ansvar for gjennomføring av prosjektet.

Et CO_2-fangstanlegg krever store investeringer, og størrelsen på utslippet er avgjørende for kostnadseffektiviteten i prosjektet. I mulighetsstudiet defineres "fullskala" til årlige CO_2-utslipp over 400.000 tonn. Det vises i denne sammenheng til definisjonen av "fullskala" internasjonalt [1, 2 og 3].

Gassnova har, med assistanse fra det britiske konsulentselskapet Mott MacDonald, utarbeidet en metode for evaluering av utslippskildene tilpasset studiets behov med definerte sjekklister innenfor kategoriene tekniske, kommersielle og finansielle forhold samt gjennomførbarhet. Mott MacDonald er et internasjonalt anerkjent selskap med kompetanse og erfaring knyttet til vurdering av CO_2-håndteringskjeder.

Basert på kartleggingen av utslippskilder, er det er gjennomført en evaluering med utgangspunkt i evalueringskategoriene for utslippskilder som fyller kravet om årlige CO_2-utslipp tilsvarende minst 400.000 tonn. Utslippseierne har selv fremskaffet relevant informasjon, mens Gassnova, Mott MacDonald og utslippseierne i felleskap har kvalitetssikret resultatene som har fremkommet.

Metoden som er benyttet, sikrer deltagelse fra utslippseiere som har positive interesser i realisering av CO_2-håndtering fra sine utslippskilder. Dette er en vesentlig forskjellig tilnærming sammenlignet med andre utredninger om CO_2-håndteringskjeder i Norge.

Utslippskildene er enten ansett som <u>relevant</u> eller <u>ikke-relevant</u> for videre studier. For de relevante er det ikke funnet vesentlige hindre for realisering av CO_2-håndtering i henhold til kategoriene som ligger til grunn for relevansvurderingen. Aktøren ser kommersielle muligheter ved CO_2-håndtering og er villig og i stand til å ta ansvar for videreføring i studier og av en eventuell realisering. Der hvor utslippseier ikke var relevant for videre studier, finnes det ett eller flere avgjørende hindre mot CO_2-håndtering.

Etter at grensen på 400.000 tonn CO_2 ble definert, ble det tatt utgangspunkt i 9 eksisterende og 4 potensielle landbaserte utslippskilder. I tillegg ble to teoretiske scenarier evaluert. Med teoretiske scenarier menes i denne sammenhengen mulige nye CO_2 utslipp fra off-shore petroleumsvirksomhet. Fem av disse anses som relevante for videre studier og utgjør et foreløpig mulighetsrom for fullskala CO_2-håndtering knyttet til landbaserte utslippskilder i Norge (se tabell 1).

Tabell 1. Oversikt over mulighetsområdet for CO_2-utslippskilder relevant for videre studier

Kilde	Beskrivelse	Utslippseier(e) Mororganisasjon	Hovedgrunn for relevans
Industrikraft Møre, Elnesvågen	Potensielt nytt gasskraftverk på Elnesvågen	Tafjord Kraft, Norsk Mineral og Hustadmarmor (Sargas har opsjon på å overta 89 % av aksjene)	• Integrert og relevant teknologi tilgjengelig fra eier (Sargas) • Utslippseier antar at kraftunderskudd i regionen kan gi grunnlag for lokalt kraftsalg
Norcem, Brevik	Eksisterende utslipp fra sementfabrikken i Brevik	Norcem AS HeidelbergCement	• Bruk av overskuddsvarme kan gi lavere kostnader • Overførbarhet til andre deler av konsernet
Yara Norge, Porsgrunn	Eksisterende utslipp fra ammoniakk-fabrikken på Herøya	Yara Norge AS Yara International ASA	• Deler av utslippet har høy CO_2-konsentrasjon • Utslippseier har ambisjon om bærekraftig produksjon.
Ironman, Tjeldbergodden	Potensielt nytt jernverk på Tjeldbergodden	Höganäs AB og LKAB	• Ca 70 % av utslippet er høykonsentrert CO_2, gjør fangstdelen enklere • Overførbarhet av teknologi og kompetanse til andre deler av stålindustrien.
Longyearbyen Bydrift, Svalbard	Potensielt nytt kullkraftverk i Longyearbyen, Svalbard	Longyearbyen Bydrift KF Longyearbyen Lokalstyre Justisdepartementet	• Mulighet for tett integrasjon med kilden • Målsetting om Svalbard som et bærekraftig samfunn

Det er flere årsaker til at 9 av de 14 kildene som er evaluert, ikke anses som relevante for videre studier. I tabell 2 gjengis en oppsummering av årsakene for hver enkelt utslippskilde. Alle årsakene er basert på evalueringer knyttet til de forhåndsdefinerte kategoriene 1) tekniske, 2) kommersielle 3) finansielle forhold, samt 4) gjennomførbarhet. Utslippskildene som er ansett som ikke relevante for videre studier, er nærmere beskrevet senere i rapporten.

Tabell 2. Hovedårsaker til ikke relevans

Kilde	Tekniske forhold	Kommersielle forhold	Finansielle forhold	Gjennom-førbarhet
Statoil, Melkøya Tog 1 Gasskraft, Eksisterende		X		
Statoil, Melkøya Tog 2 LNG/Gasskraft, Potensiell				X
Alcoa, Mosjøen Aluminium, Eksisterende	X	X		
Hydro Aluminium, Sunndal, Eksisterende	X		X	
Naturkraft, Kårstø Gasskraftverk, Eksisterende		X		
Gassco, Kårstø Gassprosessering, Eksisterende	X	X		
Noretyl, Bamble Etylen-produksjon, Eksisterende	X		X	
Norcem, Kjøpsvik Sement, Eksisterende	X			X
Longyearbyen Bydrift, Svalbard Kullkraftverk, Eksisterende	X	X		

1. INNLEDNING

I arbeidet som har vært gjennomført så langt, har kun fangstdelen av CO_2-håndteringskjeden vært evaluert. Det videre utredningsarbeidet vil omfatte en evaluering av de mest formålstjenlige hele CO_2-håndteringskjedene med utslipp, fangst, transport og lager og/eller utnytelse av CO_2. Det vil i denne sammenheng gjennomføres en offentlig anskaffelsesprosess hvor CO_2-håndteringsprosjekter kan legge inn et tilbud om videre deltagelse. Det er forventet at utslippskilder som er vurdert som relevante i den første kartleggingen som nå er avsluttet, vil delta i det videre arbeidet. Det er også åpent for andre utslippskilder, som ikke har vært en del av den første kartlegging eller for utslippskilder som er vurdert som ikke relevante, men der forutsetningene er vesentlig endret.

1.1. Mandat

Med bakgrunn i Meld. St. 9 (2010-2011) *Fullskala CO_2-håndtering* ga Olje- og energidepartementet (OED) i brev av 11. mai 2011 følgende mandat til Gassnova:

> *Gassnova skal gjennomføre et utredningsarbeid hvor hensikten er å bidra til en bred og oppdatert kartlegging av mulighetsområdet for realisering av fullskala CO_2-håndtering utover prosjektet på Mongstad.*

Ved epost av 28. august 2012 fikk Gassnova et tilleggsmandat fra OED, i forbindelse med Stortingets behandling av Meld. St. 21 (2011-2012) *Norsk Klimapolitikk*. Utredningsarbeidet ble utvidet til også å omfatte en vurdering av mulighetene for CO_2-håndtering av utslipp fra et eventuelt nytt kullkraftverk i Longyearbyen. Begge brev kan finnes i vedlegg 1.

Utredningsarbeidet har til hensikt å kartlegge, evaluere og deretter rangere de mest formålstjenlige fangst-, transport- og lagringskjeder i Norge utover Mongstad og består av mulighetsstudier til industrielt definert modenhetsnivå (DG1 +/- 40 % som beskrevet i vedlegg 2). Sluttleveransen av utredningsarbeidet (mulighetsstudien) vil være en rapport som inneholder evaluering av tekniske, finansielle og kommersielle forhold samt gjennomførbarhet av den/de mest formålstjenlige CO_2-håndteringsprosjektene utover Mongstad. Sluttrapporten skal leveres 2014.

1.2. *Forutsetninger*

Mandatet vektlegger "realisering av fullskala CO_2-håndtering".

CO_2-håndtering kan være et relevant tiltak for industrien for å redusere egne CO_2-utslipp, men vil innebære betydelige tekniske, kommersielle og finansielle konsekvenser for bedriften. CO_2-håndtering kan enten besluttes på bakgrunn av at det foreligger krav fra myndighetene eller at det finnes drivere slik at industrien ser kommersielle muligheter som oppveier ulempene ved et slikt tiltak.

Realisering av fullskala CO_2-håndtering betinger at utslippseierne selv ser at en potensielt vil kunne oppnå gevinster som kompenserer for ulempene ved tiltaket og er villige til å ta ansvar for gjennomføring av et mulig prosjekt, eventuelt sammen med andre industrielle aktører. Realisering krever kompetanse og kunnskap om egen virksomhet og evne til å gjennomføre CO_2-håndteringsprosjekter som en integrert del av sin kjernevirksomhet.

Denne tilnærmingen, som vektlegger utslippseiernes tekniske og kommersielle egenevaluering, anses som hensiktsmessig når mulighetsrommet for realisering av fullskala CO_2-håndtering utover prosjektet på Mongstad skal defineres.

Fullskala omfatter utslippskilder over en viss størrelse. I utredningsarbeidet er fullskala definert til årlige CO_2-utslipp tilsvarende minst 400.000 tonn. Til sammenligning definerer Global CCS Institute fullskala til CO_2-håndtering (fangst, transport og lagring) av 400.000 tonn per år for gasskraft og industriutslipp [1]. Et CO_2-fangstanlegg krever store investeringer, og størrelsen på utslippet er avgjørende for hvor kostnadseffektivt anlegget vil bli.

CO_2-håndtering omfatter utslipp, fangst, transport og lagring og/eller utnyttelse av CO_2. Statusrapporten omhandler ikke transport- og lagerløsninger knyttet til utslippskildene. Evaluering av transport- og lagerløsninger vil inngå i det videre arbeidet med CCS mulighetsstudien. Myndighetene arbeider med forskrifter som vil regulere transport og lagring av CO_2 på norsk sokkel. Forskriftene planlegges sendt på høring i nærmeste framtid. Olje- og energidepartementet og Gassnova arbeider også med organisering av transport og lagring av CO_2 fra fullskalaprosjektet på Mongstad. Det videre arbeidet med transport og lagring i CCS mulighetsstudien vil blant annet måtte sees i sammenheng med de nevnte arbeider.

Øvrige forutsetninger for studien [6]:

- Ikke forplikte staten utover denne studien
- Evalueringsmetoder og kriterier skal være transparente og etterprøvbare
- Industrien ansvarlig for eventuell videre gjennomføring etter DG1
- Kartlegging av eksisterende og potensielle utslippskilder på land i Norge (ikke offshore)
- Muligheter og utfordringer for alternativene skal kartlegges
- Samlagring og økt oljeutvinning er aktuelt i tillegg til ren langtidslagring
- Løsninger for transport og lagring samordnes med OEDs prosesser for organisering av CO_2 lagring
- Studien skal blant annet baseres på erfaring fra tidligere arbeider i Gassnova

1.3. Hensikt med statusrapporten

Hensikten med denne rapporten er å gi en status for utredningsarbeidet med bakgrunn i de resultater som har fremkommet i forbindelse med den gjennomførte kartleggingen og evalueringen av eksisterende og potensielle landbaserte utslippskilder i Norge utover prosjektet på Mongstad. I det videre arbeidet vil hele CO_2-håndteringskjeden evalueres og rangeres. Hele mulighetsstudien skal ferdigstilles i løpet av 2014.

For at CO_2-håndtering skal kunne realiseres, må gapet mellom dagens og nødvendige, framtidige rammebetingelser identifiseres. Sluttrapporten fra studien har mål om å dokumentere dette gapet. Arbeidet tar utgangspunkt i dagens rammebetingelser ved vurdering av mulighetene for realisering av CO_2-håndtering. Dagens rammebetingelser er derfor kartlagt gjennom arbeidet. Dette har vært et nødvendig underlag for å utforme evalueringsmetoden og for å forstå aktørenes vurderinger om egen relevans for videre studier.

Statusrapporten inneholder to hoveddeler:

1. Evalueringsmetode: Beskriver evalueringsprosessen med eierne av utslippskildene som har årlige CO_2-utslipp på minst 400.000 tonn. Utslippskildene er evaluert med tanke på tekniske, kommersielle og finansielle forhold samt gjennomførbarhet (kapittel 2 og 3).

2. Resultater fra kartlegging og evaluering av landbaserte fullskala utslippskilder (kapittel 4).

1.4. Relevant bakgrunn og erfaring

OED har i mandatet til Gassnova spesielt vektlagt bruk av relevant erfaring for gjennomføring av arbeidet. Gassnova har derfor jobbet systematisk med å innhente og sammenstille slik erfaring, både internasjonalt og nasjonalt.

Denne innledende kartleggingen baserer seg på studier utført av Det Norske Veritas (DNV) [8-13], Scandpower i samarbeid med Lloyds register, Sund Energy og Norges Geologiske Institutt [14-16], Mott MacDonald i samarbeid med Senergy [17,18] og Arntzen de Besche [19].

Underlaget som er fremskaffet til denne studien, kompletterer det erfaringsgrunnlaget som Gassnova selv sitter på og er tilgjengelig som underrapporter til arbeidet. Underrapportene er listet og beskrevet i vedlegg 3 og danner grunnlaget for utarbeidelse av evalueringsmetoden og betraktninger gjengitt i denne statusrapporten.

Tidligere studier innen CO_2-håndtering har i ulik grad hensyntatt industriens kommersielle drivere for selv å realisere CO_2-håndtering. I hovedsak har det vært fokusert på et teknisk potensial og tilhørende kostnader gitt at de nødvendige rammebetingelsene er på plass.

2. EVALUERINGSMETODE

2.1. Organisering av arbeidet

Måten arbeidet er organisert på, sikrer at alle involverte (utslippseiere, Gassnova og Mott MacDonald) står bak resultatene som fremkommer. Metoden som er benyttet, sikrer deltagelse fra aktører som har insentiver for realisering av CO_2-håndtering fra sine utslippskilder.

Gassnovas rolle:

Gassnova er ansvarlig for mulighetsstudien og har utarbeidet metode og evalueringskategorier for studien i samarbeid med Mott MacDonald. Gassnova har også ledet arbeidsmøter med utslippseierne og kvalitetssikret resultatene som har fremkommet. Gassnova har erfaring fra planlegging, bygging og drift av CO_2 Technology Centre Mongstad (TCM), planlegging av fullskala CO_2-fangst og lagring fra prosjektene på Mongstad og Kårstø og innehar generell bred kompetanse knyttet til CO_2-håndtering.

Mott MacDonalds rolle:

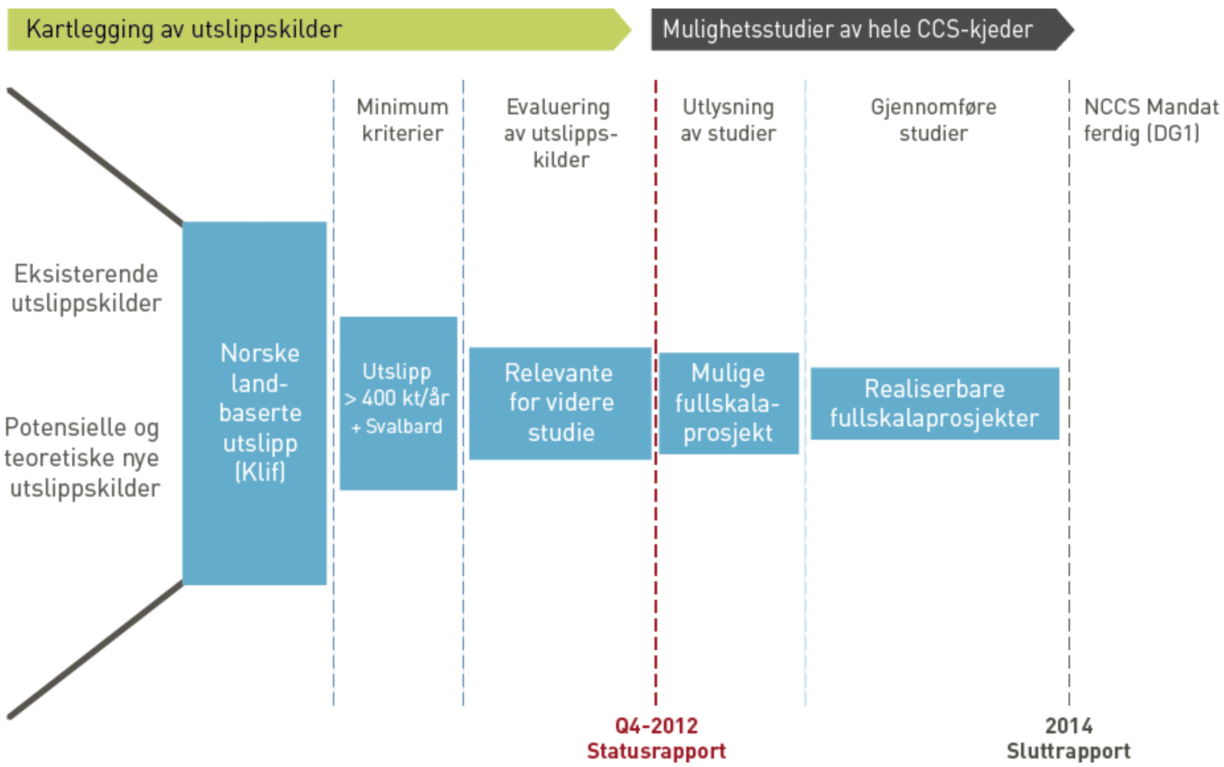
På bakgrunn av sin brede internasjonale og industrielle erfaring ble Mott MacDonald i en åpen anbudsrunde tildelt rollen som rådgiver og samarbeidspart for studien. Selskapet, som har spesifikk kompetanse på å vurdere CO_2-håndteringskjeder, har bistått Gassnova i utarbeidelsen av metode og evalueringskategorier og lagt til rette for arbeidsmøtene med utslippseierne. Selskapet bistår også Department of Climate Change (DECC) i Storbritannia i den pågående prosessen med utvelgelse av CO_2-håndteringsprosjekter i konkurransen de britiske myndighetene har utlyst.

Utslippseiers rolle:

Utslippseierne har bidratt med informasjon om egen virksomhet og forutsetninger for videre drift innenfor oppsatte metode og evalueringskategorier, samt deltatt på arbeidsmøter med Gassnova og Mott MacDonald. Omtalen av de ulike utslippskildene (vedlegg 6) er gjort i forståelse med utslippseierne.

2.2. *Stegvis evaluering*

Arbeidet med kartlegging av utslippskilder er gjennomført i tre steg som illustrert i figur 2. Denne figuren illustrerer også arbeidet som er gjort til nå sett i sammenheng med det videre arbeidet.



Figur 2. Stegvis evaluering

Statusrapport

Første steg kartlegger alle landbaserte utslipp, basert på Klima- og forurensingsdirektoratets (Klif) rapporterte data fra 2009. For å begrense omfanget av beskrivelsene ble alle utslippskilder i Norge med årlige CO_2-utslipp over 100.000 tonn kartlagt og danner utgangspunktet for en uttømmende liste over utslippskilder i Norge.

Andre steg definerer en nedre grense for størrelsen på utslippene (minimumskriterium) og generer et foreløpig mulighetsområde før evaluering. Basert på en avveiing mellom internasjonale definisjoner av fullskala med årlige CO_2-håndtering (fangst, transport og lagring) av minst 400.000 tonn [1] (vedlegg 3) og norske forhold, ble "fullskala" definert til årlige CO_2-utslipp tilsvarende minst 400.000 tonn. Nivået på utslippene er også vurdert med hensyn til kostnadseffektivitet. På bakgrunn av dette ble det identifisert 10 eksisterende, 4 potensielle og 2 teoretiske utslippskilder som danner grunnlaget for det foreløpige mulighetsområdet før evaluering. Som definert i tilleggsmandatet gjengitt i vedlegg 1 er vurdering av fangst fra et eventuelt, nytt kullkraftverk i Longyearbyen på Svalbard inkludert i utredningsarbeidet. I tillegg er utslipp fra det eksisterende kullkraftverket også vurdert. Dette er den eneste kilden med årlige CO_2-utslipp under 400.000 tonn som er inkludert.

Tredje steg består av en evaluering av kilder med CO_2-utslipp tilsvarende minst 400.000 tonn per år, samt utslipp fra det eventuelle nye kullkraftverket på Svalbard. Hovedspørsmålet for evalueringen er å finne andre grunner, utover størrelsen på utslippet, som forhindrer eller muliggjør CO_2-håndtering. Utslippskildene ble definert som relevant eller ikke relevant for videre studier.

For de relevante er det ikke funnet vesentlige hindre for realisering av CO_2-håndtering i henhold til kategoriene. Aktøren ser kommersielle muligheter ved CO_2-håndtering og er villige og i stand til å ta ansvar for videreføring av en eventuell realisering. Der hvor utslippseier ikke er relevant for videre studier finnes det et eller flere avgjørende hindre mot CO_2-håndtering, og utslippseieren ser ikke tilstrekkelige kommersielle muligheter ved tiltaket.

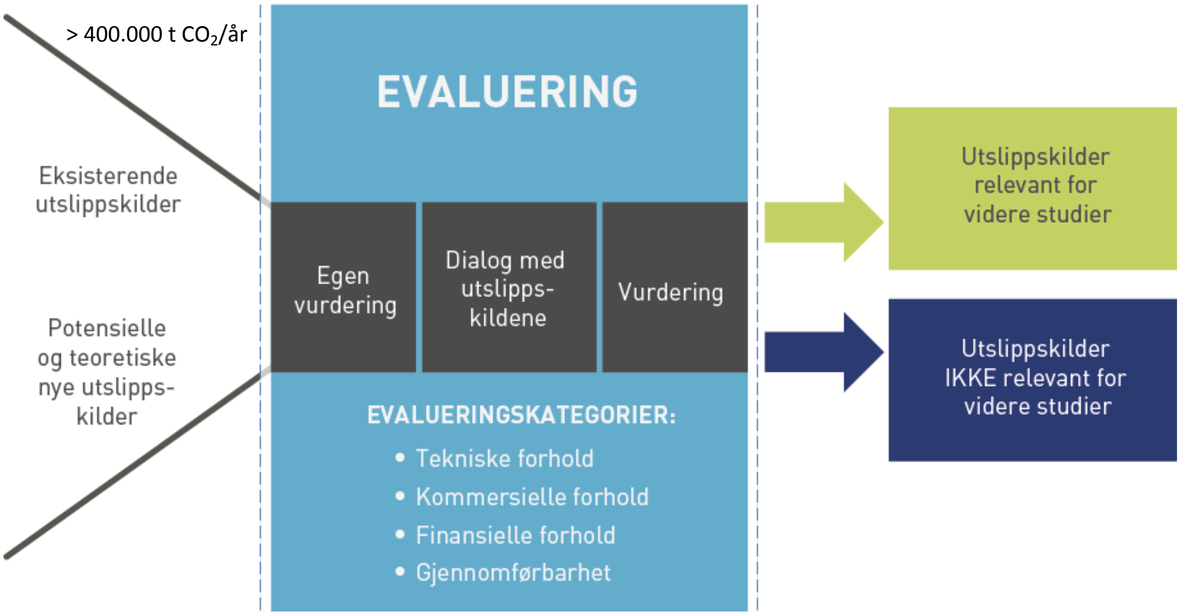
Utslippskildene som defineres som relevante, utgjør et foreløpig mulighetsområde etter evaluering. Basert på detaljert informasjonsinnhenting, analyser og evaluering, anses disse utslippskildene foreløpig som de mest formålstjenlige for fullskala CO_2-håndtering i Norge utover prosjektet på Mongstad. Det understrekes imidlertid at vurdering av transport- og lagerløsninger ikke har inngått i den første kartleggingen. Det skal gjøres i neste steg.

Sluttrapport

Videre steg omfatter studier av fullstendige CO_2-håndteringskjeder. Det vil i denne sammenheng utlyses en konkurranse, hvor det forventes at utslippskilder som i denne første fasen er ansett som relevante, legger inn tilbud på gjennomføring av videre studiearbeid. Det er også åpent for utslippskilder som ikke har vært del av den opprinnelige evalueringsprosessen. For de CO_2-håndteringsprosjektene som tildeles kontrakt, utføres det en mulighetsstudie. Mulighetsstudien vil danne grunnlaget for å identifisere de mest formålstjenlige prosjektene i henhold til mandatet for studien.

2.3. Evalueringsmetode og -kategorier

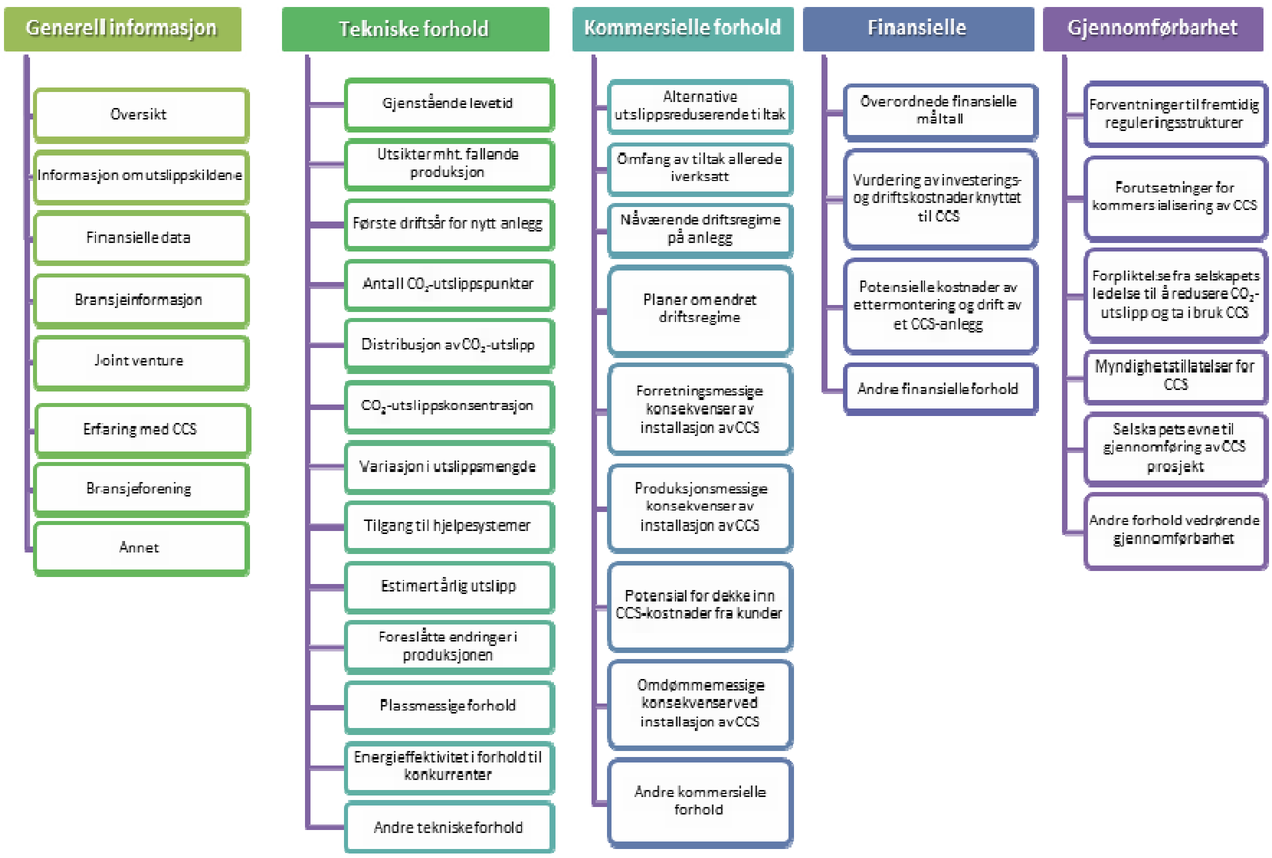
Hensikten med evalueringen av utslippskilder er å identifisere grunner som forhindrer eller muliggjør CO_2-håndtering. Evalueringsprosessen starter med egenevaluering fra utslippskilden i henhold til definerte evalueringskategorier med etterfølgende arbeidsmøte og dialog med Gassnova og Mott MacDonald. Internasjonal erfaring tilsier blant annet at kvalitative vurderinger innenfor spesifikke evalueringskategorier bør vektlegges i en innledende fase, fremfor detaljerte krav (vedlegg 3).



Figur 3 Evalueringsprosessen

For å sikre utslippseiers involvering er evalueringsprosessen basert på arbeidsmøter med dem for å få deres egenevalueringer. Gassnova har kvalitetssikret resultatene ved at all vurdering er gjort i henhold til den valgte evalueringsmetoden. Utslippseier selv har ansvaret for at informasjonene som er gitt om egen virksomhet og forutsetninger for videre drift er korrekt. Verken Gassnova eller Mott MacDonald har hatt forutsetninger for å overprøve aktørenes egenevaluering.

Følgende kategorier er lagt til grunn for evalueringen: tekniske, kommersielle og finansielle forhold samt gjennomførbarhet:



Figur 4 Evalueringskategorier lagt til grunn

Til venstre i figur 4 er generell informasjon listet. Denne inngår ikke i selve evalueringen, men er nødvendig for beskrivelse av de ulike utslippskildene. Nedenfor er de fire evalueringskategoriene beskrevet noe mer utfyllende. Det foreligger detaljerte sjekklister for hver enkelt av de fire kategoriene som er benyttet i arbeidsmøtene med utslippseierne.

<u>Tekniske forhold:</u>

Tekniske forhold viser til om det er praktisk mulig å implementere CO_2-håndteringsløsninger på anlegget uten at det påfører utslippskilden for store ulemper. Senere i studien vil man vurdere tekniske forhold for alle leddene i CO_2-håndteringskjeden og aspekter vedrørende integrasjon av kjeden. Så langt er det kun fangstdelen i kjeden som er evaluert. Eksempler på tekniske forhold kan være: utslipp fordelt på mange kilder, lav CO_2-konsentrasjon, manglende plass til fangstanlegg og gammelt anlegg med begrenset levetid.

Kommersielle forhold:

Kommersielle forhold viser blant annet til den underliggende økonomien i prosjektene. Utslippseierne ble bedt om å tilkjennegi sitt syn på forretningsvirksomhet og rammebetingelser, samt på utsiktene fremover. De ble også spurt om hva det vil bety for lønnsomheten å installere et CO2-fangstanlegg, og om hva som må til for å gjøre prosjektet økonomisk robust.

Finansielle forhold:

Finansiell løfteevne vil anvendes som et kriterium i den formelle anskaffelsesprosessen i det videre arbeidet. I denne innledende fasen, har fokuset vært på utslippseiernes syn på finansielle problemstillinger som er relevante for deres anlegg. De ble for eksempel spurt om de hadde en formening om hvor mye det ville koste å ettermontere og drive et CO_2-fangstanlegg.

Gjennomførbarhet:

Gjennomførbarhet dreier seg om i hvilken grad forutsetningene for å realisere CO_2-håndteringsprosjekter er på plass. Dette dekker alt fra lov- og regelverk, egen kompetanse og kapasitet til å skaffe til veie nødvendige tillatelser, reise finansiering og søke støtte fra bedriftens ledelse.

Evalueringen snevrer inn det sannsynlige mulighetsområdet for CO_2-håndtering for videre studier. Resultatet av evalueringen gir et foreløpig mulighetsrom for landbaserte utslippskilder i Norge utover prosjektet på Mongstad.

De kartlagte utslippskildene er ansett som relevante eller ikke relevante for videre studier.

Relevant:

Med relevant menes relevant for videre studier. Konklusjonen er basert på tilfredsstillende vurderinger i henhold til evalueringskategoriene over. Aktøren må se kommersielle fordeler ved CO_2-håndtering og være villig og i stand til å ta ansvar for videreføring av prosjektet.

Ikke-relevant:

Det eksisterer et eller flere avgjørende hindre som vanskeliggjør CO_2-håndtering.

3. UTSLIPPSKILDER

3.1. *Oversikt over eksisterende landbaserte utslippskilder*

I den innledende kartleggingsfasen ble alle utslippskilder i Norge med årlige CO_2-utslipp tilsvarende minst 100.000 tonn identifisert og beskrevet basert på offentlig tilgjengelig informasjon. Hver kilde er beskrevet med lokalitet, eierskap, teknisk prosess, historikk, utslippsmengde, antall utslippspunkter og andre fakta. Videre er kildene beskrevet i en regional kontekst med hensyn til eksisterende [9]. Dette har gitt et godt utgangspunkt for arbeidet med å identifisere mulighetsområdet for formålstjenlige CO_2-håndteringsprosjekter. Som tidligere beskrevet, er kilden for CO_2-utslipp utgangspunktet for et potensielt CO_2-håndteringsprosjekt. Uten utslipp av CO_2 vil det ikke være noe grunnlag for et CO_2-håndteringsprosjekt.

Det er totalt 34 eksisterende landbaserte utslippspunkter med årlige CO_2-utslipp tilsvarende minst 100.000 tonn i Norge. Som del av tilleggsmandatet kommer utslippet fra et eventuelt nytt kullkraftverk i Longyearbyen som antas å ha et årlig CO_2-utslipp mellom 50.000 og 100.000 tonn. Det er kun tre kilder som overskrider 1 million tonn CO_2 per år. Vedlegg 4 viser alle utslippskilder over 100.000 tonn CO_2 per år, ifølge Klifs rapporterte tall fra 2009.

3.2. *Utslippskilder over 400 000 tonn CO_2 per år*

Som forklart i kapittel 2 ble det definert en nedre grense for årlige CO_2-utslipp på 400.000 tonn.

I tillegg til de eksisterende utslippskildene er også potensielle prosjekter som vil resultere i CO_2-utslipp, kartlagt basert på åpen, tilgjengelig informasjon. Dette gjelder i hovedsak industriprosjekter som har vært omtalt i media eller er kjent gjennom andre åpne kanaler. Noen av disse er blitt evaluert videre etter kontakt med fremtidig utslippseier, mens andre ikke har vært en del av evalueringsprosessen som følge av at prosjektene er besluttet ikke videreført, som for eksempel Alcoas planer for et kombinert gasskraft- og aluminiumsverk i Finnmark.

Det er gjort teoretiske studier for å ta høyde for eventuelle fremtidige utslipp fra potensielle gasskraftverk som et resultat av mulig elektrifisering av nye olje- og gassfelt på norsk sokkel og CO_2-utslipp som et resultat av rensing av CO_2-rik ilandført gass. Disse teoretiske utslippskildene er beskrevet i mer detalj senere i rapporten.

Tabell 3 nedenfor viser alle eksisterende utslippskilder over 400.000 tonn CO_2 per år som har vært utgangspunktet for evalueringen. I tillegg er det eksisterende kullkraftverket i Longyearbyen tatt med.

Tabell 3. Eksisterende landbaserte utslippskilder i Norge

Utslippseier	Lokasjon	Beskrivelse	Utslipp [Klif 2009] kt CO_2 per år
Kraftgenering			
Naturkraft AS	Kårstø	Elektrisitet – Gasskraft	1020
Statoil ASA	Melkøya, tog I	Elektrisitet og varme - Gasskraft	805
Longyearbyen Lokalstyre, Bydrift KF	Longyearbyen, Svalbard	Elektrisitet og varme - Kullkraft	60
Olje- og gass prosessering			
Gassco AS	Kårstø	Gassterminal	1129
Metallindustri			
Hydro Aluminium AS	Sunndalsøra	Aluminium	530
Alcoa AS	Mosjøen	Aluminium	409
Petrokjemisk industri			
Yara Norge AS	Porsgrunn	Mineralgjødsel – ammoniakk	815
Ineos Noretyl AS	Bamble	Etylen	469
Sementindustri			
Norcem AS	Kjøpsvik	Sement	429
Norcem AS	Brevik	Sement	927

- Naturkrafts gasskraftverk på Kårstø ble åpnet i 2007 og produserer kraft levert ut på strømnettet. Kraftverket står ved siden av gassbehandlingsanlegget på Kårstø hvor Gassco er operatør. Eierne, Statkraft og Statoil, står ansvarlig for anskaffelse av gass til anlegget og salg av produsert kraft. Kraftverket har hatt begrenset driftstid det siste året på grunn av høy gasspris i forhold til prisen på kraft.

- Statoils gassdrevne energiverk på Melkøya er integrert med og forsyner LNG-anlegget med kraft og varme. Anlegget ble satt i produksjon i 2007 og leverer LNG (flytende naturgass) som fraktes med skip til markedet. CO_2 fra naturgass fra Snøhvitfeltet fanges, transporteres og lagres. Statoil har gjort egne omfattende arbeider knyttet til mulighet for CO_2-håndtering på energiverket.

- Det kullbaserte energiverket i Longyearbyen produserer kraft og varme til lokalsamfunnet i Longyearbyen på Svalbard. Det er ingen andre kraftkilder i Longyearbyen. Anlegget ble satt i drift sommeren 1983 og er eid av Longyearbyen Lokalstyre v/ Bydrift KF. Svalbard ligger i et arktisk område med spesielt sårbar natur, og en egen miljølov gjelder for området (Svalbardmiljøloven). I Adventdalen utenfor Longyearbyen er det gjennomført boringer for å studere mulighetene for lagring av CO_2.

- Aluminiumsprodusentene Hydro og Alcoa har aluminiumsverk henholdsvis på Sunndalsøra og i Mosjøen. Fra et aluminiumsverk slippes det ut CO_2 som et resultat av selve produksjonsprosessen når råstoffet alumina reduseres til aluminium. Norske aluminiumsverk har ikke egen kraftproduksjon fra fossile brensler, men kjøper kraft fra kraftleverandører levert gjennom strømnettet. Omfanget av utslipp av CO_2 fra aluminiumsproduksjon er relativt beskjedent internasjonalt, og avgassen har meget lav CO_2-konsentrasjon. Både Alcoa og Hydro har de siste årene gjennomført kraftig utslippsreduksjon av andre klimagasser som for eksempel perfluorkarboner (PFK).

- Yara Norge i Porsgrunn produserer blant annet ammoniakk med våtgass (LPG) som råstoff. Dette innebærer dannelse av og utslipp av CO_2. En del av prosessen gir høykonsentrert CO_2 som i dag prosesseres og selges blant annet til matvareindustrien (til kullsyreholdig drikke og til andre industrielle formål). CO_2 fraktes både med skip og tankbil fra Herøya i Porsgrunn. Yara Porsgrunn har derfor erfaring med håndtering av CO_2 for kommersielle formål. Yara har de siste årene gjennomført kraftig utslippsreduksjon av andre klimagasser som for eksempel lystgass (N_2O).

- Noretyl i Bamble, eid av Ineos, produserer etylen ved cracking av råstoffene etan og LPG (propan/butan) ved høy temperatur. Dette medfører utslipp av CO_2. Hovedproduktene, etylen og propylen, går hovedsakelig med som råstoff i den øvrige petrokjemiindustrien i Bamble, samt noe til eksport. Etylenfabrikken har vært i drift siden 1977 og har tilsammen 11 utslippspunkter. Noretyl, sammen med INEOS Bamble er en del av INEOS Olefins & Polymers Europa.

- Norcem produserer sement i både Kjøpsvik og Brevik, og er eid av det globale, tyskbaserte selskapet HeidelbergCement. CO_2-utslippene kommer fra forbrenning av kull samt fra en kjemisk prosess når kalkstein utsettes for høy temperatur (kalsinering). CO_2 fra kalsineringen står for mer enn 50 prosent av CO_2-utslippene ved en moderne sementfabrikk. HeidelbergCement har mål om å redusere egne CO_2-utslipp med 25 prosent innen 2015 i forhold til 1990. Norcem i Brevik er i oppstartsfasen av et prosjekt for å prøve ut ulike teknologier for CO_2-fangst fra sementfabrikken. Tilnærmingen for å nå målet har blant annet vært å investere i energieffektive teknologier og produksjonsprosesser og øke bruk av alternative brensler som biomasse.

Tabell 4 viser alle potensielle utslippskilder over 400.000 tonn CO_2 per år som har vært en del av evalueringen. Som tidligere nevnt, er det gjort unntak for planene for et nytt kullkraftverk i Longyearbyen.

Tabell 4. Potensielle landbaserte utslippskilder i Norge

Utslippseier	Lokasjon	Beskrivelse	Utslipp [estimat fra eier] kt CO_2 per år
Kraftgenerering			
Industrikraft Møre	Elnesvågen	Gasskraft	1756
Statoil ASA	Melkøya, tog II	Gasskraft Et gasskraftverk ble opprinnelig utredet som en alternativ kraft/varmekilde	Ikke definert
Longyearbyen lokalstyre v/Bydrift KF	Longyearbyen, Svalbard	Kullkraft	Ca 50
Olje- og gassprosessering			
Statoil ASA	Melkøya, tog II	LNG produksjon Gassfyrte kjeler for varme (damp) generering med strøm fra nettet	291
Metallindustri			
Ironman Höganäs AB og LKAB	Tjeldbergodden	Jern ved direkte reduksjon	800
Relevante teoretiske scenarier Som resultat av offshore virksomhet			
Gasskraft som resultat av potensiell elektrifisering	Definerte scenarier	Gasskraft	Ikke definert
Fangst fra ilandført CO_2-rik naturgass	Definerte scenarier	CO_2-fangst fra naturgass	Ikke definert

- Industrikraft Møre har planer om et gasskraftverk, og fikk i 2009 konsesjon under forutsetning om CO_2-håndtering fra dag en. Lønnsomheten i prosjektet er knyttet til regional ubalanse i kraftforsyningen. Realisering av planene betinges av at eierne finner kommersielt bærekraftige løsninger. Teknologiselskapet Sargas kjøpte i 2011 rettighetene til å overta 89 % av aksjene i Industrikraft Møre.

- Statoils planer for Snøhvit tog II på Melkøya har som hovedalternativ tatt utgangspunkt i elektrisitet fra nettet og varmegenerering ved gassfyrte kjeler. Et gasskraftverk ble utredet som en alternativ kraft/varmekilde. Denne kilden vil avhenge av realisering av LNG-anlegget til Statoil og av hvorvidt Statoil vil ta strømmen fra nettet eller produserer den slik som for tog I.

- Et potensielt nytt kulldrevet energiverk i Longyearbyen på Svalbard er ment å erstatte det eksisterende kulldrevne energiverket.

- Planene om et jernverk på Tjeldbergodden, basert på gassfyrt direktereduksjon av jern, innebærer en mer miljøvennlig jernproduksjon enn tradisjonelle masovner. Prosessen vil danne høykonsentrert CO_2, som vil kunne begrense kostnadene ved fangst av CO_2. Tilgang til malm, naturgass og effektiv logistikk er i følge eierne, Höganäs AB og LKAB, viktige fortrinn for prosjektet. Malmtransport fra Narvik til Europa passerer Tjeldbergodden, hvor naturgass og arealer er tilgjengelig. Prosjektet betinges av at eiernes vilje og evne til å realisere prosjektet.

- I tillegg er to teoretiske scenarier vurdert; potensielt behov for gasskraftverk som et resultat av elektrifisering av fremtidige olje- og gassfelter og utslipp som resultat av utskillelse av CO_2 fra ilandført CO_2-rik naturgass. Vurderingene er basert på offentlig tilgjengelig informasjon og avstemt med relevante offentlige instanser; NVE, OD og Petoro.

Figur 5 viser eksisterende og potensielle utslippskilder før evaluering.

Figur 5. Mulighetsområdet for CO_2-utslippskilder før evaluering

3.3. Bransjebeskrivelse

Utslippseierne som er omfattet av denne studien tilhører ulike bransjer med ulike kommersielle og tekniske forutsetninger og dermed også svært ulike drivere for CO_2-håndtering. I underlagsrapporter fra DnV og Scandpower [13 og 16] er det sammenstilt informasjon om de ulike bedriftene og bransjene. Dette avsnittet oppsummerer kort de vesentligste elementene fra disse rapportene som kan ha betydning for vurderingen av mulighetsrommet for CO_2-håndtering framover. Avsnittet er viktig for forståelse av utslippseiers nåværende posisjon og argumenter gjengitt i kap.4 og vedlegg 5 og 6.

Kraftsektoren

Den samlede norske kraftproduksjonen i 2011 var i henhold til SSB 128 TWh. Ca 95 % av kraftproduksjonen stammer fra vannkraftverk, hvor årsproduksjonen avhenger av nedbørsvariasjoner over år og mellom regioner [20]. De siste årene har overføringskapasiteten mellom Norge og utlandet økt, noe som gir økt fleksibilitet i systemet for import og eksport av kraft. Norge har i perioden 2007-2011 vært netto eksportør av kraft tilsvarende ca 4% av produksjonen.[21].

Fra 2012 ble det innført et felles norsk-svensk el-sertifikatmarked med målsetting om å tilføre 26,4 TWh ny fornybar kraft innen 2020 i forhold til 2012 [13]. Utsiktene er at Norge vil øke sin netto eksport av kraft fram mot 2025 [16]. Imidlertid er slike prognoser heftet med usikkerhet og også avhengige av forhold som årstemperaturer, endring i industriproduksjonen og endret forbruksmønster for øvrig.

På grunn av forventet økt kraftproduksjon, er det rimelig å anta at kraftprisene i Norge vil kunne ligge noe lavere enn gjennomsnittlig prisnivå i våre naboland [13].

Dette har betydning for forventningene som investorer vil legge til grunn når beslutning om nye kraftverksutbygginger skal vedtas. Den regionale kraftbalansen er avhengig av lokal overføringskapasitet og lokal kraftproduksjon. Dermed kan investeringssignalet for ny kraft være ulikt fra sted til sted. I sum vil likevel disse forholdene begrense sannsynligheten for lønnsomhet i nye gasskraftinvesteringer i Norge [16].

Gasskraft bidro i 2010 og 2011 til ca 4 % av årsproduksjonen i Norge [20]. Produksjonen avhenger av prisforskjell på gass og kraft. På grunn av lave kraftpriser og høye gasspriser har lønnsomhet ved produksjonen av gasskraft vært lav det siste året.

Petroleumsindustrien - Gassprosessering

Alle de åtte fullskala CO_2-håndteringsprosjektene som er i drift internasjonalt, hvorav to er i Norge, er drevet av petroleumsindustrien [1]. Petroleumsindustrien innehar derfor betydelig relevant egenkompetanse i hele CO_2-håndteringskjeden.

Ifølge OD har den årlige ressurstilveksten på norsk sokkel vært betydelig høyere de siste fem årene enn i årene fra 1997-2007, og de samlede investeringskostnadene har økt i samme periode [22].

Annen eksportrettet industri

Annen landbasert norsk industri har utslipp av CO_2 gjennom prosessutslipp og/eller bruk av fossil energi. Dette gjelder sement, aluminium, stål og petrokjemisk industri. Industrien kjennetegnes ved at den er lokalisert nær viktige råvarekilder, og hvor det ferdige produktet i selges i et internasjonalt marked. Prisene (og dermed også lønnsomheten) er varierende etter konjunkturforholdene.

Norsk industri brukte 78 TWh energi i 2010 [16], hvorav 56 % var forbruk av elektrisitet. Andelen naturgass i energiforbruket har økt betydelig siden 1990.

Norsk energiintensiv industri mottar støtte fra Enova til tiltak for energieffektivisering. Siden oppstarten av Enova er det kontraktsfestet besparelse på 4,3 TWh i industrien og det er innvilget mer enn 1,3 milliarder i støtte for dette [25]. I følge Enova er energiintensiteten i Norge (bruk av energi per BNP) redusert med ca 35 % siden 1990 [24].

Prosessindustrien har i lang tid arbeidet med klimagassreduserende tiltak i dialog med Miljøverndepartementet og Klif[24 – Figur 1.4]. Dette har gitt resultater og bidratt til betydelig reduksjon av andre klimagasser enn CO_2 [9].

Dette viser at industrien har gjort omfattende tiltak som har resultert i blant annet redusert utslipp av klimagasser noe som er trukket frem av utslippseierne (se kap.4).

4. RESULTATER FRA EVALUERINGEN

Som beskrevet i kapittel 2 er evalueringen gjort i henhold til fire hovedkategoriene tekniske, kommersielle og finansielle forhold samt gjennomførbarhet av CO_2-håndtering. Metoden sikrer at resultatene er i overensstemmelse med hensikten med studien. På denne måten går Gassnova god for resultatene, forutsatt at informasjonen fra utslippseierne er korrekt.

De fullstendige beskrivelsene av utslippskildene og evalueringen i forhold til de fire kategoriene, omforent med utslippseierne, er vedlagt rapporten (vedlegg 6). Dette vedlegget er engelsk, da det er et utdrag fra arbeider utført av Gassnova sammen med Mott MacDonald [4].

Det er viktig å understreke at informasjonen mottatt fra utslippseierne ikke er overprøvd, men forutsatt korrekt. Evalueringen utført så langt har ikke tatt mål av seg å overprøve selskapenes tekniske, kommersielle eller finansielle detaljer om sin utslippskilde. Neste fase av mulighetsstudien vil involvere grundig og uavhengig gjennomgang av utslippseiers informasjon.

Resultatene fra evalueringen viser mulighetsområdet for fullskala CO_2-håndtering for norske landbaserte utslippskilder. Hvorvidt en utslippskilde anses som relevant eller ikke relevant for videre studier, avhenger av informasjonen gitt av utslippseierne og resultatet fra arbeidsmøtene og evalueringen i henhold til tekniske, kommersiell og finansielle forhold samt gjennomførbarhet for CO_2-håndtering.

Som resultat av evalueringen anses fem utslippskilder relevante for videre studier, hvorav to eksisterende og tre potensielle. Videre er det åtte eksisterende og en potensiell utslippskilde som ikke anses som relevante for videre studier. Ingen av de to teoretiske scenariene er ansett som relevante, noe som beskrives i et eget kapittel 4.3.

Figur 6 viser mulighetsområdet for utslippskilder der CO_2-håndtering kan være aktuelt.

Figur 6. Mulighetsområdet for CO_2 utslippskilder etter evaluering

4.1. *Utslippskilder relevant for videre studier*

Det er ulike grunner til at de fem utslippskildene anses relevante for videre studier. Hovedgrunnene oppsummeres i tabell 5.

Tabell 5. Oversikt over mulighetsområdet for CO_2-utslippskilder relevant for videre studier

Kilde	Beskrivelse	Utslippseier(e) Mororganjsasjon	Hovedgrunn for relevans
Industrikraft Møre, Elnesvågen	Potensielt nytt gasskraftverk på Elnesvågen	Tafjord Kraft, Norsk Mineral og Hustadmarmor (Sargas har opsjon på å overta 89 % av aksjene)	• Integrert og relevant teknologi tilgjengelig fra eier • Antar at kraft-underskudd i regionen kan gi grunnlag for lokalt kraftsalg
Norcem, Brevik	Eksisterende utslipp fra sementfabrikken i Brevik	Norcem AS HeidelbergCement	• Bruk av overskudds-varme kan gi lavere kostnader • Overførbarhet til andre deler av konsernet
Yara Norge, Porsgrunn	Eksisterende utslipp fra ammoniakk-fabrikken på Herøya	Yara Norge AS Yara International ASA	• Deler av utslippet har høy CO_2-konsentrasjon • Ambisjon om bærekraftig produksjon.
Ironman, Tjeldbergodden	Potensielt nytt jernverk på Tjeldbergodden	Höganäs AB og LKAB	• Ca 70 % av utslippet er høykonsentrert CO_2, gjør fangstdelen enklere • Overførbarhet av teknologi og kompetanse til andre deler av stålindustrien.
Longyearbyen Bydrift, Svalbard	Potensielt nytt kullkraftverk i Longyearbyen, Svalbard	Longyearbyen Bydrift KF Longyearbyen Lokalstyre Justisdepartementet	• Mulighet for tett integrasjon med kilden. • Målsetting om Svalbard som et bærekraftig samfunn

I de påfølgende faktaboksene beskrives utslippskildene som er relevant for videre studier i henhold til evalueringskategoriene som det er redegjort for i kapittel 2.

En fullstendig beskrivelse av hver utslippskilde gis i vedlegg 6.

Tabell 6. Norcem, Brevik – vurdering av relevans

Bransje	**Sement**
Utslippskilde	Eier: HeidelbergCement Lokasjon: Norcem, Brevik Type: Eksisterende Utslippsmengde: 927 kt CO_2/år [Klif 2009] 
Tekniske forhold	Høy CO_2-konsentrasjon (16-19 %) forenkler fangst og bidrar til lavere kostnader Tilgjengelig overskuddsvarme til 30 % CO_2-fangst Planlagt pilotanlegg for uttesting av teknologi
Kommersielle forhold	Overførbarhet til andre deler av konsernet
Generelle kommentarer	Selskapets fokus og erfaring med bærekraftig produksjon kan styrke gjennomførbarhet

Tabell 7. Yara, Porsgrunn – vurdering av relevans

Bransje	**Mineralgjødsel** **Ammoniakkproduksjon**
Utslippskilde	Eier: Yara Norge AS Lokasjon: Porsgrunn Type: Eksisterende Utslippsmengde: 825 kt CO_2/år [Klif 2009] 
Tekniske forhold	Deler av utslippet har høy CO_2-konsentrasjon
Kommersielle forhold	Ambisjon om å sikre bærekraftig produksjon Mulig salg av CO_2 til økt oljeutvinning Overførbarhet av teknologi og erfaring innenfor eget konsern og til liknende anlegg
Gjennomførbarhet	Har kompetanse på CO_2-håndtering. Har evne til gjennomføring av store prosjekter

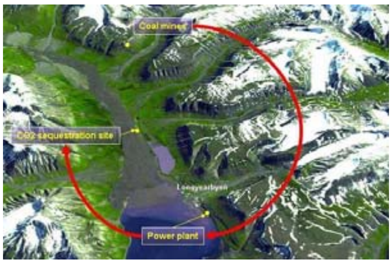
Tabell 8. Industrikraft Møre – vurdering av relevans

Bransje	**Elektrisitet – Gasskraft**
Utslippskilde	Eier: Tafjord Kraft, Norsk Mineral og Hustadmarmor (Sargas har opsjon på å overta 89 % av aksjene) Lokasjon: Elnesvågen Type: Potensielt Utslippsmengde: 1,756 mill. t CO_2/år [estimert av eier] 
Tekniske forhold	Integrert og relevant teknologi tilgjengelig fra eier (Sargas)
Kommersielle forhold	Antatt kraftunderskudd i regionen kan gi grunnlag for lokalt kraftsalg CO_2-håndtering er i henhold til konsesjonen en forutsetning for realisering av kraftverket Mulig salg av CO_2 til økt oljeutvinning
Generelle kommentarer	Tidligere studier og konsesjonsgrunnlag er basert på annen teknologi

Tabell 9. Ironman – vurdering av relevans

Bransje	**Metall – Jernproduksjon**
Utslippskilde	Eier: Höganäs AB og LKAB Lokasjon: Tjeldbergodden Type: Potensiell Utslippsmengde: 800 kt CO_2/år [estimat fra eier] 
Tekniske forhold	Ca 70 % av utslippet er høykonsentrert CO_2. Mulighet for tett integrasjon med kilden
Kommersielle forhold	Jern med svært lavt karbonavtrykk kan gi høyere pris i markedet Overførbarhet av teknologi og kompetanse til andre deler av stålindustrien
Finansielle forhold	Relativt lave fangst-kostnader

Tabell 10. Longyearbyen Bydrift – vurdering av relevans

Bransje	**Elektrisitet og varme/ Kullkraft**
Utslippskilde	Eier: Longyearbyen Bydrift KF, Longyearbyen Lokalstyre Lokasjon: Longyearbyen, Svalbard Type: Potensiell Utslippsmengde: ca. 50 kt CO_2/år [estimat fra eier] 
Tekniske forhold	Antatt tilgang til egnet lager i rimelig avstand Mulighet for tett integrasjon mellom kullkraftverk og fangstanlegg
Kommersielle forhold	Andre energikilder enn kullkraftverk vanskelig tilgjengelige for Svalbard
Generelle kommentarer	Det er ikke gjort helhetlige studier på nytt kullkraftverk integrert med fangst, transport og lagring Målsetting om bærekraftig Svalbard-samfunn

Alle de relevante utslippseierne mener at CO_2-håndtering vil være en del av et sannsynlig tiltak under fremtidige rammevilkår for sin industri (eksisterende utslippskilder) eller som en betingelse for realisering av deres prosjekt (potensielle utslippskilder).

Det er enten fordi det allerede er pålagt CO_2-håndtering (Industrikraft Møre, Elnesvågen), antatt pålagt (Ironman, Tjeldbergodden og kullkraftverket i Longyearbyen) eller forventet å bli underlagt strengere kvoteregime i fremtiden. (Yara Porsgrunn og Norcem, Brevik).

De fem relevante utslippskildene representerer ulike bransjer og vil dermed også ha ulike rammebetingelser å forholde seg til. Bransjene er nærmere beskrevet i kapittel 3.

4.2. *Utslippskilder ikke relevant for videre studier*

Tabell 11 viser oversikten over utslippskildene som ikke anses som relevante for videre studier i henhold til evalueringskategoriene beskrevet i kapittel 2. Hver utslippskilde er beskrevet med en faktaboks i vedlegg 5 og en utfyllende beskrivelse på engelsk i vedlegg 6.

Tabell 11. Hovedårsaker til ikke relevans

Kilde	Tekniske forhold	Kommersielle forhold	Finansielle forhold	CCS gjennom førbarhet
Statoil, Melkøya Tog 1 Gasskraft, Eksisterende		X		
Statoil, Melkøya Tog 2 LNG/Gasskraft, Potensiell				X
Alcoa, Mosjøen Aluminium, Eksisterende	X	X		
Hydro Aluminium, Sunndal, Eksisterende	X		X	
Naturkraft, Kårstø Gasskraftverk, Eksisterende		X		
Gassco, Kårstø Gassprosessering, Eksisterende	X	X		
Noretyl, Bamble Etylen-produksjon, Eksisterende	X		X	
Norcem, Kjøpsvik Sement, Eksisterende	X			X
Longyearbyen Bydrift, Svalbard Kullkraftverk, Eksisterende	X	X		

4.3. *Potensielle utslipp basert på teoretiske scenarier*

Mandatet for studien baserer seg på at det finnes kommersielle aktører som har, eller har planer om industriell som medfører utslipp av CO_2. Slike planer er som oftest offentlig kjent. I ulike rapporter og medieoppslag har det også vært diskutert muligheten for at ny aktivitet innen petroleumsbransjen vil kunne medføre nye CO_2-utslipp på land. Konkret er dette knyttet til elektrifisering av sokkelen, som vil kunne gi behov for ny, gassbasert kraftproduksjon, eller at produksjon av naturgass fra nye, CO_2-rike gassfelt kan medføre utskillelse og utslipp av CO_2 på land.

Gassnova har ved hjelp av Sund Energy vurdert om dette er sannsynlig innen en tidshorisont på 5-7 år [5]. Vurderingene som er gjort av de ulike, teoretiske scenariene er basert på offentlig, tilgjengelig informasjon. Fokuset har vært på funn som kan være aktuelle for utvikling og produksjonsstart i perioden. Området Haltenbanken Nord, Oseberg/Troll og Utsirahøyden Sør har i den sammenheng syntes mest interessant. Gassnovas vurderinger er også drøftet med NVE, Petoro og OD.

Resultatene fra vurderingen er i hovedtrekk at potensiell elektrifisering ikke vil være av et slikt omfang at det sannsynliggjør behovet for et nytt gasskraftverk. Det er sett i lys av det kraftoverskuddet som er forventet frem mot 2025 [13,16]. Videre er det ikke forventet grunnlag for nye CO_2-utslipp på land i tilknytning til CO_2-rike gassfelter. Det er i dag ingen planer utover Gudrun/Sigrun som er planlagt samlagret i Utsira.

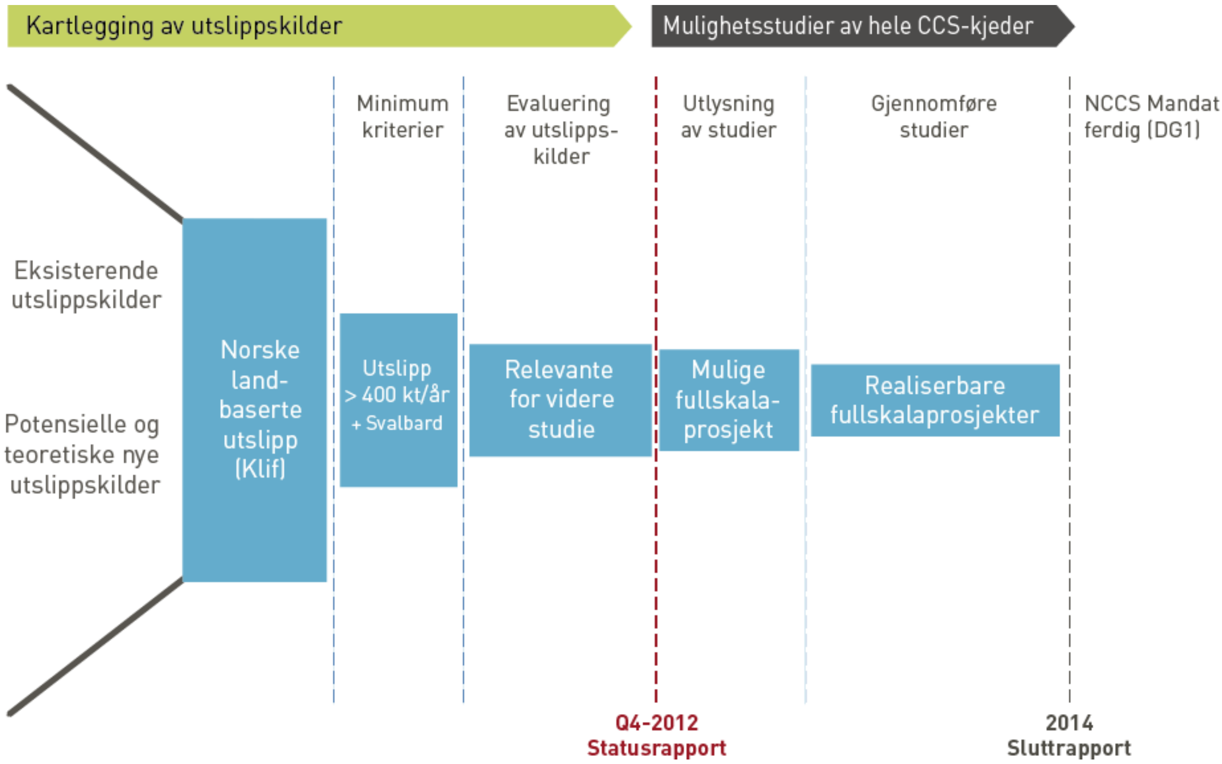
5. RAMMEBETINGELSER OG DRIVERE

Gjennom innhentede underlagsrapporter[13, 16 og 19], har Gassnova fått oppsummert industriens kommersielle og regulatoriske rammebetingelser som har vesentlig betydning for realisering av CO_2-håndtering i Norge. Disse rapportene har vært viktige for å utforme evalueringsmetoden som er benyttet i studien, samt for å forstå og drøfte aktørenes vurderinger om egen relevans for videre studier.

Utviklingen av nasjonale og internasjonale rammer og regelverk for hele CO_2-håndteringskjeden samt scenarioer for markedsutviklingen, vil være viktig i vurderingen av mulighetsrommet for CO_2-håndtering framover.

6. VIDERE ARBEID

Så langt i prosessen er kun utslippskildene evaluert. I det videre arbeidet skal hele CO_2-håndteringskjeder studeres.



Figur 8. Videre arbeid

I første del av den videre prosessen vil det utlyses en anbudskonkurranse. Det forventes at de utslippskilder som i inneværende fase er ansett som relevante, ønsker å være med videre og legger inn tilbud til dette arbeidet. Det er også åpent for andre, nye utslippskilder som foreløpig ikke har vært identifisert eller kilder som i inneværende fase er vurdert som ikke relevante, dersom forutsetninger endrer seg.

Studien kan utføres på ulike måter, enten av utslippseier selv eller i samarbeid med andre industrielle aktører. Der dette er aktuelt, vil Gassnova kunne bidra med finansiell støtte. Alternativt kan studien ledes av utslippseier selv eller av en av samarbeidspartnerne, med støtte fra Gassnova.

Det vil bli gjennomført en mulighetsstudie av de CO_2-håndteringsprosjektene som tildeles kontrakt. Formålet med den neste fasen av arbeidet er å utrede potensielle CO_2-håndteringsprosjekter til et modenhetsnivå som dokumenterer et kostnadsestimat med +/- 40 % nøyaktighet (beskrevet i vedlegg 2). Denne mulighetsstudien vil danne grunnlaget for de meste formålstjenlige prosjektene i henhold til mandatet til studien.

7. REFERANSER

[1] Global CCS Institute (GCCSI), The Global Status of CCS, 2012
As defined by Global CCS Institute (see http://www.globalccsinstitute.com/): Large-scale integrated projects are defined as those which involve the capture, transport and storage of CO_2 at a scale of

- not less than 800 000 tonnes of CO_2 annually for a coal-based power plant
- not less than 400,000 tonnes of CO_2 annually for other emission-intensive industrial facilities (including natural gas-based power generation)

[2] NER300:NER 300 Decision, Annex I. A. (I).: Minimum capacity thresholds power generation: 250 MWe Capacity thresholds should be considered as aggregate figures, as a project possibly being modular in design – also given the distribution of modules within the project boundary.

[3] Meld. St. nr 9 (2010–2011) Fullskala CO_2-håndtering Storskala er definert som minst én million tonn CO_2 fanget fra kullkraftverk eller minst en halv million tonn CO_2 fanget fra industrielle prosesser

[4] Gassnova and Mott MacDonald (2012), Norwegian Carbon Capture and Storage (NCCS) study, Status report: Realisation of full-scale CCS in Norway, Areas of feasibility, Doc.no. 301700/TGU/A-063/A, Unpublished version from December 2012.

[5] Sund Energy, Nye felt på NCS innen 2020; Løsninger for gassfelt med høy CO_2-innhold, Sannsynlighet for elektrifisering, 2012

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[7] Norges vassdrags- og energidirektorat (NVE), www.nve.no, 2012

[8] Det Norske Veritas (DNV), Final Report: Activity 1: Project evaluation methodology and criteria, 2012.

[9] Det Norske Veritas (DNV), Final Report: Activity 2: Activity report 2: CO_2 Sources in Norway, 2012.

[10] Det Norske Veritas (DNV), Final Report: Activity 3: CO_2 capture, compression and conditioning, 2012.

[11] Det Norske Veritas (DNV), Final Report: Activity 4: CO_2 storage, 2012.

[12] Det Norske Veritas (DNV), Final Report: Activity 5: CO_2 transport, 2012.

[13] Det Norske Veritas (DNV), Final Report: Activity 6: The CCS value chain and its surroundings, 2012.

[14] Scandpower Risk Management, Sund Energy, Lloyd's Register, Norwegian CCS Study – Task 1. Evaluation and ranking processes - methods and criteria, 2012.

[15] Scandpower Risk Management, Sund Energy, Lloyd's Register, Norwegien CCS Study – Task 4. CO_2 Storage in the North Sea Basin, 2012.

[16] Scandpower Risk Management, Sund Energy, Lloyd's Register, Norwegien CCS Study – Task 6. Conditions for Industrial CCS in Norway, 2012.

[17] Senergy, North Sea CO_2 Storage Activity outside the Norwegian Continental Shelf, Draft June 2012

[18] Senergy, Decision Gate Approach to Storage Site Appraisal, Draft May 2012 [to check].

[19] Artnzen de Besche, Gassnova NCCS project - Applicable law, permit issues and liability regime, 2012

[20] Statistisk Sentralbyrå, Statistisk årbok 2012, 387 Tilgang og bruk av elektrisk kraft , http://www.ssb.no/aarbok/tab/tab-387.html

[21] Statistisk Sentralbyrå, Statistisk årbok 2012, 24 Tilgang og forbruk av elektrisitet, http://www.ssb.no/emner/01/03/10/energiregn/tab-2012-11-13-24.html

[22] Statistisk Sentralbyrå, Statistisk årbok 2012, 4 Antatte og påløpte investeringskostnader til olje- og gassutvinning og rørtransport, http://www.ssb.no/oljeinv/tab-2012-12-06-04.html

[23] Meld. St. 21 (2011–2012), Melding til Stortinget, Norsk klimapolitikk

[24] Enova, Grafer og statistikk 2011, http://resultat.enova.no/resultatrapport-2011/grafer-og-statistikk

[25] Enova, En energieffektiv industri på fornybar energi, 2012, http://resultat.enova.no/resultatrapport-2011/arbeidsomrader/industri

8. VEDLEGG

1. A. Tildelingsbrev fra OED ved brev av 11. mai 2011
   B. Tilleggsmandat fra OED ved epost av 28. august, 2012

2. Prosjektgjennomføringsmodellen benyttet med relevante definisjoner

3. Liste og beskrivelse av underrapporter til denne statusrapporten

4. Eksisterende utslippskilder over 100.000 t CO_2/år (ref Klif 2009)

5. Faktabokser for utslippskilder ikke relevant for videre studier

6. Resultater fra evaluering av utslippseiere – omforent tekst med utslippseiere
   "Output from workshops with emission sources"

Vedlegg 1A: Brev av 11. mai 2011 fra OED (opprinnelig mandat)

11/74

DET KONGELIGE
OLJE- OG ENERGIDEPARTEMENT

Gassnova SF
Porsgrunn Næringspark
Dokkveien 10
3920 PORSGRUNN

Deres ref	Vår ref	Dato
	11/00626-2	11.5.2011

Meld. St. 9 (2010-2011) Fullskala CO_2-håndtering. Mandat for utredning.

Olje- og energidepartementet (OED) viser til Meld. St. 9 (2010-2011) kap. 3.3.7, der det varsles at Gassnova skal gjennomføre et utredningsarbeid om CO_2-håndtering utover prosjektet på Mongstad. OED viser også til møte mellom departementet og Gassnova den 29.4.2011. OED ønsker med dette å presisere mandatet for Gassnovas arbeid.

Mandat

Olje- og energidepartementet (OED) viser til Meld. St. 9 (2010-2011) Fullskala CO_2-håndtering, kap. 3.3.7:

> *"Gassnova skal gjennomføre et utredningsarbeid hvor hensikten er å bidra til en bred og oppdatert kartlegging av mulighetsområdet for realisering av fullskala CO_2-håndtering utover prosjektet på Mongstad"*

Regjeringen er opptatt av å bidra til gode løsninger som både kan dekke verdens energibehov og redusere utslippet av klimagasser. Det er derfor et mål å utvikle og realisere fullskala fangst, transport og lagring av CO_2 på en måte som kan bidra til bred anvendelse av slik teknologi. Departementet ønsker i den forbindelse en grundig kartlegging av muligheten for å realisere CO_2-håndtering i Norge utover prosjektet på Mongstad.

Gassnova er etablert som statsforetak for å følge opp statens roller og interesser i arbeidet med CO_2-håndtering. Departementet ønsker med dette å klargjøre oppdraget

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Org no.
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Avdeling for klima, industri og teknologi
Telefaks
22 24 95 66

Saksbehandler
Marius Knagenhjelm
22246376

som er varslet i Meld. St. 9 (2010-2011).

For det videre arbeidet med CO_2-håndtering i Norge er det behov for bedre kunnskap om ulike mulige CO_2-håndteringsprosjekter utover Mongstad. Det er ønskelig at ulike typer punktutslipp kartlegges, analyseres og vurderes, og at disse omfatter utslipp fra eksisterende og eventuelt nye anlegg innen kraftproduksjon og industri.

Departementet ønsker at utredningen identifiserer og analyserer hvilke muligheter og utfordringer man står overfor ved etablering av en fullstendig CO_2-håndteringskjede for fullskala CO_2-håndtering. I den sammenheng er det viktig å vurdere økonomiske og tekniske sider samt ulike kommersielle modeller.

Det er nødvendig at det etableres gode evalueringsmetoder og kriterier for kartleggings- og analysearbeidet som muliggjør sammenligning mellom potensielle muligheter.

Departementet ønsker at utredningen baseres på det erfaringsgrunnlaget som er bygget opp i forbindelse med arbeidet med CO_2-håndtering på Mongstad og Kårstø, resultater og erfaringer fra Climit-programmet, dialog med relevante markedsaktører og annet arbeid som er utført hos Gassnova. Det er også relevant å se hen til erfaringer fra arbeid knyttet til CO_2-håndtering i andre land. Dette inkluderer spørsmål knyttet til blant annet ulike teknologiske løsninger, vurderinger rundt aktør- og leverandørbildet, økonomiske forhold og ulike kommersielle modeller.

Utredningen vil skje parallelt med teknologikvalifiseringen i Mongstad-prosjektet.

Det bes om at Gassnova innen 30.6.2011 leverer forslag til budsjett, arbeidsprogram med leveranser og milepæler samt evalueringsmetoder og kriterier som skal ligge til grunn for arbeidet.

Med hilsen

Ove Flataker (e.f.)
ekspedisjonssjef

Marius Knagenhjelm
rådgiver

Side 2

Vedlegg 1B: Epost av 28. august, 2012 fra OED (tilleggs mandat Longyearbyen, Svalbard)

From: Brekke Cathrine [mailto:Cathrine.Brekke@oed.dep.no]
Sent: 28. august 2012 14:36
To: postmottak
Cc: Julia Lindland; Meisingset Egil
Subject: CCS Mulighetsstudien

Gassnovas utredningsarbeid – CCS Mulighetsstudien

Det vises til brev av 11. mai 2011 fra Olje- og energidepartementet med mandat for det utredningsarbeidet som følger av Meld St 9 (2010-2011). Det vises også til tildelingsbrev til Gassnova for 2012 pkt 4.2.4 (CCS mulighetsstudie)og møter mellom Gassnova og departementet, sist den 8. august i år.

Ved Stortingets behandling av Meld St 21 (2011-2012) *Norsk klimapolitikk*, jf. Innst 390 S (2011-2012), fremgår følgende flertallsmerknad;

"Komiteen ser også med interesse på det betydelige arbeid som er foretatt på Svalbard for å se på hvordan et eventuelt nytt kullkraftverk i Longyearbyen også kan brukes som et demoprosjekt for fangst og lagring av CO_2*, og imøteser Gassnovas vurdering av dette prosjektet."*

På denne bakgrunn legger departementet til grunn at utredningsarbeidet omfatter en vurdering av mulighetene for CO_2-håndtering av utslipp fra et eventuelt nytt kullkraftverk i Longyearbyen, basert på mandat av 11. mai 2011 og Gassnovas arbeidsprogram av 4. november samme år. Departementet ber Gassnova kontakte eier av kraftverket, Longyearbyen lokalstyre v/Bydrift Longyearbyen, vedrørende definisjon av prosjektet og avklaring av arbeidsfordeling. Departementet vil samtidig be om at en vurdering av CO_2-håndtering i Longyearbyen inngår i den rapporteringen som skal leveres innen utgangen av 2012.

Mvh Cathrine Brekke

Cathrine Brekke
underdirektør

Avdeling for klima, industri og teknologi

Olje- og energidepartementet
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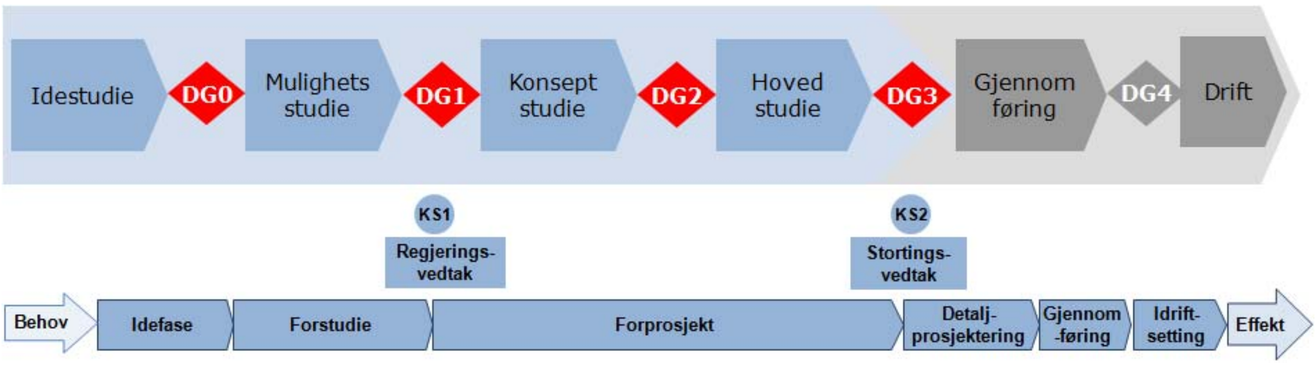
Vedlegg 2: Prosjektgjennomføringsmodellen benyttet for utredningsarbeidet

En etablert prosjektmodell (Gassnova 2011a og b) med definerte beslutningspunkter -"Decision gates"- vil bli brukt (ref. øvre del av Illustrasjon 1) i utredningsarbeidet.

Denne prosjektmodellen definerer de prinsipper som gjelder for planlegging og gjennomføring av prosjekter. Den baserer seg på god industriell praksis, og er koblet opp mot finansdepartementets krav til statlig finansierte prosjekter (se nedre del av Illustrasjonen 1), bl.a. kvalitetssikringspunktene KS1 og KS2.



Illustrasjon 1: Prosjektmodellen i Gassnova (øverst) sett i sammenheng med Finansdepartementets prosjektmodell (nederst).

Fram mot hvert beslutningspunkt (DG) forberedes underlaget for å kunne ta beslutning; både når det gjelder definisjon av det endelige anlegget, hvilke alternativer som bør videreføres eller frafalles og gjennomføring av neste fase. Denne studien vil kun omfatte fasene frem til utført mulighetsstudie og ha en sluttleveranse ved hovedmilepæl DG1.

Med tidligere bygde referanseprosjekter, vil en ved NCCS sluttleveransen DG1 ha såkalte første klassifiserte kostnadsestimat ofte forenklet til en usikkerhet i kostnadsestimatet på +/- 40 %. Da det ikke er tidligere bygde fullskala CCS referanseprosjekt, vil en usikkerhet i kostnadsestimatet på +/- 40 % ved DG1 være er et overordnet mål, men vil kunne være vanskelig å oppnå for enkelte områder spesielt innen lagring.

<u>Referanser til vedlegg 2:</u>

Gassnova (2011a) Prinsippdokument Prosjekter, dokumentnummer PR-002-09, rev. 2.0, datert 03.01.2011, 29 sider.

Gassnova (2011b) Prosjektutvikling og DG krav, dokumentnummer PR-011-10, rev. 1.0, datert 31.01.2011, 11 sider.

Vedlegg 3: Liste over og beskrivelse av underrapporter

Følgende relevante underrapporter, er gjort tilgjengelig av Gassnova, som del av arbeidet

1. **Det Norske Veritas (DNV), Final Report: Activity 1: Project evaluation methodology and criteria, 2012.**

   Denne rapporten er en del av forundersøkelsene som ble foretatt årsskiftet 2011/12 og var grunnlaget for å utforme evalueringskategoriene og evalueringsprosessen.
   Bestillingen for denne rapporten var
   a. Gjennomgå og utarbeide sammendrag av relevante internasjonale og nasjonale rapporter som omhandler evaluerings- og rangeringsprosesser
   b. Kartlegge alle benyttede rangeringsprosesser og hvilke konkrete CO_2-håndteringsprosjekter som har blitt vurdert og fremmet med disse
   c. Kartlegge benyttede kriterier og gjøre en vurdering av disse
   d. Kartlegge leverandører/markedsaktører som har bidratt i utvikling og bruk av de identifiserte rangeringsprosesser
   e. Basert på innhentet informasjon, lage en oversikt over relevante alternative evaluerings- og rangeringsmetoder med tilhørende kriterier
   f. Utføre en analyse av evaluerings- og rangeringsmetode og gi en vurdering av kritiske forhold ved anvendelse i CCS Mulighetsstudie, og eventuelle mangler
   g. Hvis tid, gi forslag til prosess med milepæler og kriterier

2. **Det Norske Veritas (DNV), Final Report: Activity 2: Activity report 2: CO_2 Sources in Norway, 2012.**

   Denne rapporten er en del av forundersøkelsene som ble foretatt årsskiftet 2011/12 og var grunnlaget for å utforme evalueringskategoriene og evalueringsprosessen.
   Bestillingen for denne rapporten var
   a. Identifisere eksisterende og potensielt nye fullskala utslippskilder i Norge:
   b. Gjennomgå og utarbeide sammendrag av relevante åpne rapporter for de identifiserte utslippskildene (basert på f eks konsesjonssøknader, utslippssøknader, årsrapporter, langtidsplaner, strategiske planer etc)
   c. Beskrive og vurdere virksomhetene for de identifiserte eksisterende og potensielle CO_2 -kilder med tanke på f eks kommersielle aktører/modeller, markedsvurdering, råstofftilgang involvert etc
   d. Utarbeide en teknisk beskrivelse og utføre en teknisk vurdering av de identifiserte utslippskildene med tanke på tilknytning, spesifikasjoner eller annen føring på nedstrømsanlegg

3. **Det Norske Veritas (DNV), Final Report: Activity 3: CO_2 capture, compression and conditioning, 2012.**

   Denne rapporten er en del av forundersøkelsene som ble foretatt årsskiftet 2011/12 og var grunnlaget for å utforme evalueringskategoriene og evalueringsprosessen.
   Bestillingen for denne rapporten var
   a. Gjennomgå og utarbeide sammendrag av relevante åpne rapporter som f eks GCCIs statusrapporter, IEAGHG Technology roadmap etc
   b. Identifisere og vurdere prosjekter, både demo og fullskala under utvikling inkludert teknologivalg, aktører involvert etc
   c. Utarbeide en markedsoversikt over leverandører av fangstteknologi med tilhørende aktiviteter, modenhetsgrad, prosjekter etc
   d. Identifisere og vurdere kvalifikasjonsprosedyrer og tilhørende teknologikvalifisering for de identifiserte prosjektene
   e. Utarbeide oversikt over testanlegg – leverandør, teknologi, størrelse, anvendelse og status
   f. Identifisere eventuelle ulikheter i teknologikrav og utfordringer mellom fangst fra gass-, bio- og kullkraftverk og fra industrielle utslipp
   g. Vurdering av tidspunkt for når relevante teknologier er kvalifisert
   h. Sammenstille status med risikovurdering

4. **Det Norske Veritas (DNV), Final Report: Activity 4: CO_2 storage, 2012.**

   Denne rapporten er en del av forundersøkelsene som ble foretatt årsskiftet 2011/12 og var grunnlaget for å utforme evalueringskategoriene og evalueringsprosessen.
   Bestillingen for denne rapporten var
   a. Utarbeide en status for CO_2-lagring og anvendelse (f eks økt oljeutvinning) internasjonalt og nasjonalt:
   b. Utarbeide en oversikt over allerede identifiserte lageralternativer i Nordsjøen (bl.a. ODs lagringsatlas og andre nominerte områder fra industrien)
   c. Identifisere og beskrive pågående prosjekter, både demo og full-skala under utvikling inkludert type lager, beliggenhet, eventuell anvendelse, aktører involvert, status etc
   d. Utarbeide en markedsoversikt over eksisterende lageraktører og rettighetshavere med tilhørende aktiviteter, modenhetsgrad, prosjekter etc
   e. Utarbeide en status av benyttede og utviklede metoder, guidelines og retningslinjer for å identifisere og kvalifisere lagringsalternativer internasjonalt og nasjonalt

5. **Det Norske Veritas (DNV), Final Report: Activity 5: CO_2 transport, 2012.**

   Denne rapporten er en del av forundersøkelsene som ble foretatt årsskiftet 2011/12 og var grunnlaget for å utforme evalueringskategoriene og evalueringsprosessen.
   Bestillingen for denne rapporten var
   a. Gjennomgå og utarbeide sammendrag av rapporter for ulike relevante transportmuligheter og eventuelle mellomlager internasjonalt og nasjonalt
   b. Identifisere og beskrive prosjekter, både demo og fullskala under utvikling inkludert transportløsning, aktører involvert etc
   c. Utarbeide en markedsoversikt over transportaktører med tilhørende aktiviteter, markedsandel, prosjekter, status på transportløsning etc
   d. Identifisere og vurdere kvalifikasjonsprosedyrer og tilhørende teknologikvalifisering benyttet for de identifiserte transportløsninger
   e. Identifisere og vurdere benyttede og potensielle modeller for nettverksløsninger med tilhørende kommersielle modeller

6. **Det Norske Veritas (DNV), Final Report: Activity 6: The CCS value chain and its surroundings, 2012.**

   Denne rapporten er en del av forundersøkelsene som ble foretatt årsskiftet 2011/12 og var grunnlaget for å utforme evalueringskategoriene og evalueringsprosessen.
   Bestillingen for denne rapporten var
   a. Regulatoriske og kommersielle rammevilkår for fremtidig verdiskapning og sikring for Norge
   b. Vurdering av kraft- og energimarkedet
   c. Nåværende reguleringer og juridiske forhold relevant for prosjektgjennomføring
   d. Kommersielle modeller for prosjektgjennomføring og drift

7. **Scandpower Risk Management, Sund Energy, Lloyd's Register, Norwegian CCS Study – Task 1. Evaluation and ranking processes - methods and criteria, 2012.**
   For detaljer – se pkt. 1

8. **Scandpower Risk Management, Sund Energy, Lloyd's Register, Norwegian CCS Study – Task 4. CO_2 Storage in the North Sea Basin, 2012.**
   For detaljer – se pkt. 4

9. **Scandpower Risk Management, Sund Energy, Lloyd's Register, Norwegian CCS Study – Task 6. Conditions for Industrial CCS in Norway, 2012.**
   For detaljer – se pkt. 6

10. **Senergy, North Sea CO_2 Storage Activity outside the Norwegian Continental Shelf, Draft per June 2012**

    Denne rapporten beskriver relevant rammeverk for CO_2-lagring og aktiviteten knyttet til fremtidig lagring av CO_2 i Nordsjøen utenfor norsk kontinentalsokkel. Bl.a. beskrives aktiviteten i Danmark, Tyskland, Nederland og Storbritannia.

11. **Senergy, Decision Gate Approach to Storage Site Appraisal, Draft per May 2012**

    Denne rapporten beskriver en generisk prosess for kvalifisering av CO_2-lager knyttet opp mot standard prosjektgjennomføringsmodell med beslutningspunkter fra DG0 til DG3 (investeringsbeslutning). Rapporten definerer hvilken informasjon som bør være tilgjengelig ved de ulike milepælene

12. **Arntzen de Besche, Gassnova NCCS project - Applicable law, permit issues and liability regime, 2012**

    The aim of the legal workstream will be to provide to Gassnova an overview of the legal regime for CCS in Norway, in particular on its suitability for CCS projects. This will be looked at from the perspective of domestic and international investors, and using the Scandpower and DNV studies as starting points. The overview shall enable an understanding of the risk for the parties involved in a CCS chain and identify the legal gaps that must be filled in order to make a CCS chain happen. The overview will serve as a base case for the project on legal matters. When specific projects (chains) are defined, a detailed assessment of the elements may be required.

    In this work we would work to understand (i) CCS specific law to the extent it exists, or (ii) to the extent it is defined by international regulations and EU directives that the Norwegian government have the intention to adapt and (iii) the extent to which the oil and gas regime is applicable to CCS, and if not whether it provides a useful example and / or could be extended to cover it. In each of the separate work packages we will also examine the extent to which the CCS Directive as implemented in Norway provides coverage.

    The overview needs to cover each element of the CCS chain (capture, transport, and storage) and all related issues, for example as to security for long-term liabilities.

Vedlegg 4: Eksisterende utslippskilder over 100,000 t CO_2/år (ref Klif 2009)

Utslippskilde	CO_2 utslipp (1000 tonn/år)
Statoil Mongstad	1,553
Gassco as, Kårstø	1,129
Naturkraft Kårstø	1,020
Norcem Brevik	927
Yara Norge as, Yara Porsgrunn	815
Hammerfest LNG Snøhvit	805
Hydro Aluminium as Sunndal	530
Noretyl as	469
Norcem Kjøpsvik	429
Alcoa Mosjøen	409
Esso Norge as, Slagentangen	349
Hydro aluminium as Karmøy	318
Statoil asa Tjeldbergodden metanolfabrikk	315
Hydro aluminium as Årdal, Årdal metallverk	322
Peterson linerboard as, Moss	288
Borregaard ind. ltd., Cellulosesektor	272
Eramet Titanium & iron as, Odda	248
Fesil rana metall as	198
Elkem Bremanger	186
Elkem Salten	183
Finnfjord as	179
Klemetsrud energigjenvinningsanlegg	170
Eramet Norway Kvinesdal as	170
Eramet Norway as, Sauda	169
Norske Skog Skogn	165
Alcoa, Lista	163
Sør-Norge Aluminium	161
Elkem Thamshavn as	155
Norske skogindustrier asa, Saugbrugs	137
Wacker chemicals Norway	136
Haraldrud energigjenvinningsanlegg	125
Hydro aluminium as Årdal, Årdal karbon	116
Frevar kf – forbrenningsanlegget	107
Hydro Aluminium as Høyanger	100

Vedlegg 5. Faktabokser for utslippskilder ikke relevant for videre studier

Tabell v5.1. Statoil, Melkøya, Tog I – vurdering av relevans

Bransje	**Elektrisitet- og varmeproduksjon, Gasskraft**
Utslippskilde	Eier: Statoil Lokasjon: Melkøya Type: Eksisterende Utslippsmengde: 805 kt CO_2/år [Klif 2009] 
Tekniske forhold	Andre tiltak er identifisert og presentert Klif som gir tilsvarende CO_2 reduksjon som CO_2 fangst og innebærer lavere risiko
Kommersielle forhold	Mer lønnsomt å gjennomføre andre tiltak (i.e. elektrifisering) for å redusere CO_2-utslipp ytterligere. Alternativ løsning er å kjøpe strøm fra nettet
Gjennomførbarhet	Lagringsdirektivet gir urimelig usikkerhet og risiko på aktørene som skal stå for transport og lagring
Generelle kommentarer	Godt utredet allerede, og konklusjonen fra disse er fortsatt gyldig

Tabell v5.2. Statoil , Melkøya, Tog II – vurdering av relevans

Bransje	**Gassprosessering LNG** **Varme**
Utslippskilde	Eier: Statoil ASA Lokasjon: Melkøya Type: Potensiell  Hovedalternativ for et Tog II var strøm fra nettet og varmegenerering ved gassfyrte kjeler. Et gasskraftverk ble utredet som en alternativ kraft/varmekilde. Utslippsmengde: 291 kt CO_2/år med oljefyrte kjeler for varmeproduksjon.
Gjennomførbarhet	Prosjektet er stanset på grunn av at nåværende gassfunn ikke gir tilstrekkelig basis for videre ekspansjon

Tabell v5.3. Alcoa, Mosjøen – vurdering av relevans

Bransje	**Aluminium**
Utslippskilde	Eier: Alcoa Lokasjon: Mosjøen Type: Eksisterende Utslippsmengde: 409 kt CO_2/år [Klif 2009] 
Tekniske forhold	Lav CO_2-konsentrasjon som vanskeliggjør fangst Mange spredte kilder Ikke tilgjengelig plass for CO_2-fangstanlegg
Kommersielle forhold	Alcoa vurderer andre tiltak gjennom prosess og driftsforbedringer Urimelige store konsekvenser ved driftsforstyrrelser Markedet er ikke villig til å betale ekstra for grønn aluminium

Tabell v5.4. Hydro, Sunndal – vurdering av relevans

Bransje	**Aluminium**
Utslippskilde	Eier: Hydro ASA Lokasjon: Sunndal Type: Eksisterende Utslippsmengde: 530 kt CO_2/år [Klif 2009] 
Tekniske forhold	Lav CO_2-konsentrasjon som vanskeliggjør fangst I følge Hydro kan avgassen oppkonsentreres, men relevant teknologi under utvikling av Hydro svært umoden. Mange spredte kilder
Finansielle forhold	Stort økonomisk og teknisk gap for å kunne fange (capture ready)
Generelle kommentarer	Hydro har jobbet med teknologi for oppkonsentrering av CO_2, men "flere år" med utvikling gjenstår.

Tabell v5.5. Naturkraft, Kåstø, – vurdering av relevans

Bransje	Gasskraftverk
Utslippskilde	Eier: Naturkraft AS Lokasjon: Kårstø Type: Eksisterende Utslippsmengde: 1029 kt CO_2/år [Klif 2009] 
Kommersielle forhold	Hittil lite driftstid. Usikker fremtidig drift pga relativt høy gasspris vs kraftpris. Utviklingen framover gir begrenset lønnsom drift
Gjennomførbarhet	Naturkraft AS som organisasjon har ikke kapasitet til prosjektgjennomføring
Generelle kommentarer	CO_2-fangst fra kraftverket på Kårstø er godt utredet og konklusjonene er fortsatt gjeldende

Tabell v5.6. Gassco, Kåstø, – vurdering av relevans

Bransje	Gassprosessering
Utslippskilde	Eier: Gassco Lokasjon: Kårstø Type: Eksisterende Utslippsmengde: 1129 kt CO_2/år [Klif 2009] 
Tekniske forhold	Mange utslippspunkter med store avstander og med komplisert tilgang. Innebærer omfattende endringer på anlegget
Kommersielle forhold	Integrasjon avhenger av fangstløsning ved Naturkrafts kraftverk. Potensielt urimelige store kommersielle konsekvenser ved driftsforstyrrelser av gassterminalen.
Generelle kommentarer	Integrert fangstløsning (med Naturkraft) er tidligere studert og konklusjonene er fortsatt gjeldende.

Tabell v5.7. Ineos Noretyl – vurdering av relevans

Bransje	**Etylen-produksjon**
Utslippskilde	Eier: Ineos Lokasjon: Bamble Type: Eksisterende Utslippsmengde: 469 kt CO_2/år [Klif 2009] 
Tekniske forhold	Teknisk komplisert tilknytning av et potensielt fangstanlegg. Flere utslippspunkter og vanskelige tilkoblinger Lange vedlikeholdssykler gir liten mulighet for tilkobling av CO_2-håndteringsanlegg uten at ekstraordinær nedstengning av produksjonen må foretas
Kommersielle forhold	Stor risiko for prosessforstyrrelser med påfølgende nedstenginger ved avtak av utslipp. Urimelige store kommersielle konsekvenser ved driftsforstyrrelser
Finansielle forhold	Små driftsmarginer gir lite vilje til kapitalintensive prosjekter uten positive resultateffekter.
Generelle kommentarer	Begrenset kapasitet for prosjektgjennomføring

Tabell v5.8. Norcem, Kjøpsvik – vurdering av relevans

Bransje	**Sement**
Utslippskilde	Eier: HeidelbergCement Lokasjon: Kjøpsvik Type: Eksisterende Utslippsmengde: 429 kt CO_2/år [Klif 2009] 
Tekniske forhold	Begrenset plass til CO_2-fangstanlegg
Gjennomførbarhet	Aktøren anser Brevik som bedre alternativ Begrenset kapasitet for to CO_2-håndteringsprosjekter

Tabell v5.9. Longyearbyen Bydrift – vurdering av relevans

Bransje	**Kullkraftverk**
Utslippskilde	Eier: Longyearbyen Bydrift KF, Longyearbyen Lokalstyre, Lokasjon: Svalbard/ Longyearbyen Type: Eksisterende Utslippsmengde: 60 kt CO_2/år [Klif 2009] 
Tekniske forhold	Ikke tilgjengelig energi for å drive et fangstanlegg
Kommersielle forhold	Forventet kort gjenværende levetid på eksisterende kraftvarmeverk

En mer utfyllende beskrivelse kan finnes i vedlegg 6, som er omforent tekst fra arbeidet med utslippseierne i henhold til de fire evalueringskategoriene.



CCS Mulighetsstudie – Vedlegg 6

Output from workshops with emission sources

Excerpt from English Status Report
Doc. No.: 301700/PWR/TGU/A-063/D December 2012
[See Norwegian Reference list, 4]

GASSNOVA

Mott MacDonald

GASSNOVA

Mott MacDonald

Contents

1. Introduction

This appendix presents the output from the workshops with the owners of the emission sources that were identified using the NCCS screening methodology. At these workshops, Gassnova, Mott MacDonald and the representatives of the emission source owners discussed the possibility of these emission sources participating in NCCS Study. Gassnova are specifically interested in identifying emission sources that would be interested in applying for funding for a pre-feasibility study.

Discussion of the suitability of a particular emission source for CCS was broken into four areas:

- Technical viability: could the project be practically implemented and would it work without causing excessive adverse impacts on the host plant?
- Commercial viability: is the project commercially viable and if not, what would it take for the project to become viable?
- Financial viability; is there a means to raise funding and what is the financial capability (strength) of the project sponsors?
- CCS deliverability: are the conditions present to facilitate the implementation of CCS?

The assessment presented in this appendix reflects the views expressed by the owners and the data has been provided by them, both during the workshops held in October and early November 2012 and in subsequent correspondence. The texts and pictures are published here with the companies' knowledge and consent. Gassnova and Mott MacDonald, acting as advisors and facilitators, sought to apply a consistent set of evaluation categories to all parties. At this stage in the process there has been no independent scrutiny and verification of the data and information provided by the emitters. Therefore this report is reliant on the data and information provided by the owners of the emission sources. The next stages of NCCS Study, particularly when emitters seeking funding for studies by submitting formal proposals, will involve full and independent scrutiny of bidders' evidence, in terms of both data and logic.

This appendix is an extract of the English Status Report [see Norwegian Reports reference list, 4].

2. Alcoa Norway

This section is based on an assessment form agreed by Alcoa during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. This assessment form was signed by an Alcoa representative to declare that, to the best of their knowledge, the information provided in the form was accurate [13].

Alcoa Norway is a subsidiary of the global aluminium company Alcoa, which has its headquarters in New York, and produces 3.8 million tonnes of aluminium per year. The Norwegian operation, which is a merger of Alcoa and Elkem, has two smelting plants in Norway have a nameplate capacity of 282 kt/y of aluminium and emit about 600 kt/y of CO_2 equivalent (CO_2e). Alcoa's total global CO_2e emissions from its own facilities are about 9 Mt/y.

Alcoa Norway's total CO_2e emissions per ton aluminium have fallen substantially in recent decades (although CO_2 emissions have remained stable); emissions fell by 55% between 1990 and 2010, while output of aluminium increased by 20%. This was largely the result of initiatives following an agreement between the Climate and Pollution Agency (KLIF, formerly SFT, now merging with another agency and will become the Environmental Agency from 2013) and Alcoa (and Hydro, the other aluminium producer in Norway) to cut process emissions. The reductions were achieved through process improvements, with the basic core smelting process remaining unchanged. Alcoa is continuing to pursue process technologies and production technologies in aluminium smelting, to improve performance and reduce emissions.

2.1 Alcoa Mosjøen Plant

Table 2.1: Alcoa fact box

Major Activity	Aluminium Smelting
Existing or New / Potential Source	Existing
Estimated future emissions of CO_2 from facility	Anode plant: 103.7 kt/y Pot rooms:283.7 kt/y Cast house: 15.7 kt/y Total: 403.1 kt/y
Does the owner consider the facility relevant or not relevant for the NCCS study?	Not Relevant
Technical reasons for relevance decision	• The sources of CO_2 on site are widely distributed • The concentration of the flue gas is very low i.e. down to 0.9% CO_2 • Capture of the CO_2 is challenging from the pot rooms as the piping system would need to be redesigned. • No steam is available on site • Very limited space for building a CCS plant.

Commercial reasons for relevance decision	• Alcoa are investigating other carbon saving options through process and operation improvements. • Any disruption to the smelting process would lead to lost production and sales revenue as this plant operates 24 hours a day 365 days a year.
Deliverability reasons for relevance decision	• Aluminium buyers recognise the relatively low carbon footprint of Norway's product but they are currently not prepared to pay a premium for them

Figure 2.1: Alcoa Mosjøen Plant

Source: Alcoa

Alcoa has not pursued CCS at Mosjøen due to significant technical and commercial challenges with the process, particularly the low CO_2 concentration, the dispersed emission points and the lack of ready process heat for driving the capture plant.

Alcoa points out that aluminium produced in Norway from clean hydro power has a total carbon footprint 8 to 10 times lower than aluminium produced in countries that use fossil fuel sources, e.g. in China where the indirect emissions (e.g. emissions from the electrical power generation used in the aluminium smelting process) are higher as power is predominantly from coal-fired power. Regarding direct emissions, Alcoa state that the Mosjøen plant is among the best in the world. Alcoa also state that there are indirect carbon benefits from using aluminium, as the metal is highly recyclable, has a high strength-to-weight ratio and is easier to form than steel and steel-based alloys.

Alcoa Norway state that their Mosjøen plant is not relevant for the NCCS study or CCS given the technical challenges mentioned above. These are exacerbated by constrained site space. This leads to extremely high costs and also a non trivial risk to core production at the site from installation and operation of CCS. At the same time there are limited revenue benefits, as buyers are unwilling to pay a premium for low carbon aluminium products.

2.1.1 Technical viability

The Mosjøen plant has 9 stacks that are widely distributed across the site and all have relatively low concentrations of CO_2. The CO_2 concentrations for each stack have been calculated to be between 0.9 to 2.5%. The concentrations have been calculated as there is no requirement to measure the stack concentrations of CO_2 from KLIF.

CCS has been considered by Alcoa, but was discounted as being overly complex, expensive and high risk. Alcoa is seeking alternative carbon reduction measures through process optimisation at Mosjøen.

Capturing CO_2 from the pot rooms, where 70% of the site emissions are produced, is particularly challenging. The gas here has been calculated to be only 0.9% CO_2 and is considered very expensive to capture as the piping system for the gas would need to be redesigned.

Space is limited on this site, with 75% of the land already being reclaimed to build this plant. More land would need to be reclaimed to install CCS equipment. No steam is available on site and heat recovery from the pot lines would be difficult, impractical and costly. This is because the outlets from the pots are low temperature (80ºC to 90ºC), dispersed and space constrained.

2.1.2 Commercial viability

Alcoa does not see a role for CCS under the current smelting technologies deployed worldwide and it argues that it has already adopted the cost effective measures to reduce emission at many of its sites. In Norway it has cut CO_2e emissions by 55% between 1990 and 2010, while increasing production by 20%; Alcoa states it cannot maintain this rate of improvement as its sites are reaching their technical limits of emission reduction.

Alcoa consider that retrofitting CCS is not commercially viable given the very high costs which reflect the technical challenges described in section 2.1.1.

Alcoa state that global aluminium producers currently face a difficult market, with many producers operating with little or no operating margin, which means that investment is focussed on measures to reduce costs. The aluminium industry competes on cost and their ability to adapt to changes in market. This requires a lean and flexible business, which creates challenges for the implementation of CCS on existing aluminium facilities. Any disruption to the smelting process would lead to lost production and sales revenue as this plant operates 24 hours a day 365 days a year. The target maximum downtime for this plant is just 10 hours a year.

2.1.3 Financial capability

Although not investigated in any detail, Alcoa believes that capital and operating cost of retrofitting CCS at the Mosjøen plant would be extremely high, resulting in an elevated cost of carbon abated. There would also be increased risks of loss to production and damage to facilities.

Alcoa also believes that transport and storage costs would also probably be high given the isolated location of Mosjøen and the lack of clustering opportunities.

2.1.3.1 CCS Deliverability

Alcoa believes any roll out of CCS would need to be done on a commercial basis and after much better information on costs and benefits becomes available. Alcoa believes it would need to be done in a way that did not disadvantage Norwegian primary commodities processors including aluminium. Under current best practice smelting technology, Alcoa believes there is no viable option for CCS and so the industry's efforts are focussed on reducing emissions through process and operation enhancements.

While aluminium buyers recognise the low carbon embedded in Norway's products (given the reliance on hydropower energy to drive the processes), they have as yet not been prepared to pay a premium for this.

If CCS was found to be cost competitive, Alcoa state that they would have the capability to execute a CCS project.

2.1.4 Relevance decision

Alcoa consider that its Mosjøen facility is 'Not Relevant' for further participation in the NCCS Study because the sources of CO_2 on site are widely distributed and the concentration of the flue gas is only 0.9 to 2.5%. Capture of the CO_2 is challenging from the pot rooms as the piping system would need to be redesigned. No steam is available and space is limited on site for CCS.

Alcoa are investigating other carbon saving options through process and operation improvements. Any disruption to the smelting process would lead to lost production and sales revenue as this plant operates 24 hours a day 365 days a year.

Aluminium buyers recognise the relatively low carbon footprint of Norway's product but they have as yet not been prepared to pay a premium for this.

2.2 Previous experience and knowledge of CCS

Alcoa have no previous experience or knowledge of studies on CCS at the Mosjøen site.

3. Gassco

This section is based on an assessment form agreed by Gassco during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. The assessment form was signed by a Gassco representative to declare that to the best of their knowledge the information provided in that form was accurate [2].

Gassco was founded by the Norwegian Ministry of Petroleum and Energy (MPE) in 2001 and took operational responsibility for all gas transport from the Norwegian continental shelf in 2002. Gassco is also the operator of the gas processing and export terminals at Kårstø and Kollsnes, as well as natural gas receiving terminals in Germany, Belgium, France and the UK. Gassco is involved in several projects related to transportation of CO_2.

3.1 Kårstø Gas Processing

Table 3.1: Gassco fact box

Major Activity	Gas processing and transportation
Existing or New / Potential Source	Existing
Estimated future emissions of CO_2 from facility	Between 1,000 kt – 1,250 kt/y
Does the owner consider the facility relevant or not relevant?	Not Relevant
Technical reasons for relevance decision	• Previous CCS studies show a complicated site with many spread emission sources that would need extensive tie-ins, dismantling and reconstruction. Combining the flue gas from the stacks would be challenging due to the distance between them.
Commercial reasons for relevance decision	• CCS could negatively impact the facility's availability which would have a high cost taken into account the value of gas delivered through their terminal every day. • Integration scenarios rely on Naturkraft's CCGT running at a high capacity factor, which was concluded to be unlikely due to economic constraints. • Previous studies concluded "There is no commercial basis for realising any of the scenarios, taken into account all relevant costs, expected CO_2 quotas and other benefits and savings." • Costs of the investigated scenarios were significantly

	higher than the expected European emission allowance (EUA) prices in 2020.
Deliverability reasons for relevance decision	• Construction activities will be complicated by site rules for 'hot-works' with high associated costs.

Figure 3.1: Kårstø site

Source: Gassco

The gas processing plant at Kårstø processes rich gas from gas fields in the Statfjord and Haltenbanken areas. It delivers a daily rich gas capacity of up to 88 million Sm³.

The processing facilities at Kårstø comprise of four extraction/fractionation trains for methane, ethane, propane, butanes, and naphtha, plus a fractionation train for stabilising condensate. Ethane, isobutene and normal butane are stored in refrigerated tanks, while naphtha and condensate are held in tanks at ambient temperature. Propane is stored in large refrigerated rock caverns. 7.5 million tonnes of natural gas liquids (NGLs) are produced annually and are exported from Kårstø by ship. The dry gas is exported from Kårstø by pipelines.

Annual CO_2 emission from the Kårstø gas processing plant is currently between 1.1 and 1.2 million tonnes from eight different point sources, mainly directly driven gas compressors. The plant is one of the three largest CO_2 emitters in Norway.

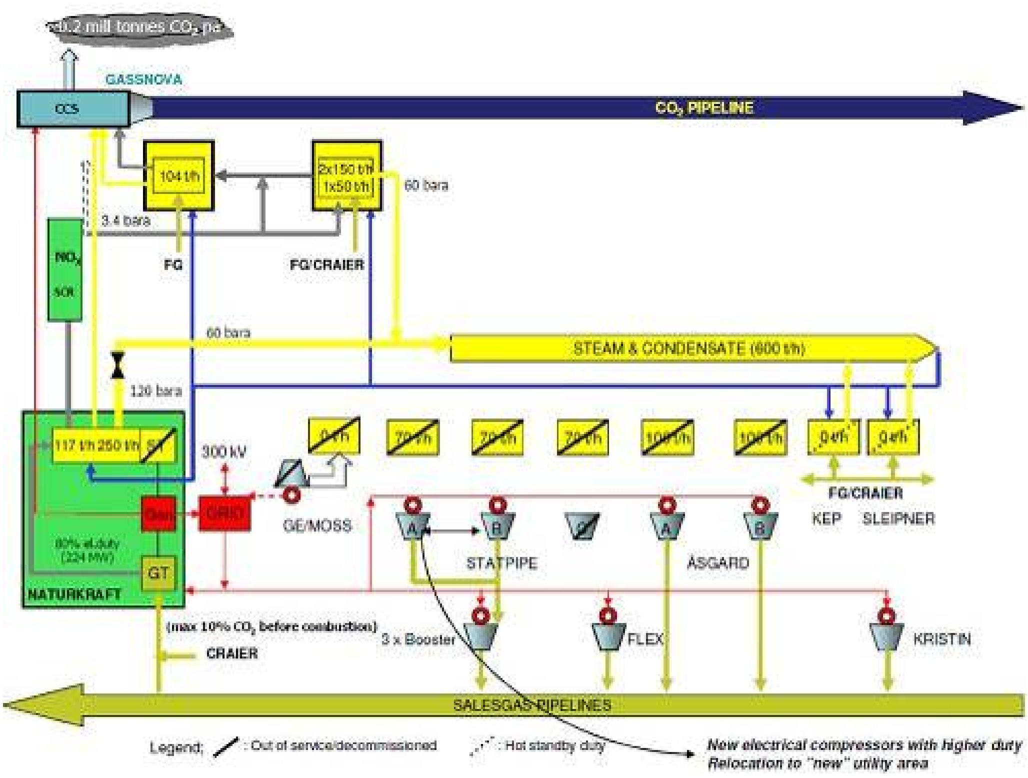
3.1.1 Technical viability

The Kårstø gas plant has substantial utilities requirements, mainly motive power for compressor drives and pumps and heat input (steam) for the gas processing operations. The current steam demand is around 600 t/h and the electrical demand is around 100 MW. The power consumption data however excludes the major contribution currently provided by a selection of five gas turbines providing direct drive to process compressors.

The plant already makes efficient use of the gas it consumes by means of the extensive application of combined heat and power (CHP). In this case, each one of the gas turbines used to provide compressor drive (and one old gas turbine used for power-generation) is fitted with a heat recovery steam generator (HRSG). These HRSGs provide most of the steam needed by the processing plant. The overall efficiency of gas use in the processing plant is approximately 77%.

The main sources of CO_2 emissions on the site are the stacks of the gas turbines. While these units are located in one area of the extensive site, the eight individual stacks are still quite far apart and would require extensive tie-ins, dismantling and reconstruction to apply CCS. Due to the high excess air ratio used in gas turbines, the exhaust CO_2 concentration is on average 5-6%.

Figure 3.2: Schematic overview of Kårstø integration pre-feasibility study, scenario 5d



Source: Gassco

Gassco have studied the possible integration of the utility requirements for the site with modifications to the nearby combine cycle gas turbine (CCGT) power plant owned by Naturkraft. The aim of the integration study was to identify alternative configurations for reducing CO_2 emissions at Kårstø. This study investigated five scenarios. The most complete reduction in CO_2 emission from the site came from a configuration which converted the CCGT into a high efficiency CHP plant (Figure 3.2). This option maximised the steam yield from the reconfigured plant by adding re-firing to the exhaust from the CCGT to raise the necessary additional steam. This resulted in a single main emission source that increased the concentration of CO_2 in the exhaust to a level that made efficient capture practical and would maintain supply of motive power to the process compressors. The compressor-drive gas turbines would be shut down and replaced by electric drives running on imported (hydro generated) electric power.

Gassco believes this latter configuration offers a practical approach to carbon capture for the site as it offers a large, single point of collection and a CO_2 concentration potentially attractive to carbon capture technology. Space is available for CCS alongside the existing CCGT plant.

3.1.2 Commercial viability

Gassco is a state-owned company that operates the Kårstø gas terminal on behalf of the owners, Gassled. The commercial interest in emissions reductions and CCS lies with Gassled, the site owners. However, Gassco has the relevant insight into the owners' priorities related to CCS based on there close involvement with Gassled on the development of the Kårstø facilities, and the previous CCS projects. Gassco therefore represents and speaks on behalf of the owners for this report.

Gassco states that it already takes CO_2 emissions into consideration as part of its selection criteria for new developments at all of its facilities, including Kårstø. Currently the gas-fired power unit (rated at 40 MW) is not operating and all power is being taken from the grid. Other areas are being studied, like reducing the splitting capacity to produce mixed LPG products.

In the above mentioned study from 2010, Gassco, Gassled along with Gassnova (and the Naturkraft owners), investigated a number of CCS options through integration of operations with Naturkraft's CCGT. These were based on Gassnova's studies on retrofitting CCS at the Naturkraft plant. The cost estimates for these options were significantly higher than the CO_2 tax applied to offshore facilities in Norway or current expectations of European emission allowance (EUA) prices in 2020. The disadvantage of the integration options is that their effectiveness rests upon Naturkraft's CCGT running at a reasonably high capacity factor, which is recognised as there is an issue regarding the plant's future utilisation. The study concludes that "there is no commercial basis for realising any of the scenarios, taken into account all relevant costs, expected CO_2 quotas and other benefits and savings."

Gassco argue that high availability is critical as interruption to the gas processing plan would have a high cost for the Norwegian society. Hence, Gassco's position is that any decarbonisation solution will have to compensate for any negative impact on the availability of the petroleum products shipped through the Kårstø terminal.

3.1.3 Financial viability

Gassco investigations into the costs of CCS indicate that CCS is likely to be an expensive decarbonisation option for the Kårstø gas processing facility, certainly in comparison with any reasonable assessment of future carbon prices. The lowest levelised cost in 2010 integration pre-feasibility study was over 1,150 NOK per tonne of CO_2 avoided, including transport and storage.

3.1.4 CCS deliverability

Gassco assumes that Government agencies will be able to implement (or oversee establishment of) suitable regulations for CO_2 capture, transportation and storage in due course. Gassco states it is fully committed to adhere to the authorities' requirements. It has already implemented a strategy to ensure that CO_2 emissions are identified and made part of the concept selection criteria for new projects.

The company does not envisage any particular challenges in permitting new CCS.

Gassco state that it and Gassled will be able to mobilise the organisational capability to execute CCS projects. Gassco believes both technical capacity and technology readiness are likely to be resolvable without major challenges.

Kårstø is a complicated site for construction activities due to site rules for hot-works during plant operation. This will increase both capital costs and running costs for CCS development.

3.1.5 Relevance decision

Gassco consider the gas processing site as ‘Not Relevant’ because combining the flue gas from the eight stacks would be challenging due to the distance between them.

The Kårstø integration study showed that this site is complicated for CCS with many emission sources that would need extensive tie-ins, dismantling and reconstruction. Further, the costs of the investigated scenarios were significantly higher than the Norwegian offshore CO_2 tax or the expected European emission allowance (EUA) prices in 2020. The integration scenarios rely on Naturkraft’s CCGT running at a reasonably high capacity factor, which was concluded to be unlikely given the economic drivers. The study concludes that “there is no commercial basis for realising any of the scenarios, taken into account all relevant costs, expected CO_2 quotas and other benefits and savings”. CCS has the potential to negatively impact on the facility’s high availability which would have a high cost.

Construction activities at Kårstø will be complicated by site rules for ‘hot-works’ during plant operation which will increase both the capital costs and the running costs for CCS, these requirements will be of high importance for Gassco due to the cost of interruptions of the gas terminal under construction or operation phase. Close to 20% of Europe’s gas consumption is handled through Kårstø (Source: Gassco’s annual report 2011).

3.2 Previous experience and knowledge of CCS

In 2005, Gassco participated in an investigation for retrofitting CCS at Naturkraft’s gas-fired power plant in Kårstø. The possibilities of creating a value chain for CO_2 by using it with enhanced oil recovery (EOR) in the Norwegian continental shelf oil fields were investigated by Gassco, Gassnova and Petoro in 2006 [3] These reports concluded that the business drivers were not sufficient to make EOR viable for the targeted fields due to the high investment cost of installing CO_2 handling facilities at existing offshore installations. Gassco still believes these studies are relevant.

The Kårstø Integration Pre-Feasibility Study [4] concluded that the most complete reduction in CO_2 emissions from the site came from the scenario showing the conversion of the CCGT into a high efficiency CHP plant and adding re-firing to the exhaust from the CCGT to raise the necessary additional steam. The lowest levelised cost in this study was over 1,150 NOK per tonne of CO_2 reduced, including transport and storage. The study concludes that “there is no commercial basis for realising any of the scenarios, taken into account all relevant costs, expected CO_2 quotas and other benefits and savings.”. Gassco still believes the study findings are relevant. The cost figures are however not updated to reflect the recent market condition development.

Gassco operates the Norwegian upstream gas infrastructure on behalf of the infrastructure owners. To manage energy efficiency and minimise the CO_2 footprint of the operations, several studies have been performed to explore potential emission reduction. Studies related to CO_2 capture were either financed by the owners of the relevant facilities, third parties requesting Gassco's competence or, as in the case of the Kårstø Integration Pre-Feasibility Study, by the Norwegian Government. The latter report has been made public while other studies belong to the sponsor(s) of such studies. All studies related to CO_2 capture at Kårstø or in the vicinity of Kårstø were dependent on the presence of a full CCS chain to capture CO_2 from the Naturkraft power plant.

4. Hydro

This section is based on an assessment form agreed by Hydro Aluminium during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. This assessment form was signed by a Hydro Aluminium representative to declare that to the best of their knowledge the information provided in the form was accurate [5].

Hydro Aluminium is one of the world's largest fully integrated aluminium companies and is based in Norway. The group's combined primary metal production is about 2 million tonnes, of which about 0.7 million tonnes are from three Norwegian plants. Hydro group's emissions are about 15 million tonnes a year CO_2 equivalent (CO_2e) across the aluminium production chain.

Hydro's Norwegian aluminium production is powered entirely by hydro power, which means that, along with Iceland, it produces the world's lowest carbon footprint aluminium,. Its emissions are about 4 kg equivalent CO_2 per kg aluminium produced, of which 2.2kg CO_2e /kg aluminium is from the broader smelting process, which includes, anode production, electrolysis and anode effects. An equivalent carbon footprint for gas-fired and coal-fired aluminium production chains would be about 10kg and 17.5 kg of CO_2e per kg of aluminium, respectively.

Hydro has an operational focus to optimise all processes to reduce CO_2 emissions by reducing energy consumption. Hydro reports that the average electricity intensity of its Norwegian aluminium production has fallen from about 15 kWh/kg of aluminium in 1993 to about 13.5 kWh in 2011. These reductions have come mainly from the closure of the smaller inefficient Soederberg pot lines. The company states that its HAL4e technology is expected to bring a further incremental improvement to around 12.5 kWh/kg. Hydro is working on a so-called Ultra technology that could potentially cut long run electricity use to just 10 kWh/kg of aluminium.

Hydro has also taken measures (and spent over NOK 200m) to reduce emissions of hydrogen fluoride (HF gas) from operations, such that it now recovers 99.5% of fluoride emissions at its Sunndal plant, one of the best performances worldwide.

4.1 Hydro Sunndal

Table 4.1: Hydro Sunndal fact box

Major Activity	Process Industry – Aluminium and Energy
Existing or New / Potential Source	Existing
Estimated future emissions of CO_2 from facility	490 – 530 kt/y for full site
Does the owner consider the facility relevant or not relevant for the NCCS study?	Not Relevant
Technical reasons for relevance decision	• The carbon capture ready (CCR) design to increase flue-gas CO_2 concentration will take years to develop

	• Technical challenges for CCR include; - significant changes to the superstructure - integration of heat recovery - the design of high temperature equipment and components - potential upsets in process stability and profitability
Commercial reasons for relevance decision	• Conversion of production line 4 (Su4) will take at least 6-7 years • The reduction in potential income from recovered excess heat if distributed pot suction is installed could have an impact on the economics of CCS
Financial reasons for relevance decision	• At current costs and carbon prices, investment in CCS would provide a negative Internal Rate of Return • The aluminium industry would need to make a significant investment in making their process CCR, which increases the overall costs of implementing CCS.

Figure 4.1: Hydro Sunndal facility

Source: Hydro

Sunndal is the largest and most modern primary aluminium plant in Europe with its close to 'state of the art' emissions of about 13kWh/kg of aluminium produced. This plant's annual greenhouse gas emissions are about 530 kt/y. The Sunndal plant comprises two main production units, the Su3 and Su4 facilities.

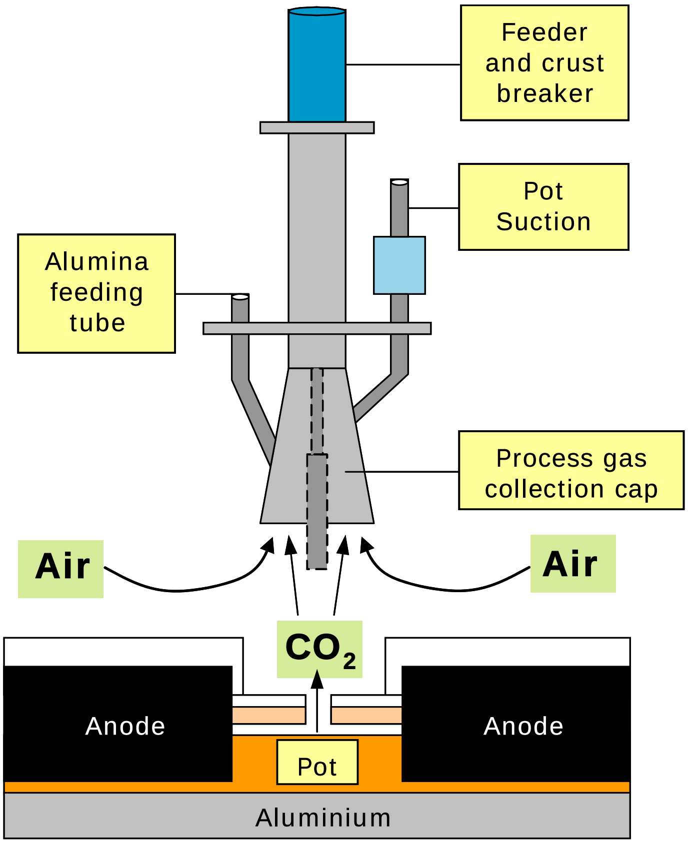
The Su4, is the larger and more modern part with an electrolysis capacity of about 300kt, while the Su3 is older and smaller (rated at 100 kt/y) and tends to operate as a swing producer – which means output depends on the market conditions. Production line 3 (Su3) at Sunndal was built in 1967. Production line 4 (Su4) was built in 2004. The facility has also re-melting operations and considerable casthouse production.

In terms of CO_2 emissions reduction efforts, Hydro is exploring options for making Sunndal carbon capture ready (CCR). To do this it is evaluating options to adjust dilution air flow from the smelting pots (where the electrolysis takes place) to raise the CO_2 concentration in the process gas from about 0.8% (existing) to near 4%.

4.1.1 Technical viability

As described above, Su3 is an older design and a swing producer, Hydro has therefore concentrated efforts on the Su4 production line to investigate methods of making it carbon capture ready. CO_2 emissions from Su4 accounts for about 85 – 90% of the site's total emissions (2011).

Figure 4.2: Hydro's Distributed Pot Suction to concentrate off-gas CO2 concentration for carbon capture readiness



Source: Hydro

CO_2 emissions from the pots are sucked into an off-gas system with a significant quality of air. This air dilutes the concentration of this off-gas to approximately 0.8% CO_2. Hydro is investigating the use of a distributed pot suction (DPS, see Figure) system that will reduce the quantity of air being sucked into the off-gas, thus increasing the concentration of CO_2 to approximately 4%. This off-gas can then be treated more economically by conventional CCS technologies such as amine carbon capture.

DPS also increases the concentration of other trace components in the flue gas (HF and SO_2 removal), reducing air blower duty and subsequently auxiliary power demand.

Increasing the concentration of the off-gas through reduced air dilution would increase its temperature. This provides the opportunity for heat recovery, but Hydro has calculated that this does not provide all the heat required for the current best available amine-based CCS system, so additional steam would be required. Heat recovery would only allow capture of 65-70% of the plants CO_2 emissions.

Increasing the off-gas concentration also increases the temperature close to the pots which introduces challenges on the design of the mechanical and automation equipment and components. Hydro state that the market is limited for electronic equipment that can operate with expected temperatures of greater than 200ºC. Hydro state that these hot surfaces with high heat radiation would result in an unacceptable heat stress on operators attending the process and could hamper maintenance activities.

In principle, there would be space for a CCS facility adjacent to Su4. For utilities, cooling water is available on site but new infrastructure may be required. The electrical demand of a CCS plant will be small compared to existing demand so spare electrical capacity is available on site.

The changes required to make Su4 carbon capture ready (CCR) would require Hydro to change the superstructure of the process to include both aluminium production and heat recovery. This would require significant changes to off-gas piping, fans, heat exchangers and scrubbers. It might be possible to change the equipment during the pot relining outages, which occur every 5-6 years.

Hydro believes CCR could affect the heat balance which consequently has implications on process stability. The process stability is an area which is influenced by various parameters and has considerable challenges.

The challenges described above show that Hydro does not have the final solution today for CCR. Hydro believes that it will take years to develop solutions to these challenges as this will be a state of the art technology.

The combination of this CCR process and CCS could achieve a capture rate of 85% and a carbon footprint of 1.5 kg CO_2/kg of aluminium.

4.1.2 Commercial viability

Hydro's improvements in its energy and emissions performances reflect its drive to reduce costs and improve product quality. The company has set itself targets and has tended to meet these through incremental process and operational improvements, often achieved by closing the least efficient production facilities. It is now seeking to make a business case for making its smelters CCR.

Like other owners of continuous process industries, Hydro states that any measures that it takes must be carefully integrated into the servicing cycles and should not jeopardise core production. This would mean that changes to the pot-lines at least would need to be implemented on an incremental basis. If CCR technology can be demonstrated, the company estimates that it would be able to install the appropriate new off-gas capture technology and control equipment on all its Su4 pots over a 6-7 year servicing cycle. Hydro has presented a paper at the TMS 2009 conference on making smelters CCR.

Hydro state that the heat recovered in the CCR process would cover around 65-70% of the energy required for the for the current best available amine-based CCS system if it was installed. The income from recovered excess heat by other users would thereby be eliminated and has an impact on the project economics.

Hydro does not expect that consumers would be prepared to pay a significant premium for low carbon aluminium, so sees little scope to recover costs from its core product sales. However, it does recognise that as a low carbon producer already, it is seen as a preferred supplier among its more environmentally aware customers.

4.1.3 Financial viability

Hydro does not have any strong views as yet on the capital expenditure or operational costs of CCS. It does however recognise that there is a considerable spread between the high cost estimates for the detailed CCS studies at Mongstad and Kårstø and the lower costs shown in the higher level conceptual studies for other sites in the SINTEF / Klimakur (2011) study, such as Sunndal.

The aluminium industry would need to make a significant investment in making their process CCR, which increases the overall costs of implementing CCS.

4.1.4 CCS deliverability

Hydro states that it would only consider actually fitting CCS once there is a clear business case and this would almost certainly depend on there being a high and predictable carbon price applied across the world's major trading nations. Hydro expects that by 2030 there might be a global carbon price applied to all the significant greenhouse gas emissions deriving from controllable human activities, including the aluminium production chain. Early implementation of carbon pricing may arise, however Hydro states that the arrangements will need to be global, or at least apply equivalent measures on its major trading competitors, otherwise, the European smelters will be unfairly handicapped, which could lead to plant closures. A carbon pricing scheme restricted to the EU would put Hydro and other global players at a disadvantage, potentially to a point of jeopardising their survival.

Hydro believes that its past record and commitment to further energy and emissions reductions and its ambition of making its smelters CCR in the future demonstrates a strong commitment to the environment and tackling climate change. While CCS is not considered a core activity, Hydro has the necessary project management and process engineering skills to implement CCS. The company also does not foresee any special obstacles in securing the necessary consents for CCS, but this will depend on whether the local community around the plants see CCS as contributing to the sustainability of operations and continued employment.

4.1.5 Relevance decision

Hydro considers the Sunndal site as not relevant for further participation in the NCCS programme. Hydro has developed a prototype design for a carbon capture ready smelting facility but they believe that it will take years to develop. The technical challenges of this CCR system include; significant changes to the superstructure, integration of heat recovery, the design of high temperature equipment and components and potential upsets in process stability.

Hydro state a CCR conversion of the Su4 plant would take at least 6-7 years as it has to follow the pot service cycle.

The reduction in potential income from recovered excess heat if distributed pot suction is installed could have an impact on the economics of CCS.

There is currently no business case to fit CCS. Hydro's assessment is that at current carbon prices, installing CCS would not even provide a positive IRR on investment when taking a 15-year operation.

The aluminium industry would need to make a significant investment in making their process CCR, which increases the overall costs of implementing CCS.

4.1.6 Previous experience and knowledge of CCS

Hydro presented a paper called CCS Ready [6] at the minerals, metals & materials society (TMS) conference in 2009. Hydro still considers this paper relevant.

The Tel-Tek study from 2009 included seven reports including literature surveys regarding capture techniques, transport and storage, terminology in the field etc. In addition there was a report with case studies regarding capture costs from the aluminium industry. This study looked into different cases with respect to both CO_2 content in the flue gas and capture rate. The study concluded that capturing CO_2 from a flue gas with a 4% level of CO_2 was the most cost effective option and that a level of 85% capture rate would be the best level to aim for. Hydro state that it is vital to understand that the capture costs calculated were based on a future scenario with a flue gas concentration of CO_2 that Hydro do not have today and that it will take years to develop into state of the art technology. These results are still of interest, but Hydro believes the validity of the financial calculations are questionable because the capture costs were calculated for the MEA process alone and did not include all the costs connected to changing the Hydro process.

The SINTEF / Klimakur report sums up the work performed in a 'Heat recovery' project (2008), financed by Hydro Aluminium. This report investigated solutions for recovering heat from the cathode, anode and the flue gas. This report concluded that there were several reasons for recovering this heat:

- Converting the waste heat into electricity was an attractive option due to increasing energy prices and shortage of electrical energy.
- There was growing political pressure for large scale emitters of CO_2 to investigate CCS. A CCR aluminium plant needs heat recovery to provide the steam required for stripping of CO_2 in a CCS process.
- Increasing the amperage was described as the most profitable project in aluminium electrolysis. The next step in amperage increase needed to involve active cooling devices to get rid of the extra heat, with or without utilisation of the heat extracted.

Hydro state that the interest in this subject had not decreased during the duration of the present project. The HAL Ultra Performance concept (HAL-UP) was introduced in 2009. The aim of this project was to develop new electrolysis technology with ultra high performance with integrated heat recovery.

Hydro suspects that the cost estimates from these previous studies do not take account of the practical issues of integrating a capture plant into the smelting process and the pre-treatment of off-gases to make them amenable for capture.

5. Industrikraft Møre

This section is based on an assessment form agreed by Industrikraft Møre during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. This assessment form was signed by an Industrikraft Møre representative to declare that, to the best of their knowledge, the information provided in the form was accurate [8].

Industrikraft Møre AS (IKM) is an industrial company owned by the Norsk Mineral AS, Tafjord Kraftproduksjon AS and Hustadmarmor AS. IKM was formally founded on 28 February 2006, but Hustadmarmor AS has been developing its plans since 2003. IKM works alongside Sargas, a technology development company, which has an option to acquire control of IKM over the next year. IKM is effectively the chosen vehicle by which Sargas can deliver its technology in Norway.

Sargas's main business is to develop clean power generation from fossil fuels and license its technologies for further deployment. It has a secondary aim of being a provider of clean CO_2 for enhanced hydrocarbon recovery and other potential users. As yet Sargas has no full scale generation assets in operation or under construction, but it is pursuing two utility scale projects in the USA and one in Norway.

5.1 Industrikraft Møre

Table 5.1: Industrikraft Møre fact box

Major Activity	Power generation and CO_2 sales
Existing or New / Potential Source	Potential
Estimated future emissions of CO_2 from facility	Net 256 kt/y after capture of 1,500 kt/y
Does the owner consider the facility relevant or not relevant for the NCCS study?	Relevant
Technical reasons for relevance decision	• Carbon capture is integrated into the IKM design for a pressurised combustion process, with 85% of the total CO_2 emissions captured • The CO_2 product is low in oxygen and is suitable for EOR • The purified waste gas has very low levels of NO_x, SO_x, and other pollutants • The Sargas demonstration facility has verified the expected effect of pressurised CO_2 removal.
Commercial reasons for relevance decision	• CCS is a permit compliance requirement for IKM in developing a new gas fired power plant. • The NCCS study is an opportunity to explore alternative markets for CO_2 sales

	• IKM take the view that there is a market for power in the region and a potentially market for CO_2 in Norway and Europe
Deliverability reasons for relevance decision	• Sargas states that it is exclusively and 100% committed to carbon capture and has therefore secured arrangements with major subcontractors to execute projects.

Figure 5.1: 3D representation of potential Industrikraft Møre site

Source: IKM

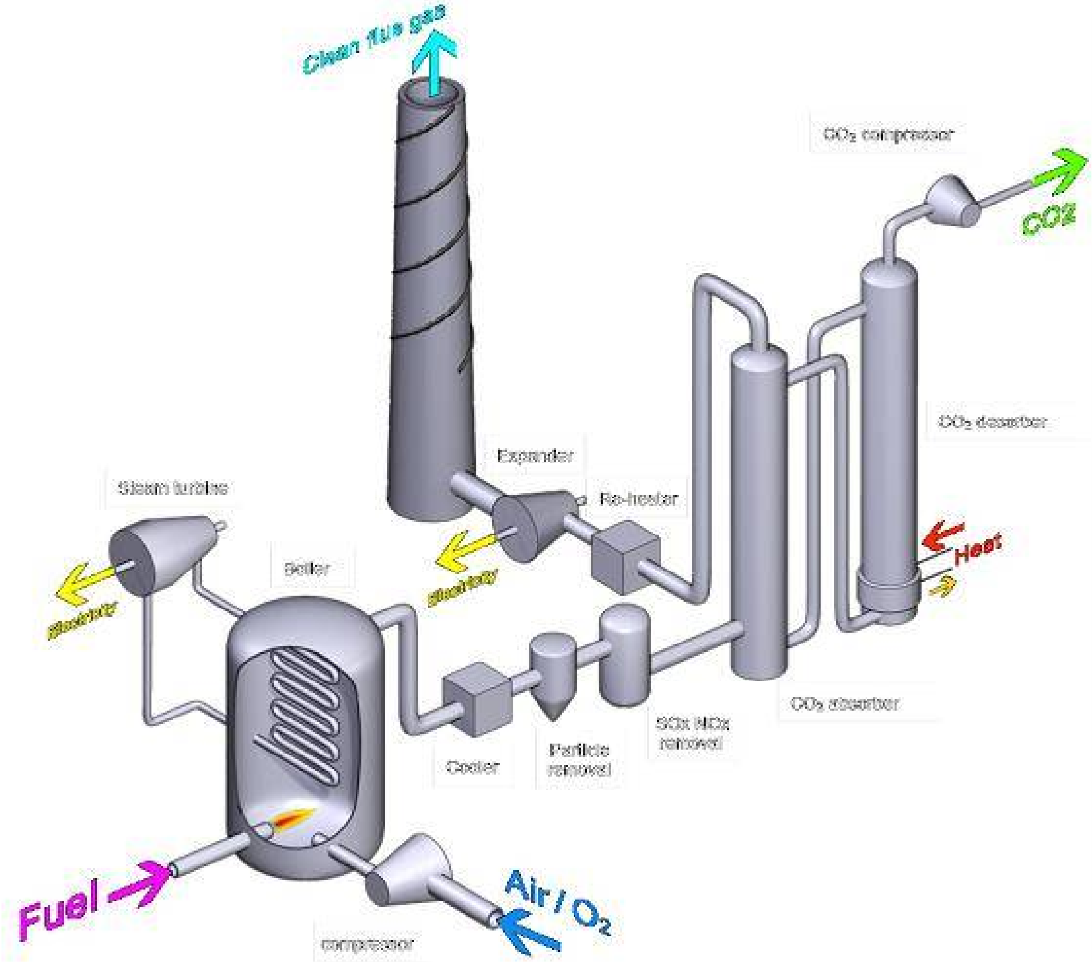
The IKM project was granted the necessary licenses in February 2010 to develop a 500MW gas power plant with full CCS (85% CO_2 capture), which would be located at Elnesvågen in Fræna municipality on the west coast of Norway. The site is close to the gas terminal for Ormen Lange and the future gas hub at Nyhamna for new gas fields (Aasta Hansteen, Linnorm and Zidane) in the Norwegian Sea.

Statnett has stated that the site of Industrikraft Møre is the best location for new permanent electricity production in Norway. This is due to a deficit of electricity capacity in the region, and an insecure supply to the Ormen Lange gas hub at Nyhamna. The electricity supply currently comes through a 100 km 420 kV connection from Sunndalsøra to Nyhamna. The maximum electrical load for the gas hub today is about 170 MW, which is likely to increase to approximately 300 MW in a few years.

The new power plant would be connected to the national grid system through the Hustadmarmor facility which produces calcium carbonate for the international paper industry.

5.1.1 Technical viability

Figure 5.2: Principle schematic of the Sargas system for a coal-fired plant



Source: IKM

The Industrikraft Møre plant uses an aeroderivative gas turbine to provide the pressure required for the downstream processes. The Sargas hot potassium carbonate CO_2 capture process captures 85 – 90% of the CO_2 from downstream of the pressurised heat recovery steam generator (HRSG). After purification, the waste gas is reheated in the gas/gas heat exchanger before entering a gas turbine, providing additional power. The hot potassium carbonate CO_2 capture system is fully integrated into the power production system. The CO_2 product from the capture process is low in oxygen and is suitable for EOR and the purified waste gas has very low levels of NO_x, SO_x, and other pollutants.

The Sargas capture process for IKM is based on the results from a demonstration plant at Fortum's site in Värtan-Stockholm and from the test facility in Pittsburgh in the USA. The Stockholm capture demonstrator was installed downstream of a coal pressurised fluidised bed combustion chamber which has been operating since 1991. Sargas states that the test plants in Stockholm and Pittsburgh verify the expected effect of this pressurised treatment, and the test results in both cases are consistent.

There is enough space available on site for this facility. The area required for this system is only approximately 115m by 90m because the gas, flue gas and waste gas are all pressurised. As this capture technology is fully integrated with combustion process, all utilities requirements are part of the original design.

5.1.2 Commercial viability

For IKM to develop a new gas-fired power plant, CCS is required to comply with their emissions permit.

Sargas has studied the costs of a two by 250MW plant on the Texas Coast and concluded that the plant could generate power below 5 UScents/kWh with capture operating. They acknowledge that the costs would be higher in Norway than in the USA due to higher gas costs and labour costs. It is recognised that levelised costs would be well above Norway's current electricity prices. For the plant to be economically viable, CO_2 will need to have a substantial value, either being sold for EOR or urea production, etc, or through some measures which increase the (EU-wide) carbon price. IKM wish to investigate potential uses of CO_2 further in Norway. It is possible that IKM may be able to secure a premium over the normal energy price to local process industries though providing guaranteed reserve and response capability. IKM expect that they will also reduce the need for investments in more grid lines in to the region and the transmission loss of power.

According to the latest regional estimates of future electricity demand (Istad study - 2012), local power production in Møre and Romsdal will only meet 50% of local demand in 2025. Three customers, Norsk Hydro in Sunndal, Ormen Lange in Aukra and Hustadmarmor in Fræna, represent more than 60% of the total consumption in the area and have a relatively constant load. This generation capacity deficit reduces the security of supply to Ormen Lange gas field and the gas hub at Nyhamna, which depend on a single 100 km transmission line. There have been numerous blackouts at Ormen Lange since it started in 2007. IKM considers that a power plant in constant operation close to Nyhamna, which is the Sargas concept, would increase security of supply significantly for these key export hydrocarbon facilities. The challenge is to develop a commercial model that is robust to times when surplus electricity is available from elsewhere in Norway.

All this suggests that commercial arrangements for the IKM plant will need to be carefully structured and IKM consider it would be prudent to consider this aspect as a part of any further study.

5.1.3 Financial viability

Sargas/IKM's analysis of the total investment costs and the annual operational costs show that both their coal and gas-fired power generation options with full CO_2 capture (but excluding transport and storage) are low compared with any other power generation option with CCS. This clearly needs to be confirmed, however Sargas state that it expects to have a more precise estimate of its gas plant costs by summer 2013 based on its ongoing project in Texas.

5.1.4 CCS deliverability

Sargas/IKM expects no immediate change in regulations regarding CCS. Under current regulations new power plant with CCS must be built on near commercial terms, in competition with conventional plants without CCS. IKM believes the produced CO_2 must therefore be sold in order to make the project cost competitive.

Sargas/IKM seek to show that this can be done using appropriate technology solutions, which in their opinion is an efficient pressurised combustion and capture system. IKM states the technology is expected to be proven in ongoing projects in Texas (gas-fired) and in Illinois (coal-fired plant) over the next two to three years.

Sargas states that it is exclusively and 100% committed to CCS. It has no revenue model other than selling power and carbon from CCS-equipped fossil fuel plant but the company supplies the core technology only. Execution will need to be by major international players. In this respect, Sargas has recently secured agreements from General Electric, Daewoo and SNC Lavalin. GE has agreed to provide its LM100 GT and market and sell the combined technology package worldwide. Daewoo will build the plants on barges in dry docks, and offer turn-key plants with industry standard performance guarantees, while SNC will provide detailed design as the owner's engineer.

5.1.5 Relevance decision

IKM considers this potential site as 'Relevant' for further participation in the NCCS Study because carbon capture is integrated into the IKM pressurised combustion process and captures 85% of the total CO_2 emissions. The CO_2 product from the capture process is low in oxygen and is suitable for EOR. The purified waste gas has very low levels of NO_x, SO_x, and other pollutants. According to Sargas, the demonstration facility at Värtan-Stockholm, has verified the expected effect of pressurised CO_2 removal.

For IKM to develop a new gas-fired power plant, CCS is required to comply with their emission permit. IKM see the NCCS study as an opportunity to explore the markets for EOR, and urea production as well as potential shipping options for CO_2 to enable full chain CCS in Norway. IKM take the view that there is a market for power and potentially CO_2 in Norway

Sargas states that it is exclusively and 100% committed to carbon capture and has therefore secured arrangements with major subcontractors to execute projects.

5.2 Previous experience and knowledge of CCS

Sargas have conducted a number of studies on the performance of the demonstration plants and for the potential future plant in Norway and the USA but due to the confidential nature of this first of a kind technology, they have not been released to the public.

Sargas has some experience in CCS, in that it has operated two demonstration capture projects on coal-fired plant at Värtan in Sweden and at Pittsburgh in the USA. Both of these projects were seen as successful in demonstrating high scrubbing rates and plant availabilities for capture integrated with generation.

Sargas state that it expects to have a more precise estimate of its gas plant costs by summer 2013 based on its ongoing project in Texas.

6. Ineos

This section is based on an assessment form agreed by Ineos during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. These assessment forms were signed by an Ineos representative to declare that to the best of their knowledge the information provided in that form was accurate [9].

Ineos is one of the world's major petrochemicals producers, making intermediate products for the plastics sector including ethylene. The company has four ethylene cracker sites in Europe, including one at Rafnes, near Porsgrunn, which is operated under the Noretyl AS subsidiary.

6.1 Ineos Noretyl

Table 6.1: Ineos Noretyl fact box

Major Activity	Steam cracking of ethane
Existing or New / Potential Source	Existing
Estimated future emissions of CO_2 from facility	470 kt/y
Does the owner consider the facility relevant or not relevant for the NCCS study?	Not Relevant
Technical reasons for relevance decision	• Challenging flue gas tie-ins due to multiple emission sources and furnace/reactor pressure sensitivity • Long maintenance cycle means tie-ins could not occur until 2022 • Land available for CCS is approximately 700m from the process • No spare utilities are available on site
Commercial reasons for relevance decision	• Risk of business interruption to the plant's core ethylene production
Financial reasons for relevance decision	• Risk averse to capital programs that do not bring improvements to the operating bottom-line
Deliverability reasons for relevance decision	• Emissions reduction will only occur if a commercial case can be made and the core process remains unaffected. • Ineos lacks the capacity to implement major engineering projects

Figure 6.1: Ineos Rafnes

Source: Ineos

The Rafnes plant has an annual capacity of 550kt of ethylene and annual CO_2 emissions of about 470kt based on continuous operation. It has eleven emission points across its site, with seven stacks associated with furnaces providing the majority of the emissions at a CO_2 concentration of about 5%.

6.1.1 Technical viability

The plant's feedstock is a mixture of ethane shipped from Kårstø and LPG. The feedstock is heated with steam in a cracker to break down or 'crack' the ethane into ethylene, hydrogen and other by-products. Sudden cooling then stops the reaction and the subsequent mixture of gases is compressed, chilled and separated in a series of distillation towers. Products from the site include ethylene, propylene and by-products, but by-products are low due to the light feedstock.

In June 2012, Ineos-Noretyl completed a 40 day turnaround (a shutdown for a major overhaul) on the plant after 6.5 years of operation. The next turnaround is planned for 2022. This is significant for CCS as tie-ins into the existing system require a plant shutdown. Any shutdown for CCS tie-ins would have to wait for the next planned turnaround in 2022 as an additional shutdown would cause a financial strain due to loss of production.

The site has eleven emission points distributed around the site. Seven stacks are clustered above eleven furnaces/reactors with a CO_2 concentration of approximately 5% that emit 350 kt/y of the sites 470 kt/y. These stacks have the potential to be combined and CO_2 collected for CCS but integration will be difficult. The furnaces/reactors are sensitive to positive and negative pressures and tie-ins must not impact operation. A furnace trip could take weeks to de-coke and would have a significant financial impact. This tie-in is further complicated as not all furnaces/reactors operate at the same time, usually ten out of eleven are in operation.

Space for CCS is limited as open areas close to the process are reserved as laydown and welfare areas for turnarounds. Land available for CCS could be up to 700m from the process. This combined with tying into seven separate stacks means that the expected cost to install and operate a CCS plant at Noretyl are expected to be high.

There is no spare capacity for the utilities that would be required for CCS on site. Cooling water and electricity for CCS would require new connection to the sea and to the grid. Steam is also not available for CCS from site but heat integration may be possible as the furnace/reactor outlets can be as high as approximately 250ºC.

6.1.2 Commercial viability

As mentioned above, retrofitting CCS at Rafnes would be complicated (and therefore likely to be expensive) and would also increase the potential for unplanned outages to the ethylene production process.

The Rafnes plant is subject to the EU ETS as well as the Norwegian gas tax, so is already incurring a charge for its CO_2 emissions.

The company says that the commercial incentives for carbon abatement measures will clearly be linked to the future carbon price which is currently uncertain. However, Ineos argue that any carbon price arrangements adopted in Norway should be aligned with those in the EU and preferably beyond this to its major international trading competitors.

6.1.3 Financial viability

Ineos have studied the costs of CCS, however, Ineos-Noretyl has not carried out a detailed assessment of costs of CCS at Rafnes. Ineos expects that the costs of retrofitting post combustion capture, conditioning and compression plant would be high given the complicated tie-in arrangements with the core plant, where dismantling and reconstruction would be required to handle tie-ins, and the lack of easily accessible waste heat and utilities for the capture plant. Previous cost estimates may also be low due to potential changes that may be required to update the furnaces/reactors to overcome their pressure sensitivity. Ineos also expect that costs may be higher than previously estimated due to potential costs associated with commercial risks such as construction schedules and plant performance.

Ineos runs its businesses on a lean production model with high financial gearing (high debt-equity ratio) which means that they take a risk averse approach to capital programmes, especially projects that do not bring improvements to the operating bottom-line.

6.1.4 CCS Deliverability

Given the poor cost-benefit balance for CCS at Rafnes, Ineos-Noretyl has no interest in pursuing CCS at this site. More generally, Ineos-Noretyl says they will only pursue emission reduction measures where a commercial case can be made and where it does not have any detrimental impacts on its core production activities.

Ineos-Noretyl says that whatever the Norwegian authorities adopt with regards to carbon pricing arrangements, it is important that Norway adopts a consistent approach to that followed in the EU and across Norway's main trading competitors.

The company has no view on the expected regulatory framework or permitting challenges in developing new CCS facilities.

In terms of practicalities, Ineos-Noretyl says that its lean production approach means that it lacks the capacity to implement major engineering projects such as carbon capture and so would need to secure support for this, should this ever become a commercially viable option.

6.1.5 Relevance Decision

Ineos consider the Noretyl site as 'Not Relevant' for further participation in the NCCS programme because it believes applying CCS to the site is not appropriate given the technical challenges which would make the capital and operational costs high. The majority of emissions come from eleven emission points leading to seven stacks which pose technical challenges for tie-ins due to the pressure sensitivity of the connected furnaces/reactors. The installation of the required tie-ins for CCS would not be able to occur until the next plant turnaround, planned for 2022. Land available for the CCS could be up to 700m from the process. There is no spare utilities capacity for CCS on site.

Even a well designed facility would increase the risks of disruption to the plant's core ethylene production.

Ineos take a risk averse approach to capital programs that do not bring improvements to the operating bottom-line.

Ineos will only pursue emission reduction measures where a commercial case can be made and it does not have any detrimental impacts on its core production activities. There is also no real prospect of recovering the costs of CCS, under the current carbon pricing arrangements in Norway and the EU. Ineos's lean production approach means that it lacks the capacity to implement major engineering projects such as carbon capture.

6.2 Previous experience and knowledge of CCS

A high level assessment of capture at Rafnes was carried out in 2005 [10]. This concluded that CCS would be complicated given the multiple emission points, moderate CO_2 concentration and the need to guarantee no interference with the core ethylene production process to install CCS. The lack of easily available waste heat sources and other utilities would also increase the costs of capture, conditioning and compression.

Ineos has previously identified 30-50kt a year of potential CO_2 emission savings through equipment modifications. These changes are expensive and might be difficult to justify. Ineos note that the refrigeration compressors (20 MW) in the plant are already electrically driven. This avoids around 150 kt a year of CO_2 emissions versus what the plant would have produced running on the more conventional steam drives, typical elsewhere in Europe.

[HOLD] Descriptions of further studies are still to be provided by Ineos.

7. IRONMAN Consortium

This section is based on assessment form agreed by IRONMAN during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. The assessment form was signed by an IRONMAN representative to declarer that to the best of their knowledge the information provided in that form was accurate [11].

The sponsors of the IRONMAN project comprise of Swedish Höganäs, LKAB and the Norwegian government-owned SIVA. The IRONMAN sponsors have conducted a feasibility study that concluded with a recommendation to build a plant to produce direct reduced iron (DRI) at Tjeldbergodden, in Western Norway. DRI is an intermediate product in the iron and steel sector. The proposed plant has been called IRONMAN.

The IRONMAN sponsors are looking to build a consortium, which comprises companies across the value chain, from iron ore production/sourcing to the production of high purity steel with the intention of building a DRI plant with a low carbon footprint, incorporating an element of carbon capture and storage/use.

7.1 IRONMAN Project

Table 7.1: IRONMAN project fact box

Major Activity	Producing Direct Reduced Iron (DRI)
Existing or New / Potential Source	Potential
Estimated future emissions of CO_2 from facility	800,000 t/y
Does the owner consider the facility relevant or not relevant for the NCCS study?	Relevant
Technical reasons for relevance decision	• DRI process requires CO_2 separation technology to function • The CO_2 that is already captured is relatively easy to condition and compress for transport and storage/use. • Space for required utilities is available
Commercial reasons for relevance decision	• Iron with the toughest embodied carbon limits in the EU may attain a premium over general prices

Financial reasons for relevance decision	• The incremental costs of conditioning and compressing the concentrated CO_2 stream is comparatively low
Deliverability reasons for relevance decision	• IRONMAN will strive to condition and compress the CO_2 rich gas stream • Transferable technology

Figure 7.1: 3D representation of potential IRONMAN project

Source: IRONMAN

The DRI process provides approximately a 60% reduction in CO_2 emissions compared to the traditional coking oven/blast furnace route, even without CCS. In addition, this process requires the separation of a high concentration stream of CO_2 from the outlet of the reactor which provides a relatively easy opportunity to treat and store the CO_2. The IRONMAN sponsors are keen to pursue this option to further reduce the site's carbon footprint.

The current plans are to produce 1.6 million tonnes a year of high purity DRI, which would emit about 800 kt/y of CO_2. IRONMAN sponsors state the project offers proven technology and efficient logistics as it is close to raw materials and markets.

The project's capital costs are estimated to be around 5.7bn NOK and the plant would take approximately three years to commission from final investment decision. Investment will only go ahead once a long term gas supply agreement and sale agreements for DRI are in place, covering the bulk of the plant's expected output. The IRONMAN sponsors state that they have identified more than 40 potential customers in Europe, representing a total production capacity of more than 40 Mt/year of high quality steel products. The consortium claim that DRI sourced from IRONMAN will provide the customers with at least 50-100 USD/tonne in improved added value, based on lower cost, improved product quality and improved sourcing reliability.

In addition, there are a number of North-European, blast furnace operating steel producers that see great challenges in decreasing the CO_2 emissions due to their dependency of coking coal as a reduction agent. They are currently investigating the possibility of replacing some of their iron ore raw material for prereduced DRI. This could be a transferable technology that will give them an overall decrease in CO_2 emissions and increase the productivity of the blast furnace at the same time.

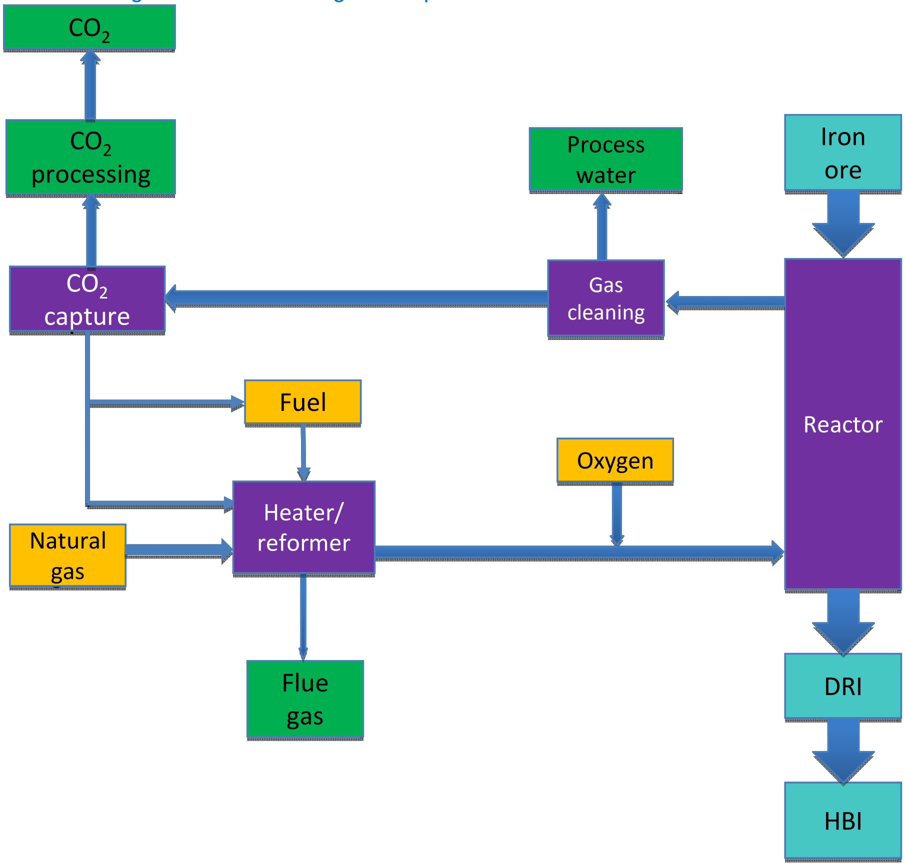
7.1.1 Technical viability

The IRONMAN Project will be a plant for producing directly reduced iron (DRI) pellets from iron ore, by the use of natural gas as the reduction agent. The DRI pellets are further compacted into solid briquettes, hot briquetted iron (HBI) for improved handling and transportation. Natural gas, normally as methane (CH_4), is reformed to carbon monoxide (CO) and hydrogen (H_2) in the process to reduce and separate the oxygen content in the iron ore, and to create high purity iron with high quality characteristics (DRI/HBI).

The DRI/HBI is further used in electric arc furnaces to produce high quality steel slabs and billets, as well as iron powder, and in blast furnaces and basic oxygen furnaces to produce high quality steel slabs and billets.

Operated at full capacity, the IRONMAN plant will produce 1.6 million tonnes of HBI per year, equivalent to 15% of Europe's current demand (2012) for high quality raw material input. Höganäs has already invested 25 million NOK to use this product in their electric arc furnaces. DRI/HBI products are currently being supplied to Höganäs by non-EU-based commercial suppliers.

Figure 7.2: Block flow diagram of the natural gas DIR process with CCS



Source: IRONMAN

The gas at the outlet of the reactor is a mixture of CO, H_2, CO_2 and CH_4, with additional trace components. The gas is cleaned and passed through a hot potassium carbonate CO_2 removal process to separate the CO_2 from the other components. In the potassium based technology, heated K_2CO_3 is combined with glycine and amine. Even if this technology is used to a lesser degree than the amines-based technology, the requirement for water and steam will be lower leading to a potentially lower consumption of energy per tonne of separated CO_2. The potassium based technology has been considered to be the most suitable technology for the IRONMAN project, even if no final decision has been taken.

The CO_2 scrubbed gas is required as fuel for the natural gas heater/reformer and must therefore be separated from the reactor outlet gas for the process to work. The DRI process therefore requires CO_2 separation technology to function. The CO_2 exiting the hot potassium carbonate CO_2 removal process is 90% CO_2 with 10% water and trace components such as H_2S. The plant can operate with 65% to 81% (520 – 650 kt/y) of the total site emissions being captured in the hot potassium carbonate CO_2 removal process. Process optimisation can drive the volume of CO_2 captured up to 81%. This gas is suitable for conditioning for transport and storage or for the production of food-grade CO_2. The tentative plant lay-out includes a dedicated area for CO_2 conditioning and compression.

The remaining 35% to 19% of the site's total CO_2 emissions come from the flue gas from the combustion of the CO_2 scrubbed gas used in the heater/reformer. This gas has a CO_2 concentration of about 8%, the rest being a mix of N_2, H_2O and O_2, and has the same capture challenges as the flue gas from a gas-fired power station. The CO_2 emissions from this stream amount to 150 – 280 kt/y. The total emissions from the site are dependent on production and are expected to be around 800 kt/y.

Significant investment in infrastructure, approximately 1 billion NOK, is planned by SIVA for the site and the surrounding area. This will ensure that there are no constraints for the construction of the IRONMAN site, or any carbon capture facilities.

In terms of access to utilities for the DRI plant and capture facilities, there is no spare steam available on site. Cooling water is available but the distance between the site and the existing supply is significant enough to make new cooling water infrastructure more cost effective. Electricity from the grid for a CCS facility is expected to be available in 2016. Utilities such as air and nitrogen are expected to be shared with the adjacent methanol plant. There is space available for required utilities.

7.1.2 Commercial viability

IRONMAN states that the European steel industry has gone through significant change, consolidation and efficiency improvement during the past 15-20 years. Today, the industry serves a variety of high quality, specialty applications, with a total production capacity of more than 200 Mt/y. Current strategic initiatives include upstream integration, focus on high value added applications, operational excellence and emissions mitigation, although this must be seen within a context of extremely tight profit margins for many manufacturers.

Steel products are produced both through blast furnaces (BF) and electric arc furnaces (EAF) value chains. The increased focus on climate impacts and need to reduce CO_2 and other climate gas emissions, favours the EAF route, which is preferred by the majority of the European steel specialty industry. Sourcing of raw materials to EAF based mills is mainly through the combination of imported and local steel scrap (both recycled and virgin) with a smaller contribution from imported iron ore based material (pig iron and direct reduced iron, DRI). A real prospect of increasing scarcity of high quality scrap and the industry's increasing demand for more direct ore based raw material, provides a strong opportunity for an expanded European based DRI capacity.

The combination of direct access to high quality iron ore, natural gas as reduction agent for producing the DRI and compact and efficient infrastructure for handling the material throughout the European supply chain, favours Norway as the preferred location. The Tjeldbergodden industrial site, which includes Statoil's methanol plant, offers a natural choice for Norway's first DRI plant.

The key business drivers in influencing the returns for the IRONMAN DRI project are the commodity prices of iron ore and steel, and the natural gas price. Carbon prices are an important, although secondary driver in the overall project economics. However, the carbon price will be a key factor in determining what level of CO_2 emissions would be captured. Even though the DRI process provides a rich (90% concentrated) CO_2 stream (and so mitigates capture costs), the additional costs of gas conditioning, compression, transport and storage/use will require a carbon price well above current market levels.

It is therefore a critical precondition for CCS to be commercially viable at the IRONMAN facility, that the authorities treat emissions from the plant on an EU wide or even broader perspective and that a significant and not too volatile carbon price is guaranteed to be applied across the iron and steel sector.

In general, there is likely to be limited scope to charge a significant premium on the price for DRI produced products which come from a lower carbon footprint process. That said, iron producers with lower carbon emissions – such as IRONMAN would achieve – would be expected to comply with the toughest embodied carbon limits in the EU, and so may attain a premium over general prices, depending on how fiercely contested this market segment is.

Taking a broad perspective, it is worth noting that the high value of the DRI product (high purity iron) also leads to a higher value added per tonne of CO_2 from gas in the DRI process than in gas conversion to electricity at a state-of-the-art CCGT.

7.1.3 Financial viability

This DRI production process includes built-in CO_2 separation for up to 81% of the sites total emissions. This means that the incremental costs of conditioning and compression of this CO_2 for transport and storage/use is low compared to the incremental costs of capturing and treating the remaining 19% from the heater/reformer. The option of capturing CO_2 from the smaller and more dilute flue gas stream is thought by IRONMAN to be uneconomic given the additional effort to treat this relatively small gas flow. These costs have not yet been analysed in detail. However, IRONMAN is keen to evaluate options for the capture and evacuation/ use of its rich CO_2 stream, in order to improve the project economics and reduce its CO_2 footprint. The chances of achieving these goals will depend on there being a significantly high value for avoided CO_2 emissions. This could be provided by either a high carbon price (or equivalent cross border tariff) that were applied consistently across all major global iron and steel makers, or else a user prepared to pay for CO_2.

7.1.4 CCS deliverability

One critical factor influencing the deliverability of the IRONMAN project is the regulatory framework for CO_2 emissions and permitting related to this. The government will need to take an EU wide or broader view in order to create the industrial climate necessary for attracting the considered consortium members to invest in Norway. A significant higher and stable carbon price than seen to date in the EU ETS will be required to provide an incentive for emission capture at IRONMAN. This carbon price will need to be applied across the EU and preferably extending to major global players in the iron and steel sector.

IRONMAN's sponsors are keen to stress the low carbon merits of the project, and will be striving to condition and compress at least the CO_2 emissions in the CO_2 rich gas stream as long as this is economically viable. The reduced carbon footprint of this project has the potential to be transferred to other locations, helping reduce the overall emissions of the iron and steel sector.

IRONMAN sponsors are looking to strengthen their consortium by bringing in a further partner. However, they will still face a challenge of structuring deals for long term gas supplies and sale of products. However, this is a normal commercial challenge for large infrastructure products, but made more difficult in the current uncertain macro-economic environment with very low steel sector margins.

The existing IRONMAN consortium is capable of working up to realisation phase of this project. Post project realisation, a new entity must be capable for realisation of the whole project, including conditioning, compression, transport and storage/use.

7.1.5 Relevance decision

The IRONMAN sponsors consider the IRONMAN project as 'Relevant' for further participation in the NCCS programme because the DRI process requires CO_2 separation technology to function. The already captured CO_2 is relatively easy to condition and compress for transport and storage/use. Space for required utilities is available.

The IRONMAN sponsors believes iron producers with the toughest embodied carbon limits in the EU may attain a premium over general prices, depending on how fiercely contested this market segment is.

The incremental costs of conditioning and compression of the concentrated CO_2 stream is low compared to the costs of capturing and treating the low concentration CO_2 stream.

If economically viable, the IRONMAN's sponsors will strive to condition and compress the CO_2 rich gas stream.

7.2 Previous experience and knowledge of CCS

The project is already at Decision Gate 2 level (DG2 ±25%) having finalised a concept study in 2010.

Gassco [12] has investigated the costs related to the different transportation solutions as well as the cost of conditioning and compression of the CO_2 from IRONMAN. The Haltenbanken storage via pipe line has been estimated to 761 NOK/tonne of CO_2. A ship based transportation solution via Mongstad was estimated to 572 NOK/tonne CO_2. Both options were concluded to be technically feasible.

IRONMAN is also investigating the potential for industrial use of CO_2. The CO_2 from the CO_2 removal plant can be compressed, dried and liquefied in a separate plant. It can, in an additional step, also be purified into a food grade quality for storage and shipment to potential customers. Potential customers can be found both in food industry and metallurgical industry, and discussions with relevant CO_2-providers into these industries have been initiated.

The CO_2 issue at Tjeldbergodden was studied earlier in conjunction with the study of a potential gas fired power plant. In a project called "Halten-CO_2-projektet i 2007", by Statoil [13] , the possibility of storing CO_2 in the Alpha-structure, 120 km north of Tjeldbergodden, was investigated. CO_2 separation from the methanol plant has however not been studied, as it would not be a financially viable solution. Other storage formations closer to land have also been evaluated, included other CO_2 volumes such as volumes from Mongstad and Kårstø. The unit costs for transport and storage were at that time estimated to 77 – 93 €/tonne of CO_2, based on a volume of 700 kt/y of CO_2. Using CO_2 for Enhanced Oil Recovery (EOR) was also evaluated in the study, but was rejected based on high costs. IRONMAN state that even if the findings are based on best available information in November, 2010, they do not see the occurrence of any major changes in current conditions that would alter the drawn conclusions.

8. Naturkraft

This section is based on an assessment form agreed by Naturkraft during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. This assessment form was signed by a Naturkraft representative to declare that, to the best of their knowledge, the information provided in the form was accurate [14].

Naturkraft was established in August 1994 and Statoil and Statkraft currently own a 50% share each. The company owns and operates Norway's first and only commercial gas-fired power plant which officially opened on 1 November 2007. The company has approximately 34 employees.

The sole business of Naturkraft is to own, operate and maintain this power generation facility at Kårstø. The decision of whether the plant should be in operation or not is at the sole discretion of the owners (Statoil and Statkraft), and the decision is made on daily basis.

8.1 Naturkraft Power Plant

Table 8.1: Naturkraft fact box

Major Activity	Gas-fired power generation
Existing or New / Potential Source	Existing
Total estimated annual emissions of CO_2 from facility	Between 0-1200 kt/y depending on load factor
Does the owner consider the facility relevant or not relevant for the NCCS study	Not Relevant
Commercial reasons for relevance decision	• Plant operation is still uncertain due to the current power spark spread between electricity and gas prices • Longer term outlook is even more uncertain due to expected over-capacity of power generation in the Scandinavian countries
Financial reasons for relevance decision	• The unit-costs of reducing CO_2 emissions will escalate if the utilisation of the power station is low. • Investment cost (CAPEX) and operating costs (OPEX) of a CCS plant are likely to be high due to the CCGT being located within the Kårstø 'safety zone'.
Deliverability reasons for relevance decision	• There is no additional commitment to CCS from the board/owners of the power plant unless it improves the financial standing of the company. • Naturkraft does not have the capability to execute major projects.

Figure 8.1: Naturkraft power plant

Source: Naturkraft

The power plant was supplied by Siemens and is still world class in terms of efficiency (approximately 59%) and environmental standards. The capacity of the plant is about 430 MW, giving an annual production of 3.5 TWh at continuous baseload operation threw the year. This is equivalent to almost 3% of the total demand of Norway. Approximately 0.6 billion standard cubic meters of natural gas is required for a year's operation at full load, which is equivalent to approximately 0.5% of Norway's total annual gas production.

8.1.1 Technical viability

Naturkraft's gas power plant at Kårstø is a combined cycle gas turbine (CCGT) power plant, designed to maximise electrical power production. At continuous operation, the CO_2 emissions from the Naturkraft power plant would be approximately 1.2 million tonnes annually.

CO_2 capture at the plant has been investigated in numerous studies along with integration options with the adjoining Kårstø gas processing facility. The aim of the integration study was to identify alternative configurations for reducing CO_2 emissions at Kårstø. This study investigated five scenarios. The most complete reduction in CO_2 emission from the site came from a configuration which converted the CCGT into a high efficiency combined heat and power (CHP) plant. This option maximised the steam yield from the reconfigured plant by adding re-firing to the exhaust from the CCGT to raise the necessary additional steam. This resulted in a single main emission source that increased the concentration of CO_2 in the exhaust to a level that made efficient capture practical and would maintain supply of motive power to the process compressors at the Kårstø gas processing site. The gas-processing compressor-drives (currently driven by gas turbines) would be shut down and replaced by electric drives.

Naturkraft believes this latter configuration offers a practical approach to carbon capture for the site as it provides a large, single point of collection and a CO_2 concentration potentially attractive to carbon capture technology. Space is available for CCS alongside the existing CCGT plant.

8.1.2 Commercial viability

The sole business of Naturkraft is to own, operate and maintain the power generation facility at Kårstø. However, Naturkraft is willing to co-operate with any initiatives to explore CCS at Kårstø, as demonstrated by the previous studies. These studies have shown all CCS initiatives to be high cost and without any significant business drivers.

Naturkraft are not responsible for determining when the Kårstø power plant operates. The owners, Statoil and Statkraft, decide whether or not to run the facility on a daily basis depending on the difference between gas and electricity prices. Except from some minor periods, the Kårstø power plant has not been operating for over a year and its operation is currently not attractive for the owners. The forecast for future power balance in the Nordic sector does not indicate a change to this situation, however Naturkraft states the market outlook is uncertain and it remains ready for operation if requested by the owners. The CO_2 Kårstø 2009 study concluded similarly that the operational outlook for the Naturkraft facility was weak due to potentially high gas prices and low electrical prices. Naturkraft stated that the current forecast in 2012 for future power balance is even less favourable than it was when this conclusion was reached in 2009.

The commercial decision for CO_2 emission reduction / CCS is in the hands of Statoil and Statkraft but this will be in response to drivers outside their control, such as carbon prices and the electricity demand/supply balance.

In the above mentioned study from 2010, Gassco, Naturkraft and Gassnova investigated a number of CCS options through integration of operations with the Kårstø gas processing facility. These were based on Gassnova's studies on retrofitting CCS at the Naturkraft plant. The cost estimates for these options were significantly higher than the CO_2 tax applied to offshore facilities in Norway or current expectations of European emission allowance (EUA) prices in 2020. The disadvantage of the integration options is that their effectiveness rests upon Naturkraft's CCGT running at a reasonably high capacity factor, which is recognised as there is an issue regarding the plant's future utilisation. The study concludes (summary p.9) that "there is no commercial basis for realising any of the scenarios, taken into account all relevant costs, expected CO_2 quotas and other benefits and savings."

8.1.3 Financial capability

As capital costs will represent a significant proportion of the cost in a full operating chain, the costs per tonne of CO_2 reduced will escalate if the load factor of the power station is reduced to its current level.

Naturkraft expect to be indemnified by the owner of the CCS plant for both investment costs (CAPEX) and operational costs (OPEX) of any CCS installation.

Naturkraft is located inside the safety zone of the gas facility at Kårstø. This will increase both CAPEX and OPEX for CCS development as gas alarms from the adjacent Gassco gas processing plant typically delay work for one hour per day and hot-works are an issue during plant operation.

8.1.4 CCS Deliverability

Naturkraft has some concerns over power plant availability and environmental emissions being affected as a result of carbon capture or transport and storage operational problems.

Naturkraft state that it is likely that the plant will be shut down if the CO_2 price is too high, or if the government stated that CCS must be installed at the generator's cost.

Naturkraft will follow the existing permitting obligations at Kårstø. Naturkraft have co-operated with the different CCS studies that have been performed e.g. the Kårstø Integration Pre-Feasibility Study. There is no additional commitment to CCS from the board/owners but Naturkraft state that CCS could be of interest if it improved Naturkraft's financial standing through reduced costs or improved market position/income.

As an operator of a single unit, Naturkraft is a lean organisation that does not have the capability to execute major projects on its own.

8.1.5 Relevance decision

Naturkraft consider the Kårstø CCGT power plant as 'Not Relevant' because the likelihood of future operation is uncertain due to the current high gas price (when compared to the electricity price). An estimate of the future power balance does not indicate any improvement to this situation.

The costs of reducing emissions (per tonne of CO_2) will escalate if the load factor of the power station is reduced to its current level on longer term. In addition the CAPEX and OPEX for CCS development are likely to be high due to the CCGT being located within the safety zone of the Kårstø gas processing facility.

There is no additional commitment to CCS from the board/owners of the power plant unless it improves their financial standing through reduced costs or improved market position/income. Naturkraft is a lean organisation that does not have the capability to execute major projects.

8.2 Previous experience and knowledge of CCS

The Kårstø facility has been studied several times since the mid 2000s in relation to CCS.

The Kårstø Integration Pre-Feasibility Study [4] concluded that the most complete reduction in CO_2 emission from the site came from the scenario showing the conversion of the Naturkraft CCGT into a high efficiency CHP plant and adding re-firing to the exhaust from the heat recovery steam generator to raise the necessary additional steam. The lowest levelised cost in this study was over 1,150 NOK per tonne CO_2 reduced, including transport and storage. The study concludes "there is no commercial basis for realising any of the scenarios, taken into account all relevant costs, expected CO_2 quotas and other benefits and savings." Naturkraft still believes this study is relevant.

The study named 'Supply of electricity to CO_2 capture plant, Kårstø' [15] considered the supply of electricity to a full scale CO_2 capture plant at Kårstø from several sources. The study evaluated the options and consequences of power outlet from the Naturkraft generating plant. This study concluded that power outlet at generator voltage level and 300 kV level are technically feasible and that modifications could cause downtime of up to 7 weeks. Naturkraft still believe the results of this study are relevant.

The ‘Recommendation concept for technical solution and input data for the FEED studies’ [16] made a recommendation for technical solutions for the tie-in systems between a new carbon capture and compression plant and the existing combined cycle power plant. The tie-in systems comprised flue gas plenum, duct and stack, steam line, and condensate line. Naturkraft still believe this study is relevant but the solution has been superseded by the Kårstø Integration Pre-Feasibility Study [4].

The study ‘Et fullskala fangstanlegg for CO2 på Kårstø’ [17] describes the environmental impacts of constructing and operate an amine based, full scale, Carbon Capture facility at Kårstø. The study is a requested study by the Norwegian pollution control agency, SFT (now KLIF). In order to get a permit from the authorities to construct and operate a large chemical process industry, such a consequence study must be executed. The study describes all known impacts of a capture plat to the environment, ranging from amine-slip and cooling water emissions from the process to the number of possible jobs at the capture plant. Naturkraft still believe the study is relevant, as the amine technology still is the most considered basis for a retrofit carbon capture plant.

The study ‘Carbon Capture and Storage at Kårstø’ [18] describes technical, economic and scheduling aspects of a CO_2 capture and storage facility at Kårstø. The costs of the planning phase were estimated to be approximately NOK 330 million, investment in the capture plant around NOK 3.46 billion, and the costs of transportation and storage were estimated at NOK 1.56 billion. Based on the assumption of 8000 hours of operation, annual operating costs were estimated to be about NOK 370 million, leading to a cost of CO_2 abatement of about NOK 700 per tonne of CO_2 captured. Naturkraft consider that the prices in this study are no longer relevant and the study has been superseded by several studies listed above.

The ‘Kårstø Combined Cycle Power Plant, Tie-In Study for CO_2 Removal Plant’ [19] assessed the technical interface issues for the Kårstø CCGT in connecting to CO_2 removal plant. Connection of exhaust gas as well as extraction of process steam with return of condensate was investigated. Naturkraft consider this report as been superseded by the Norsk Energi, 2008 study [16].

In 2005, Gassco initiated an investigation for retrofitting CCS at Naturkraft’s gas-fired power plant in Kårstø [**Error! Reference source not found.**]. The possibilities of creating a value chain for CO_2 by using it with enhanced oil recovery (EOR) in the Norwegian continental shelf oil fields were investigated by Gassco, Gassnova and Petoro in 2006 [3]. These reports concluded that there was no business case for EOR at the targeted fields due to the high investment cost of installing CO_2 handling facilities at existing offshore installations. Naturkraft still believe these studies are relevant.

The CO_2 Kårstø Project was carried out by Gassnova between 2007 and 2009 [20] which included four parallel capture plant FEED studies and one on tie-in and civil work. These projects were also aligned with the joint Gassco / Gassnova project on transport and storage of the CO_2 from Kårstø. This project was halted by the MPE in 2009 due to the low utilisation of the power plant. Naturkraft still believe this study is relevant but the solution has been superseded by the Kårstø Integration Pre-Feasibility Study [4].

9. Heidelberg Norcem cement plants

This section is based on assessment forms agreed by Norcem during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. These assessment forms were signed by a Norcem representative to declare that to the best of their knowledge the information provided in those forms was accurate [21][22].

Norcem AS develops, produces, markets and sells all types of cement to the civil engineering and oil and gas industries in Norway. The company has around 500 employees and is part of the HeidelbergCement Group. Norcem is the only cement producer in Norway, and have two factories, Kjøpsvik and Brevik. Norcem's main markets are in Norway, Scandinavia and the Baltic states, with smaller amounts exported to USA and Russia.

HeidelbergCement describes itself as 'the global market leader in aggregates for cement and a prominent player in the fields of cement, concrete and other downstream activities, making it one of the world's largest manufacturers of building materials'. The Group's total cement production capacity is over 100m tonnes a year. It has about 54,000 employees and is present in more than 40 countries and on all continents except South America..

HeidelbergCement has expressed a goal of reducing its CO_2 emissions by 25% in 2015, compared to 1990. Their approach has been to invest in energy-efficient technologies and production processes, increase the use of composite cement, and increase use of alternative fuels including biomass. So far their progress is ahead of schedule. The company's total emissions of CO_2 are about 50m tonnes a year, which is broadly equivalent to Norway's total emissions. Its two Norwegian cement plants' emissions account for about 1.3m tonnes of CO_2 a year.

9.1 Norcem Brevik cement plant

Table 9.1: Norcem Brevik cement plant fact box

Major Activity	Grey Cement Production
Existing or New / Potential Source	Existing
Estimated future emissions of CO_2 from facility	760 kt/y (net)
Does the owner consider the facility relevant or not relevant for NCCS Study?	Relevant
Technical reasons for relevance decision	• The flue gas has a high concentration of CO_2 (16-19%); • Heat recovery from the cement process could be used to meet the carbon capture process heat needs for the

	capture of 30% of the sites CO_2 emissions. • The site has already made considerable improvements with CO_2 emission, CCS being a possible next step. • Norcem have participated in early attempts to undertake small-scale CCS
Commercial reasons for relevance decision	• The cement industry needs more information on the potential of CCS. • Any experience on Brevik could be extended to other parts of the cement industry.
Financial reasons for relevance decision	• The kiln already has acid gas cleanup facilities that would reduce the investment cost of flue gas cleanup for CCS. • The authorities' willingness to support early installations of CCS is likely to reduce risk.
Deliverability reasons for relevance decision	• Transport and storage needs to be investigated to better understand future commercialisation of CCS. • Norcem's good environmental reputation makes the implementation of CCS more realistic at Brevik

The Norcem Brevik cement factory is located in Porsgrunn kommune in Telemark. The factory has an annual production of approximately 1.2 million tonnes of cement, with around 180 employees. Norcem extract limestone from a quarry and mine located near the production site. The Brevik site has two point sources with combined emissions of approximately 925 kt/y of CO_2 (gross). Brevik is among the world's leading cement plants in terms of utilization of alternative fuels for decarbonisation.

9.1.1 Technical viability

At the Brevik plant, Norcem has already made substantial reductions in coal consumption by progressively increasing the use of 'waste derived fuels '. This waste includes; hazardous waste, refuse derived fuel (RDF) and animal meal. Brevik is the Norwegian national solution for hazardous waste incineration. The total energy from this waste now meets approximately 57% of the total energy demand for the kiln. The remaining energy is provided by coal. Norcem plans to further increase the proportion of the Brevik kiln energy obtained from waste to between 67% and 75% in the long term, with a corresponding continued reduction in the requirement for coal firing. This 75% target is the likely maximum local supply of waste suitable for Brevik. It should be noted that even if the use of primary fuel could be reduced to close to zero, it would have no effect on the volume of CO_2 released from the calcining process. Norcem has therefore already made considerable improvements with CO_2 reduction measures, with the next step being CCS.

Brevik indicated that the average use of waste and other non-primary fuel in the European cement industry was in the range 15 - 25%.

Figure 9.1: Norcem Brevik cement plant

Source: Heidelberg Norcem

The main exhausts from the kiln processes are combined into a single stack and the CO_2 content of the combined exhaust is approximately 18%. This CO_2 concentration makes it suitable for the application of post combustion CCS but the corrosive nature of the exhaust gases means that further cleanup of this gas stream is likely to be required before CCS techniques can be applied reliably. The site already has acid gas cleanup facilities on the kiln which will help flue gas cleanup for CCS.

Norcem's view is that CCS is a good idea and they have a lifecycle analysis-based target of zero net CO_2 emissions for their concrete products by 2030, providing the economics are sustainable. Norcem states that there are several similar scale plants in Europe where CCS-technologies could be applied.

Norcem has participated in early attempts to undertake small-scale CCS trials with funding from cement industry and CLIMIT. Together with its parent company Heidelberg Cement and ECRA (European Cement & Research Academy), Norcem has applied for funding for a CO_2 capture test facility with ESA approval (state aid) targeted before the end of 2012. The pilot should have a nominal annual capacity of 2000 tonnes of CO_2 per year.

In 2005, Norcem carried out a high level costing exercise for a full scale carbon capture plant at the Brevik site and have identified central estimates of a capital cost of NOK 1bn and running costs of NOK 250m per year (excluding CO_2 compression, transport or storage). This design would capture 85% of the CO_2 with the energy required being supplied partly from separate generation plant as well as waste heat.

Norcem believes that heat recovery from the cement process could in principle be used to meet the carbon capture process heat needs for the capture of 30% of their CO_2 emissions. The company states that this is a preferable option to 85% CO_2 capture, which would require significant changes to the existing system (in addition to extensive costs both for investments and operations).

9.1.2 Commercial viability

The demand for cement and concrete as construction materials is increasing and Norcem states that it is important for them to offer the market environmentally and technically sustainable construction materials. Norcem believe that long term commercial viability is one important factor for a company's capability to offer sustainable products.

It is Norcem's view that the cement industry needs well documented experience of the technical, environmental and economic aspects related to CO_2 capture, to be able to assess the potential for carbon capture at existing kilns. Experience and knowledge developed through testing will be critical in assessing the optimum scale of the technology and the use of waste heat in capturing the CO_2. With the most mature capture technologies currently available, Norcem believes that approximately 30% of CO_2 emissions can be treated utilising the existing waste energy at the site, thus reducing the potential investment needs and operating costs of a CCS facility.

After 2020, Norcem believes that implementation of CO_2 capture technologies will be fully dependent on international regulation. Norcem anticipates that an international CO_2 regime must be established where the cement industry is given the same framework conditions as its competitors; it is possible to ship cement from Asia to Europe with limited additional costs, and the cement industry must be confident that it will not be challenged by players with less stringent environmental constraints.

9.1.3 Financial viability

At this stage, Norcem does not know the costs of CCS with any certainty though they expect that the first CO_2 capture plant will be more expensive than later installations. The uncertainties are illustrated by the wide spread in estimates from technical consultants and Norcem point out that Mott MacDonald estimates of capture costs for cement plants published (by IEA) in 2008 were about three times those of Tel-Tek's 2005 study[1].

Norcem believes that the best way to narrow down the uncertainty is to build a pilot scale facility; this should allow a higher degree of confidence in cost estimates, although uncertainties will remain in scaling-up the technologies.

There are two factors that would mitigate the capture costs at Brevik versus some other installations, assuming that the capture plant is optimised in scale and configuration. Firstly, there is an option for heat recovery (up to about 24MWh) that can be exploited without affecting the core production process. This would allow about 30% of the total CO_2 emissions to be scrubbed. Going beyond this level would require the addition of a new process heat supply, or extraction of energy from the core process, which would substantially increase costs. Secondly, the plant has already installed SNCR (selective non catalytic reduction plant) and GSA (gas suspension analyser) thereby substantially reducing the need for investment in flue gas conditioning.

[1] The difference may have reflected escalation in process equipment prices in international markets during 2007-2009

Despite these mitigating factors, Norcem believes that the total costs for installation and operation of the capture and compression stages of CCS will be large in comparison to current expectations of the carbon price. Adding on transport and storage would make CCS even less financially viable, without some form of substantial financial assistance in the early stages.

Norcem believes that the first CO_2 capture plant will carry a larger risk compared to later installations; commercial viability will depend on the authorities' willingness to support promising upcoming test and demonstration projects.

9.1.4 CCS deliverability

Norcem believe that the carbon price should provide the main financial 'carrot' for decarbonisation. The Heidelberg Cement Group/ Norcem follows the development in CO_2 price closely. In addition to actively trading, the Group are in contact with big international banks and other actors in this market. Estimates differ, but the Group thinks a realistic level in 2020 would be between €17 and €20/tonne of CO_2. In the period until 2030 the Group expects a further price increase to a level of €30-35/tonne, with the EU ETS connected to other emissions trading schemes worldwide.

Before promoting CCS, Norcem needs demonstration projects (such as the one planned at Brevik) where testing is executed on a real and representative industrial flue gas to develop experience and knowledge on technical, environmental and economic aspects of capture options. In addition to needing documentation on performance on energy consumption, capture efficiency, utilisation of available waste heat and underlying economics, Norcem would need documentation on safety aspects and environmental aspects to convince the public of the merits of CCS.

The cement industry in general (through the European Cement and Research Academy) and the managing board of Norcem AS and HeidelbergCement in particular are positive about exploring decarbonisation options including CCS. At present, the cement industry is concentrating on the CO_2 capture part of the chain but views transport and storage as a major hurdle for future commercialisation of CCS. These parts of the chain need to be investigated in parallel by other parties, better able to assess these matters.

With regard to permitting challenges, Norcem states that this is currently difficult to answer, but their experience to date is that the Norwegian government has been supportive and as long as such installations are not seen to result in a novel or additionally negative influence on the environment, the permitting challenges should not be a big issue. Regarding public acceptance, Norcem at Brevik already have a good environmental reputation and this makes the implementation of CCS more realistic.

If Norcem were to embark on full-scale CCS, they would need external support to execute the project as they no longer have dedicated teams of engineers to do this work. Norcem will therefore require external support for transport and storage as this is vital for commercialisation of CCS. Norcem know that local industry (Yara) already has experience in drying, compressing and transporting CO_2 and believe sustainable ways of transportation will be available when capture and storage are commercially viable.

9.1.5 Relevance decision

Norcem consider the Brevik site as 'Relevant' for further participation in the NCCS Study because the site is expected to have future emissions of 760 kt/y with a flue gas concentration of 16 to 19%. This flowrate and concentration are suitable for CO_2 capture with the current best available capture technology. Heat recovery from the cement process could be used to meet the carbon capture process heat needs for the capture of 30% of the sites CO_2 emissions. The site has already made considerable improvements with CO_2 emission, CCS being the next step. Norcem have participated in early attempts to undertake small-scale CCS projects.

Norcem also believe that the cement industry needs more information on the potential of CCS. Any experience on Brevik could be extended to other parts of the cement industry.

The kiln at Brevik already has acid gas cleanup facilities that would reduce the initial investment cost of flue gas cleanup for CCS. The authorities' willingness to support early installations of CCS is likely to reduce the risk of commercial viability.

Norcem believe transport and storage needs to be investigated further to better understand future commercialisation of CCS. Norcem's good environmental reputation at Brevik makes the implementation of CCS more realistic.

9.2 Norcem Kjøpsvik cement plant

Table 9.2: Norcem Kjøpsvik cement plant fact box

Major Activity	Grey Cement Production
Existing or New / Potential Source	Existing
Estimated future emissions of CO_2 from facility	375 kt/y (net)
Does the owner consider the facility relevant or not relevant for NCCS Study?	Not Relevant
Technical reasons for relevance decision	• Space is not available for CCS solutions at the Kjøpsvik plant. • Kjøpsvik does not have as good harbour facilities as Brevik for transporting materials and handling big vessels for CCS; especially space for storage of materials and equipment
Financial reasons for relevance decision	• Norcem believe that there are better alternatives than Kjøpsvik to apply CCS to after Brevik;
Deliverability reasons for relevance decision	• Norcem do not have the internal resources to investigate and develop CCS solutions for both plants in parallel.

Figure 9.2: Norcem Kjøpsvik cement plant

Source: Heidelberg Norcem

Norcem Kjøpsvik is located in the county of Nordland approximately 100km southwest of the city of Narvik. The cement plant supplies local markets from Trondheim to Kirkenes as well as some exports.

Technical viability

Norcem Kjøpsvik is a smaller plant that Norcem Brevik with a yearly production volume of approximately 500 kt of clinker, which is one half of Norcem Brevik's production. The net CO_2 emissions in 2011 were approximately 360 kt from one point source. The majority of CO_2 emissions (appr. 60 %) are as a result of the calcination of limestone and are unavoidable unless CCS is deployed. The remaining emissions come from the combustion of fuels to achieve the temperature at which the calcination process takes place.

The Kjøpsvik plant is physically constrained and space is therefore not available for CCS without land reclamation. The harbour facilities at Kjøpsvik are therefore not as good as at Brevik for the transportation and storage of materials and the handling of big vessels for CCS.

9.2.1 Financial viability

Norcem believe that there are better alternatives than Kjøpsvik to apply CCS to after Brevik; at least in the short term. The plant is much smaller, and from a cost/benefit view, Norcem believes that before CCS technologies are fully developed, the Kjøpsvik plant will not be relevant for CCS.

9.2.2 CCS deliverability

First; Norcem do not have the internal resources to investigate and develop CCS solutions for both the Brevik and Kjøpsvik plants at the same time. Second; CCS in the cement industry is still on a developing stage; ref. the comment on cost/benefit above.

9.2.3 Relevance decision

Norcem consider the Kjøpsvik site as 'Not Relevant' for further participation in NCCS Study because the physical constraints on site mean that space is not available for CCS solutions at Kjøpsvik. The harbour facilities at Kjøpsvik are not as good as at Brevik for transporting and storage of materials and handling large vessels for carbon compression and transportation.

Norcem believe that because of the technical constraints, and from a cost/benefit point of view, there are better alternatives than Kjøpsvik to apply CCS after Brevik.

Norcem state that they do not have the internal resources to execute large scale engineering projects and can therefore not investigate and develop CCS solutions for both plants.

9.3 Previous experience and knowledge of CCS

A study looking at the 'concept and pre-engineering of a post-combustion CO_2 capture test facility at Norcem Brevik' was carried out in 2011 [23] with support under the CLIMIT Program. The partners were Norcem AS, Heidelberg Cement and the European Cement and Research Academy. The main recommendation of the study was for a test facility for parallel testing of the three post-combustion technologies: Aker's Clean Carbon's Amine Process; Alstom's Chilled Ammonia Process; and Alstom's Carbonate Looping Process. The estimated total project costs were NOK 160m and due to these high costs, the project was not approved or supported by the industry.

The outcome of the project is still relevant and valid and is the basis for a new attempt to establish a sequential test facility for testing of Aker Clean Carbon's amine process in addition to the testing of two small scale technologies; membrane (DNV KEMA/ Yodfat & NTNU) and a solid sorbent technology (RTI). The decision whether CLIMIT will fund the project will probably come late 2012 or early 2013.

Table 9.3: List of relevant reports available from the 2011 study (Concept- and Pre-Engineering)

Name of Report	Description	Norcem assessment if study is still relevant
Concept Study report [24]	Identification of possible post-combustion technologies and providers. Recommendations of technologies for pre-engineering.	Yes
Pre-Engineering report [25]	Pre-engineering of parallel test facility. Description of technologies. Identification of utility requirements and first cost estimate.	Yes
Design Basis [26]	Design of infrastructure. This report is the basis for the detail engineering and construction. Includes the following attachments: TP data Sheets Flue Gas System, CO2 and Utilities Arrangements (DAC) Cement Production Flue Gas data	Yes

Name of Report	Description	Norcem assessment if study is still relevant
	Electrical, Instrument and Tele-Communication/ IT Master equipment List	
Draft R&D Test Program [27]	First draft test campaign report. This report discusses various tests and investigations to be carried out with regards to targets defined by the cement industry but also the technology providers.	Yes
Final Report [28]		Yes

In 2005, Norcem undertook a project to look at ‘CO_2 capture at Norcem’s cement plant; technical possibilities and economical estimates’ [29]. This project was initiated by Norcem AS and executed in cooperation with GassTEK. The adoption of a full scale amine CO_2 capture process was studied. Removal of NO_X and SO_X from the flue gas was also included in the study. The energy requirement was partly generated by heat recovery from the kiln off-gases and partly by a gas-fired plant. The costs of the compression, drying and transportation of the captured CO_2 to a planned gas-fired power station at Herøya was included. Total investment costs were estimated at NOK 877m plus the first fill of chemicals (NOK 5m). Operational costs were calculated to be NOK 162m per year giving a total cost of NOK 262 per tonne of CO_2 captured. Norcem consider this study to no longer be relevant as a lot has been learned since this study was concluded. The concept for CCS at Brevik has changed and Norcem therefore consider these costs as no longer valid.

10. Statoil

This section is based on an assessment form agreed by Statoil during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. This assessment form was signed by a Statoil representative to declare that, to the best of their knowledge, the information provided in the form was accurate [30][31].

Statoil is an international energy company with over 40 years' experience on the Norwegian continental shelf and with operations worldwide. Statoil is the largest operator on the Norwegian continental shelf, and a license holder in numerous oil and gas fields.

Statoil also has onshore facilities in Norway for gas treatment, a crude oil terminal, a crude oil refinery and a methanol production facility. Statoil has many years experience with CCS activities, not only with Snøhvit but also with Sleipner where the extracted natural gas has a CO_2 content that is too high for export. Statoil was the project executioner and holds a 20% share in the Test Centre at Mongstad. Statoil is also the project executioner for the full-scale CO_2 Capture Mongstad project.

As a technology-driven upstream oil and gas company, Statoil's response to the climate challenge is to: reduce its own greenhouse gas emissions; provide technology solutions; drive development of industry standards; strive for transparency; as well as engage in the design of international and national political climate measures. Statoil is regarded as a pioneer and a front runner in CCS. Statoil has many years experience of capture, transportation as well as storage of CO_2.

10.1 Snøhvit Train I

Table 10.1: Snøhvit Train I Fact Box

Major Activity	Oil an gas production
Existing or New / Potential Source	Existing
Estimated future emissions of CO_2 from facility	1,165 kt/y
Does the owner consider the facility relevant or not relevant for the NCCS study?	Not Relevant
Technical reasons for relevance decision	• A recent study has concluded that other technical solutions obtained the same CO_2 reductions as CCS with lower risk. The results and findings of this study were accepted by KLIF.
Financial reasons for relevance decision	• A study showed that alternative CO_2 reduction measures cost much less than the CCS scenario investigated for Snøhvit Train 1. KLIF accepted this study's findings.
Deliverability reasons for relevance decision	• Statoil state the current CCS regulatory framework places burdens, uncertainties and risks on transport

and storage providers.

Figure 10.1: Snøhvit Train I

Source: Statoil

Located in the north of Norway, Snøhvit is a gas processing plant, commissioned in 2007, where natural gas (from the Snøhvit field) is processed into LNG and some LPG and condensate for onward export. The processing unit has an annual CO_2 release of 1025 kt/y (2010) that is mainly emitted by five gas turbines, with waste heat recovery supporting the plant, in addition to a high pressure flare system and a couple of minor sources.

Statoil is the operator of the Snøhvit facilities and also the largest owner. Other owners are Petoro, Total, GDF Suez and RWE-Dea.

10.1.1 Technical viability

The Hammerfest LNG, Snøhvit plant is one of the very few places in the world where there is an operational CCS chain. The natural gas from the Snøhvit field has a high CO_2 content (5-6 % vol) that has to be extracted before it is processed into LNG.

The CO_2 is captured from the natural gas using an amine process. The CO_2 is then released from the amine by using hot oil as a heat recovery medium to transfer waste heat from the turbines. The CO_2 is liquefied and exported back to the Snøhvit field through a 153 km long offshore pipeline.

Snøhvit has a CO_2 capture capacity of about 800 kt/y and is able to transport more than this but due to pressure build-up in the Tubåen formation, there was little spare injection capacity remaining in 2011. A well intervention was performed in the CO_2 injector in April 2011, where the Tubåen formation was isolated and CO_2 was injected in the Stø formation. The injection capacity of the Stø formation is currently sufficient for the CO_2 captured at Melkøya, but Snøhvit is considering drilling a new CO_2 injector to avoid contamination of the gas resources.

Studies showing that CCS is technically feasible at Snøhvit Train I facility have been conducted. Further details can be found in section 10.3. These studies concluded that various technical solutions, including site electrification, obtained the same CO_2 reduction as CCS but with lower risk and cost. These studies were initiated by KLIF and the results and findings were accepted by KLIF. Statoil believe that the findings of these studies still valid. Electrification could reduce CO_2 emissions as long as the power is from a renewable source.

10.1.2 Commercial viability

Statoil states that a predictable and higher long-term global CO_2 price has to be established. The CO_2 price should give incentives for investments in research and development, e.g. in Europe, the EU ETS. The CO_2 price should form the basis of a long term business model for CCS.

Statoil believes that public funding of demonstration projects is vital to secure wide and accelerated deployment, e.g. In Europe, both at EU level as well as member state funding.

10.1.3 Financial viability

In the screening phase of the "CO_2 reduction measures for Snøhvit Train I" – initiated by KLIF in 2010 [32] Statoil have estimated abatement costs to be about 5000 NOK per tonne of CO_2. Studies have shown that alternative CO_2 reduction measures cost much less than the CCS scenario investigated for Snøhvit Train I. KLIF accepted this study's findings.

10.1.4 CCS Deliverability

Statoil believe the CCS regulatory framework has to be developed and implemented in various different countries. They believe the regulatory framework must be a tool for the safe, wide and accelerated deployment of CCS. Statoil states that the current framework appears to perceive CCS as a high risk activity which they believe is placing burdens, uncertainties and risks on storage providers, e.g. in Europe, the CCS Directive and the implementation of the regulatory framework in the respective member states.

Statoil believe the early demonstration of CCS is vital to promote commercialisation of the technology. They believe this requires public funding, a long term business model, a high, predictable CO_2 price, removal of roadblocks and hurdles from the regulatory framework and establishment of an environment which perceives CCS as a low risk activity in order to establish public acceptance/support for the technology. Statoil also believes a commercial roll-out of CCS requires the price of CCS to be drastically reduced and at the same time infrastructure has to be deployed.

Statoil state that permitting challenges will depend on the regulatory regime – but they believe there are challenges in Europe for transportation and storage of CO_2. Statoil believes that the implementation of the CCS Directive (and the EU ETS Directive) imposes burdens, uncertainties and risks on both transportation providers as well as storage providers. Statoil also states that projects may be delayed if the EU Commission review the national permitting procedures and think that transboundary issues linked to both transportation and storage of CO_2 are still unresolved.

Statoil has many years experience in CCS design, construction and operation and have a significant organisational and management capability in CCS and associated technologies.

10.1.5 Relevance Decision

Statoil considers the Snøhvit Train I site as 'Not Relevant' for further participation in the NCCS programme because a recent study has concluded that other technical solutions, including electrification of the site, obtained the same CO_2 reductions as CCS with lower risk. The results and findings of this study were accepted by KLIF.

A study showed that alternative CO_2 reduction measures cost much less than the CCS scenario investigated for Snøhvit Train I. KLIF accepted this study's findings.

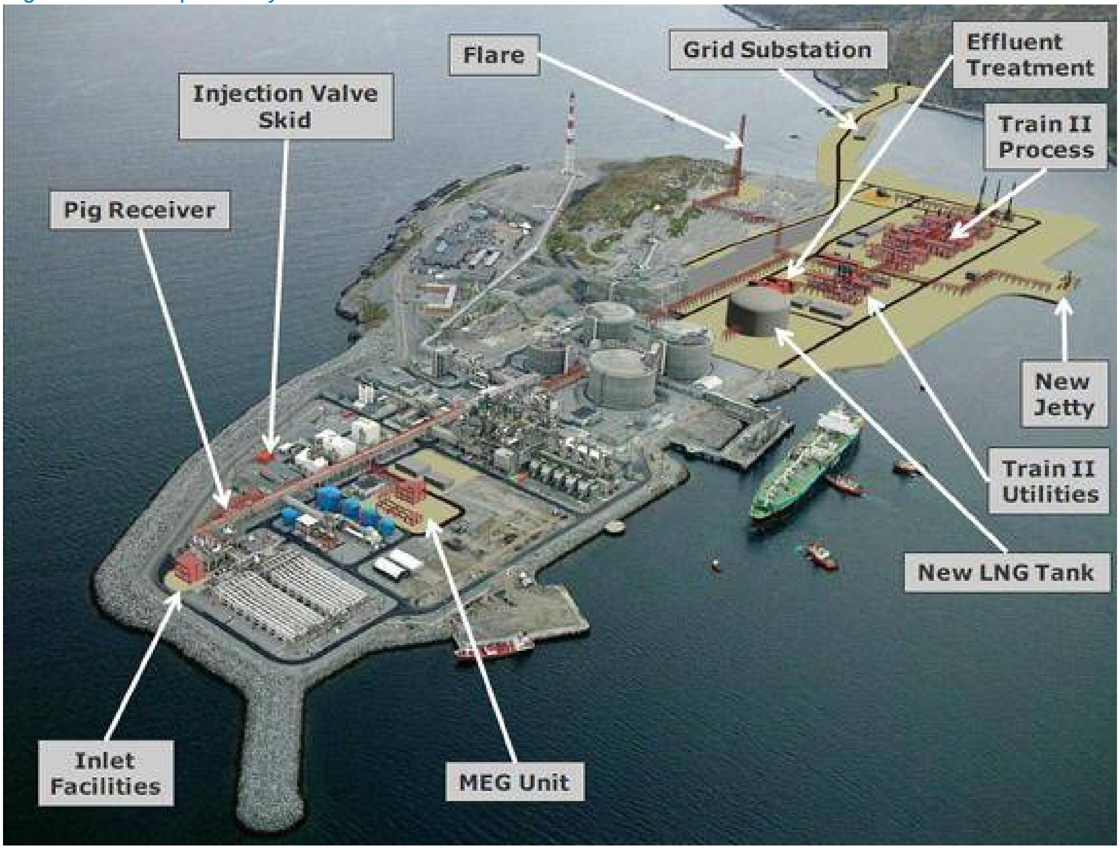
Statoil states that the current framework appears to perceive CCS as a high risk activity which they believe is placing burdens, uncertainties and risks on storage providers. Statoil believe that the implementation of the CCS Directive (and the EU ETS Directive) imposes burdens, uncertainties and risks on both transportation providers as well as storage providers.

10.2 Snøhvit Train II

Table 10.2: Snøhvit Train II Fact Box

Major Activity	Oil an gas production
Existing or New / Potential Source	Potential
Estimated future emissions of CO_2 from facility	291 kt/y
Does the owner consider the facility relevant or not relevant for the NCCS study?	Not Relevant
Reasons for relevance decision	• This project has stopped because current gas discoveries do not provide a sufficient basis for further capacity expansion

Figure 10.2: Proposed layout for Snøhvit Train II



Source: Statoil

This project has stopped [33]. This project is not regarded as sufficiently robust by the owners. The energy solution for the Train II project was based on power from the grid and heat generation by gas-fired burners (base case) or from a separate gas-fired power supply. For the base case solution CCS would have only been required for the heaters. An internal study where the conclusions were highlighted to KLIF in a letter dated 14/07/2010 stated CCS had been evaluated and found to be expensive. The cost of CCS (excluding transport and storage) was found to be 3700 NOK/t CO_2. The total emissions from the base case were 291 kt/y.

The base case has an abatement cost of below 1000 NOK/t CO_2 compared to a gas-fired power station without CCS. The abatement costs are sensitive to future electricity cost.

The full costs of CCS were not studied for Train II. Studies of CO_2 capture and storage for Train I indicate that abatement costs are in the order of 5000 NOK/ t CO_2.

10.2.1 Relevance Decision

Statoil considers the Snøhvit Train II site as 'Not Relevant' for further participation in the NCCS programme because the project has been stopped. The press release [33] states that Statoil "has concluded that the current gas discoveries do not provide a sufficient basis for further capacity expansion. "

10.3 Previous experience and knowledge of CCS

A screening study was performed by Statoil during the spring of 2010 to investigate several alternatives for heat generation and the capture and storage of CO_2 from the exhaust flue gas from the existing Snøhvit Train 1 gas turbines [34]. The screening study concluded that replacing the existing gas turbines with power imported from the national grid was the most promising and cost efficient CO_2 reduction measure for Hammerfest LNG, provided that imported power is produced by renewable sources.

Table 10.3: Studied emissions reduction alternatives

Scenario		Power Generation		Heat Generation						
1	CCS	1	Post combustion gas turbines	Heat recovery from gas turbines and heater						
		2	Pressurised combustion	Heat recovery						
2	Electrification	1	Replacement of all turbines – new grids required	A	B	C	D	E	F	G
				Gas fired without capture	Gas fired with capture	Biomass	Oxyfuel	Pre-combustion	Heat pump	Electrical
		2	Replacement of one turbine – use of existing grid	Heat recover from remaining gas turbines						

Based on the results above, Statoil and KLIF agreed to carry out a feasibility study for the electrification of Hammerfest LNG, based on importing electricity from the national grid and generating heat through either hot oil furnaces, fired with natural gas, or biomass fired boilers (screening phase - 2010).

Both the hot oil furnace and the biomass boiler options show potential for reducing CO_2 emissions. An important assumption for the biomass-fired boiler alternative is that combustion of biomass fuel can be considered CO_2 neutral. Emissions of CO_2 from the harvesting and transportation of biomass were estimated but not included in the calculations. Neither of the two alternatives for heat generation included CO_2 capture from the flue gas.

A capital cost estimate was developed according to Statoil's Class B (+/- 40%) and abatement costs calculated based on assumptions used in "Klimakur" [7].

Table 10.4: Emission reduction abatement costs from studies

Option	Description	CO_2 [kt/yr]	CAPEX MNOK	Abatement Cost NOK/tonne CO2
1	Power import and gas fired hot oil furnaces	300	2 522	1478
2	Power import and biomass fired steam boilers	69	10 023	1918

The Ministry of Environment (ME) have stated that they are satisfied with the work performed by Statoil relating to the CO_2 reduction measures and that the work is in line with the requirements from KLIF. KLIF has submitted the study to ME as an input to the White Paper regarding Climate.

11. Longyearbyen Lokalstyre Bydrift KF (Bydrift)

This section is based on text agreed by Bydrift during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. The outcome was an assessment form that was signed by a Bydrift representative to declare that to the best of their knowledge the information provided in that form was accurate [36][37].

Svalbard is a part of the Kingdom of Norway pursuant to the Svalbard Act (17 July 1925). The Svalbard Treaty (of 9 February 1920) recognizes Norway's sovereignty over Svalbard, and obligates Norway to grant equal rights in certain fields to citizens and companies from all the parties to the Treaty. On this basis several Norwegian laws do not automatically apply, but are adopted on a selected basis. The environment of the archipelago is preserved through special environmental laws and EU or equivalent rulings do not automatically apply. Longyearbyen's population is around 2100.

A municipal owned company, Longyearbyen Lokalstyre Bydrift KF (Bydrift) is responsible for city operations, including utilities, harbour, fire department etc. Bydrift has about 50 employees. Bydrift's role involves taking a long view for infrastructure development including utilities planning and operations as well as day-to-day operations and maintenance.

11.1 Svalbard existing coal-fired power plant

Table 11.1: Existing Svalbard coal-fired power plant fact box

Major Activity	Production of electrical and thermal energy
Existing or New / Potential Source	Existing
Estimated future emissions of CO_2 from facility	60 kt/y
Does the owner consider the facility relevant or not relevant for the NCCS study?	Not Relevant
Technical reasons for relevance decision	• The existing power plant is not able to produce enough additional energy to support a CCS plant.
Commercial reasons for relevance decision	• Installation of CCS to a low efficiency boiler with limited expected lifetime is unlikely to be a sound investment.
Financial reasons for relevance decision	• There is no financial incentive for avoiding CO_2 emissions • No obvious mechanism to raise or recover costs through a tariff on energy consumers

Figure 11.1: Location of potential emission and storage sites for Svalbard

Source: *UNIS CO2 Lab*

There is a combined heat and power plant located at Longyearbyen, which is fired on local coal. The plant is 30 years old and is beginning to show signs of ageing with increased outages and maintenance requirements. It comprises of two boilers paired with steam turbines and generators, so as to provide sufficient redundancy, as well as a diesel generator for additional back-up and peaking generation.

Total annual CO_2 emissions are around 60 kt/y, which is half the emission cap agreed with KLIF in the Svalbard environmental law.

Power and heat tariffs, which are reasonably cost reflective, are high by the standards of mainland Norway, which mainly reflects the high fuel and maintenance costs versus the mainland hydro-based system.

11.1.1 Technical viability

The existing boilers, which are 30 years old, provide 11MW of electricity and 20MW of heat for the homes and the mines close to Longyearbyen. The total CO_2 emissions from this power plant are around 60 kt/y but the Bydrift's current plant permit allows up to 120 kt/y. Availability and redundancy is the main driver for this power plant as the district heating is necessary all year round. The two boilers are therefore not operated at the same time and so the boilers are operated 6 months at a time to ensure even wear and tear of the equipment. This system also has another layer of redundancy with 3 emergency diesel generators for electrical power and five emergency diesel heaters distributed around Longyearbyen.

The existing boilers are currently having reliability issues and an investigation is under way to determine the remaining life of the plant and how much it will cost to maintain in the coming years. The results from this study are due in February/March 2013. The plant has an efficiency of 27% on the condenser turbine and 86% on the backpressure turbine giving an overall plant efficiency of about 45%. Installation of CCS to a low efficiency boiler with limited expected lifetime is unlikely to be a sound investment.

For CCS to be installed, additional steam and power would be required to operate the CCS plant. This would require the operation of both existing boilers in parallel, doubling the fuel use to provide enough steam for CCS. This removes required redundancy and is not an option for this site.

The condenser turbine is sea water cooled and the back pressure turbine is cooled via the district heating. There is enough land to build CCS close to the existing power plant. Additional sea water for CCS cooling is available on site. Sufficient water for CCS is likely to be available year round via a nearby lake depending on requirements.

11.1.2 Commercial viability

The existing business and regulatory drivers do not provide any incentive for Longyearbyen to install CCS. KLIF has agreed a CO_2 emission limit which is double the current level, while there is no applicable carbon price for Svalbard.

There is no commercially viable option for reducing CO_2 emissions at the existing Svalbard coal plant. At 30 years old, it is not viable to continue the existing plants operation for many more years, without seriously increasing maintenance costs or seriously jeopardising supply of power and heat to the community.

11.1.3 Financial viability

The unit costs of retrofitting CCS at the existing Longyearbyen coal-fired plant would be very high given the small scale and the need to provide its own heat and power requirements, while the old age of the host plant would lead to increasing risk of outages so breaching Bydrift's obligations to supply power and heat to Longyearbyen.

There is also no financial incentive in terms of value for avoided CO_2 emissions and neither is there an obvious practical mechanism for Bydrift to raise the investment funds and recover costs through the tariff on Longyearbyen energy consumers.

11.1.4 CCS Deliverability

In principle, given the small scale of a potential CCS plant at Longyearbyen (which reduces the scale-up challenge compared to other potential sites in Norway), it would appear to be comparatively manageable to deliver CCS in Longyearbyen. There would however be construction challenges in the arctic environment. Bydrift states that they themselves, the local authorities and University's CO_2 lab are all keen to pursue the CCS option.

The commercial rationale for a retrofit on the existing coal plant is weak and would raise potential risks regarding future reliability of power and heat supply in Longyearbyen, given the old age and capacity of the existing host plant.

11.1.5 Relevance Decision

Bydrift consider the existing Svalbard coal-fired power plant site as 'Not Relevant' for further participation in the NCCS programme because the existing plant cannot support the power and heat demands required for a CCS facility and still meet current demand (without removing the required redundancy). The plant is 30 years old and is beginning to have increased outages and maintenance requirements.

Installation of CCS to a low efficiency boiler with limited expected lifetime would not be a prudent option compared with the other potential low carbon options for meeting Svalbard's heat and power needs.

While the costs and risks are high, there is also no financial incentive for avoiding CO_2 emissions and there is no obvious mechanism for Bydrift to raise or recover costs through a tariff on Longyearbyen energy consumers.

11.2 Svalbard proposed coal-fired power plant

Table 11.2: Potential Svalbard coal-fired power plant fact box

Major Activity	Production of electrical and thermal energy
Existing or New / Potential Source	Potential
Estimated future emissions of CO_2 from facility	Approximately 50 kt/y based on estimate of improved efficiency of new coal plant
Does the owner consider the facility relevant or not relevant for the NCCS study?	Relevant
Technical reasons for relevance decision	• CCS with transport and storage would be situated within a radius of 8 km. • Most of the infrastructure already exists • The logistics would be extremely efficient. • The long lifetime of the new plant lends itself to being integrated with CCS. • The new plant can be designed to provide steam to cover the CCS plant and existing demand.
Commercial reasons for relevance decision	• Bydrift states that, based on previous studies, a new coal plant with CCS is likely to be the least cost low carbon option for Svalbard's heat and power needs that meets the reliability requirements.
Financial reasons for relevance decision	• The scale of the energy generation results in relatively low investment costs for a new coal-fired power plant with CCS.
Deliverability reasons for relevance decision	• Delivery of CCS and a new power plant is likely to be relatively easy due to the scale of the project • This project will generate knowledge of CO_2 capture for new coal-fired power plant and in storage and transport.

Bydrift state that the option of a new coal plant on the existing site should be considered as it provides better value in terms of costs and reliability for energy production. Bydrift is keen to explore options for a new power plant and CCS at its site and believes that Svalbard represents a willing and "bite size" opportunity to implement a full chain CCS in Norway. The University of Svalbard (UNIS) has an interest in the handling aspects of CO_2 storage, as its CO_2 lab already since 2007 is focusing on storage options for Svalbard. The geology at Svalbard is similar to that in Barentshavet and further south on the Norwegian continental shelf but is accessible from onshore, which provides a unique opportunity to investigate storage at lower cost than offshore.

11.2.1 Technical viability

The distance from the coal mine (Gruve 7) to the power plant is 15 km and the CO_2 injection research site (the CO_2 well park), currently being investigated by the UNIS CO_2 lab, is situated approximately half way between the two sites. The knowledge gained from the ongoing research at the CO_2 well park – using water injection underground in order to simulate CO_2 dispersion and leakage - should however make it easier to find a permanent storage in that area or another site nearby. New seismic and drilling tests will need to be carried out to confirm this.

This arrangement provides an opportunity to evaluate a full CCS chain from mining and combustion of the coal to capture, transport and storage of the CO_2 in a compact location with extremely efficient logistics. Most of the infrastructure already exists and would not therefore generate large additional environmental impacts. The geology at Svalbard is similar to the Norwegian continental shelf but is onshore. This provides a special opportunity to investigate storage at lower cost than offshore.

The long lifetime of the new plant lends itself to being integrated with CCS. The new plant can be designed to provide steam to cover the CCS plant and the existing demand.

Investigations into a new power station in Longyearbyen are at a very early stage: no vendors have been contacted, no feasibility studies have started and no money is currently available from the government for this project.

There is enough land to build a new power plant with CCS. Additional sea water for CCS cooling is available on site. Sufficient water for CCS is likely to be available year round via a nearby lake depending on requirements.

The site is situated close to the UNIS CO_2 Lab which is investigating storage potential for Svalbard. UNIS CO_2 Lab states the expected size and injectivity of onshore storage will be released next year. The project has demonstrated and characterised the reservoir and the cap rocks.

11.2.2 Commercial viability

The existing business drivers do not provide an incentive for Longyearbyen to install CCS as this would add a substantial uplift for user tariffs. However as mentioned earlier Bydrift states that a new clean coal plant with CCS is likely to be the least cost low carbon heat and power option which meets Svalbard's demanding reliability requirements. Of course this is more costly than a new coal CHP without CCS.

Taking a broader perspective, the Norwegian government has agreed under the Svalbard environmental law to take measures to "preserve the distinctive wilderness of Svalbard". One interpretation of this is that

Svalbard should be aiming for minimal acid gas, particulate and CO_2 emissions, so should seek to adopt the best low carbon option.

11.2.3 Financial viability

The unit costs of building new coal-fired cogeneration capacity with CCS integrated in Longyearbyen are likely to be high given the small scale of the plant. In addition, there is an absence of any financial incentive in terms of value for avoided CO_2 emissions or practical mechanism for Bydrift to raise the necessary investment funds and recover costs through the tariff on Svalbard energy consumers. Bydrift state that this financing gap would need to be bridged by funding facilitated by the Norwegian state, if CCS is to go ahead in Longyearbyen. Fortunately, the small scale of the Longyearbyen project means that the total cost is likely to be comparatively small when compared to other low carbon energy initiatives being supported by the Norwegian authorities.

11.2.4 CCS Deliverability

The government has through the 'Svalbard Environmental Law' and various publications (e.g. White Paper 22), committed to keep Svalbard as the best preserved nature area in the world. Gruve 7 would be the source of coal for the next 70-80 years. There are other known coal reserves near Longyearbyen.

In principle, given the special status of Svalbard and the small scale of a potential CCS plant at Longyearbyen, it would appear to be comparatively manageable to deliver CCS in Longyearbyen. Bydrift states that they themselves, the local authorities and UNIS CO_2 lab are all keen to pursue the CCS option.

According to Bydrift, a new coal-fired power plant with CCS option appears to provide a practical low carbon option for Longyearbyen as it would continue to use local coal, provide the appropriate level of security of supply and offer the lowest levelised cost over a long term period.

This prototype may generate knowledge in building and operation in all CCS stages, i.e. knowledge in the running of capture plant, transport and storage combined. It could provide a prototype of a purpose-built integrated CHP and CO_2 capture plant that could be applied elsewhere. A Svalbard project would make available for its experience in developing and operating onshore storage to offshore sites with similar geological formation, so providing the potential for easier and lower cost learning than offshore projects.

Bydrift states this project would be consistent with the decision from Parliament in White Paper 21 relating to Norwegian Environmental Politics.

Although Bydrift KF would like to organize and contribute throughout a CCS project, they are a small organization and they state that they would have to depend on external resources for project management and supervision of a CCS project.

11.2.5 Relevance Decision

Bydrift considers the potential Svalbard coal-fired power plant site as 'Relevant' for further participation in the NCCS programme because the coal mine, power plant, storage site and UNIS are all situated within a radius of 8 km. Most of the infrastructure already exists and would not therefore generate large additional environmental impacts. The logistics would be extremely efficient. The long lifetime of the new plant lends itself to being integrated with CCS. The new plant can be designed to provide steam to cover the CCS plant and the existing demand.

According to Bydrift, a new clean coal-fired plant with CCS is likely to be the least cost low carbon heat and power option which meets Svalbard's demanding reliability requirements and would preserve its special wilderness status.

The scale of the energy generation is relatively small resulting in low investment costs for a new coal-fired power plant with CCS.

It appears to be comparatively easy to deliver CCS with a new power plant at Longyearbyen given the special status of Svalbard and the small scale of the potential CCS plant. This project will generate knowledge of CO_2 capture for new coal-fired power plant and in storage and transport.

11.3 Previous experience and knowledge of CCS

In 2009, Bydrift commissioned a study from COWI, Ecoxy and Norsas into options for future provision of heat and power for the energy works in Longyearbyen [38]. The study showed that the refurbishment of the existing coal plant (new boilers and associated plant) was the least cost option, however a coal with CCS option was estimated to cost just 35% more, and this was also significantly less than the least cost LNG-fired option (although in terms of environmental impact gas was seen as the best option). However the study was a high level one and did not do a thorough assessment of the current plant conditions or a full risk assessment of the options. While, it provides a useful pointer, Bydrift consider that a detailed assessment is needed to confirm the relative merits of a new coal fired station with CCS.

'CO_2-fritt Svalbard, fra visjon til virkelighet' [39] study investigates if Svalbard can be CO_2 free by 2025. The study concluded that it was possible if electricity is generated from coal with 90% capture and storage of CO_2, and with standby and auxiliary power based on biodiesel and hydrogen produced from coal. The study concluded that in the short term, the power station in Longyearbyen should be upgraded and it recommended that the possibility of geological storage of CO_2 should be investigated at Svalbard. In the longer term, it recommend the construction of a new power plant with CO_2 capture in Longyearbyen, the construction of a CO_2 storage facility near Longyearbyen, the establishment of hydrogen production from coal with CO_2 capture near the coal-fired power plant, and the conversion of vehicles and snowmobiles to be powered by hydrogen. Bydrift is investigating the lifetime of the existing power plant to determine if it is cost effective to upgrade the existing plant before construction of a new power plant.

'Energiforsyningen – framtidig energibærer Vurdering av framtidig energisystem i Longyearbyen' (Svalbard Samfunnsdrift AS 2004) [40] study considered various energy sources that may be relevant in the energy system in Longyearbyen to the year 2030. This study considered natural gas, diesel, and wind power. Wind was considered on a fuel displacement basis because of the requirement for firm capacity. This study recommended that the coal-fired power plant should continue its operation.

UNIS CO_2-lab has demonstrated and characterised the reservoir in two steps. Analysis and modelling from one of the wells shows a storage capability of approximately 2 years CO_2 emissions form the power plant. UNIS expect that use of the upper area of the reservoir and horizontal drilling will reveal a larger storage capacity. UNIS have also analysed and characterised the fracture systems of the different layers of the reservoir and identified and tested the cap rocks on top of the reservoir.

12. Yara International

This section is based on an assessment form agreed by Yara International during meetings, presentations and subsequent correspondence during the fourth quarter of 2012. These assessment forms were signed by a Yara representative to declare that to the best of their knowledge the information provided in that form was accurate [41].

Yara International is a global scale fertiliser manufacturer producing a little over 20 million tonnes of nitrogenous fertilisers and associated products and with annual greenhouse gas (GHG) emissions of about 10mt of CO_2 equivalent.

12.1 Yara Porsgrunn

Table 12.1: Yara fact box

Major Activity	Chemical industry, fertiliser
Existing or New / Potential Source	Existing
Estimated future annual emissions of CO_2 from facility	Approximately 825 kt/y with 200 kt/y recovered for use.
Does the owner consider the facility relevant or not relevant for the NCCS study?	Relevant
Technical reasons for relevance decision	• Some of the emission points at Porsgrunn have a relatively high CO_2 concentration making CCS less technically challenging for those streams.
Commercial reasons for relevance decision	• Yara prides itself on being environmentally responsible and want to produce ammonia with greatly reduced CO_2 emissions.
Financial reasons for relevance decision	• Yara is interested in exploring other sales opportunities for CO_2 as it already sells food-grade CO_2.
Deliverability reasons for relevance decision	• Yara has considerable experience in CO_2 conditioning, handling and transport • It understands chemical processes and is comfortable executing large projects, comparable to CCS.

Figure 12.1: Yara, Porsgrunn

Source: Yara

Yara's Norwegian operation, Yara Norge AS, has its production centre in Porsgrunn in Eastern Norway, where it produces around 3Mt of fertiliser. Its emissions are about 825kt CO_2 a year, including some 200kt of near food grade CO_2, which is sold to various customers. CO_2 emissions from the ammonia production represent approximately 60 % of the total GHG emissions from Yara Porsgrunn. The remainder is nitrous oxide (N_2O - laughing gas).

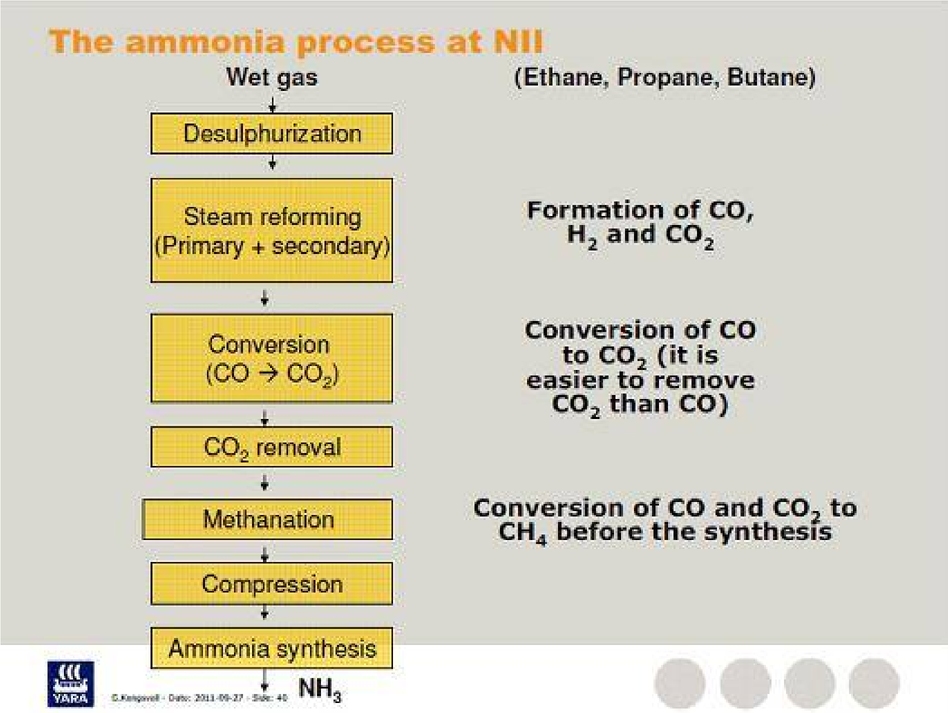
Total GHG emissions at Porsgrunn site have decreased substantially in recent years as Yara has introduced a new catalyst to reduce the emissions of nitrous oxide in ammonia production. Emissions fell by 70% between 2005 and 2011. In terms of net energy efficiency Yara's Porsgrunn ammonia plant is ranked 12th out of 76 European ammonia plants.

Yara has been capturing a small share of its CO_2 emissions (the higher concentrated flow with about 20% CO_2) at the ammonia production process for several decades, with 150-200kt CO_2 a year captured in recent years. This operation is commercially driven with food grade CO_2 being supplied to adjacent industrial facilities and also shipped further afield. In doing this Yara has established considerable experience in CO_2 capture, handling and transport.

Yara is keen to explore decarbonisation initiatives including CCS, though this needs to be assessed on a commercial basis. In this context, Yara is keeping a close watch on developments in the EU ETS (and other carbon tax developments) as well as potential new utilisation options for CO_2.

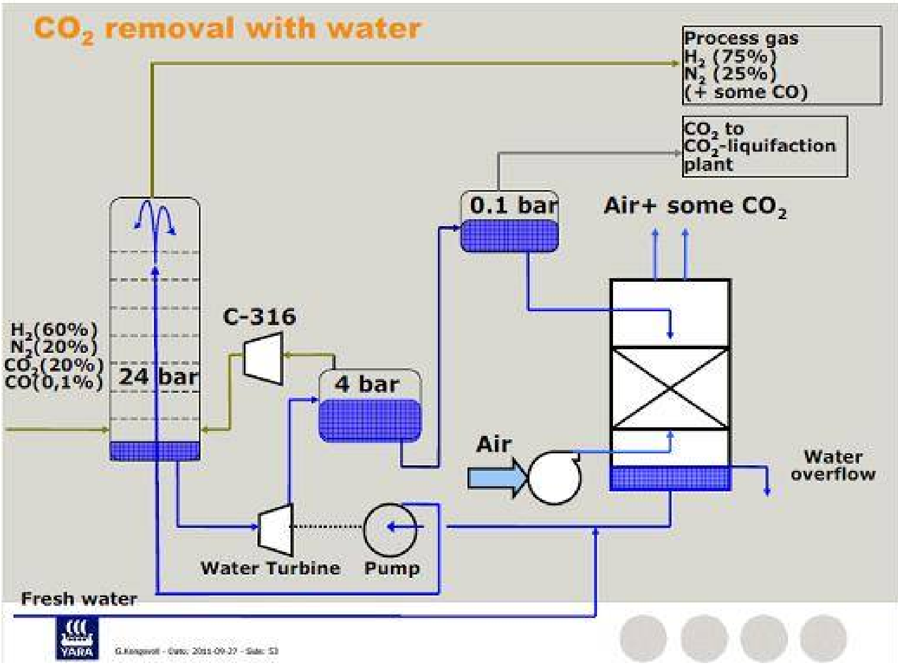
12.1.1 Technical viability

Figure 12.2: The ammonia process at Porsgrunn



Source: Yara

Figure 12.2: CO_2 capture at Porsgrunn



Source: Yara

There are three main emission points at the Porsgrunn site, and each is associated with the ammonia production process. Ammonia is produced by feeding cleaned feedstock of ethane, propane and butane into steam reformers with the addition of steam and air to ‘crack’ the feedstock into CO, H_2 and CH_4. After heat is reclaimed in the convection heating section of the reformers, water shift reactors are used to convert the CO and water into CO_2 and more hydrogen. The CO_2 in the Syngas is then captured using a physical absorption process using purified water. Syngas enters the absorption columns at 24 bar(g) and 20 to 22% CO_2, but leaves with a concentration of <0.2% CO_2. The water CO_2 mixture is then depressurised through a water turbine to 4 bar(g) to release CO_2 with a purity of 95 – 97%, with the remaining 3 – 5% being hydrogen and nitrogen. The water pressure is further reduced to 0.1 bar(g) where the water goes through the air stripping tower to release the remaining CO_2 in the water before being pressurised (through a pump co-driven by the water turbine) to return to the absorption columns.

The first CO_2 emission source is the flue gas exhaust from the steam reformers. The heat required for these reformers comes from the combustion of feedstock or waste fuel gas from a neighbouring industrial facility. This emits around 357 ktonnes of CO_2 per year with a concentration of 13% at a temperature of 220ºC.

The second emission source is the off-gas from the air stripping tower. This releases approximately 224 ktonnes of CO_2 per year with a concentration of at 8%.

The final source is the excess CO_2 that is captured but released before the purification and liquefaction part of the CO_2 capture process. This stream historically releases around 144 kt of CO_2 per year with a very high concentration of CO_2 (95 – 97%). The CO_2 that is not released is purified to food-grade and liquefied (at around 15 bar(g)) to be shipped to businesses such as the soft drinks industry and other industrial applications.

Cooling water, steam and power are all available on site but with unknown capacity to supply additional CCS equipment. A study is required on the existing utility systems to determine spare capacity.

The three CO_2 emission sources are not a significant distance apart and there is a brownfield area adjacent to the ammonia plant that is suitable for additional CCS plant.

12.1.2 Commercial viability

Yara’s Porsgrunn ammonia plant is a ‘swing producer’ in the market, given its high feedstock costs. The plant uses LPG rather than more common and cheaper natural gas feedstock. To meet the fertiliser process requirements, Yara imports ammonia when its own facility is not running. Its CO_2 emissions, which are largely linked to ammonia production, fall when ammonia production decreases. Potentially, there could be circumstances when the site produces no CO_2 and hence has to buy in CO_2 to meet its customer requirements. Porsgrunn has therefore become a distribution centre for CO_2 as well as fertiliser products and by-products.

Given the Porsgrunn site is covered by the EU ETS, Yara Norge is already actively trading in CO_2 to cover its emission needs and sells allowances when it has surpluses. Yara believes that appropriate CO_2 pricing could provide incentives to consider full CCS across the site, but it states that any new obligations taken on by Norwegian emitters should be harmonised with measures across EU and among Norway’s main trading competitors. Without this harmonisation, Norway’s export business will be seriously handicapped. Yara often imports ammonia from countries outside the EU.

The Yara group prides itself on being environmentally responsible and trying to mitigate its carbon emissions. The group markets its fertilisers with a statement that states that its fertiliser has less than 3.6kg of CO_2 per kg of nitrogen. Yara also want to position themselves to produce ammonia with greatly reduced CO_2 emissions. While Yara sees its customers becoming increasingly concerned about embodied carbon, the company thinks it unlikely that customers will pay a premium for the low carbon footprint of the fertiliser.

12.1.3 Financial capability

The capital and operating costs of CCS have not been assessed in any real detail; however the latest study estimated fully built-up costs of €67-89 per tonne of CO_2 depending on fuel costs [42].

Yara states that it typically favours projects with short payback periods preferably in core business areas, i.e. those increasing production or reducing costs. This would present a challenge for any investment in CCS.

Yara already produces significant quantities of food-grade CO_2 which it sells and it is interested in exploring whether there are other sales opportunities (in the chemicals, food and EOR sectors).

12.1.4 CCS deliverability

Yara is committed to exploring GHG reduction options but its deployment will be dependant on a commercial case being presented.

Yara states that promotion of CCS will be dependent on the financial rewards and/or support provided for emission sources considering this option. This may be in the form of carbon prices or in the initial transition phase through other financial support.

The company has been involved in capturing, handling and transporting CO_2 for many years and has not seen any particular issues relating to public acceptance of CO_2 options. Yara actually operate a harbour operation with CO_2 import/export facilities in addition to regular CO_2 shipments by truck.

In terms of organisational capability, Yara has experience in the sector and familiarity with chemical process activities including CO_2 transport and handling and project execution management.

12.1.5 Relevance decision

Yara considers that its Porsgrunn facility is 'Relevant' for further participation in the NCCS Study because some of the emission points at Porsgrunn have a relatively high CO_2 concentration, making CCS less technically challenging for those streams.

The Yara group prides itself on being environmentally responsible and wants to position themselves to be able to produce ammonia with greatly reduced CO_2 emissions.

Yara is interested in exploring other sales opportunities for CO_2 as it already sells food-grade CO_2.

Yara has considerable experience in CO_2 conditioning, handling and transport. It understands chemical processes and is comfortable executing large projects, comparable to CCS.

12.2 Previous experience and knowledge of CCS

Yara refers to the following studies:

- Oppsamling og fangst av CO_2 i avgasser fra NII på Herøya og crackere og dampkjeler på Rafnes, sluttrapport [42].
- CO_2 fangst av utslipp fra Industrianlegg [43].
- Klimakur 2020. Fangst, transport og lagring av CO_2. 17th February 2010 [44].
- Activity report 2: CO_2 Sources in Norway. Report No/DNV Reg No.:2012-0322/13TK0XP-1. Rev 1,2012-03-07 [45].
- Carbon Capture and Storage in the Skagerak/Kattegat Region, Final Report, Tel-Tek February 2012 [46].

Yara Porsgrunn has only provided emissions and technical data for previous studies on CCS at its Porgrunn site but they fully supported the most recent CCS study [46] which estimated the full chain levelised CCS cost at €67-89/t CO_2 equivalent, depending on the energy price assumed. This cost is significantly higher than earlier studies, but Yara believes this represents the most reliable assessment to date. Yara has limited knowledge about technical solutions and investment cost for a CCS plant, or about transportation and storage cost.

A previous study called 'Oppsamling og fangst av CO_2 i avgasser fra NII på Herøya og crackere og dampkjeler på Rafnes, sluttrapport.' [42] investigated the collection and capture of CO_2 exhaust gases from the Hydro Ammonia Plant at Porsgrunn and the crackers and steam boilers at Ineos Noretyl Rafnes. This study concluded that accumulation of CO_2 containing flue gases is feasible both from the ammonia plant at Porsgrunn and from Noretyl Rafnes. Cost estimates were based on rough estimates of required duct lengths for different locations of the system components. At both sites it was assumed that steam was available for the regeneration of the amine solution.

The study concluded:

- There were no savings available by integrating parts of the existing CO_2 capture system with the nearby gasfired power plant;
- That separate CCS systems should be chosen for greater flexibility;
- That capture of the CO_2 from the ammonia facility requires over 100 million NOK higher investment more than at Noretyl, but larger volumes of CO_2 can be captured making the cost per tonne of CO_2 captured significantly lower. About 260 NOK / tonne of CO_2 captured at the ammonia plant against approximately 335 NOK / tonne of CO_2 captured at Noretyl.

Yara considers that this study is now superseded by the Tel-Tek (2012) study [43].

The study 'CO_2 fangst av utslipp fra Industrianlegg' by Tel-Tek [43] concluded that the generic costs associated with CO_2 capture at Yara Porsgrunn were estimated to be 450 NOK [2009] per tonne of CO_2

captured. The estimate did not include costs for utilities or seawater systems. This low capture cost was due to the significant proportion of CO_2 already being captured at Yara Porsgrunn plant. Yara consider that this study's results have again been superseded by the latest Tel-tek report, 2012.

The Klimakur 2020 report 'Fangst, transport og lagring av CO_2' [44] was prepared to investigate the capture, transport and storage of CO_2 (CCS) as a contribution to the reduction of Norwegian CO_2 emissions. This report summarises the possible actions with cost estimates, and provides a basis for discussing the consequences related to the capture, transport and storage of CO_2. This study concluded that the cost of capture, transport and storage was approximately 1,210 NOK per tonne of CO_2 avoided. Yara consider that this study's results have also been superseded by the latest Tel-Tek report in 2012.

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