Project Greensand Phase 1

Risk Register

Risk register, Nini West

Project Greensand Phase 1

Definitions

PROBABILITY "P"		Consequence "C" (% of Managed Value) V.LOW 2	LOW 4	MEDIUM 6	HIGH 8	V. HIGH 10
	VERY HIGH 5 Will probably occur in most circumstances	MEDIUM	HIGH	HIGH	VERY HIGH	VERY HIGH
	HIGH 4 Might occur under most circumstances	LOW	MEDIUM	HIGH	HIGH	VERY HIGH
	MEDIUM 3 Might occur at some time	LOW	LOW	MEDIUM	HIGH	HIGH
	LOW 2 Could occur at some time	VERY LOW	LOW	LOW	MEDIUM	HIGH
	VERY LOW 1 May occur in exceptional circumstances	VERY LOW	VERY LOW	LOW	LOW	MEDIUM

Mitigation Effectiveness "ME"= mp*mc	
90%	Almost always effective
75%	Mostly effective
50%	In the balance
25%	Mostly ineffective
10%	Almost always ineffective

Severity "P*C(1-ME)" (% of Managed Value)
VERY HIGH >40
HIGH 20-39
MEDIUM 10-19
LOW 6-9
VERY LOW 1-5

Table 1 — Criteria description for the identification of threats

No.	Criteria description
1	The site has sufficient capacity to accept required CO_2 injection volumes.
2	The site has sufficient injectivity to allow CO_2 injection at required rates.
3	The site will provide long-term containment, i.e. prevention of leakage at rates or in a total mass sufficient to cause an adverse impact or greater than limits set by local regulations or licence terms.
4	The CO_2 injection operations will not lead to seismicity or earth deformation sufficient to cause an adverse impact.
5	Modelling and cost-effective monitoring are feasible and a) allow timely implementation of appropriate risk treatment, b) provide confidence that the storage site is suitable for continued CO_2 injection operations, and c) ensure that related criteria for site closure will be met [see 10.2 a) to e)].
6	The project operational procedures ensure operational safety and environmental protection, i.e. avoidance of impacts to health, safety and the environment stemming from construction and operation of wells and the project surface infrastructure, and from project interactions with non-project human activities local to the project site and surrounding area.

Elements of Concern (EoC) and thresholds for acceptable/tolerable/unacceptable

EoC no.	Description	Risk evaluation criteria Acceptable	Tolerable	Unacceptable
EoC1	Human Health and Safety			
EoC2	Environment	Unintended leakage requiring rectifying action at appropriate time.	Unintended leakage requiring rectifying action within 1 year	Unintended leakage requiring immediate rectifying action or unstoppable leakage to surface
EoC3	System performance, e.g.			
EoC4	Delay	project delayed less than 12 months	project delayer 1-2 years	project delayed more than 2 years
EoC5	Reputation	Minor comments regarding Consortium	Consortium partners are being questioned about their ability/interest in CO2 storage activities	Consortium partners are no longer able to do CO2 storage activities and/or offshore activities in general due to reputation issues
EoC6	Cost	<10 mio USD	10-50 mio USD	>50 mio USD

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	Risk Identification					Risk Analysis						Risk Evaluation			
Risk ID	Criteria 1-6 (ref ISO27914/2017)	Event	Threat description	Risk Scenario	Impact Phase	EoC	Likelihood (1-5)	Consequence (2-10)	Unmitigated risk level	Uncertainties and uncertainty management	Mitigation of scenario	Control cost - mill DKK	Effectiveness to mitigate probability (mp)	Effectiveness to mitigate Consequence (mc)	Post-treatment level of risk
101	1. The site has sufficient capacity to accept required CO2 injection volumes	Capacity of reservoir is less than estimated	Reservoir compartmentalization	Compartmentalization of reservoir results in lower capacity than estimated	Operation	System performance	2	8	16	• Detailed seismic mapping • History matching with calibrated earth model • Offshore injection test	• Drill more wells	300 mill DKK per well	50%	50%	4
102		Capacity of reservoir is less than estimated	Shallow structural spill point	Inaccurate mapping of spill points results in smaller container size	Operation	System performance	2	8	16	• Detailed mapping of existing seismic • Re-processing of existing seismic • Aquisition of new seismic	• Monitoring of CO2 plume distribution in storage unit - verification of earth model	50 mill DKK per time	50%	50%	4
103		Capacity of reservoir is less than estimated	Reduced acquifer size	Failure to displace fluids into the acquifer could lead to increase in reservoir pressure above acceptable levels, limiting the amount of CO2 that can be injected	Operation	System performance	1	8	8	• Seismic mapping of acquifer • Perform prod/inj tests on existing wells • Dynamic earth modelling	• Pressure release well/period	10 mill DKK	50%	50%	2
104		Capacity of reservoir is less than estimated	Inhomogeneous sweep effect	Reservoir fluid displacement by CO2 less efficient than expected	Operation	System performance	1	4	4	• Core flow experiments • Dynamic earth modelling	• Drill more wells • Change of injection rates • Viscosity chemicals	300 mill DKK per well	30%	30%	2
201	2. The site has sufficient injectivity to allow CO2 injection at the required rates	The planned injection rates cannot be reached	Reservoir injectivity overestimated	The planned injection rates cannot be reached because the injectivity is wrongly assessed because fex. relative permeability of CO2 to oil/water	Operation	System performance	3	4	12	• Further lab work on core data • Reservoir model and history matching • Offsore injection test	• Additional injection well • Include tolerance in operational setup • Intermediate CO2 storage	300 mill DKK per well	30%	30%	6
202		The planned injection rates cannot be reached	Scaling in mid to far wellbore	Formation of scale (iron carbonates) caused by reservoir reaction with CO2 could reduce permeability with time	Operation	System performance	3	6	18	• Further lab tests for scale formation in reservoir conditions (chemical modelling)	• Chemical injection from surface • Drill of new well after some years	50	30%	30%	9
203		The planned injection rates cannot be reached	Salt clogging around wellbore	Dehydration around the wellbore caused by CO2 effect on the brine could lead to precipitation of salt and near wellbore permeability reduction	Operation	System performance	4	6	24	• Lab test for salt formation in reservoir conditions (geochemical modelling) • Analogue assessment • Offsore injection test (?)	• CT intervention - Flushing with water from surface		30%	30%	12
204		The planned injection rates cannot be reached	Swelling of glauconite	Glauconite clay minerals could swell in contact with CO2, leading to a reduction of permeability	Operation	System performance	2	8	16	• Lab test for glauconite behaviour when exposed to CO2 • SCA-11 learnings • Offshore injection test	None		30%	30%	8
205		The planned injection rates cannot be reached	Glauconite mobilization	With high injection rates, glauconite grains could be mobilized leading to local reduction of permeability	Operation	System performance	3	6	18	• Lab test for glauconite behaviour in CO2 flow experiments • SCA-11 learnings • Offshore injection test	None		30%	30%	9
206		The planned injection rates cannot be reached	Reservoir framework deterioration due to cyclic temperature changes	Stress induced by rapid T changes can create fines - reduce reservoir grain size - in turn reducing permeability	Operation	System performance	3	6	18	• Geomechanical modelling	• No cyclic injection • Intermediate storge • Heat up CO2 to higher T • Adjustment of injection rate		30%	30%	9
207		The planned injection rates cannot be reached	Reservoir framework deterioration due to high flow rates	Reservoir loss of structural strength when subject to high injection rates could lead to compaction and reduction of permeability	Operation	System performance	3	6	18	• Perform critical velocity test in lab conditions • Offshore injection test	• Include tolerance in operational setup • Intermediate CO2 storage		30%	30%	9
208		The planned injection rates cannot be reached	Reservor framework deterioration due to chemical reaction to CO2	Dissolution of framework minerals affects the geomechanical stability of the reservoir in a negative manner, reducing its permeability	Operation	System performance	3	6	18	• Perform lab test for geochemical effects • Combine the above with critical velocity tests • Offshore injection test	• Include tolerance in operational setup • Intermediate CO2 storage		30%	30%	9
209		The planned injection rates cannot be reached	Asphaltene precipitation	CO2 strips light HC and precipitates heavy components	Operation	System performance	4	4	16	• Perform lab test for geochemical effects Oil composition analysis • Combine the above with critical velocity tests • Offshore injection test in oil leg	Inject into water leg		30%	30%	8
210		The planned injection rates cannot be reached	Residual CO2 saturation during cyclic injection		Operation	System performance	3	6	18	• Perform lab tests • Offshore injection test	• Include tolerance in operational setup • Intermediate CO2 storage		30%	30%	9
211		The planned injection rates cannot be reached	Clogging by impurities in fluid		Operation	System performance	1	6	6	Specifications of fluid	Filter in topsides (?)		50%	70%	1

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	3. The site will provide sufficient long-term containment														
301		Leakage in non-well area	Natural open faults	Leakage of injected CO_2 via faults into other permeable layers or surface	Operation	Environment	1	10	10	• Subsurface fault mapping • Geomechanical modelling	• Monitoring in wells and sea-bed targeting key risk elements (specific faults for ex.) • Stop injection, Monitor Leak, Update Injection Strategy	5	10%	0%	9
302		Leakage in non-well area	Opening of faults due to chemical effects of CO_2	Interaction with CO_2 could cause reactivation of faults due to drying/swelling, causing leakage through the fault	Operation	Environment	1	8	8	• Lab testing for this effect on the seal rock • Geomechanical model and fault seal analysis • Seismic interpreation	• Monitoring in wells and sea-bed targeting key risk elements (specific faults for ex.) • Stop injection, Monitor Leak, Update Injection Strategy		50%	50%	2
303		Leakage in non-well area	Opening of faults due to P/T effects	P and or T development due to CO_2 injection leass to opening of faults causing leakage through fault into permeable layers or surface	Operation	Environment	1	8	8	• Subsurface fault mapping • Geomechanical modelling	• Monitoring in wells and sea-bed targeting key risk elements (specific faults for ex.) • Stop injection, Monitor Leak, Update Injection Strategy		50%	50%	2
304		Leakage in non-well area	Fracturing of reservoir and caprock	Injection rates lead to reservoir pressures above frac pressure of reservoir and caprock, leading to leakage from storage complex	Operation	Environment	3	6	18	• Reservoid modelling • Geomechanical modelling	• Monitoring in wells and sea-bed targeting key risk elements (specific faults for ex.) • Stop injection, Monitor Leak, Update Injection Strategy		50%	50%	5
305		Leakage in non-well area	Leakage via spill-point	Reservoir geometry wrongly assessed or movement of the CO_2 plume wrongly assessed could lead to leakage via structure's spill-point	Operation	Environment	2	8	16	• Seismic mapping • Reservoir modelling	• Monitoring of CO_2 plume distribution in storage unit		50%	50%	4
306		Leakage to Nini Main area	Leakage via spill-point	Reservoir geometry wrongly assessed or movement of the CO_2 plume wrongly assessed could lead to leakage via structure's spill-point into Frigg sandstones in the area around NA-7	Operation	Environment	1	6	6	• Seismic mapping • Reservoir modelling	• Monitoring of CO_2 plume distribution in Frigg sandstones in the NA-7 area Assessment of NA-7 Integrity and potential P&A NA-07		50%	50%	2
307		Leakage to Nini Main area	Leakage via spill-point followed by leakage via NA-7 wellbore	CO_2 entering wellbore in the NA-7 area leading to potentially leakage to producing Hermod reservoir zones in Nini Main	Operation	Environment	1	8	8	COPY MILLING MITIGATION AS NA3 AND NA5	Monitoring in well. Integrety of existing bridge plug in NA-7 between Frigg and Hermod reservoir sections		75%	75%	1
308		Leakage of oil outside the structural trap	Residual oil saturation is underestimated	Oil leakage due to CO_2 injection and oil displacement	Operation	Environment	4	4	16	• Detailed modeling	• Monitor oil leakage outside of storage complex		50%	50%	4
309		Leakage via abandonned legacy exploration well	P&A of exploration/appraisal well Nini-4/4A not suitable for CO_2 storage	Abandonment plugs for reservoir sections in Nini-4 and in Nini-4A are not able to maintain integrity permanently when exposed to a high CO_2 concentration. While CO_2 may not escape to the atmosphere, it may be able to penetrate unintended formations.	Operation	Environment	3	2	6	Cement integrity E C3 F1	Material testing of cement types in CO_2-rich reservoir conditions Baseline and periodic monitoring of well location Assess the option of well tie-in/re-entering operations (e.g. Aquaterra technology)		0%	50%	3
310						Environment	3	8	24	Cement integrity	Assess the option of well tie-in/re-entering operations (e.g. Aquaterra technology)	X	25%	0%	18
311		Leakage via abandoned legacy wells (yet to be abandonned)	Existing annular cement in NA-05 and NA-03B not suitable for permanent abandonment barrier purpose	Cement is either poor and/or is not suitable for a CO_2 environment. Section milling to open up to bare rock and placement of new, CO_2 compatible cement plug in openhole.	Pre-operation	Environment	3	6	18		10 days of section milling and placing new cement plug as part of P&A in both wells (2wells x30 mmDKK). cost covered in other mitigation steps	60	75%	75%	1
312		Leakage via abandoned legacy wells during CO_2 injection	Corrosion of tubulars in legacy wells NA-03B and NA-05	CO_2 corrodes the steel tubulars in legacy wells and create a leak path upwards (steel pipe between annular cmt and cmt plug, corrodes away over time). Corrosion risk is rather unknown over extended period of time.	Operation	Environment	3	8	24	Materials assessment, upfront engineering and planning	CO_2 injection assumed coming to a halt. Leaking well has to be re-entered to remove and re-instate permanent P&A barriers. Do not abandon wells at seabed but maintain access into well from platform.	60	75%	75%	2
313		Leakage via abandoned legacy wells during CO_2 injection	Chemical degradation of cement in legacy wells NA-03B and NA-05	Annular cement loses their barrier integrity by degradation from being exposed to high concentration of CO_2, and a leak path upwards is created. Chemical degradation of cement risk is rather unknown over extended period of time	Operation	Environment	3	8	24				75%	75%	2

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401	4. the CO_2 injection operation will not lead to seismicity or earth deformation sufficient to cause an adverse impact	Injection induced seismic event	CO_2 injection re-activates fault activity leading to seismic event/s	Increase in reservoir pressure due to injection of CO_2 could lead to re-activation of faults and generation of seismic events which could have a negative effect on nearby infrastructure	Operation	Human health and safety	1	8	8	Geomechanical modelling	Monitoring - Passive sensors in sea-bed.		50%	50%	2
501	5. Modelling and cost-effective monitoring are feasible and 1) allow timely implementation of appropriate risk treatment, ii) provide confidence that the storage site is suitable for continued CO_2 injection operation, III) ensure that related criteria for site closure will be met	Failure of monitoring device in the well bore during injection phase	Gauge or other electronic equipment busted	temperature or stress effects in the well bore impacts measurement resulting in interruption of injection operation (downtime)	Operation	Delay	3	4	12	Assess market and analogue projects	Use simple gauges / devices preferrably without electronics, e.g. fibre optics, minimize operational downtimes Redundancy well or cooperation (spare storage) with Northern Light Implement redunancies if possible. Test monitoring concept in Phase 2 Well workover		90%	90%	0
502		Failure of monitoring device on Topside / Riser during injection phase	CO_2 monitoring in air or P/T/Flowrate device busted	temperature or stress effects in the flowline or well head impact measurement resulting in interruption of injection operation (downtime)	Operation	Delay	3	2	6	Assess market and analogue projects	Use simple gauges / devices preferrably without electronics, e.g. fibre optics, minimize operational downtimes Redundancy well or cooperation (spare storage) with Northern Light Implement redunancies if possible	50	90%	90%	0
503		Failure of monitoring device on sea floor / in water column during injection phase	Geophone / hydrophone or power supply / data communication busted	Fishery activiy / collision or driftwood or simply mechnical / electronical failure resulting in interruption of injection operation	Operation	Delay	2	4	8	Regular maintenance and inspection, notify safety zone	Use back up systems and battery / data buffer / manual data read out to minimize operational downtimes. Redundancy well or cooperation (spare storage) with Northern Light	20	90%	90%	0
504		Failure of monitoring device in post-injection phase	Any of the post-injection monitoring setup busted	Long term lifetime expectation not given or mechanical / electronic failure	Post-Operation	Reputation	3	4	12	Regular maintenance and inspection	Acquire conventional seismic on demand	100	90%	90%	0
505		Resolution of seismic monitoring data not sufficient to update reservoir model	Plume migration cannot be detected due to lack of impedance contrast or resolution of the monitoring seismic	Undetected migration updip into faults / leak points	Operation	Reputation	2	4	8	Test monitoring concept in Phase 2	Acquire conventional seismic on demand	100	90%	90%	0
601	6. Operational procedures ensure operational and environmental safety	Logistical challenges regarding discharge	Discharge longer than planned due to well performance	The discharge at the site exceeds the planned logistical setup, as the well cannot take the expected volume	Operation	Cost	2	8	16		Use larger ships to reduce influence of hoo-up time. Drill additional well	500	90%	90%	0
602		Logistical challenges regarding discharge	Discharge takes longer than planned due to weather conditions	The discharge at the site exceeds the planned logistical setup, as weather conditions are poorer than modelled	Operation	Cost	3	2	6	Dedicated dialogue and support to relevant decisions makers	Include an additional ship.	1	50%	10%	3
603		Topside does not comply with requirements (temperature/pressure/rates/...)	6' riser can not be used	Topside does not comply with requirements because 6' riser can not be used	Operation	Cost	2	8	16	Current state of 6 " riser not known.	Inspect riser, NDT or similiar.	1	75%	90%	0
604		Capacity of reservoir is less than estimated	Pressure and temperature drop at the wellhead related to prod cycle.	Topside does not comply with requirements because if challenges related to preassure drop at wellhead during production cycle	Operation	Cost	2	6	12		Design operation procedures to avoid risk. Must be in place prior to pilot test. Perform stress analysis study covering relevant scenarios		75%	75%	1
605		Topside does not comply with requirements (temperature/pressure/rates/...)	Flow assurance. Corrosion	Integrity of installation, Equipment	Operation	Cost	2	8	16	Verify material selection suitable for application.	Replacement of equipment, and establish operational philosophy	5	75%	90%	0
606		Topside does not comply with requirements (temperature/pressure/rates/...)	Flow Assurance, Pressure control	Operation potential non feasible	Operation	Cost	2	8	16	Establish model to evaluate pressure in different operational scenarios	Development of operation envelope	2	75%	90%	0
607		Troublesome well conversion to CO_2 injector	Drilling and completing a new well as a slot recovery of NA-03B re-using the 13-3/8" casing for sidetracking, not feasible due to excessive wear or other integrity issue. Need to kick off shallower and include new casing section.	Increased well construction complexity. Time and cost overruns	Pre-operation	Cost	3	8	24	Existing casing and cement condition. Drilling, casing, cementing and wellbore stability risks	Prepare for shallower sidetracking as part of more detailed well planning	50	0%	75%	6

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	7 Commercial risks														
701		Storage Site Permit not ready in time	Authority requirements not being honoured by project. Storage Site being rejected by emitter. Pre-FEED and FEED costs not being paid	The Storage Site is not ready in due time	Pre-operation	Delay	2	6	12		Dedicated Project Setup required after Satement of Endorement	1	75%	10%	3
702		The Storage Site is not ready in due time	Commercial Contracts not being established, resulting in project delay	Delay in FID of 1 year	Pre-operation	Delay	3	2	6		Commercial draft agreements needs to drafted after Statement of Endorsement	1	50%	10%	3
703		The Storage Site is not ready in due time	Financial capability of consortium members. Storage Site being rejected by emitter. Pre-FEED and FEED costs not being paid	Delay in FID of 1 year	Pre-operation	Delay	3	6	18		CEO level Board to be established Q1 2022	1	50%	10%	8
704		Lack of regulatory support	Danish Regulators and Authorities fails to support CO2 storage with the adequate framework		Pre-operation	Delay	4	4	16	Keep close dialogue with Regulators and Authorities	Create flexibility in project schedule to allow for postponment		50%	50%	4
705		Lack of value chain alignment	Lack of full-value chain alignement/CO2 emitter not ready for 2025		Pre-operation	Delay	4	2	8	The final spending of construction CAPEX to await signature on a CO2 Storage Contract			50%	10%	4
706		Failure to create sustainable business model	Competing CO2 Storage Sites offers storage at lower cost		Pre-operation	Cost	3	4	12	Constantly focus on delivering cost-effective CO2 storage in Greensand			75%	10%	3
707		Failure to create sustainable business model	No available funding beyond the 0.9 mtpa market-based pool		Pre-operation	Cost	3	4	12	Keep close dialogue with Regulators and Authorities . Keep focus on international emitters			75%	10%	3
708		Failure to create sustainable business model	International 'event' from a CO2 storage site stops the forward investments in CO2 storage		Pre-operation	Cost	1	4	4	Keep close dialogue and knowledge sharing with international project and service companies to gain insight and share observations			50%	10%	2

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Heatmap

Probability "P"		Consequence "C" (% of Managed Value): V. LOW 2	LOW 4	MEDIUM 6	HIGH 8	V. HIGH 10
	VERY HIGH 5 Will probably occur in most circumstances					
	HIGH 4 Might occur under most circumstances	705	209, 308, 704	203		
	MEDIUM 3 Might occur at some time	309, 502, 602, 702	201, 501, 504, 706, 707	202, 205, 206, 207, 208, 210, 304, 311, 703	310, 312, 313, 607	
	LOW 2 Could occur at some time		503, 505	604, 701	101, 102, 204, 305, 601, 603, 605, 606	
	VERY LOW 1 May occur in exceptional circumstances		104, 708	211, 306	103, 302, 303, 307, 401	301

Severity Post Mitigation	
VERY HIGH	
HIGH	
MEDIUM	203, 310
LOW	201, 202, 204-210, 301, 607, 703
VERY LOW	101-104, 211, 302-309, 311-313, 401, 501-505, 601-606, 701-702, 704-708

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Heatmap

EoC no.	Description	Risk evaluation criteria (unmitigated)		
		Acceptable	Tolerable	Unacceptable
EoC1	Human health and safety			
		401	–	–
EoC2	Environment	Unintended leakage requiring rectifying action at appropiate time	Unintended leakage requiring rectifying action whithin 1 year	Unintended leakage requiring immediate rectifying action or unstoppable leakage to surface
		301-303, 306, 307, 309	304, 305, 308, 310-313	–
EoC3	System performance			
		103, 104, 201, 211	101, 102, 202-210	–
EoC4	Delay	Project delay <12 months	Project delay 1-2 years	Project delay >2 years
		501-503, 701, 702, 705	703, 704	
EoC5	Reputation	Minor comments regarding Consortium	Consortium partners are being questioned about their ability/interest in CO2 storage activities	Consortium partners are no longer able to do CO2 storage activities and /or offshore activiteis in general due to reputation issues
		504, 505	–	–
EoC6	Cost	<10 mio USD	10-50 mio USD	>50 mio USD
		602,604, 706-708	601, 603, 605-607	–