

Project Greensand Phase 1

Monitoring Plan

Monitoring plan, Nini West

Project Greensand Phase 1

Overview



PROJECT GRE₂NSAND

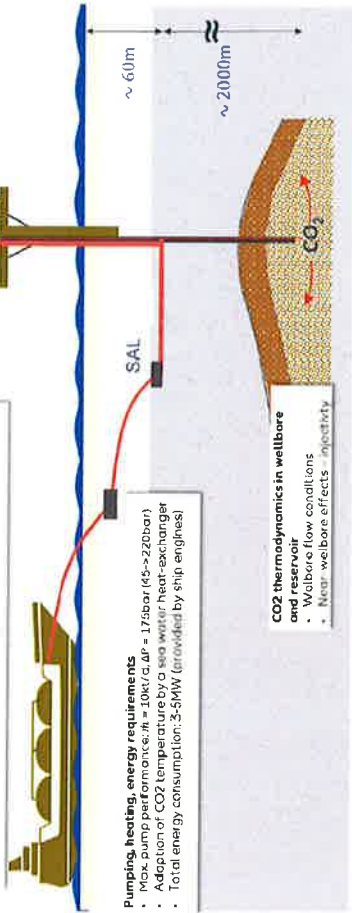
MONITORING FLOWLINE

CO₂ thermodynamics at the WH

- Well head (WH) at the platform → regulates the CO₂ injection stream via choke
- Heater required to warm up choked CO₂

Ship design parameters:

- Transport conditions: vessel, T₁=10°C, P=45 Bar → Higher energy efficiency compared to the usual set up, T=40°C, P=10 bar
- Zero-emissions transport → all CO₂ being released as well as engine exhaust fumes are captured
- CO₂ mass to be stored ≈ 12kt



Downhole measurements of interest:

- Temperature
- Pressure
- Flow rate
- CO₂ emplacement (borehole seismic methods)

GREENSAND PHASE 1

| T ₂₋₁₀ | EU Directive Requirements | Technology | Location and spatial sampling | Sampling frequency |
|-------------------|---------------------------|------------|-------------------------------|--------------------|
| T ₁₋₁₀ | EU Directive Requirements | Technology | Location and spatial sampling | Sampling frequency |
| T ₀ | EU Directive Requirements | Technology | Location and spatial sampling | Sampling frequency |

EU Directive Requirements

- Fugitive emissions of CO₂ at the injection facility
- CO₂ volumetric flow at injection wellheads
- CO₂ P&T at injection wellheads
- Chemical analysis of the injected material
- Reservoir P&T
- Leak to seabed/water body
- Subsurface (plume) migration
- Seismicity

Standard

Site specific – link to risk-register

| No. | Reference |
|-----|--|
| [1] | Implementation of Directive 2009/31/EC on the Geological Storage of Carbon Dioxide; Guidance Document 2; Characterisation of the Storage Complex, CO ₂ Stream Composition, Monitoring and Corrective Measures (p. 94) -> also referred to as the EU Directive Guideline |

1. Fugitive emissions of CO2 at the injection facility (and vessel + SAL)

Time period: T₀ (pre-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|--|--|----------------------------------|--------------------|-------------|
| Fugitive emissions of CO ₂ at the injection facility (and vessel + SAL) | Pressure and temperature gauges | ship, wellhead, connection pipes | continuous | intended |
| | Laser technique for CO ₂ -detection | ship, wellhead, connection pipes | continuous | intended |
| | Passive acoustics (geophones, -> UoS) | water column | baseline | alternative |
| | GHR Lidar Dial measurements (-> DFM& NLIR) | ship (DNMI), facility | baseline | alternative |
| | Lander (-> NOC) (pH-detecter) | seafloor (SAL) | baseline | alternative |

Time period: T₁ to T₁₀ (injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|--|--|-------------------------------|-----------------------------|-------------|
| Fugitive emissions of CO ₂ at the injection facility (and vessel + SAL) | Pressure and temperature gauges | wellhead, connection pipes | continuous | intended |
| | Laser technique for CO ₂ -detection | wellhead, connection pipes | continuous | intended |
| | Passive acoustics (geophones, -> UoS) | water column | injection phase, continuous | alternative |
| | GHR Lidar Dial measurements (-> DFM& NLIR) | ship (DNMI), facility | injection phase, continuous | alternative |
| | Lander (-> NOC) | seafloor (SAL) | injection phase, continuous | alternative |

Time period: T_{>10} (assumption: well not yet abandoned); (post-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | Status | Remark WD_INEOS |
|--|---------------------------------|-------------------------------|--------------------|----------|-----------------|
| Fugitive emissions of CO ₂ at the injection facility (and vessel + SAL) | Pressure and temperature gauges | wellhead, connection pipes | continuous | intended | |

Time period: T_{>>10} to T₄₀ (assumption: abandonment); (post-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | Status | Remark WD_INEOS |
|--|-------|-------------------------------|--------------------|--------|-----------------------------------|
| Fugitive emissions of CO ₂ at the injection facility (and vessel + SAL) | --- | --- | --- | --- | Equipment would be decommissioned |

REMARK:

1) Each section is labeled as a 'STAND-ALONE CHARACTER: (causing repetition of devices)



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2. CO2 volumetric flow at injection wellhead

Time period: T₀ (pre-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|---|-------------------------------------|-------------------------------|--------------------|----------|-----------------|
| CO ₂ volumetric flow at injection wellhead | Pressure gauges -> permanent gauges | wellhead | continuous | intended | |
| | Temperature detector | wellhead | continuous | intended | |

Time period: T_{1 to T₁₀} (injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|---|-------------------------------------|-------------------------------|--------------------|----------|---|
| CO ₂ volumetric flow at injection wellhead | Pressure gauges -> permanent gauges | wellhead | continuous | intended | |
| | Temperature detector | wellhead | continuous | intended | |
| | Flow meter | wellhead | injection phase | intended | Fiscal meter on platform, reference meter on vessel; That will be a parameter in the fiscal model (include heel). |

Time period: T_{>10} (assumption: well not yet abandoned) (post-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|---|-------------------------------------|-------------------------------|--------------------|----------|-----------------|
| CO ₂ volumetric flow at injection wellhead | Pressure gauges -> permanent gauges | wellhead | continuous | intended | |
| | Temperature detector | wellhead | continuous | intended | |

Time period: T_{>>10} to T₄₀ (assumption: abandonment); (post-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|---|-------|-------------------------------|--------------------|--------|
| CO ₂ volumetric flow at injection wellhead | --- | --- | --- | --- |

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3. CO2 pressure and temperature at injection wellhead

Time period: T₀ (pre-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|---|---|--|--------------------|-------------|
| CO ₂ pressure and temperature at injection wellhead | Pressure gauges -> permanent gauges | Injection facility, wellhead | continuous | intended |
| | Temperature detector | Injection facility, wellhead | continuous | intended |
| wellbore (and well integrity) CO ₂ pressure and temperature | Permanent Downhole Pressure Gauge (PDG) | Downhole injection well, at reservoir interval | continuous | intended |
| | Permanent Downhole Temperature Gauge | Downhole injection well, at reservoir interval | continuous | intended |
| | Distributed Temperature Sensing Systems (DTS) | Injection well, along wellbore | optional/ baseline | alternative |
| | Distributed Acoustic Sensing Systems (DAS) | Injection well, along wellbore | optional/ baseline | alternative |

Time period: T_{1 to T₁₀} (injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|---|---|--|--|----------------------------|
| CO ₂ pressure and temperature at injection wellhead | Pressure gauges -> permanent gauges | Injection facility, wellhead | continuous | intended |
| | Temperature detector Flow meter | Injection facility, wellhead wellhead | continuous injection phase | intended intended |
| wellbore (and well integrity) CO ₂ pressure and temperature | Permanent Downhole Pressure Gauge (PDG) | Downhole injection well, at reservoir interval | continuous injection stage; later stage: Essential for reservoir simulation. | intended |
| | Permanent Downhole Temperature Gauge | Downhole injection well, at reservoir interval | continuous | intended |
| | Distributed Temperature Sensing Systems (DTS) Distributed Acoustic Sensing Systems (DAS) | Injection well; along wellbore Injection well; along wellbore | optional/periodical (re-start injection/ 1/2 year) optional/periodical | alternative alternative |

REMARK:

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3. CO2 pressure and temperature at injection wellhead

Time period: T_{>10} (assumption: well not yet abandoned); (post-injection phase)

| Directive 2009/31/EC [1] | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|---|---|--|---------------------------|----------------------|
| CO ₂ pressure and temperature at injection wellhead | Pressure gauges -> permanent gauges Temperature detector | Injection facility, wellhead Injection facility, wellhead | continuous continuous | intended intended |
| wellbore (and well integrity) CO ₂ pressure and temperature | Permanent Downhole Pressure Gauge (PDG) | injector well, downhole at reservoir interval | continuous | intended |
| | Permanent Downhole Temperature Gauge | injector well, downhole at reservoir interval | continuous | intended |
| | Distributed Temperature Sensing Systems (DTS) | injection well; along wellbore | optional/periodical (tbd) | alternative |
| | Distributed Acoustic Sensing Systems (DAS) | injection well; along wellbore | optional/periodical (tbd) | alternative |

Time period: T_{>10} to T₄₀ (assumption: abandonment); (post-injection phase)

| Directive 2009/31/EC [1] | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|---|-------|-------------------------------|--------------------|--------|
| CO ₂ pressure and temperature at injection wellhead | --- | --- | --- | --- |
| wellbore (and well integrity) CO ₂ pressure and temperature | --- | --- | --- | --- |

REMARK:

1) Each section is labeled as a 'STAND-ALONE CHARACTER: (causing repetition of devices)



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4. Chemical analysis of the injected material

Time period: T₀ (pre-injection phase)

| Directive 2009/31/EC ^[1] | | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|---|---------------------------|---------|-------------------------------|--------------------|---|-----------------|
| 4. Chemical analysis of the injected material | Analytical Sensor Systems | onshore | per each ship transfer | intended | Recommend onshore certificate, offshore analysis not feasible QC recommended (onshore) e.g. optical sensor, GC-measurements | |
| | Analytical Sensor Systems | onshore | tbd | alternative | | |

Time period: T_{1 to 10} (injection phase)

| Directive 2009/31/EC ^[1] | | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|--|---------------------------|----------|---|--------------------|---|-----------------|
| Chemical analysis of the injected material | Analytical Sensor Systems | onshore | per each ship transfer, injection phase | intended | Recommend onshore certificate, offshore analysis not feasible QC recommended (onshore) e.g. optical sensor, GC-measurements | |
| | Analytical Sensor Systems | offshore | tbd | alternative | | |

Time period: T₁₋₁₀ (assumption: well not yet abandoned); (post-injection phase)

| Directive 2009/31/EC ^[1] | | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|--|--|-------|-------------------------------|--------------------|--------|-----------------|
| Chemical analysis of the injected material | | | | | | |

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5. Reservoir pressure and temperature (CO₂ phase behaviour)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|--|---|--|--------------------|-------------|
| Reservoir pressure and temperature (CO ₂ phase behaviour) | Permanent Downhole Temperature Gauge (PDG) | Downhole injection well, at reservoir interval | continuous | intended |
| | Permanent Downhole Pressure Gauge (PDG) | Downhole injection well, at reservoir interval | continuous | intended |
| | Distributed Temperature Sensing Systems (DTS) | Injection well; along wellbore | optional/ baseline | alternative |
| | Simulation (PVT/EOS...Equation of Si--- | | continuous | intended |

Time period: T_{1 to T10} (Injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|--|---|--|---|-------------|
| Reservoir pressure and temperature (CO ₂ phase behaviour) | Permanent Downhole Pressure Gauge (PDG) | Downhole injection well, monitoring wells, at reservoir interval | continuous | intended |
| | Permanent Downhole Temperature Gauge (PDG) | Downhole injection well, at reservoir interval | continuous | intended |
| | Distributed Temperature Sensing Systems (DTS) | Injection well, along wellbore | optional/ periodical (re-start injection/ 1/2 year) | alternative |
| | downhole fluid sampling | Injection well, all spots of interest | optional/ periodical (re-start injection) | alternative |
| | Simulation (PVT/EOS...Equation of Si--- | | continuous | intended |

Time period: T_{1 to T10} (assumption: well not yet abandoned); (post-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|--|--|--|--------------------|----------|
| Reservoir pressure and temperature (CO ₂ phase behaviour) | Permanent Downhole Pressure Gauge (PDG) | Downhole injection well, monitoring wells, at reservoir interval | periodical (tbd) | intended |
| | Permanent Downhole Temperature Gauge (PDG) | Downhole injection well, at reservoir interval | periodical (tbd) | intended |
| | Simulation (PVT/EOS...Equation of Si--- | | continuous | intended |

Time period: T_{1 to T10} to T₄₀ (assumption: abandonment); (post-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS |
|--|---|-------------------------------|--------------------|----------|
| Reservoir pressure and temperature (CO ₂ phase behaviour) | Simulation (PVT/EOS...Equation of Si--- | | continuous | intended |

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6. Location and migration paths of CO₂ (subsurface, surface)

Time period: T₀ (pre-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS | |
|--|---|---|--------------------|-------------|--|---|
| 6. Location and migration paths of CO ₂ (subsurface, surface) | Bottom Hole Pressure (BHP) -gauge by intervention using an adequate logging tool to obtain the required information (-> standard/specialized logging tools) | Injection well | continuous | intended | essential for simulation Cement Bond Logging; Multifinger Caliper ; Variable Density Sonic Logging (VDSL); Ultra Sonic Imaging tool (USIT) ; Electromagnetic imaging... e.g. Cement Bond Logging; Variable Density Sonic Logging (VDSL); Ultra Sonic Imaging tool (USIT) ; | |
| | by intervention using an adequate acoustic logging tool (cement issues) | Injection well (problem specific) | tbd | alternative | | |
| | Pressure testing of annulus | Injection well (problem specific) | tbd | alternative | | |
| | Leakoff test/FIT | Injector / monitoring wells; preferably at any well in CO ₂ contact injection well | baseline | intended | | |
| | Seismic spot imaging | water surface; all spots of interest (Siri fairway) seafloor -> aquifers | baseline | intended | | |
| | Micro-seismicity | Faults & Fractures | --- | intended | | |
| | Streamer 3D seismic | water surface; all spots of interest (Siri fairway) | --- | alternative | | |
| | using an adequate logging tool to obtain the required information wrt saturation near wellbore) | | optional/ | alternative | | |
| | Simulation | | baseline | intended | | |
| | Eddy Covariance (flux concentration measurement) | water column, flux measurement | history match | intended | | Risk register: no potential high leakage detected; tools are denoted as alternative |
| | ROV (Remotely Operating Vehicle) - visual inspection | water column | baseline, | | | |
| | Lander/in-situ benthic chambers -> equipped with chemical sensors (lab-on-chip chemical sensors for pH, Optode optical sensors) | benthic, at risk areas (wells, seismic anomalies) | baseline | | | |
| | Monitoring bubbles in the water column (sonar technology); mounted on lander | water column (in risk areas) | baseline | | | |
| | Conductivity-Temperature-Depth (CTD) Casts | water column (in risk areas) | baseline | | | |
| | Lander- Acoustic (passiv) | water column | baseline | | | |
| | Sediment microprofiler | seafloor and sub-seafloor, insitu-profile | baseline | | | |
| | Autonomous Underwater Vehicle | seafloor and sub-seafloor | baseline | | | |
| Chirp Profiler (AUV) | | baseline | | | | |

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6. Location and migration paths of CO2 (subsurface, surface)

Time period: T_{1 to T10} (injection phase)

| EU Directive MANDATORY ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD INEOS |
|--|---|--|----------------------|---|---|
| location and migration paths of CO2 (subsurface, surface) | Bottom Hole Pressure (BHP) -gauge | Injection well | continuous | intended | essential for simulation |
| | by intervention using an adequate logging tool to obtain the required information (-> standard/specialized logging tools) | Injection well (problem specific) | tbd | intended | Cement Bond Logging; Multifinger Caliper; Variable Density Sonic Logging (VDSL); Ultra Sonic Imaging tool (USIT) ; Electromagnetic imaging, Distributed Acoustic Sensing Systems (DAS), Distributed Temperature Sensing Systems (DTS) |
| | Seismic spot imaging | water surface; all spots of interest (Siri fairway) seafloor -> aquifers | continuous (monthly) | intended | to be tested in phase 2 |
| | Micro-seismicity | Faults & Fractures | continuous | intended | would be included in spot imaging |
| | Streamer 3D seismic | water surface; all spots of interest (Siri fairway) | every 5 years | alternative | |
| | Simulation | | adapted to outcome | intended | |
| | using adequate logging tool to obtain the required information wrt saturation near wellbore) | | optional | alternative | |
| | Eddy Covariance (flux concentration measurement) | water column, flux measurement | continuous, tbd | | |
| | ROV (Remotely Operating Vehicle) - visual inspection | water column | continuous | | |
| | Lander/in-situ benthic chambers -> equipped with chemical sensors (lab-on-chip chemical sensors for pH, Optode optical sensors) | benthic, at risk areas (wells, seismic anomalies) | continuous | | |
| Monitoring bubbles in the water column (sonar technology); mounted on lander | water column (in risk areas) | tbd | alternative | Risk register: no potential high leakage detected; tools are denoted as alternative | |
| Conductivity-Temperature-Depth (CTD) Casts | water column (in risk areas) | tbd | | | |
| Lander- Acoustic (passiv) | water column | tbd | | | |
| Sediment microprofiler | seafloor and sub-seafloor, insitu-profile | continuous | | | |
| Autonomous Underwater Vehicle | seafloor and sub-seafloor | continuous | | | |
| Chirp Profiler (AUV) | | | | | |

REMARK:

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6. Location and migration paths of CO2 (subsurface, surface)

Time period: T₁₋₁₀ (assumption: well not yet abandoned); (post-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|---|--|--|--------------------|-------------|--|
| location and migration paths of CO2 (subsurface, surface) | Bottom Hole Pressure (BHP) -gauge Injection well | | continuous | intended | essential for simulation |
| | by intervention using an adequate logging tool to obtain the required information (-> standard/specialized logging tools) | Injection well (problem specific) | tbd | intended | Cement Bond Logging; Multifinger Caliper; Variable Density Sonic Logging (VDSL); Ultra Sonic Imaging tool (USIT); Electromagnetic imaging, Distributed Acoustic Sensing Systems (DAS), Distributed Temperature Sensing Systems (DTS) |
| | Pressure testing | Injection well | tbd | intended | |
| | Seismic spot imaging | water surface; all spots of interest (Siri fairway) seafloor -> aquifers | tbd | intended | to be tested in phase 2 |
| | Streamer 3D seismic simulation | water surface; all spots of interest (Siri fairway) seafloor -> aquifers | every 5 year | alternative | |
| | Eddy Covariance (flux concentration measurement) | water column, flux measurement | adapted to outcome | intended | |
| | ROV (Remotely Operating Vehicle) - visual inspection | water column | continuous, tbd | | |
| | Lander - in situ chemical sensors - > equipped with chemical sensors (lab-on-chip chemical sensors for pH, Optode optical sensors) | benthic, at risk areas (wells, seismic anomalies) | continuous | | |
| | Monitoring bubbles in the water column (sonar technology); mounted on lander | water column (in risk areas) | tbd | | Risk register: no potential high leakage detected; tools are denoted as alternative |
| | Conductivity-Temperature-Depth (CTD) Casts | water column (in risk areas) | tbd | | |
| Lander - Acoustic (passiv) | water column | tbd | | | |
| Sediment microprofiler | seafloor and sub-seafloor, insitu-profile | continuous | | | |
| Autonomous Underwater Vehicle Chirp Profiler (AUV) | seafloor and sub-seafloor | continuous | | | |

REMARK:

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6. Location and migration paths of CO₂ (subsurface, surface)

Time period: T>>10 to T₄₀ (assumption: abandonment); (post-injection phase)

| Directive 2009/31/EC ^[1] | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|---|---|--|--------------------|-------------|-------------------------|
| location and migration paths of CO ₂ (subsurface, surface) | Seismic spot imaging | water surface; all spots of interest (Siri fairway) seafloor -> aquifers | not yet regulated | intended | to be tested in phase 2 |
| | Streamer 3D seismic | water surface; all spots of interest (Siri fairway) seafloor -> aquifers | not yet regulated | alternative | |
| | simulation | | adapted to outcome | intended | |
| | Eddy Covariance (flux concentration measurement) | water column, flux measurement | continuous, tbd | | |
| | ROV (Remotely Operating Vehicle) - <u>visual inspection</u> | water column | continuous | | |
| | Lander/in-situ benthic chambers -> equipped with chemical sensors (lab-on-chip chemical sensors for pH, Optode optical sensors) | benthic, at risk areas (wells, seismic anomalies) | continuous | | |
| | Monitoring bubbles in the water column (sonar technology): mounted on lander | water column (in risk areas) | tbd | | |
| | Conductivity-Temperature-Depth (CTD) Casts | water column (in risk areas) | tbd | | |
| | Lander- <u>Acoustic</u> (passiv) | water column | tbd | | |
| | Sediment microprofiler | seafloor and sub-seafloor, insitu-profile | continuous | | |
| Autonomous Underwater Vehicle Chirp Profiler (AUV) | seafloor and sub-seafloor | continuous | | | |

REMARK:

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7. CO2 plume

Time period: T₀ (pre-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|---|--|--|--------------------|-------------|-------------------------|
| CO ₂ plume (pressure volume and areal/vertical behaviour) purpose: refinement of 3D simulation | Permanent Downhole Pressure Gauge (PDG) | Downhole injection well; at reservoir interval | continuous | intended | |
| | by intervention using adequate logging tool to obtain the required information (-> standard/specialized logging tools) | Injection well (problem specific) | periodically | intended | |
| | Seismic spot imaging | water surface; all spots of interest (Siri fairway) seafloor -> aquifers | baseline | intended | to be tested in phase 2 |
| | Streamer 3D seismic | water surface; all spots of interest (Siri fairway) | -- | alternative | |
| | Simulation | -- | history match | intended | |

Time period: T_{1 to T10} (injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|---|--|--|----------------------|-------------|--|
| CO ₂ plume (pressure volume and areal/vertical behaviour) purpose: refinement of 3D simulation | Permanent Downhole Pressure Gauge (PDG) | Downhole injection well, monitoring wells; at reservoir interval | continuous | intended | |
| | by intervention using adequate logging tool to obtain the required information (-> standard/specialized logging tools) | Injection well (problem specific) | periodically | intended | |
| | Seismic spot imaging | water surface; all spots of interest (Siri fairway) seafloor -> aquifers | continuous (monthly) | intended | to be tested in phase 2 |
| | Streamer 3D seismic | water surface; all spots of interest (Siri fairway) | every 5 years | alternative | Define in terms of injection volume for the monitor survey (e.g. @ 10%, 50%, 100%) |
| | Simulation | -- | adapted to outcome | intended | |

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7. CO2 plume

Time period: T₁₋₁₀ (assumption: well not yet abandoned); (post-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|---|---|--|----------------------|-------------|-------------------------|
| CO ₂ plume (pressure volume and areal/vertical behaviour) purpose: refinement of 3D simulation | Permanent Downhole Pressure Gauge (PDG) | Downhole injection well, monitoring wells: at reservoir interval | continuous | intended | |
| | Seismic spot imaging | water surface: all spots of interest (Siri fairway) seafloor -> aquifers | continuous (monthly) | intended | to be tested in phase 2 |
| | Streamer 3D seismic | water surface: all spots of interest (Siri fairway) | every 5 years | alternative | |
| | Simulation | --- | adapted to outcome | intended | |

Time period: T_{1>10} to T₄₀ (assumption: abandonment); (post-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|---|----------------------|--|--------------------|-------------|-------------------------|
| CO ₂ plume (pressure volume and areal/vertical behaviour) purpose: refinement of 3D simulation | Seismic spot imaging | water surface: all spots of interest (Siri fairway) seafloor -> aquifers | not yet regulated | intended | to be tested in phase 2 |
| | Streamer 3D seismic | water surface: all spots of interest (Siri fairway) seafloor -> aquifers | not yet regulated | alternative | |
| | Simulation | --- | adapted to outcome | intended | |

REMARK:

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8. Potential leakage pathway (areal dimension)

Time period: T₀ (pre-injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|--|---|--|----------------------|-------------|---|
| 8. Potential leakage pathway (areal dimension) | Eddy Covariance (flux concentration measurement) | water column, flux measurement | baseline, continuous | alternative | Risk register: no potential high leakage detected; tools are denoted as alternative |
| | ROV (Remotely Operating Vehicle) – <u>visual inspection</u> | water column | baseline | | |
| | Lander/in-situ benthic chambers -> equipped with chemical sensors (lab-on-chip chemical sensors for pH, Optode optical sensors) | benthic, at risk areas (wells, seismic anomalies) | baseline, continuous | | |
| | Monitoring bubbles in the water column (sonar technology): mounted on lander | water column (in risk areas) | baseline | | |
| | Conductivity-Temperature-Depth (CTD) Casts | water column (in risk areas) | baseline | | |
| | Lander- <u>Acoustic</u> (passiv) | water column | baseline, continuous | | |
| | Sediment microprofiler | seafloor and sub-seafloor, insitu-profile | baseline | | |
| | Autonomous Underwater Vehicle Chirp Profiler (AUV) | seafloor and sub-seafloor | baseline | | |
| | Seismic spot imaging | water surface; all spots of interest (Siri fairway) seafloor -> aquifers | baseline | | |
| | Micro-seismicity | Faults & Fractures | --- | | |
| Streamer 3D seismic | water surface; all spots of interest (Siri fairway) | --- | | | |
| Simulation | --- | continuous | intended | intended | to be tested in phase 2 would be included in spot imaging |

REMARK:

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8. Potential leakage pathway (areal dimension)

Time period: T₁ to T₁₀ (injection phase)

| Directive 2009/31/EC ⁽¹⁾ | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|--|---|--|----------------------|----------------------|---|
| 8. Potential leakage pathway (areal dimension) | Eddy Covariance (flux concentration measurement) | water column, flux measurement | continuous, tbd | alternative | Risk register: no potential high leakage detected; tools are denoted as alternative |
| | ROV (Remotely Operating Vehicle) – visual inspection | water column | continuous | | |
| | Lander/in-situ benthic chambers -> equipped with chemical sensors (lab-on-chip chemical sensors for pH, Optode optical sensors) | benthic, at risk areas (wells, seismic anomalies) | continuous | alternative | |
| | Monitoring bubbles in the water column (sonar technology); mounted on lander | water column (in risk areas) | tbd | | |
| | Conductivity-Temperature-Depth (CTD) Casts | water column (in risk areas) | tbd | | |
| | Lander- Acoustic (passiv) | water column | tbd | | |
| | Sediment microprofiler | seafloor and sub-seafloor, insitu-profile | continuous | | |
| | Autonomous Underwater Vehicle (Chirp Profiler (AUV)) | seafloor and sub-seafloor | continuous | | |
| | Seismic spot imaging | water surface; all spots of interest (Siri fairway) seafloor -> aquifers | continuous (monthly) | | |
| Seismicity | Micro-seismicity | Faults & Fractures | continuous | intended | to be tested in phase 2 |
| | Streamer 3D seismic | water surface; all spots of interest (Siri fairway) | every 5 years | intended alternative | would be included in spot imaging |
| | Simulation | --- | adapted to outcome | intended | |

REMARK:

1.) Each section is labeled as a 'STAND-ALONE CHARACTER: (causing repetition of devices)



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8. Potential leakage pathway (areal dimension)

Time period: T_{>10} (assumption: well not yet abandoned); (post-injection phase)

| Directive 2009/31/EC ^[1] | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|--|--|---|--|---|---|
| 8. Potential leakage pathway (areal dimension) | Eddy Covariance (flux concentration measurement) ROV (Remotely Operating Vehicle) – visual inspection Lander/in-situ benthic chambers -> equipped with chemical sensors (lab-on-chip chemical sensors for pH, Optode optical sensors) Monitoring bubbles in the water column (sonar technology); mounted on lander Conductivity-Temperature-Depth (CTD) Casts Lander–Acoustic (passiv) Sediment microprofiler Autonomous Underwater Vehicle Chirp Profiler (AUV) | water column, flux measurement water column benthic, at risk areas (wells, seismic anomalies) water column (in risk areas) water column (in risk areas) water column seafloor and sub-seafloor, insitu-profile seafloor and sub-seafloor | continuous, tbd continuous continuous tbd tbd tbd continuous continuous | alternative | Risk register: no high potential leakage detected; tools are denoted as alternative |
| Seismicity | Seismic spot imaging Micro-seismicity Streamer 3D seismic Simulation | water surface; all spots of interest (Siri fairway) seafloor -> aquifers Faults & Fractures water surface; all spots of interest (Siri fairway) --- | continuous (monthly) continuous every 5 years adapted to outcome | intended intended alternative intended | to be tested in phase 2 would be included in spot imaging |

Time period: T_{>>10} to T₄₀ (assumption: abandonment); (post-injection phase)

| Directive 2009/31/EC ^[1] | Tools | Location and spatial sampling | Sampling frequency | STATUS | Remark WD_INEOS |
|-------------------------------------|---|--|--|-------------------------------------|-------------------------|
| Seismicity | Seismic spot imaging Streamer 3D seismic Simulation | water surface; all spots of interest (Siri fairway) seafloor -> aquifers water surface; all spots of interest (Siri fairway) --- | not yet regulated not yet regulated adapted to outcome | intended alternative intended | to be tested in phase 2 |

REMARK:

1) Each section is labeled as a 'STAND-ALONE CHARACTER: (causing repetition of devices)



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