Hornsea Project Four

Applicant's response to the Rule 17 request dated 14 April 2022 and submission in respect of bp's technical evidence

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1 Introduction

1.1.1.1 On 14 April 2022 the Examining Authority (ExA) published a written request under Rule 17 of the Infrastructure Planning (Examination Procedure) Rules 2010. In that the ExA requested the following information:

- BP Exploration Operating Company Ltd to put in any further evidence, including any further legal submissions and supporting evidence, considered necessary to justify why the Interface Agreement should be disapplied by Deadline 4, Tuesday 10 May 2022.
- The Applicant to respond and submit any further evidence, including legal submissions, considered necessary to explain why the Interface Agreement should not be disapplied. This response and any supporting documentation should be submitted by Deadline 5, Monday 20 June 2022.

1.1.1.2 The Applicant's response to the Rule 17 request comprises two parts:

- The legal submissions relating to the disapplication of the Interface Agreement, prepared by James Maurici QC, and submitted to the ExA on 10 June 2022 **(G5.22 Applicant's comments on bp's legal submissions)**; and
- This document and its appendices, which include a report prepared by Andrew Sewell of Xodus dated June 2022 entitled "*Hornsea 4 - NEP Overlap Independent Report*" and revised draft protective provisions for the benefit of the licensee from time to time of United Kingdom Carbon Dioxide Appraisal and Storage Licence CS001 ("licensee") prepared by Pinsent Masons LLP, marked "*DL5: 20 June 2022*". That licensee is a consortium, the Northern Endurance Partnership ("NEP"), represented in this Examination by bp.

1.1.1.3 At Deadline 4, bp submitted a revised version of its proposed draft protective provisions for the benefit of the licensee **(REP4-059 Deadline 4 Submission)**. This document also responds to that submission.

2 Applicant's response to the Rule 17 request

2.1.1.1 Given the clear difference of opinion and position of the Applicant and bp in relation to the terms of protective provisions and reliance that should placed on the Interface Agreement, Pinsent Masons LLP instructed James Maurici QC to prepare detailed legal submissions explaining why it would not be lawful or appropriate to include protective provisions in the DCO for the purpose of "disapplying" the Interface Agreement. The ExA has received those submissions and so nothing further need be said in this document on that subject.

2.1.1.2 Pinsent Masons LLP also instructed expert, Andrew Sewell of Xodus. He was instructed to provide independent advice, on the evidence submitted to the Examination to date, by the Applicant and bp, in so far as it relates to the monitoring of the Endurance aquifer, with and without, the proposed authorised development colocating the area of seabed referred to in this Examination as the overlap zone.

2.1.1.3 Mr Sewell's advice is appended to this document. The executive summary reads:

"NEP and bp state that the only proven method of acquiring 3D seismic data for CO2 monitoring offshore is using towed streamers, and that this is precludes any wind turbines

being placed in the overlap zone between the Endurance CCUS project and the Hornsea 4 wind farm. There has not been sufficient detailed survey design and evaluation work presented by either bp or Orsted to be able to demonstrate with confidence whether towed streamer is the only method that will deliver seismic data of sufficient quality, or whether an OBN-based solution can also deliver such data once wind turbines are constructed. The use of forward modelling techniques to evaluate these issues should not be particularly time consuming or expensive

Both towed streamer and OBN based 3D seismic programmes should be able to provide the necessary 4D seismic monitoring of the CO2 plume. Towed streamer will have a lower cost and is the default choice for a reservoir such as Endurance if there is no requirement to consider an overlap with a wind farm or any other infrastructure at the surface. However if it is necessary to find a way for wind farms and CCUS to co-exist, then conventional towed streamer (with cables longer than 1km) is not possible and OBN is the only viable technology, probably combined with a system such as P-cable. This latter option may be more expensive in terms of seismic costs, but the overall economic and environmental value of having both a wind farm and a CCUS project operating in the same area could outweigh this additional cost.

The key recommendation of this report is that comprehensive evaluation of different seismic acquisition and processing techniques and survey designs, using an approach such as forward modelling is needed to investigate the impact on imaging from seabed to Bunter, and thus the ability to monitor the spread of the CO2 plume. Part of this evaluation should include field trials investigating, for example, if the sand waves on the sea bed at the Endurance site will cause a significant problem for the use of ocean bottom systems. The modelling work undertaken prior to 2016 as part of the White Rose project planning, as described in the K42 report [19] could be used as a basis and refreshed."

2.1.1.4 Mr Sewell's advice can give the ExA and Secretary of State confidence that it is not necessary to adopt bp's position and exclude Hornsea Four from the overlap zone at the point of determining the DCO application.

2.1.1.5 Mr Sewell's advice shows that one can expect, with a reasonable degree of confidence, that seismic monitoring of the Endurance aquifer could be undertaken using short towed streamers (also known as "P-cable") in conjunction with ocean bottom seismic monitoring systems, e.g. ocean bottom nodes. Mr Sewell also recommends that further evaluation is required to be undertaken before a definitive view can be taken in this regard. He opines that such evaluation should not take too much time or cost. However, it is unlikely that such an evaluation could be completed within the time left of this Examination. If so, this would not be an impediment to the grant of the DCO. The Applicant 's proposed protective provisions provide a mechanism for the necessary preparatory work to be undertaken and an agreement reached between the parties concerning the interface between the two projects. If agreement cannot be reached, then it is for the Secretary of State to determine following arbitration.

2.1.1.6 The Applicant's protective provisions provide adequate protection for the NEP project. They also offer the Secretary of State the opportunity to grant consent without having to decide whether offshore wind should trump offshore CCUS, or vice versa. This is an important and relevant matter to consider, particularly given the significant potential in the future for offshore wind projects coming forward under leasing Round 4 (and others) to similarly overlap with aquifers deemed suitable for CCUS.

2.1.1.7 Also appended to this document are the Applicant's revised draft protective provisions. These feature amendments to earlier drafts submitted to the Examination, which have been made in light of Mr Sewell's advice. The changes made add more protection and certainty for both parties, in terms of the detail required for the coexistence and proximity agreement.

3 The Applicant's comments on bp's draft protective provisions

3.1.1.1 In **REP4-059**, bp introduced a 5 year longstop date in its without prejudice version 3 draft protective provisions. The Applicant views this longstop date as providing disproportionate protection for the NEP project at the expense of Hornsea Four.

3.1.1.2 More specifically, a 5 year longstop date, after the coming into force of Hornsea Four's DCO, for bp to obtain its necessary consents, following which the protective provisions would fall away, introduces significant uncertainty for Hornsea Four.

3.1.1.3 Without clarity on the extent of development rights for the overlap zone, Hornsea Four cannot optimise its layout, supply chain or bid for a future Contract for Difference auction round, particularly as it is a single-phase project. Additionally, the uncertainty created by such a longstop date is further exacerbated by bp's suggestion that the Secretary of State should have the ability to further extend the longstop date for unforeseen delays to the NEP project or to preserve the future viability of the Endurance aquifer for carbon storage (section 1.7.3 of **REP4-059**, electronic page 4).

3.1.1.4 bp has stated in **REP 3-047**, electronic page 89, that it anticipates securing the necessary consents for the NEP project by June 2023. The Applicant has previously amended its protective provisions for NEP based on this information, such that both parties will have clarity on the overlap zone within a reasonable time frame of the expected necessary consents for both Hornsea Four and NEP.

Hornsea 4 - NEP Overlap

Independent Report

This report has been prepared by Andrew Sewell of Xodus Group Limited upon the instructions of Pinsent Masons LLP for Orsted UK Limited. The purpose being an Independent Technical Expert Report

June 2022

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GLOSSARY

2D seismic – Two dimensional seismic data. A group of 2D seismic lines acquired individually, as opposed to the multiple closely spaced lines acquired together that constitute 3D seismic data.

2DHR – High resolution 2D seismic which is defined by closer spacing of seismic lines and seismic receivers along each line in comparison to conventional 2D

3D seismic – Three dimensional seismic data. A set of numerous closely-spaced seismic lines that provide a high spatially sampled measure of subsurface reflectivity. In a properly migrated 3D seismic data set, events are placed in their proper vertical and horizontal positions, providing more accurate subsurface maps than can be constructed on the basis of more widely spaced 2D seismic lines. In particular, 3D seismic data provide detailed information about fault distribution and subsurface structures.

4D seismic – Four dimensional seismic data. Three-dimensional (3D) seismic data acquired at different times over the same area to assess changes in a producing hydrocarbon reservoir with time. Changes may be observed in fluid location and saturation, pressure, and temperature. 4D seismic data is one of several forms of time-lapse seismic data. The interval between each 3D survey is usually two to five years.

Acoustic – Pertaining to sound. Generally, acoustic describes sound or vibrational events, regardless of frequency. Seismic surveys can measure changes in acoustic properties between different layers of rock in the subsurface and different fluids within those rocks.

Air gun – A source of seismic energy used in acquisition of marine seismic data. This gun releases highly compressed air into water. The seismic energy is a result of the cavitation caused by the collapsing air bubble.

Airborne – Airborne geophysical surveys can measure earth's magnetic field, gravity, naturally occurring gamma radiation from soils and bedrock, as well as electrical conductivity in the ground. The measurements are usually done with 200 m separation between the survey lines at an altitude of 60 m above ground.

Anhydrite – A member of the evaporite group of minerals and the soft rock comprising anhydrite formed by precipitation of calcium sulphate from evaporation of seawater. Anhydrite can also form through the dehydration of gypsum, another sulphate mineral found in evaporites. Anhydrites can form effective caprocks or seals.

Bandwidth – The range of frequencies or wavelengths in a signal. Higher resolution seismic data requires as broad a bandwidth in the reflection signal as possible

Bin size – A bin is a subdivision of a seismic survey. The area of a three-dimensional survey is divided into bins, which are commonly on the order of 25 x 25 m. Seismic traces are assigned to specific bins according to the midpoint between the source and the receiver, reflection point, or conversion point

Brine – Water containing more dissolved inorganic salt than typical seawater.

CCUS – Carbon capture, utilisation and storage

Clay – Fine-grained sediments less than 0.0039 mm in size. Usually impermeable to fluids in the subsurface and therefore a good seal rock.

Compressional wave – An elastic body wave or sound wave in which particles oscillate in the direction the wave propagates. P-waves are the waves studied in conventional seismic data.

Compressive sensing – compressive sensing is a way of recovering a full wavefield from sparse measurements. It is an area of active research within the seismic industry.

Electromagnetic methods –A group of techniques in which natural or artificially generated electric or magnetic fields are measured at the Earth's surface or in boreholes in order to map variations in the Earth's electrical properties (resistivity, permeability or permittivity). Most applications of surface electromagnetic methods today are for mineral and groundwater exploration or for shallow environmental mapping

Geophone – A device used in surface seismic acquisition, both onshore and on the seabed offshore, that detects ground velocity produced by seismic waves and transforms the motion into electrical impulses.

Halite – A soft, soluble evaporite mineral commonly known as salt or rock salt. Halite can be critical in forming hydrocarbon traps and seals because it tends to flow rather than fracture during deformation, thus preventing hydrocarbons from leaking out of a trap even during and after some types of deformation.

Hydrophone – A device designed for use in detecting seismic energy in the form of pressure changes under water during marine towed streamer seismic acquisition. Hydrophones are combined to form streamers that are towed by seismic vessels. Geophones, unlike hydrophones, detect motion rather than pressure.

Microseismic – Microseismic monitoring is a passive technique that involves using seismic sensors to detect small seismic events, such as rocks "cracking" when they are put under pressure, e.g. from injected CO2.

Migration – A step in seismic data processing in which reflections in seismic data are moved to their correct spatial locations. Migration improves seismic interpretation and mapping because the locations of geological structures, especially faults, are more accurate in migrated seismic data.

Mirror imaging – Water-bottom reverberations in marine seismic data can be used to separate out the down going wavefield from the full wavefield and this can be used to improve the image quality and illumination of the shallow subsurface. Imaging with the down-going wavefield is called the mirror imaging method.

MMV – MMV stands for Measurement, Monitoring and Verification, which is a group of techniques used in the management of CCUS projects. The primary purpose of an MMV plan is to evaluate and demonstrate the performance of the storage site. Conformance monitoring is designed to compare the forecast and actual behaviour of CO2 in the storage site in order to demonstrate that the long-term forecasts are valid. Containment monitoring is designed to demonstrate containment and to detect any significant irregularities, migration and leakages of CO2 outside the storage reservoir in order to trigger timely corrective measures.

MT – million tonnes, which is the usual way of accounting for CO2

Node – a node is a standalone seismic sensor which usually measures motion in three dimensions (using geophones or accelerometers) and pressure (using a hydrophone). This is known as 4-component (4C) data. Nodes are battery powered so that they do not need to be connected by cable. Nodes can be used on land or on the sea bed.

OBC – Ocean Bottom Cable seismic acquisition systems are an assembly of geophones and hydrophones connected by electrical wires and deployed on the seafloor to record and relay data to a seismic recording vessel. Such systems were originally introduced to enable surveying in areas of obstructions (such as production platforms) or shallow water inaccessible to ships towing seismic streamers (floating cables).

OBN – Ocean Bottom Node seismic acquisition systems are made up of hundreds or thousands of independent nodes deployed on the sea bed

OBS – Ocean Bottom Systems is a way of referring to all seismic acquisition systems which deploy sensors on the sea bed rather than towing them in streamers behind large vessels.

Offset – In surface seismic acquisition, the horizontal distance from source to geophone. Offset between seismic source and receiver creates a delay, or moveout, in the arrival time of a reflection that can be corrected before stacking and can be used to determine velocity. It is important to have a wide range of evenly spaced offsets to obtain an accurate seismic image

Overburden – Rocks which are overlying an area or point of interest in the subsurface

Passive seismic – Passive seismic is a technique which does not use an active seismic source, but relies on natural movements in the earth to provide seismic energy which is then measured by the seismic sensors. It can provide useful data over long periods of time but is usually limited to the lower end of the seismic frequency range. Microseismic monitoring of CCUS stores is one application.

P-Cable – P-Cable is a system of very short seismic hydrophone streamers towed behind a small seismic vessel. It is designed to acquire very high resolution 3D seismic images of the near surface, i.e. down to 500m below sea bed. Streamer lengths are typically 100-200m.

Permeability – The ability, or measurement of a rock's ability, to transmit fluids, typically measured in Darcies or milliDarcies

Porosity – The percentage of pore volume or void space, or that volume within rock that can contain fluids

PRM – Permanent Reservoir Monitoring is a technique used mostly in the oil and gas industry for obtaining 4D seismic data at a lower cost. For offshore projects, it usually involves the burying of OBC cables in trenches. Once the sensors are in place, the only acquisition costs for each 3D survey is the seismic source vessel.

ROV – Remote Operated Vehicles are essentially mini submarines which are used for many purposes in offshore energy projects, including the deployment and retrieval of seismic sensor nodes on the sea bed

S/N - Also SNR, stands for signal-to-noise ratio. The ratio of desirable to undesirable (or total) energy.

Saline aquifer – A brine water-bearing porous and permeable subsurface reservoir.

Seal - A relatively impermeable rock, commonly shale, anhydrite or salt, that forms a barrier or cap above and around reservoir rock such that fluids cannot migrate beyond the reservoir. A sealing rock can also be called a caprock.

Shear Wave – Also known as S-wave, an elastic body wave in which particles oscillate perpendicular to the direction in which the wave propagates. S-waves are generated by most land seismic sources, but not by air guns.

SNS – Southern North Sea

Sonic velocity – or acoustic velocity is the rate at which a sound (seismic) wave travels through a medium, such as a subsurface rock formation. This velocity is a function of the rock properties and the fluid that it contains.

Supercritical – A supercritical fluid is a fluid that is in a state above its critical temperature and pressure, where it has properties of a gas and a liquid simultaneously.

Swath – in 3D seismic a swath is the are covered by the seismic receivers for an individual source point

Towed Streamer – A surface marine cable, usually a buoyant assembly of electrical wires that connects hydrophones and relays seismic data to the recording seismic vessel. Multistreamer vessels tow more than one streamer cable to increase the amount of data acquired in one pass. There can be up to 20 streamers towed behind a large seismic vessel and streamer lengths are typically 4-8km.

Triassic – A geological period relating to or denoting the earliest period of the Mesozoic era, between the Permian and Jurassic periods.

TVDSS – True Vertical Depth Subsea is the typical way of expressing depths of subsurface formations

UKCS UK Continental Shelf

Note, some definitions used in this glossary are taken from the Schlumberger's Oilfield Glossary, available publicly online

1 INTRODUCTION

An application for a development consent order ("DCO") has been made to the Secretary of State for Business, Energy & Industrial Strategy ("BEIS") by Orsted Hornsea Four Limited for the Hornsea Project Four Offshore Wind Farm. At the time of writing this report that application is currently being examined by the Planning Inspectorate, with the aim of providing a recommendation to BEIS in due course on whether or not a DCO should be granted and, if granted, on what terms. The proposed location of the wind farm overlaps with an aquifer known as "Endurance", which has been identified as potential store for CO2. That CCUS project is being promoted by a consortium including bp. I am aware that concerns have been expressed by bp in the examination of the DCO application as to the feasibility of collocating both projects in the overlap zone. In summary, bp's position is that such colocation is not possible due to inter alia the nature and extent of seismic surveys required to image the Endurance aquifer and impediment to those that would be caused by wind farm infrastructure, whereas Orsted's position is that colocation may be possible, if the parties have more time to investigate feasibility further.

I am aware that evidence has already been submitted to the examination by both parties. I have considered all of that and the purpose of this report is to provide an independent, desk-top review of the available evidence to assist the Examining Authority in its understanding of it. I have adopted a position of policy and technology neutrality and opined only on matters of a technical nature relating to seismic surveying techniques and the requirements of MMV for CCUS projects.

Therefore, this report is focused on the technical feasibility of acquiring repeat 3D seismic surveys over the Endurance area to map the spread of the injected CO2 plume in the subsurface while the area is partially covered with wind turbines. The process of acquiring and processing multiple 3D seismic surveys with a period of time (usually 2-5 years) between each survey is known as 4D monitoring. This is an important element in the overall process known as MMV, which stands for Measurement, Monitoring and Verification for CCUS projects. This report will assume familiarity with both the basics of MMV for CCUS projects, and the previous documents on this issue published by OREC-NZTC, bp and Orsted as listed in Section 1.3. The terms 3D and 4D seismic are used somewhat interchangeably depending on the context.

Good quality 3D seismic data is a firm requirement for MMV of CCUS projects to enable 4D seismic monitoring. Passive seismic, airborne and well based measurements may also add useful data but cannot replace "traditional" 3D seismic. 4D seismic monitoring is particularly effective when dense phase CO2 is injected into a saline aquifer because the CO2 is in a supercritical state. This provides a strong sonic velocity contrast to the initially brine filled reservoir, which stands out clearly when the data from a baseline 3D seismic survey are subtracted from a repeat 3D seismic survey. This is the 4D seismic effect. This technique is also used in the hydrocarbon industry but the it is usually less effective when trying to track the movement of water and hydrocarbon fluids in oil and gas reservoirs. So if a 3D seismic technique is shown to work for oil and gas 4D, it is likely to work for 4D CO2 monitoring.

There are two main issues with regards to seismic data where CCUS and wind farm projects overlap. The first is how to acquire 3D data of sufficient signal-to-noise ratio (s/n) to enable a 4D effect to be measurable in the presence of surface obstructions such as wind turbines. The second is how much additional noise is added to the seismic data by operating wind turbines through "shaking the sea bed", and does this decrease s/n enough to hamper the use of 4D seismic for MMV? For this latter point, there could also be a mitigation to turn off those turbines in the overlap area for the duration of the seismic acquisition, which may be only a few months every two to five years, and therefore not a huge economic impact for the wind farm operator. This report will focus on the first issue, related to seismic data acquisition.

The challenges associated with seismic data acquisition will exist for both fixed and floating wind turbines, although the relevant factors will not be exactly the same for the two types of wind farm, e.g. floating wind may present a greater hazard to snagging of seismic equipment because of mooring lines, but may add less noise to the seismic data as the turbines are not in direct contact with the sea bed. For now, we are focused on fixed wind turbines as planned for Hornsea 4.

The White Rose reports [10] [19] describe how the 3D seismic data required for the Endurance CCS project need to be able to accurately image from the Bunter sandstone reservoir at approximately 1,500m TVDSS to the sea bed. The water depth is approximately 60m.

1.1 Executive Summary

NEP and bp state that the only proven method of acquiring 3D seismic data for CO2 monitoring offshore is using towed streamers, and that this is precludes any wind turbines being placed in the overlap zone between the Endurance CCUS project and the Hornsea 4 wind farm. There has not been sufficient detailed survey design and evaluation work presented by either bp or Orsted to be able to demonstrate with confidence whether towed streamer is the only method that will deliver seismic data of sufficient quality, or whether an OBN-based solution can also deliver such data once wind turbines are constructed. The use of forward modelling techniques to evaluate these issues should not be particularly time consuming or expensive

Both towed streamer and OBN based 3D seismic programmes should be able to provide the necessary 4D seismic monitoring of the CO2 plume. Towed streamer will have a lower cost and is the default choice for a reservoir such as Endurance if there is no requirement to consider an overlap with a wind farm or any other infrastructure at the surface. However if it is necessary to find a way for wind farms and CCUS to co-exist, then conventional towed streamer (with cables longer than 1km) is not possible and OBN is the only viable technology, probably combined with a system such as P-cable. This latter option may be more expensive in terms of seismic costs, but the overall economic and environmental value of having both a wind farm and a CCUS project operating in the same area could outweigh this additional cost.

The key recommendation of this report is that comprehensive evaluation of different seismic acquisition and processing techniques and survey designs, using an approach such as forward modelling is needed to investigate the impact on imaging from seabed to Bunter, and thus the ability to monitor the spread of the CO2 plume. Part of this evaluation should include field trials investigating, for example, if the sand waves on the sea bed at the Endurance site will cause a significant problem for the use of ocean bottom systems. The modelling work undertaken prior to 2016 as part of the White Rose project planning, as described in the K42 report [19] could be used as a basis and refreshed.

The table below summarises the key conclusions of this report

ISSUE	OPINION
Requirement for 'long' towed seismic streamers	It is not the case that only towed streamer can be used for 4D CO2 monitoring. Ocean Bottom systems such as OBN could be suitable. However cost will be a key issue.
Technical applicability of OBN technology	Technically, a combination of OBN and short streamers under 1km length (e.g. P-cable) would be feasible for CO2 monitoring.
Commercial feasibility of using OBN for Endurance CCS monitoring	There is a lack of survey design work based on seismic forward modelling studies to be able to understand the cost of a technically adequate OBN-based solution.
The impact of seabed sand waves on the use of OBN at Endurance	This is one purely technical/logistical issue that could make the use of OBN inappropriate. However it has not yet been adequately studied to draw any firm conclusions.
bp's argument that new technology enabling co-existence will not be available for another 10-20 years	I agree with bp's comments about the unproven technology. However OBN and P-cable are not one of them and should enable co-existence already.
The impact of a more sparse wind turbine layout with a 2x2km grid on the options for seismic monitoring	A sparser turbine grid will make any seismic acquisition easier, but will still not allow conventional towed streamers longer than 1km to be feasible within a wind farm.

1.2 Scope of review

I have prepared this review according to instructions received from Pinsent Masons LLP acting on behalf of Orsted UK Ltd. In summary, those were to undertake an objective and independent review of all the evidence relating to seismic surveying of the Endurance aquifer submitted to the Examination of the DCO application referred to above and draw my own conclusions on technical feasibility that may assist the Examining Authority. Whilst my fees and expenses are being met by the applicant for the DCO, I confirm that for the purposes of this review I consider myself an Independent Expert. I would be willing to respond to any questions posed by the Examining Authority and bp.

My CV is provided in Appendix A. I am the Head of Subsurface for Xodus Group Limited and I have 31 years of experience in the oil and gas industry after graduating from the University of Cambridge with an MA in Natural Sciences (Physics). I have experience in seismic data acquisition and processing from working with Seismograph Service Ltd (SSL), Schlumberger Geco-Prakla, WesternGeco and in consultancy. I also have experience at planning and reviewing CCUS projects from working with Schlumberger, and in consultancy with Senergy and Xodus. I have experience of providing independent expert reports in respect of disputes, and for regulatory purposes such as Competent Persons Reports.

The scope of this review is to focus on the issues related to acquisition of seismic data for the purpose of CO2 monitoring as raised in the various documents listed in Section 1.2. Particular attention has been paid to the following issues:

- Requirement for conventional "long" towed seismic streamers, meaning cable lengths in excess of 1km
- Technical applicability of OBN technology
- Commercial feasibility of using OBN for Endurance CCS monitoring
- The impact of seabed sand waves on the use of OBN at Endurance
- bp's argument that new technology enabling co-existence will not be available for another 10-20 years
- The impact of a more sparse wind turbine layout with a 2x2km grid on the options for seismic monitoring

1.3 Documents Provided for review

The following documents were provided to me by Orsted as the basis for the review:

- CCUS and Offshore Wind Overlap Report, Catapult (aka OREC-NZTC) for The Crown Estate, April 2021, (aka The Project Vulcan report) [1]
- REP1-057 Northern Endurance CCUS Co-Location Review, Catapult (aka OREC-NZTC), Jan 2022 [3]
- REP1-057 Hornsea Project Four - Position Statement with bp, Orsted, March 2022 [4]
- REP1-057 Endurance and Hornsea 4 Overlap - Technical Assessment Report by bp, Dec 2021 [5]
- APP-203 Hornsea Project Four - Endurance Protective Provisions, Orsted, [6]
- bp pre-read slides for bp-Orsted OBN workshop in October 2021 [7]
- Q&A following OBN workshop, November 2021 [8]
- REP2-062 bp response to Orsted's first DCO submission, March 2022 [9]
- REP3-047 bp submissions for deadline 3 [24], [25], [26]
- REP4-059 bp submission for deadline 4 [28]

In addition I made use of public domain literature, including the K42 and K43 reports for the White Rose project, [19], [10]. A full list of all documents reviewed can be found in Section 5 of this report and electronic copies can be provided on request.

2 DOCUMENT REVIEW AND COMMENTS

2.1 OREC-NZTC report PN000520

OREC-NZTC 2022 report [3]

When discussing MMV (Measuring, Monitoring and Verification) methods, the final paragraph of section 3.2.2 on page 16 states "*With the potential co-location of offshore wind farms and CCUS sites the use of towed streamer acquisition for time lapse studies needs to be reconsidered. The repeatability and quality of the 4D time lapse signal is one of the biggest concerns with the overlap of wind farms and CCUS sites especially for towed streamer acquisition. The installation of the wind farm could make it difficult for the seismic vessel to navigate on the same acquisition geometry therefore compromising repeatability and introducing too much noise from differences in acquisition geometry, positioning or ambient noise*."

This does not fully capture the problems with streamer acquisition in a wind farm. It is likely to be highly impractical for a vessel towing streamers of several km length to operate in a wind farm. And even if it is possible, the gaps in the data acquisition would be so large that basic 3D imaging would be badly compromised, and therefore the use of the data for CO2 monitoring would not be possible.

Section 3.3.1 deals with MMV technologies and reflection seismic in particular. The first paragraph states *"initiating research into cost-effective solutions for monitoring CO2 injection that minimise the use of marine seismic acquisition in the short term, and potentially replace seismic acquisition in the long term once the technology has been proven and matured."*

The alternative MMV technologies discussed at the end of section 3.3.1 on pages 19 and 20 are unlikely to replace the need for good quality 3D/4D seismic data. These alternative technologies include electromagnetism, mirror imaging, compressive sensing, and full wavefield migration (FWM) amongst others. In some cases they may add additional useful data that would allow for longer gaps between repeat 3D surveys. Some of them (e.g. full wavefield inversion, gravity) are already reasonably standard tools in the oil and gas industry and their limited impact on 4D monitoring can be taken into account already.

In my opinion it is unlikely that there will be a replacement technology for 3D seismic with the availability to provide monitoring over the whole areal extent of a CO2 storage site for a long time. The use of 3D/4D seismic in the MMV plan for Northern Endurance is a necessity.

On page 17 the report states: "*Advances in the speed of deployment and retrieval of ocean bottom nodes could reduce the cost of OBN acquisition, and the development of autonomous nodes .... could decrease this cost still further making it a viable alternative to towed streamer acquisition and significantly reducing the cost of ocean bottom monitoring for CCUS*". I agree the costs of OBN are likely to come down faster than towed streamer, but they are also likely to remain generally higher for the next 5-10 years at least. In discussing the results of the CO2 monitoring at the Sleipner storage site in Norway, Furre et al [14] make the point that permanent nodes could be comparable to the cost of towed streamers, depending on the density of nodes and the frequency of repeat surveys expected.

As an aside, but related to this point, the White Rose K42 report [19] rules out the use of OBN on grounds of cost rather than any inherent properties. Section 5.8.1.3 contains "*Ocean bottom acquisition methods, utilising geophones, have some attractive properties over more conventional towed streamer methods particularly the acquisition of shear wave data. Logistically* ***the technique allows for greater operational flexibility where surface obstructions such as platforms and wind farms preclude the use of vessels towing many kilometres of hydrophone cables****. In addition to operational advantages, ocean bottom surveys typically have greater fold (number of shot receiver combinations that record reflected energy from a given point in the subsurface) and a wider range of recorded azimuths associated with the survey geometry which can have a* ***demonstrable uplift on data quality****, especially in areas of geological complexity. These benefits though are* ***weighed against the substantially higher costs*** *and on this basis taking into account that the data provides only confirmation of conformance and does not relate to containment or potential threats to containment, this technology is not proposed for use.*" My emphasis.

Essentially the White Rose report says that the consortium at the time (2016) decided it did not need to use the higher quality but costlier OBN methodology at the Endurance site because the MMV plan was focused on conformance rather than containment. It made this determination because the White Rose plan was to inject a relatively small volume of CO2, equivalent to 50MT, occupying only 2% of the available pore volume in the reservoir. However the current Northern Endurance project, led by bp, is to inject much more CO2, up to 450MT, which implies that containment should now be a consideration, and therefore the advantages of OBN should be considered despite the additional cost.

Section 3.3.2 discusses the use of permanent seismic arrays for CO2 monitoring. The report mentions "*Seabed nodes as part of permanent reservoir monitoring*" and I believe this must be referring to Ocean Bottom Cable (OBC) rather than Ocean Bottom Node (OBN) systems, because it is not currently possible to provide battery power to nodes for the length of time needed for CO2 monitoring. Permanent array OBC is a proven technology for 4D seismic in oil and gas (for example at the Valhall field in Norway operated by Aker BP) and has the potential to be applicable for CCS. However, as stated in 3.3.2, *"Initial investment cost of PRM is relatively large and may not offer sufficient benefit at an acceptable cost level"*. A further word of caution is that the idea of using permanent arrays for 4D monitoring for hydrocarbon fields (as well as CO2 stores) has been around for a long time but has not made a significant impact on the market, either onshore or offshore, presumably because of the high initial cost and uncertainty at the start of a project as to how many repeat surveys will actually be needed. Why spend the capital up front when it can be spread over a longer time?

Passive seismic and the use of wind turbines as a seismic source are also mentioned in this section in the context of additional benefits of permanent arrays. However this is mixing different requirements. Passive seismic for the measuring of microseismic events generated by small changes in the stress state of the subsurface rocks is a recognised and important part of the MMV toolbox, and was part of the MMV plan for the White Rose project as detailed in section 5.8.2.4 of the White Rose K42 report [19], and is apparently still being assessed by bp [27]. However this requires a small number of nodes as it is for detection rather than imaging. White Rose planned for 31 nodes around the injection wells and crest of the structure. I assume bp is now planning for a larger number of nodes to cover the larger injection scheme, but this will still be nowhere near the thousands of nodes needed for subsurface imaging and monitoring of the spread of the CO2 plume. These permanent nodes for microseismic monitoring would usually be connected by wire for power and data transfer, and so are different to the autonomous nodes used for 3D seismic.

The use of wind turbines, or anything else, as a passive seismic source, will not replace the need for conventional 3D seismic with active source. The temporal frequency range of the "noise" produced by wind farms is too restricted to provide useful 3D imaging.

It is unlikely that any alternative technology will be able to work around the fundamental problem of the need for a certain density of spatial sampling to obtain an adequate seismic image. Particularly so when trying to image a relatively shallow (1km) reservoir in shallow water depths (<100m).

Section 3.4 discusses acoustic noise that may be added to the seismic data by the presence of a wind farm. It is clear that a seismic survey should not be acquired during the construction phase of a wind farm as the noise from piling and other activities will be significant. However, that phase of a wind farm is relatively short (1-2 years) and it should be possible to co-ordinate activities between the CCUS operator and the wind farm operator such that this is not an issue. The noise generated by running turbines during the operational life of the wind farm would be picked up by seismic sensors, but there is general agreement that this can be attenuated sufficiently during seismic data processing. However, it would be worth having some additional studies and modelling on this. Be that is it may, there is always the last resort of turning off the turbines that overlap the seismic survey for the duration of the survey, which should be a few months every 5 years or so.

One of the conclusions on page 58 of the OREC-NZTC report [3] is "…. *a standard minimum square grid formation of one turbine every 2 km would need to be implemented …. and opens the potential to use towed streamer acquisition for monitoring storage conformance and CO2 plume development away from wells*". I don't agree with this conclusion if this is referring to conventional length (2km or longer) streamers. Clearly turbine spacing will have an impact on seismic acquisition designs. A typical towed streamer configuration, such as used at Sleipner [11], would have 10 streamer cables with 75m cross line separation between streamers. This means the cables cover a swath width of 750m, and allowing a 100m buffer to each side, means the streamers cover almost 1km with each sail line. So, while it should be feasible to sail such a streamer configuration through a wind farm with 2km turbine spacing safely, the gaps in coverage of seismic data that would result make this approach impractical for CO2 monitoring at Northern Endurance. Hence the only viable seismic acquisition technology will be some form of ocean bottom system, probably in combination with a very short (100m) streamer system (such as P-cable) which covers a much narrower swath with each sail line, e.g. 150m.

The OREC-NZTC report PN000452 [1] covers some the same topics but is higher level and more general than report PN000520 [3] which has been commented on above.

<u>Conclusion on this section:</u>

The OREC-NTZC reports attempt to show that current and future seismic acquisition technologies will be able to work in the overlap zone of a CCUS storage site and a wind farm. I agree that this should be technically possible for existing OBC, OBN systems and short streamer systems, such as P-Cable. However streamers with any length beyond a kilometre will not be able to obtain the required coverage of data. Many of the other technologies may provide supporting data in time, but are not going to replace the need for good quality 3D seismic data.

2.2 OBN technology workshop and Q&A

Comments on the pre-read slide pack [7] for the OBN workshop held in October 2021 by bp for Orsted are below.

On slide 3, bp makes statements about the data quality, unproven use and cost of OBN technology which are more definite than is justified. OBN is only poorer data quality than towed streamer if one makes certain assumptions about source and receiver geometries. It does not acquire inherently poorer quality data than towed streamer. In fact on slide 4 bp highlights that it has *"applied the technology to the most of its major oil and gas fields"* and OBN has been used for acquiring high resolution data in many parts of the world [17] [18]. All seismic acquisition systems are unproven for use within a large wind farm. The actual cost comparison between OBN and towed streamer will depend on the survey designs used and can be calculated more accurately than "*up to* …." during a detailed survey evaluation and design study.

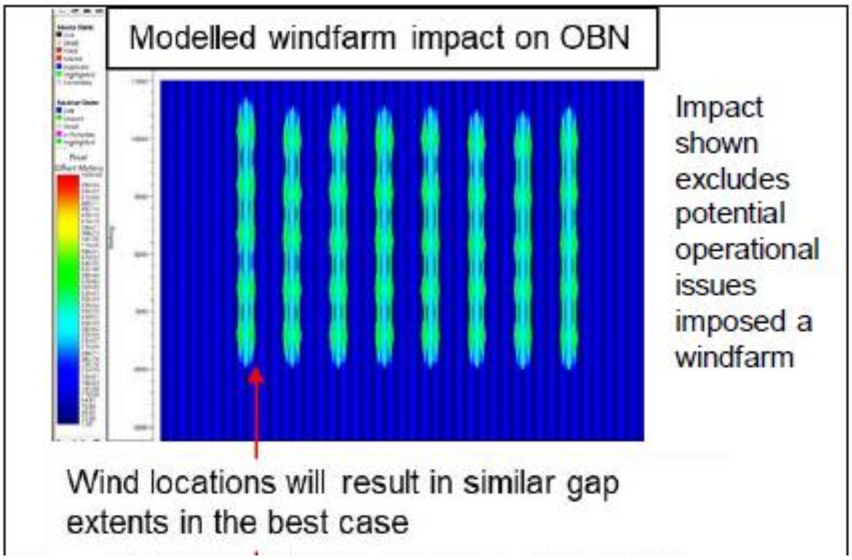
bp is a party to various efforts underway to develop technologies that may improve OBN efficiency and thereby reduce the costs of such operations. The autonomous and uncrewed node technologies, shown on slide 5 will be aimed at reducing cost rather than having an impact on data quality per se. I agree with bp's conclusion that these cannot be relied upon as making a difference in the near term for Endurance.

When developing a monitoring plan (MMV plan), bp states on slide 6 that *"For 4D differencing to work, the acquisition and processing of the baseline and repeat surveys must be the same."* The degree to which baseline and repeat surveys need to be similar is something that can be modelled. Experience from Sleipner [11] [13] [14] as well as 4D oil and gas projects show that 4D is quite robust, particularly so for CO2, as bp highlights in the final bullet point on this slide, with the comment "*As seismic is very sensitive to low concentrations of CO2 , it will show where even small amounts of CO2 are present outside of the main plume, but high resolution seismic is required to image this at the scale of geological variations*".

Slide 7 presents the challenges associated with acquiring seismic within a dense windfarm. It should be possible to test and model how well a source boat (which could be a small size for the Endurance surveys) will be able to manoeuvre amongst wind turbines in different grid patterns. The currents will also be a problem for towed streamer acquisition to repeat source and receiver locations even with modern steerable streamers, with or without a wind farm in place. bp states that "*The mobile sand waves on the seabed have caused significant problems for previous ocean bottom acquisition in the area*." I agree that these sand waves on the seabed could be a challenge for OBN, but bp does not describe in detail the problems with previous surveys in the area, nor does there seem to have been any testing or other work to quantify how big a problem this might be at the Endurance site. The answer provided by bp to question 5 in the Q&A document [8] that followed the workshop says "*Regarding sand waves - we have not done detailed modelling of what the impact is. Note that sand waves will create issues on 4D signals in general, also for Towed Streamer*."

Slide 8 addresses data quality feasibility. bp states that "*Standard OBN data performs poorly relative to towed streamer at shallow depth ranges (as at Endurance) due to its lack of near offsets*". Data quality for different acquisition schemes and different wind turbine grids can and should be modelled in detail, using forward modelling techniques. There is always a trade-off between cost and data quality when designing a seismic survey. Unless this is modelled, it cannot be quantified.

bp states on slide 9, that if baseline and repeat surveys "*cannot be matched exactly, or the data coverage is poor*, [then the] *4D differencing will be inaccurate*". The reality is that baseline and repeat surveys are never "matched exactly". As above, the degree to which a repeat survey needs to be similar to the baseline should be part of the modelling work prior to deciding on a survey design.



The figure above is shown on slide 9 and also appears in bp's technical assessment [5] as Figure 30. It appears to show the nearest offset in each subsurface bin. It is not explained how this map was created but the vertical stripes would imply that sources were acquired in one azimuth only. It would be useful for bp to explain this map in more detail and whether maps from other possible acquisition templates were created for comparison.

In slide 10 bp highlights that their risk management relies strongly on 4D seismic to provide information on the spread of CO2, "*if CO2 starts to leave the store in small quantities it is likely that only 4D seismic will be able to detect this*". I agree with bp's view that *"As a responsible operator, we are obliged to use the best available technology. To change this, the operator (bp) will have to be instructed by the regulator and reduced data quality for MMV activity explicitly deemed acceptable in the TRI business model."* The key issue here is that it is not clear that towed streamer represents the best available technology, given the previously discussed advantages of OBN data, as long as an OBN survey can be designed to image the near surface adequately, perhaps in combination with short streamers as provided by the P-cable system or Magseis-Fairfields' XHR system.

bp has made comparisons between different seismic acquisition methods on slide 11. However it is unclear if any survey design and modelling work has been done to back up the assumptions in this table, particularly that a node grid of 100m x 50m only has a "*moderate/low*" chance of success. Such a dense grid of nodes would most likely have a maximum minimum offset of well under 100m, even with source locations missing due to wind turbines. The 2016 K42 report for White Rose [19] mentions in section 5.8.2.3 that "*Petro-acoustic modelling can be carried out to further investigate sensitivity and allow the results to be interpreted in a quantitative fashion although preliminary studies, which have already been made, indicate that results will have good sensitivity* [to CO2 replacing brine]. *These sensitivity thresholds have already been investigated through a time lapse synthetic seismic modelling study.*" If this preliminary synthetic seismic modelling work is still available it should be straightforward to expand it to cover a wide range of acquisition options.

The Q&A document [8] which followed the OBN workshop covers some of the same points made above. Some additional comments based on the Q&A are below.

Q3 on slide 8 asks "*Can you comment on the cross line receiver separation of the data shown compared to your planned OBN receiver line interval? How does this compare to the inline image/sampling?*" The answer to Q3 contains "*The expected required OBN line interval for CCUS monitoring purposes would be around 100 m, while going denser in the in-line (e.g. 50 m or 25 m).*"

This implies that some modelling work has been done by bp and refers to some assumptions based on the old OBC data. Is this the extent of the modelling or is it more detailed? If the latter, then it would be useful if this could be shared.

Q5 on slide 9 asks "*Is the 4D change shown in the section a result of the sand dune movement?*" The answer describes the 2D/4D repeat lines that were acquired as a test over Endurance and highlight the difficulty of acquiring the same source-receiver pairs even on consecutive days, and what the impact is on near surface imaging. Of course, this test line was acquired with towed streamer, where the current causes feathering on the streamer and serves to highlight how repeat surveys can never be "*matched exactly*", regardless of the acquisition system used. In the case of this test, it is quite likely that if the line had been acquired with nodes there would have been more similarity in the two sections, because with node acquisition only the source is being towed through the variable currents, whereas with the towed streamer it is both source and receiver being towed, with the receivers being affected more by the currents due to the length of the streamer behind the boat.

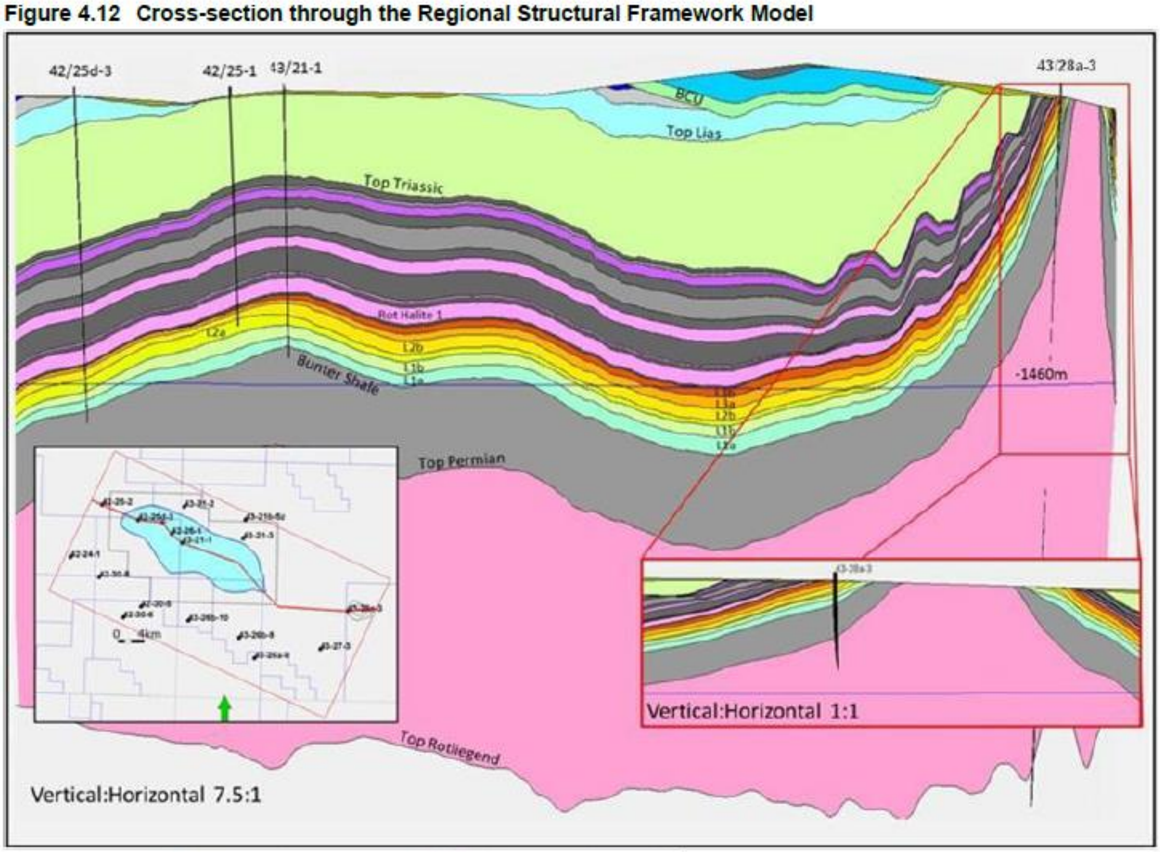
The answer to Q7 states that a dense layout of nodes is not possible in a wind farm. Why is this the case? Nodes can be positioned very close to wind turbine foundations with remotely operated vehicles (ROV), particularly in shallower water such as at Endurance. This would be more of a problem in deeper water with floating wind turbines where the anchor cables would present a hazard to node deployment.

bp's answer to Q9 states "*Modelling done to look at near offsets with the wind turbine restrictions on sources and receivers shows that along the line of turbines the closest near offset increase from 30m to over 500m. In reality we would expect overburden imaging in this scenario to be similar or slightly worse than the overburden image to the existing legacy OBC data, which would mean shallowest useful imaging would start around the upper Triassic stratigraphy (essentially about half of the overburden would be missing).*" So clearly some modelling work has been done, but it is not presented in any detail. Nor are the assumptions behind a "*closest near offset*" of "*over 500m*" made clear. This is quite a pessimistic assumption and must involve large exclusion zones for both sources and receivers around each wind turbine location.

FQ3 and its answer are not particularly interesting in themselves and so I won't quote them. But they do bring up an interesting point. The monitoring area extends vertically from reservoir to seabed, and the MMV plan needs to address all of this. Any CO_2 leaks at the seabed will be detected through environmental monitoring techniques such as those described in section 5.8.2.5 of the White Rose K42 report [19]. These include monitoring of seawater chemistry, seabed sampling and gas analysis. The CO_2 is being injected in to the Bunter sandstone at over 1km below the seabed. Between the top Bunter and the seabed there are multiple potential sealing zones starting with the Rot clay and halite directly on top of the Bunter, but also including several other halite, anhydrite and clay zones up to the top Triassic at about 500m TVDSS at the shallowest point, see the figure below from K42 White Rose report [19].

There are some faults interpreted in the overburden but these are not likely to be open through the halite and anhydrite zones. Sutherland et al [27] describe it thus "…. *only minor faulting is observed in the overburden above the storage area …. The possibility of seal failure along these faults is not deemed to be a risk as the overburden faults appear to sole out in the overlying Rot Halite, and there is an approximately 1 km thick section of sealing stratigraphy. This has been confirmed by geomechanical modeling*." And "*Geologic leakage (through open faults/fractures or induced faults/fractures) from a fully evaluated and characterized store with a proven seal is extremely unlikely if injection pressures are adhered to*." The high quality sealing formations are one of the reasons why the Endurance structure was chosen as a CCS site. According to bp's answer to Q9, even a sparse OBN survey should be able to image from the upper Triassic (500m TVDSS) down to the reservoir. If there was to be a leak of CO2 to the seabed through the overburden (as opposed to through wells which are not sealed properly) it would take many years and the CO2 would likely have to pond at various intermediate depths before breaking into the Lias. In other words, OBN 4D monitor surveys should pick up any CO2 escape through the Rot seals long before the CO2 reached the top Triassic. In addition if there was a baseline survey acquired with good imaging of the near surface (<500m below seabed) before the wind farm is in place, then a repeat survey using a short streamer system such as P-cable could be run quickly after any CO2 detection at the seabed, just in the area around that detection point, and provide an ability to see how the CO2 has risen up through the shallow overburden.

Figure 4.12 Cross-section through the Regional Structural Framework Model



Conclusion on this section:

bp attempts to make the argument that only towed streamer is suitable for acquiring 3D seismic data at Endurance. However it does not present data or the results of any modelling that would conclusively rule out the use of schemes based on OBN. Some of the arguments presented by bp on the difficulty of repeating source and receiver locations between surveys applies equally, or more, to towed streamer as they do to OBN.

2.3 bp's Technical Assessment

bp's overall technical assessment is contained in a report [5] from December 2021, called "*Carbon Capture, Usage and Storage (CCUS) and Offshore Wind (OW) Project Overlap Report - A Technical Assessment of the Endurance Reservoir and Hornsea Project Four Wind Farm*"

The third paragraph on page 8 describes the issue of locating CO2 injector wells and brine producer wells and states "…. *any encroachment of fixed wind turbine structures risks preventing NEP from locating CO2 injector wells and brine producer wells to manage overpressure of the reservoir relative to seal capacity. The immediate consequence is a loss of up to 70% of the Endurance reservoir storage capacity if NEP is solely reliant on the safe pressure limits of the natural seal without brine production*." The 2016 K43 White Rose Field Development report [10] states that Endurance can store up to 2600 MT of CO2. The 50 MT from the White Rose power plant (phase 1) equates to 2% of the storage capacity. The 450 MT described by bp would therefore be 17% of the storage capacity. How has the 70% reduction in available pore space been calculated by bp from the available data?

The next paragraph on page 8 addresses the issue of seismic data quality, where bp states "*Towed streamer (TS) seismic acquisition is uniquely suited to the shallow geology and CO2 plume detection within a saline aquifer, is the most established and well-understood technique, and offers unparalleled quality of data*". The consensus in the seismic industry is that OBC/OBN is inherently higher quality in terms of s/n, bandwidth, and azimuths. For example it allows "true 3D" with equal offset ranges for all azimuths, rather than the narrow azimuths provided by conventional streamer acquisition (ref [16] Kjolhamar et al, 2020). OBN can also provide multicomponent shear data which streamer cannot. For any given project the relative data quality between the two methods will be determined by the configuration of sources and receivers. There are published data comparing streamer with OBN and even showing OBN as repeat surveys after streamer for 4D (ref [12] Detomo et al, 2012).

There are also many examples of OBC being used for 4D. OBC is Ocean Bottom Cable, and is essentially the older version of OBN. The relevant point is that with both OBN and OBC the sensors lie on the sea bed and therefore employ the same data acquisition technique. bp itself is party to one of the best known examples of permanently placed Ocean Bottom Cable being used for 4D at the Valhall field in Norway, as described by Haller et al [21]. Aker BP has recently moved from acquiring data with a permanent OBC array to the use of OBN. 19 Ocean Bottom time lapse (4D) surveys have been acquired at Valhall since 2003. Other examples include Cailly et al [22] describing how they obtained a "reliable 4D signal" using baseline and repeat OBC surveys offshore Abu Dhabi, and Reddy et al [23] discussing the success of the first 4D OBC project in 2010 at the Ravva field offshore India.

4D for CO2 monitoring in a saline aquifer is theoretically less of a geophysical challenge than 4D for oil and gas, because the replacing of brine with CO2 stands out more clearly as a difference in the seismic data than other fluid substitutions. Therefore if a technology works for 4D oil and gas monitoring, it can reasonably be expected to work well for CO2 monitoring, assuming the surveys are designed correctly for the targets.

bp goes on to state that "*Given the stated minimum distance between wind turbines and array density in the Hornsea 4 wind farm development consent order (DCO), it is not possible to run conventional towed streamer seismic acquisition within the wind farm*". I understand that the original 1km x 1km turbine spacing could be relaxed to 2km x 2km in the overlap zone. However, I agree with bp that it will not be possible to acquire data of sufficient quality with conventional (1km or longer) streamers through a wind farm with an acceptable level of risk.

Referring to the table showing risk assessment on page 28 of the document, and the section of that dealing with "*Store Monitorability*" which is reproduced below, I agree with bp that OBN will be more expensive for the foreseeable future, particularly with the denser source and receiver geometry that will be required for effective 4D in relatively shallow reservoirs such as Endurance. However the cost will be driven largely by the density of nodes.

Category	Concern	Risk Impact	Mitigations incorporated within Endurance development plan
Store Monitorability	<u>4D seismic monitoring</u>: Towed streamer 3D seismic surveys are not possible in the windfarm	4D seismic data must be acquired by OBN within the windfarm which has not been proven to provide high quality results in this scenario and increases the risk of an inability to continue injection if containment cannot be proven from the results of the surveys.	Very dense OBN at over 10x cost than the towed streamer seismic option and the residual risk is still higher for OBN. There are also acquisition challenges due to strong, variable currents and vessel safety concerns as a result of months of operations within the wind turbines.
	<u>Store closure</u>: Insufficient 4D data to prove long term CO_2 containment and conformance after injection has ceased	Unable to hand over the long-term leakage liability of the CO_2 store to the Government, resulting in increased monitoring cost and risk.	Very dense OBN at over 10x cost than the towed streamer seismic option and the residual risk is still higher for OBN.

A dense layout of source points is achievable at low cost, particularly as it should be possible to use a smaller source vessel with smaller gun arrays given the relatively shallow Bunter sandstone target, as shown by bp in Sutherland et al [27] which concludes that a source of 320 cu in is acceptable at Endurance compared to a normal

3D source size of 2380 cu in, or larger for deep targets. So the question becomes what is the cost vs data quality trade-off for different densities of nodes, and at what point does OBN become too expensive to provide an economically feasible solution?

Section 7.3.1 on pages 44 – 46 outlines the requirements for 4D seismic data in relation to the highly stratified Bunter sandstone. "*To simulate CO2 in high porosity/permeability in thin beds a fluid substitution was carried out with a porosity cut off at 28%*" as shown in figure 25 in bp's report, reproduced below and in Sutherland et al [27]. bp goes on to say "*whilst any standard resolution seismic will detect thicker layers of CO2, the thinner layers only show a 4D response …. at high resolution*". This describes standard resolution vs high resolution in terms of temporal frequencies. But the issue under discussion is the spatial sampling of OBN compared to streamer. In this report bp is only showing how spatial sampling affects temporal bandwidth for 2D high resolution (2DHR) towed streamer compared to 3D conventional towed streamer. There is no reason to assume that OBN data would have the same bandwidth as the 2013 conventional 3D streamer data, as implied by bp. Sutherland et al [27] gives more details on the fluid substitution modelling and how the bandpass filters were derived from analysis of 2D high resolution test lines acquired over Endurance in 2020. I propose that this work should be expanded to include synthetic seismic datasets from different survey designs (OBN and others) for comparison.

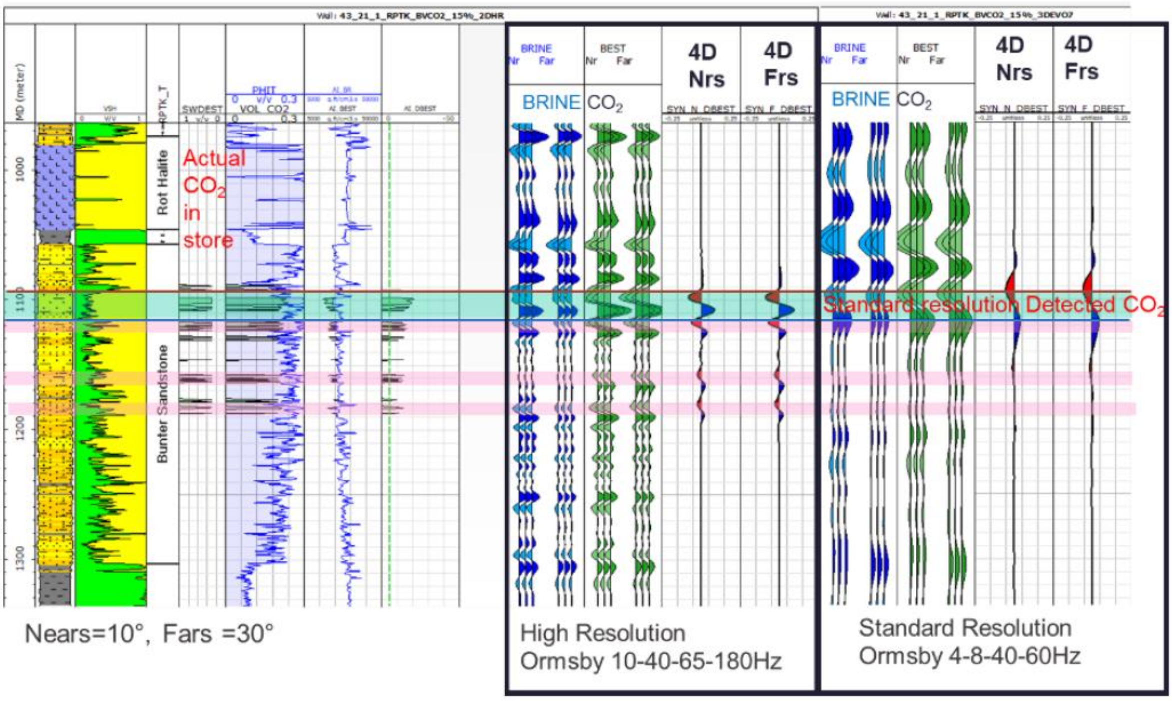


Figure 25: Detectability of CO_2 in thin beds. The seismic response is shown in tracks '4D Nrs and 4D Frs' (Nears = 10° and Fars =30°). Standard resolution only detects part highlighted in green and misses the additional CO_2 shown in pink, which is detected at high resolution.

bp then goes on to compare one of the 2020 high resolution 2D test lines with a 1997 sparse 3D OBC line in an attempt to demonstrate the differences in data quality between different data acquisition methods. This is shown in figures 26 and 27 which are reproduced below. As can be seen, the sparse line OBC data does not have good coverage in shallow section and has lower signal-to-noise ratio at the Bunter level. This is not a like for like comparison and therefore not a fair representation of OBN vs towed streamer for the issues under discussion.

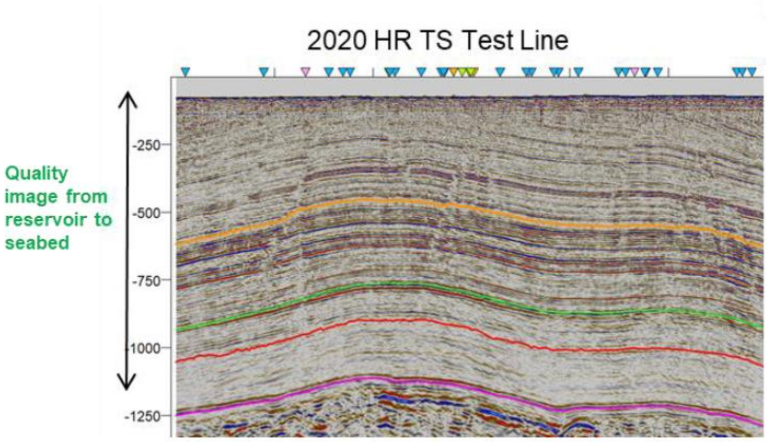


Figure 26: Example of high resolution towed streamer data over Endurance

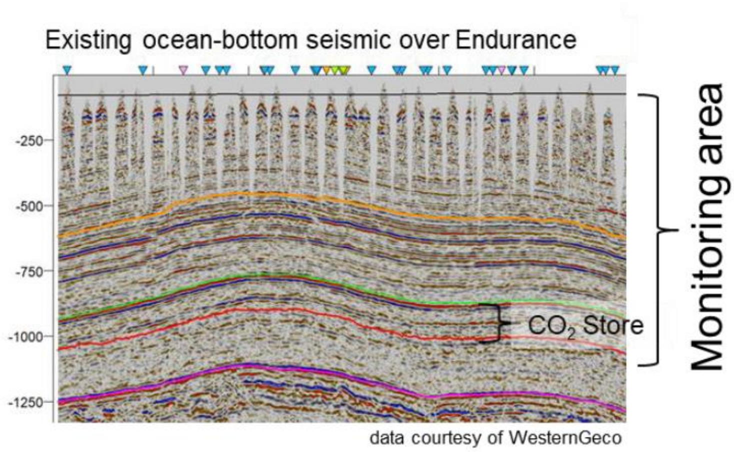


Figure 27: Matching line to Figure above for the legacy OBC data

Section 7.3.2 on pages 47-48 explores the alternative options to towed streamer, and describes some of the studies undertaken by bp in the last two years. Following the acquisition of 4 2D high resolution seismic lines over Endurance, bp states that "*It was proven that the shorter streamer HR data provided excellent imaging of the reservoir (Figure 26) at much higher resolution than traditional data, and that acquisition direction was not a particular concern on imaging quality, which would allow a survey to be optimised with the windfarm in mind. It allowed for a reduction of the seismic survey overlap by 90km2 (and with the new Hornsea 4 outline this is reduced to a total 110km2 overlap from an initial 220km2), by shifting to short streamers and changing acquisition orientation*." In addition, to test the potential of P-cable "*the 2DHR lines were reprocessed with only 200m streamer length to test the feasibility of P cable imaging of the reservoir. It was found that the top of the Bunter sandstone was not imaged on this data, which made it unsuitable. Even with a 200m long streamer, the safety margins around the turbines would create significant holes in the survey, which would not be filled due to the lack of offsets. Additionally, P cable has not been proven for use in 4D and works best in deep water where multiples become less of an issue*".

bp does not make clear in the report what parameters were used in the 2DHR acquisition, although some details are provided in Sutherland et al [27] which shows that inline receiver interval was 12.5m. P-cable often uses an inline receiver interval of 3.125m, so simply cutting the offset range in the 2DHR dataset to 200m is not going to provide the same fold of coverage and therefore s/n that a real P-cable acquisition would. Be that as it may, I agree with bp that it would not be recommended to try to image a target at depths of over 1km with a streamer length of only 200m or less.

bp also describes how a 2D/4D approach is not suitable, and I agree that 2D/4D and P-cable are not going to be suitable on their own. But something like P-cable in combination with OBN should be a viable solution. The effectiveness of P-cable for near surface (e.g. 0 to 500m depth) imaging is well understood and there is no reason to think it won't be a very effective CO2 monitoring tool for near surface. Waage et al [15] describe a field test and modelling with P-Cable for 4D CO2 monitoring and conclude: "*Based on our results, we conclude that the P-Cable acquisition system, being a cost-effective method, has the potential to be used in both frontier and mature regions to acquire successive small-size surveys (25 to 250 km2) in areas of particular interest, e.g., 4D seismic monitoring of the shallow overburden at CO2 storage sites that have suspected leakage from the reservoir and supplement conventional time-lapse surveys for monitoring storage site integrity in the future*."

On page 49, bp compares the option of a sparse vs dense OBN survey over Endurance. However it does not define the parameter range assumed for "sparse" or "dense" OBN. How did bp generate the "*modelled windfarm impact*" in Figure 30 of its report (reproduced below)? What assumptions were made on source and receiver spacing? In reality, there is a continuum between "sparse" and "dense". There is no reason to think that OBN will not produce good 4D results, given that it usually gives high quality 3D results when used in the oil and gas industry [18].

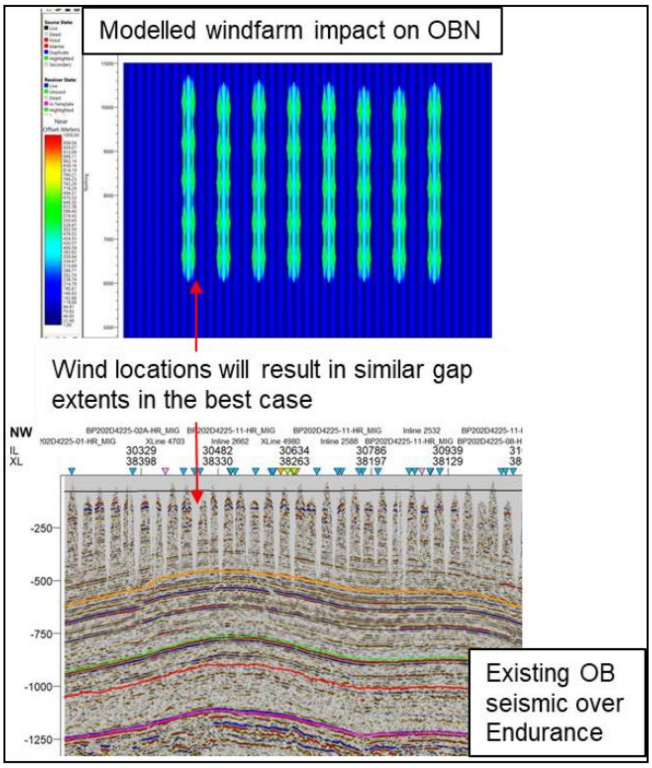


Figure 30: Modelled near offsets with wind turbine exclusion zones

OBN can provide a technically sound method of acquiring 4D seismic data for CO2 monitoring at the Endurance site, particularly if backed up by the use of something like P-Cable for investigating the very near surface in specific areas of concern. According to bp's answer to question 9 in the Q&A document [8] which followed the OBN workshop in October 2021, even a fairly sparse OBN survey with a conservative approach to positioning nodes near wind turbines would be able to image from the upper Triassic (500m TVDSS) down to the reservoir. A denser OBN design with nodes placed 50m and source points 100m from turbines can reasonably be expected to do much better, and should be modelled. The OBN 4D data would then be able to monitor the spread of the CO2 plume in the reservoir, and also detect if any CO2 has breached the primary seals (Rot clay and Rot halite). Repeat P-cable surveys could be run quickly after any indication of seal breach, or if CO2 is detected at the seabed with non-seismic monitoring methods, and provide an ability to see if and how the CO2 has risen up through the shallowest part of the overburden (sea bed to 200m TVDSS).

In general, OBN may give better 4D repeatability than streamer because the uncertainties of towing a 3-4km long streamer (e.g. feathering) do not exist with OBN. There are OBN 4D baseline surveys acquired with the expectation of monitor surveys to come in the next few years (e.g. Total in Qatar [17] and [18]). The reason there has not been more 4D OBN already is the high cost in comparison to streamer.

There will be room for a source boat to sail between turbines, particularly if the wind turbines are on a 2km x 2km grid as proposed by Orsted. However, it is also correct to say that the coverage of source points will have gaps of at least one hundred metres (at the surface) around each turbine. The impact of this with different node and air gun configurations needs to be modelled, particularly the smaller air gun array sizes described by bp in Sutherland et al [27].

It should be eminently possible to do detailed survey design modelling for a range of OBN (and streamer) source and receiver layouts that demonstrate what data quality (in terms of s/n and bandwidth) are achievable, and combine those with relevant cost assumptions. Has this been done by bp or any other party yet? The summaries and descriptions presented by bp, that I have access to, contain only partial details of the underlying technical or commercial work that bp's opinions are based on.

OBN is going to be the only realistic way to acquire seismic data in a wind farm, probably in combination with short streamers (such as P cables). The main objection to OBN must be the cost rather than the technique or the data quality when compared to streamer. And while this is a valid concern, it is ultimately an economic one. It would be useful to model the overall economic impact of reducing the size of Hornsea 4 to totally avoid Endurance, compared to the economic impact of acquiring 4D OBN instead of streamer, and various other combinations of wind farm and seismic survey layouts.

Section 7.3.3 and Figure 34 (reproduced below) describe the challenges related to strong currents in the Endurance area. bp states "*Acquisition in the area around Endurance is complicated by the strong tidal currents. The maps below illustrate the change of direction of the dominant current every 12 hours. This will make sailing the seismic source boat along specific lines inside the windfarm difficult. We anticipate that at least 25% extra time will be required for weather restrictions and difficulty in achieving matched source-receiver pairs for accurate 4D differencing.*" Data acquisition problems related to strong tides are going to be worse for streamers compared to OBN when it comes to matching source-receiver pairs between survey, whether or not there is a wind farm in place.

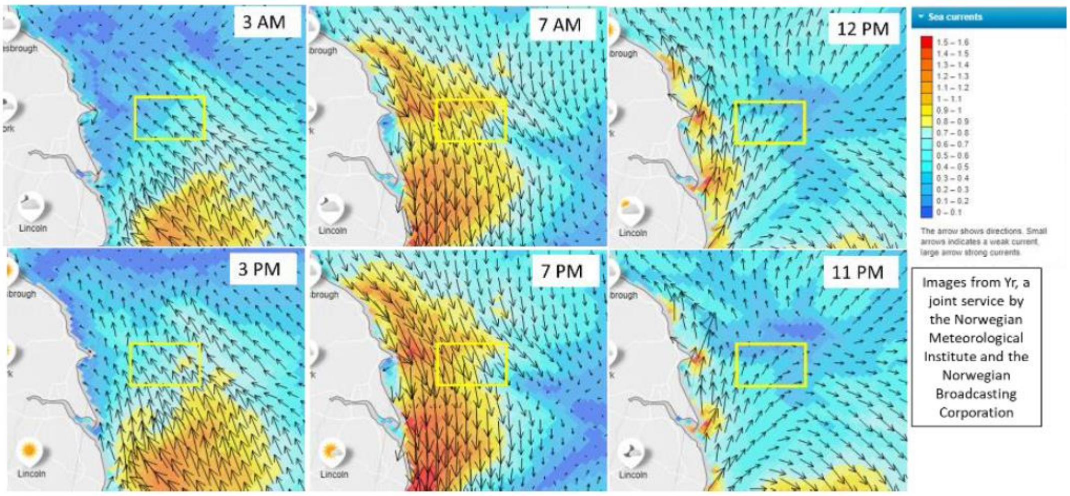


Figure 34: Example of variation in current direction and strength in the area (yellow box) over a 24-hour period (22/09/21)

In section 7.3.4 bp moves on to discussing the Sleipner CCS project as the key example for endurance to use as a benchmark. bp makes the point that Sleipner has used towed streamer data acquisition for its 3D/4D seismic, and that therefore this "*demonstrates that towed streamer seismic monitoring is the most efficient and effective means of acquiring the high resolution data needed to verify containment and conformance of the CO2 plume within the storage site*". Using Sleipner as an example as bp does is fine. However there are so few CCS saline aquifer projects offshore that it cannot be assumed that Sleipner shows the only way to do it. There is a good argument that one should use the best technology available at the time for each monitor survey, and aim to acquire the highest s/n and broadest bandwidth data possible. And indeed this is what has happened at Sleipner. It is inconceivable that operators will use old technology when acquiring repeat 4D surveys just because the original baseline only had that technology available at the time. It is certainly possible that nodes (maybe permanently placed) will become the standard technology for 4D seismic.

The experience from Sleipner also shows that quite significant changes in the design of the repeat streamer surveys, and changes in equipment, do not remove the ability of the seismic to produce meaningful 4D results [13] [14]. Furre et al, 2017, [14] say this about the seismic monitoring at Sleipner: "*The seismic monitoring programme at Sleipner consists of repeated 3D towed seismic surveys, acquired in 1999, 2001, 2002, 2004, 2006, 2008, 2010, 2013, and 2016 .... Seismic acquisition technology has improved significantly over the last two decades. Most surveys were acquired using conventional streamers, with increasing number of receiver cables over time. Also source and receiver configurations, and even tow direction have varied over the years .... The six first acquisitions were .... not optimized for the CO2 monitoring at shallow depths, neither in the initial base line nor the later repeats. Two surveys were acquired using broadband technologies; dual source in 2010, and slanted cable in 2013. The repeated datasets have all been through a common time-lapse processing to enhance repeatability ..... Despite these challenges related to variation in acquisition parameters and image quality, all surveys have been valuable for understanding the CO2 plume development. This favourable outcome is attributed to the time-lapse processing and the large contrast in acoustic properties between the in-situ saline aquifer and the injected CO2.*"

The website [redacted] [11] contains a summary of the acquisition parameters used for Sleipner 4D surveys between 1994 and 2010, and shows some of the differences highlighted by Furre et al. Nonetheless the 4Ds have been successful at tracking the CO2 plume.

Survey	ST9407	ST9906	ST0106	ST0403	ST0607	ST0814	ST10018
Date acquired	6/8/94 - 10/9/94	8/10/99 - 10/10/99	27/9/01 - 1/10/01	13/6/04 - 13/8/04	2/6/06 - 20/6/06	4/5/08 - 15/6/08	15/10/10 - 17/10/10
Shotpoint interval [m]	18.75	12.5	12.5	18.75	18.75	18.75	12.5
Streamer type	Nessie III	Nessie IV	Nessie IV	Syntrak	PGSRDH / Teledyne	PGSRDH / Teledyne	Geostreamer
No. of cables	5	4	6 (on 4 streamer preplot)	10	8 (on 6 streamer preplot)	9 (on 8 streamer preplot)	12 (on 10 streamer preplot)
Cable separation [m]	100	100	100	37.5	100	50	75
Swath separation [m]	250	200	200	250	300	200	375
Cable length [m]	3000	3600	1500 (3000)	4500	3600	3000	6000 (1500)
Near offset [m]	195	165	150	77	130	130	85
Tow depth [m]	8	8	8	8	8	8	15
Bin-size acq.	6.25 x 25 m	6.25 x 25 m	6.25 x 25 m	6.25 x 18.75 m	6.25 x 25 m	6.25 x 25 m	6.25 x 18.75 m

The following image taken from [13], Raknes et al, 2015, shows the fold of coverage of the Sleipner baseline survey in 1994 compared to the repeat survey in 2006. Fold of coverage is a proxy for s/n. As can be seen the fold maps are quite different. Nevertheless the 2006 survey still provided useful CO2 monitoring data.

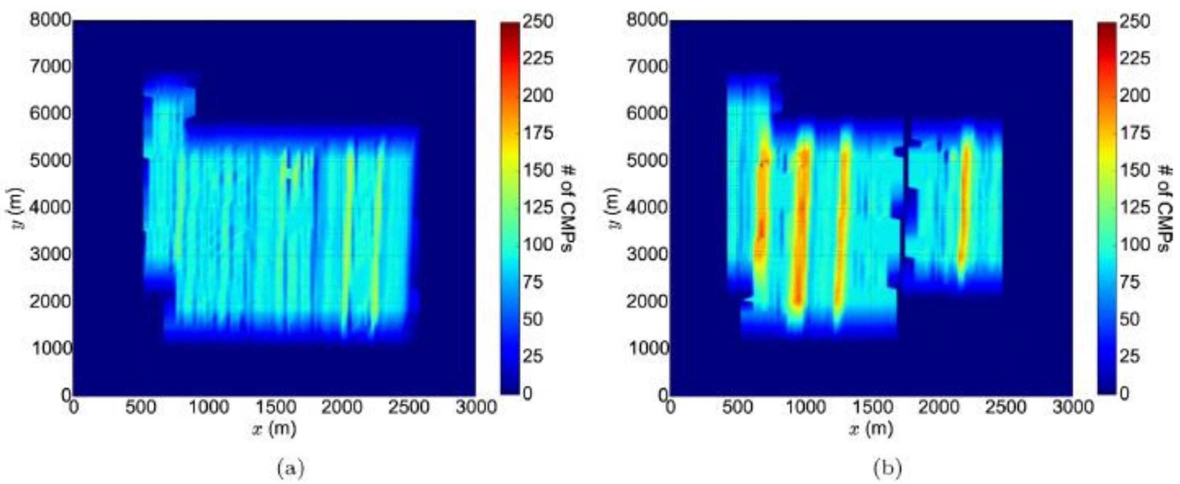


Fig. 4. Fold map of (a) 1994 dataset and (b) 2006 dataset.

The following paragraph from [14] Furre et al is also interesting as a conclusion from the operator of Sleipner as it shows that they believe ocean bottom systems are technically capable, and maybe the preferred method for CO2 monitoring. "*It is possible to take remote CO2 injection monitoring one step further, by installing sensors on the sea bed instead of operating streamer surveys. The added value of three component data would provide separation of compressional and shear waves, which could in turn provide aid in pressure and saturation separation. The ability to monitor geomechanical changes through shear-wave splitting is an important new use of multicomponent seismic data. Retrievable Ocean Bottom Seismic (OBS) surveys are, however, usually several times more costly than streamer surveys, …. Permanent Reservoir Monitoring (PRM) seismic systems on the other hand could be an option. Though these have relatively high initial installation costs, they might over time be competitive with towed streamer surveys, depending on sampling frequency. …. Permanent systems usually have superior repeatability over retrievable systems …. A permanent layout could in particular compete with towed streamer data if there are sea surface installations at the field. Such installations would prevent the towed streamers from accessing the area near the installations….*"

<u>Conclusion on this section:</u>

bp states that towed streamer acquisition will not be possible within a wind farm and I agree with this in respect of streamers with any length beyond a kilometre, but shorter streamers, such as P-Cable, are feasible. bp does not rule out the use of OBN but essentially makes three claims. The first is that the experience of Sleipner shows that towed streamer is the only proven method of acquiring seismic data for 4D CO2 monitoring. While it is true that Sleipner uses towed streamer, this does not mean that other acquisition methods cannot. In fact the operator of Sleipner does not rule out the use of OBN for 4D CO2 monitoring. Furthermore OBN has some inbuilt advantages over towed streamer and there are many examples of OBN providing higher quality data. bp's second claim is that OBN is significantly more expensive than towed streamer. This is generally true, although does depend on acquisition geometry. However if towed streamer cannot be used in a wind farm, and both CCUS and wind farm projects are approved, then OBN/OBC will be the only option for acquiring 3D seismic. The third claim is that other technologies such as compressive sensing or passive seismic will not be a substitute for properly acquired 3D seismic data, and I agree with this.

2.4 Position Statement between Hornsea Project 4 and bp

<u>Orsted's position paper</u>

The below comments relate to *Section 5: Status of discussions* from the combined Orsted-bp submission of March 2022 [4], that starts on page 7.

Section 5.8 states that "*It is understood on bp's timescales that the third survey is therefore unlikely to occur before 2032. The Applicant therefore considers it highly likely that either the cost of Ocean Bottom Node seismic monitoring will have significantly reduced or emerging technology would have reached maturation to allow for seismic to be undertaken with wind turbines in situ, particularly with the added certainty of a sparser layout*."

I don't agree that this is highly likely as described. OBN may always be higher cost than streamer and making predictions about seismic technology is difficult. Current technology allows for non-streamer seismic to be acquired in wind farms anyway. The issue is about how well the near surface of the seabed can be imaged given the exclusion zones around the turbines. This can only really be understood by forward modelling and/or field trials, and it does not appear that sufficient work has been done on this by either party. Forward modelling of seismic data is an established technique that creates synthetic seismic models from known geological information. This can be in 3D and is used to simulate the result of a seismic survey and more specifically to estimate the expected seismic expression of a geological feature or fluid effect, such as CO2 replacing brine in the Endurance reservoir and (overburden).

I am in agreement with section 5.8.3 where Orsted states "*For the avoidance of doubt the Applicant maintains that OBN seismic monitoring and short offset towed streamers are available today. The focus therefore is the application of acquiring seismic data for CCUS utilising this existing technology*."

<u>bp's position paper (summary)</u>

bp lays out its overall position in a document titled "SUMMARY OF bp POSITION WITH REGARD TO THE IMPACT OF HORNSEA 4 ON THE NORTHERN ENDURANCE PARTNERSHIP PROJECT" which is part of the combined Orsted-bp submission of March 2022 [4].

bp claims in section 6.6 that it is necessary to use "*the same technology and control parameters*" each time repeat surveys are required. As shown by Sleipner and other non-CO2 4Ds, this is not necessarily the case. And in fact it could be argued that one would want to use the best technology available at the time to acquire data with the highest possible s/n.

In section 6.8, bp makes the observation that local compartmentalisation may not be fully identified in the baseline image, and that "*4D vessel towed streamer seismic acquisition is particularly effective in detecting compartmentalisation effects*". The imaging of potential compartments and 4D effects for tracking the CO2 plume are not limited to seismic data acquired with towed streamers. Any properly designed acquisition should provide this, whether streamer or ocean bottom systems are used.

In section 6.9 bp makes the point that OBN and other alternatives to towed streamer do not have the "*equivalent level of proven track record, particularly in shallow water and shallow geology like that of the Endurance Store in the SNS*". This may be the case but, as previously discussed, ocean bottom systems do have a track record of good quality imaging in such an environment if an appropriate survey design is used. bp has not presented the detailed modelling and survey design studies to demonstrate the benefits vs costs of streamer and OBN for this project. Has this work been done?

In section 8, bp states that the seismic technology described in the second OREC-NZTC report [3] is immature and not suitable for CCUS 4D. Also that the report agrees with bp's view and supports its case. As discussed elsewhere, I would agree with bp that some of the options suggested in the OREC-NZTC report [3] would not be suitable, however the use of OBN is potentially suitable and further work to demonstrate this is required. While there are clearly areas where bp's assessment is supported by the comments in the OREC-NZTC report [3], it is also clear that they do not fully agree. bp's position is that using towed streamers is the only proven method of acquiring 4D seismic for CO2 monitoring, and that this is precludes any wind turbines being placed in the overlap zone. Orsted and OREC-NZTC believe that an acceptable solution for both parties can be found which would enable bp to acquire 3D seismic data suitable for CO2 monitoring, and allow Orsted to construct wind turbines in the overlap zone.

Section 14.3.3 states that "*the technological developments that would need to happen in order for NEP to use anything other than 4D vessel towed streamers will not occur before a FID decision has to be made in 2023 (see Sections 8 and 9 above)*." bp should demonstrate clearly that the existing technology (OBN, P-cable) is not going to be suitable. The current presentations and reports that I have access to do not contain the detailed modelling work to show this.

bp makes the point in 14.4.2 that if they were to deviate away from towed streamer then it would "*need to be sufficiently proven and reliable that the relevant regulators would need to agree to any proposed change*". Currently the regulator's view on seismic technology to use for CCUS is not fixed yet and one would hope that they would be open to any method that can be shown to have a high chance of succeeding though suitable modelling and field trials.

bp is correct to say that OBN has not been used for 4D CO2 monitoring before. Similarly neither P-cable nor any other very short streamer systems, have been used for this purpose. I am also not aware of OBN and P-Cable being used together in a planned 4D "hybrid" survey, either for oil and gas or for CO2 monitoring. However, there are very few large scale CCS projects injecting into saline aquifers and only two offshore with any history, Sleipner and Snohvit in Norway. Of those two, Sleipner is the one with the longer history and more substantial data released. bp is essentially recommending that future projects have to follow the Sleipner model. This is quite a restrictive approach.

There can be little doubt that OBN technology is capable of acquiring high quality 3D data for 4D purposes. It has been used multiple times around the world for acquiring 3D data and there are increasing examples of its use for 4D in an oil and gas context.

Kiyashchenko et al [20] describe the use of OBN for time lapse seismic monitoring (4D) offshore Brazil. Detomo et al [12] describe the acquisition of an OBN 4D baseline survey in Nigeria and compare it to the previous 4D streamer data on the same field. They concluded that the OBN data quality is comparable or better than the streamer seismic and that, although it was not part of the design, they were able to see significant 4D results comparing the OBN data to the previous 4D streamer surveys. Brunellière et al [18] also compare new OBN 4D baseline data with previous streamer data and conclude that the OBN shows improvements in data quality and resolution.

Conclusion on this section:

The documents reviewed for this section largely go over the same ground as the previous sections. bp reiterates the same point as in several places that repeat surveys must use the same technology and match the baseline survey as closely as possible. The history of Sleipner, and other 4D surveys generally, is that the latest technology is often used for repeat surveys, and that locations of source and receiver can differ significantly between surveys without compromising the ability of the 4D data to image the CO2 plume.

2.5 bp's response to Orsted's Deadline 1 Submissions (REP2-062)

In section 5.2 bp reiterates the comments made in section 8 of its submission (position paper) which are that Orsted's submission and the 2022 OREC-NZTC report [3] are aligned with bp's own view about the feasibility of different seismic acquisition systems being able to acquire adequate data in the overlap zone.

In section 5.3.1 bp states that there are no proven technologies that will enable seismic data of sufficient quality to enable 4D monitoring of Endurance to be acquired in the presence of the wind farm. OBN and P-cable are both proven technologies. What needs to be demonstrated through an approach such as forward modelling is whether there are survey designs based on these acquisition systems that will provide the necessary imaging. Referring back to the frames I described in the Introduction, if one determines that it is important to find a way for the two projects to co-exist then the task is to show through modelling, and/or field trials, that adequate seismic data can be acquired for a given turbine spacing. Then the question becomes at what cost, and is that cost acceptable given the economics of both projects? That is something that can be determined through economic modelling of the various configurations available for NEP and Hornsea Four. The overall value of both projects to the UK is also a consideration, and some of that transcends purely economic value.

In sections 5.3.3, 5.4 and 5.5 bp implies that the regulator would require evidence of the successful deployment of any technology other than towed streamer before approving its use for CCUS. It may be the case that bp has already had clear indications from the regulator that any OBN would not be allowed. But this would be surprising given that OBN is a proven technology for acquiring high quality seismic data. I would suggest that it is worth having these discussions again with the regulator, if backed up by modelling work that shows an OBN-based seismic monitoring scheme can provide the required 3D data coverage and quality at Endurance specifically. There are very few large scale CCS projects injecting into saline aquifers and only two offshore with any history, Sleipner and Snohvit in Norway. Of those two, Sleipner is the one with the longer history and more substantial data released. bp is essentially recommending that future projects have to follow the Sleipner model. This is quite a restrictive approach.

2.6 bp's Submission for Deadline 3 (REP3-047)

2.6.1 NSTA Carbon dioxide storage permit application guidance

Section 1.1.1 describing the Seismic Database needed contains "*To make a detailed evaluation and delineation of the storage site and complex, recent high quality seismic data is required as a baseline survey. Consideration needs to be given to the repeatability of the baseline survey if time lapse monitoring is required in the future.*" Although not specifically mentioned, it is clear that NSTA is describing 3D seismic data as the requirement.

Appendix 2, section 2. Monitoring plan, final paragraph states "*The choice of monitoring technology will be site specific and based on best practice available at the time of design*."

Section 2.1 contains "*The types of monitoring measurements that could be considered include: Time Lapse Seismic, 4C Seismic – for certain storage sites seismic data monitoring* ***may*** *be appropriate to detect the movement of injected*

CO_2 plume into the formation. This can either be a time-lapse seismic monitoring where 3D surveys are repeated at various intervals over time, or as a 4C seismic survey where Ocean Bottom Cables are permanently installed *and able to record the shear (S) waves as well as the P waves. A baseline seismic survey will be required prior to commencing injection of CO_2. The value of deploying these techniques will be dependent on the depth and geology of the storage site and shall be* ***reviewed on a case by case basis****.*" My emphasis.

NSTA is leaving it open for deciding what is appropriate on a case by case basis. But the one technology they highlight is an ocean bottom system. Towed streamer is not mentioned specifically.

2.6.2 HSF Legal Note on Consenting Regime for NEP

Section 6.4 quotes Reg 8 of the Storage regulations, which deals with Monitoring, and 7.1 highlights the requirement that updates to the monitoring plan should take account of "*improvements in best available technology*". However, 7.2 acknowledges that NSTA does not provide a list of "best available technology" that should be used. In fact, as described above, the only seismic acquisition technology mentioned by NSTA in it's guidance document is an ocean bottom system.

Despite this, 7.4 states bp's opinion that towed streamer is the "*best available technology*". In 8.1 bp acknowledges that OBN and short streamer are "available" and by implication therefore possible solutions, but questions whether this is "best available" for Endurance. Given that OBC/OBN provides 4C seismic data, as mentioned by NSTA (see above), while towed streamer does not, it could be argued that OBC/OBN is the "best available technology". Anyway, bp has not yet presented clear evidence via modelling and design work that OBN (plus P-cable) will not provide an acceptable solution for Endurance.

8.2 says that "*It is important to note that in assessing what is 'best available technology', the NSTA will not be able to take account of the fact that bp's options are limited by the existence of the windfarm above part of Endurance, and therefore accept a lower standard of imaging. The NSTA will expect the best possible image quality, particularly given that this is a first of a kind project*." Firstly, if BEIS decides that co-existence is compulsory then NSTA will take account of the limited options (i.e. no towed streamer, greater than 1km). Secondly, as stated before, bp has not yet demonstrated that OBN plus P-cable gives a "lower standard of imaging" than towed streamer (exceeding 1km).

8.3 acknowledges that NSTA refers to OBC and then argues that OBC and OBN are different because of how they are powered. That is irrelevant to imaging and data quality. It then argues that OBC and OBN will have the same problems with "*seabed tidal movement*" and therefore provide lower quality data then towed streamer. While I agree that this is a potential problem for ocean bottom systems, at present bp's opinion is not supported with evidence. Some simple field trials at the Endurance site would provide data to show how big of a problem this might be for ocean bottom systems.

In section 9 HSF discusses the "hybrid solution" without defining what that is. By implication it is OBN plus short streamer (P-cable). The use of the hybrid solution is framed as being used for repeat surveys after a baseline is established with towed streamer. As I have already described, both OBN and P-cable are established technology and do not need further development to be applicable to CO2 monitoring. What is needed is modelling to demonstrate that such a hybrid solution can provide data that is capable of imaging the CO2 store at least as well as towed streamer would, and with the added advantage of providing 4C data. Then it can be used from the start, and provide the baseline.

2.6.3 bp's response to the Jan 2022 OREC/NZTC report

I am limiting my comments on this document to only those which are additive to previous comments, because I have already reviewed and commented on the documents that bp is referring to.

In 1.1, 1.9.1 and elsewhere bp refers to OREC/NZTC (and Xodus) as the Energy Transition Alliance (ETA). bp suggests that the ETA report of January 2022 was written in response to bp's technical assessment report but that it does not refer or respond to it in any way. My understanding is that the ETA report was commissioned and largely completed before bp's technical assessment was released, which would resolve the inconsistency that bp is questioning.

In 1.9.4 bp states "*the OREC/NZTC report's analysis of what theoretically might be possible in terms of MMV for the NEP project is based on the ETA's* "inference of likely activities" *based on its* "review of the MMV plan proposed by the White Rose project". *The use of that plan from 2016, and* "inferences" *drawn from it, indicates the OREC/NZTC report does not take account of the extensive site specific information about Endurance and its development plan as described in the bp Technical Assessment or reflect the detailed review and assessment of that information and plan undertaken during Orsted's and bp/NEP's discussions and collaboration over the course of the last two years*."

In 2.9 bp states "…. *the development of Endurance by NEP will use much more of the capacity of the Endurance store and is a phased development with many more CO2 injector wells than was envisaged by the White Rose project. The increased number of injector wells means the MMV needs across the entire Endurance store is more significant by comparison. For example, particular 4D seismic monitoring, which provides a time-lapsed 4D image of CO2 in the store, is needed in order to ensure the additional wells are correctly located in the Endurance store*"

Time lapse 3D seismic across the Endurance storage site was a part of the White Rose plan already. Section 5.8.2.3 of the K42 White Rose report describes it thus "*The development of the plume and the migration of the injected CO2 to its crestal location is not critical for the operation of the injection wells. As it will not affect either the rate or volumes of CO2 injected, it is proposed to* ***minimise the frequency of the 3D surveys*** *and to* ***constrain the area of the surveys to the injection wells and the crest of the structure*** *where the migration footprint will be present*." My emphasis

I have reviewed bp's technical assessment report as well as other submissions to the Examining Authority and have not seen any description of precisely how the surface seismic part of the MMV has been changed from the White Rose project plan in 2016. I assume that the area has been increased to cover the entire storage site, but not the entire monitoring area as that would include the Bunter outcrop to the east. Has the frequency and number of repeat surveys also increased compare to the 2016 plan? It would be useful if bp could be specific about these issues, with for example, maps comparing full fold survey outlines.

In 2.19 bp takes issue with OREC/NZTC stating that ocean bottom surveys typically provide better data quality by stating that "*This is a generalised statement and is not applicable to the Endurance structure which is in shallow water (~60m) and has a relatively shallow crest (~1000m below seabed).*" However it is still the case that ocean bottom surveys are generally regarded as providing better imaging, and also as previously noted provide additional useful shear wave data. This would also be applicable to a shallow imaging target such as Endurance if a sufficiently dense layout of ocean bottom receivers is used. As previously discussed in section 2.2. of this report and elsewhere, this then boils down to how much will it cost to provide sufficiently good imaging at different depths with an ocean bottom system.

In 2.19 to 2.24 bp makes the argument that ocean bottom systems, and OBN in particular, will be susceptible to the receivers being moved around by the sand waves on the seabed in the Endurance area. In my opinion this is likely to be the main technical challenge for the use of nodes in this area. If too many nodes change position during the acquisition of a survey then it will degrade the 3D imaging and the utility of the data for 4D monitoring. However bp has not provided much evidence of this and in the Q&A following the OBN workshop in October 2019 [8], bp stated that "*we have not done detailed modelling of what the impact is*". The magnitude of this problem could be quantified with some reasonably simple field trials and modelling work which I would recommend is done as soon as possible. bp also makes reference to the strong tidal currents in this area being a particular problem for OBN. In general strong currents would be more of a problem for 4D with long towed streamers than OBN.

Section 2.23.2 provides some photographs of nodes being deployed by rope, which is the fastest method for OBN. Nodes can also be deployed by ROV (remote operated vehicle) which can allow individual nodes to be placed closer to infrastructure such as wind turbines. bp also provides a link to a Geo Expro article which discusses OBN and how nodes are deployed, and the potential for autonomous deployment at a lower cost. bp correctly notes in section 2.18 that the autonomous technology is not yet commercial and so cannot be used for planning MMV at Endurance. However nodes on a rope, and deployment by ROV are both viable options and mature technology.

The Geo Expro article linked by bp is a good summary of OBN and opens with "*It is generally accepted within the seismic acquisition industry that seabed seismic receivers deliver superior seismic data and consequently better seismically derived subsurface images. However, seabed receiver or ocean bottom node surveys (OBN) are currently not as widely used as towed streamer seismic, primarily because of the higher acquisition costs. In general, seabed surveys are only considered for the most challenging geophysical objectives such as reservoir management projects and the imaging of complex geological objectives where high repeatability and full azimuth measurements are required. A modern quality OBN design can deliver many times the data of a streamer survey. It may also offer superior azimuthal distribution, and in some cases can even be more cost effective through higher productivity enabled by simultaneous source acquisition and refinements in node handling systems*."

Section 2.26.1 states that OREC/NZTC "*does not provide any examples of an offshore CCS/CCUS facility in the world using OBN or OBC to acquire seismic imaging for purposes of MMV*". As I have already described there are only two offshore saline aquifer CCS projects globally at the moment, Sleipner and Snohvit. These both used towed streamer for 4D seismic, but that does not mean all future CCS projects need to use towed streamer.

In 2.26.2 bp makes the claim that NSTA Guidance "*refers to the possible use of OBC to carry out monitoring, but only if they are permanently installed*". What the guidance actually says is "*This can either be a time-lapse seismic monitoring where 3D surveys are repeated at various intervals over time, or as a 4C seismic survey where Ocean*

Bottom Cables are permanently installed and able to record the shear (S) waves as well as the P waves". This is clearly not intended to demand that any ocean bottom system needs to be permanently installed, or to be prescriptive as to allowed methods, or it would also rule out the use of towed streamer, which is not explicitly mentioned.

2.26.3 discusses the use of nodes permanently installed on the seabed and says "*Permanent arrays are also known as PRM (permanent reservoir monitoring). Essentially PRM involves leaving OBNs on the seabed for the lifetime of the project. As bp has described above, using OBNs is not feasible given the seabed and tidal current conditions where Endurance is located. The problems that exist in terms of using OBNs for a specific survey also apply to installing OBNs for the duration of the NEP project. Additionally, the batteries on each node only last for a matter of months, making permanent installation impractical.*"

There are reportedly now systems with nodes that can last for up to five years on one battery charge. However I agree that even this would not be long enough for the duration of the NEP project and therefore the nodes would need to be picked up for recharging at some interval. It might be possible to acquire the baseline and the first repeat surveys without picking up the nodes. Having said that, the longer the nodes are left on the seabed, the more likely they are to be moved by the sand waves. So it would be more sensible to plan for deploying and retrieving nodes for each survey.

In the section quoted above and in other documents, bp makes the claim that the strong tidal currents in the area are a particular problem for OBN. I do not follow the reasoning for this as the currents will affect any data acquisition method. I believe bp is referring to the claim it makes in section 7.3.3 of its Technical Assessment report that the strong currents will make sailing specific source lines within the wind farm difficult and add at least 25% to the survey duration. I would be interested to see how this was evaluated. Once again this something that could be investigated in the field in the short term. But in any event it is going to be an issue for any acquisition method and regardless of whether there are wind turbines there or not.

In 2.28.1 bp states that "*the possibility of using short-streamer (e.g. P-cable) acquisition was investigated in detail by bp. Streamer length determines the depth of imaging in the subsurface, and bp conducted tests on streamer lengths*". The information provided by bp so far does not contain any details on this testing. Is there a report that can be provided?

The rest of this section explains why (a) the short streamer systems such as P-cable will not be able to image the Bunter reservoir adequately on their own, and (b) it will not be possible to use towed streamers of any length sufficient to image the Bunter reservoir at Endurance, and I agree with this assessment.

2.28.2 again covers some of bp's reasons for identifying towed streamer as the preferred option which are related to seismic resolution, and which I have already commented on when reviewing bp's Technical Assessment report. However it includes a reference to some modelling work with "*bp has also carried out seismic rock property modelling of CO2 replacing brine to understand what resolution of seismic data is required for the Endurance store*". This is shown briefly in bp's Technical Assessment report in section 7.3.1 and figure 25 of that report. However I assume that is a small part of a larger study, which it would be useful to review if bp can make it available.

3 CONCLUSION

The table below summarizes my opinion on the key issues.

ISSUE	OPINION
Requirement for 'long' towed seismic streamers	It is not the case that only towed streamer can be used for 4D CO2 monitoring. Ocean Bottom systems such as OBN could be suitable. However cost will be a key issue.
Technical applicability of OBN technology	Technically, a combination of OBN and short streamers under 1km length (e.g. P-cable) would be feasible for CO2 monitoring.
Commercial feasibility of using OBN for Endurance CCS monitoring	There is a lack of survey design work based on seismic forward modelling studies to be able to understand the cost of a technically adequate OBN-based solution.
The impact of seabed sand waves on the use of OBN at Endurance	This is one purely technical/logistical issue that could make the use of OBN inappropriate. However it has not yet been adequately studied to draw any firm conclusions.
bp's argument that new technology enabling co-existence will not be available for another 10-20 years	I agree with bp's comments about the unproven technology. However OBN and P-cable are not one of them and should enable co-existence already.
The impact of a more sparse wind turbine layout with a 2x2km grid on the options for seismic monitoring	A sparser turbine grid will make any seismic acquisition easier, but will still not allow conventional towed streamers longer than 1km to be feasible within a wind farm.

There have only been two long term offshore CO2 storage into saline aquifer projects worldwide, Sleipner and Snohvit, both in Norway. While these provide valuable insights, they cannot be said to define how CO2 storage should be done offshore in all future cases.

bp's position is that Sleipner shows that the only proven method of acquiring seismic data for CO2 monitoring is using towed streamers, and that this is precludes any wind turbines being placed in the overlap zone. Orsted and OREC-NZTC believe that an acceptable solution for both parties can be found which would enable bp to acquire seismic data suitable for CO2 monitoring, and allow Orsted to construct wind turbines in the overlap zone.

There has not been sufficient detailed survey design and evaluation work presented by either party to be able to demonstrate with confidence whether towed streamer is the only method that will deliver seismic data of sufficient quality, or whether an OBN-based solution can also deliver such data once wind turbines are constructed. The use of forward modelling techniques to evaluate these issues should not be particularly time consuming or expensive. Modelling of this nature was undertaken prior to 2016 as part of the White Rose project planning, as described in the K42 report [19], but this modelling appears to have been focused on demonstrating that 3D seismic should be able to detect CO_2 replacing brine in the reservoir, rather than examining different data acquisition and processing options.

Ultimately this is not only a technical argument. Both towed streamer and OBN based 3D seismic programmes should be able to provide the necessary 4D seismic monitoring of the CO_2 plume. Towed streamer will have a lower cost and is the default choice for a reservoir such as Endurance if there is no requirement to consider an overlap with a wind farm or any other infrastructure at the surface. However if it is necessary to find a way for wind farms and CCUS to co-exist, then conventional towed streamer (with cables longer than 1km) is not possible and OBN is the only viable technology, probably combined with a system such as P-cable. This latter option may be more expensive in terms of seismic costs, but the overall economic and environmental value of having both a wind farm and a CCUS project operating in the same area could outweigh this additional cost.

4 RECOMMENDATIONS

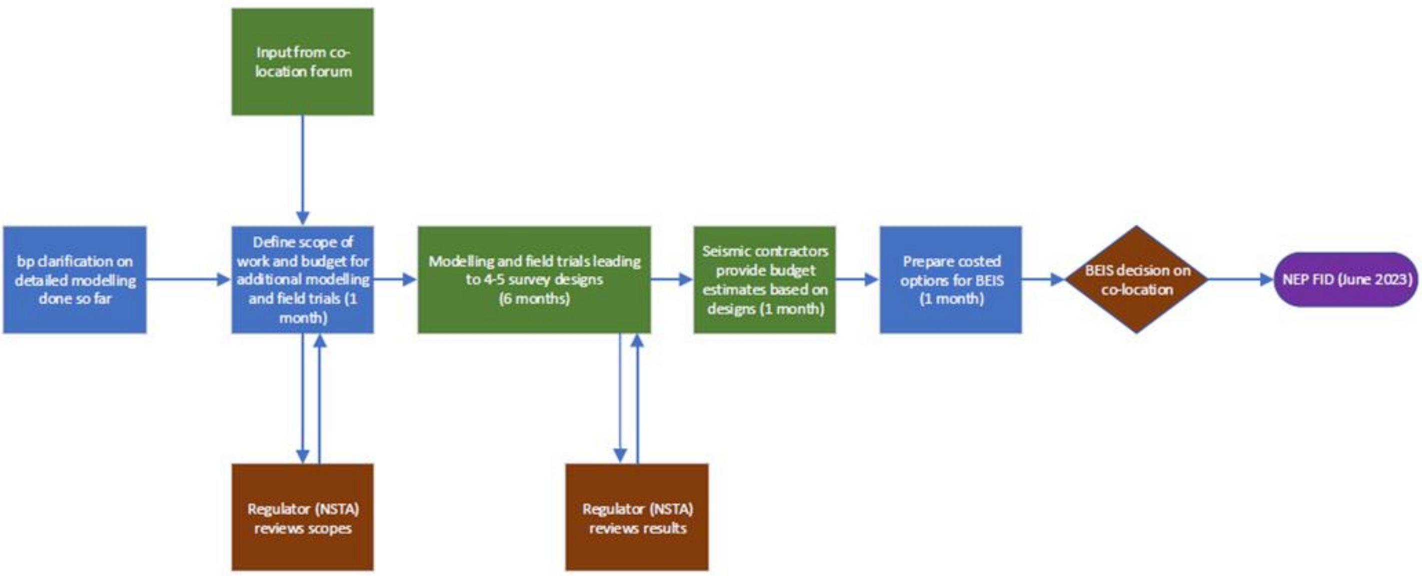
The key recommendation is that comprehensive evaluation of different seismic acquisition and processing techniques and survey designs, using an approach such as forward modelling is needed to investigate the impact on imaging from seabed to Bunter, and thus the ability to monitor the spread of the CO2 plume. Part of this evaluation should include field trials investigating, for example, if the sand waves on the sea bed at the Endurance site will cause a significant problem for the use of ocean bottom systems. The modelling work undertaken prior to 2016 as part of the White Rose project planning, as described in the K42 report [19] could be used as a basis and refreshed.

The modelling would also be able to investigate the potential acoustic noise of an operating wind farm and its impact on the quality of seismic data recorded during 3D surveys.

The financial feasibility of acquiring two baseline surveys, one with towed streamer and the other with OBN, before any development work starts should be evaluated. Acquiring two baseline surveys would provide the greatest flexibility for future CO2 monitoring at Endurance, give more time for the two parties to agree on how the projects can co-exist, and provide valuable data for future CCUS projects, either with or without overlapping wind farms.

This could be undertaken as a Value of Information (VOI) study. There is a detailed decision tree analysis in the K42 White Rose report [19] which provides a methodology that could be used, however that did not include decision support for different seismic data acquisition methods.

The flow chart below illustrates a process for how the proposed investigations could progress to enable a fully informed decision to be made on the feasibility of co-location from a seismic data acquisition perspective. A more detailed decision flow chart is provided in Appendix B.



4.1 Request to bp for additional information

Whilst reviewing the various documents referred to in this report, I have identified some gaps in the available evidence, particularly the technical documents provided by bp. Whilst the absence of this information would not necessarily alter my conclusions or recommendations, it may assist the parties (and me if I am asked to assist) in moving discussions forward. Therefore, I have set out below a list of queries to bp:

1. Ref section 2.27 of [26] bp's Response to the Jan 2022 OREC/NZTC report, slides 8 and 11 of the OBN workshop pre-read [7], and the answer to Q9 in the OBN Q&A document [8]:

   Has bp undertaken detailed 3D/4D finite difference forward modelling survey design projects for different possible acquisition schemes, including different densities of OBN/OBC vs towed streamer, and with/without wind turbines? If so, please can it provide the reports on this exercise.

2. Ref the same as for request 1, and the table in Section 7.0 on page 28 of bp's Technical Assessment [5]:

   Has bp modelled the relative cost vs image quality at different depths for a range of densities of ocean bottom nodes? Please share if available.

3. Ref slides 6 and 9 of the OBN workshop pre-read [7]:

   Does any survey design work undertaken by bp also model the degree to which differences in acquisition parameters between baseline and repeat surveys impacts the ability to detect fluid differences over time?

4. Ref section 2.28.1 of [26] bp's Response to the Jan 2022 OREC/NZTC report:

   bp states that it has investigated in detail the possibility of using a short streamer system such as P-cable for 4D monitoring down to the Bunter reservoir (TVDSS > 1000m) and concluded that it won't be suitable. But has bp modelled how well P-cable can image the near surface (<500m TVDSS) and provide CO2 monitoring for those depths? Please share the results if so.

5. Ref section 2.27 of [26] bp's Response to the Jan 2022 OREC/NZTC report:

   bp implies that it has studied combinations of OBN and P-cable as potential hybrid solutions for 4D monitoring to cover the range for depths from seabed to base Bunter as part of its "significant work and assessments undertaken …. during 2019-2021". Is there a report on this work that can be provided that goes into more detail than what has been provided so far in bp's submissions?

6. Ref the answer to Q7 in the OBN Q&A document [8]:

   bp has stated that a dense layout of nodes Is not possible in a wind farm. What experience or modelling is this statement based on and can it be shared with us?

7. Ref sections 7.3.2 and 7.3.3 of bp's Technical Assessment [5], slide 7 of the OBN workshop pre-read [7], and the answers to Q9 and FQ7 in the OBN Q&A document [8]:

   Has bp investigated the size of source vessel required to tow the smaller air gun array that would be appropriate for the relatively shallow Bunter sandstone target at Endurance? Please share any data on this.

8. Ref section 1.0, third paragraph of page 8, of bp's Technical Assessment [5]:

   bp states that only 30% of storage capacity can be used if there are no brine production wells. Is the work that underpins this estimate available for review? The 2016 White Rose reports do not cover this.

9. Ref section 2.9 of [26] bp's Response to the Jan 2022 OREC/NZTC report:

   bp has stated that the CCS project is now significantly different from when it was White Rose and will require many more CO2 injection wells for example. However it has not made clear how the MMV plan is different from that which is described in the K42 White Rose report for example. Please can bp explain what are the significant changes in the MMV plan with regards to surface seismic.

10. Ref section 2.9 of [26] bp's Response to the Jan 2022 OREC/NZTC report:

    What schedule of repeat seismic surveys does bp now envisage for Endurance, or is it still the same as in the White Rose plan?

11. Ref section 2.28.2 of [26] bp's Response to the Jan 2022 OREC/NZTC report and Sutherland et al [27]:

    bp has carried out seismic rock property modelling of CO2 replacing brine to understand what resolution of seismic data is required for the Endurance store. We have been shown a very brief summary of this. Is there a more detailed report that can be provided?

12. Ref section 2.40 of [26] bp's Response to the Jan 2022 OREC/NZTC report:

    What has bp learnt from the use of OBC and now OBN for 4D imaging at the Valhall field?

5 REFERENCES

[1] PN000452-LRT-002 CCUS and Offshore Wind Overlap Report, Catapult (aka OREC-NZTC) for The Crown Estate, April 2021, (aka The Project Vulcan report); available at: [redacted]

[2] Orsted comments on OREC-NZTC 2021 report (Project Vulcan)

[3] PN000520-RPT-001 - Northern Endurance CCUS Co-Location Review, Catapult (aka OREC-NZTC), January 2022 (REP 1-057, Deadline 1 Submission - G1.29 Position Statement between Hornsea Project Four and BP Exploration Operating Company Limited (BP), electronic pages 22-75)

[4] EN010098-001067-Hornsea Project Four - Position Statement with bp, Orsted, March 2022 (REP 1-057, Deadline 1 Submission - G1.29 Position Statement between Hornsea Project Four and BP Exploration Operating Company Limited (BP))

[5] Endurance and Hornsea 4 Overlap - Technical Assessment Report by bp, December 2021 (REP 1-057, Deadline 1 Submission - G1.29 Position Statement between Hornsea Project Four and BP Exploration Operating Company Limited (BP), electronic pages 146-207)

[6] Hornsea Project Four - Endurance Protective Provisions, Orsted (APP-203 C.1.1 Development Consent Order (DCO) Volume C1 draft DCO including draft Deemed Marine Licence (DML) Schedule 9, Part 8)

[7] bp slides for OBN workshop, October 2021

[8] Q&A from OBN workshop, November 2021

[9] bp response to Orsted's first DCO submission, March 2022 (REP2-062 BP Deadline 2 Submission - Response to the Applicant's Deadline 1 submissions and response to the Examining Authority's First Written Questions (ExQ1))

[10] K43: Field Development Report, White Rose, February 2016, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/531187/K43_Field_Development_Report.pdf

[11] CO2 Datashare, Sleipner 4D Seismic Dataset, https://co2datashare.org/dataset/sleipner-4d-seismic-dataset

[12] Ocean Bottom Node Seismic: Learnings from Bonga, Deepwater Offshore Nigeria, Detomo et al, 2012

[13] Seismic imaging of the carbon dioxide gas cloud at Sleipner using 3Delastic time-lapse full waveform inversion, Raknes et al, 2015

[14] 20 years of monitoring CO2-injection at Sleipner, Furre et al, 2017

[15] Feasibility of using the P-Cable high-resolution 3D seismic system in detecting and monitoring CO2 leakage, Waage et al, 2021

[16] Seismic Acquisition and Processing: The Technology Race, KJØLHAMAR et al, 2020

[17] High Density OBN Seismic in Shallow Waters of Arabian Gulf: Acquisition Review and Processing Strategy, Bovet et al, 2020

[18] High Density OBN over Giant Arabian Field: Early Results from P & PS-Waves Processing, Brunellière et al, 2020

[19] K42: Storage Risk Assessment, Monitoring and Corrective Measures Reports, White Rose, February 2016

[20] Unlocking seismic monitoring of stiff reservoirs with 4D OBN: A case study from Brazil pre-salt, Kiyashchenko et al, 2020

[21] 4D/4C Practical Interpretation at the Valhall Field: Dealing with Technology Change, Seismic Imaging Challenge, and Complex Subsurface on a Mature Field, Haller et al, 2019

[22] A Successful 4D Seismic Monitoring in Middle-East Carbonate Reservoir Context, Cailly et al, 2018

[23] 4D Seismic Application in Ravva Field: Methodology, Well Results and Key Learnings, Reddy et al, 2015
[24] NSTA Carbon dioxide storage permit application guidance (REP 3-047, BP Deadline 3 Submission, electronic pages 96-108)
[25] Legal Note on Consenting Regime for NEP, HSF, April 2022 (REP 3-047, BP Deadline 3 Submission, electronic pages 86-95)
[26] BP's response to the 24 Jan 2022 OREC/NZTC report, April 2022 (REP 3-047, BP Deadline 3 Submission, electronic pages 5-36)
[27] Seismic monitoring for subsurface uncertainties at the Endurance CO2 store, Sutherland et al, TLE April 2022
[28] BP Deadline 4 Submission (REP4-059)

APPENDIX A CV

Name & Position	Andrew Sewell, Head of Subsurface, Xodus Group Limited
Qualifications:	MA Physics - University of Cambridge
Professional Affiliations:	Society of Exploration Geophysicists (SEG), European Association of Geoscientists and Engineers (EAGE), Petroleum Exploration Society of Great Britain (PESGB)
Years' Experience:	31

PROFILE

Andy Sewell has an MA in Physics from Cambridge University and 31 years' experience in the oil and gas, and energy transition industries, the first 17 of which were with Seismograph Service and Schlumberger as a geophysicist, operations manager and global discipline manager. Subsequently Andy has been a geophysicist and subsurface manager in consultancy, including working either as a project manager or acting as a technical resource in a wide variety of technical and commercial projects.

EXPERTISE

Management of exploration and development projects

Planning and review of subsurface elements of CCUS projects

Seismic operations (data acquisition and processing) planning and management

Provision of independent technical/commercial due diligence advice to operators, private equity parties, infrastructure funds and trading companies

Preparation of field development plans and Reserve Audits and Competent Person's Reports

Independent Expert for disputes, recent projects:

- Hurricane Energy vs Crystal Amber – I was lead geoscientist on the team providing technical expert witness to Crystal Amber's legal team
- Confidential middle east oil and gas operator in dispute with local government – ongoing work as lead geoscientist on the team providing technical expert witness

EXPERIENCE

Xodus Group Limited	Head of Subsurface	June 2012 to December 2017, and November 2018 to present.
RPS Energy	Managing Director	January 2018 - October 2018
Senergy (GB) Ltd	Head of Subsurface and Seismic Operations	May 2009 to May 2012

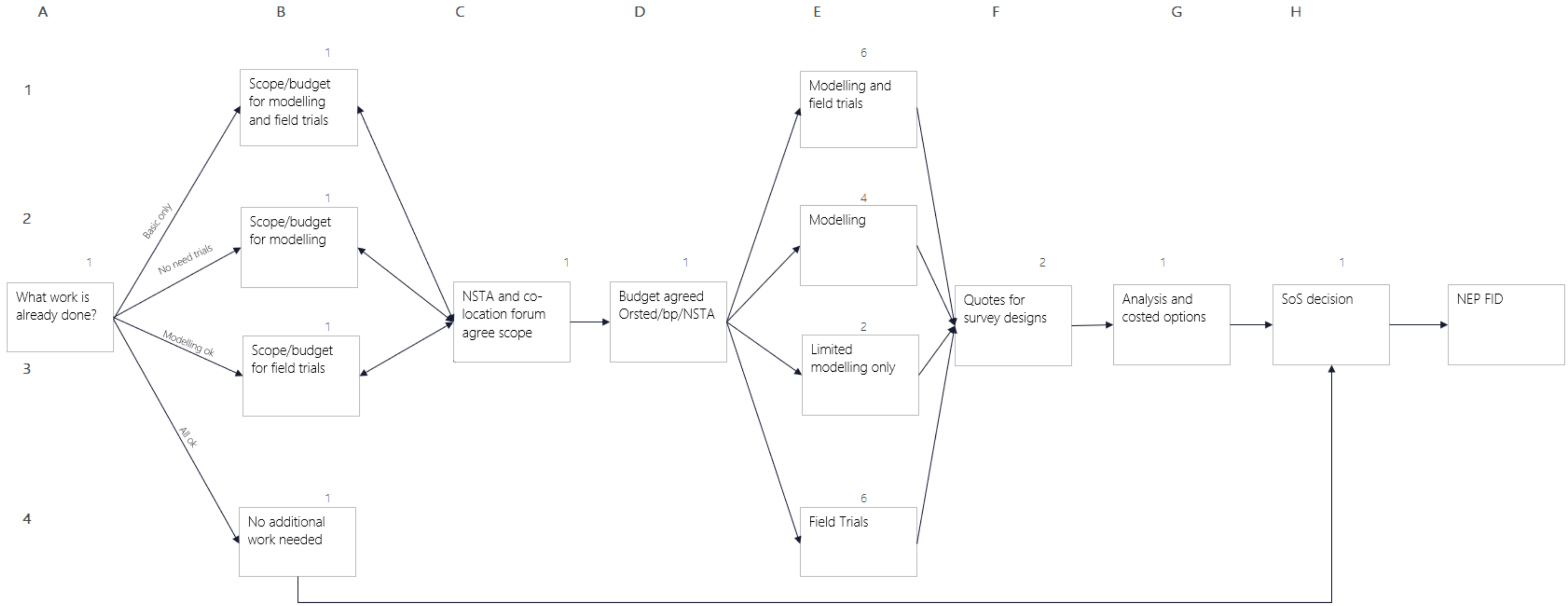
Schlumberger (SSL, Geco-Prakla, WesternGeco)

Global Geophysics Manager	November 2007 - April 2009
North America Operations Manager	February 2006 - November 2007
Global Operations Support Manager	January 2005 - January 2006
Country Manager, Sudan	December 2003 - January 2005
Geophysicist / Operations Supervisor	October 1991 – November 2003

APPENDIX B DECISION FLOW CHART

The decision flow chart shown below indicates some of the choices and outcomes associated with further work that may need to be done to assist the Examining Authority and Secretary of State with making a decision on co-location of Hornsea 4 and the Northern Endurance CCUS project.

The starting point is understanding how much modelling and evaluation work has already been done by bp and others. This ranges from extensive, which would mean there is no need for further work, through to high level only, which would imply that additional modelling and field trials would provide useful information into an informed decision. I have made soe initial assumptions as to how long each step in this process would take, so that an overall timeline for different options can be estimated. The timing ranges from 3 months if no further work is necessary, through to 14 months if a program of forward seismic modelling, survey design and field trials is justified.



Options

A-B4-H	3	months
A-B1-C-D-E1-F-G-H	14	months
A-B3-C-D-E3-F-G-H	10	months

[PART 1

FOR THE PROTECTION OF CARBON STORAGE LICENSEE

Application

1. For the protection of the licensee from time to time of United Kingdom Carbon Dioxide Appraisal and Storage Licence CS001, unless otherwise provided for in this Schedule or otherwise agreed in writing between the undertaker and the licensee the provisions of this Part of this Schedule shall have effect for so long as the Licence shall remain in full force and effect.

2. In the event that—

(a) the licence is terminated and no longer has effect; or

(b) the consents required to develop the NEP Project endurance consents are not obtained by the date specified in paragraph 5;

(b)(c) the licensee has not undertaken and completed the evaluation and shared that with the undertaker,

the obligations on the undertaker in this Part this Schedule shall no longer have effect.

Interpretation

3. In this Part of this Schedule—

"applicable laws" means applicable laws, rules, orders, guidelines and regulations, including without limitation, those relating to health, safety and the environment and logistics activities such as helicopter and vessel operations;

"BP Exploration Operating Company Limited" means BP Exploration Operating Company Limited, with Company Registration Number 00305943, whose registered office is at Chertsey Road, Sunbury On Thames, Middlesex TW16 7BP;

"Carbon Sentinel Limited" means Carbon Sentinel Limited, with Company Registration Number 08116471, whose registered office is at 1–3 Strand, London WC2N 5EH;

"coexistence and proximity agreement" means an agreement entered on reasonable terms between the undertaker and the licensee in respect of the undertaker's works and licensee's works to reconcile and protect the interests of the parties as are known at the time to secure the implementation of the undertaker's works and the licensee's works, taking account of the matters in paragraph 10;

"endurance consents" means all necessary consents, licences and permissions required to allow the licensee to carry out the licensee's works;

"evaluation" means a Value of Information study, including but not limited to:

(a) comprehensive evaluation of different seismic acquisition and processing techniques and survey designs, using forward modelling to investigate the impact on imaging from seabed to Bunter, and the ability to monitor the spread of the CO2 plume;

(b) field trials investigating the sand waves on the seabed and an assessment of the potential for those to impact on the use of ocean bottom seismic acquisition systems to monitor the spread of the CO2 plume;

(c) investigation and assessment of the potential acoustic noise of an operating wind farm and the potential impact of that on the quality of seismic data recorded during 3D seismic surveys;

(d) an evaluation of the financial feasibility of acquiring two baseline surveys, one with towed streamer and the other with ocean bottom seismic acquisition systems, with the objective of achieving the greatest flexibility for future CO2 monitoring in the overlap zone;

(e) field trials to determine the appropriate size of exclusion zone required in respect of the vessels deployed on the NEP Project.

"good offshore wind farm construction practice" means the application of those methods and practices customarily used in construction of wind farms in the United Kingdom continental shelf with that degree of diligence and prudence reasonably and ordinarily exercised by experienced operators and contractors engaged in the United Kingdom continental shelf in a similar activity under similar circumstances and conditions;

"good carbon storage practice" means the maintenance of all apparatus and appliances in good repair and condition and the execution of all operations in or in connection with the area subject to the Licence in a proper and workmanlike manner in accordance with methods and practice customarily used in good industry practice (as defined in the licence) and taking all steps practicable in order to prevent damage to adjoining strata;

"interface agreement" means the agreement dated 14 February 2013 between (1) The Crown Estate Commissioners (2) Carbon Sentinel Limited and (3) Smart Wind Limited, as varied and adhered to by an agreement dated 12 September 2016 between (1) The Crown Estate Commissioners (2) Smart Wind Limited (3) Carbon Sentinel Limited and (4) the Undertaker and a Deed of Covenant and Adherence dated 10 February 2021 between (1) The Crown Estate Commissioners (2) the Undertaker (3) Smart Wind Limited (4) Carbon Sentinel Limited and (5) BP Exploration Operating Company Limited, or such other agreement as may be entered into by the parties in substitution for those agreements;

"licence" means United Kingdom Carbon Dioxide Appraisal and Storage Licence CS001;

"licensee" means the licensee from time to time of the Licence (or any one of them);

"licensee's works" means the installation, operation, monitoring and decommissioning of the NEP Project in the overlap zone; —

~~the operation of any infrastructure existing in the overlap zone; and~~

~~any monitoring in the overlap zone at the time of this Order, or any infrastructure and monitoring to be installed, operated or undertaken (as applicable) in the overlap zone after the date of this Order, and owned, occupied or maintained by or on behalf of the licensee, and authorised by the licence;~~

"monitoring" means ~~any means~~ the monitoring of the licensee's works ~~monitoring~~ within the overlap zone, including repeatable 3D seismic surveying undertaken over periods of up to 5 years, known as 4D monitoring;

"NEP Project" means the Northern Endurance Partnership project comprising an offshore transportation and geological storage facility which is, in part, proposed to be situated in the overlap zone and owned, occupied or maintained by or on behalf of the licensee, and authorised by the licence;

"overlap zone" means the area of seabed with the coordinates below and shown shaded orange on the protective provisions plan;

Polygon Vertex	*Longitude*	*Latitude*
1	1° 0' 34.075" E	54° 8' 51.929" N
2	1° 0' 43.850" E	54° 9' 13.497" N
3	0° 58' 21.782" E	54°10' 49.480" N
4	0° 58' 31.095" E	54° 12' 37.143" N
5	1° 12' 18.263" E	54° 12' 17'413" N
6	1° 15' 35.528" E	54° 10' 48.297" N
7	1° 13' 54.364" E	54° 9' 52.770" N
8	1° 11' 0.989" E	54° 8' 17.458" N

"plan of the licensee's works" means an exploration and development programme, method and details and location of licensee's works and minimum requirements known at that time in accordance with good carbon storage practice and applicable laws to enable the licensee to, as applicable, explore, appraise, develop and/or decommission carbon dioxide storage as permitted by the licence;

"plan of the undertaker's works" means a construction programme, method and details of the proposed location of the undertaker's works and minimum requirements known at that time such as safety in accordance with good offshore wind farm construction practice and applicable laws to enable the undertaker to construct and operate the undertaker's works;

"the protective provisions plan" means the plan entitled protective provisions plan and certified as the protective provisions plan for the purposes of this Part of this Schedule;

"Relevant Activities" means all development activity relating to the carrying on of the undertaker's and licensee's businesses within, or adjacent to the overlap zone, including (but not limited to) the preparation of development proposals, the submission of applications for statutory consents associated with those proposals and consultation in respect thereof;

"Smart Wind Limited" means Smart Wind Limited, with Company Registration Number 07107382, whose registered office is at 5 Howick Place, London, England SW1P 1WG;

"The Crown Estate Commissioners" means The Crown Estate Commissioners on behalf of Her Majesty the Queen, acting in exercise of the powers of the Crown Estate Act 1961([1]); and

"undertaker's works" means the ~~indicative works~~authorised development permitted by this ~~o~~Order within the overlap zone, or to be installed within the overlap zone.

Coexistence and Proximity Agreement

4. Save as provided in paragraphs 9, 11 and 13 no part of the undertaker's works shall commence until in respect of the overlap zone, one of the following applies—

(a) one or more coexistence and proximity agreement(s) has been concluded between the undertaker and the licensee in respect of the undertaker's works and the licensee's works;

(b) the undertaker and the licensee shall have agreed in writing that no coexistence and proximity agreement is required in respect of the undertaker's works and the licensee's works; or

(c) the Secretary of State has determined that a coexistence and proximity agreement is not required.

5. Within 4~~four~~ months of the coming into force of this Order (or such other timescale as may be agreed between the undertaker and the licensee) the undertaker must commence preparation of a coexistence and proximity agreement by serving notice on the licensee including a plan of the undertaker's works along with a request for the licensee to produce a plan of the licensee's works.

6. In response to the notice the licensee shall produce a plan of the licensee's works within 28 days of service of the notice.

7. Preparation of a coexistence and proximity agreement must be concluded within 3 months of the date for production of the plan of the licensee's works under paragraph 6 above unless otherwise agreed in writing between the undertaker and the licensee.

8. If either party ("the notifying party") considers that the plan of the works of the other party ("the receiving party") produced pursuant to paragraph 5 or 6 above (as relevant) provides insufficient detail of—

(a) in respect of the plan of the licensee's works—

(i) the ~~endurance~~ consents required to develop the NEP Project;

(ii) the level of brine release;

([1]) 1961 c.55.

(iii) the nature and location of the licensee's works;

(iv) any area of sea and/or airspace required for the licensee's works; and/or

(v) any monitoring required for the licensee's works;

(b) in respect of the plan of the undertaker's works—

(i) the nature and location of the undertaker's works;

(ii) any area of sea and/or airspace required for the undertaker's works; and/or

(iii) any ~~monitoring~~ maintenance required for the undertaker's works,

in each case having been minimised to avoid adverse effects on the programming siting design construction or operation of the other party's works then the notifying party must notify the receiving party of the additional detail required whereupon the receiving party must provide all such additional detail to the notifying party within 28 days of such notification.

9. Subject to paragraph 13 below, paragraph 4 shall not apply if the plan of the licensee's works or additional detail provided pursuant to paragraph 8 above provides insufficient detail for the purposes set out in paragraph 4 above. In the event of any dispute on the sufficiency of the detail provided by the licensee pursuant to paragraph 8 then paragraph 11 shall apply to that dispute.

10. The coexistence and proximity agreement must be based on the plan of the licensee's works and the plan of the undertaker's works and must take account of—

(a) the nature and location of each party's works on any plan of each party's works as known at that time;

(b) the location and extent of sea and/or airspace required for each party's works (including all applicable exclusive zones) as known at that time;

(c) all such evidence as is available at the time to support the existence of a prospect for the storage of carbon dioxide (with a view to its permanent disposal) in the area subject to the licence in respect of the licensee's works;

(d) the objectively assessed ability of the licensee to reduce or remove its sea and/or airspace area requirement under (b) above in light of evidence at (c) above, whether with immediate effect or at a specified later date;

(e) the objectively assessed ability of the undertaker to reduce or remove its sea and/or airspace area requirement under (b) above;

(f) the date by which the licensee will seek to commence operation, or at which works of appraisal will cease, as known at that time;

(g) the siting and design of the undertaker's works on any plan of the undertaker's works as known at that time;

(h) the minimum feasible exclusive zones, buffer zones or safety zones required for safe construction and operation between the undertaker's works and the licensee's works and compliant with the relevant law and guidance in force at the time of undertaking those works;

(i) protocols protective of navigation communication and use of the sea or air by third parties;

(j) possible future transfer of the benefit of the Order or of the licence; ~~and~~

(k) the national policy requirements for co-existence and the ongoing commercial viability of the authorised development permitted under ~~the order~~this Order and the NEP Project ~~together with carbon dioxide appraisal and storage in the overlap zone~~;

(l) the means and programme of access by sea to the undertaker's works and the licensee's works; and

~~(k)~~(m) an allocation between the undertaker and/or the licensee of the cost of monitoring based on an objective and independently verified assessment of the difference in cost between monitoring undertaken with and without the authorised development in the overlap zone.

11. If there is a dispute pursuant to paragraph 9, or if no coexistence and proximity agreement is concluded, or the parties shall not have agreed whether a crossing and proximity agreement is required pursuant to paragraph 4(b) within the period specified in paragraph 7, the outstanding matters in dispute must be determined by the Secretary of State following the process in article **Error! Reference source not found.** (arbitration) of this Order as modified by paragraph 11. The undertaker's and the licensee's works must not commence until the determination of the Secretary of State has been made and must only be implemented in accordance with that determination which is final and binding on the parties (save for manifest or legal error)—

(a) the arbitration shall be conducted by a sole arbitrator appointed by the Secretary of State;

(b) the Secretary of State must consult the parties on the candidates for the role of arbitrator;

(c) the Secretary of State must appoint an arbitrator within 14 days of the delivery of a notice of arbitration;

(d) unless otherwise agreed between the Secretary of State, the undertaker and the licensee, the arbitrator shall be a person (including one who has retired) with not less than fifteen years' aviation, radar or shipping and marine navigation, experience (as applicable) associated with a combination of offshore oil and gas development and offshore wind farm development or as a lawyer or other professional advisor serving those industries and having that experience;

(e) the arbitrator should make a recommendation to the Secretary of State as to the determination of the matters in dispute within 1 month of appointment;

(f) the Secretary of State must determine the arbitration within 1 month of receiving the recommendation of the arbitrator; and

(g) when determining the arbitration the Secretary of State must—

(i) have regard to the recommendation of the arbitrator, but may reach an alternative view; and

(ii) give reasons for the determination.

Provision of information

12. Without prejudice to any other rights or obligations under this Part of the Schedule the licensee and the undertaker shall from time to time keep each other informed of relevant activities such that the licensee and the undertaker may seek to agree solutions to allow the undertaker's works and the licensee's works to successfully co-exist as far as reasonably practicable.

Interface agreement

13. Nothing in this Part of the Schedule shall affect any rights or obligations of the licensee or the undertaker under the terms of the interface agreement, and should a conflict arise between the terms of these protective provisions and the terms of the interface agreement, the interface agreement shall prevail.]