Department for
Business, Energy
& Industrial Strategy

Measurement Monitoring and Verification (MMV) Plan for Endurance

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Acknowledgements

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1.0 Foreword

The Net Zero Teesside (NZT) project in association with the Northern Endurance Partnership project (NEP) intend to facilitate decarbonisation of the Humber and Teesside industrial clusters during the mid-2020s. Both projects will look to take a Final Investment Decision (FID) in early 2023, with first CO2 capture and injection anticipated in 2026.

The projects address widely accepted strategic national priorities – most notably to secure green recovery and drive new jobs and economic growth. The Committee on Climate Change (CCC) identified both gas power with Carbon Capture, Utilisation and Storage (CCUS) and hydrogen production using natural gas with CCUS as critical to the UK's decarbonisation strategy. Gas power with CCUS has been estimated to reduce the overall UK power system cost to consumers by £19bn by 2050.[1]

1.1 Net Zero Teesside Onshore Generation & Capture

NZT Onshore Generation & Capture (G&C) is led by bp and leverages world class expertise from Equinor and TotalEnergies. The project is anchored by a world first flexible gas power plant with CCUS which will compliment rather than compete with renewables. It aims to capture ~2 million tonnes of CO2 annually from 2026, decarbonising 750MW of flexible power and delivering on the Chancellor's pledge in the 2020 Budget to "support the construction of the UK's first CCUS power plant." The project consists of a newbuild Combined Cycle Gas Turbine (CCGT) and Capture Plant, with associated dehydration and compression for entry to the Transportation & Storage (T&S) system.

1.2 Northern Endurance Partnership Onshore/Offshore Transportation & Storage

The NEP brings together world-class organisations with the shared goal of decarbonising two of the UK's largest industrial clusters: the Humber (through the Zero Carbon Humber (ZCH) project), and Teesside (through the NZT project). NEP is led by bp, supported by partners Eni, Equinor, Shell and TotalEnergies, along with National Grid, who bring valuable expertise on the onshore gathering network.

The Onshore element of NEP will enable a reduction of Teesside's emissions by one third through partnership with industrial stakeholders, showcasing a broad range of decarbonisation technologies which underpin the UK's Clean Growth strategy and kickstarting a new market for CCUS. This includes a new gathering pipeline network across Teesside to collect CO2 from industrial stakeholders towards an industrial Booster Compression system, to condition and compress the CO2 to Offshore pipeline entry specification.

Offshore, the NEP project objective is to deliver technical and commercial solutions required to implement innovative First-of-a-Kind (FOAK) offshore low-carbon CCUS infrastructure in the UK, connecting the Humber and Teesside Industrial Clusters to the Endurance CO2 Store in

[1] https://www.netzeroteesside.co.uk/wp-content/uploads/2020/06/System_Value_to_UK_Power_Market_of_Carbon_Capture_and_Storage_June20.pdf

the Southern North Sea (SNS). This includes CO_2 pipelines connecting from Humber and Teesside compression/pumping systems to a common subsea manifold and well injection site at Endurance, allowing CO_2 emissions from both clusters to be transported and stored. The NEP project meets the CCC's recommendation and HM Government's Ten Point Plan for at least two clusters storing up to 10 million tonnes per annum (Mtpa) of CO_2 by 2030.

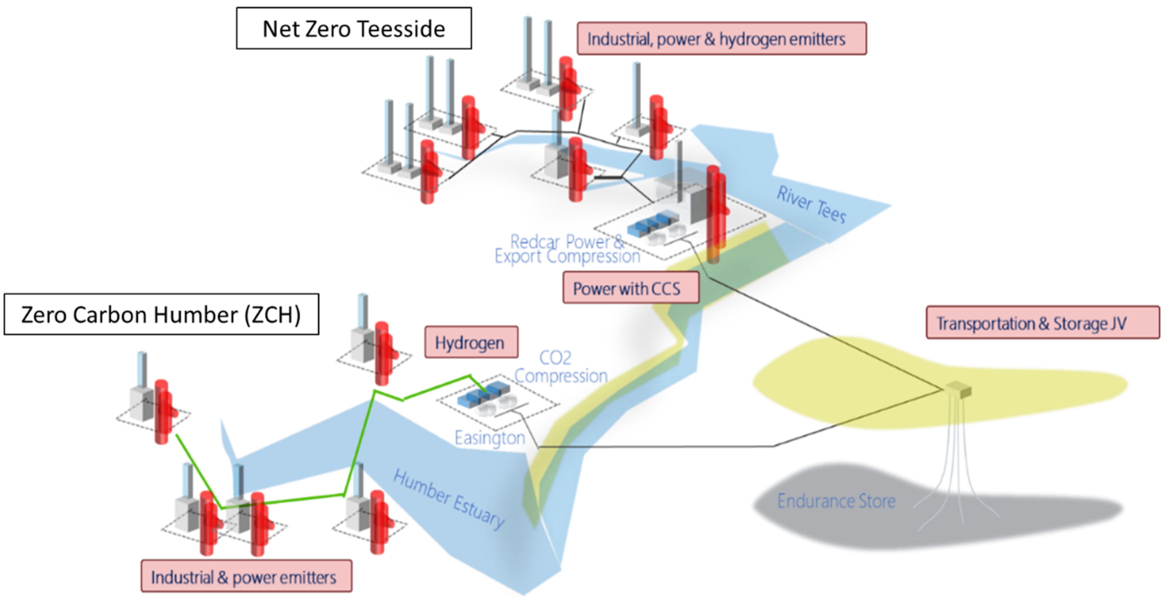

Figure 1: Overview of Net Zero Teesside and Zero Carbon Humber projects.

The project initially evaluated two offshore CO_2 stores in the SNS: 'Endurance', a saline aquifer formation structural trap, and 'Hewett', a depleted gas field. The storage capacity requirement was for either store to accept 6+ Mtpa CO_2 continuously for 25 years. The result of this assessment after maturation of both options, led to Endurance being selected as the primary store for the project. This recommendation is based on the following key conclusions:

- The storage capacity of Endurance is 3 to 4 times greater than that of Hewett
- The development base cost for Endurance is estimated to be 30 to 50% less than Hewett
- CO_2 injection into a saline aquifer is a worldwide proven concept, whilst no benchmarking is currently available for injection in a depleted gas field in which Joule-Thomson cooling effect has to be managed via a CO_2 heating solution.

Following selection of Endurance as the primary store, screening of additional stores has been initiated to replace Hewett by other candidates. Development scenarios incorporating these additional stores will be assessed in addition to the Endurance development.

2.0 Scope and Exclusions

This document applies to Net Zero Teesside and Northern Endurance Partnership Projects Phase 1 and describes current provisional MMV program developed during NZT/NEP Pre-FEED studies. This plan is still subject to regulatory change as part of the storage permitting process.

The Monitoring, Measurement, and Verification (MMV) program is one of the central and visible parts of safe CCUS operations, and an important communication tool for authorities, public, internal and external stakeholders.

CCUS MMV Objectives and Approach

- Verify the storage and absence of leakage, prepare for effective communication and actioning if required.
- The MMV plan is linked to project/storage risk assessment and addresses corrective measures to the identified risks.
- Agree the proposed MMV plan with partners and authorities.

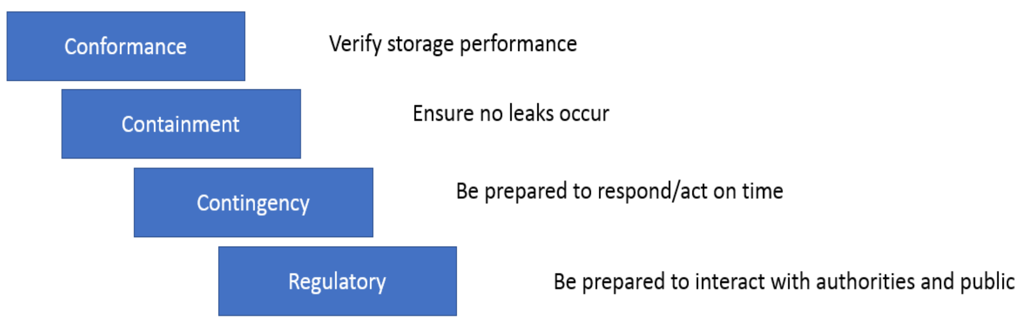

Figure 2: Four Pillars of MMV

3.0 Symbols and Abbreviations

For this document the following symbols and abbreviations apply:

MTPA Million metric Tons of CO_2 per Annum (~52 mmscfd)

MMV Measurement Monitoring and Verification Plan

4.0 Introduction

4.1 Key facts about Endurance (primary store for Northern Endurance Partnership project)

Endurance is a large anticlinal Bunter structure (25km long and 8 km wide) located in the Southern North Sea, UK sector (quadrants 42 & 43) and is penetrated by 3 wells 43/21-1, 42/25-1, and 42/25d-3, as shown below (Figure 3). 42/25d-3 was drilled in 2013 by National Grid Carbon Ventures with the intent to appraise the store for CO2 sequestration. Data acquired includes 190 meters of core acquired from Rot Clay down to the Bunter L1 with extensive conventional and special core analysis, a DST production and injection test over 20 meters in the upper Bunter, mini-frac tests in the Rot Clay caprock as well as in the Bunter sandstone. The 4-way structure presents circa 400 meters of structural relief which holds circa 26 billion barrels of brine above the spill point to be displaced for CO2 storage (Net Pore Volume).

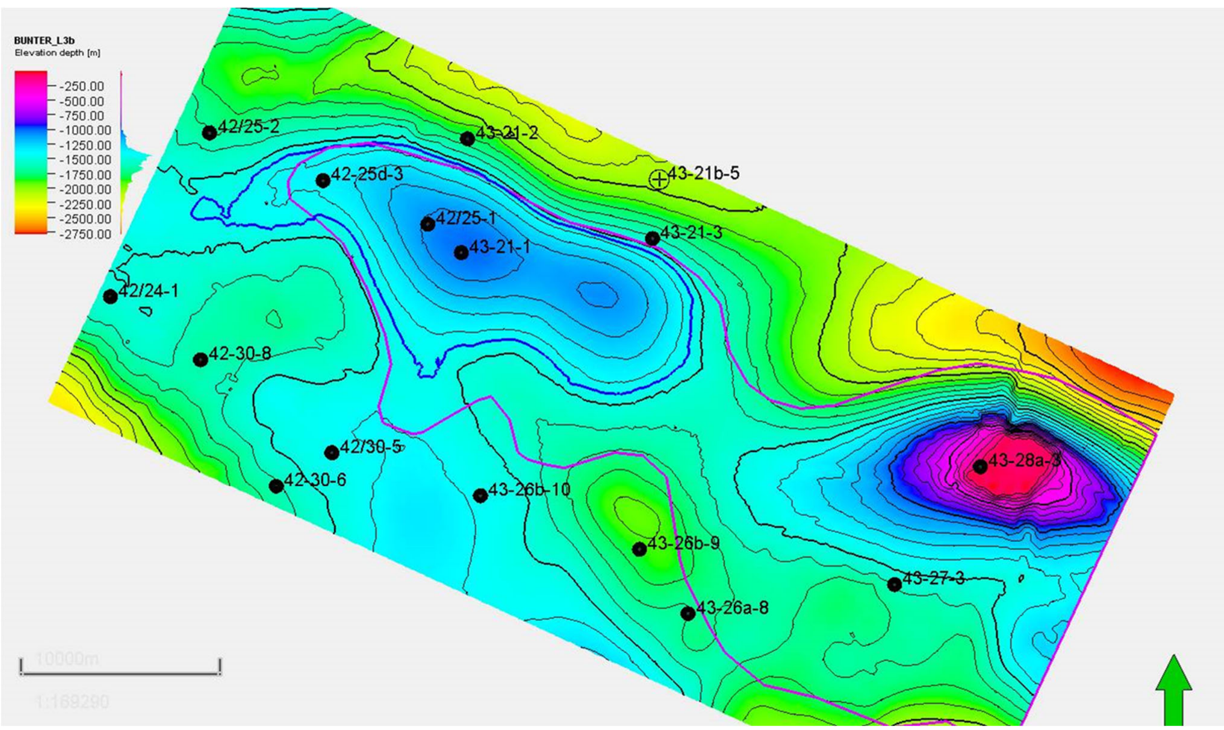

Figure 3: Endurance structure and legacy wells drilled in the area.

The subsurface team has been carrying out due diligence on the store characterization throughout 2H 2019 to 2Q 2020 to assess capacity and integrity of the structure to support sequestration of CO2 captured from the Teesside and Humber regions.

4.2 Project Summary

Net Zero Teesside/Northern Endurance Partnership is an integrated Carbon Capture, Utilisation and Storage (CCUS) project based in the North East of England.

The aim is to decarbonise a cluster of carbon-intensive businesses by as early as 2030 (power generation and industrial emissions) from two industrial clusters (Humber and Teesside). For phase 1, the project plans to capture up to 4 million tons of carbon dioxide emissions in average each year (MTPA). Future expansion for NZT/NEP will come from a variety of industrial emitters in the Teesside and Humberside regions such as bioenergy carbon capture and storage (BECCS), industrial decarbonisation, and hydrogen (as shown in Figure 4)

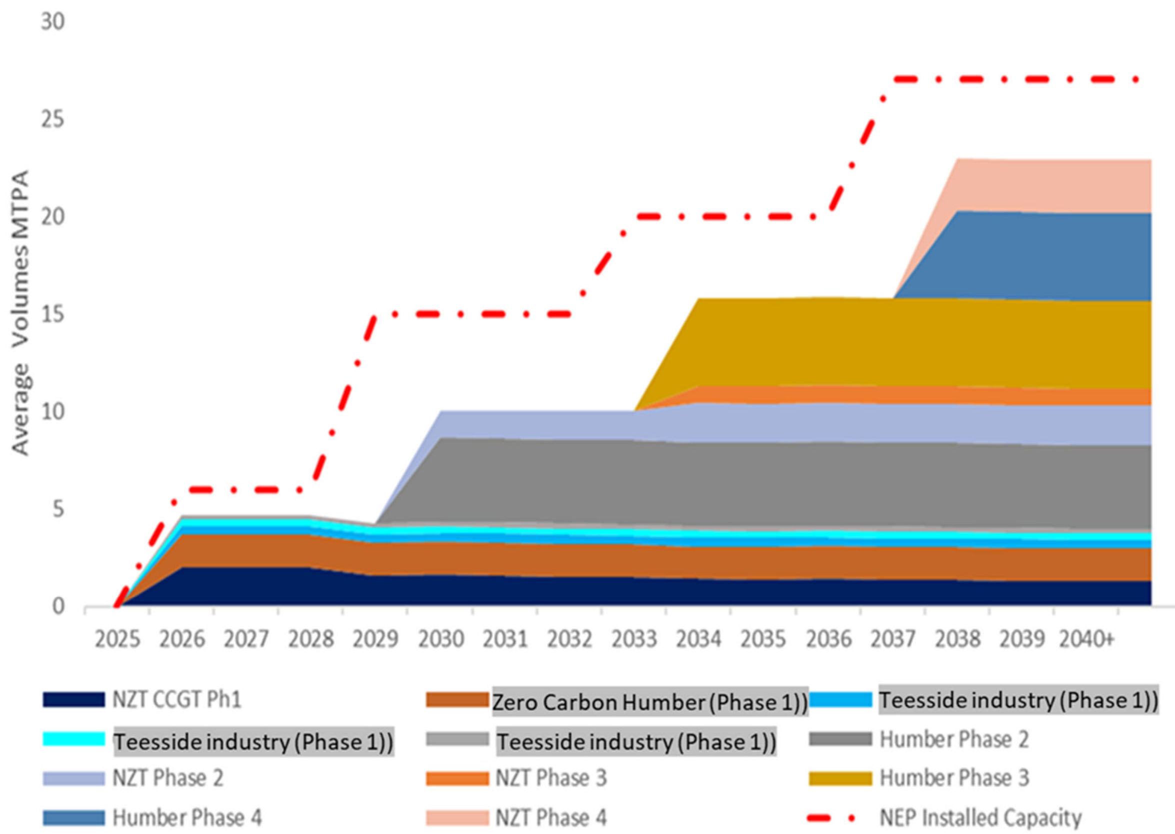

Figure 4: Phased infrastructure development for NEP (MTPA peak value).

The CCUS Project comprises both onshore and offshore elements, with a high-pressure CO2 pipeline being utilized to transport the captured CO2 to the Endurance storage offshore site with a capacity of circa 450-500 MT.

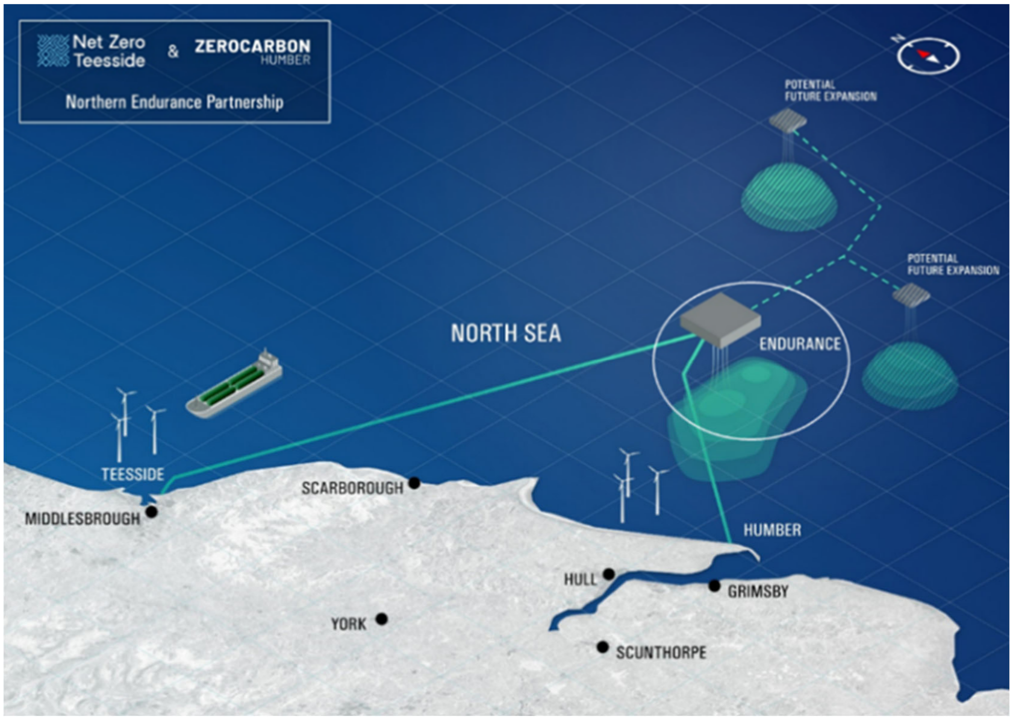

Figure 5: Northern Endurance Partnership along with associated clusters .

Average injection rates once load factors are included are shown in Figure 5 (dispatchability mode for CCGT power plant is assumed i.e. intermittent use as back-up load along with renewables) which would represent a total volume of 50 MT over 25 years. In addition, circa 40 MT are expected to be captured from the Zero Carbon Humber cluster leading to up to 90-100 MT stored over 25 years for Phase 1.

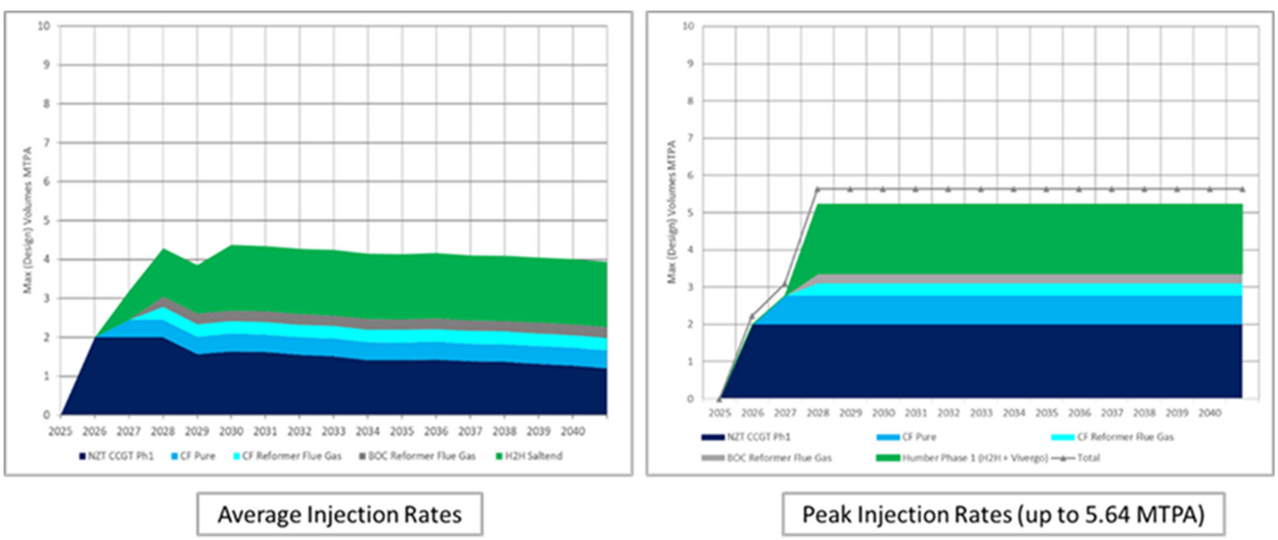

Figure 6: Average and Peak CO2 injection rates for Phase 1 (NZT Phase 1 + ZCH Phase 1).

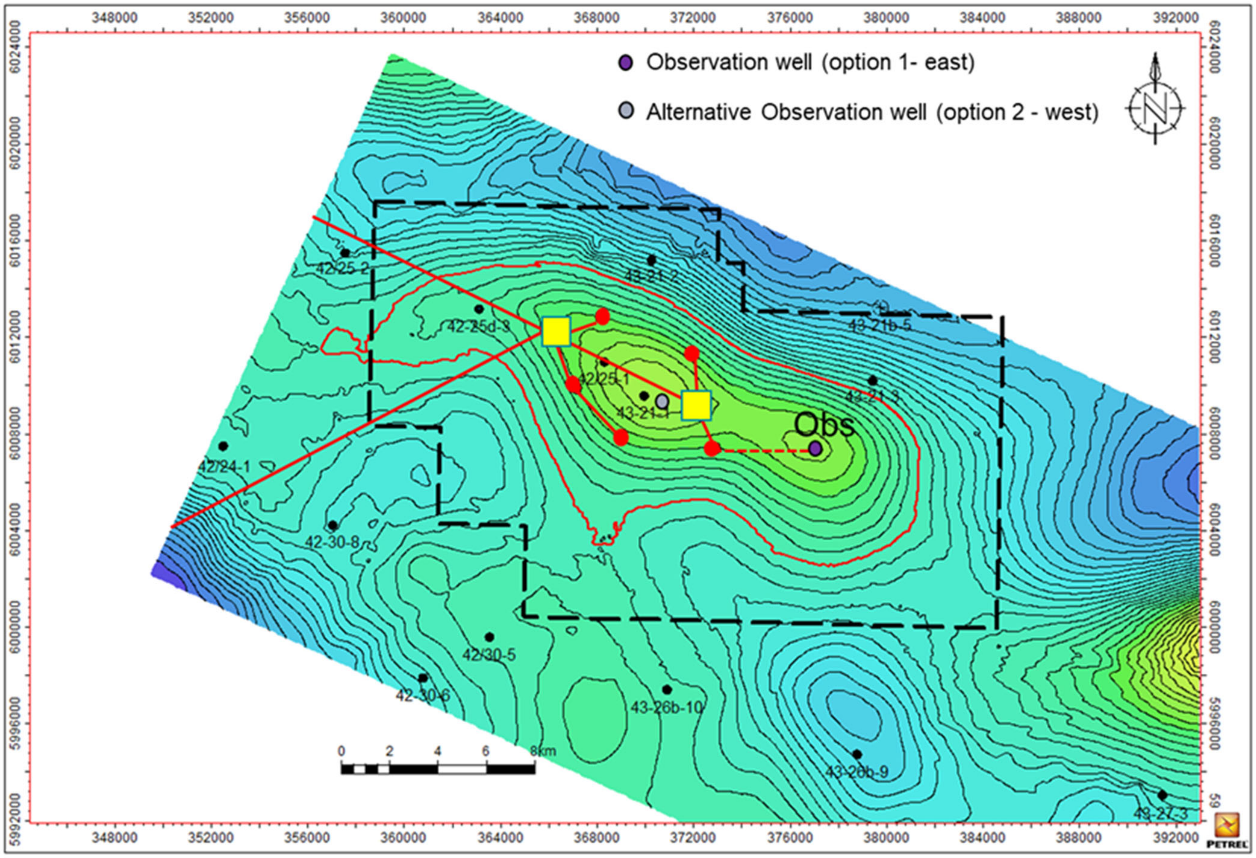

Figure 7: Phase 1 development (5 CO2 injectors and 1 observation well) – 4 MTPA.

4.3 Development Plan

Phase 1 would consist of five CO2 injection subsea wells which are considered to deliver an initial capacity of 4 MTPA average over 25 years (with one observation well in the east), as shown above in Figure 7. Exact well location will be finalized during the optimize phase (there is an opportunity to de-cluster the wells for Phase 1 in order to maximize pressure dissipation and mitigate against any potential sub-seismic baffling or compartmentalization). Expansion to 10 MTPA would require the addition of 5 CO2 injectors (1 MTPA per injector over field life and 6 brine producers (10 CO2 injectors (red)- and 8 brine producers(blue)).

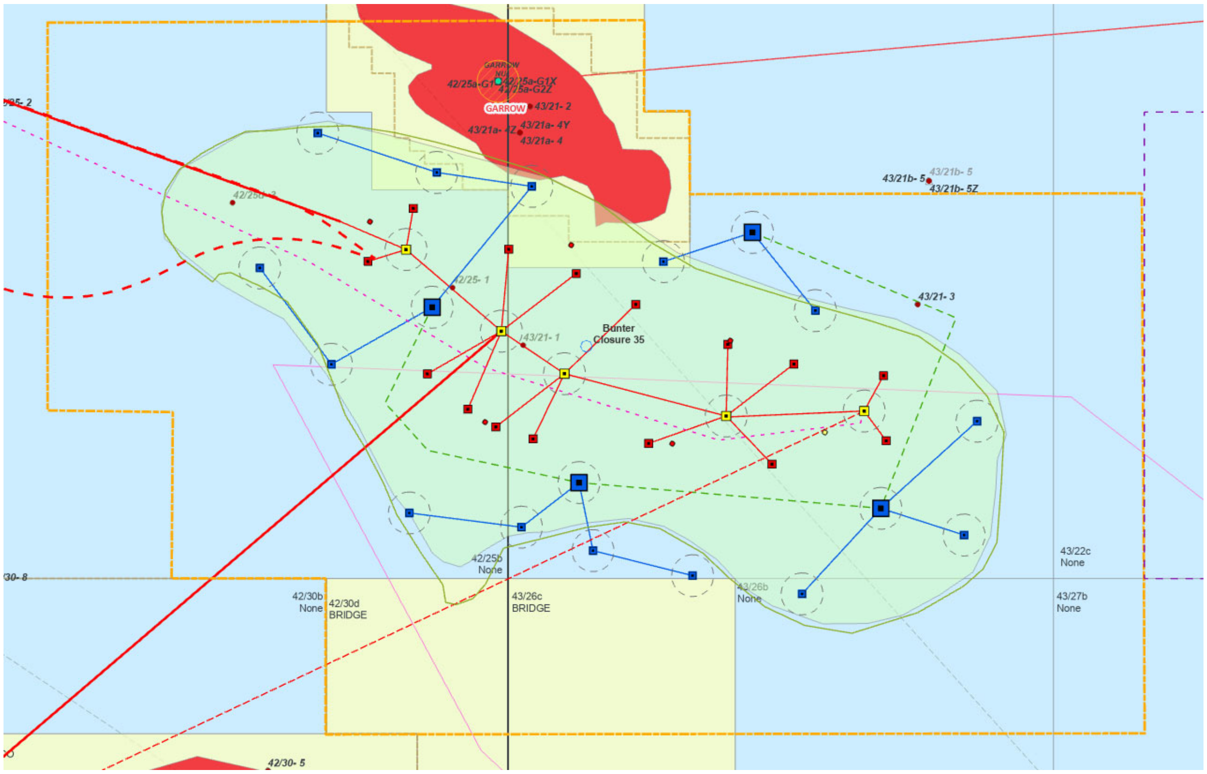

Figure 8: Notional Development beyond Phase 1 over Endurance (15 MTPA with 15 injectors and 14 brine producers). Exact location of wells will be subject to further refinement in optimize stage (top Bunter structure map).

4.4 Description of the Reservoir Management Unit (Bunter Sandstone)

The Triassic-age Bunter sandstone was deposited in a broad, land-locked, and gradually subsiding basin situated between 20-30 degrees N of the Equator. The rivers and streams drained into the basin from surrounding highs in a semi-arid climate and terminated in a playa lake situated within the basin centre. During drier periods, aeolian processes dominated, redistributing the sands and desiccating the mudstones leading to expected excellent lateral continuity (Figure 9).

Bunter Sandstone Formation comprises several large-scale fining upwards units in which predominantly fluvial and aeolian sandstones fine upwards into siltstone and claystone alternations of the playa margin facies. Lower permeability facies such as clay-rich playa mudstones and playa margin flood plain siltstones, deposited during periods of low energy or lake expansion, are abundant in the Lower Bunter (L1). Coarser grained deposits are more common in the middle and upper parts of the Bunter Sandstone (L3 and L2). Key reservoir properties are summarized in Table 1 and Table 2.

Parameter	Units	Value/Comment
Reservoir Rock		Sandstone
Reservoir Type		Fluvial-Aeolian Clastics
Reservoir Reference (Datum) Depth	mTVDss	1300
Initial Reservoir Pressure at Reference Depth	psi	2030
Spill Point	mTVDss	1450
Minimum Reservoir Pressure at Reference Depth	psi	2030 at 1300 m TVDss
Temperature at Reference Depth	°C	57

Table 1: Bunter Reservoir Management Unit for Endurance.

Formation Properties	Units		Comments
Permeability (P90-P50-P10)	mD	100-300-500	Expected range for any given well.
Kv / Kh	Fraction	Macroscale: 0.04 (derived from DST in 42/25d-3), core scale ranging from 0.01 (heterolithics or cemented sand facies) to 10% (clean sand facies)	
Porosity (P90-P50-P10)	Fraction	0.164-0.225-0.241	Expected range for any given well.
Net-to-Gross (P90-P50-P10)	Fraction	0.74-0.94-0.97	Expected range for any given well.

Table 2: Key reservoir properties for Bunter Reservoir in Endurance.

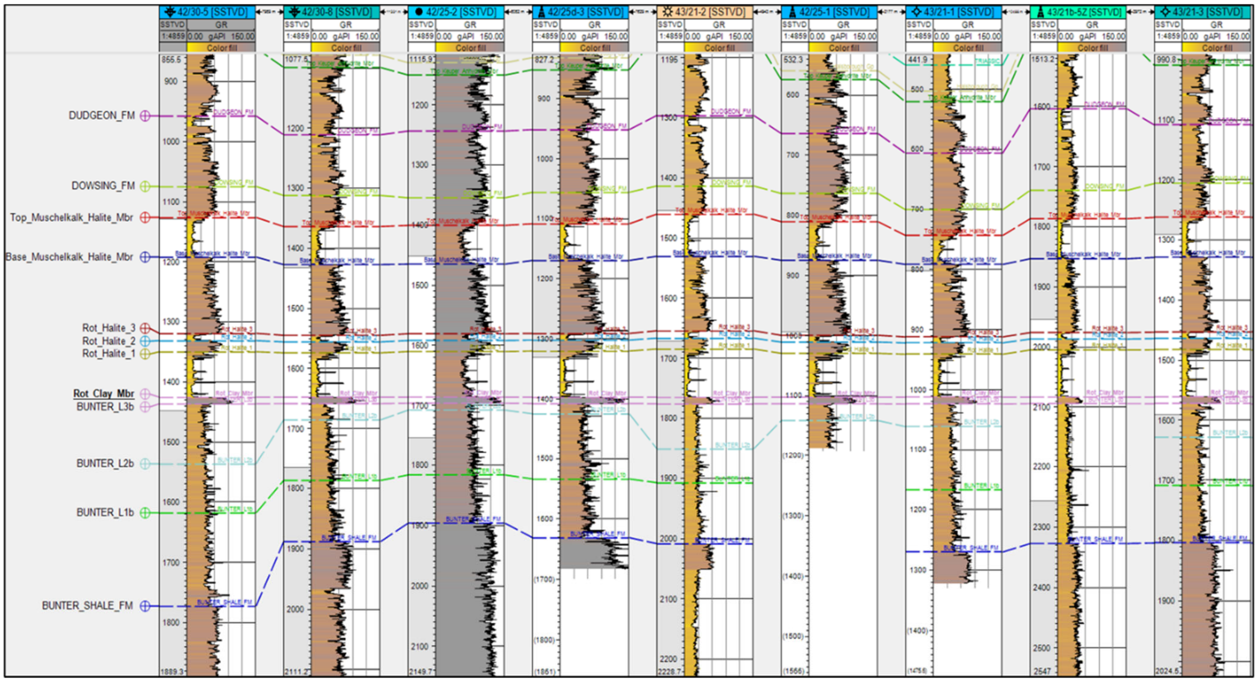

Figure 9: Well correlation panel showing GR (0-150 API) in 9 wells around the Endurance structure

Figure 10 shows the unconformity at seabed, and apparent parallel nature of the top Bunter sandstone (blue), the top Zechstein (green), as well as the Triassic reflectors (orange and pale blue). Around the outcrop, above the Top Triassic, wedging reflectors indicate growth sometime after the base Cretaceous unconformity (BCU). Such reflectors cannot be seen over Endurance due to the unconformity. The adjacent outcrop (see detailed map in Figure 11) is particularly important and requires special interest for the MMV program, including risk of leakage and flux of brine due to hydraulic communication with seabed.

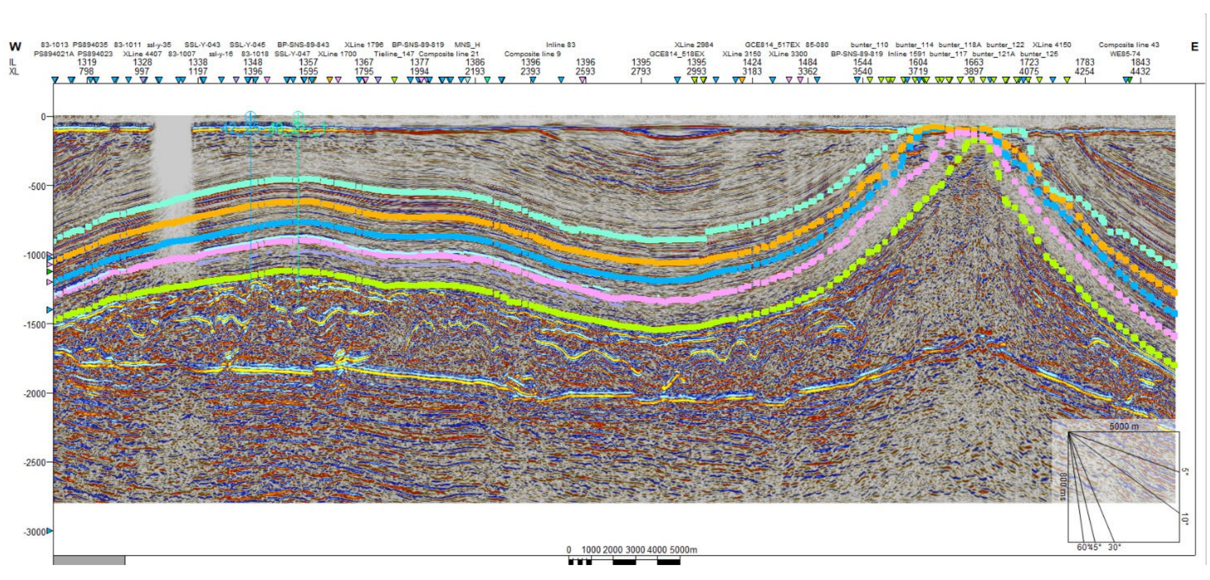

Figure 10: Seismic section along the length of the Endurance structure and outcrop.

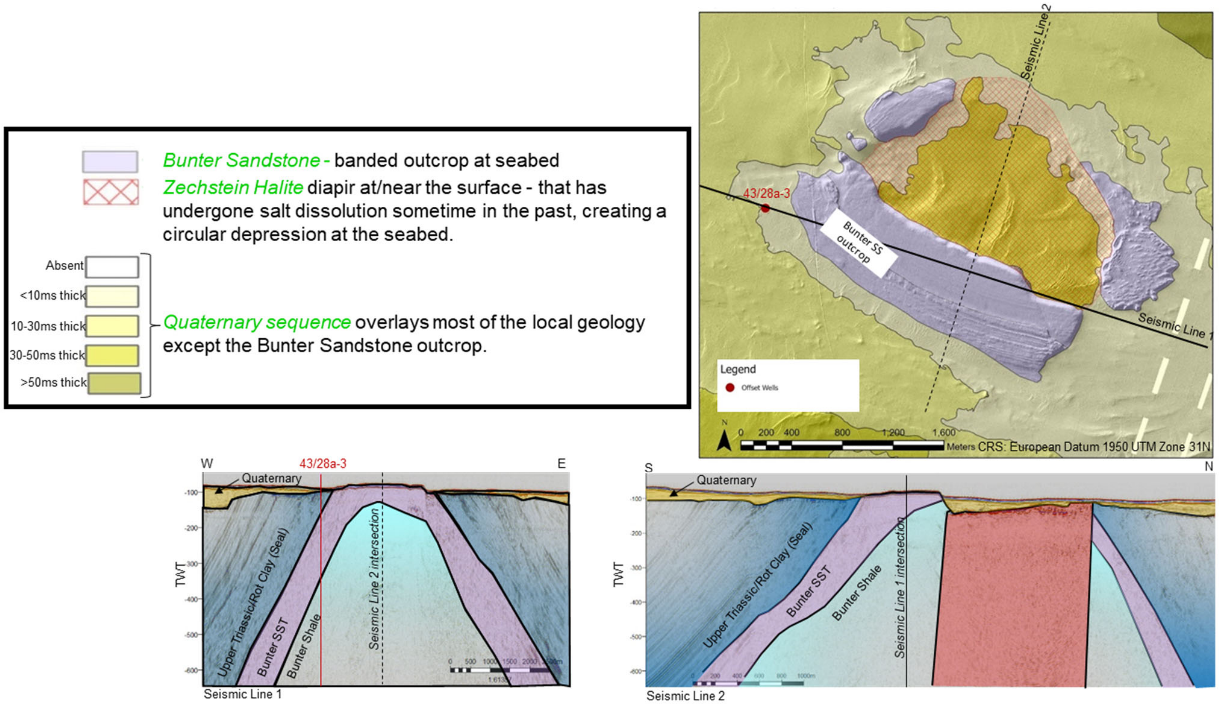

Figure 11: Outcrop bathymetry - Top Bunter Outcrop Interpretation.

A DST in 42/25d-3 has demonstrated good reservoir properties across the tested interval (20 meters tested out of 230 meters of reservoir gross thickness) with permeability around 290 mD and low Kv/KH (~0.4%) i.e. limited partial penetration effect due to extensive lateral barrier over instigated volumes (radius of investigation estimated of the order of 1.2 km).

5.0 MMV Approach

The Monitoring Measurement and Verification program is one of the central and visible parts of safe CCUS operations, and an important communication tool for authorities, public, internal and external stakeholders. The key objectives are as follows:

- Verify the storage and absence of leakage, prepare for effective communication and actioning if required.
- MMV is linked to project/storage risk assessment and provides corrective measures to the identified risks.

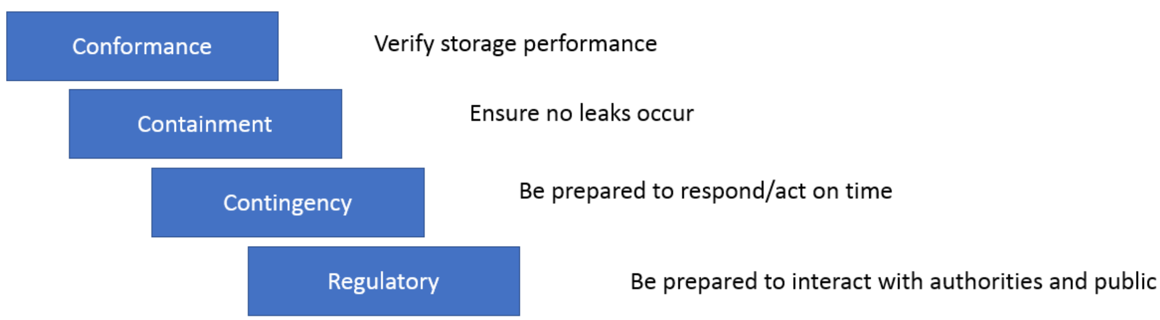

Figure 12: MMV Methodology

5.1 MMV Regulation Documents

The main piece of regulation for CCS across Europe is the EU CCS Directive on Geological Storage of Carbon Dioxide (Directive 2009/31/EC), which came into force on 25 June 2009. This Directive is an enabling Directive, which means it does not require CCS to be developed, but if an EU Member State or company chooses to develop a CCS project, then the provisions of this Directive must be followed.

The Directive establishes a legal framework for the environmentally safe geological storage of carbon dioxide (CO_2) – and does not cover capture or transport in detailed fashion. It lays down extensive requirements for storage covering the entire lifetime of a storage site with detailed focus on selection of storage sites (Art. 4), exploration permits (Art. 5), storage Permits (Art. 6) along with operation, closure and post-closure obligations (Chapter 4) and provision for transfer of responsibility (Art. 18).

The CCS Directive is implemented in the UK mainly through the Energy Act 2008 (Chapter 3), which introduces a new regulatory framework to facilitate the offshore storage of carbon dioxide.

BEIS (DECC) released Carbon Storage Permit application guidance with monitoring guidelines in Appendix 2.

The MMV plan is to be followed up by authorities once injection operation has commenced and to be updated every year.

In addition to the UK legislation and implementation of the EU CCS Directive, monitoring will also need to meet the requirements under the European Union Emission Trading Scheme (EU ETS) and its Monitoring, Reporting and Verification (MRV) procedure including article 12 and 13 (CO2 acceptance criteria and monitoring), Annex II 1.1(establishment the monitoring plan) and Article 21 (Access to transport network and storage sites).

Important terms used in this document are taken from the relevant EU directives and are listed here for convenience:

- Storage site is a defined volume area within a geological formation used for the geological storage of CO2 and associated surface and injection facilities.
- Storage complex is the storage site and surrounding geological domain that can influence overall storage integrity and security – i.e. secondary containment formations. The boundaries of the Storage Complex are therefore determined to contain any possible CO2 migration in the secondary containment intervals in any eventuality where it should leak out from the reservoir. This is addressed more fully in Part II, Section 7 of the Storage Permit Application (Characterisation of the Geological Storage Site and Complex).
- **Leakage** refers to any release of CO2 from the storage complex.
- **Emission** refers to any release of CO2 into the atmosphere or water column.
- **Migration** means the movement of CO2 within the storage complex.
- **CO2 plume** is the dispersing volume of CO2 in the geological formation.
- **Significant irregularity** is any irregularity in the injection or storage operations or in the condition of the storage complex itself, which implies the risk of a leakage or risk to the environment or human health.
- **Corrective measures** are any measures taken to correct significant irregularities or to close leakages in order to prevent or stop the release of CO2 from the storage complex.

5.2 Evolution of Offshore MMV Programs: Industry MMV Experience and Approach

Numerous CCS projects have been launched in the last 25 years, mostly onshore with a few offshore projects. Years of industry experience has proven the ability to design and perform safe CCS operations. In addition, these projects demonstrated the ability to conduct comprehensive MMV programs compliant with regulations, and with ability to understand CO2 migration in the reservoir.

Due to origin and nature of the Northern Endurance Partnership project - offshore, UK regulated project with injection in saline aquifer (Endurance), the most relevant MMV experience comes from implemented and planned European projects (Sleipner, Snohvit, Peterhead, Northern Lights), In addition, valuable technical and methodology learnings were taken from pioneering Canadian projects (Quest and Aquistore).

Overall, the 30-year history of CCUS projects proves safe long-term CO2 injection and industry has developed the means for effective monitoring. A central part of MMV, with associated cost, is 4D seismic to monitor plume migration. Time-lapse towed-streamer seismic imaging combined with comprehensive well data acquisition provides the necessary detailed view of CO2 movements in the storage complex to minimize and mitigate any risks.

5.2.1 Endurance MMV Approach

Endurance will be one of the first CCUS stores developed in the UK, however as documented above, significant experience in CCUS and CCUS MMV has been gathered around the world .

The current philosophy is to be cost effective and utilise a risk-based approach. The focus is as follows:

- To be risk-based and follow bow-tie methodology assessment
- To have robust seismic acquisition to monitor plume migration
- Provide accurate well parameter reading
- Monitor the crestal pressure

There are few peculiarities of Endurance reservoir and fluid nature to be considered:

- Large structure (over 25 km long)
- Seabed bunter outcrop with the possible hydraulic communication with the main reservoir, which can be a release brine due to pressurization.
- Hypersaline brine (250 000 ppm%w)

Therefore, the MMV plan for Endurance is focused on:

- Comprehensive baseline surveys
- Comprehensive tool set for well parameters monitoring
- Cost effective interim surveys and rely on the trigger surveys when deviation from expected behaviour is observed
- Specific solutions for outcrop monitoring.

6.0 Endurance MMV AOI: Storage Site and Storage Complex

The storage site, storage complex and monitoring area are indicated in Figure 13 and Figure 14. Note that final border is to be agreed with the regulator.

The size of the storage complex dictates the area that needs to be monitored in agreement with the OGA.

The US Environmental Protection Agency has rules based on the pressure required to lift brine into the nearest aquifer, which, of course, is particularly relevant in an onshore environment. There are no similar UK or EU regulations. The NZT/NEP team will propose that the monitoring area extends to and includes the outcrop. This proposal will limit the area of the storage complex. It is possible that there could be a requirement to monitor abandoned wells to the south and the north of the storage complex depending on how legislation is interpreted, although this is not the preferred approach. The monitoring requirements and monitoring area will need to be known prior to the FEED for detailed engineering. Abandoned wells area could be visited by an AUV. It is therefore needed to know whether monitoring these wells will be a requirement.

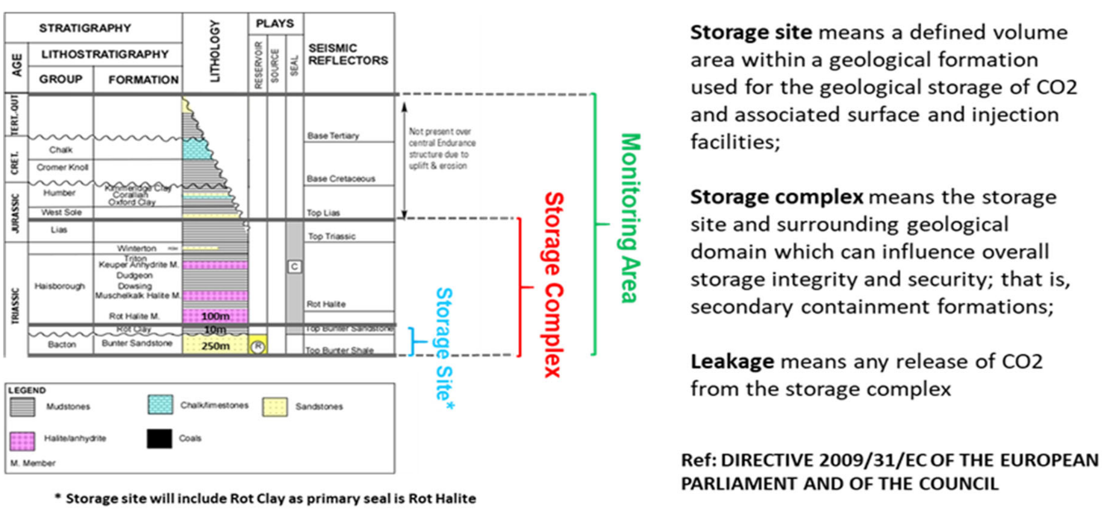

Figure 13: Vertical extend of Endurance storage site/complex and monitoring area

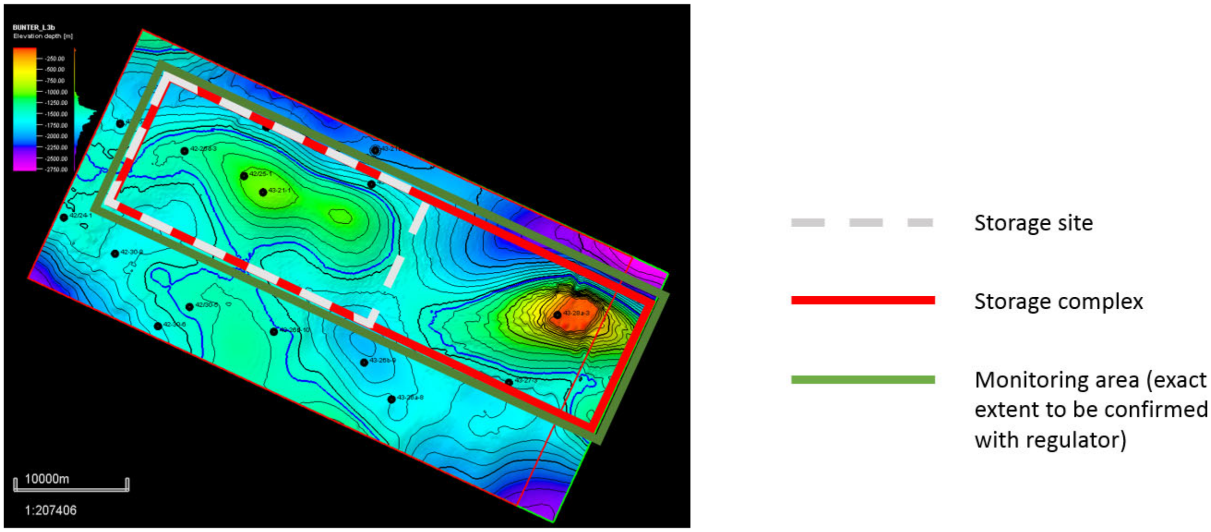

Figure 14: Lateral extent of Endurance storage site/complex and monitoring area

7.0 Endurance MMV Timeline

The MMV program is designed to be safe and comprehensive in order to provide an extensive validation data set to the authorities. This will give confidence for handover operations at the end of injection and provides a cost-effective solution for authorities and companies.

During the pre-injection period there will be comprehensive baseline data acquisition for technical and environmental assessment, and for the future comparison. Main studies are to be performed in the period of 2020-2023, including baseline seismic survey, improved outcrop understanding and extensive environmental baseline.

Injection period is to be 25 years with a strong focus on gathering data and ensuring safe operations. Main elements are crestal well monitoring, seismic imaging of plume movements, and well parameters reading.

Site closure is assumed to be performed in 2050 with conditional surveys over Endurance area. Post-closure period and obligations are to be defined during dialogue with the relevant authorities.

Current views and industrial experience on the post closure period supports a recommendation to shorten this period if the CO2 plume migration behaviour is as expected during injection period as it has been seen on the active and completed CCUS projects.

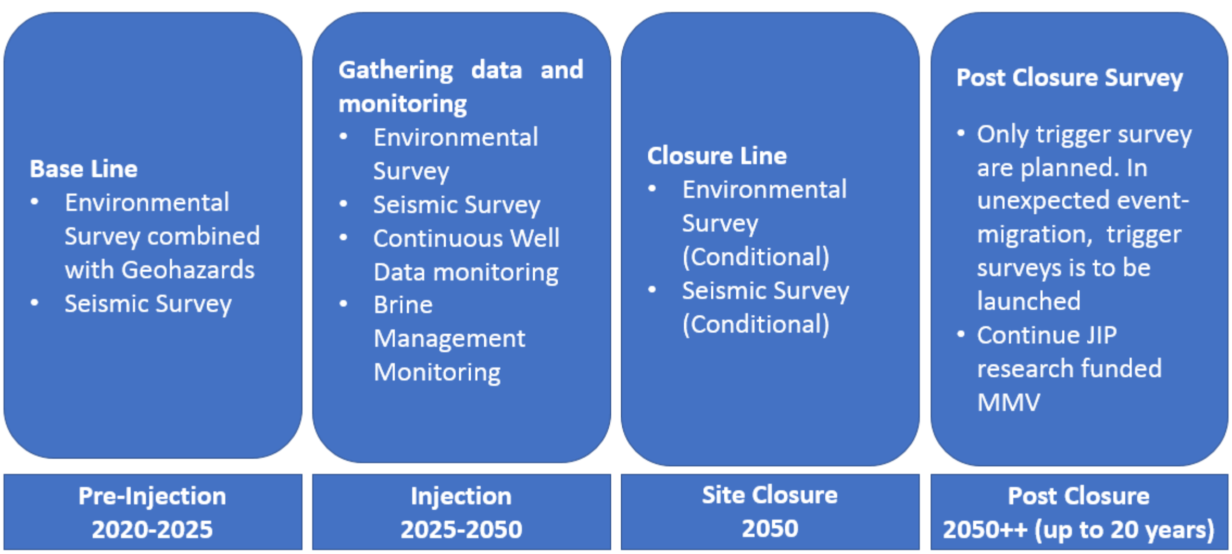

Figure 15: Endurance MMV Timeline

8.0 Endurance Risk Assessment

CCUS projects consider three main risk categories in subsurface work – capacity, injectivity and loss of containments (leakage). The methodology applied was bowties.

The project team has performed numerous risk sessions with experts to identify, quantify the risks.

8.1 Bow Tie Risk Assessment Methodology

The bowtie method entails building a bowtie diagram below, step-by-step, to produce a qualitative risk assessment of the hazard under consideration.

Hazards normally do not cause harm because they are kept under control. However, if control of the hazard is lost, an initial incident will occur – this is the top event and is shown at the centre of the bowtie diagram. For example, for the NZT/NEP project, the top event could be defined as movement of CO2 outside the confines of the storage site.

The threats (sometimes called 'causes') illustrate the various ways in which the hazard could be realised i.e. ''what could cause loss of control of the hazard?''. For subsurface storage of CO2, each individual bowtie threat describes a specific type of leak path by which CO2 could escape from the storage site. Examples of threats include CO2 leakage through existing faults which cross the primary seal, injection induced stress causing new fractures or re-opening existing faults or fractures, and flow of CO2 up through abandoned well bores.

Once control is lost and the top event occurs, there may be several ways in which the event can develop to an ultimate consequence. Each consequence will result in a specific extent of harm i.e. severity of impact. The impact might be on people, the environment, physical assets or the reputation of the company, or all the above. Examples of potential consequences relevant to the NZT/NEP Project are CO2 presence at the seabed, or CO2 presence in discharged brine.

There are barriers (also referred to as controls) in place which can prevent the realisation of the hazard (i.e. prevent the threat leading to the top event) or mitigate the consequences should the top event occur. The barriers on the left side of the bowtie diagram are prevention measures and can be items of equipment or actions taken in accordance with training and procedures. They also include natural barriers such as impermeable geological layers within the storage site. The barriers on the right side of the bowtie are mitigation measures and are called upon if the preventive measures fail to maintain control and the top event occurs. The mitigation measures are in place to interrupt development of the event and limit, or recover from, the consequences, and may include natural geological barriers outside of the storage site, items of equipment or monitoring activities and corrective actions.

In addition to the classical categories, studies are considered as additional piece of information to improve robustness.

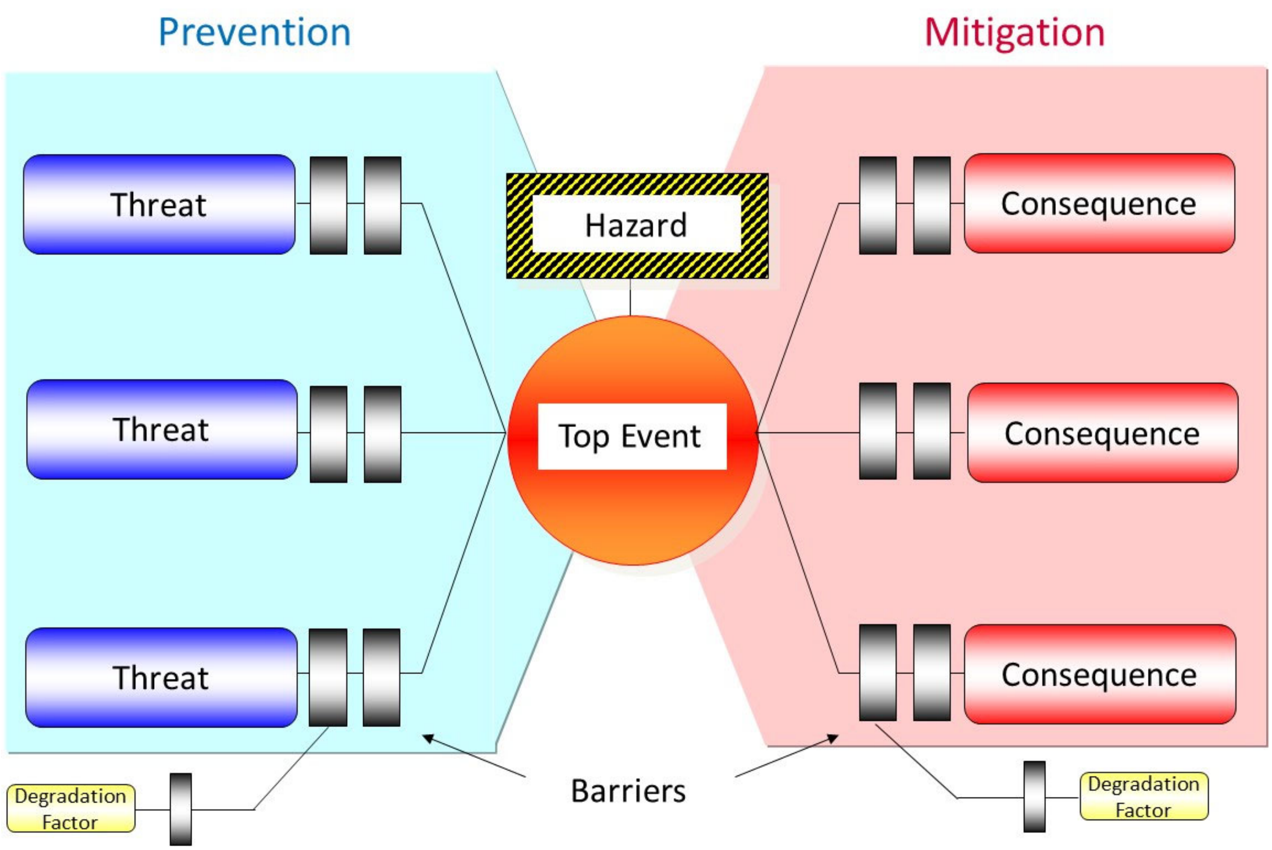

Figure 16: Bow tie methodology – Threat – Barrier – Consequences.

8.2 5 Major Subsurface Risks for Phase I

1. Unexpected plume migration

2. Loss of Containment

3. Reservoir architecture uncertainty and implication on injectivity

4. Reservoir architecture uncertainty and implication on capacity

5. Halite precipitation and impact on injectivity

Additional concern is environmental acceptance of outcrop brine release.

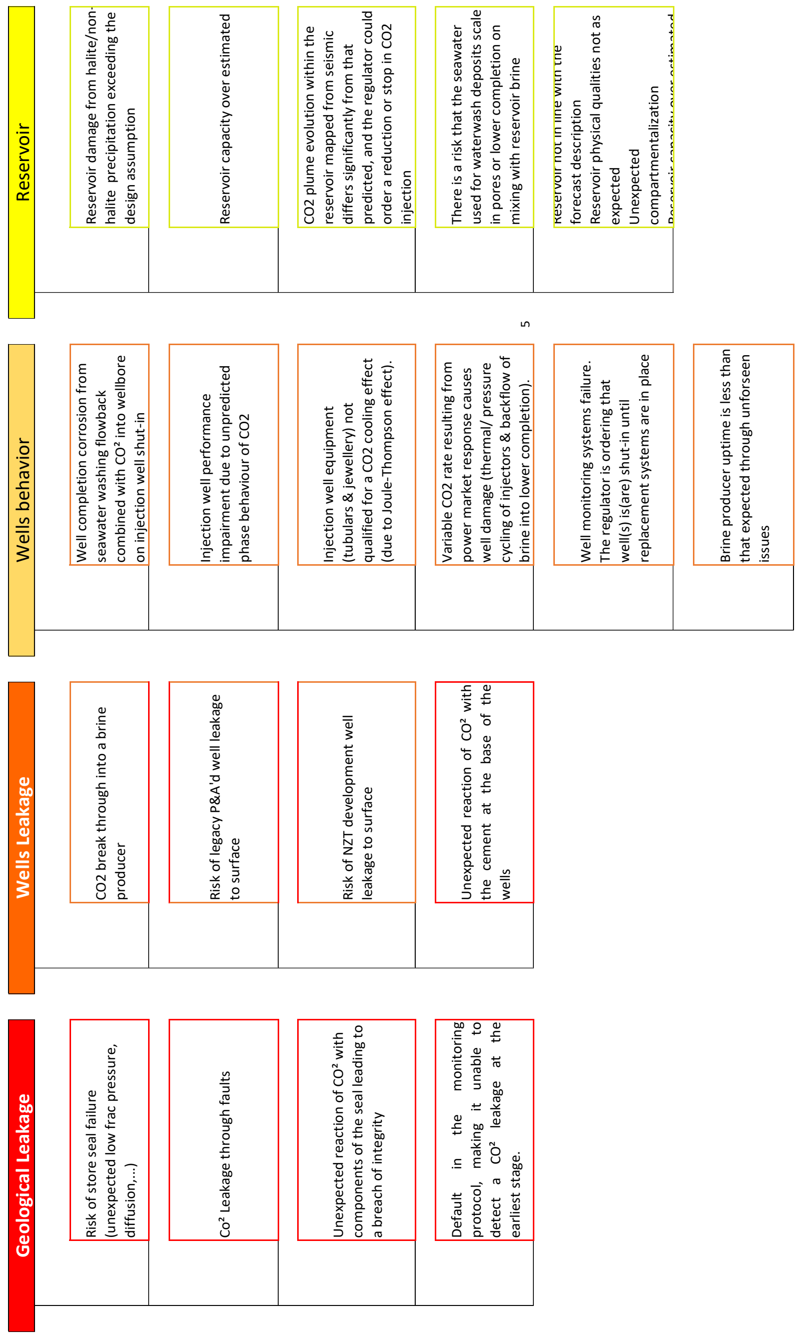

Figure 17: Risks for Endurance

8.3 Loss of Containment

The qualitative risk assessment conducted with NEP partners [3] for Endurance subsurface containment of CO2 using classical bowtie analysis. A total of 27 treats/leak path were identified and assessed in prospective of mitigation plan.

Assessment confirms minimum risk of CO2 leaks for the Phase I volumes.

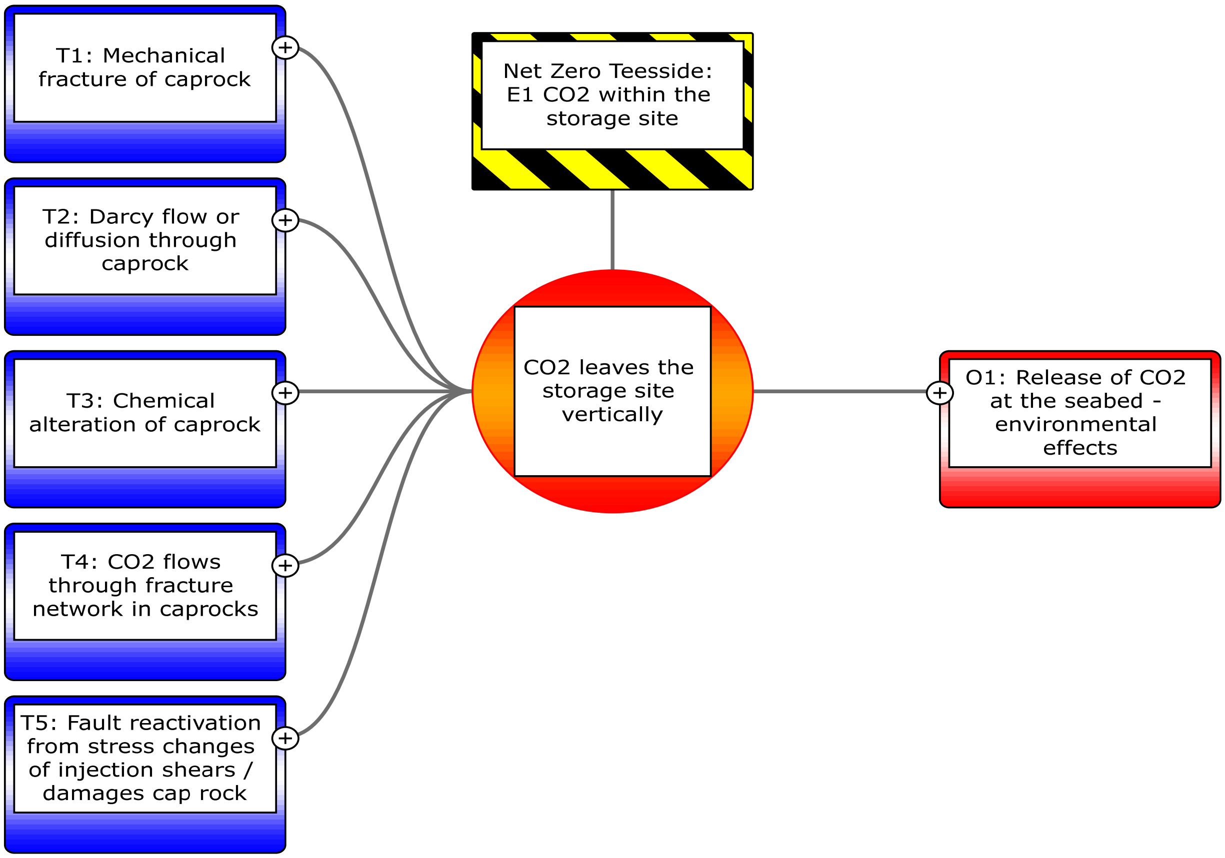

Figure 18: Risk assessment for loss of containment

8.4 Well Integrity

A rigorous legacy well assessment has been carried out to cover the three on-structure wells (TD in the Bunter) and two off-structure wells that TD'ed in the Carboniferous below.

All wells have one primary barrier to CO_2 leakage, though not necessarily verified to current OGA or BP standards. Secondary barriers only exist in one well. While well locations are known, no pre-emptive interventions are planned. However, all legacy well locations is planned to be equipped with permanent landers for CO_2 leakage monitoring to provide evidence of no leaks. In additional, regular AUV inspection is planned.

9.0 MMV Technology Assessments

Technology assessment for monitoring needs has been conducted focusing on the risk mitigation for Endurance. Major identified risks for the phase 1 (with no brine production) are: unexpected plume migration, outcrop possible brine flow and wells leakage.

Below is a figure (Figure 19) produced as an outcome of this assessment.

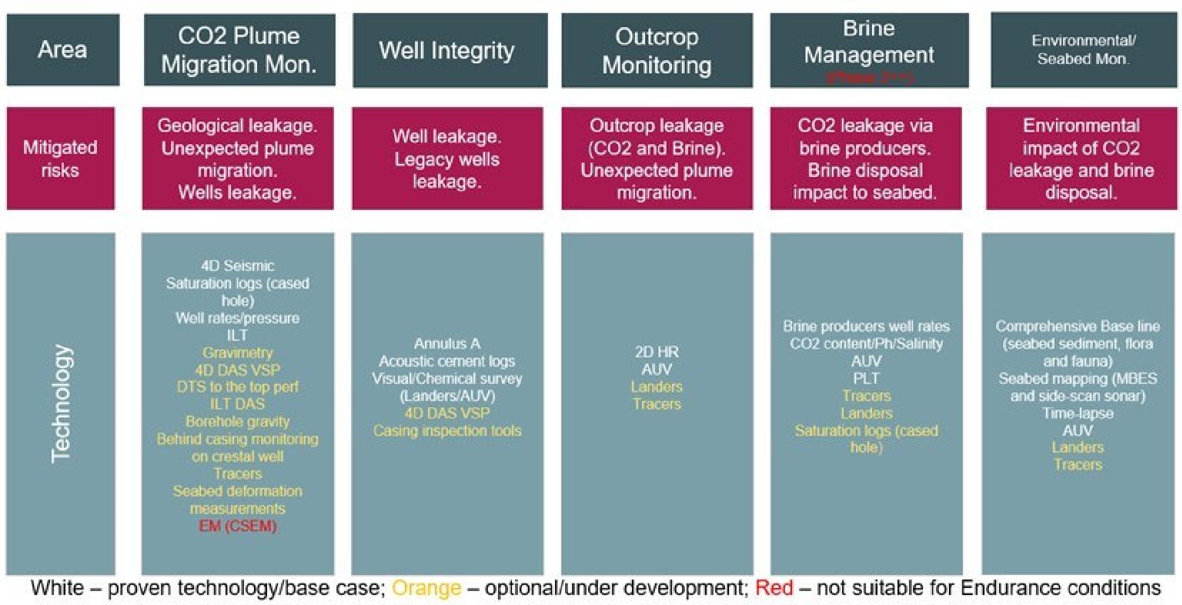

Figure 19: Monitoring technology assessment for Endurance

9.1 Plume Migration Monitoring

Seismic monitoring with complimentary gravity and VSP survey were identified for further application for plume monitoring.

High Resolution towed seismic streamer 3D acquisition is the base case for the seismic survey baseline as for the 4D monitoring of the CO2 plume (The seismic response of CO2 has been modelled to be very large (12-20% AI change)). It might be possible to also acquire 2DHR streamer surveys as intermediate surveys, between two 3D acquisitions, Ocean Bottom Node (OBN) acquisition has also been considered but is currently discarded due to lower quality of the seismic data (especially vs HR streamer acquisition) and cost consideration: an OBN acquisition can be 10 times the cost of a streamer one. Technology is progressing and one can expected to observe a decrease of the acquisition cost with time but only in the long term (15 years). Base case remains streamer acquisition.

The use of time-lapse distributed acoustic sensor vertical seismic profiling (DAS-VSP) and well-bore gravimetry is also being considered

9.2 Seabed CO2 and Brine Leakage Monitoring

Based on the risk assessment, legacy wells leakage risk is identified and to ensure continuous monitoring around the legacy wells, seabed monitoring using lander and an autonomous underwater vehicle (AUV) system is being considered for the project (being developed and tested for CO2 leak detection during ETI, STEMM-CCS projects). There is currently limited equipment available on the market, but work streams are in place to help progress this for NZT/NEP.

9.3 Outcrop Monitoring

Natural flux from outcrop is expected in Endurance after reservoir pressure reaches ~155 bar. Further investigation with authorities is planned to understand the specific requirement for monitoring this flux. However comprehensive base line environmental monitoring, initial 2D HR seismic survey (performed in 2020) and continuous AUVs and lander monitoring is seen as a core part of monitoring program.

9.4 In Well Monitoring

A standard set of pressure, temperature and wells rates are included in the basic monitoring program. Downhole pressure-temperature gauge (DHPTG) in both the tubing and the annulus. The annulus gauge is included to allow ‘A’ annulus pressure monitoring when the fluid level drops due to thermal contraction on injection. Under these conditions, the conventional gauge in the tree is not in contact with the fluid and so does not register. An alternative is to install a nitrogen-cushion to expand to fill the void, but this is operationally more complex.

Tracer injection is considered with detailed analysis for the different vendors to be proceeded on the next stage of the project.

Behind-casing pressure monitoring is a technology option and planned to be installed monitoring/observation well. This type of gauge is believed to be at a high Technology Readiness Level (TRL). The casing design will need to be carefully engineered to preserve the integrity of the cement job. Systems are available from several vendors that allow pressure to be monitored behind cemented casing, which would enhance reservoir surveillance particularly in the observation well close to the crest.

In addition, distributed acoustic sensor (DAS) fibre technology is proposed for phase 1. However, the 140 km (Teesside)/80 km (Humberside) distance from shore is currently a technology stretch and needs to be matured.

Distributed temperature sensing (DTS) is also being investigated for use in the project as this will provide a temperature profile along the wellbore in the reservoir which enables the interpretation of depths into which CO2 injection is occurring. Also, as DAS, DTS is also not yet available for the Endurance due to distances to shore) but may also be matured in the next few years.

Intentional Surveillance (light interventions) is planned for Endurance development as following:

- Baseline Injection Logging Tool (ILT) in the 5 wells for NZT/NEP Phase 1 to establish inflow profile after one year of injection.
- Regular ILT surveys carried out from a light well intervention vessel (LWIV) to provide time-lapse monitoring of sweep.
- Time-lapse Saturation log in the observation well

Heavy intervention from a rig might be required for well intervention such as recompletion or workovers.

10.0 Notional Endurance Monitoring Plan

Figure 20 is produced as Notional monitoring program for Endurance and summarize the above chapters.

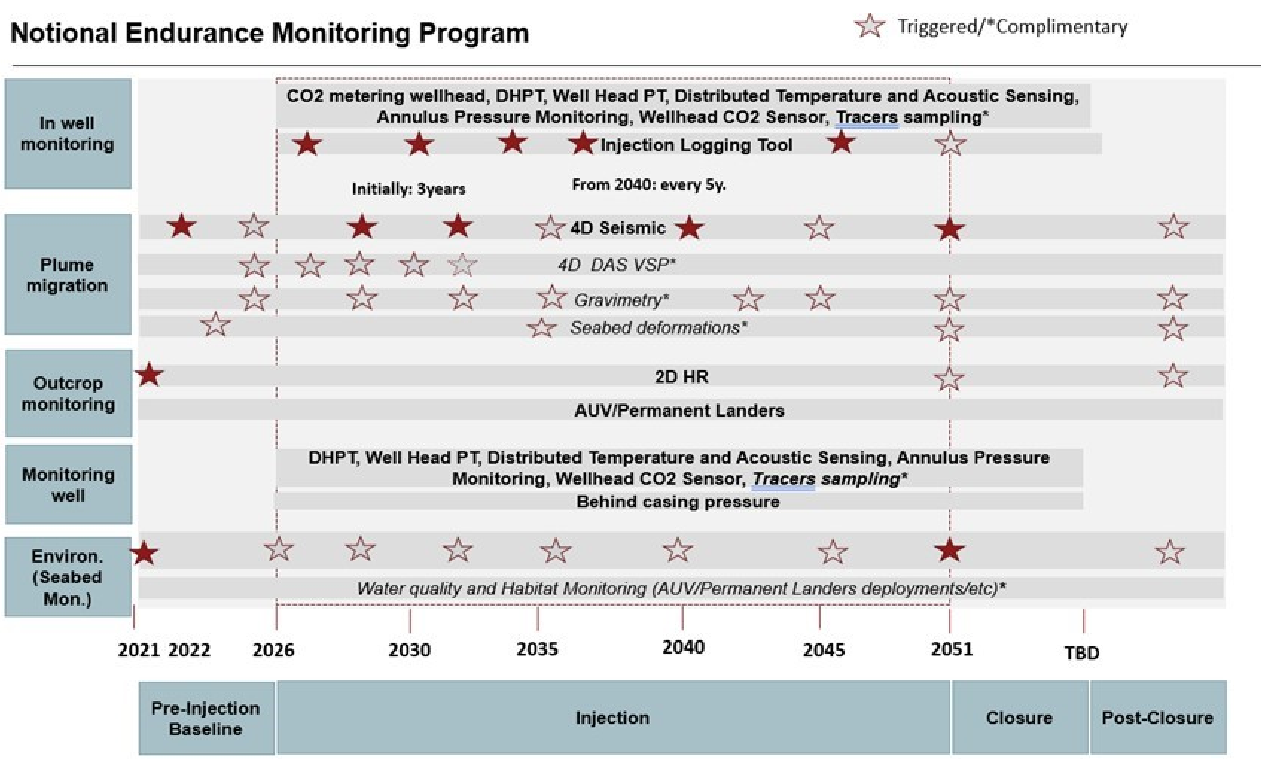

Figure 20: Provisional Monitoring Plan for Endurance

11.0 Summary

- MMV is planned for 25 years safe CO2 injection with comprehensive set of proven technologies and will provide confidence to operator, partners, authorities and community.
- MMV is designed to follow risk-based approach to ensure robust risk mitigation identified during comprehensive Endurance risk assessment.
- 30 years of CCUS industry experience proven the use of 4D seismic, extended well monitoring and seabed surveys as the core set of data acquisition for MMV in offshore fields. This strategy and set of associated technologies are taken to enable effective CO2 monitoring for Endurance.
- In addition to the mentioned monitoring technologies, fibre optic-based technology is seen as attractive for the use to refine plume migration via DAS VSP, discretization of the PT parameters along the well and well integrity monitoring, seen to be advance significantly and provide refine monitoring data. Current DAS distance-to-shore limit is 100 km and for DTS is 40 km, which limits sub-sea application, but this may possibly be resolved in the next 3 years. Hence, fibre optic technologies included as complimentary part of MMV.
- A base line environmental survey, with the focus on seabed observations and fluctuations over the seasons, is critical for interpretation of future data. New technology development based on autonomous underwater vehicles and landers should allow for sufficient seabed monitoring for both CO2 leaks and environment impact assessment (including legacy wells location monitoring).

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