Department for Business, Energy & Industrial Strategy

Multi-Store Development Philosophy

Key Knowledge Document

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This Key Knowledge Document (KKD) was generated as part of the pre-FEED project stage for NEP/NZT and completed in June 2021. This document release was put on hold to allow for the application process for the carbon dioxide licenses CS006 and CS007 by the North Sea Transition Authority to be completed and the licenses awarded in May 2022. The contents of the KKD does not fully reflect the subsequent work after drafting in June 2021.

May 2022

Acknowledgements

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Terms and abbreviations

BEIS	Department of Business, Energy and Industrial Strategy
CAPEX	Capital Expenditure
Capture	Collection of CO2 from power station combustion process or other facilities and its process ready for transportation.
Carbon	An element, but used as shorthand for its gaseous oxide, CO2.
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation and Storage
CfD	Contract for Difference
CGP	Clean Gas Project
CI	Climate Investments LLP
CO2	Carbon Dioxide
DHPTG	Downhole Pressure-Temperature Gauge
DST	Drill-Stem Test
EOS	Equation of State
FEED	Front-End Engineering Design
FID	Final Investment Decision
GRV	Gross rock Volume
Key Knowledge	Information that may be useful, if not vital, to understanding how some enterprise may be successfully undertaken
MMV	Monitoring, Measurement, and Verification
MT	Mega Tonnes
MTPA	Million Tonnes per Annum, a=average, i=instantaneous
NEP	Northern Endurance Partnership
TVDSS	True Vertical Depth Subsea

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 independently estimated to reduce the overall UK power system cost to consumers by £19bn by 2050 (compared to alternative options such as energy storage).

1.1 Net Zero Teesside Onshore Generation & Capture

NZT Onshore Generation & Capture (G&C) is led by bp and leverages world class expertise from ENI, 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 T&S includes the G&C partners plus Shell, along with National Grid, who provide valuable expertise on the gathering network as the current UK onshore pipeline transmission system operator.

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 the Southern North Sea (SNS). This includes CO2 pipelines connecting from Humber and Teesside compression/pumping systems to a common subsea manifold and well injection site

at Endurance, allowing CO2 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 CO2 by 2030.

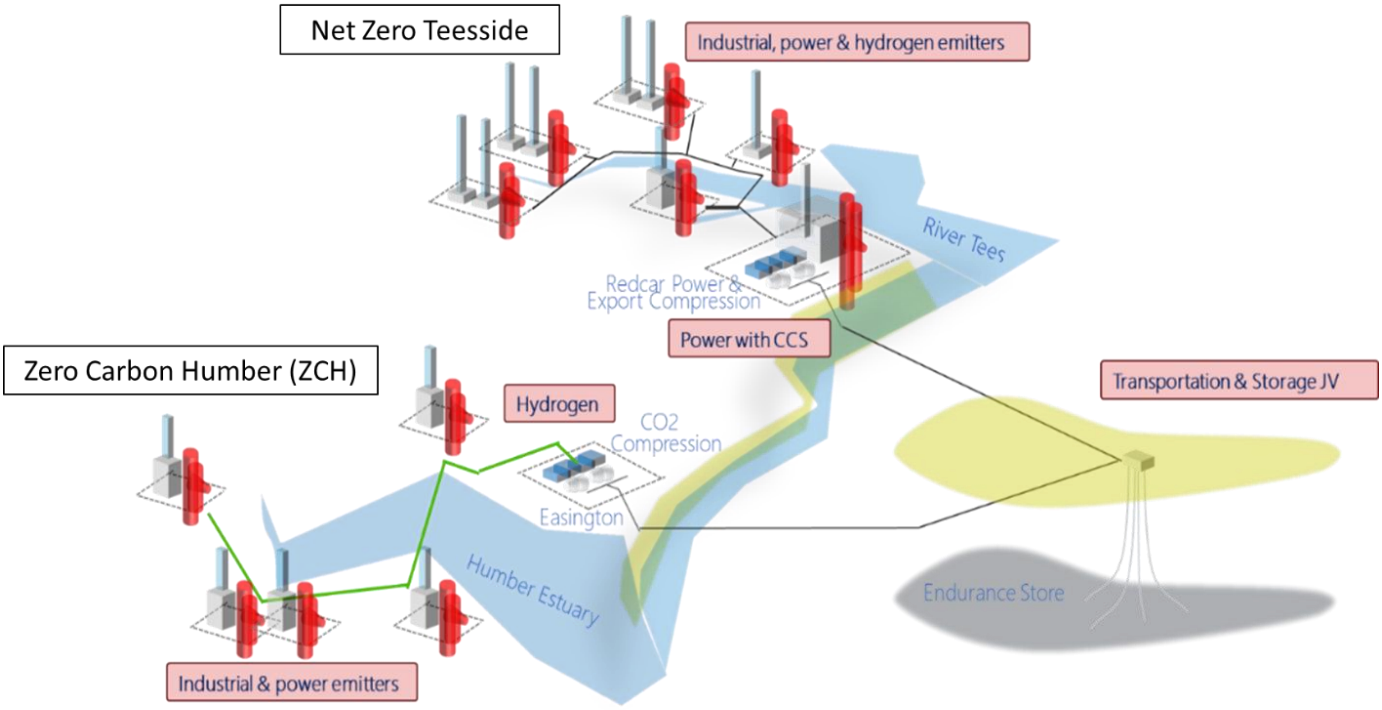

Figure 1: Overview of Net Zero Teesside and Zero Carbon Humber projects.

The project initially evaluated two offshore CO2 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 CO2 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
- CO2 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-Thompson cooling effect has to be managed via an expensive surface CO2 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 as an alternative to the sole Endurance development.

2.0 Rationale for Multi-Store Development Strategy

The Northern Endurance Partnership (NEP) project will transport CO2 emissions captured from the Teesside and Humberside industrial clusters and inject it into subsurface stores located offshore in the Southern North Sea (Figure 2). NEP is supported by six partners: bp, Shell, Total, eni, Equinor, National Grid New Ventures, with bp designated as operator.

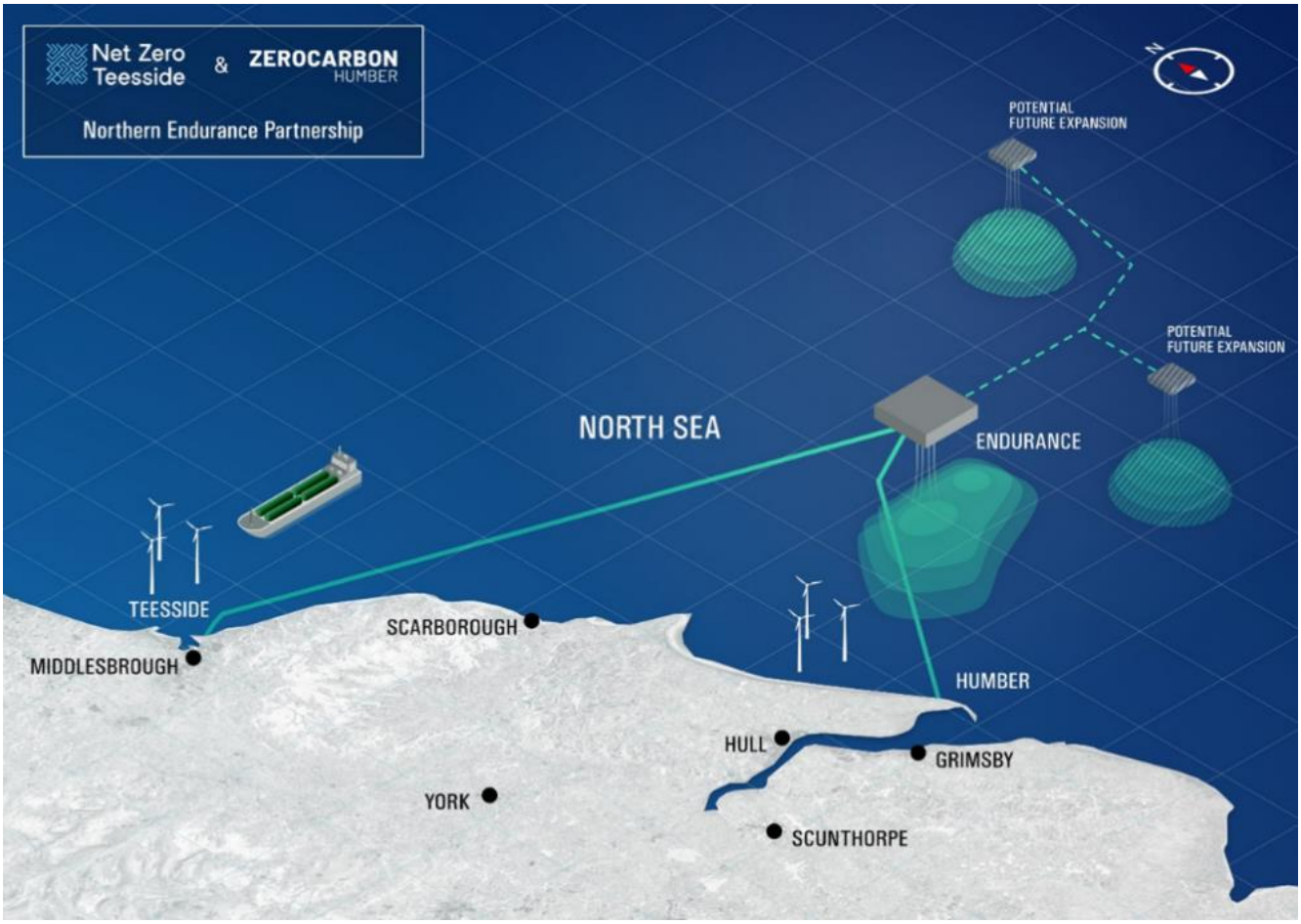

Figure 2: Net Zero Teesside and Zero Carbon Humber clusters with Endurance store and future expansion stores.

As decarbonization of the two industrial clusters is rolled out, the CO2 injection rate will progressively increase, and the proposed expansion development scenario enables a ramp up in injection rates to 23MTPA (average) by 2038 across four notional phases as shown in Figure 3:

- Phase 1: 4 MTPA average (5.6 MTPA peak) from 2026: no brine, Endurance store only, 5 subsea wells + 1 observation well, with entry to FEED scheduled for Nov'21.
- Phase 2: 10MTPA average (14 MTPA peak) from 2030: expansion to 10 MTPA with the development of the alternative stores east of Endurance.
- Phase 3: 16MTPA average (20 MTPA peak) from 2034 with expansion of Endurance to 10 MTPA
- Phase 4: 23MTPA average (27 MTPA peak) from 2038

The profile is composed of distinct expansion phases with indicative capacities based on an efficient development of available stores. Initial volumes (Phase 1) include the anchor projects, a natural gas-fired power plant with post-capture combustion in Teesside and the Saltend Hydrogen project in Humber. Phasing is based on the expected project start-up of 2026 and aligns with the government target to achieve start-up of the first projects in the mid-2020s and 10 MTPA injection by 2030. Subsequent expansions have been assumed at 4-years intervals but may vary according to cluster requirements. Future development of 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.

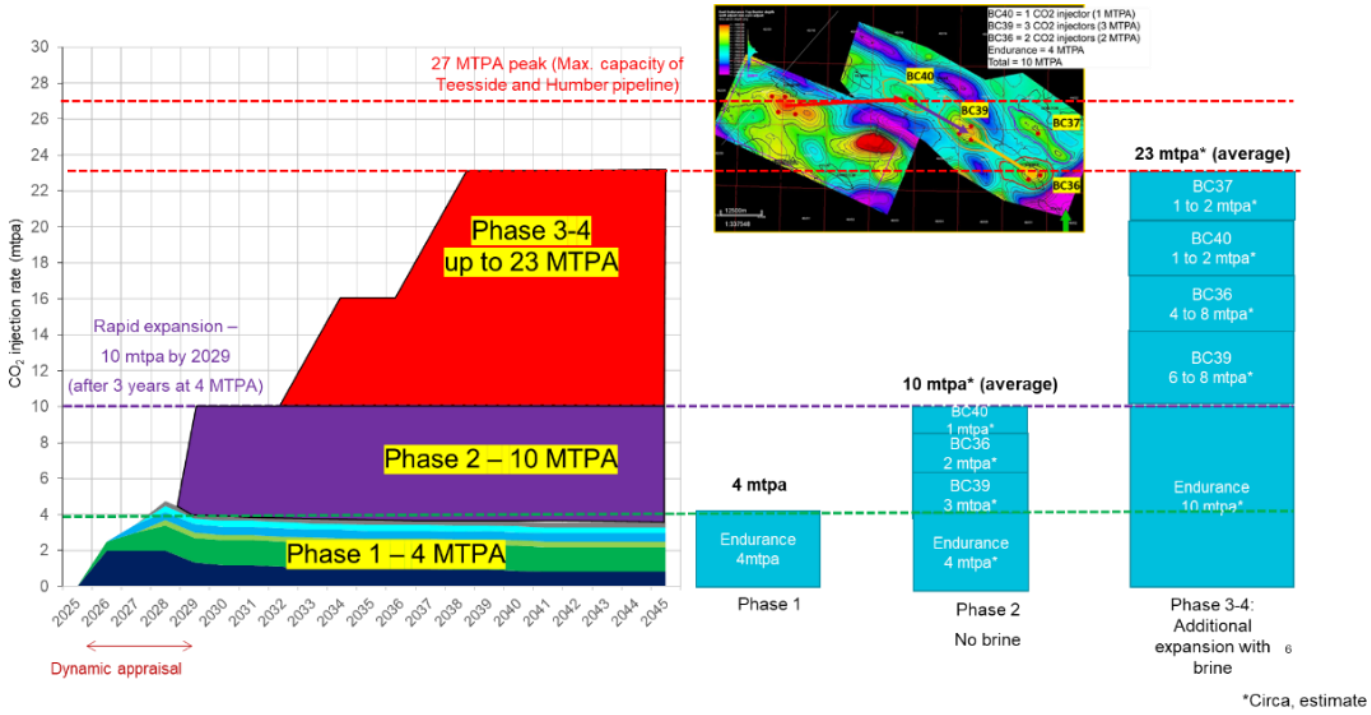

Figure 3: Notional NEP expansion strategy from 4 to 10 MTPA to 23 MTPA.

The existing reference case is to utilize a single subsurface store: Endurance, a large anticline structure with a hypersaline brine aquifer (Triassic-age Bunter Sandstone Formation) which has a potential storage capacity of up to 15 MTPA average (on plateau) and a cumulative storage capacity of 450 MT of CO2. Reservoir studies for Endurance have shown that for an injection rate of circa 4 MTPA (average over 25 years), no brine production is needed to accommodate the reservoir pressurization caused by the cumulative injected volumes, due to dissipation of the pressure into a large, connected aquifer. However, to expand to a 10 MTPA plateau, it will be necessary to remove the brine from the reservoir to ensure reservoir pressure is maintained within safe limits.

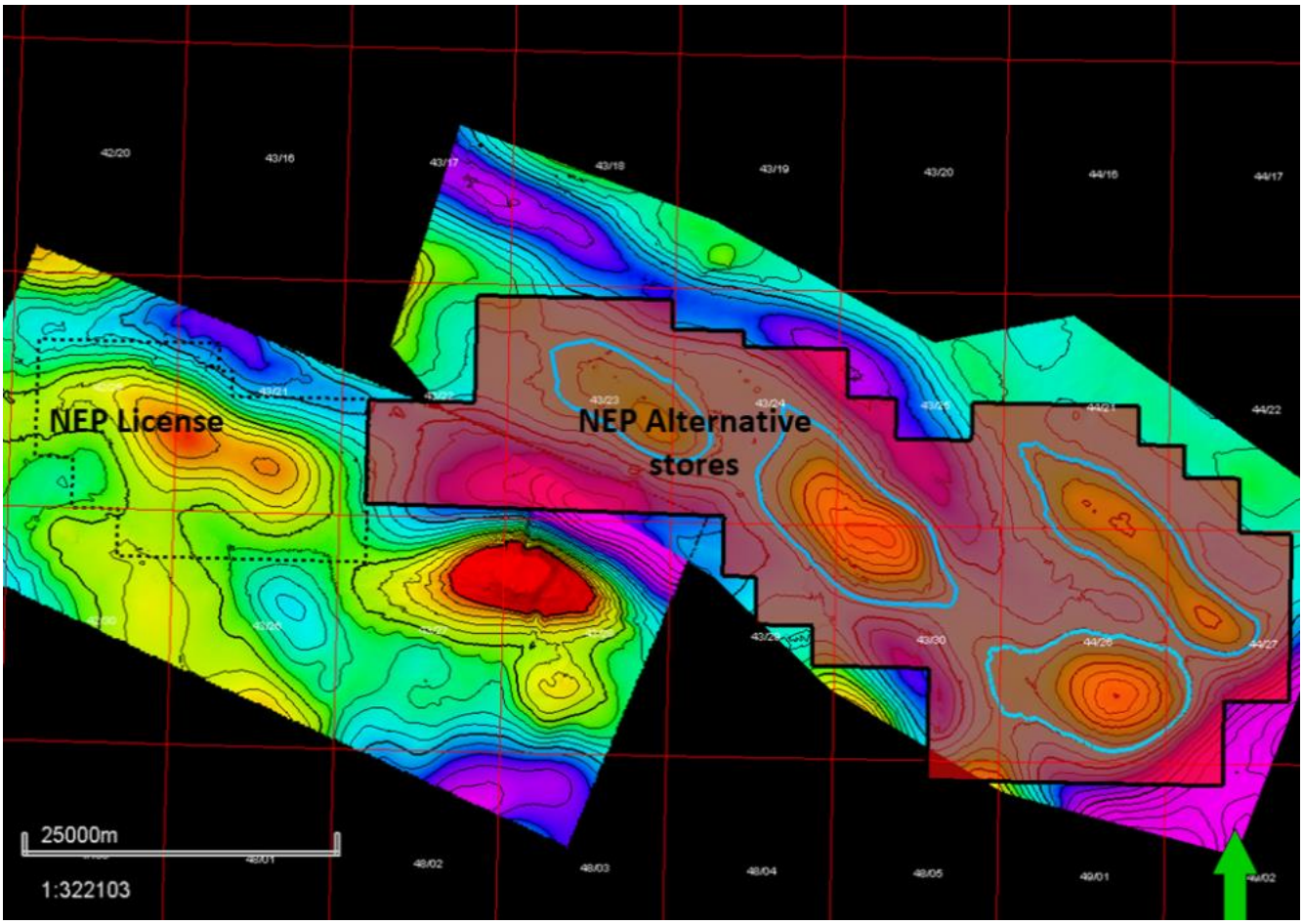

Figure 4: Potential store license boundaries covering the additional Bunter structures identified as suitable for CO2 storage near Endurance (BC40, BC39, BC36, and BC37).

Given the novelty of brine production not currently covered by any UK regulation for CO2 storage, and the "appraisal while developing" nature of CO2 injection operations at Endurance, it is necessary to enable optionality to deliver at pace, the ambition of injecting 10 MTPA by 2030 as set out by the UK Ten Points Plan. The Northern Endurance Partnership therefore proposes an alternative expansion strategy to achieve Phase 2 injection rates (10 MTPA average) by injecting into other nearby Bunter stores – the Bunter Closures (BC) 36, 37, 39 and 40, as shown in Figure 3.

Initial screening assessments have identified this as a potentially lower cost option which will help reduce cost to the taxpayer and kickstart the nascent CCUS industry.

In addition to delaying the production of brine, this will enable an improved subsurface understanding of Endurance and the greater Bunter Sandstone Formation's response to CO2 injection, which will provide greater clarity around the timing, rates, and optimized development scheme for brine production to reach the projected peak injection rates stated above. The structures described above (Figure 4) have been mapped on 3D seismic data and are analogous to Endurance. They all fit the basic criteria for CO2 storage: crest deeper than 800m TVDSS (for CO2 to be stored in dense phase), and a thick, high-quality sandstone overlain by a regional seal. A summary of the basic volumetrics and storage potential of these four structures is shown in Table 1.

The risk and uncertainty profile for these structures is not the same: BC36 and BC37 are expected to be very analogous to Endurance and have low reservoir uncertainty but have legacy wells near the crests of the structures which provide a leak risk present day. BC39 and BC40 sit in area with slightly different reservoir properties and are lacking data to demonstrate injectivity. B39 requires complete seismic coverage and an appraisal well, data and tests from an appraisal well could be applied to BC40 evaluation.

	P50 Volumetrics			
	GRV above spill point (m3)	Volume CO2 with brine production for pressure management (MT)	Volume CO2 without brine production for pressure management (MT)	Key Risks/Uncertainty
BC36	1.50E+10	293	78	Legacy well leak risk
BC37	1.40E+10	271	74	Legacy well leak risk
BC39	2.20E+10	376	83	Reservoir injectivity
BC40	5.50E+09	93	25	Reservoir injectivity
Total		1033	260	

Table 1: Calculated volumetric ranges for CO2 storage.

A CCS license application for the alternative Bunter stores was made in early February 2021.

3.0 Endurance Storage Site Development (Primary Store)

3.1 Phase 1 (4MTPA)

Five CO2 injection subsea wells (CI1, CI2, CI3, CI4, and CI5) are considered to deliver an initial injection average volume of circa 4 MTPA over 25 years as shown in Figure 5 (with peak injection rates of up to the equivalent of 5.6 MTPA). One additional well CI6 is to be utilized as an observation cum spare injection well to support dynamic appraisal of Endurance (and future expansion). The well OE1 will indeed record the on-structure pressurization passively 4 kilometres east of the central manifold while providing critical appraisal data in terms of reservoir quality and structural control.

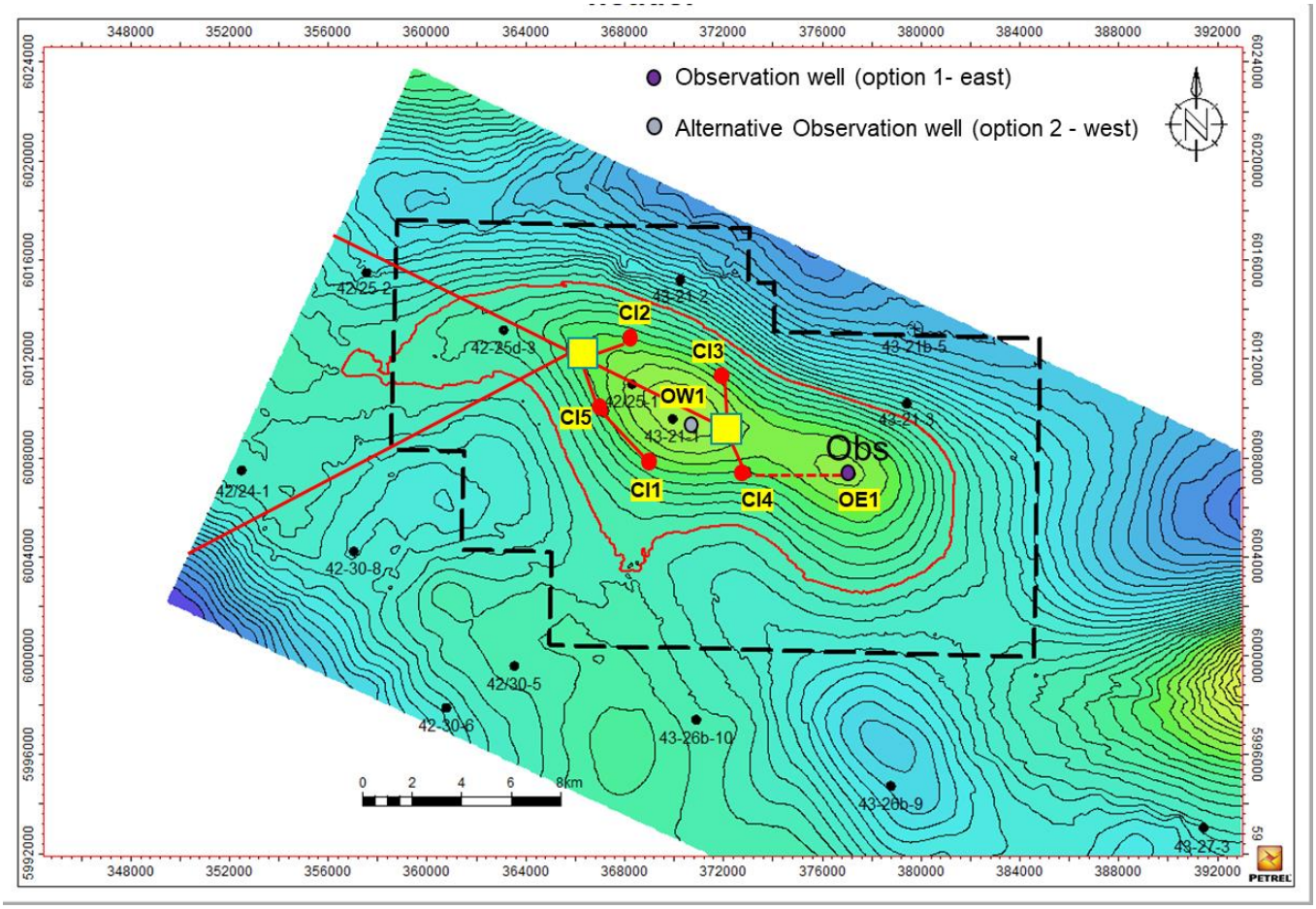

Figure 5: Phase 1 subsea development with 5 CO2 injectors and 1 observation well.

The distributed layout will enhance the dynamic appraisal of the structure as well as providing better mitigation against any unforeseen field heterogeneities or on-structure compartmentalization.

3.2 Future Expansion at Endurance

3.2.1 Initial Dynamic Appraisal

A period of 3 to 5 years of dynamic appraisal (up to 20 MT of Co2 injected into the store or 20 % of Phase 1 volumes) will be required to determine the system connectivity (i.e. how connected the structure is to the Greater Bunter Aquifer) and the ability for the installed capacity of Phase 1 to meet average volumes above 4 MTPAa (injectivity per well and field-wide capacity). Even in the downside case (P90), a 4 MTPAa plateau for 25 years could be accommodated. At the contrary, an upside geologic scenario could potentially accommodate a 5-6 MTPA plateau for instance without pressure management. Due to the relatively incompressibility of the system (brine-filled pore volume), any high-rate development such as 10 or 15 MTPA and beyond will require active pressure management at some point to maintain store reservoir pressure below caprock frac-pressure with a safe margin (Figure 6).

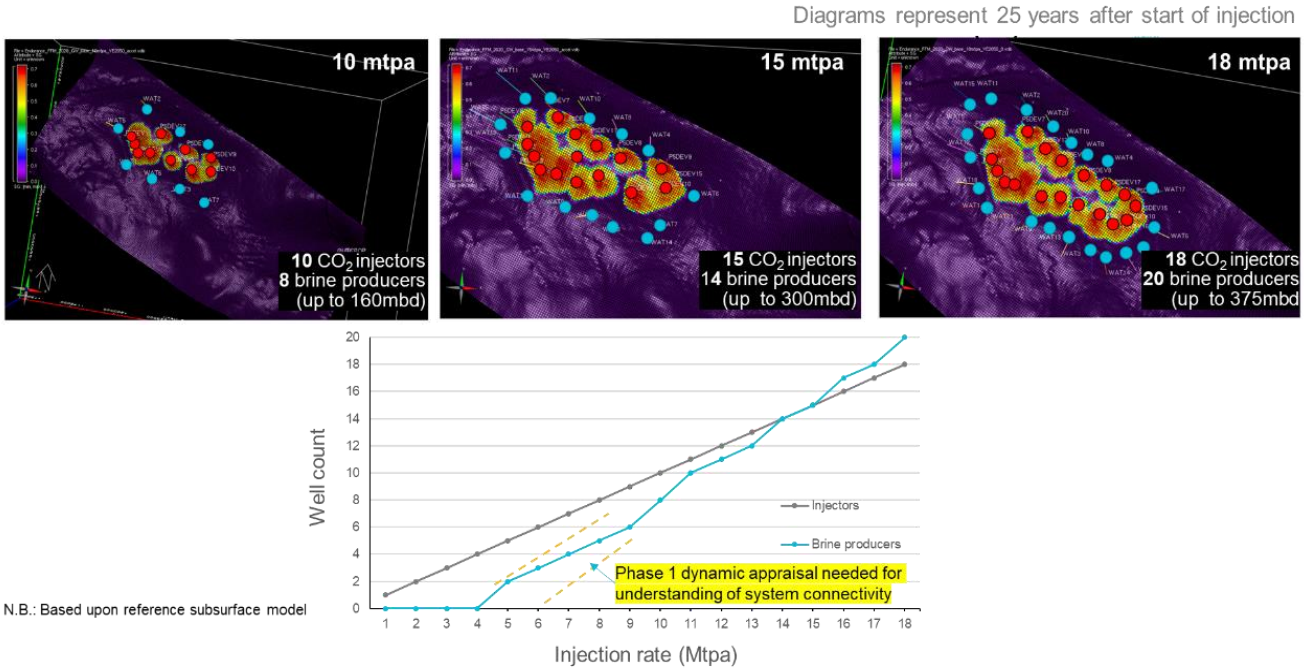

Figure 6: Technical limits for Endurance store.

3.2.2 Brine Management for Endurance

At the time of writing environmental and engineering studies are being conducted to determine the adequate engineering solution for the potential discharge of the Endurance store hypersaline brine and its potential impact.

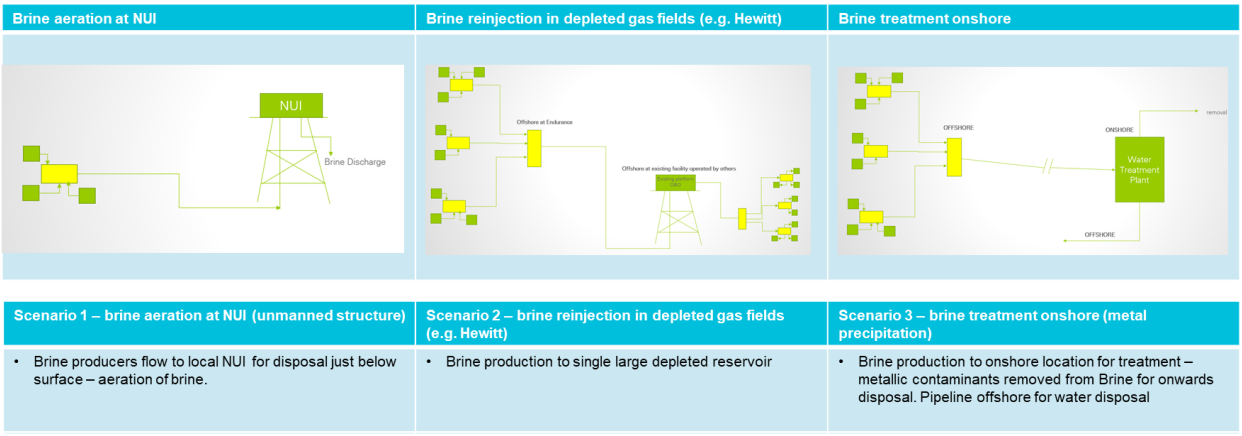

Figure 7: Brine management scenarios for Endurance (10 MTPAa plateau, up to 160 kbwpd of brine).

Brine management screening has identified three potential development schemes for a capacity of up to 160,000 bpwd of brine being produced:

- Scenario 1: Local brine discharge from NUI's located at the Endurance field
- Scenario 2: Brine injection into suitable geologic structures in the South North Sea (depleted gas fields or other fields)
- Scenario 3: Brine treatment onshore (metal precipitation)

A notional 10 MTPAa development is described in Figure 8 with the addition of 6 CO2 injectors and an associated manifold in the eastern side of the structure. 8 brine producers are being tied up to 3 Normally Unmanned Installations (NUI's) assuming the platform located within 5km of wells to enable free flow of brine with the capacity to produce up to 160,000 bwpd of brine:

- Umbilical from NUI to wells (power)
- NUI receiving power from shore
- Discharge from NUI at agreed depth (Assume aeration required)
- 20 kbwpd per brine producer

The viability of this option will be determined by regulator alignment & approval of local discharge of the brine (following up with the results from the environmental impact assessment). The collection of additional brine sample during the Phase 1 well drilling campaign will also help refine understanding of any spatial brine composition variability.

The high concentration of heavy metal components means it is unlikely the brine can simply be released to sea and will require capital intensive treatment to enable sufficient dispersion (i.e. surface aeration at a minimum) and, in the worst case, onshore treatment to reduce the quantity of heavy metal components (case 3), or re-injection (case 2).

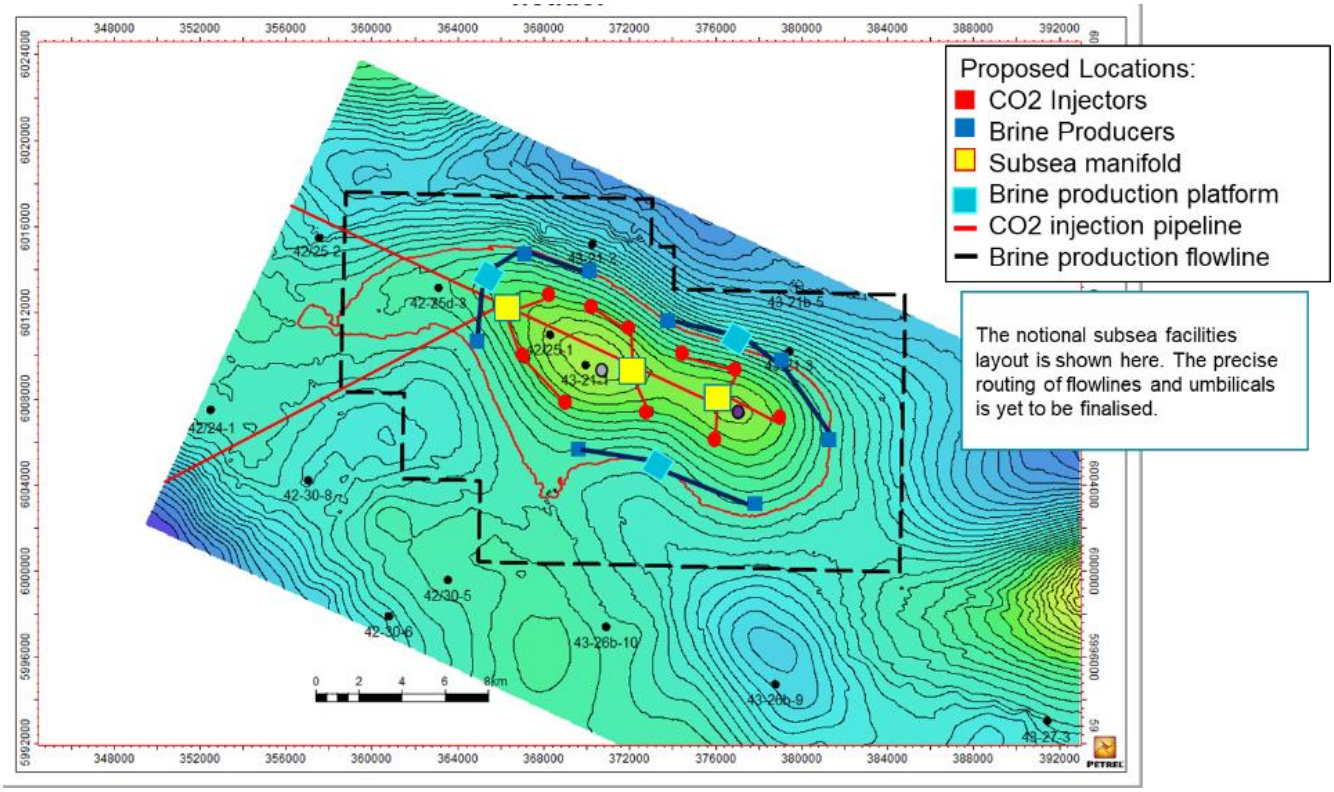

Figure 8: Notional 10 MTPA development with 10 CO2 injectors and 8 brine producers (surface discharge)

4.0 Northern Endurance Partnership Multi-Store Expansion Strategy

4.1 Notional Phasing for Future Phases

The Endurance CO2 storage site constitute the cornerstone of the storage strategy for the Northern Endurance Partnership by its size and low risks thanks to the available appraisal data. Its capacity of the order of 450 MT (achieved with Brine production) will not be sufficient to meet the potential throughput rates from the combined capacity of the Humber and Teesside pipelines (up to 27 MTPAi). Additional store sites will have to be considered to support future phases by building upon the infrastructure developed at Endurance as the hub (whose actual capacity will be refined through dynamic appraisal over the first 3 to 5 years).

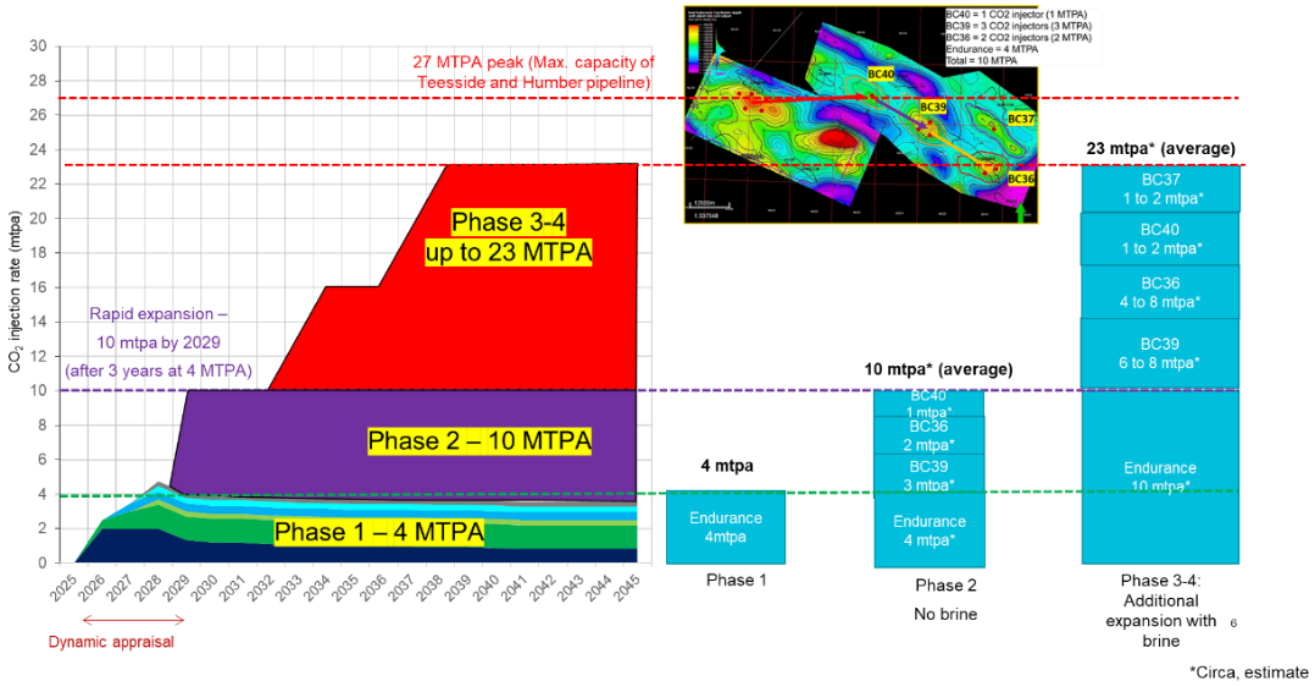

Figure 9: Notional NEP expansion strategy from 4 to 10 MTPA to 23 MTPA.

4.2 NEP Phase 2: Expansion at Pace to 10 MTPA

In order to accommodate potential future volumes from Humber and Teesside industrial clusters (up to 23 MTPAa /27 MTPAi combined from the two pipelines), a CCS license application has been made in February 2021 to capture the acreage covering the Bunter Structure BC36, 37, 39 & 40 stores located 40 to 80 km to the east of Endurance (Figure 10). The Bunter Closure reservoirs have been selected in this early phase due to the significant potential capacity and injection rates they offer in aggregate, and their similarities with the Endurance reservoir.

Utilisation of the nearby Bunter Closures ('BC') BC36, BC37, BC39 & BC40 may enable a cost effective and low risk expansion beyond the phase 1 development of Endurance to reach 10 MTPA (average), as well as providing further opportunities for longer term expansion (23 MTPA).

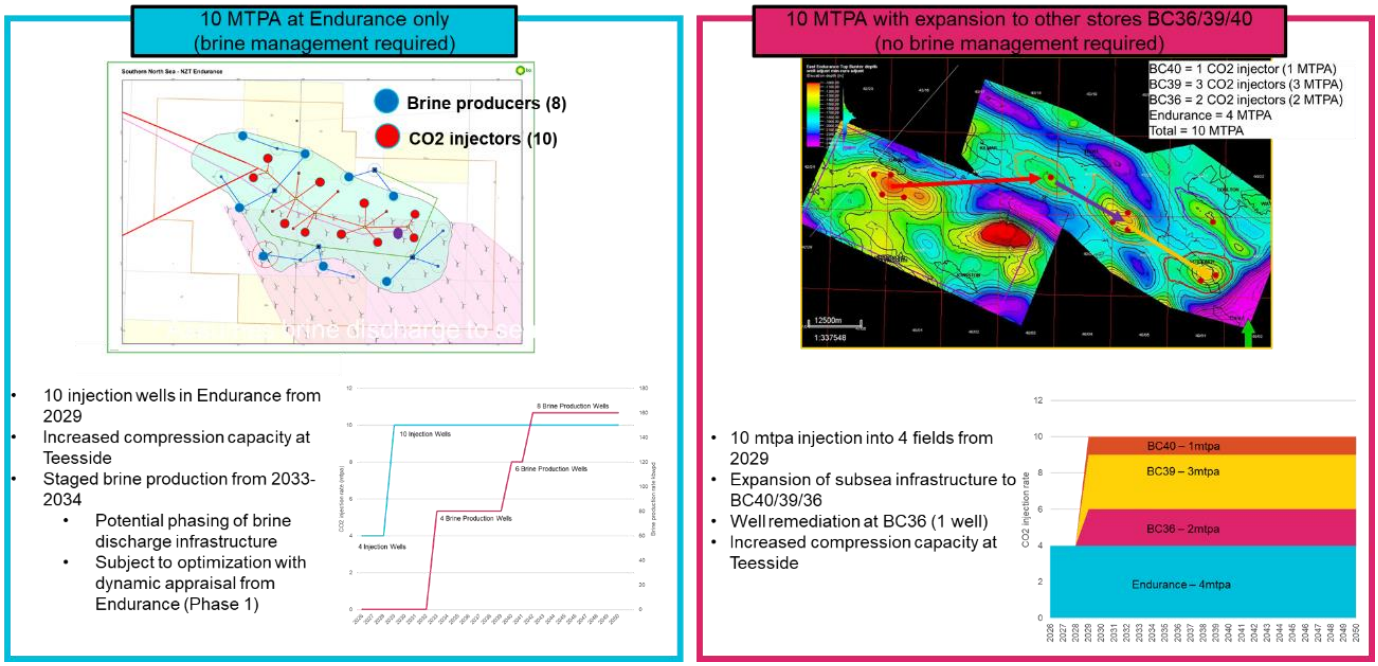

Figure 10: Path to 10 MTPAa (Phase 2) from Phase 1 (4 MTPAa at Endurance). Option 1 would involve expanding Endurance to 10 MTPAa with brine production facility while option 2 would require expansion into additional stores (BC36/39/40) to add 6 MTPAa capacity (no brine production would be expected).

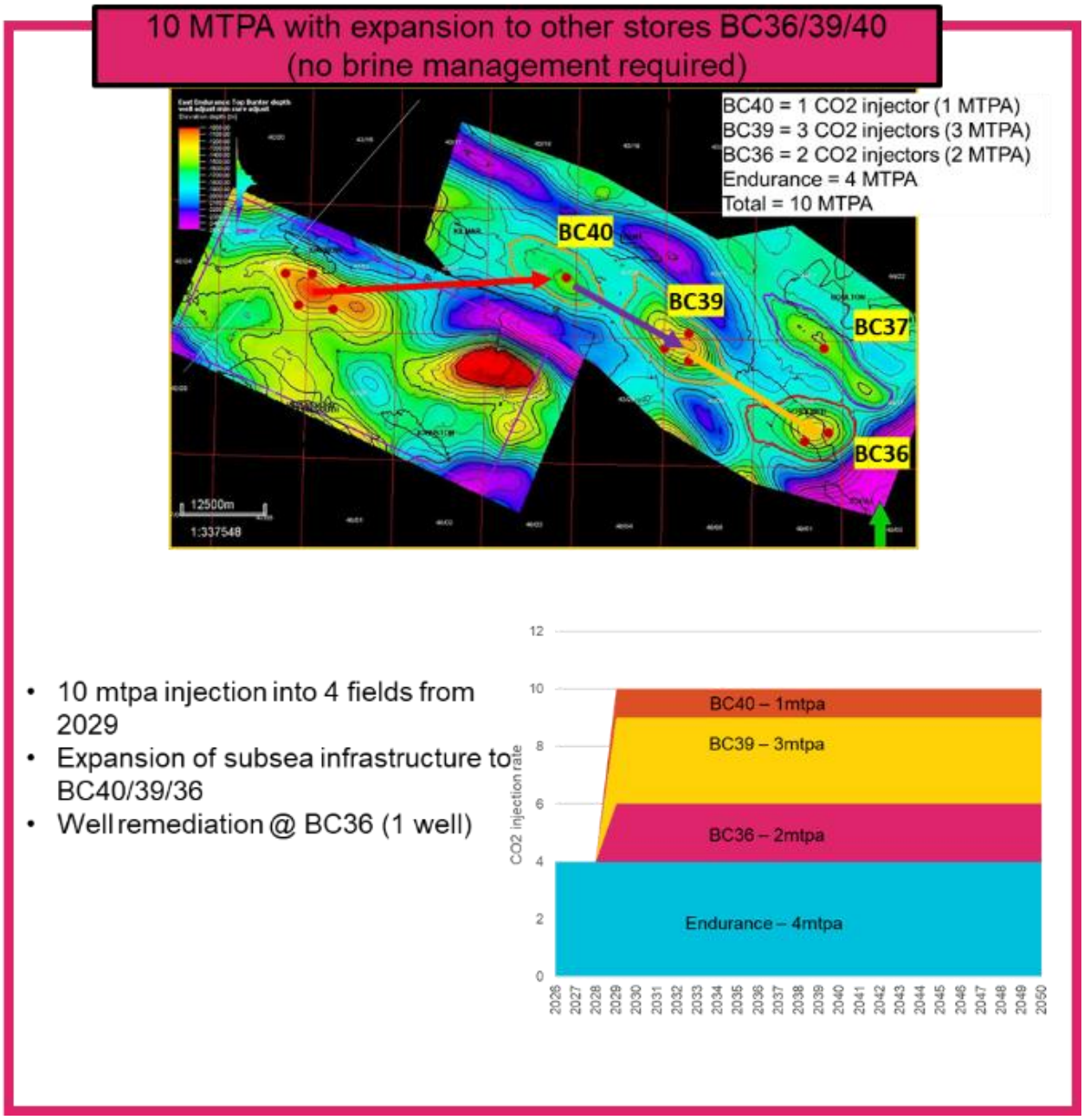

Figure 11: Path to 10 MTPA (Phase 2) from Phase 1 (4 MTPA at Endurance) with the expansion into additional stores (BC36/39/40) to add 6 MTPA capacity (no brine would be expected).

The expansion to 10 MTPA with the development of BC36, 37, 39 & 40 (Phase 2 10 MTPA) would notionally comprise (Figure 11), provisional on successful license application and completion of the relevant appraisal work program.

Increased onshore compression capacity to 10MTPA (average)

- Six new injection wells (6 MTPA capacity)
- 2 in BC36
- 3 in BC39 (contingent on successful appraisal of the structure)
- 1 in BC40

- New subsea infrastructure to connect the additional stores to the existing subsea network at Endurance
- A well remediation operation in BC36 targeting one of the two crestal legacy wells over the structure (i.e. 44/26-3)
- An agreement with DNO to remediate to integrity risks of the 10 development wells targeting Schooner

An expansion of the NEP development through utilization of the nearby Bunter Closure reservoirs may enable the following benefits to be realized:

- It enables “appraisal while developing” for Endurance, significantly improving subsurface understanding and the forecast of brine production timing, volumes, and rates.
- Earlier incorporation of additional reservoirs provides mitigation of the geological risks by using a multistore approach rather than a single store.
- Securing a licence for BC36/37/39/40 early in 4Q 2021 provides opportunity to optimise development by engaging early with potential future wind developers
- An opportunity to demonstrate a regional basin approach that maximises UKCS storage resource as per OGA and BEIS’ ambition
- Benefit from pipeline pre-investment and development 150 MT of storage capacity (at a lower cost

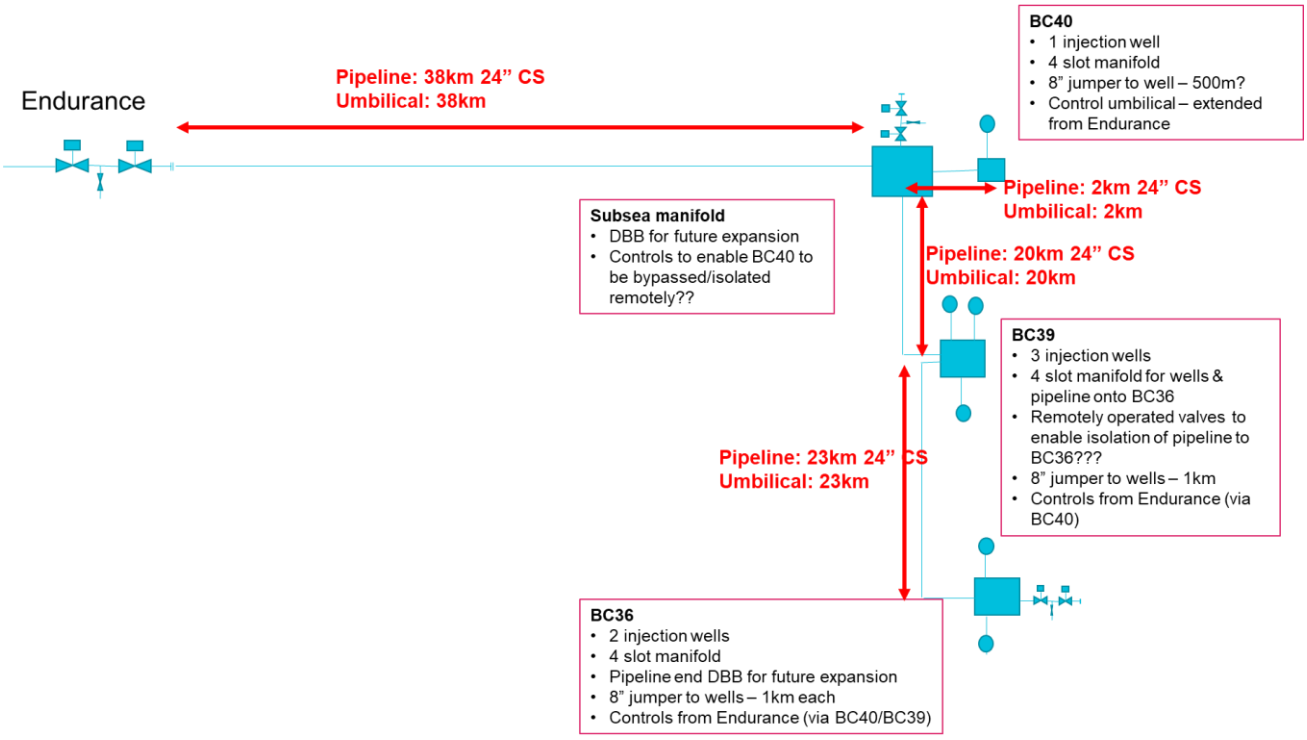

Figure 12: Notional subsea expansion from Endurance to BC40, BC39, and BC36 (subsea system will have the ability to be connected to BC37 as well to support future phases).

The development of the alternative Bunter stores will be facilitated by the ability to connect the flowlines back to Endurance subsea infrastructure (5 subsea injectors and 2 manifolds) as

shown in Figure 13. The tie-in point at the Wye will allow the use of Endurance and existing pipeline infrastructure for injection further east.

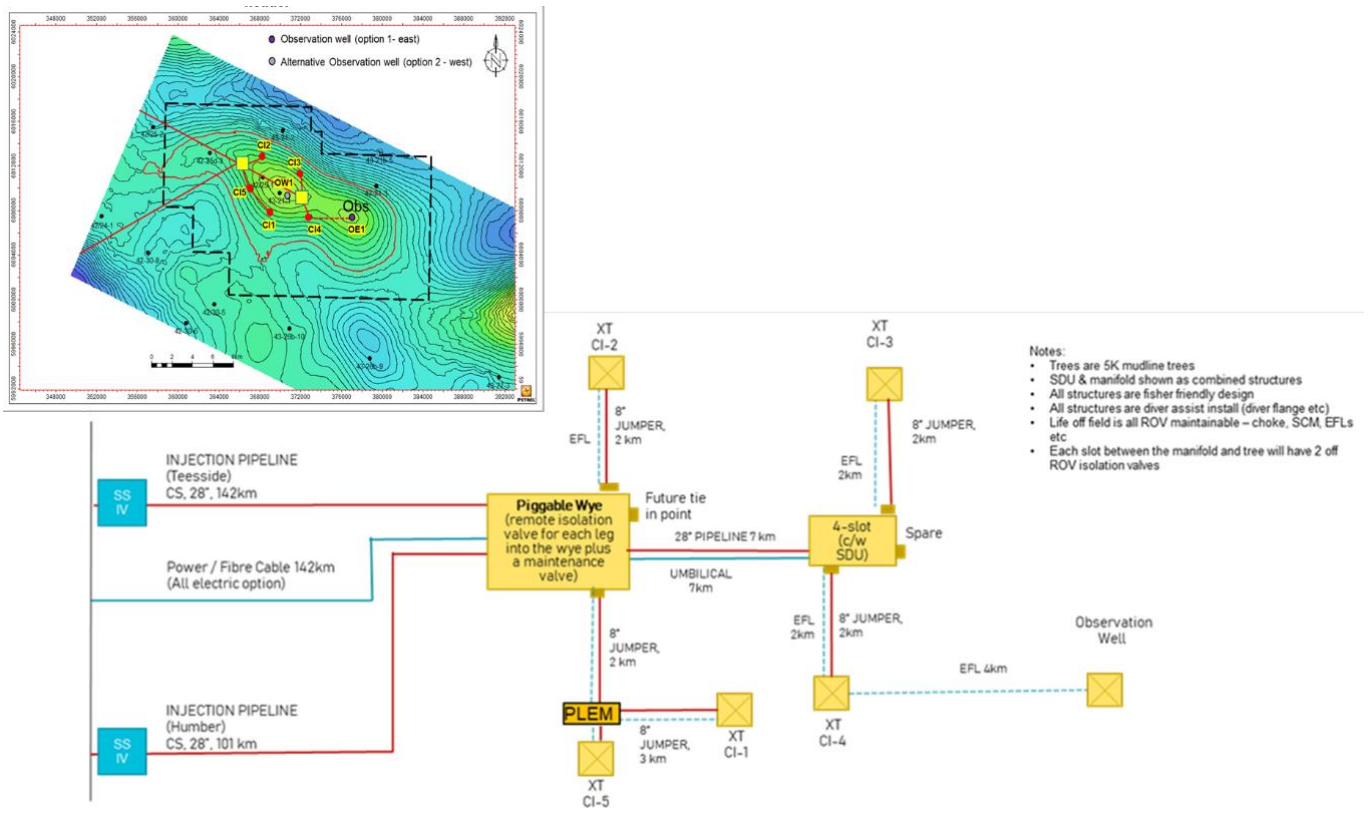

Figure 13: Endurance Phase 1 subsea development

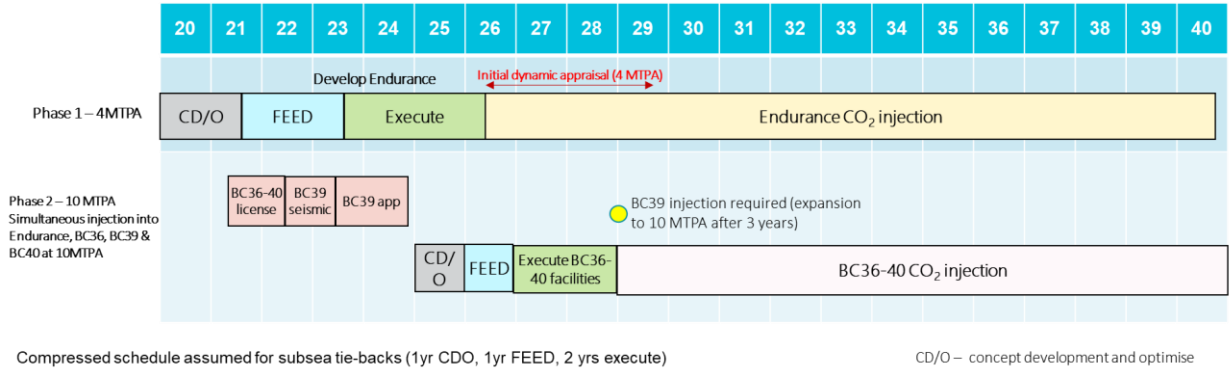

Figure 14: Indicative expansion strategy to 10 MTPA (Phase 2).

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