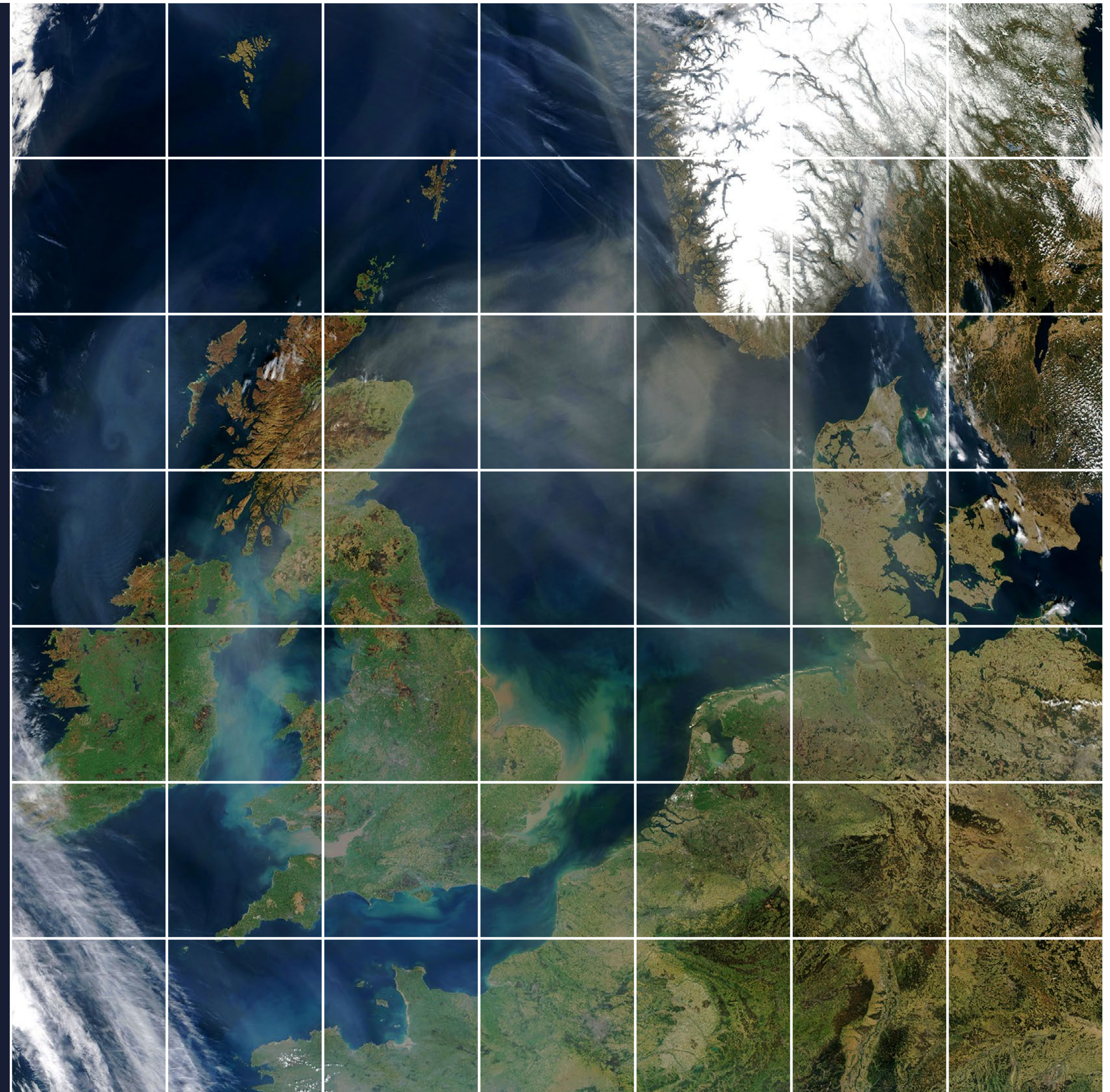




FORECASTING THE NORTH SEA CCUS INFRASTRUCTURE TO 2050

WWW.XODUSGROUP.COM





This paper has been prepared by Xodus, a Subsea7 company

Xodus is a global energy consultancy, we unite our unique and diverse people to share knowledge, innovate and inspire change within the energy industry. We provide support across the energy spectrum, from advisory services to supply chain advice across the full lifecycle of energy projects. Our people strive to ensure global energy supply as we all work together to realise a net zero world.

As we progress through the energy transition, Xodus continues to deliver high quality, fit-for-purpose solutions to the industry. The key sectors that we work in span oil and gas, offshore wind, carbon capture, utilisation and storage, cables and interconnectors, hydrogen and marine energy. Xodus is a market leader in Carbon Capture, Utilisation and Storage (CCUS) with over 14 years of experience on over 35 projects advising developers, governments and financial institutions from feasibility studies through to operational performance.

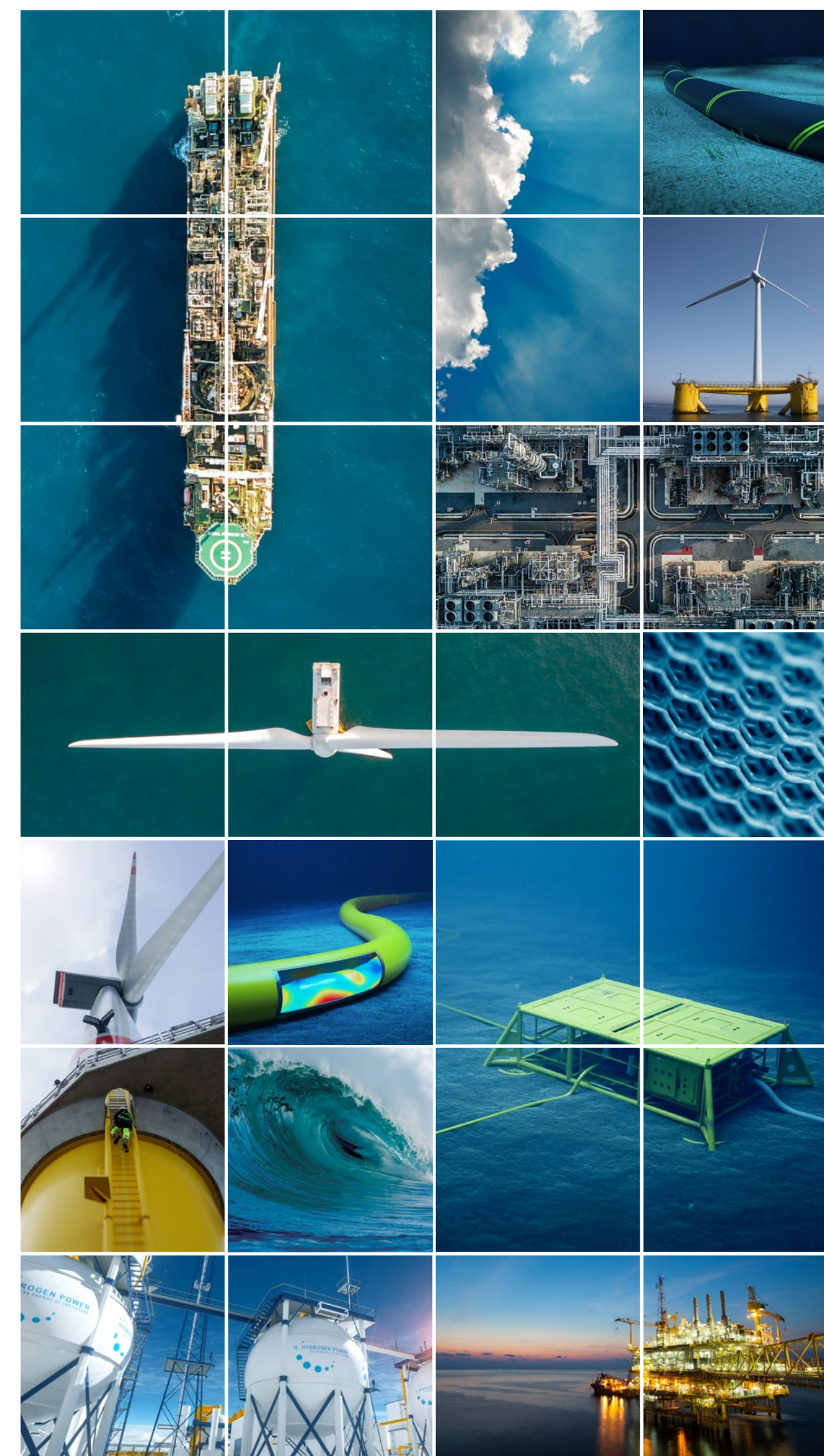
Subsea7 is a global leader in the delivery of offshore projects and services for the energy industry. Subsea7 makes offshore energy transition possible through the continuous evolution of lower-carbon oil and gas and by enabling the growth of renewables and emerging energy.

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INTRODUCTION

As the urgency to combat climate change intensifies, innovative technologies like CCUS have emerged as key solutions to mitigate greenhouse gas emissions.

As CCUS scales up, how will the infrastructure in the North Sea be repurposed and constructed to provide storage capacity?

CCUS involves capturing carbon dioxide (CO₂) and safely storing or using it to prevent its release into the atmosphere. CCUS is a component of a comprehensive net-zero strategy that encompasses energy efficiency, renewable energy sources, and sustainable practices.

While CCUS alone cannot solve the climate crisis, it offers significant advantages as a mature technology that can be deployed immediately without substantial changes in consumer behaviour and is a solution to hard to abate sectors.

Objective of our study

The CCUS outlook is uncertain in terms of timing, volume and optimal locations for storage. Our study focuses on the required infrastructure needed to enable delivery of the CCUS value chain.

Europe and the North Sea have vast geological storage potential, well above any potential CCUS need. However, it is challenging to assess the relative cost efficiency of projects or frame in what market conditions or time horizon a project would become viable.

We have developed a tool to do so. Through a bottom-up analysis, we assessed 560 potential storage sites, North Sea gas pipelines and potential new pipelines to identify cost efficient storage. This tool can support and facilitate investment decisions of North Sea operators and their stakeholders. An output of this tool is to generate scenario-based forecasts which we provide in this document.

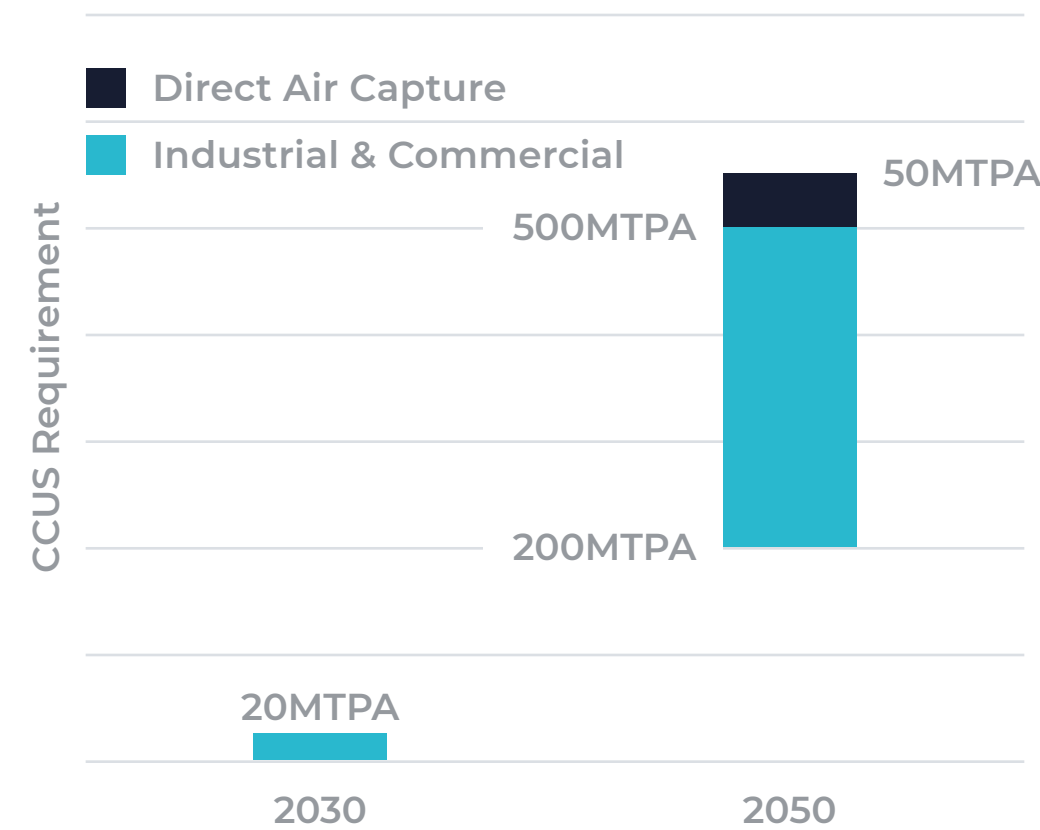


OUR APPROACH

Our objective is to rank the cost efficiency of potential storage sites and their associated transport infrastructure. Our model works in five year increments and covers 2025 to 2050. The model assesses existing infrastructure within the North Sea, identifying when infrastructure could be repurposed for CCUS. Our tool includes licenced CO₂ storage sites as well as potential future licence areas as identified by public studies, and we have included potential saline aquifers and new pipelines to serve future demand. Our assumptions on the market size rely on a range of third-party forecasts to represent the potential variance in future required storage capacities; this is a variable in our algorithm. We have modelled over 560 storage sites cost competitiveness across a range of criteria to assess construction and operating costs including distance to shore, distance to major trunklines, several reservoirs' characteristics, and location.

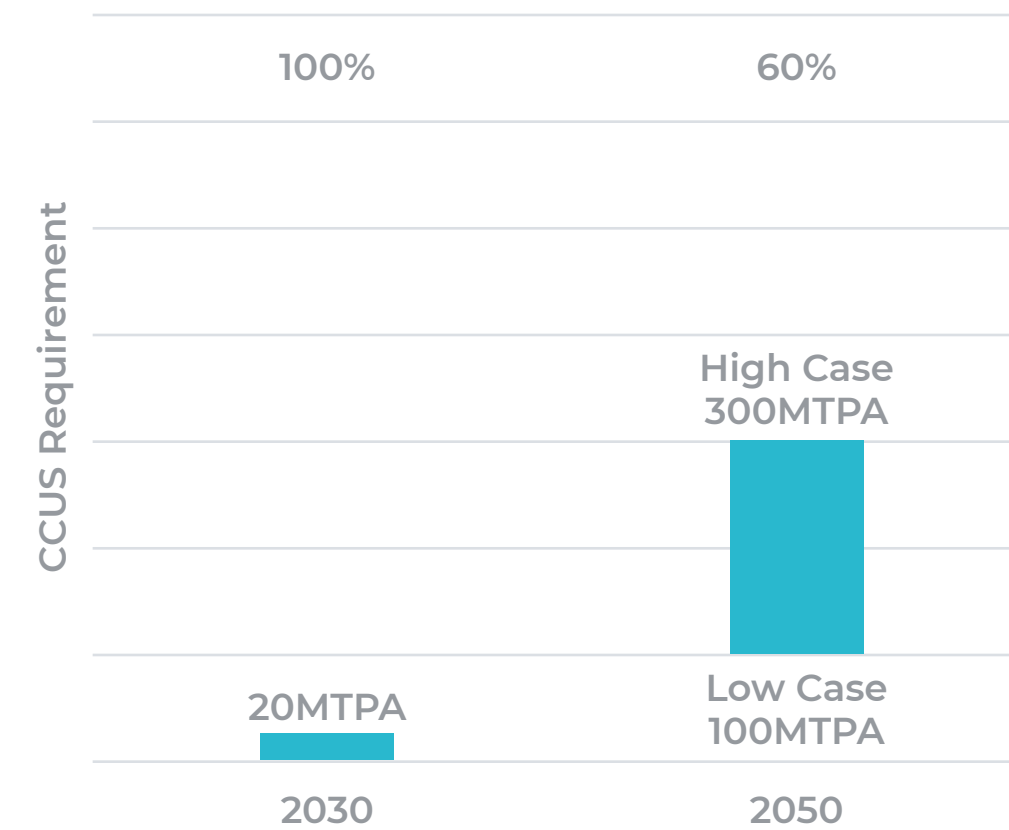
How much CO₂ storage is needed (MTPA)?

European CCUS Storage Market Size



Xodus assessment is based on various public sources (UK, IEA, EU, S&P). Range is large but not uncommon to other energy transition markets such as hydrogen or offshore wind a decade ago. MTPA: Million Ton Per Annum.

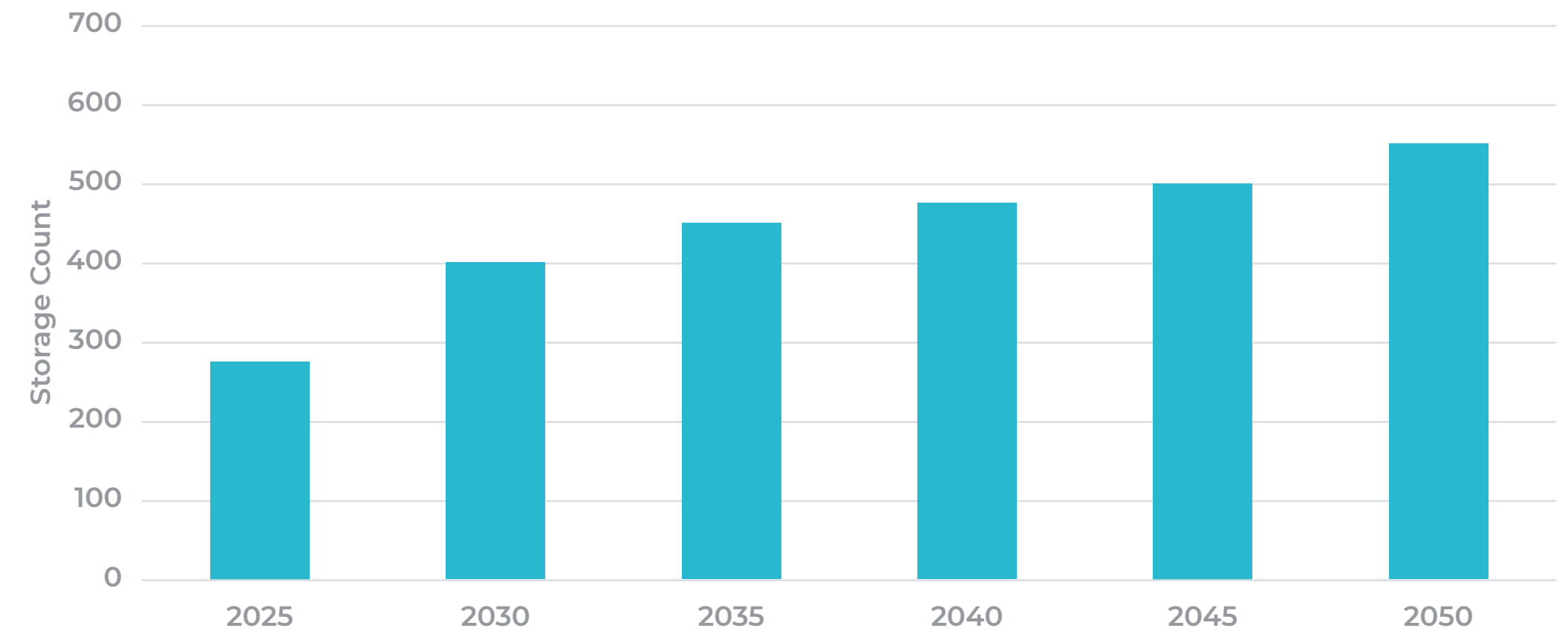
Scenarios of CCUS Volume In the North Sea



Xodus assessment – 300MTPA is the high case by 2050, and 100MTPA is the low case. North Sea's current 100% market share of 2030 European CCUS projects is expected to decrease over time but should remain dominant thanks to existing infrastructure and location near CO₂ emissions.

Algorithm to select most efficient storage sites

Number of Storage assessed in the algorithm during the period



The algorithm selects the most efficient available, or to be-built transport and storage infrastructure to meet a demand requirement. The assessment is done in five years increments and is path-dependant. The cost assessment is grounded in a wealth of data, drawing from more than 35 studies in the field of CCUS. The range in required storage volume forecasts, the simplification inherent in modelling hundreds of sites as well as selecting aquifers and locations of new pipeline need to be kept in mind when reviewing the output presented in this paper.



The near term outlook – by **2030**, 100% of projects operated are in the North Sea.

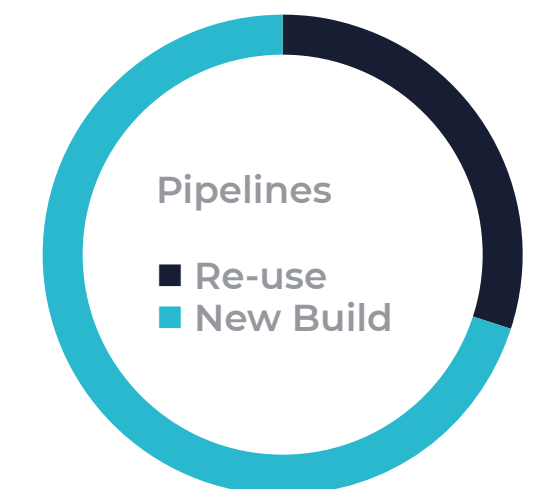
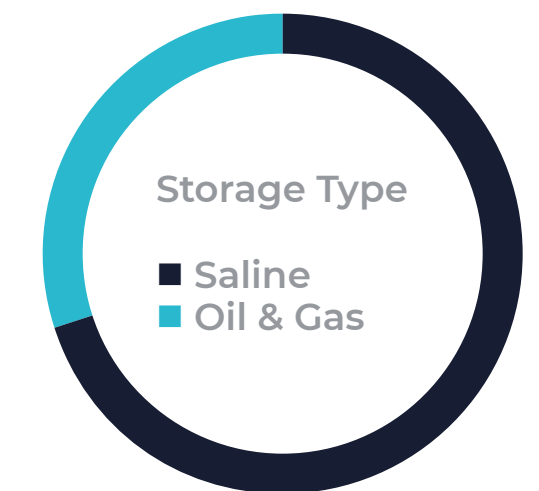
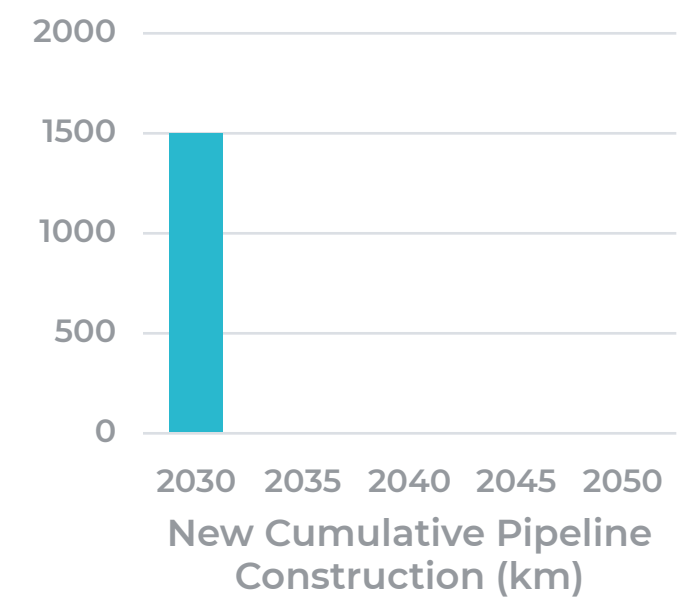
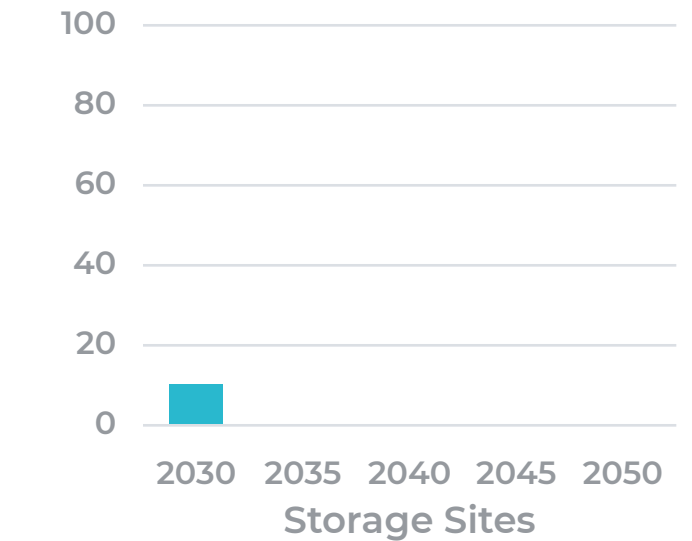
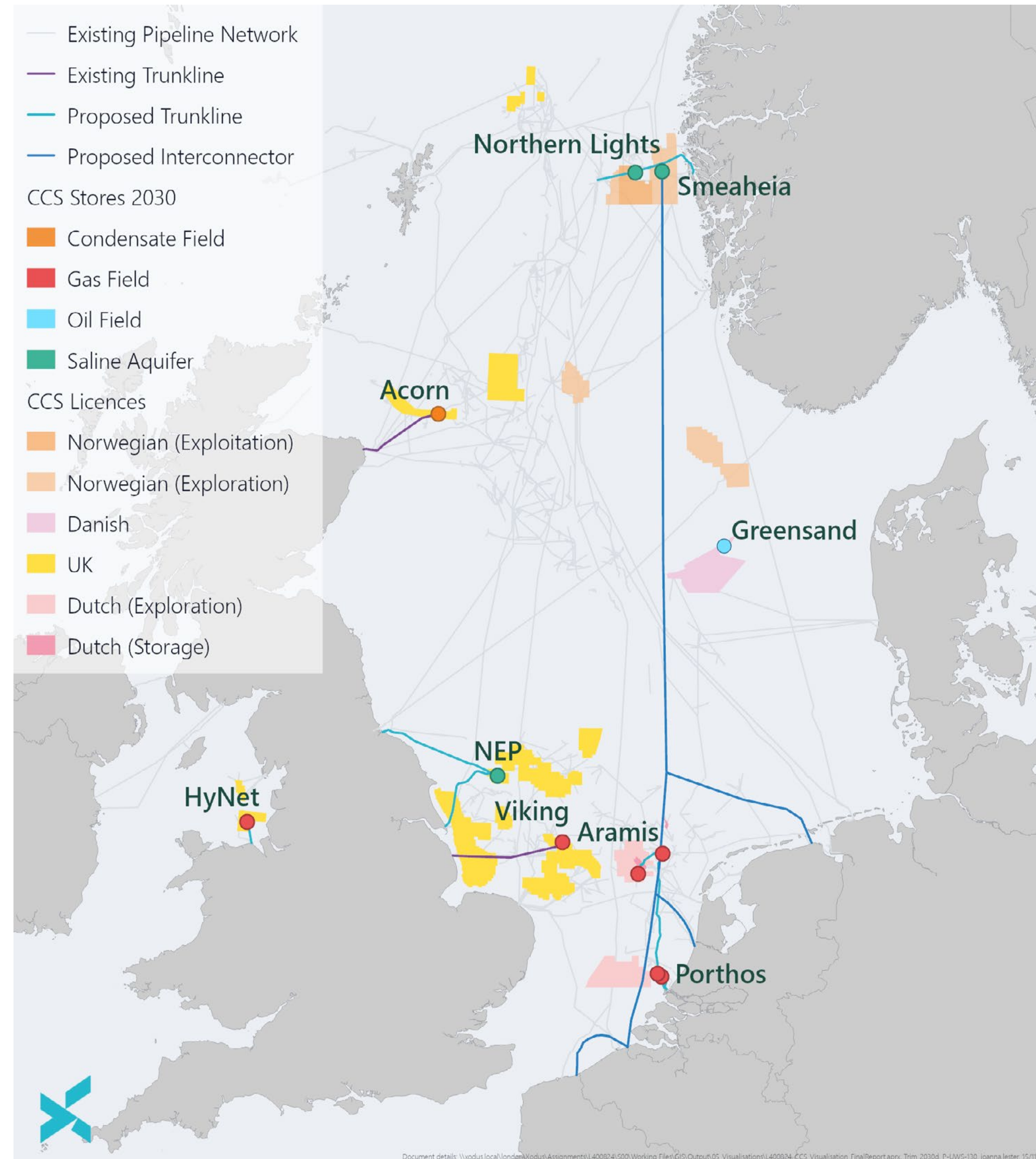
We expect eight projects to be on-line by 2030 providing 20MTPA CO₂ with four UK sites, including Viking and Acorn alongside the track#1 cluster projects HyNet and East Coast NEP.

Storage Serves a Localised Market – All carbon storage is jointly developed or closely linked to industrial decarbonisation clusters, serving carbon captured mostly by local emitters anchored by local industries.

Direct Government Support – Developments are supported by direct subsidies alongside commercial contracts which are indirectly incentivised through the ETS / UKTS scheme.

Focus – Northern Lights

- First commercial CCUS project in development in Norway
- Due to be operational by 2024
- Includes 100km of new pipeline and will use a saline aquifer to store CO₂
- The first phase of carbon capture is from a connected site (Longship part of the project)
- Subsea7 is installing the subsea infrastructure



Percentage in round charts based on sites storage capacity



CLICK TABS TO VIEW MAPS

By **2040**, the CCUS infrastructure needs to grow fast as it internationalises.

In our forecast, we anticipate the need for 48 storage sites to accommodate an annual volume of 130MTPA.

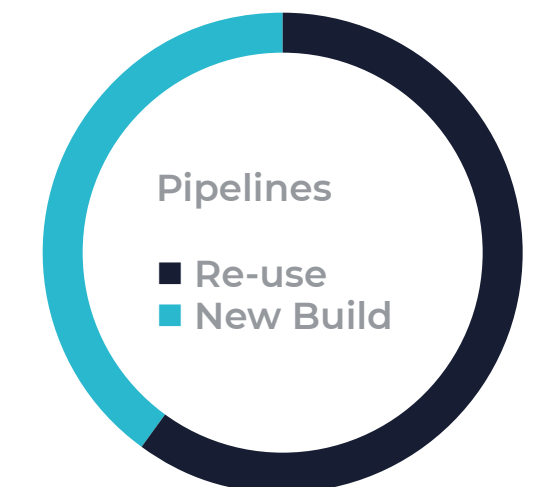
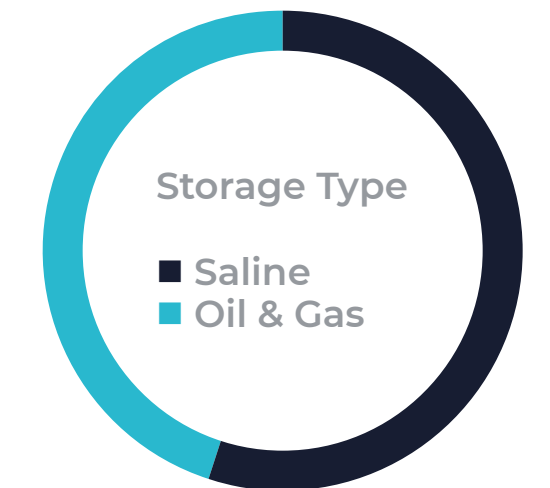
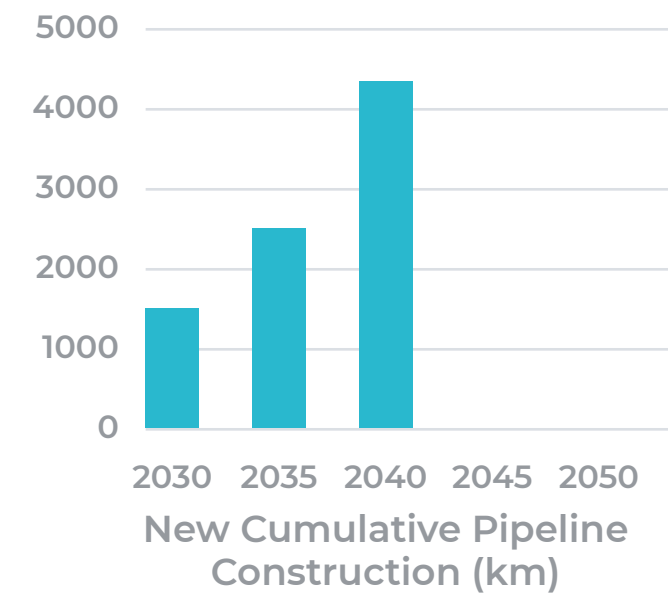
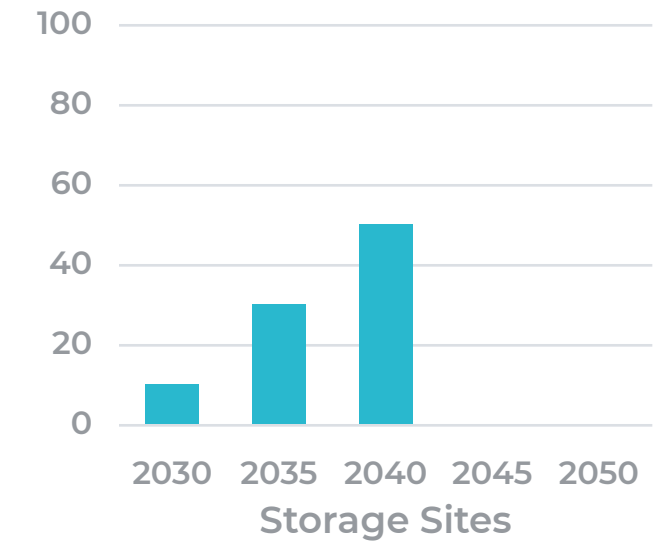
These 48 fields are selected by our algorithm among 480 storage sites. **Sites selection in our framework is driven by cost and the availability of trunklines.**

As many large gas fields reach their end of operations, we expect an increase in the proportion of project reusing existing infrastructure in that decade.

Additionally, **the CCUS market will internationalise with significant volumes of CO₂ transported to the UK and Norway.** The Smeaheia project will take CO₂ from North-West Europe to a Saline Aquifer in Norway. This transport can occur via pipelines (interconnectors), shipping, or likely, a combination of both methods.

Focus – Bacton Energy Hub

- Bacton and the UK Southern North Sea is one of the most attractive areas identified as it has significant re-use potential offshore (pipeline and depleted gas field) and onshore
- The Bacton Energy Hub is developing this opportunity, and Xodus is the infrastructure theme lead



Percentage in round charts based on sites storage capacity

Selected Infrastructure represents the pipeline and storage sites chosen by the algorithm. All Infrastructure Options represent the pipeline and storage assessed by the algorithm in 2040.



CLICK TABS TO VIEW MAPS

In **2050**, an infrastructure similar to the current natural gas industries.

To fulfil the market's demand for 300MTPA of capacity, we anticipate the need for over 100 storage sites.

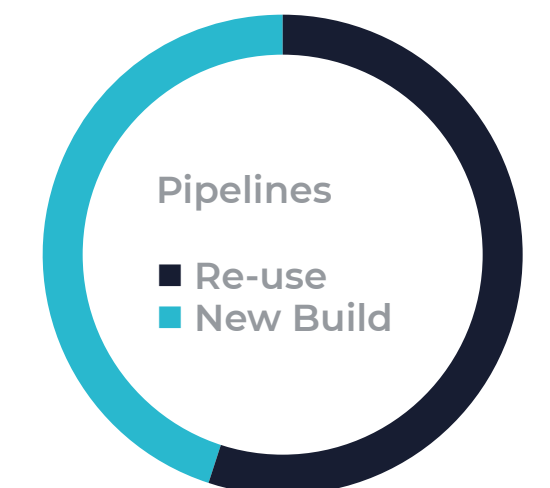
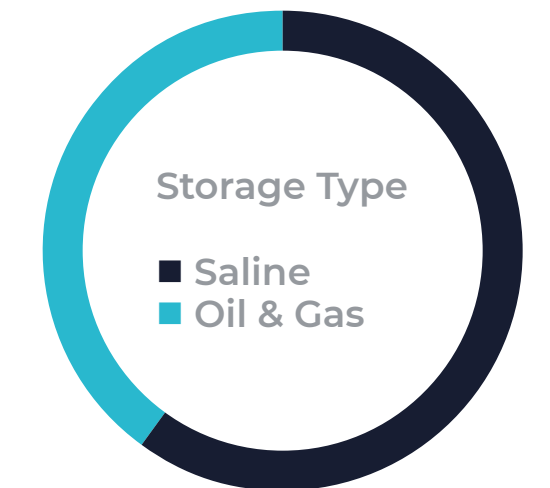
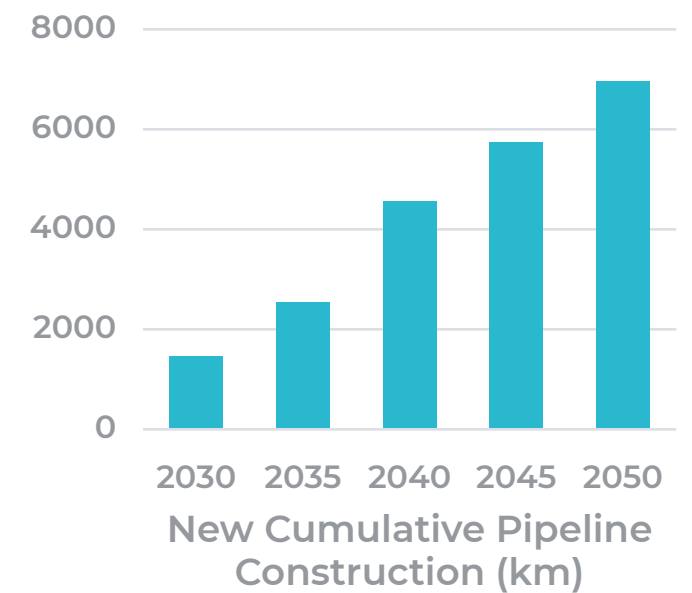
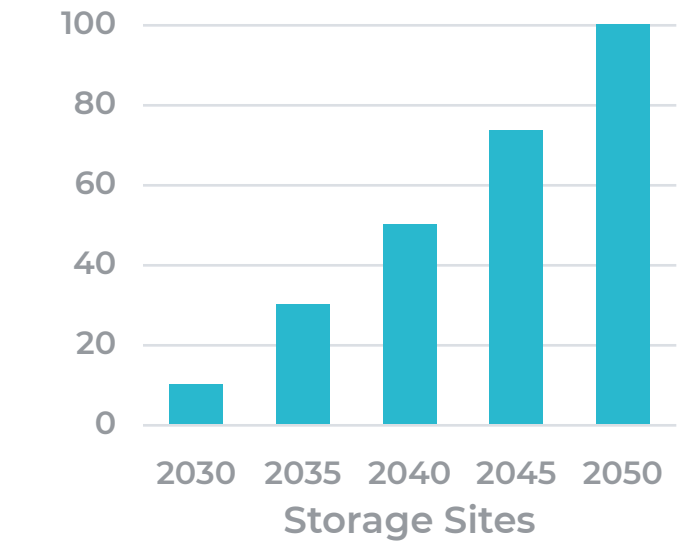
This expansion will be facilitated by the development of multiple new pipelines to serve these storage sites.

We anticipate the utilisation of saline aquifers across the North Sea and the repurposing of numerous gas fields in the Southern North Sea, Dutch and Danish sector to meet this demand.

The forecast level of CCUS activity is likely to lead to competition for seabed area with other developing industries such as offshore wind, and hydrogen production, which could also lead to the opportunity to collaborate between these industries.

Focus – The 2050 CCUS Market Size in Context

- The CCUS market has reached a scale comparable to the current natural gas production market
- The annual volume of 300MTPA of CO₂ is equivalent to 160 billion cubic meters (bcm) of gas, akin to the volume of natural gas currently produced in the North Sea



Percentage in round charts based on sites storage capacity

LOW AND HIGH CASE COMPARISON

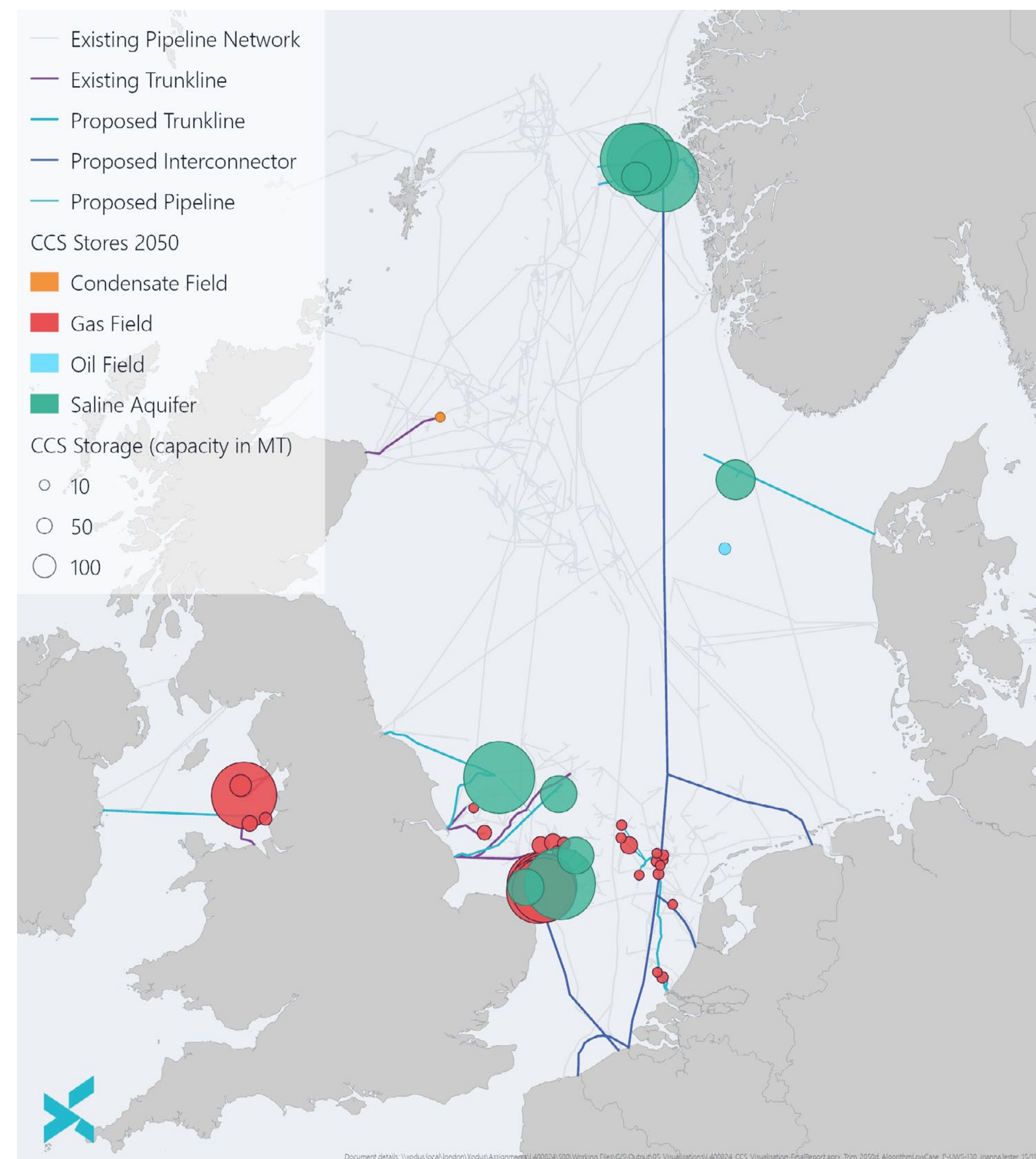
In our assessment, we've observed that the reduction in volume does not result in a pro-rata decrease in the number of required storage sites or pipelines.

Initially, we anticipate a relatively high number of new storage sites. However, as these sites can efficiently cater to a more significant portion of the demand, this reduces the need for new stores afterwards.

As demand drops, the length of newly constructed pipelines would decrease from 6,900 to 2,900 kilometres.

In a smaller North Sea CCUS market, the prevalence of re-use projects doesn't necessarily increase significantly as saline aquifers remain cost-competitive options.

Notably, some storage sites (or pipelines) demonstrate competitiveness in low- and high-case scenarios, emphasising their adaptability and resilience within a changing market landscape. These versatile projects are well-positioned to navigate evolving market conditions.





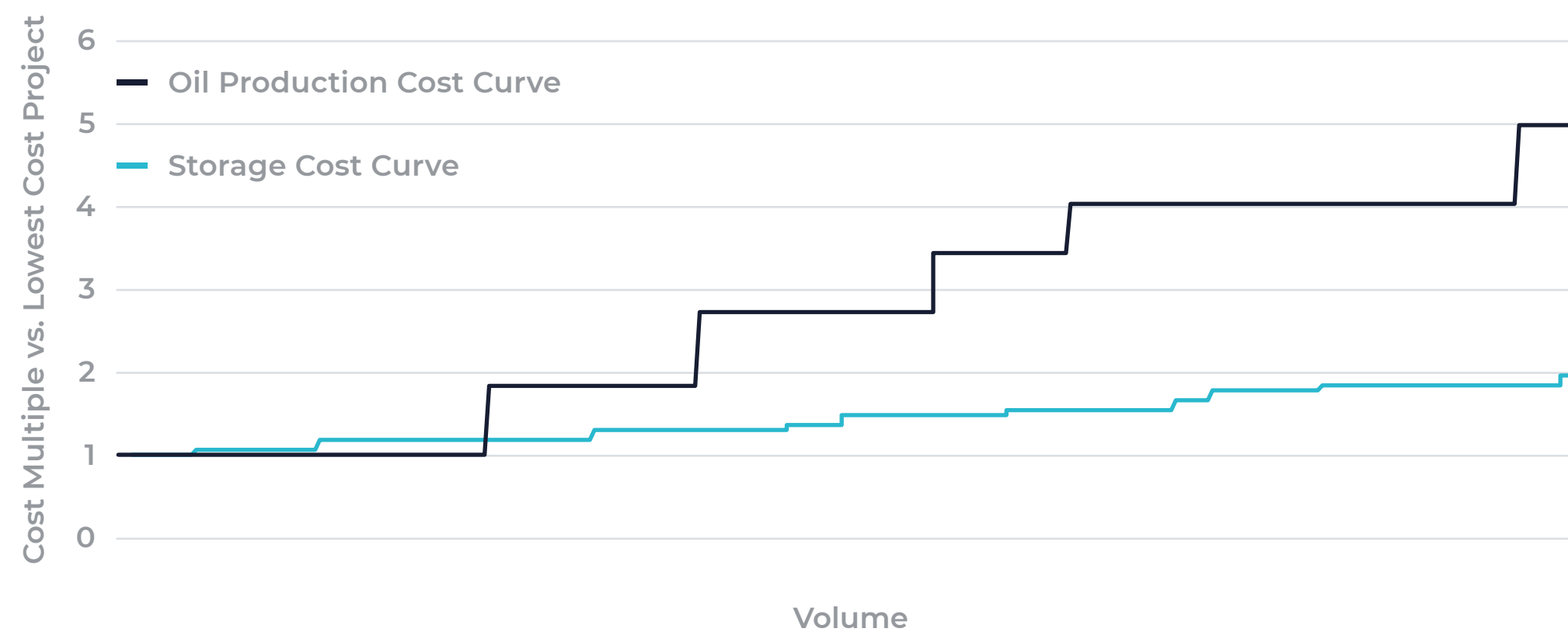
STORAGE MODELS

The storage cost curve in our forecast remains relatively flat, characterised by a modest 1 to 1.5 multiple between the lowest and highest cost projects. This is primarily attributed to the substantial availability of storage capacity.

This stands in stark contrast to the cost curve for oil production, where there is a more significant disparity between the costs of Middle East onshore oil production and marginal fields. In this context, projects with higher relative costs will need to rely on compelling local differentiators or unique advantages to enhance their competitiveness.

With this limited cost differential, a strategic approach supported by government intervention can significantly change the location of the CCUS transport and storage infrastructure, as exemplified by Norwegian projects such as Northern Lights and Smeaheia.

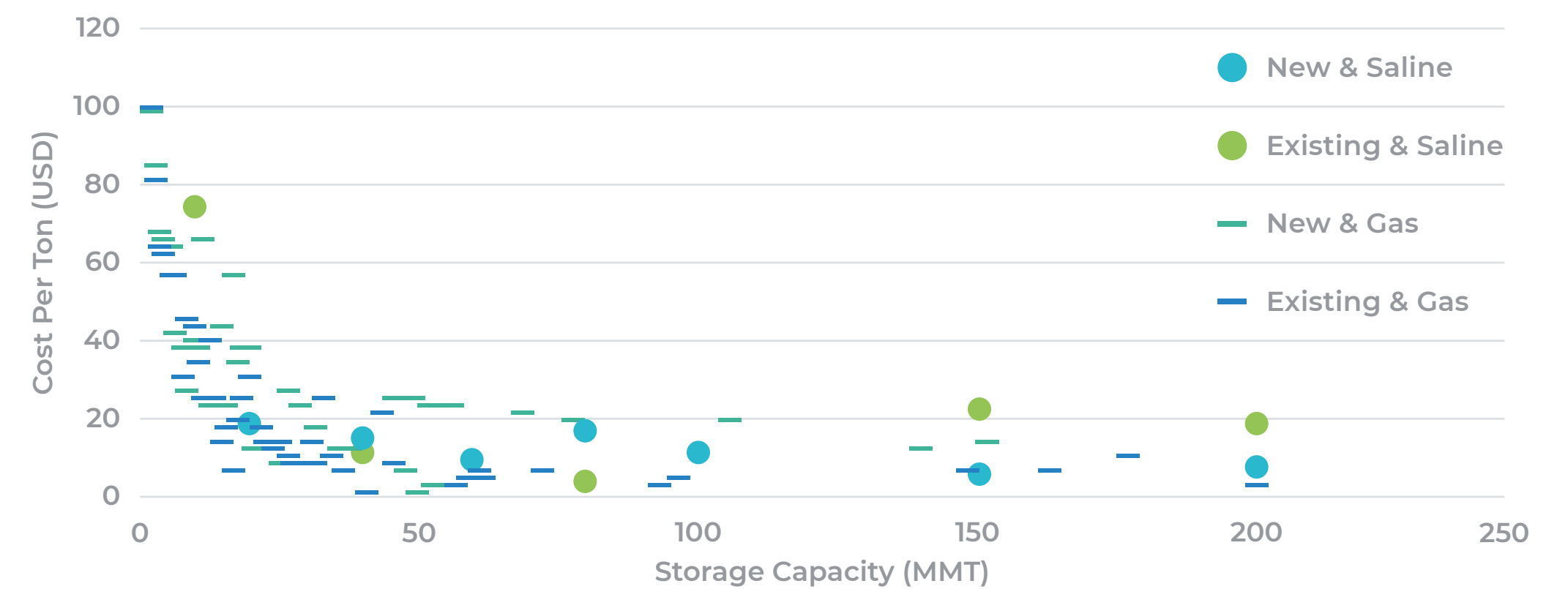
Storage Cost Curve vs. Oil & Gas Cost Curve



The chart below shows how cost per ton reduces gradually with the storage capacity for all 560 sites. These economies of scale become limited once the storage site reach 50-70 million tons. The assessment becomes more intricate in a low-case scenario where the realisation of economies of scale may not be as straightforward, necessitating a deeper examination of the variables at play.

This cost assessment also shows that all delivery models can be cost efficient. Saline aquifers and depleted oil and gas fields both emerge as competitive storage options. Additionally, projects that choose to reuse existing infrastructure or invest in new infrastructure can both achieve cost-efficiency, recognising that even reuse projects typically involve the installation of new spur lines, potential platform bypasses, and new wells.

Economies of Scale in Transport & Storage Cost





UNIQUE GEOGRAPHY OF THE NORTH SEA

Europe is the only leading economic region with its largest hydrocarbon basin at the heart of its economy.

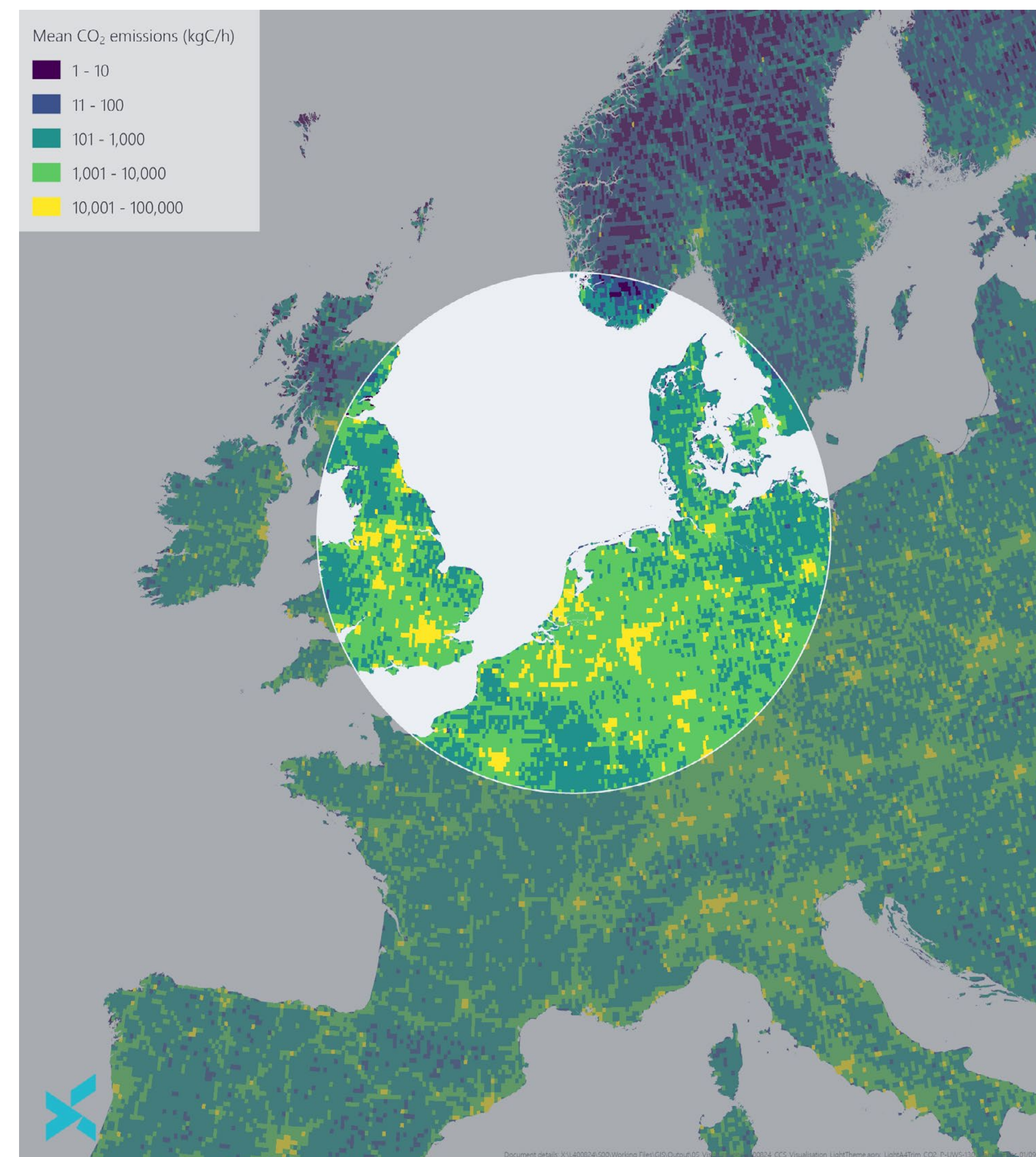
40% of European industrial emissions are generated within 500km of the North Sea. North America and East Asia do not have access to a similar well-located basin.

This location advantage will reduce the cost of developing CCUS projects by providing nearby storage sites, a deep skill base and infrastructure.

In the coming decade, the North Sea looks to accommodate 100% of European projects. Over time, the market share of the North Sea will reduce.

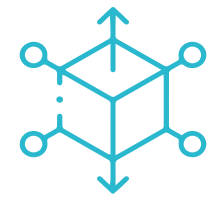
While the North Sea might continue to capture the CO₂ from its proximity, the ability to capture CO₂ further afield will be driven by a range of considerations from transport costs (shipping, further pipeline, collection cost), competing storage sites both locally and internationally, as well as societal acceptability of onshore storage.

Our high case estimates that the North Sea would retain a 60% market share of a 500MTPA market, with the North Sea importing CO₂ via shipping lines and long-distance pipeline.





HIGHLIGHTS



The scale of the CCUS industry is likely to be vast

In our 2050 high-case scenario, the volume of CO₂ re-injected in the North Sea will be equivalent to the natural gas currently extracted from the North Sea. This operation will require 100 storage sites, over 6,900km of new pipelines, and dozens of onshore CO₂ capture / gathering sites.



Limited price differentiation puts focus on cost and design efficiency

Our work has shown that the cost per tonne of CO₂ stored in a CCUS project rapidly decreases with the capacity of the CO₂ store to a constant level above 3MTPA, but that the type of store or extent of re-use of existing structure isn't a major driver in the overall cost of CCUS. As such, successful operators in the CCUS space will need to concentrate on selecting partners who can deliver projects and operations efficiently for stores that are optimally located to take advantage of the unique opportunities in the North Sea.



The proximity and dense distribution of stores in the North Sea offers a unique opportunity to Europe

The North Sea boasts ample storage capacity to meet the demands of CCUS, as approximately 40% of CO₂ emissions are concentrated within a 500km radius. This geographical proximity provides a unique opportunity to kickstart the CCUS industry in Europe.



With a strategic approach, over 50% of CO₂ storage could re-use infrastructure

Our work shows that re-use of existing infrastructure can be achieved for between 50% and 70% of the storage needs within the North Sea, leading to cost reductions and reduced carbon footprints for both CCUS projects and the owners of that infrastructure. However, a strategic national and cross border infrastructure build-out strategy is required to ensure optimal network design and protect key infrastructure from becoming abandoned / removed ahead of reuse.



Synergies with offshore industries

The transport and storage infrastructure has many similarities with offshore oil and gas exploration and, to a lesser extent, offshore wind farms. The development of CCUS infrastructure is therefore a significant opportunity to transition the existing skillsets and industrial base of the North Sea.



Projects will require significant subsea work

Whether or not an infrastructure is re-used, the majority of CCUS projects will require new subsea infrastructure to link the overall bulk transport systems to injection systems. In many cases these modifications may require seabed by-pass of decommissioning oil and gas platforms and may rely heavily on diving activities due to design period of existing infrastructure.



Subsea7 Group CCUS Track Record

- Decarbonisation / CCS Type:
- Decarbonisation of High CO₂ Fields
 - Low Carbon Energy
 - Industrial Emitters

