Countdown to CCS

Between 2020 and 2030, several large-scale CCS facilities will become operational in north-west Europe. While not the first, that honour already taken by the Sleipner CO_2 storage site, they represent a significant step forward in that CO_2 will be sourced from onshore industry and power generation, transported offshore and stored in the subsurface.

In this contribution, we share a summary overview of those sites focusing on Northern Lights, Northern Endurance and Acorn.

Operator	Expected First Injection	Age	Crest	Reservoir	Seal	Storage Capacity (MT)	CO_2 Injection (MT/pa)
Northern Endurance Partnership	2026	Triassic	1,040m	Bunter Sandstone	Triassic Halite and Shale	450	4 up to 10 by 2030
Northern Lights JV DA Aurora	2024	Jurassic	2,100m (post migration)	Johansen and Cook/ Dunlin Gp.	Lower Jurassic Drake Shale	minimum 100	1.5
Pale Blue Dot Acorn / Goldeneye	2024	Cretaceous	2,500m	Carrack Fm. Captain Sandstone	Lower Jurassic Rødby Paleocene Lista	152 (at Goldeneye) 500 (East Mey)	5 by 2030
INEOS Oil and Gas Denmark Project Greensand (Nini)	2025	Eocene/ Paleocene	1,700m	Siri Fairway	Eocene Claystones	4.5	0.5 (2025) 3.5–4 (2030)
Porthos JV P18-2, P18-4, P18-6	2024	Triassic	3,000–3,500m	Bunter Sandstone	Triassic and Jurassic Shale	38 expansion potential	c. 2.5

Table 1: Data gathered from company websites, TGS data and interpretive products (full references and additional data available Geo ExPro online).

NW EUROPE OFFSHORE CARBON STORAGE SITES

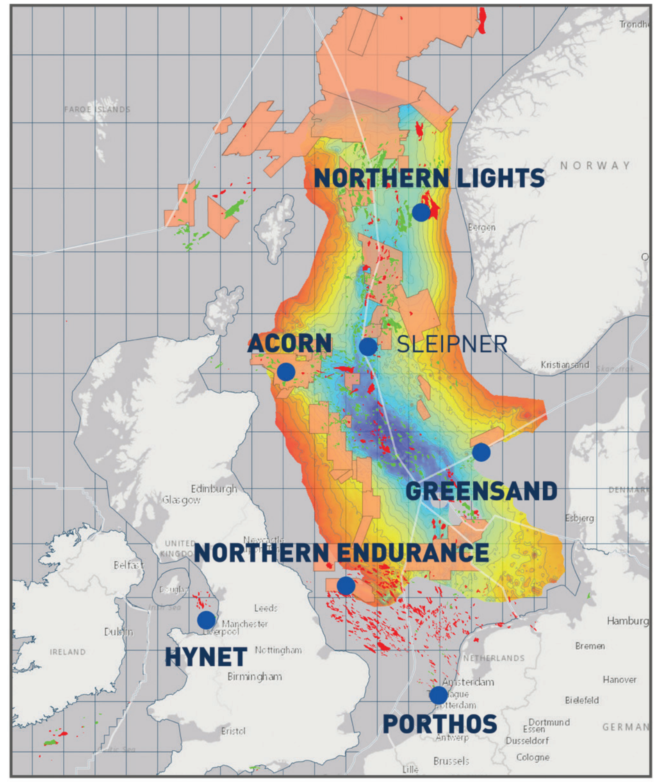
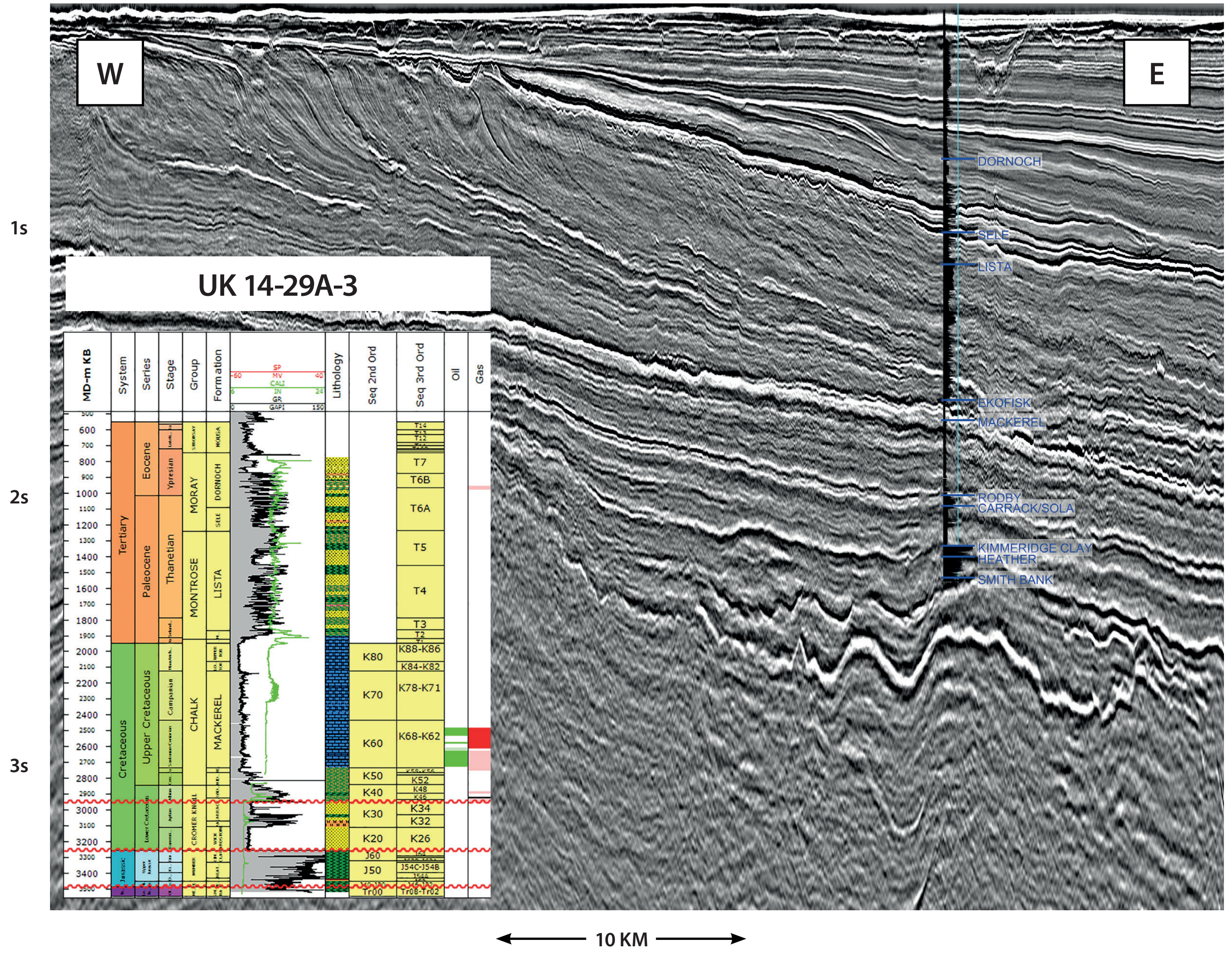


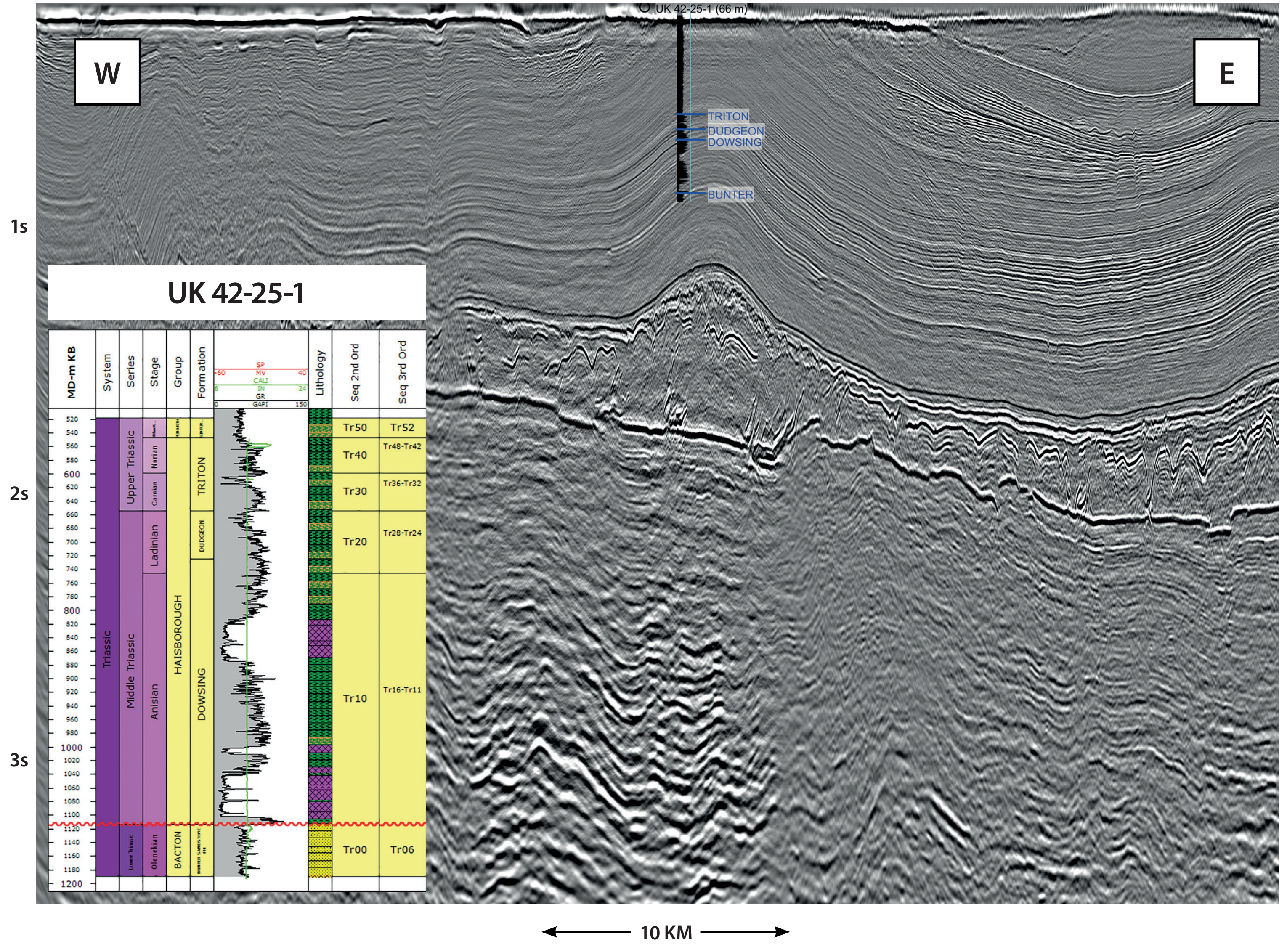
Figure 2: Map showing the location of the more advanced offshore carbon storage developments in the North Sea. Northern Endurance, Acorn and Northern Lights are expected to be the larger storage sites with Hynet, Porthos (plus other Dutch CCS sites) and Greensand representing either smaller storage potential or earlier phase development.

Figure 1: Foldout shows three seismic sections through TGS's 3D data over the Acorn CCS site, the Northern Endurance CCS site and a 2D line from TGS's CFI-NSR dataset over the Northern Lights CCS site. Inset well images are taken from TGS's Facies Map Browser.

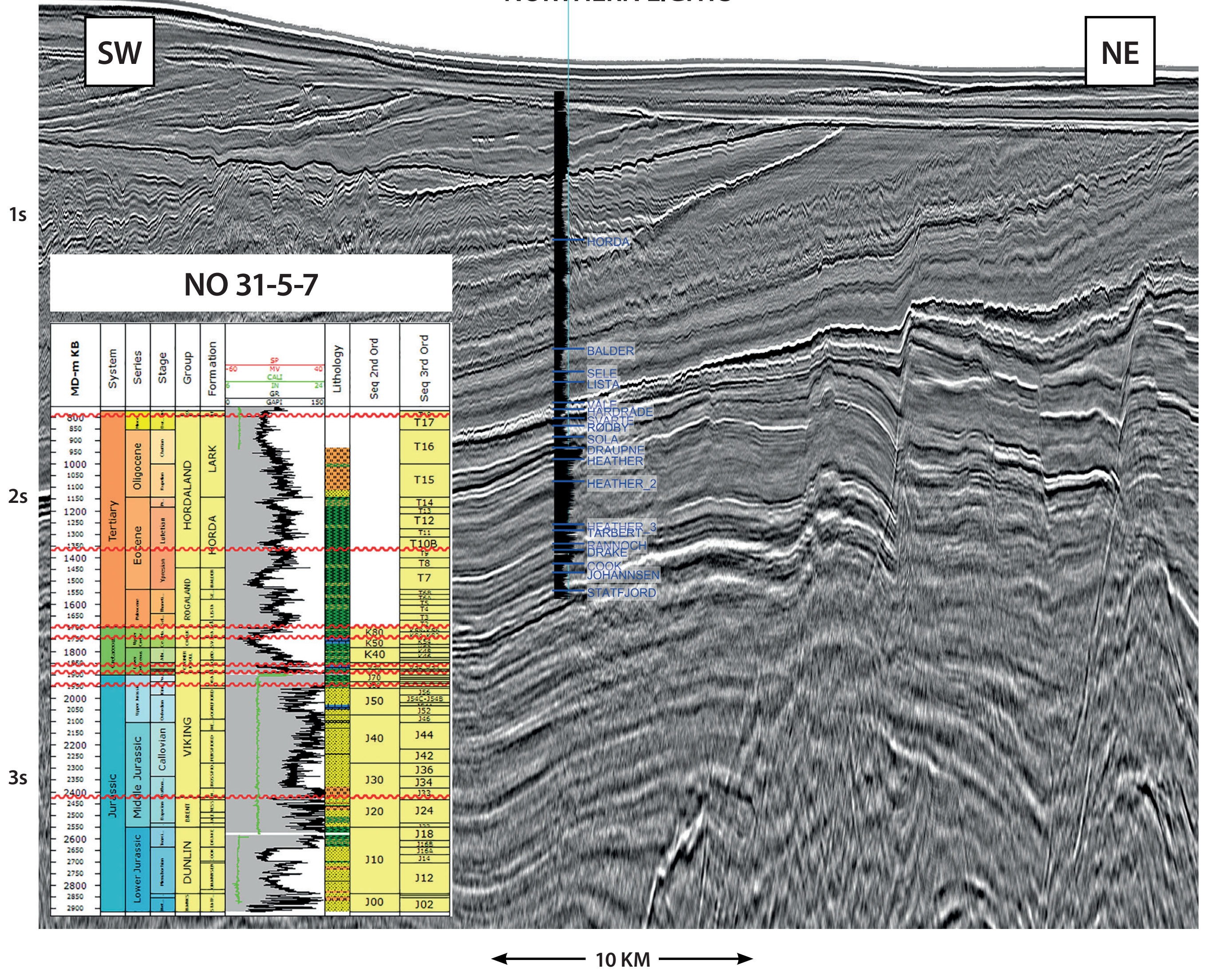
ACORN



NORTHERN ENDURANCE



NORTHERN LIGHTS



Large Commercial Scale CCS Projects Less Than Five Years Away in Europe

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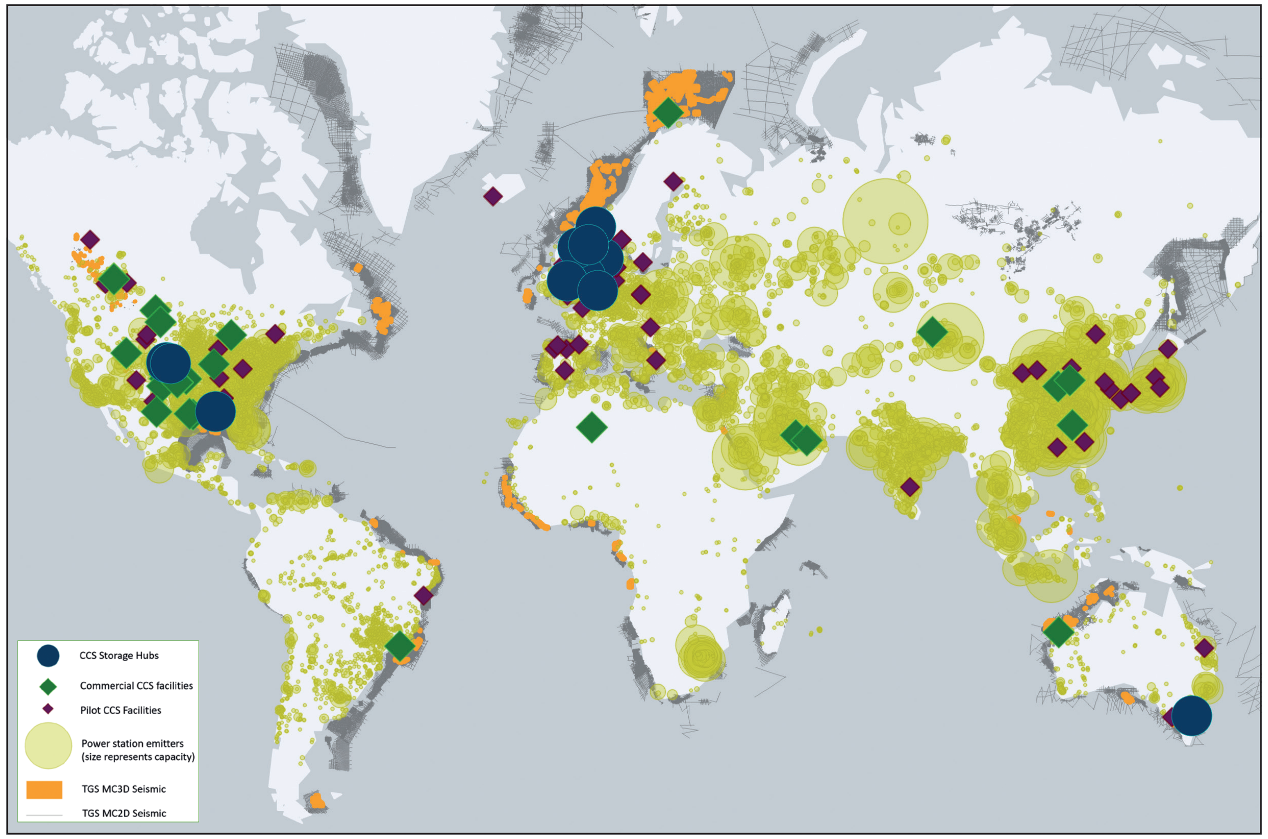
Europe is leading the way in the energy transition with growth in renewable energy sources being part of a wider story with many elements needed to deliver a sustainably developing and economically viable energy transition. The International Energy Association (IEA) estimates that the emissions generated by industrial processes from energy production to product creation constitute a quarter of the world's carbon emissions. Figure 1 shows a map of global CO_2 emissions from power generation highlighting optimal areas for Carbon Capture and Storage (CCS) project development. Carbon capture and storage are required to deliver the integrated energy system that facilitates efficiencies and transition while global energy demand continues to grow. The IEA includes the need for CCS in its roadmap to net zero by 2050, stating that reducing the role of carbon capture (as well as nuclear) will make achieving the net zero goal more costly and less likely (IEA, 2021).

The CCS Sites

The Global CCS Institute reports that the worldwide 2020 carbon capture capacity is about 40 megatons and needs to increase to more than 5 gigatons by 2050 for a two-degree trajectory. The current biggest European marine CCS hubs typically aim to store up to 5 megatons per year by 2030 albeit with expansion potential indicating undercapacity in storage relative to emitted CO_2, with the link between capture rates and injection rates expected to evolve over the coming years.

Figure 1: TGS worldwide CCS Pathfinder showing emissions, subsurface data availability and CCS sites in testing, currently operational and large-scale planned facilities.



Stakeholder engagement and support for CCS technologies will be needed alongside a commercial model that can take carbon storage beyond reliance on government subsidy. Evolving regulatory processes, carbon pricing or taxes are expected to support a global market; however, these are yet to drive wider scale nonsubsidized commercial developments. Focusing on the specific sites currently under development in the North Sea region we see that they represent a diverse range of solutions employing different subsurface, transportation and sourcing strategies. While a review of the risks and risk mitigation measures associated with one form of transport or site over another is beyond this contribution's scope, a summary of currently planned solutions is provided.

The primary European CCS sites such as Phase 1 of the Acorn project, will target the depleted Goldeneye field whereas the Northern Endurance project has targeted the Bunter Sandstone saline aquifer. Several different transport mechanisms are also planned, e.g., Northern Endurance and Porthos will primarily use pipelines from capture sites associated with industry, port facilities and power generation. Northern Lights will pipe CO_2 from a port facility onshore Norway. The onshore port will receive its CO_2 via shipping routes initially from emissions captured in the Oslo area; however, longer distance shipping and growth in supply routes is expected to drive expansion of operating storage hubs.

Table 1 on the main foldout summarizes some of the key elements of the existing storage sites. All are sandstone reservoirs possessing good porosities and thick, regionally extensive and often proven shale caprocks. Typically, the saline aquifers offer larger overall storage capacity compared to depleted fields, and all structural crests are deeper than 1,000m to accommodate CO_2 in an optimum state for storage. These sites will leverage the vast experience of the oil and gas industry in these play types. Further into the future more exotic solutions may be developed as alternatives; for example, storage within basalts offering a different solution to long-term fixing of CO_2 (Kjølhamar et al., 2021) that is currently being tested onshore at sites in Iceland and the US.

Leveraging Decades of Exploration

Decades of oil and gas exploration has led to the acquisition of vast volumes of subsurface seismic and well data across the North Sea. In more recent times, attention has begun to shift into leveraging this information and the wider geological understanding of the subsurface to evaluate saline aquifers for new potential CCS sites. Regional assessments and containment analysis of various stratigraphic intervals across the North Sea have also seen recent growth in fields of research and wider discussion within the energy industry (e.g., Heinemann et al., 2012; Norwegian Petroleum Directorate, 2014; Lloyd et al., 2021).

A detailed understanding of historical wells and their place in the basin's broader geological context is crucial to assess a potential candidate site. Reconciliation of all available well data integrated with high-resolution seismic data can build a robust and detailed geological model to accurately predict the presence and properties of potential injection intervals. Existing datasets, such as the TGS Facies Map Browser, are suitable for reconnaissance and identification of CCS sites.

A recent example of new data for CCS is the well NO 31/5–7 (see foldout), completed by Equinor in March 2020 close to the Troll field as part of the Northern Lights Project. This was the first dedicated CCS well to be drilled within the North Sea with the objective of assessing the CO_2 injection and storage potential.

There is a trade-off to be made when it comes to current subsurface understanding and risking. Depleted fields commonly have the largest amount of available data with which to understand the subsurface and feasibility of injecting CO_2. Conversely, older depleted fields will have multiple penetrations from older wells resulting in a different set of risks to consider. Saline aquifers typically don't have the volume of high quality data from seismic or wells; however, the storage capacity potential can be greater. This data gap between a saline aquifer target with limited data-derived subsurface constraint and an injectable CO_2 reservoir must be bridged. If this can be achieved with a cost-effective data acquisition program in the form of a well (as in the case of Aurora site for Northern Lights) or new/reprocessed seismic data, then less structurally complex saline aquifers may offer lower cost, lower risk carbon storage opportunities.

Monitoring

Site selection has implications for the monitoring solutions. 4D monitoring programs to screen ongoing reservoir conditions need to be fit-for-purpose, cost-effective and supportive of positive margins.

Thus, from a monitoring data perspective an element of the ongoing success of a CCS project is meeting the economic challenge of monitoring the integrity of the store. Fortunately in a basin as mature as the North Sea a vast array of geophysical technologies have been developed, tested and put into wide scale use with increasingly innovative solutions since the oil price started to rise at the end of the 1990s and early 2000s. Industry can draw from this experience to deploy smaller scale, more efficient, higher resolution solutions such as P-Cable-type streamer acquisition together with in well solutions such as optical fiber recording to deliver the data needed to demonstrate conformance and containment of the CO_2 stored.

Over the next 10 years Europe will see between three and six major CCS sites come online and likely a clear intent to expand these existing hubs as well as develop new sites. Continued and new support from stakeholders such as regulators, industrial partners, and the public will need to be in place for CCS to be an accepted technology with a key role to play in a sustainable, economically viable and integrated energy system for Europe.

References available online. ■