# Appendix A12 – Storage Study Report

Northern Gas Networks

# East Coast Hydrogen - Pre-FEED Study

## Storage Study Report

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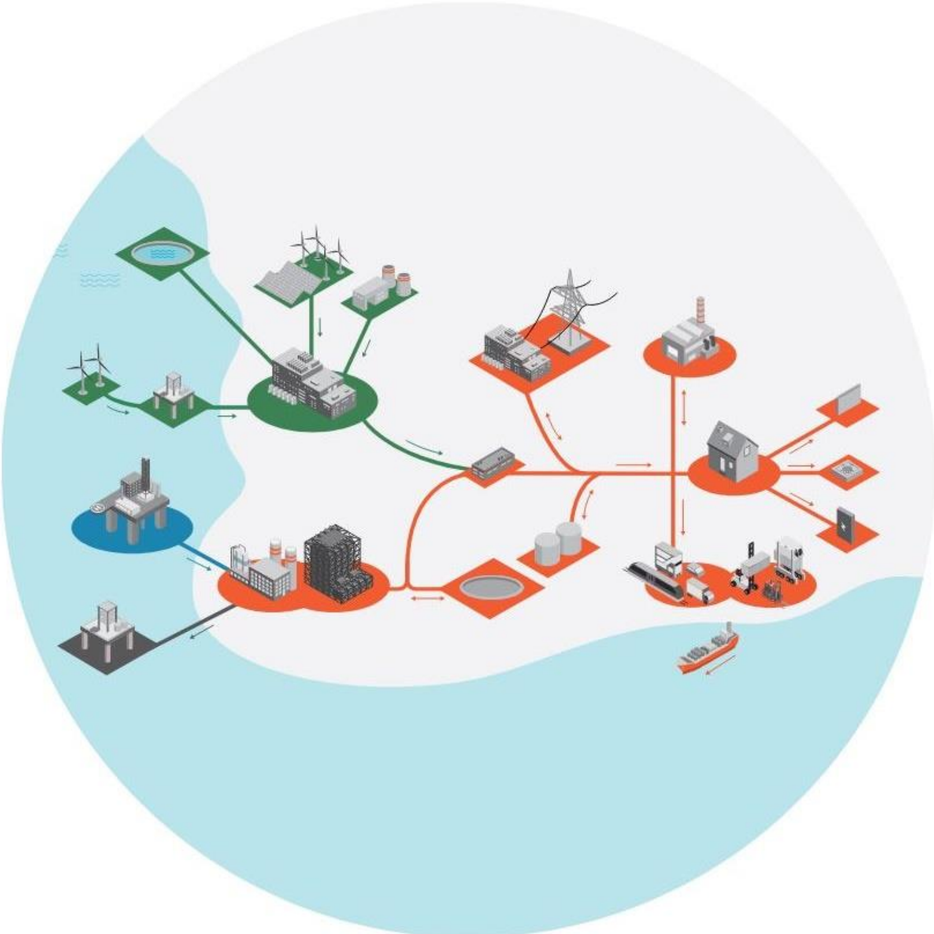





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# Contents



## Tables



## Figures



## Appendices

# 1. Introduction

Northern Gas Networks (NGN) are the company responsible for distributing gas to homes and businesses across the north of England, an area covering West, East & North Yorkshire, the North East and Northern Cumbria.

East Coast Hydrogen (ECH) provides a solution to connect these industrial clusters with other supply points, such as the East Midlands Hydrogen Innovation Zone, and export hydrogen production across the North of England enabling the seamless conversion of businesses and homes to 100% hydrogen where it is best deployed.

This collaborative programme between Northern Gas Networks, Cadent Gas and National Gas Transmission (NGT) represents an opportunity for the Government and the private sector to work together in delivering on our ambitious decarbonisation targets. ECH has the potential to connect over 7GW of hydrogen production by 2030, alone exceeding the UK Government's 10GW by 2030 target in a single region.

ECH can utilise the natural gas assets of the North of England, including existing natural gas storage and potential hydrogen storage facilities, and build on the hydrogen production in two of the UK's largest industrial clusters in the North East and North West and in turn ensure significant private sector investment in the UK's industrial heartlands.

ECH is a 15-year programme that will be carried out in multiple discrete phases to decarbonise industrial processes and domestic heating in the East Coast region. Proposed phases can be seen below:

Phase 1 - (2022 2026) - Completion of Pre-FEED, FEED Study and development of East Coast Cluster infrastructure

Phase 2 - (2024 2030) - Connection of Humber and Teesside clusters, and growth into Yorkshire and East Midlands

Phase 3 - (2028 2037) - Expansion from the industrial Clusters into Northern urban areas and the Midlands

Phase 4 - (2032+) - Connection of the network into further regions and future growth opportunities

NGN will look to trigger the Net Zero and Small Projects (NZASP) Reopener to undertake the subsequent phase i.e., FEED study.

Arup have been commissioned by NGN to undertake a Pre-FEED study to support the Net Zero and Small Projects (NZASP) Reopener and subsequent project phases e.g., FEED study.

# 2. Purpose of Document

The purpose of this document is to describe the data collection and processing stages which have been undertaken to demonstrate the resilience of the future hydrogen transmission and distribution system and the external hydrogen storage availability and requirements. This document will utilise data provided by NGN supplemented with publicly available and internal data as a part of this assessment.

This document also outlines the assumptions which have been made up to the stage of issue, which are also captured in the project assumptions register. The information relating to the storage is correct at the date of issue of this document. However, it is expected that this information will be continually refined during this project due to the fast-moving nature of the industry and upon further engagement with third party storage operators.

# 3. Storage overview

Storage is a critical aspect of the hydrogen economy if the Net-Zero target of 2050 is to be realised, ensuring network balancing and security of supply. There is an evident reliance of hydrogen storage and transport infrastructure on enabling the other. This critical relationship has been identified by the Department for Energy Security & Net Zero (DESNZ) in the hydrogen transport and storage networks pathway document in December 2023 [1].

Hydrogen storge can be broadly thought of in three classifications:

1. Above ground – this is typically in the form of pressure vessels and is a high-cost option which provides localised energy security.
2. Below ground – geological storage that has various forms (eg salt caverns or porous gas fields), but broadly is large scale long-duration storage which provides security of supply.
3. Linepack – this is the storage which is inherent in pipeline networks due to the operating pressure ranges in which they operate.

The scope of this study will focus on the storage types which are applicable to the development of the ECH network, which are below ground and linepack.

# 4. Data analysis

Data from NGN's third-party stakeholder data and business development tracker was used to identify potential external hydrogen storage sites. This data was based on stakeholder engagement held by NGN with Centrica for the Rough gas reservoir and SSE for the Aldborough and Hornsea (Atwick) salt caverns.

A literature review was carried out based on the current natural gas storage and potential gas storage capacity in the UK, and is based on National Gas' "2022 Gas Ten Year Statement" [2], North Sea Energy's Project Atlas [3], and Atkin's Hydrogen Cavern Storage – WS10 & WS11 Report [4].

To demonstrate the resilience of the future hydrogen transmission and distribution system, an assessment into the potential storage capacity utilising linepack of the National Transmission System's (NTS) feeder pipeline, Feeder 7, for conversion into 100% hydrogen transmission was carried out. Feeder 7 was selected as the basis for capacity within the distribution system based on NGN's guidance, which suggests that it would provide hydrogen closer to the NGN distribution network in West Yorkshire, as well as the Project Union timeline and plans for the hydrogen backbone structure [5]. Some qualitative assessment has also been carried out to assess the potential scope for additional capacity within the distribution network through blending.

The sites in the areas of locality for the East Coast Hydrogen network were further investigated based on publicly available data from the operators and internal Arup data.

Hydrogen production sites are likely to have their own dedicated on-site or external storage capacity dependent on scale. Storage requirements will be more important for green hydrogen production sites due to limitations in flexibility for ramp up / down hydrogen production. Whereas blue hydrogen sites are more flexible than green hydrogen sites due to their ability to ramp down and up based on demand. Therefore, NGN data on hydrogen producers was examined and supplemented with publicly available and internal Arup data.

# 5. Storage methodology

The Energy Networks Association's "Britain's Hydrogen Network Plan" report [6] suggests at least 300 GWh of hydrogen storage capacity will need to be brought online each year from 2025, with a need for 3.4TWh of storage capacity by 2030 [7]. The national transmission system and local transmission system pipelines are critical for diurnal storage and the need for storage will increase due to the volumetric energy content of hydrogen being about one third of that of natural gas. Therefore, the linepack flexibility of Feeder 7 should be assessed against production and demand in order to determine the external storage requirements or additional capacity requirements in NGN's distribution network, through 100% hydrogen distribution or through blending into either the transmission system or the distribution network, whilst also balancing the security of supply risks associated with loss of natural gas storage capacity.

The potential external storage capacity was assessed based on the above data analysis and the total energy capacity for each of the sites was calculated. The total energy capacity of the sites was calculated on the basis of the volumetric capacities listed above combined with the operating conditions of the storage and the lower heating value (LHV) of hydrogen (119.96 MJ/kg) [8].

The methodology for assessing the resilience of the future hydrogen transmission and distribution system will primarily assess the linepack flexibility National Transmission System's feeder pipeline, Feeder 7, if converted to a 100% hydrogen feeder. Project Union's timeline for the hydrogen backbone suggests this will come online by the early 2030s. The linepack flexibility was calculated based on a minimum and maximum pressure of 50 and 70 barg [9, 10] respectively and an assumed gas temperature of 5 °C, based on thermophysical properties from AspenTech HYSYS. [11]. Further details on this calculation are shown in Appendix A.1.1.

**Table 1: Feeder 7 summary information**

[redacted]

## 5.1 Key assumptions

Some assumptions have been made to enable forecasting of potential hydrogen storage as detailed below:

- The operating conditions of Feeder 7 have been assumed based on typical operational data and discussion with NGN [9, 10].
- Operating conditions for the storage facilities currently operating as natural gas storage sites will be maintained for hydrogen storage.
- The lower heating value of hydrogen was used to calculate the energy capacity of the storage sites for conservatism [8].

- An operating pressure of 100 barg was assumed for storage sites without public operational data.
- SSE’s Atwick storage facility was assumed to operate at the same conditions as their Aldborough site (270 barg).

# 6. Results

This section will outline the results of the above data analysis and methodology to assess the resilience of the future hydrogen transmission and distribution system and the external hydrogen storage availability and requirements.

## 6.1 Existing gas storage sites

Table 2: Summary of potential hydrogen storage sites based on NGN data

| Organisation | Project Name | Location | Type | Capacity (GWh H2) | Comments |
|---|---|---|---|---|---|
| **SSE & Equinor** | Aldborough | Hornsea | Salt Cavern | 20 | Hydrogen path finder suggests a scale of 20 GWh but the total capacity is >300 GWh. No dates specified [13, 14]. |
| **SSE & Equinor** | Atwick | Hornsea | Salt Cavern | Not provided | No plans mentioned for conversion to hydrogen [14, 13]. |
| **Centrica** | Rough | North Sea | Gas Reservoir | 10,000 | Full capacity at approx. 2050 [15] |

Table 3: Existing UK storage sites summary [2, 3]

| Site | Operator / Developer | Location | Capacity (bcm) | Capacity (TWh) | Approximate max delivery (mcm/d) |
|---|---|---|---|---|---|
| **Aldbrough** | SSE/Statoil | East Yorkshire | 0.222 | 0.554 | 31.0 |
| **Hatfield Moor** | Scottish Power | South Yorkshire | 0.07 | | 1.8 |
| **Holehouse Farm*** | EDF Trading | Cheshire | ~ | 0.060 | ~ |
| **Holford** | Uniper | Cheshire | 0.237 | | 22.0 |
| **Hornsea** | SSE | East Yorkshire | 0.308 | 0.762 | 12.0 |
| **Humbly Grove** | Humbly Grove Energy | Hampshire | 0.243 | | 7.2 |
| **Hill Top Farm** | EDF Energy | Cheshire | 0.045 | | 13.5 |
| **Rough** | Centrica Storage | Southern North Sea | 0.768 | | 3.9 |
| **Stublach** | Storengy | Cheshire | 0.43 | 1.497 | 36.0 |
| **Total** | | | **2.323** | | **127.4** |

* Holehouse farm currently mothballed.

## 6.2 Planned or potential gas storage sites

Table 4: Planned UK storage sites summary [2, 3]

| Project | Operator / Developer | Location | Capacity (bcm) | Capacity (TWh) | Status |
|---|---|---|---|---|---|
| **Gateway** | Stag Energy | Offshore Morecambe Bay | 1.5 | 4.119 | Planning granted, no FID |
| **Deborah** | Eni | Offshore Bacton | 4.6 | | Planning granted, no FID |
| **Islandmagee** | InfrasStrata | County Antrim, Northern Ireland | 0.5 | | Planning granted, no FID |
| **King Street** | King Street Energy | Cheshire | 0.3 | | Planning granted, no FID |
| **Preesall** | Halite Energy | Lancashire | 0.6 | 1.648 | Planning granted, no FID |
| **Saltfleetby** | Wingaz | Lincolnshire | 0.8 | | Planning granted, no FID |
| **Whitehill** | E.ON | East Yorkshire | 0.4 | | Planning granted, no FID |
| **Total** | | | **8.7** | | |

## 6.3 Potential hydrogen storage sites

The ECH region is extremely well placed to connect to potential geological storage sites. As can be seen in Figure 1, Yorkshires East Coast is one of the few areas in the UK with large Halite deposits. This potential is a key consideration for the routing of the ECH project, in order to enable the development of storage projects in this area.

NGN have been in discussions with potential storage providers such as Statera who are pursuing opportunities in the East Coast Region. Whilst the details of these are confidential, the Hydrogen Storage and Hydrogen Transport Business Models are designed to ensure that these infrastructure projects, which have a high reliance on each other, can be developed in tandem.

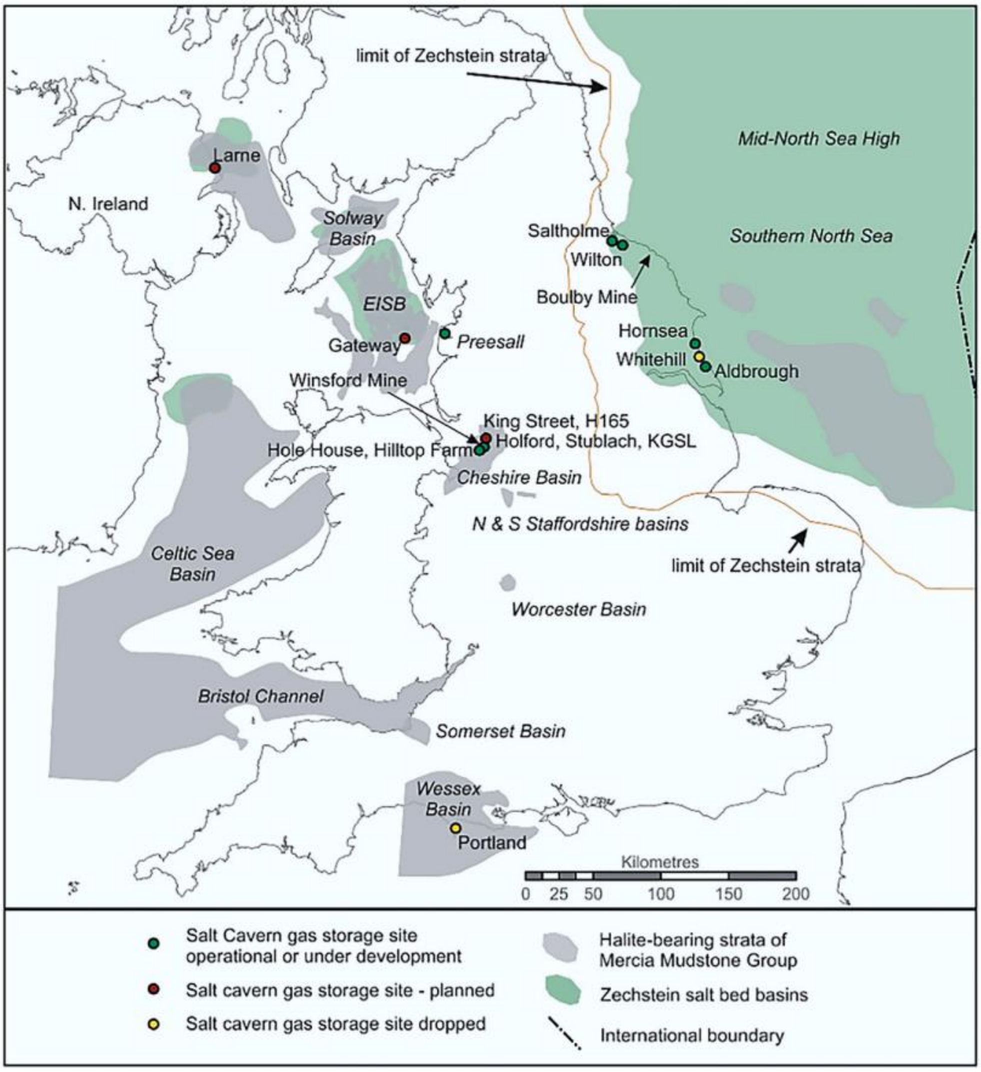


**Figure 1: UK rock salt deposits (halite) distribution [16].**

Additional sites currently storing hydrogen were also identified (Saltholme Sabic Salt Caverns [17]) and investigated further to produce the list in Table 5 below for further consideration.

**Table 5: Potential hydrogen storage sites summary**

| Project | Operator / Developer | Location | Capacity (bcm) | Comment |
|---|---|---|---|---|
| **Aldborough** | SSE/Statoil | East Yorkshire | 0.222 | Plans for hydrogen conversion through Project Hydrogen Pathfinder for total of 320 GWh by 2028. |
| **Hornsea** | SSE | East Yorkshire | 0.325 | No plans for hydrogen conversion currently. |
| **Rough** | Centrica Storage | Southern North Sea | 0.768 | Plans for total hydrogen conversion, 10,000 GWh, by approximately 2050 |
| **Saltholme** | Sabic | East Yorkshire | 0.00021 | Currently used for hydrogen storage. |

| | | | | |
|---|---|---|---|---|
| **Whitehill** | E.ON | East Yorkshire | 0.4 | Planning granted, no FID |
| **Wilton** | Sembcorp | Teesside | Unknown | Potential opportunity for two caverns as WS10 and WS11 on the Sembcorp site have been identified by Atkins. Further detail required to ascertain storage capacity of caverns. |
| **Total** | | | **1.7** | |

Two of the storage operators, SSE and SABIC, have identified local producers with a need for storage capacity. Some of the Sabic Saltholme salt caverns have been in operation as hydrogen storage facilities from as early as 1972 [17]. Therefore, the remaining caverns that are not in use for hydrogen storage can be assumed to be easily transferrable by 2025. SSE have confirmed a conversion of their Aldborough salt cavern to a hydrogen storage facility by 2028, with a capacity of 320 GWh [18]. Three other sites have been identified as potential hydrogen storage facilities, SSE's Atwick salt caverns [19], Centrica Storage's Rough reservoir [20], and E.ON's Whitehill caverns [21]. It is likely that the Rough reservoir will be available in its full capacity for hydrogen storage by 2050, with a phasing overtime [7]. However, there is minimal to no public information on timescales.

Table 6 below shows the details of the energy capacity and dates online for the potential external hydrogen storage sites. The energy capacities were calculated based on the LHV of hydrogen shown in Appendix A.1.2.

**Table 6: Hydrogen energy capacity and predicted commissioning dates for the five potential hydrogen storage sites**

| Organisation | Project Name | Location | Type | Capacity (GWh H2) | Year online |
|---|---|---|---|---|---|
| **SABIC** | Saltholme | Teesside | Salt Cavern | 26 | 2025 |
| **SSE & Equinor** | Aldborough | Hornsea | Salt Cavern | 320 | 2028 |
| **SSE & Equinor** | Atwick | Hornsea | Salt Cavern | 210 | Unknown |
| **Centrica** | Rough | North Sea | Gas Reservoir | 10,000 | Approx. 2050 |
| **E.ON** | Whitehill | Humber | Salt Cavern | 108 | No FID |
| **Total** | | | | **10,664** | |

## 6.4 Feeder 7 linepack potential

This section will outline the linepack flexibility of Feeder 7 and the potential external storage capacity based on the above data gathering and analysis. Table 7 shows the total volumetric capacity and the linepack flexibility of Feeder 7 in terms of mass and energy capacity of hydrogen, based on a minimum and maximum operating pressure in Feeder 7 of 50 barg and 70 barg respectively. Figure 2 presents a summary of the linepack availability of Feeder 7 based on various initial line operating pressures and final linepack pressures. This illustrates that Feeder 7 has the potential to provide an additional system storage of between 4 and 14 GWh.

**Table 7: Linepack capacity and flexibility of Feeder 7**

| | |
|---|---|
| **Volumetric Capacity, $m^3$** | ***$2.18 \times 10^5$*** |
| **Mass Capacity (50 barg, 5°C), tonnes** | 963 |
| **Mass Capacity (70 barg, 5°C), tonnes** | 1335 |
| **Mass Flexibility, tonnes** | ***372*** |

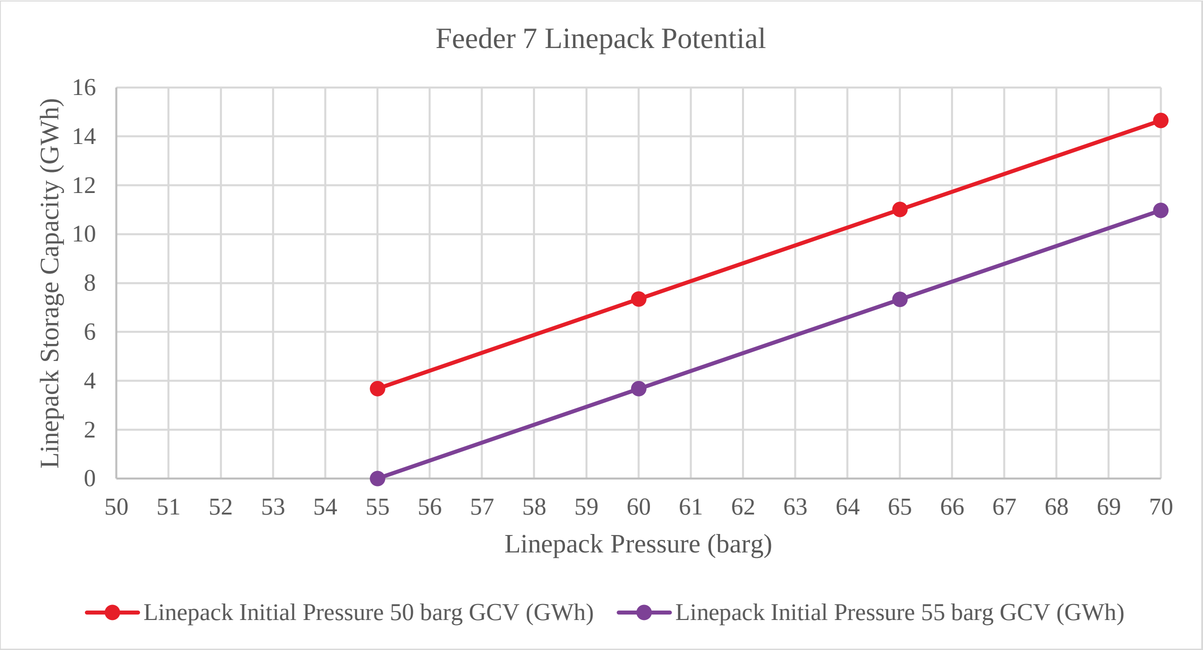


Figure 2: Feeder 7 linepack storage potential

## 6.5 Hydrogen producer storage potential

Table 8 shows production sites that have identified storage opportunities.

Table 8: Hydrogen producer storage sites summary [22]

[redacted]

## 6.6 Blending potential

There is also additional potential linepack storage ability through blending within the natural gas network. The UK Government has taken a strategic policy decision to support blending of up to 20% hydrogen by volume into GB gas distribution networks [23]. Industry trials to gather evidence will follow, as well as the production of a safety assessment, prior to a final government decision on whether to enable blending in the GB gas distribution network. Blending to 20% has been shown to be the limit at which no change for domestic appliances is required as per the HyDeploy project [24]. Based on this decision, further quantitative analysis onto the linepack capacity of the distribution network can be carried out during FEED.

A key issue with blending is the reduction in energy density (volumetric). To achieve the required energy demand, a larger volume of hydrogen is required which may impact the total energy capacity of the gas network. To meet energy demand, capacity can be maintained through either an increase in pressure or an increase in gas velocity. However, quantitative analysis into blending should assess the need for increased pressure or gas velocities.

Blending potential should be considered for domestic, commercial, and industrial user demand for switching to a blended supply for the 2028, 2032, and 2037 scenarios, with the potential for a step approach to achieve a 100% hydrogen network for full decarbonisation by 2050. There are three prospective options for blending at various levels of gas distribution, which will impact the permissible volumetric percentage for hydrogen and the injection points and their infrastructure.

- Blending in the national transmission system (NTS).
- Blending in the local distribution network (i.e. the NGN distribution network) for both domestic and industrial users.
- Blending into the local IP/MP distribution network for industrial users only.

It should be noted that National Gas are currently not carrying out any studies into the potential for blending due to the more stringent Gas Safety (Management) Regulations (GSMR) which currently limits hydrogen content in the NTS to 0.1 mol% and has limitations on the Wobbe Index which may be impacted by hydrogen blending [24]. However, work is currently underway by the Gas Quality working group to reduce the stringency on the hydrogen content limits, through a gas quality standard [25]. Additionally, the risk of hydrogen embrittlement is more likely in higher strength carbon steel pipelines at higher pressures, such as those used in the NTS. Therefore, it is more likely that blending will be more suitable within the local distribution network, with the scope for future blending into the NTS and a phased conversion to 100% hydrogen across the gas network for full decarbonisation.

To ensure security of supply for blended gas, it will be essential that injection points are located nearby hydrogen production and storage sites. As shown above, storage is predominantly located in the Teesside and Humber regions. Therefore, primary injection locations should be strategically located in these areas. However, the key issue with hydrogen blending is inconsistency in concentration across the distribution network, with the potential for some users receiving highly concentrated blended gas, whilst others receive low concentration blended gas. This is especially an issue in the case where either industrial technology or existing domestic systems high sensitivity to gas quality and limitations on hydrogen content. Therefore, consistency of blending should also be considered in the location and type of injection equipment and in the case of users highly sensitive to gas quality, they may require additional onsite conditioning prior to use.

SGN's Aberdeen Vision Report outlines potential gas entry unit (GEU) schemes to ensure consistency and safety of blending, which include hydrogen compression, flow ratio control, a static mixer, downstream gas quality measurement, emergency shutdown valves, non-return vales, and isolation valves. The GEU is shown in Figure 3 below.

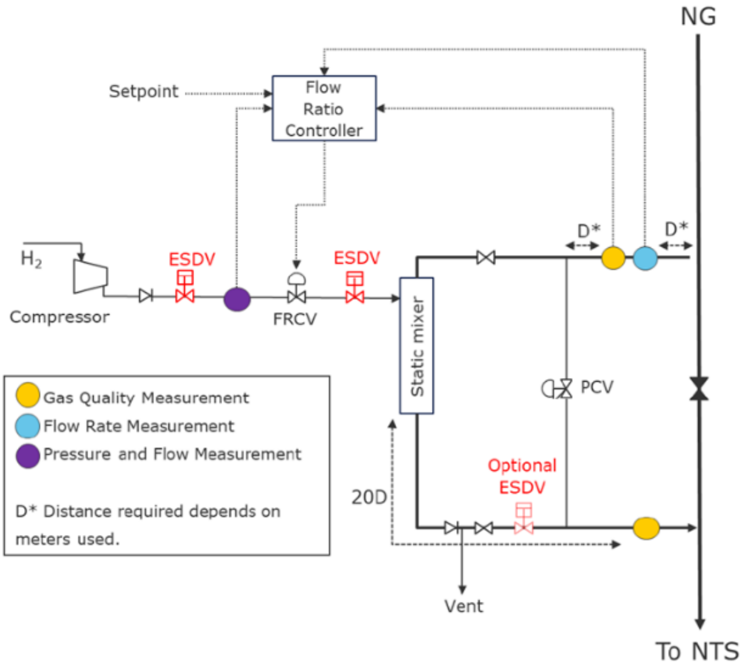


**Figure 3: SGN Aberdeen Vision Project sample gas entry unit for hydrogen blending [25]**

# 7. Summary

Figure 4 from OFGEM illustrates that the UK has less available gas storage capacity relative to its natural gas consumption than any other European country [26]. In the context of partial or total conversion to hydrogen, this issue becomes significantly more important in terms of security of supply, due to the volumetric energy content of hydrogen being about one third of that of natural gas.

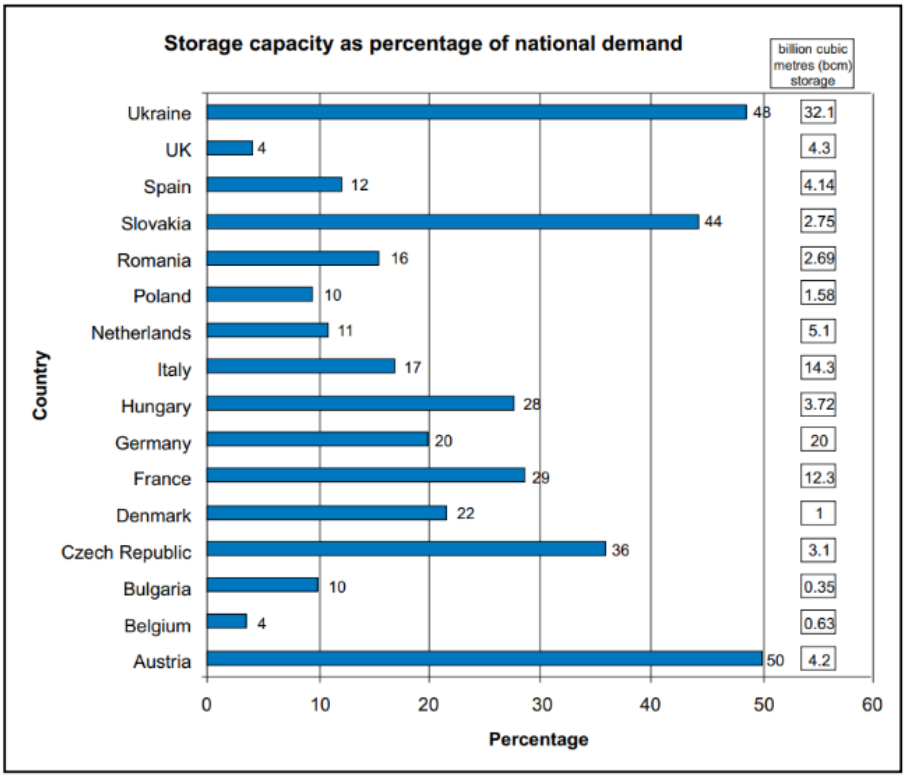


**Figure 4: European gas storage availability relative to natural gas consumption [26].**

Various studies from the ENA [6], Hydrogen UK [7], and the University of Edinburgh [27] highlight the need for significant storage infrastructure to meet the government's Net Zero targets. The need for storage becomes increasingly important as green hydrogen projects are used in an effort to reduce intermittent renewable energy curtailment costs. The University of Edinburgh's "A quantitative assessment of the hydrogen storage capacity of the UK continental shelf" suggests a total requirement of 150 TWh of hydrogen storage to fully decarbonise gas [27]. However, the use of alternative energy sources and decarbonisation methods may reduce this figure. Hydrogen UK suggest a requirement for 3.4 TWh of storage by 2030 increasing to 9.8 TWh by 2035 [7]. Whilst the ENA suggest at least 300 GWh of storage will need to be brought online from 2025 with a total requirement of 17-20 TWh by 2050 [6].

The Humber and Teesside are well placed due to the availability of existing salt caverns and gas reservoirs. The ENA's "Britain Hydrogen Network Plan" suggests that clusters are likely to require more storage capacity. For example, Humberside alone is likely to need 8 TWh of storage [6]. Based on the above results, there is a total potential hydrogen storage capacity in the Humberside and Teesside region of 10.7 TWh, with likely availability of approximately 320 GWh by 2028 via the SSE Aldborough storage and an additional 330 GW by 2033 via the Rough storage site. However, it should be noted that some of these sites will already have agreements with hydrogen production sites decreasing the flexibility of available capacity to the distribution network.

The national transmission system and local transmission system pipelines are critical for diurnal storage and the need for storage will increase due to the volumetric energy content of hydrogen being about one third of that of natural gas. Based on the above assessment, the linepack flexibility of Feeder 7, in terms of energy capacity ranges from 4 to 14 GWh depending on initial system pressure and resultant linepack pressure.

Figure 5 shows a summary of the existing potential hydrogen storage capacity in the Humberside and Teesside region across salt caverns, depleted gas reservoirs, and Feeder 7 linepack capacity. The non-existing gas reservoir, Whitehill, was not shown on the diagram as there is limited information available on its location.


**Figure 5: Map to show hydrogen storage capacity in the Humberside and Teesside region.**

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# A.1 Calculations

## A.1.1 LinePack

### A.1.1.1 Volumetric Capacity

The total volumetric capacity (V) was calculated using the length (L) and internal diameter (d) of Feeder 7 as below:

$$V = \frac{\pi d^2}{4} * L \quad (1)$$

The linepack capacity in terms of mass was calculated based on the density of hydrogen at various operating conditions. Table 9 shows the density of hydrogen ($\rho_{H2}$) at 5 °C between the pressures of 50 to 70 barg based on thermophysical data from AspenTech Hysys.

**Table 9: Hydrogen density at various operating pressure.**

| Pressure (barg) | Density (kg/m$^3$) |
|---|---|
| **50** | 4.4104 |
| **55** | 4.8377 |
| **60** | 5.2640 |
| **65** | 5.6891 |
| **70** | 6.1131 |

The total line capacity (m) was then calculated as follows.

$$m = V * \rho_{H2} \quad (2)$$

And the energetic line capacity ($m_E$) was calculated as follows based on the higher heating value (HHV) of 141.88 MJ/kg [8].

$$m_E = m * HHV \quad (3)$$

## A.1.2 Hydrogen Storage Energy Capacity

The hydrogen storage energy capacity was calculated based on the current or assumed operating conditions of the storage sites outlined below. SSE's Aldborough site and Centrica's Rough site were not included as their public data included energy capacity data.

**Table 10: Operating conditions of potential hydrogen storage sites.**

| Storage Site | Temperature, °C | Pressure, barg | Density, kg/m$^3$ | Comment/ Reference |
|---|---|---|---|---|
| **Saltholme** | 10 | 45 | 3.75 | [17, 11] |
| **Atwick** | 10 | 270 | 19.43 | Assumed same as Aldborough [18, 11] |
| **Whitehill** | 10 | 100 | 8.07 | Assumed [11] |

The hydrogen storage energy capacity (E) was calculated as follows based on the lower heating value (LHV) of 119.96 MJ/kg [8].

$$E = V * \rho_{H2} * LHV \quad (4)$$