national gas

FutureGrid

Phase 1 Facility

Closure Report

July 2024

Contents

Foreword

National Gas is the backbone of Britain's energy system today, delivering energy where and when it is needed. We are proud to secure the energy to power Britain, achieve net zero and maintain our industrial competitiveness.

We're playing a leading role in the transition to net zero and a clean energy future. Achieving this vision, will take drive, innovation and determination – and will also see National Gas need to adapt. We will need to balance providing critical gas supplies today, maintain resilience in our energy supply while also making good on our plans to deliver our hydrogen ambitions.

At National Gas, we are working to deliver a hydrogen network across Britain – taking this low-carbon gas to where it needs to be. That includes power stations and major industrial businesses that cannot otherwise decarbonise their operations. The key to unlocking the full potential of hydrogen, is being able to show our network can safely transport it. That's where innovation – and our flagship programme, FutureGrid – have a pivotal role to play.

FutureGrid is a hydrogen test facility based in Cumbria. Over the course of Phase 1, we've used decommissioned assets, which have been in service with natural gas, to enable us to run 'real life' trials – to test the safe transport of hydrogen using repurposed assets. Phase 1 has demonstrated that our assets can transport hydrogen safely and reliably. It's also shown where there may be a requirement for some modifications to our existing approach. The results of testing are extremely positive and provide an indication that there are no major blockers to repurposing our network to transport hydrogen.

Jon Butterworth
Chief Executive Officer

These outputs, alongside our wider programme of innovation, are building the evidence base to unlock the opportunities not only for hydrogen blends to be transported across our network but also for enabling Project Union – a 1,500 mile hydrogen backbone across Great Britain.

As further work continues across our programme, we are excited to be taking the next big step in FutureGrid. In September 2023, we launched FutureGrid Phase 2, consisting of our 'Hydrogen Compression' and 'Hydrogen Deblending for Transport' projects. This is a huge step forward in building a robust evidence base for operating the National Transmission System (NTS) with hydrogen, to unlock new opportunities such as Hydrogen for transport.

I would like to thank all the National Gas staff who have played a role in the work at FutureGrid, for their passion and commitment in delivering the programme so far and taking us closer to making hydrogen a reality.

Executive Summary

The National Transmission System (NTS) is a cornerstone of the Great Britain's (GB) energy infrastructure, transporting over 800 TWh of energy annually across 5,000 miles of pipelines in the UK.

This system provides GB with a significant opportunity to decarbonise various industries by transporting low-carbon gases such as hydrogen, biomethane and various synthetic fuels. Transitioning this system would also pave the way for industrial emitters to decarbonise either through fuel switching or transporting carbon dioxide to potential storage sites around the United Kingdom (UK). Recognising the imperative to transition to a low-carbon future, the FutureGrid project sought to explore the feasibility of repurposing the NTS to transport hydrogen.

This project, an essential part of the National Gas HyNTS programme, endeavours to align the NTS with GB's net zero ambitions by demonstrating the operational viability of the system with varying hydrogen blends using decommissioned assets, typical of the natural gas network today, ultimately aiming for 100% hydrogen conveyance.

Several desktop studies were undertaken within the HyNTS programme to confirm the theoretical potential of the NTS to transport hydrogen safely and reliably. Further to these studies, practical demonstration was deemed necessary to bridge the knowledge gaps and ensure the system's transition maintains the utmost safety and reliability standards.

> FutureGrid, is a global first facility, it is a critical part of National Gas' hydrogen programme, providing physical evidence of the capability of our network to transport hydrogen."

A range of tests on decommissioned assets were conducted offline, in a controlled environment, to ensure robust outcomes that will ultimately start to build the safety case for a hydrogen network. The key deliverables and testing achievements of FutureGrid included:

- Operational testing with natural gas and 2%, 5%, 20% and 100% hydrogen to verify the network's ability to transport hydrogen and varying blends.
- Standalone offline testing modules, complementing evidence gathered on the main test facility. These address specific areas of concern including material permeation, flange integrity, asset leakage, and rupture consequence, which are essential for risk mitigation and safety assurance.

FutureGrid is a global first facility and a critical part of National Gas' hydrogen programme, providing physical evidence of the capability of our network to transport hydrogen. It provides key evidence for hydrogen blending alongside 100% hydrogen pipelines, which are planned under Project Union, our Hydrogen Backbone across GB. FutureGrid is pivotal in the journey to reaching Net Zero by 2050 and is a fully operational, proven technical demonstrator. FutureGrid's repurposed assets are representative of today's live high pressure gas network and have been subjected to testing at different blends of natural gas with hydrogen and 100% hydrogen; this was achieved with no major findings in differences in terms of how the assets interact with hydrogen.

The overall project completion date was delayed from November 2023 to February 2024, due to technical issues with the newly built hydrogen re-compressor. There were no changes made to the project costs.

Business case update

There have been no changes in the business case in this reporting period. However, the risk to the construction of the outer container (shell) of the recompression unit materialised in September 2022. Additionally, the risk to the re-compressor materialised during the 2% testing in September of 2023. This had an impact on Ofgem deliverables 1.0 and 2.0, causing them to be delayed by up to 3 months. As a result, the changes to the completion dates of these deliverables have now exceeded 1 year in total since the project direction was issued in December 2020. Therefore, as described in the Gas Network Innovation Competition Governance Document V.3.1, this is declared a material change. This has been reported to Ofgem and was approved in November 2023, with all dates quoted in this report reflecting that change.

Financial update

The total value of the project is £12.7m, which includes a significant amount of in-kind contribution and voluntary contribution. The total project funding when the project completed was £10M, spent over a two-year period. There have been no changes in the total forecasted value since the project direction was achieved. However, for various reasons, the project costs have changed for the different categories and the different years, but there has been no overall impact on costs.

Dissemination activities

The project has been a centrepiece of dynamic and collaborative engagement, thriving on the exchange of ideas and expertise. Our comprehensive dissemination strategy went beyond conventional boundaries to ensure that knowledge and innovation did not just resonate with the team but echoed across the energy sector, which in turn delivers the most value to the consumer by ensuring the stimulation of a robust hydrogen supply chain in the UK.

We launched the project with an ambitious plan to cast a wide net of communication channels, catering to a diverse audience ranging from industry to public stakeholders. The FutureGrid Explore and FutureGrid Feature became our cornerstones, offering immersive experience into our progress through regular webinars and insightful articles, which garnered valuable feedback which was then woven into the project updates.

The communication plan included, but was not limited to, the following activities:

- Monthly steering group meeting with project partners
- Quarterly network steering groups
- Quarterly subject matter expert (SME) forums for internal stakeholders
- Monthly articles (internal and external), podcasts and webinars
- Monthly site tours
- Multiple hydrogen in-person events
- Planned events for each hydrogen blend test.

FutureGrid

Phase 1 Facility

Overview and timeline

FutureGrid is National Gas's flagship demonstration project, paving the way for NG and its partners to display the potential that hydrogen can bring to the GB's energy usage.

By building, commissioning and testing a flow loop with a range of decommissioned NTS assets, for both natural gas-hydrogen blends and pure hydrogen gas, this project aimed to show that these NTS asset types will accept blends of natural gas with up to 20% hydrogen without major modification. Our testing has yielded crucial insights that will inform necessary modifications during this transition, underscoring our commitment to evolving the network to operate safely and efficiently with a full hydrogen throughput.

The project was split into two parts:

Standalone hydrogen Tests

Standalone hydrogen test modules are operating alongside the main test facility, to provide key data required to feed into the main facility.

Offline hydrogen test facility

A representative range of NTS assets of different types, sizes, and material grades have been supplied from decommissioned assets to build the test facility.

Project partners

DNV

DNV were the main delivery partner, responsible for building the test facility and developing the comprehensive master test plan across the range of decommissioned assets.

HSE

HSE Science Division (HSE SD) supported the development of the test facility and subsequent master test plan, providing technical assurance and validation across the project.

Northern Gas Networks

NGN collaborated on the project to drive closer links with the H21 project, which is building a distribution test facility at DNV's Spadeadam Facility.

fluxys

Fluxys is the Gas Transmission Operator in Belgium and were contributing a substantial level of hydrogen research, to ensure an internationally collaborative approach.

Durham University

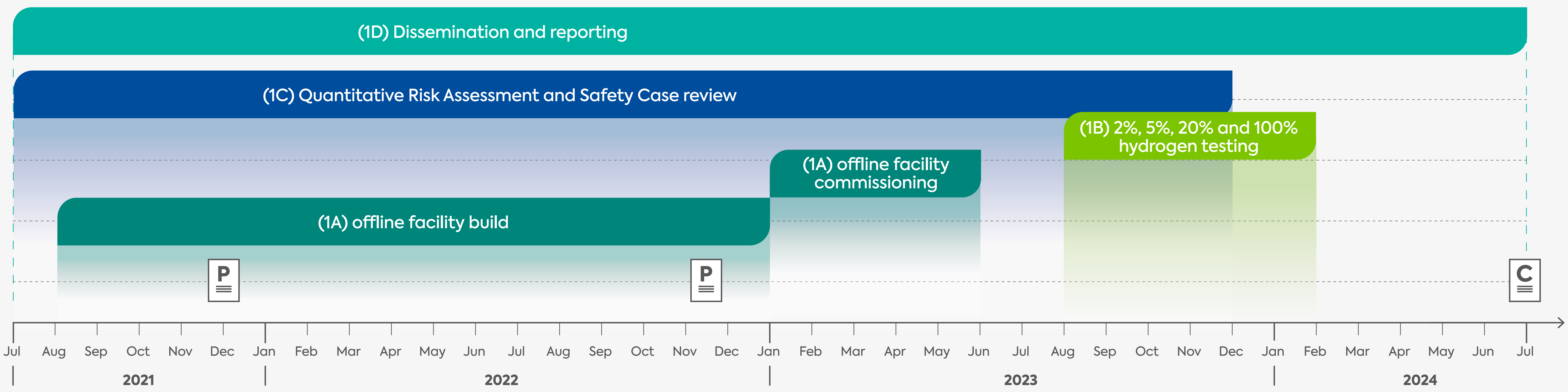
Durham University sponsored a secondment student to study the NTS asset gaps, focusing on the development skills and training courses along with Phase 2 and 3 of FutureGrid.

The University of Edinburgh

Edinburgh University supported the trials and developing technical papers and research from the project to enable dissemination, linking the H100 activities and FutureGrid/H21 activity to prevent duplication.

Key delivery stages of FutureGrid Phase One:

P Progress report
C Closure report



The hydrogen challenge

As we move towards net zero, the interaction between gas and electricity will likely increase, but do you know how they interact now? You may be surprised to learn that 40% of the UK's electricity supply is generated using natural gas.

The amount of renewable energy used across GB is growing each year, but at times, there isn't enough to meet demand. This is where natural gas steps in. We can't control when renewable energy sources, such as wind and solar, can provide power, but we can control when and where we push gas through our network.

The amount of renewable generation will grow, but not enough to meet our needs. To meet the target of net zero by 2050, we need to find a greener alternative to natural gas. This is where hydrogen can play a part. More than 80% of GB 28 million homes are using natural gas for heating and cooking, and hydrogen can be used in much the same way. People can use it to cook on their hob and for their central heating, and it provides a plausible way to decarbonise the UK gas industry.

Great Britain is a world leader in the development of both blue (CO_2-captured methane steam reformation) and green (renewable energy electrolysis) hydrogen production, as well as being at the forefront of hydrogen gas boiler development. A hydrogen transition will provide great opportunities for industry growth and the UK economy for years to come. Small-scale transportation of hydrogen is already underway in some countries, suggesting that we could re-purpose our gas network – the National Transmission System (NTS) – to carry hydrogen instead of the natural gas we transport today. Doing so would provide a cost-effective way to transition to net zero, as the need for expensive, new infrastructure would be greatly reduced. Not to mention, utilising current pipelines and equipment would minimise disruption.

The NTS has provided a safe, efficient and resilient supply of natural gas to homes, businesses and industry for over 40 years, and transitioning from natural gas to hydrogen will allow it to continue doing so. But there is a big jump from talking about using the NTS to carry hydrogen, to actually doing it. So, how do we get there? That's where FutureGrid – our project to build a hydrogen test facility comes in..

The facility has been constructed from a representative range of decommissioned NTS assets of different types, sizes, and material grades. It will initially run on 100% natural gas, capturing standard baseline data for all assets. Testing will then move through 2%, 5%, 10% and 20% hydrogen/natural gas mixtures, and then 100% hydrogen. The facility will have a maximum high flow of 1.76 MSm3/day and 0.36 MSm3/day through the low flow loop generated by using the recompression unit.

2% Hydrogen gas

5% Hydrogen gas

20% Hydrogen gas

100% Hydrogen gas

FutureGrid Phase One Facility Model Layout

1 High Pressure Reservoir
60m length of new 1200mm (48") diameter X65 grade carbon steel pipe and wall thickness 22.4 mm sourced directly from manufacturer in 2020.

2 Ball Valve
Two 450mm (18") diameter ball valves and 50mm (2") bypass pipework manufactured in 1992 sourced from Billingham, Stockton on Tees.

3 Filter
A 450mm (18") diameter filter manufactured in 1992 sourced from Billingham, Stockton on Tees.

4 Ultrasonic Meter
Two 3" ultrasonic meters which have been newly sourced to be suitable for a twin stream system.

5 Flow Control Valve
A 450mm (18") flow control valve manufactured in 1992 sourced from Billingham, Stockton on Tees.

6 Non-Return Valve
A 450mm (18") non -return valve manufactured in 1998 sourced from Sandbach, Cheshire.

7 Filter Skid
A filtering skid manufactured in 1998 consisting of two 3" filters sourced from Sandbach, Cheshire.

8 Orifice Plate Metering Skid
A metering skid manufactured in 1998 consisting of 4" parallel streams with a single orifice plate in each sourced from Sandbach, Cheshire.

9 Boiler House and Heat Exchanger
One boiler house with three boilers and one heat exchanger manufactured in 2010 sourced from Sandbach, Cheshire.

10 Regulator Skid
An 80 mm (3") regulator skid manufactured in 1998 sourced from Sandbach, Cheshire.

11 Pipeline Isolation Valve
A 900mm (36") diameter ball valve with 450mm (18") diameter bypass pipework and plug valves manufactured in 1975 sourced from Lanark, Scotland.

12 Flow Control Valve
A 200mm (8") flow control valve manufactured in 1992 sourced from Lake District, Cumbria.

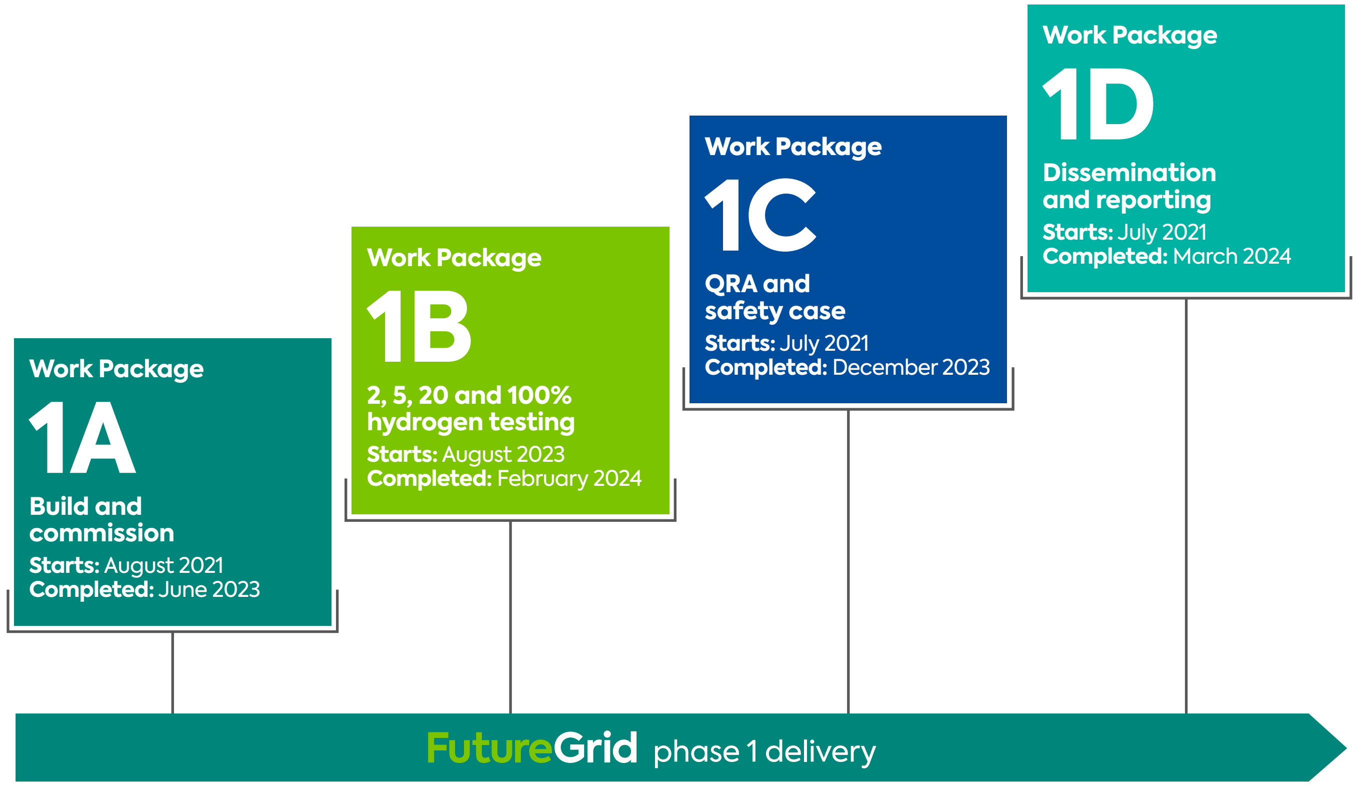
13 Low Pressure Reservoir
A 900mm (36") diameter pipe of 19.1mm wall thickness manufactured in 2007 sourced from Ambergate, Derbyshire.

14 Metering & Gas Quality Kiosks
The data centre consisting of telemetry kiosks, metering and gas quality equipment sourced from Sandbach in Cheshire.

15 Re-compression Unit
A re-compression unit manufactured in 2022 with 8" inlet and 8" outlet sourced new.

16 FutureGrid Control Room
A 6m x 10m control room manufactured in 2022 sourced new.

Details of work carried out



Project background

FutureGrid Phase 1 commenced in April 2021 after the Roadmap to FutureGrid NIA project was completed. The aim of the project was to test decommissioned NTS assets with a range of natural gas blends up to 100% hydrogen. This was to identify future investment requirements to enable the full conversion of the transmission system for hydrogen operation.

There are six project partners who worked collaboratively to deliver FutureGrid. The partners have worked closely to share knowledge and exchange ideas to deliver the project successfully. When the funding direction was provided, the primary task was to establish project controls and governance. This was vital in order to establish strong project management foundations.

FutureGrid Phase 1 project structure

Groundworks and construction on the project commenced in July 2021. The groundworks were prioritised to avoid any risks of delay due to winter. They were successfully completed before the key winter period without any delays.

The assets pre-assessments were conducted simultaneously by DNV and included visual inspections and non-destructive testing. National Gas were provided with a list of recommendations that needed to be conducted prior to the assets being installed on site. National Gas reviewed these recommendations with DNV, and authority was provided to conduct them, as they were basic maintenance tasks that are conducted on the NTS. As part of this recommendation, all valves needed to be serviced. National Gas used in-house specialists to conduct the required maintenance.

In early to mid-2022, the build phase of the project commenced in which the assets were welded together. In addition to this, the standalone tests and work on the quantitative risk assessment also commenced during this time period. The following was in the scope of the standalone tests and QRA.

The infrastructure on the site was also installed as part of the build phase, which included items such as cabling and site fencing. This phase was completed by the end of 2022. The delivery of the recompressor unit was initially delayed from mid-2022 until the end of 2022 due to critical components not being available as a result of Covid supply chain constraints. In early 2023, the delivery was further delayed due to issues identified during the factory acceptance test which the recompressor manufacturer, LMF, had to rectify. During this time period to avoid any non-productive days, DNV commenced the hydrotest on the facility. The recompressor unit was finally delivered in early 2023 and installed on site. The site acceptance test was conducted and the facility was fully built in mid-2023.

Upon completion of the build, the facility was filled with natural gas and commissioning runs were conducted for 2 days, then the 100% natural gas test was conducted to obtain baseline data. The high-flow 100% natural gas test was completed successfully. However, when we switched to low flow, we started having issues on the regulator skid. National Gas believed that this was due to excess moisture within the system, Isolations were put in place and the gas was purged from the facility. The skid was then removed and transported to National Gas' operational facility in Bishop Auckland. The skid was stripped apart and water dried properly. In addition to this, all the soft seal parts which are prone to wear and tear were replaced. This was brought back to site and the test was fully completed.

The facility was then introduced to a 2% hydrogen blend, and testing commenced on the high-flow loop. This was successfully completed in the required timescales. However, upon commencement of the low flow-test of 2% hydrogen, it was observed that one of the cylinders on the new recompressor unit from LMF was overheating causing it to trip the entire compression system. DNV worked with LMF online to rectify the issue swiftly; however, the compressor would not flow within the required parameters. An LMF engineer flew from Austria to site to rectify the issues on the recompressor unit. Upon stripping the LMF cylinders, it was found that there were broken parts within the offloading valve assemblies on the system. A root cause analysis was conducted, and it was suggested by LMF that the issue stemmed from the failure of the springs. The springs and the parts which were damaged were replaced in order to resume testing. This had an impact on the project programme and delayed it by 3 months. In order to keep on track when 2% testing resumed, DNV introduced 24-hour shifts to minimise the impact on the programme. The 2% testing was completed and there were no visual differences to 100% natural gas testing.

The 5% testing commenced and there were no noticeable observations that were different from 100% natural gas. On the boiler, the heat load requirement appeared to increase with increasing flow rate for the natural gas tests. However, for the 2% and 5% blend tests, the heat load was similar and remained fairly constant across each flow rate. This may have been due to weather conditions at Spadeadam varying significantly between the summer and winter temperatures when the testing was conducted.

Subsequent to 5% testing being completed, the facility was introduced to a blend of 20% hydrogen. No key observations were noticed when compared with 100% Natural Gas, 2% and 5% hydrogen.

No modifications were made to the boilers with the introduction of up to 20% hydrogen. A boiler specialist attended the site at each of the blends and no intervention was required.

Upon completion of the 20% hydrogen test, the facility was de-pressurised and re-configured (e.g. isolation of boiler skid and metering skid) to prepare for 100% hydrogen testing. The 100% testing was conducted successfully and no significant observations were observed with 100% natural gas and any of the blends of hydrogen. This trend is consistent with the specification for the compressor; the maximum flow rate for 100% hydrogen would be less than that for natural gas.

The fatigue rig has been subject to 30,000 pressure cycles and the cycling is still being conducted and the final outcomes for it will be issued when 75,000 cycles are completed in December 2024. The QRA has also been completed. The outputs from this have fed into new SIF and NIA projects which are key for a hydrogen transmission network.

Standalone tests completed as part of FutureGrid Phase 1 were:

- Asset leak testing
- Rupture testing
- Fatigue testing
- Flange testing
- Material permeation testing
- Pipe coating and CP testing

The scope of the QRA and safety case review included:

- Procedure review
- Hazardous assessment of the transmission system (HATS)
- Safety case
- Overpressure risk
- Hazardous area impact

Project governance

As part of the project, steering groups were established, involving all project partners. The full project meeting structure is in the table below:

Meeting	Frequency	Description
Project progress meeting	Weekly	The progress meetings were held weekly, ensuring the core Project Delivery Team remained focused on the project deliverables. They provided an opportunity to discuss any ongoing issues and identify potential threats and opportunities in future stages of the project. The weekly meetings were conducted with NG and the delivery partner (DNV).
Internal project review meeting (IPRM)	Monthly	The IPRM were conducted monthly within NG between the Project Manager and FutureGrid Manager. The aim of this meeting was to discuss the costs, key programme dates and commercial risks and to highlight any escalations.
Project Steering Group	Monthly	The Project Steering Group met monthly, with all the project partners present. The discussion in this forum was to ensure the project activities conducted are relevant and feed into the seven Ofgem deliverables. Additionally, the project programme and costs were monitored in this meeting. It's also a platform to share any key learning within the group.
Risk review	Monthly	The monthly risk review was conducted between NG and DNV. The aim of this meeting was to update the risk register. The risk register contains the risks, mitigation measures, probabilities and impacts of each of the risks.
Network Steering Group	Quarterly	The Network Steering Group met quarterly, with the project partners and other gas distribution networks present. The aim of this steering group was to provide an update of the project and it also provided a platform to share any key learning.

The governance structure mentioned above was set out initially as a foundation; however, as time went on, we further refined this structure to improve interactions. We were able to use these platforms to provide partners, internal resources and networks with a forecast on the documentation that we required support in reviewing and when it was required. This method was successful as it enabled them to manage their resources in readiness for it to be received and the turnaround period was minimised.

In addition to the structure mentioned above, we also carried out key ad hoc sessions with partners and internal resources to review key challenges and project outputs. We would pro-actively arrange these sessions to discuss key issues and then format an action plan following the meeting. Actions from all sessions (ad hoc and planned) were be added to the action tracker, where each of them was assigned a priority and a due date, These were then monitored closely till the actions are closed. This aided in producing an efficient set of outputs for the project.

Document management

When the project commenced in 2021, Microsoft Teams was just gaining popularity and was not yet the most common tool used by companies for communication. At the very initial stages of the project, we used video conferencing tools like Webex to initiate the project. During the setup stage, we discovered the capabilities of Microsoft Teams and mapped it out with our project management requirements. It was the best match and the most cost-effective compared to all other tools available. We quickly learnt the features of MS Teams that were most applicable to the project and implemented them.

A project SharePoint site had been created to facilitate document management. The documents were managed in a folder structure and access was provided to all project partners. This was all linked to MS Teams and provided a one-stop platform to access documents and communications. In addition to this, a Microsoft Teams chat was also set up for project partners. This ensured collaborative working across organisations as the documents were updated live. Moreover, this allowed partners to share large bulky files across organisations which may not have been possible using traditional communication methods e.g. emails. This means there was an efficient and effective flow of information between the partners, which allowed the actions to be conducted in a swift manner.

The tools and techniques mentioned above were very useful in Covid times, as they promoted virtual working, which meant that during isolation periods, work didn't completely halt and was still being completed. In addition to this, it also allowed us to align to government guidelines of reduced capacity in offices and sites. A major reason that Covid-19 did not significantly impact project timelines was due to robust governance set up at the start of the project. We are still continuing with this as it has proven to be successful after lockdowns were eased.

The testing data is stored on DNV's platform "Veracity"; this captures all data and can be viewed as per the required filter. All of the testing data is stored per regular intervals (seconds) on Veracity. As it is stored electronically per the second, it removes any possibility of inaccuracy of data being captured, and it can also be used to revisit the data at a later date. This data also links into National Gas's CVDT (Digital Twin project) platform and the test facility parameters could be viewed live from any remote location using a web browser. The live data on the facility during testing was reviewed by multiple users at different locations; this formed a very strong evidence case for the CVDT project's next phases and its rollout on the NTS.

Embedding learning into Phase 2

The lessons learnt in Phase 1 were embedded into Phase 2 to enhance project efficiency. One of the key positive lessons learnt in Phase 1 was governance setup structure. Upon commencement of Phase 2, a similar governance structure was assembled. In this governance structure, hierarchies within the National Gas teams were established. Moreover, the National Gas team's way of working with other project partners was also defined. Each National Gas team member is responsible for liaising with a project partner, with the project manager looking over the full project from a higher level.

In addition to this, project management structure has also been embedded in Phase 2 as that was one of the key positive lessons in Phase 1. The project meetings (IPRM, risk meeting etc.) and their frequencies have also been replicated in Phase 2 to ensure efficiency of a similar nature.

Dissemination and reporting

For the dissemination segment of the project, a robust communication plan was developed at the start of the project, and this was then further evolved to incorporate stakeholder feedback. This plan was established for internal and external stakeholder engagement.

We have hosted frequent webinars for our stakeholders to provide them with updates of projects regularly and to disseminate any key information. We have also posted blogs on LinkedIn by each of the FutureGrid team members detailing the work they have carried out as part of the project. This led to stakeholders feeling engaged from start to finish. In order to disseminate key information, we have hosted knowledge share sessions with gas networks in the UK and internationally. We have regular quarterly meetings with the gas distribution networks within the UK as a platform to share knowledge. We have also had discussions with international TSOs on a 1-1 basis e.g. PIL India delegation and APA delegation.

One of the key forums for engagement that we have found to be successful is site visits. We have hosted a number of internal and external stakeholders and provided them with site visits of FutureGrid at Spadeadam. This has been particularly successful as we were able to get the relevant team to visit the site at each stage of the project. We received their feedback which was very useful and was also a stepping stone for the project to be successful. We also hosted key stakeholders from Ofgem, DESNZ and No.10. In addition to this, we have been attending various energy conferences within the UK and providing attendees information about our project such as Innovation Zero in London, the Energy Innovation Summit (EIS) in Glasgow then Liverpool and Utility Week Live (UWL) in Birmingham.

We have also shared progress reports each year detailing our progress on the project. As part of the reports it detailed the challenges we faced and how we overcame them. These have been uploaded on our website and we have held launch webinars when we have shared them each year.

Partner contributions

Alongside the construction and delivery of Phase 1, the FutureGrid team has been working with project partners on other hydrogen development activities within the UK and Europe.

HSE

The HSE SD have been closely involved with the UK's hydrogen research schemes, playing an active role in trials undertaken by the GDNs and providing the support to enable derogations to be enacted. The HSE SD undertook an assessment for NG in 2019: "Introducing Hydrogen into the UK Gas Transmission Network: A Review of the Potential Impacts on Materials". This identified a number of key knowledge gaps which required consideration before hydrogen could be deployed onto the NTS. The findings and outcome from this report were prioritised and used to help develop the HyNTS programme and FutureGrid project.

The HSE SD's experience of working in hydrogen research projects has provided vital support to the project. As a project partner, the HSE SD have worked closely with the consortium to provide challenge and review through the development of the Master Test Plan and Facility design. Monthly progress meetings were utilised in order to provide a thorough report of deliverables, plan resources and ensure that a credible independent peer review was maintained throughout the project. They have conducted reviews on the design report, materials permeation testing, materials technical report, offline test reports, facility test reports and quantitative risk assessments.

Northern Gas Networks

National Gas, NGN and the other UK networks have co-ordinated hydrogen research activities at multiple industry groups – in particular, the Hydrogen Grid R&D Programme, sponsored by DESNZ, which seeks to address any knowledge gaps within current UK hydrogen research.

NGN's HyDeploy project was a ground-breaking project that aimed to pave the way for hydrogen use in UK distribution networks. The HyDeploy project was delivered by a consortium of partners, consisting of: Cadent; Northern Gas Networks; Progressive Energy; Health and Safety Executive – Science Division; Keele University and ITM Power. Alongside the core consortium were a number of key subcontractors, such as Dave Lander Consulting, Kiwa Gastec, Otto Simon, Orbital Gas and Thyson Technology. This pilot project demonstrated that a blend of 20% could be safely distributed and used within the current distribution network, with the goal of reducing carbon emissions without the need for significant changes to consumer appliances or the existing gas network. The successful execution of HyDeploy provided crucial data on safety, consumer experience and the technical implications of hydrogen blending, marking a significant step towards the UK goal of decarbonising the energy system.

The learnings from the HyDeploy project have directly influenced the FutureGrid project with the following key points:

- Consumers are engaged with the decarbonisation agenda.
- The importance of collaborative working.
- Expect the unexpected.
- Every penny counts.

The insights into these key points have informed Future Grid's strategies, ensuring a more informed and effective approach to integrating hydrogen into the gas network. This knowledge dissemination has been crucial for developing hydrogen deployment and moving towards a transition to a low-carbon energy future.

The H21 Phase project was a pioneering initiative geared towards converting the GB gas distribution networks from natural gas to 100% hydrogen, focusing on the safety evidence needed for such a transformation. The project was designed to affirm that by 2032, the pipes and equipment would be as safe with hydrogen as with natural gas, paving the way for a credible policy decision on the decarbonisation of heat. Phase 1 of the project involved comprehensive background and consequence testing, coupled with updates to the Quantitative Risk Assessment (QRA) model and an integrated social sciences programme to gauge public perception of hydrogen safety.

DNV

DNV were the main project partner and were responsible for delivering all of the on-site construction, commissioning and testing throughout the project. In addition to DNV's defined scope in the project, they also provided in-kind contributions.

These in-kind contributions were:

- Drone footage: DNV have used their drone each month to capture high-quality video footage and pictures of the facility. This was useful as it provided an appreciation of the project progress remotely. It was also used for comms and dissemination activities.
- New transformer installation: The location of the FutureGrid facility had no electricity available. DNV had purchased the transformer, cable and installation as part of their in-kind contribution. This was vital as it provided power to the facility.
- Use of conference rooms: DNV have allowed National Gas to use their conference room facilities for stakeholder events/site visits at Spadeadam. This includes DNV personnel escorting them around site and also canteen facilities.
- Site tours and demonstrations: DNV regularly hosted guests at Spadeadam to visit the FutureGrid site and also provided a number of hydrogen and natural gas demonstrations to high-profile guests.

fluxys

Fluxys reviewed materials work to support FutureGrid and shared the findings of its own materials work. National Gas and Fluxys are both partners in the PIPELHYNE project, a collaborative European project assessing the impact of hydrogen on pipeline steels, as well as the effects of inhibitors.

Fluxys are undertaking a series of projects in collaboration with Ghent University to develop a comprehensive fitness-for-service tool which will allow pipelines to be assessed for their hydrogen transportation capability. This research will be shared with National Gas as part of a knowledge-sharing agreement.

Durham University

During the course of the project, Durham University provided two students to review project outputs and add additional depth to the project by conducting an academic review of areas of interest identified by the project.

The first of these was a broad-ranging assessment of the academic literature available for the areas covered within the FutureGrid project. This review covered mainly embrittlement effects, fatigue, components and safety considerations. Pulling from hundreds of academic sources, this review used an understanding of the FutureGrid project deliverables to develop a clear set of knowledge gaps and recommendations to ensure all potential considerations not covered within FutureGrid are properly addressed.

THE UNIVERSITY of EDINBURGH

Edinburgh University provided a master's student to expand on the early findings of the FutureGrid project and provide a bridge between FutureGrid and SGN's H100 hydrogen programme.

This project focused on the potential implications of hydrogen leakage based on the findings of the standalone leak testing module which was completed in early 2023. The project combined the findings of the FutureGrid Phase 1 project, H100 programme and other academic sources to estimate the potential impact of hydrogen leakage across the National Transmission System.

Projects linked to FutureGrid

Throughout FutureGrid Phase 1 we have endeavoured to identify opportunities for additional innovation projects linked to FutureGrid, whether that be physically linked and demonstrated using the facility or linked through shared technical goals. This has resulted in more successful projects completed to date, with a number in the pipeline utilising the facility before the FutureGrid Deblending works begin.

Completed projects linked to FutureGrid

FutureGrid materials testing

One of the main considerations for the operation of a high-pressure pipeline system with hydrogen is the compatibility of the materials used. The UK does not have a comprehensive standard covering the operation of hydrogen pipeline. However, IGEM have produced supplements to standards TD/1 and TD/13 based on the American standard, ASME B31.12, which is typically used to assess compatibility as it is the most comprehensive hydrogen piping standard available internationally.

This standard provides criteria for the allowable design factor for an operational hydrogen pipeline – in simple terms this means how close a pipeline can be pushed to the maximum stress it's capable of withstanding. The ASME standard provides two means of assessing a pipeline's capability of transporting hydrogen:

a. A simple prescriptive assessment based on the high-level characteristics of a pipe (material grade, diameter, wall thickness etc)

b. A more detailed assessment using data gathered from mechanically testing samples from the pipe under consideration in a high-pressure hydrogen environment

The FutureGrid project was first evaluated using method a), which is considered to be overly conservative, to determine the maximum operating pressure of the facility. This assessment recommended a maximum operating pressure of 59 barg for the facility, and therefore a more comprehensive assessment was required to ensure that the facility could operate up to the planned test pressure of 70 barg.

A project was developed to address this, using material samples taken from the FutureGrid pipelines for mechanical testing and combining this with data gathered before the project to conduct an assessment under ASME B31.12 method b). This data was then used to undertake a fracture mechanics assessment of the FutureGrid facility to provide more detail on the longevity of the facility and where the potential weak points are with regards to materials.

Fracture mechanics and fatigue crack growth rate (FCGR) tests were conducted on samples of X52 and X65 carbon steel grade pipe, in addition to testing on X60, which was conducted prior to the project. These tests were conducted in a 70 barg, 100% hydrogen environment.

The toughness values measured in this project were significantly higher than the minimum requirement in the ASME standard and therefore allowed for a significantly higher design factor to be used on the facility. The updated assessment provided maximum operating pressures for different sections of the facility, the lowest of which was 106.5 barg, well in excess of the planned operating pressure of 70 barg.

The fracture mechanics assessment identified locations to consider in more detail for the long-term operation of the facility. These were assessed using conservative assumptions around pressure and temperature fluctuations, with the agreement that a follow-up assessment would be conducted following the completion of the project.

Overall, these assessments gave more robust evidence for the safe operation of the FutureGrid facility as well as providing valuable learnings which can be applied to future assessments of pipelines or Above Ground Installations transporting hydrogen.

Nevada Nano

As part of our ongoing innovation work relating to network maintenance activities, we used specialist gas sensor technology to monitor the concentration of flammable gases within a work area. Gas sensors currently in use across the NTS are only capable of detecting natural gas, and the NTS does not currently have fugitive emission continuous monitoring equipment installed. As we decarbonise the network by using hydrogen, it is crucial that sensors will be able to detect firstly various blends and then 100% hydrogen.

Currently, there is an innovation project ongoing to test innovative multi-gas sensors. Nevada Nano (NevadaNanotech Systems, Inc.) develops and manufactures micro electrical mechanical systems (MEMS)-based sensor modules and subsystems for a diverse array of commercial and government applications. The FutureGrid facility provided an opportunity to demonstrate the capability of Nevada Nano's sensors to detect both hydrogen and methane as part of Phase 1 testing, in addition to trials ongoing at Bacton. At FutureGrid, an array of sensors were installed around the site and have been tested since April 2023. The sensor system has been measured against controlled, deliberate releases from the loop, through increasing natural gas/hydrogen blends, and finally against 100% hydrogen. The sensors are also providing us with useful information about the leak behaviour of different blends, as well as the leak behaviour of 100% hydrogen compared to natural gas. There is potential for these sensors to be used in Phase 2 of FutureGrid for deblending.

The sensors were successful in picking up leaks and mapping them out. The sensors also picked up venting from temporary vent stacks that were not near the pipe array. The sensors ran uninterrupted throughout the whole project, picking up leaks and planned leaks. The sensors being added to the site had minimal impact to the design or running due to their low power requirements, and the sensor itself being battery powered.

CVDT

Overview: A digital twin is a virtual representation of a system that covers its whole lifecycle and is updated using real-time and historical data. The platform uses simulation and machine learning to help with decision-making. This advanced and intelligent model will enable the project to visualise and understand asset changes due to the effect of existing operations and hydrogen and enable the project to accelerate time and predict future areas of concern.

Maximising the value and visibility of our data so that it is more widely available is one way that we can increase the benefits we deliver to society. National Gas have been developing tools and techniques to enable this and plan to further develop this in the RIIO-2 period. We have been actively engaging with stakeholders to identify high-value opportunities for open data, particularly around datasets supporting innovation and decarbonisation, and this project supports this ambition.

Impact: The power of digital twinning is set to unlock the full potential of our network, enabling us to enhance efficiency, reduce downtime and improve overall customer experience. It also provides easy access and greater understanding of the large datasets seen in both today's gas network and the network of the future, and also provides training and development opportunities.

- Key Stakeholders: DNV, Premtech, Centre for Modelling & Simulation (CFMS) and Sustainable Grid Tech (SGT).

Our Innovation Project Collaborative Visual Data Twin (CVDT) is set to enable us to have enhanced data visualisation. CVDT phase 1 has developed the potential use cases of Digital Twins in our business and refined initial use cases to be demonstrated in the business. By utilising use cases from CVDT phase 1, CVDT phase 2 has been developed to demonstrate the potential and benefits of Digital Twins on our FutureGrid assets. Data from the FutureGrid site during flow testing is streamed to an online web platform for NG's use in calculations and monitoring, and there is potential for this to be deployed across assets on the NTS, assisting the system operator in driving towards a net zero target.

Upcoming projects linked to FutureGrid

Gas metering project:

This project will see the design, construction and installation of a new metering and gas analyser test skid at the FutureGrid facility. This new skid will not only enable testing of new hydrogen-ready metering technology as part of initial Phase 1 testing, but also future metering and gas analyser innovation projects beyond FutureGrid Phase 1.

This new 100% hydrogen metering skid will be installed alongside the existing one on the FutureGrid facility and shall comprise of three meters in a series on the mainstream, with a bypass stream running in parallel. These three meters being: a turbine meter, ultrasonic SICK meter and a Coriolis meter.

The initial testing taking place in this project will further increase our understanding of the capability of current hydrogen-ready meters and gas analysers in a blended and pure hydrogen environment.

High pressure venting demonstration:

The project explored the possible impacts of transition from natural gas fuel to hydrogen (or to hydrogen/natural gas mixtures) on the requirement to depressurise transmission pipelines and associated equipment for maintenance or other purposes. NG currently employ gas recompression or venting to atmosphere as a means of achieving safe conditions for intrusive work. The project investigated the impact of the presence of hydrogen on these and other potential technologies for providing safe conditions of work.

The FutureGrid facility might be chosen as a potential demonstrator site to test the venting, flaring and recompression of assets that may be deemed suitable for hydrogen use based on the outcomes of this innovation project. The venting may be demonstrated as a result of high-pressure venting, that might be taking place at the FutureGrid facility as limited data into this is currently available.

Gas Quality Analyser Project:

Companies such as Bohr Energy are developing gas quality analysers that require a more limited amount of supporting equipment at a smaller cost to the traditional gas chromatograph we see on the NTS.

The advantage of this is that as we move forward on the NTS with blends of hydrogen and deblending of it too, you will need more gas quality data to determine what is in the pipeline.

The bohr energy analyser can be trialled on the FutureGrid facility replicating the changing conditions of the NTS and compared to the already installed gas chromatograph.

Outcomes of the project

The core of the FutureGrid project is the design and construction of a flow facility that is representative of GB's gas transmission pipeline system, from the entry point (e.g. onshore gas terminal) to the exit point (e.g. local distribution network). The facility is constructed from fully functioning, ex-service assets that National Gas has been removing from the existing system during their decommissioning campaign.

It was considered necessary to test ex-service assets as they are representative of the current condition of the gas transmission system.

The facility enabled the performance of these assets to be evaluated using different gases (natural gas, hydrogen, and hydrogen blends) at different flow rates (up to 72,500 SCM/hour / 1.74 MSCM/day). A programme was devised to carry out a series of tests using natural gas to establish baseline performance data. Hydrogen would then be introduced into the gas and the tests repeated.

Hydrogen blends of 2%, 5% and 20% in natural gas were tested, before repeating the tests using 100% hydrogen.

The FutureGrid Flow Loop was designed to test as many different configurations of assets, gas compositions and flow rates as possible given the constraints the project. Once the assets were sourced and the design of the facility finalised, the test programme was refined based on the expected introduction of hydrogen into Great Britain's NTS and the capabilities of the test facility.

What did we test?		What were the results?
100% Natural gas	The facility was first tested using natural gas, derived from an LNG source, to generate baseline data for the performance of the assets in the facility. This also allowed any nuances of operation to be understood before moving on to testing hydrogen blends.	
2% hydrogen in natural gas	The first blend that was tested was 2% hydrogen with 98% natural gas. This was due to the market foreseeing the introduction of smaller blends as the hydrogen economy in the UK begins to grow. This creates demand for hydrogen production and enables changes to Gas Safety (Management) Regulations, GS(M)R, to be made which allows blending on the NTS.	• Testing showed minimal deviation from the 100% natural gas baseline. • Mechanical assets operated without changes. • No significant changes in noise or vibration levels. • No detectable hydrogen permeation through the pipelines.
5% hydrogen in natural gas	5% testing was conducted in response to the EU releasing a decarbonised gas package, which proposed all TSOs must be able to accommodate a 5% hydrogen blend with natural gas. It was our ambition to remain aligned with this as we are connected to the European gas market through two interconnectors, which provide flexibility and resilience to GB's energy system. The potential for varying gas blends in the early stages of blending requires a safety margin. A 2% blend would likely arrive first, so 5% allows for redundancy.	• Aligned with EU decarbonised gas package requirements. • Similar findings to 2% blend with no significant operational changes compared to natural gas baseline. • Mechanical assets operated without changes. • No changes in sealing integrity for isolation ball valves and other components.
20% hydrogen in natural gas	The last blend tested was 20% hydrogen with 80% natural gas. This is widely accepted as the limit up to which typical gas appliances, such as boilers and gas hobs, would see no noticeable difference in operation. This is also approximately the threshold under which only minimal modifications to infrastructure would be required to transport hydrogen blends.	• Considered the limit of hydrogen blending without affecting gas supply. • No significant changes in operational performance or mechanical assets behaviour. • Accurate gas analysis maintained throughout testing period. • No noticeable differences in flow rates measured by the meters. • No significant changes in noise or vibration levels emitted during venting operations.
100% Hydrogen	The final test was completed using 100% hydrogen. This allowed us to assess how 100% hydrogen will interact with our existing assets. This will enable development of appropriate processes, procedures and safety standards. The results will provide critical evidence into the repurposing of specific NTS assets to create a 100% hydrogen backbone, thus enabling Project Union.	• Critical for assessing interaction with existing assets for future hydrogen infrastructure. • All mechnical assets continued to function and control gas flows around the facility. • Shorter operation of gas chromatographs provided accurate hydrogen content measurement; longer operations faced sample failures. • Temperature change through pressure reduction was measured to be as modelled, removing the requirement for pre-heat. • Noise levels increased during venting operations, but vibration impacts were minimal. • Hydrogen flux testing showed no detectable permeation through the pipelines.

Each test phase comprised of 4 weeks of testing which was followed by a review of the data, comparing this to the baseline natural gas testing as well as any previous blends. This was a strategic decision, ensuring that any learnings were captured before moving on with the test programme.

Standalone tests

Permeation testing

In a review of academic literature, the potential for hydrogen to permeate from within the pipe, through the pipe wall and out of the external surface of the pipe wall was identified as a potential concern. There is little empirical evidence of this, however, included within the scope of the FutureGrid project was a lab-based test to assess whether this is a material concern for hydrogen transmission.

The methodology for the permeation tests on pipe coupons has been revised based on initial test findings. Testing was first conducted by creating a test cell whereby a machined 3mm-thick disk of pipeline base metal was subjected to 70 bar of hydrogen pressure, with any hydrogen being detected at atmospheric pressure on the other side of the disk. Despite holding the sample under pressure for 40 days, no hydrogen was detected, so it was proposed that it should be moved to a more rigorous test method.

The new test method involved machining a more complex sample shape in which the sample contains an inner void which is pressurised with high-pressure hydrogen and then held within a sodium hydroxide solution. Any hydrogen permeating into the solution will change the electrical potential of the solution, which will be registered by the attached potentiostat. This should allow for detection of much smaller quantities of hydrogen. The sample is also strained to provide the maximum opportunity for permeation to occur.

Pipe coating and CP testing

The condition of the external coatings on the facility was examined after the testing finished. Laboratory testing was to be initiated after the materials permeation testing, which finished in February 2024.

As this did not leave enough time or budget to start coating and cathodic protection testing, it was agreed with DNV that the condition of the external coatings on the flow facility would be reviewed after the completion of the flow testing. In addition to this, there is a separate NIA project taking place called HyNTS & CO2nnect Corrosion, which will assess the current policies and procedures to mitigate corrosion risk on the NTS and recommend updates to them, in conjunction with laboratory testing.

Flange testing

Flanges are used extensively across the National Transmission System, particularly on Above Ground Installations, and were identified as a potential risk area with regards to gas leakage. Almost all flanges on the network are either Ring-Type Joint (RTJ) or Raised Face (RF) type.

During testing, two flanges, one Ring-Type Joint (RTJ) and one Raised Face (RF), were leak tested in a single system and subjected to a 5-day hold with natural gas at 102 bar followed by a 5-day hold with hydrogen at 102 bar.

There was no leak measured for either joint under either test. This supports the evidence gathered in the H21 Phase 1a project where it was concluded that assets that are gas-tight with natural gas remain gas-tight with hydrogen.

Asset leak testing

During this testing, all planned asset leak tests were completed. The assets tested varied significantly in terms of their function as well as their received condition, which provided a good spread of results for different potential leakage scenarios. The assets tested in this work package included:

- Filter skid
- Orifice plate metering skid
- Regulator skid (including many small valves and components)
- Ball valve (tested from both sides).

The regulator skid was found to leak excessively prior to testing, possibly as a result of damage during transit; therefore, it was refurbished by Aughton Automation, both during testing and after testing had been completed. After this refurbishment and repair, the asset ceased leaking.

Similar to the flange testing, the results from the asset leak testing were in line with the evidence generated by the distribution networks at lower pressures, particularly the H21 Phase 1A project. In broad terms, for minor leaks, there is a negligible to small difference in the rate of leakage between natural gas and hydrogen. The difference in leakage between natural gas and hydrogen thereafter is generally proportional to the size of the leak (i.e. a bigger leak will show a greater difference between natural gas and hydrogen), up to a maximum of 2-3 times the rate of leakage.

Because these tests were undertaken using ex-service assets in realistic conditions, including systems with multiple components and numerous potential leak paths, it was not possible to determine an exact relationship between the natural gas and hydrogen leak rates. However, the trends shown were as expected, based on pre-existing evidence, which provides additional confidence and allows the use of this information to inform decisions on the use of existing above-ground assets.

Rupture test

Rupture tests are an important part of understanding the potential risks of operating a pipeline network containing hazardous material. Although in its 50-year history the NTS has never had a mainline pipe rupture, rupture tests have been conducted numerous times to understand the potential consequences of such an event.

For FutureGrid, the test procedure for the rupture test deviates from a traditional rupture test, as it used mechanical means to rupture the pipe, rather than an explosive charge, to allow for delayed ignition. This was done to simulate a worst-case scenario for a high-pressure gas release and to allow the capture of overpressure and thermal radiation data.

The test used a 6" pipe section in a pre-formed crater which was pressurised from both sides with 100% hydrogen at 60 barg. Instruments were situated at numerous locations around the pipe section to capture thermal radiation and overpressure data at different distances from a rupture event.

The first test focused on the question of whether the hydrogen release would automatically ignite when ruptured in such a way. Once the pipe was ruptured, the hydrogen release ignited in approximately 100ms and then formed a large jet fire, similar to what would be found in an equivalent natural gas rupture. This rapid ignition of hydrogen is a positive finding for the safety case because it prevents a flammable gas cloud forming which would present a greater risk than a jet fire. Despite the early ignition, a moderate overpressure was measured and the implications of this are described in the QRA section.

The following 4 tests simulated a 'steady-state' release, gathering empirical data to validate the modelling work that was done to predict the thermal radiation from a hydrogen pipeline rupture. These tests used the already ruptured pipe section (meaning these tests did not include a 'rupture event') as well as lower flow rates to generate more reliable data.

Interestingly, the releases did not auto-ignite, suggesting that this behaviour was either due to the rupture event or the higher flow rates used in the original test. Further testing has already been commissioned to obtain more detail on this effect.

Overall, the data gathered was broadly in line with the consequence modelling undertaken prior to the project, and this empirical data will support a robust safety case for hydrogen pipelines.

Fatigue testing

Natural gas pipelines are typically designed for a 40-year operating life; however, with good management they can last well in excess of this. This lifetime is calculated based on the assumed level of fatigue in a pipeline – in other words, how much the pressure of the gas within the pipe is increased and decreased. This change in pressure puts strain on the material and eventually wears it out. A study was recently conducted on the pipelines on the NTS that showed most pipelines had a remaining life well in excess of 100 years.

In previous studies, hydrogen has been noted as potentially reducing the fatigue life of steel pipe. In order to gain confidence that NTS pipelines would be capable of transporting hydrogen well into the future, it was proposed that a hydrogen pipe be tested in realistic conditions to study the effects of fatigue in a hydrogen pipeline.

A test rig was constructed using ex-service pipe, originally installed in 1999, which was fabricated using 9 different welding techniques, as well as a ball valve and tee section, to be as representative as possible of real NTS pipelines. This was then filled with hydrogen and the pressure within the vessel was cycled once every 6 minutes to induce fatigue. At the time of reporting, this vessel has been cycled approximately 30,000 times, equivalent to 80 years of operational life. The pipe and welds have been non-destructively tested, so no signs of fatigue damage have been detected.

This facility will continue to operate following the conclusion of the FutureGrid Phase 1 project until 75,000 cycles have been successfully completed, equivalent to 200 years of operational life. The material will then be destructively tested at a lab to check for any signs of material degradation.

Risk Management & Safety Assurance for Hydrogen Integration

The safety case for FutureGrid Phase 1 forms the backbone of our commitment to holding the highest safety standards as we decarbonise the National Transmission System, as we transition from a natural gas network to a hydrogen network. The suite of standalone tests already mentioned in the report are integral in building a robust and comprehensive safety case. These tests are not only crucial for demonstrating that the hydrogen network can operate reliably but are also essential for ensuring that it meets the specific safety standards historically associated with the operation of the natural gas network as it is today.

The tests carried out collectively inform the QRA, a systematic methodology that quantifies risks and guides mitigation strategies. The safety case synthesises the test outcomes to demonstrate that the network can operate safely and reliably with hydrogen. It serves as a detailed argument that the FutureGrid Phase 1 facility meets the required safety levels and can achieve the same operational excellence as the established natural gas system. This thorough and methodical approach not only safeguards the network but also reinforces stakeholder confidence that the transition to hydrogen, while ambitious, will not compromise safety and supports the business strategy of leading a clean future for everyone, enabling net zero.

Quantitative risk assessment

A quantitative risk assessment (QRA) is a systematic, detailed process used to quantify the risk associated with industrial operations, particularly those involving hazardous materials such as hydrogen. By applying statistical methods to evaluate potential safety hazards, QRA provides a comprehensive understanding of the risks, their likelihood and the potential impact on safety, environment and economic factors.

QRA methodologies for buried onshore natural gas transmission pipelines have become well established and are now codified in standards. National Gas currently uses a Hazard Assessment of the Transmission System (HATS) study to assess safety risks and identify areas where interventions may be required. The QRA work undertaken in the FutureGrid project followed this same approach and then compared the findings with a recent 2022 HATS study undertaken for the operation of the network with natural gas. The aim of this study was to provide awareness of the risks, from a management perspective, of the transmission system. It was an update to the HATS document, which provides an overview of the risk to the public from the gas transmission pipelines in the NTS. In this study, the population of gas pipelines as of 2016 was analysed, and it was found that the individual risks were within the acceptable level, based on a hypothetical individual located within one Building Proximity distance (BPD) from pipeline for 100% of the year. This was mostly affected by 90% of NTS pipelines that were situated in rural areas.

The results show that ruptures are predicted to occur on the NTS approximately every 21-27 years for the pipeline population analysed in this study (~7625 km current operational pipelines). The NTS has been in operation for over 50 years, with the majority of pipelines constructed in the late 1960s to the early 1980s, and to date there has not been a rupture failure on the system. The failure data suggests that two ruptures may be expected in a 50-year period for the pipeline population analysed in this assessment, which is slightly higher than the operational experience on the NTS but does not take into account the commissioning date and operating history of each pipeline, which would be required if a historical analysis were to be undertaken.

Work is ongoing to extend the risk assessment models to evaluate the consequences of hydrogen releases from buried pipelines. However, it is noted that at present, there is very limited validation data, and this is currently an active area of research and development. It is expected that the models will continue to be refined as more data becomes available and the results obtained currently represent DNV's best estimate of the consequences and risks associated with buried hydrogen pipeline releases. Notwithstanding these acknowledged uncertainties, the full report applies the available evidence for hydrogen pipelines in a risk assessment approach. This should be consistent with that adopted by the gas industry for existing high-pressure natural gas pipelines, to provide a better understanding of the implications on risk of a transition to 100% hydrogen. The assessments presented in the report consider a wide range of realistic cases representing the entire NTS pipeline population and investigate the effects of uncertainties via sensitivity analysis. The effects of different mitigation options have also been investigated, demonstrating the potential for any increase in risk associated with hydrogen to be managed effectively by appropriate mitigation measures, ensuring that the operation of the NTS remains As Low As Reasonably Practicable (ALARP).

Policies and procedures review

Operations on the NTS are governed by an extensive suite of documents, including industry standards as well as bespoke documents written and maintained by National Gas. This suite of documents has evolved over decades with the development of gas networks and wider industry and the documents therein are regularly reviewed.

A change of product will require a wholesale review of this document suite to identify the changes required, and this was undertaken as part of the FutureGrid project.

The aim of this review was to understand which documents will require changes, to what extent they need to change, and the approximate effort required to make those changes. The review identified over 550 documents to be assessed covering Policies, Specifications, Management Procedures and Work Procedures. Approximately 52% of the documents reviewed would require no changes or only minor changes, 28% of the documents would require a medium level of change and 20% a high degree of change. It was estimated that the effort required to update these policies and procedures would take upwards of 27 person-years.

This work provided clear guidance on the requirements to create a hydrogen-ready document suite to ensure the safe and effective operation of a Hydrogen Transmission System. This has already evolved into a collaborative project with the UK Gas Distribution Networks to identify ways to optimise the delivery of these documents in a way that reduces the overall cost to GB consumers.

Hazardous area impact

This work was undertaken to assess the changes required for natural gas hazardous zones to be transitioned to work with hydrogen blends and hydrogen to enable a hazardous area classification (HAC) to be created. The outputs included hazardous zones for a range of national gas assets in normal and adverse conditions. NG has also created a hazardous area drawing for an existing GT&M AGI (Above Ground Installation) and compressor site for blends of hydrogen and 100% hydrogen. Furthermore, we have created hazardous area drawings for the FutureGrid facility.

All sites handling significant quantities of flammable materials capable of potentially forming an explosive atmosphere come under the ATEX 1999/92/EC 'Worker Protection' Directive, which is implemented in the UK by means of the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR). One of the requirements of DSEAR is that a Hazardous Area Classification (HAC) of the site be undertaken with the extents and classification of the potentially explosive zones being indicated on an appropriate Hazardous Area Drawing (HAD). This report is intended to cover the HAC and HAD for the FutureGrid installation and does not assess compliance with other DSEAR aspects.

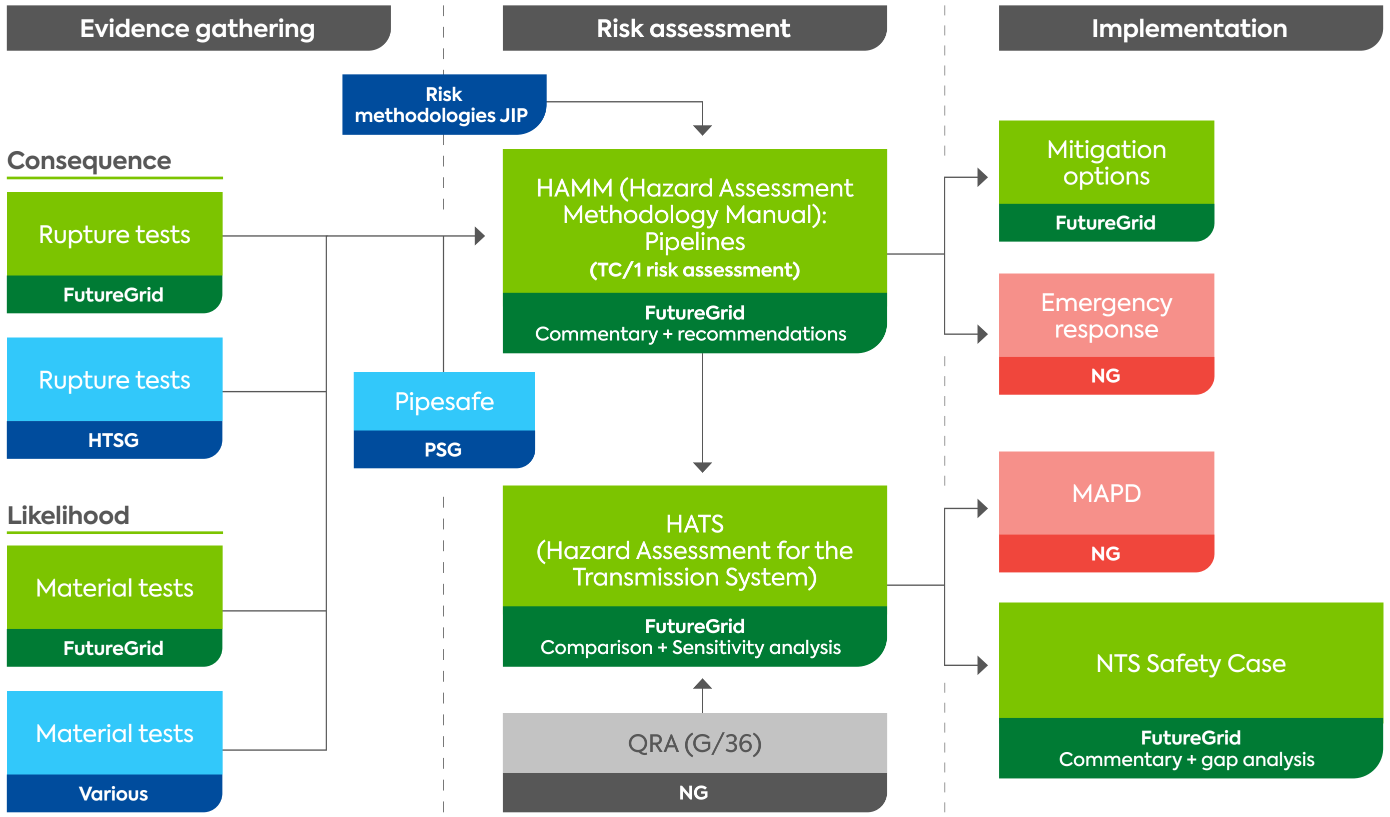
Throughout the HAC exercise, the application of the IGEM/SR/25 [1] code is based on the operational and maintenance aspects of the plant being in accordance with good industry practice. It therefore assumes that containment systems have been designed to an appropriate code and maintained in accordance with all statutory requirements (i.e. DSEAR and the Pressure Systems Safety Regulations (PSSR)) and employ a system for safe control of operations (e.g. permit-to-work systems). Given this assumption, the failure of a welded joint is a highly unlikely event that requires systematic failures in the safety management system and, as such, is not considered a defining case for hazardous area classification.

NG Safety case

The safety case is rigorously developed through a structured framework, as depicted in the QRA (Quantitative Risk Assessment) process diagram. The framework begins with meticulous evidence gathering, including rupture and material tests conducted within the FutureGrid facility, ensuring that the consequences and likelihood of various risks are well documented. These tests feed into two key methodologies for risk assessment: HAMM (Hazard Assessment Methodology Manual) and Pipesafe, providing a thorough evaluation of the pipeline's integrity and operational safety.

Following the assessment phase, the framework outlines clear implementation strategies, focusing on mitigating the potential risks identified during the assessment. These include developing specific mitigation options, preparing for emergency responses, and implementing measures as per the Major Accident Prevention Document (MAPD) guidelines. All these efforts culminate in strengthening the National Transmission System (NTS) safety case, supported by FutureGrid's insights and gap analysis, ensuring that the pipeline operations not only meet current safety standards but are also prepared for future contingencies.

QRA process – pipelines



An assessment was carried out to determine the impact that hydrogen had on the National Gas safety case. This safety case is critical in defining the aspects of operation in order to show that gas can be transported safely; in this regard, the safety case was studied to show how it had to update in order to be valid for hydrogen. The assessment found that there were updates to be made to the safety case, and options were discussed for developing a hydrogen safety case. It was estimated that it would only take 87 days to develop a safety case for a hydrogen-NTS trial.

The purpose of this work was to impact-assess all aspects of the safety case to determine what sections will be affected by a change to hydrogen and make comments to indicate what further considerations may be required to ensure that the safety case would be suitable for hydrogen operation. Comments or considerations have been categorised based on their impact magnitude (High / Medium / Low) against six implication categories, to show the level of impact as well as the area of NGGT operation which would be impacted. Additionally, a comment on the availability of data to respond to the comment / consideration raised is made. The implication categories used are:

- Safety
- Strategy
- Operations
- Legislation and policy
- Competence
- Minor text updates

A total of 215 comments / considerations have been raised across the two safety case parts and the appendices. Of these:

- 11 comments were raised where high was the highest severity category identified for any of the implication categories.
- 74 comments were raised where medium was the highest severity category identified for any of the implication categories.
- 112 comments were raised where low was the highest severity category identified for any of the implication categories.
- 18 comments were raised where no severity category was applied to any of the implication categories as they are included for information purposes only.

A total of 64 comments / considerations were raised where no known work, planned ongoing or completed, had been identified which would address the comment – these are classified as data source "Unknown". The following themes were identified where the current solution was unknown, therefore this list could be used to help identify future work requirements. Note that most of these considerations would be addressed by strategic decision-making, or would be trial specific.

Performance compared to project plan

FutureGrid

Phase 1 Facility

The Phase 1 project, a testament to robust planning and execution, was chartered on a course set by well-defined deliverables and evidence-based checkpoints.

Our project partner, DNV, has diligently worked through each stage, ensuring each test, both offline and online, aligned with the robust action plans laid out. Our checkpoints were critical in validating the results before moving forward in the project plan, preventing any need to revisit and refine later in the project, which would incur extra time and cost.

Rigorous testing has commenced at the FutureGrid research facility since the successful completion of the design and construction phases of works. Testing started with 100% natural gas and then progressed to 2%, 5% and 20% hydrogen blends. Testing has seen the completion of 100% hydrogen testing through seven different flow trials. Tests were conducted at different flows between 0.12mSCm/day to 1.74mSCm/day. Similar testing conditions and durations were also carried out for each of the 2%, 5% and 20% hydrogen blend tests.

Through the data generated and reviewed so far, no major findings have become apparent in the way 2%, 5%, 20% or 100% hydrogen impacts on our repurposed assets, which are currently used for natural gas. Assets that combust blended gas, such as the standard boilers found on the facility, which provide gas pre-heat to counteract the Joule-Thomson effect with pressure drop associated with natural gas, operated without any noticeable changes to normal operation.

FutureGrid has the potential to unlock how we shape the future for a sustainable, cheaper, alternative energy source and is paramount in enabling us to map out how we intend to progress over the coming years with the technology available to us as we embark on our clean energy journey.

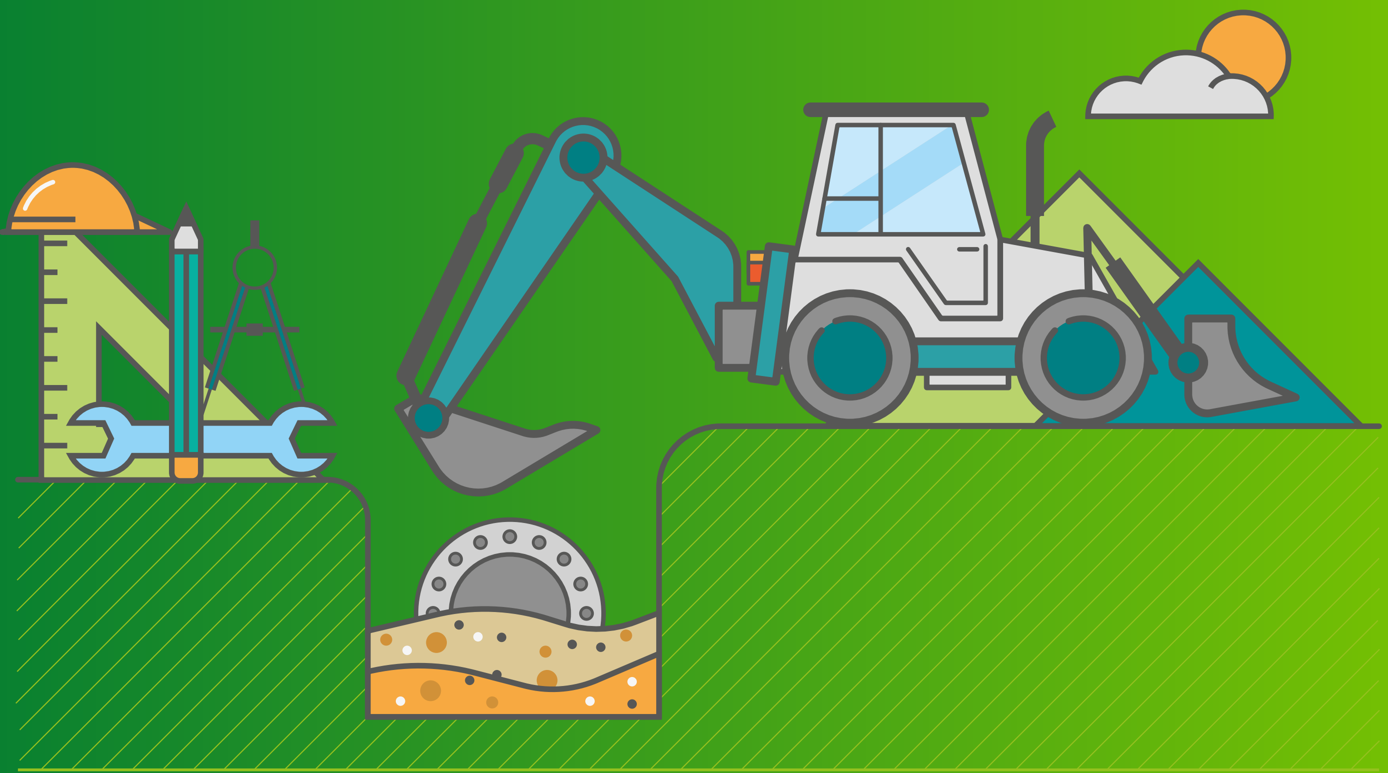
The following page shows the deliverables that kept the project focused on what we aimed to achieve: regulatory governance enabled overall transparent project delivery within budget, as shown in the following table.

Ofgem Deliverables

No.	Deliverable Title	Outputs
1.0	Groundworks & construction	As built drawings, written scheme of examination and DNV report of activity & lessons learnt.
2.0	Standalone testing & commissioning	Successful completion of testing and commissioning processes with supporting documentation & dissemination of facility design and layout to allow detailed development of Phase 2 & 3 interactions.
3.1	Testing 2% hydrogen	Completion of 2% H2 tests identified by the master testing plan inc. launch and close out events. Identification of future test requirements as a result of the findings. Results collated, documented, and validated for impact on next phases of hydrogen development activities.
3.2	Testing 5% hydrogen	Completion of 5% H2 tests identified by the master testing plan inc. launch and close out events. Identification of future test requirements as a result of the findings. Results collated, documented and validated for impact on next phases of hydrogen development activities.
3.3	Testing 20% hydrogen	Completion of 20% H2 tests identified by the master testing plan inc. launch and close out events. Identification of future test requirements as a result of the findings. Results collated, documented, and validated for impact on next phases of hydrogen development activities.
4.1	Testing 100% hydrogen	Completion of 100% H2 tests identified by the master testing plan inc. launch and close out events. Identification of future test requirements as a result of the findings. Results collated, documented, and validated for impact on next phases of hydrogen development activities.
4.2	Testing 100% hydrogen fatigue testing	Completion of fabrication and hydrostatic pressure test of the standalone fatigue test module using a selection of pipeline welding procedures. Commence pressurising the test module with hydrogen and hold at pressure to enable permeation of the hydrogen into the pipe wall. Begin the pressure cycling of the test module. Completion of the required number of pressure cycles and completion of the test. Results collated, documented, and validated for impact on next phases of hydrogen development activities. Identification of future test requirements as a result of the findings.
5.0	QRA & safety case	Overpressure testing on secondary offline NTS test facility. Validation of results into the existing QRA model and any mitigations reviewed (updated QRA and mitigation log). High-level review of NGGT's policies and procedures documented. Prepare a commented version of the safety case. Updated asset assessment and hydrogen risk review.
6.0	Knowledge dissemination	Overpressure testing on secondary offline NTS test facility. Validation of results into existing QRA model and any mitigations reviewed (updated QRA and mitigation log). High-level review of NGGT's policies and procedures documented. Prepare a commented version of the safety case. Updated asset assessment and hydrogen risk review.
7.0	Comply with knowledge transfer of the Governance Document	Annual Project Progress Reports which comply with the requirements of the Governance Document. Complete Close Down Report, which complies with the requirements of the Governance Document. Evidence of attendance and participation in the Annual Conference as described in the Governance Document.

Ofgem Deliverable 1.0

Groundworks and construction



Ofgem Deliverable 1.0	
Groundworks and construction	
Deliverable date:	**August 2023**
Evidence required:	• As built drawings. **Completed** • Written scheme of examination. **Completed** • DNV report of build activity and lessons learnt. **Completed**
Key summary:	**Preparatory Phase:** Implemented key planning activities to ensure efficient FutureGrid construction; standards and testing protocols were established in collaboration with stakeholders. **Asset Inspections:** Conducted detailed inspections post-delivery to ensure the integrity of assets, using advanced testing methods, such as ultrasonic and magnetic particle inspections. **Asset Integration and Testing:** Interconnected and tested various sections of pipework under industry quality assurance standards; ensured all connected assets were fit for purpose through rigorous non-destructive testing. **Operational Readiness and Software Upgrades:** Deployed new software on existing infrastructure to enhance monitoring capabilities; ensured modifications supported up to 30% hydrogen blend for precise flow measurements, enhancing overall system reliability and safety.

Preparatory phase

To enable FutureGrid construction to commence, key planning activities were carried out to ensure that the build/testing phases could progress as efficiently as possible.

Before construction, a working group was established to set out the key standards and policies to be used for the facility build and testing (e.g. ASME B31.12). By working in collaboration, both parties demonstrated compliance adhering to set standards, policies and procedures. In addition, the FutureGrid design report was submitted to NG for review and approved, with site construction starting in September 2021 and finishing in April 2023. In all disciplines, the design was accepted and construction completed. Compliance was demonstrated throughout the groundworks and construction phase, which ensured the safe accomplishment of the FutureGrid build, delivered efficiently within allocated budgets.

NG worked closely with the Construction Team, Operations Team and NG suppliers to develop a plan to release decommissioned assets from the network and transported to DNV Spadeadam. This required considerable effort to develop a scheme that could cost-effectively transport large amounts of NTS assets within a tight timeline. The asset identification phase continued throughout the FutureGrid project, with opportunities always being utilised to add to the asset base to maximise the contingency options should any assets not be deemed suitable.

Asset inspections

In order to ensure that the facility was fit for purpose, each asset was inspected by DNV after delivery. During the inspection, DNV carried out a detailed report on all assets with recommendations that were completed and incorporated into the FutureGrid facility. This technical report consists of visual inspections and magnetic particle inspections (MPI), followed by more thorough ultrasonic testing (UT) to confirm mechanical soundness and help identify any defects. Through testing, this identified assets that cannot be incorporated into the facility in their current condition. This ranged from assets that simply required cleaning through to assets that did not have sufficient integrity to safely test with hydrogen. Although the assets were being repurposed due to being at the end of their working life, the quantity and severity of these defects had been greater than originally anticipated.

Planned maintenance was carried out on some of the decommissioned assets to ensure safe operation within the FutureGrid test facility without compromising the project ethos of representing the NTS. NGS rectified defective Cameron isolation ball valves to ensure optimal safe operation. Other examples included planned preventative maintenance procedures, including testing and certifying primary and secondary protective devices. DNV, supported by NG, ensured that all pressure vessels supplied adhered to current PSSR examination specifications for safe operation.

Where assets were identified as not having the required integrity or functionality, remediation was not an option. The FutureGrid team invoked the contingency plan in such instances. Testing of the original sections of pipeline supplied revealed compromised integrity, showing minute cracks that had been noted during magnetic particle inspection tests, thus being recognised as a good catch. The learning outcomes were cascaded through different departments across the wider NG business.

The FutureGrid assets were interconnected and joined together using various sections of pipework, which were fabricated together in accordance with the design. This was carried out in accordance with industry quality assurance standards, with all welds being subject to monitoring and inspection, non-destructive testing being carried out and records being taken to give assurance that the facility is fit for purpose. Upon completion of all construction at the facility, a hydrostatic test was carried out at 1.5x line pressure to prove the strength of the pipework. Pipework and assets that were not suitable for hydrostatic testing underwent pneumatic testing to prove that there were no integrity issues.

In order to power the recompression unit, NTS assets and instrumentation, DNV carried out an electrical capacity review, which identified the need to carry out an upgrade to the electrical infrastructure to ensure testing could be carried out without any pauses. This involved the need to work closely with the local electricity distribution network to understand the impact of the scheme, with contingency options being prepared for commissioning in the event of any timelines that had a knock-on impact.

A wide range of instrumentation was installed onto the facility in order to gather all the data from the assets that were being tested. A design was commissioned for this, which identified all the data requirements for the facility and identified a method in which to relay the data, process it and ensure it was all stored correctly. A simple SCADA interface was developed to allow for remote monitoring of the facility while testing was being carried out.

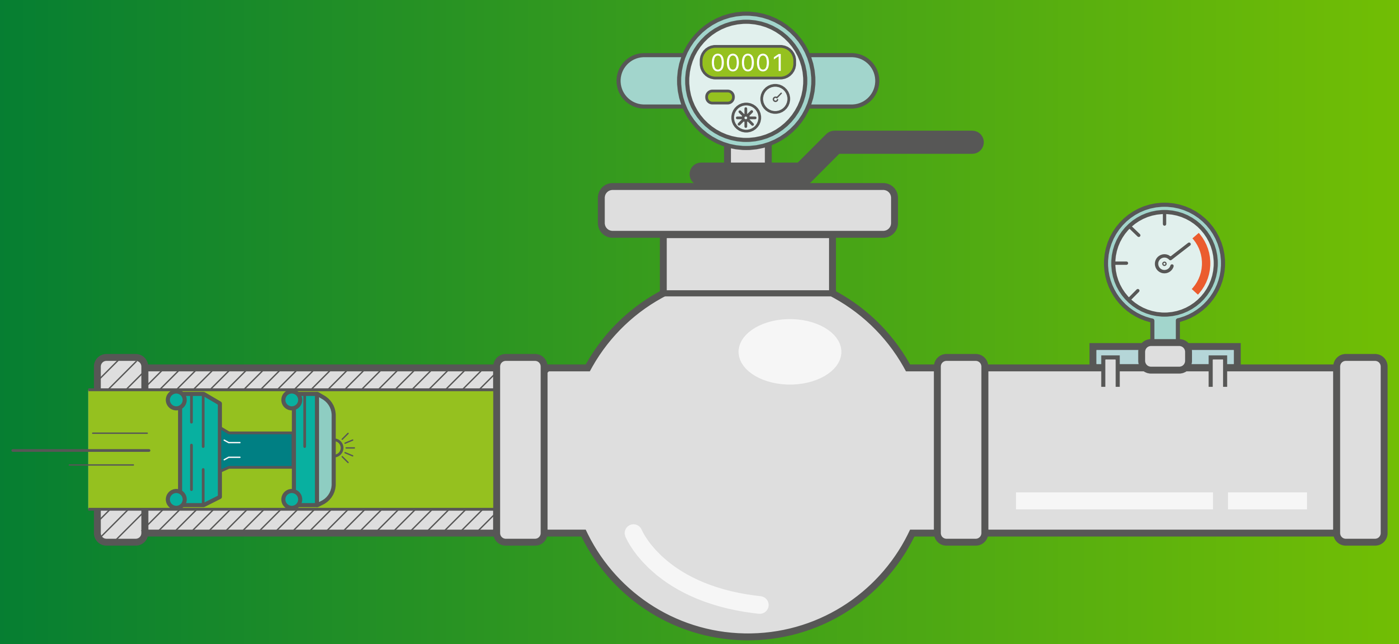
The recompression unit was ordered from the Austrian manufacturer LMF, and the design was checked to ensure hydrogen compatibility. However, a project risk was identified, and the recompression unit delivery was delayed by 1 month, subsequently delaying the commissioning stage of the facility. This did not affected the scope of the Ofgem deliverables.

Before installation, the NTS flow computers were transported to DNV's laboratories, where the software configurations were examined to determine if modification was required to calculate the flow rate of the gas blends. Following an inspection of the meters to be incorporated into the facility, issues such as corrosion rendered some meters unusable for gas blend testing. NG purchased two flow meters: a modified ultrasonic flow meter capable of working with up to a 30% hydrogen blend and a new 100% natural gas flow meter, which is representative of what is currently utilised on the NTS. These flow meters were compared to orifice plate meters on the FutureGrid facility to replicate the parts of the NTS where metering upgrades have not yet taken place. Below is a table highlighting the ex-service, decommissioned assets used to construct the FutureGrid Phase 1 facility.

		GB site	Location	Commissioned	Decommissioned	Description
Entry point assets						
1	2x 10" Cameron ball valve	Enron-Billingham	Teesside	1992	2021	Above Ground Installation supplying gas to a 1,875 MW gas-fired power station.
2	2x 12" Cameron ball valve					
3	3x 18" Audco plug valve					
4	1x 18" Mokveld non return valve					
5	1x 18" Plenty filter (with GD closure)					
6	1x Mokveld flow control valve (RZD-RESX)					
7	18" header and outlet manifold pipework					
8	2x 18" Cameron ball valve	Billingham ICI	Teesside	1992	2021	Above Ground Installation supplying a chemical manufacturing plant, mainly producing ammonia.
Block valve assets						
9	1x 36" Cort ball valve	Lanark	South Lanarkshire	1976	2021	Mainline block valve on Feeder 11, bringing natural gas south from the North Sea.
10	2x 18" Cort ball valve					
11	2x 18" Audco plug valve					
12	2x 8" Audco plug valve					
13	36", 18" and 8" associated pipework					
Exit point assets						
14	1x 8" Neles flow control valve (D1FA08 / DAE4360)	Sellafield	Cumbria	1993	2021	Above Ground Installation supplying gas to a nuclear power station.
15	1x 3" filter skid (Plenty with Swinney quick release)	Hays Chemicals	Cheshire	1998	2020	Smaller offtake supplying natural gas to a chemical plant.
16	1x 3" twin stream meter skid (Daniel, orifice plate)					
17	1x 2" regulator skid (Fiorentini)					
18	1x 4" Boiler (Potterton) with in-line heat exchanger (Paul & Lochran)					
19	1x 4", 3" and 2" associated pipework					
Other						
20	1x 3" twin stream meter skid (CLoCC-A and CLoCC-B, ultrasonic meters)	Eakring	Nottinghamshire	2016	2021	From National Gas ex. training facility.

Ofgem Deliverable 2.0

Standalone testing & facility commissioning



Ofgem Deliverable 2.0

Standalone testing & facility commissioning

Deliverable date:	**August 2023** (Original bid date: January 2022)
Evidence required:	• Successful completion of testing and commissioning processes with supporting documentation. **Completed** • Dissemination of facility design and layout to allow detailed development of Phase 2 and 3 interactions. **Completed**
Key summary:	**Permeation testing:** Revised method included machining a complex sample shape with an inner void, allowing for more sensitive hydrogen detection through electrical potential changes. **Flange testing:** Two flange types were tested for leakage under hydrogen pressure, both proving to be leak tight and indicating existing natural gas equipment compatibility with hydrogen. **Asset leak testing:** After transit-induced leaks, the regulator skid was refurbished; subsequent results from tests were in line with expectations that assets which are leak tight for natural gas will be for hydrogen. Rupture tests: A non-traditional mechanical rupture test was carried out, enabling overpressure and thermal radiation data collection, simulating a high-pressure gas release scenario. **Facility commissioning:** Initial baseline established with 100% natural gas flow. The commissioning also involved calibrating orifice plates, approving a master test plan, and ensuring site safety through hydrostatic and nitrogen leak tests.

Standalone Hydrogen Testing

Standalone testing for the FutureGrid facility was essential for several reasons. Firstly, it allows for the rigorous validation of the compatibility of our decommissioned assets with natural gas and also hydrogen, without impacting the operational integrity of the live gas network. These decommissioned assets from the National Transmission System (NTS) were assessed to indicate whether the existing National Gas infrastructure is suitable to support a safe and effective transition from natural gas to hydrogen. Hydrostatic and pneumatic pressure tests were conducted on each asset to establish their integrity before commencing with natural gas and hydrogen leak tests. Such testing provides valuable data on how current systems can handle hydrogen, informing adjustments needed for the full-scale Phase 1 facility design.

Moreover, the standalone tests undertaken enabled controlled environments to assess safety, durability, and performance under varied conditions without compromising safety and other external variables that could further hinder the safety of these assets. This isolation is crucial for accurate measurements and ensures that any findings – such as the effect of hydrogen on material integrity or on the precision of the measurement instruments – are solely attributable to the hydrogen itself. It supports the development of hydrogen-ready infrastructure, providing a roadmap for transitioning from natural gas to hydrogen and ultimately to a decarbonised energy system. This approach mitigates risks, ensures compliance with safety standards and builds a robust case for regulatory approval and confidence.

Leak tests

Static gas leak testing on several decommissioned assets was performed as stand-alone tests away from the FutureGrid flow loop. The purpose of these tests was to assess whether the specimens, representing existing National Gas infrastructure, are suitable to support a safe and effective transition from natural gas to hydrogen in the National Transmission

System (NTS). These tests were part of a critical step to ensure the integrity and safety of the assets when repurposed for hydrogen use.

A list of tested assets are as follows:

- 36" flanges supplied by NGS
- 18" filters from Enron
- 36" ball valve from Peterborough
- 4" metering stream from Hays
- 4" regulator stream from Hays.

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A series of gas leak tests were conducted on the above NTS assets to determine the differences between natural gas and hydrogen leak characteristics. Each asset was pressure tested with water for two hours at 1.5 times the working pressure except for the 4" regulators, which were pressure tested with nitrogen. This was followed by gas leak tests using natural gas for 5 days and subsequently with hydrogen for 5 days. Each asset was pressurised according to its rating and subjected to EN 1593 Leak Detection – Soapy Water/Pressure Drop Test (if detectable), allowing for comparison of the leaks between the different gases. All the assets were tested in as close to as-received condition as possible, with any openings plugged and the ends sealed with blank flanges. Some assets required remediation work where large leaks were detected. These repairs included the replacement of valves, sealing of threads, and external parties where required.

Overall, it was found that typically when an asset was leak-safe with natural gas, the same was true for hydrogen. When the asset was found to be leaking natural gas, it would typically leak hydrogen at a greater rate, proportionate to the size of the fault causing the leak (i.e. the difference between hydrogen and natural gas would be greater for a larger leak).

To understand the impact of hydrogen on leak rates, it was important to test a variety of assets and assemblies in various conditions to give a broad view of the potential impact of hydrogen across the asset base. This understanding is important in determining the approach to leak control with regards to the potential safety and environmental implications of gas escapes on Above Ground Installations.

Flange testing

Flange testing is a pivotal component of the standalone testing programme for several reasons. Flanges serve as critical junction points in pipeline systems, ensuring a tight seal where sections of piping connect. In the context of hydrogen, flanges must withstand the gas's unique properties, such as its low viscosity and high diffusivity, which can lead to increased leakage risks at connection points. The flanges tested were:

- 36" Ring-type joint (RTP)
- 36" Raised face (RF).

By conducting flange testing, an assessment was performed on the compatibility and resilience of these components in sealing against hydrogen's penetration, thus preventing leaks. This testing also provided empirical data to validate the sealing efficiency of gaskets and bolting arrangements typical of the current NTS but for hydrogen service. Moreover, flange testing ensures that each flange assembly maintains its structural integrity under hydrogen transport. This approach will ensure the long-term reliability and safety of the FutureGrid facility while also building some crucial aspects of the safety case that our assets can be repurposed for hydrogen.

The flange testing procedure involved first testing with natural gas at 101.8 barg and then hydrogen at 102.3 barg, both for a period of 5 days. The natural gas leak test saw only a leak rate of 0.013 SCMH M3, which is extremely small and likely within the experimental uncertainty of the measurements. The hydrogen test showed an average leak rate over 5 days of 0.009 SCMH m3, which is lower than what was measured for natural gas, highlighting that this rate is more likely to be due to experimental uncertainty. The normalised pressure for hydrogen appeared to be nominally constant throughout the hold, while the normalised natural gas pressure fluctuated more. The leak test data supports the growing evidence that if equipment is leak tight for natural gas, it will be the same for hydrogen.

Material Permeation testing

DNV performed material permeation testing for National Gas to evaluate the hydrogen flux of three materials exposed to high-pressure gaseous hydrogen. The objective of the project is to understand the degree of hydrogen intake by the materials of interest when they are exposed to high-pressure hydrogen in transmission pipelines. Samples from three materials were evaluated in this project: a Grade X60 line pipe, a cast steel valve material and a flange for an X52 pipe. To validate the hydrogen flux setup, a flux test was also performed in salt solution on an X52 pipe steel sample under cathodic potential. This interim report summarises the experimental efforts and the results generated to date. Four materials were provided by NG to DNV for testing:

- X60 pipe
- X52 pipe
- X52 pipe flange
- A valve.

Fatigue test

Fatigue tests are essential in understanding the long-term integrity of the network. Fatigue is one of the main limiting factors for pipeline systems and so any changes to fatigue performance can have a significant effect on the expected lifespan of the system. To test this, it was decided to choose a experimental configuration which was as representative of the network as possible.

The fatigue test rig was constructed of X60 carbon steel pipe, removed from the NTS during a diversion, which had originally been installed in 1999. This pipe section was then cut into short lengths and welded back together using 9 different welding techniques to cover the majority of welds on the live network. The system was then pressurised with hydrogen with the pressure cycled approximately once every 6 minutes.

As of writing, the fatigue rig has been subject to approximately 30,000 pressure cycles, equivalent to 80 years of operational life, with 3 NDT inspections conducted to date. These inspections have not indicated any issues relating to weld integrity and the rig will continue to be pressure cycled until reaching 75,000 cumulative cycles, equivalent to 200 years of operational life. Once the fatigue testing is complete, the welds and pipe material will be extracted and assessed for any signs of hydrogen embrittlement.

The fatigue test rig also featured two hydrogen flux monitors which have detected no hydrogen permeation throughout the course of testing.

Rupture tests

Rupture tests are crucial for understanding the potential consequences of a failure of a pipeline containing a hazardous material. Modelling work has previously been undertaken to estimate the potential consequences of a hydrogen pipeline rupture, however this has not been validated with experimental data.

The FutureGrid rupture tests used a 6" carbon steel pipe which was pressurised with hydrogen to 60 barg. This pipe was then subject to 5 rupture tests:

- Transient test (T1) used a mechanical rupture method to split the pipe and release gas. This simulated a rupture event and rapid release of hydrogen at ~25kg/s.
- Steady state tests (S1-4) used the existing ruptured pipe and passed gas through at a lower flowrate.

The results from these tests supported the prior modelling work with the findings on thermal radiation and overpressure in line with expectations. The T1 test showed an almost immediate ignition, with a delay of ~100ms, with no dedicated ignition source which is positive for the safety case owing to the slightly lower thermal radiation effects of hydrogen versus natural gas. Further work has been commissioned to understand whether delayed ignition is possible in real-world conditions, and this is expected to conclude in December 2024.

Facility commissioning

A baseline was established by testing the facility with 100% natural gas and identifying any faults in the NTS assets, such as the 36-inch valve. While this asset can accept flow through it, the valve seal is damaged, meaning an isolation is not possible and gas is constantly vented when closed. This is due to its age and condition. Therefore, it was decided that the project would exclude this valve from testing. Testing of a 36-inch valve for hydrogen and hydrogen blend flows has been identified as a future test requirement, as per Ofgem deliverable 3.1.

The baseline included, but was not limited to, results from:

- A regulator performance test
- Average differential pressures across two filter types (one for high flow and one for low flows)
- Vibration and noise monitoring
- Meter readings for ultrasonic, orifice plate and clamp meters
- Heat exchanger temperature difference.

These data points were taken to get a baseline for the flow characteristics in the facility that can be compared to the blends and 100% hydrogen testing.

Additional tests and activities were also conducted to ensure that the site was safe to operate. This involved:

- Calibrating the two orifice plates at the DNV flow test centre and installing them into the metering skid ready for the first flow tests.
- The Danalyzer being tested for measuring natural gas with up to a 100% hydrogen blend.
- Developing and approving a master test plan.
- Hydrostatic testing, which pressured the facility up to 1.5x its maximum operational pressure, was completed and passed to ensure site safety.
- A nitrogen leak test to give added reassurance that the facility had minimal leak paths.
- End-to-end checks to check the data being logged was correct.
- Site acceptance testing of the recompression unit.

Ofgem Deliverables

FutureGrid Flow Loop Testing

Our testing approach

The main test programme focused on evaluating the performance of the key assets which comprise the NTS such as valves, filters and pipework. The programme will tested both the integrity of the assets and their performance in varying network conditions and hydrogen blends.

Each hydrogen concentration was be tested in the facility for 4 weeks, operating at seven different flow rates in order to generate conditions seen on the NTS. Throughout the testing, the vibration, noise and permeation accross the facility was monitored. Leak monitoring will be completed across the facility and compared across the blends of gases.

How we operate each test

For 100% natural gas and each of the hydrogen tests we will follow a 4 week testing cycle.

START

Gas fill:
Prior to testing the facility must be filled with the gas composition being tested. Gas is vented off as necessary and then hydrogen is added to return the facility to its normal operating pressure. The gas quality is then checked before testing begins.

Week 1:
The facility is configured such that the high flow loop is tested. Calibrations are conducted on the facility and testing begins with the lowest flow rate on the high flow loop, Flow 4. Operational data is logged during testing and stored within the data centre.

Week 2:
The flow rates on which the testing is being conducted are increased incrementally until the testing on the maximum flow rate is completed. The block valve arrangement is isolated from the system.

Week 3:
The facility is configured to test the low flow loop by opening valves to the pressure reduction skid and activating the pre-heat system. Testing begins with the lowest flow rate on the low flow loop with additional data points being captured throughout the pressure reduction system.

Week 4:
The flow rates are increased in steps until testing on the maximum flow rate on the low flow loop is completed. Once testing has been completed the data is compiled into a report and the facility is vented as necessary to allow for re-fill for the next the gas composition test.

Results validation:
Each 4 week test cycle is followed by a review of the data to ensure that all data has been captured as necessary and there are no safety concerns in moving to the next blend.

FINISH

How did we operate the testing?

The recompression unit generates gas flow around the facility, simulating the operation of a typical Above Ground Installation. This unit was designed for the FutureGrid facility, to operate with natural gas and hydrogen at a wide range of flow rates and pressures to generate a broad range of data. The facility is constructed of assets representative of three different types of installation: Entry Point, Block valve & Exit Point.

Entry Point
These assets would be typically found at a gas terminal where gas enters the transmission system. This includes plug valves, ball valves, a flow control valve, a metering skid and a filter.

Block Valve
There are over 250 block valve sites across the NTS. These are used to isolate transmission pipelines for maintenance or in the event of an emergency. This includes a 36" ball valve as well as bypass pipework and additional valves.

Exit Point
These assets are typically found at locations where gas exits the transmission system such as at power stations or distribution network offtakes. This includes pre-heat, metering, a flow control valve and a pressure reduction system.

Based on the capabilities of the recompression unit, seven flow rates were chosen to demonstrate the capabilities of the assets under different conditions:

		Asset groups testing		
Flow	Flow rate	Entry point	Block valve	Exit point
1	0.12mSCm/day			
2	0.24mSCm/day			
3	0.36mSCm/day			
4	0.36mSCm/day			
5	0.82mSCm/day			
6	1.28mSCm/day			
7	1.74mSCm/day			

Key: Low flow rate High flow rate

Four key hydrogen concentrations are being tested:

2% hydrogen in natural gas

The first hydrogen blend that will flow through the FutureGrid facility will be 2% mixed with 98% natural gas. This is due to the market foreseeing the introduction of smaller scale blends while production begins to scale up. This creates demand for hydrogen produced and enables changes to Gas Safety (Management) Regulations, known as GS(M)R, to be made which allows blending on the NTS.

5% hydrogen in natural gas

A 5% hydrogen blend with 95% natural gas was incorporated into the phase 1 FutureGrid test programme The EU has released a decarbonised gas package, which proposes all TSOs (Transmission System Operator) must be able to accommodate up to a 5% blend. It's our ambition to keep aligned with this, as we are interconnected with Europe. The potential for variable hydrogen blends in the early stages of blending makes a safety margin necessary, so in the case of operating with a 2% blend, having tested up to 5% provides that margin.

20% hydrogen in natural gas

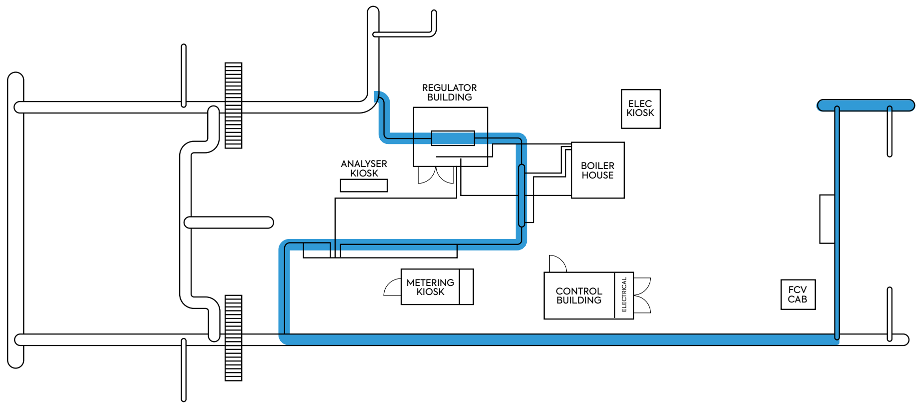
The last blend is 20% hydrogen with 80% natural gas. This has been chosen because it represents the highest level of blending that existing consumer appliances can handle without modification. This may dictate the maximum blend compatible with the NTS without needing modification.

100% Hydrogen

The final test will use flows of 100% hydrogen. When we repurpose our network to 100% hydrogen these results will further our understanding of working with hydrogen and how it interacts with our assets. This will enable the development of appropriate processes, procedures, and safety standards, which are required to operate our network safely.

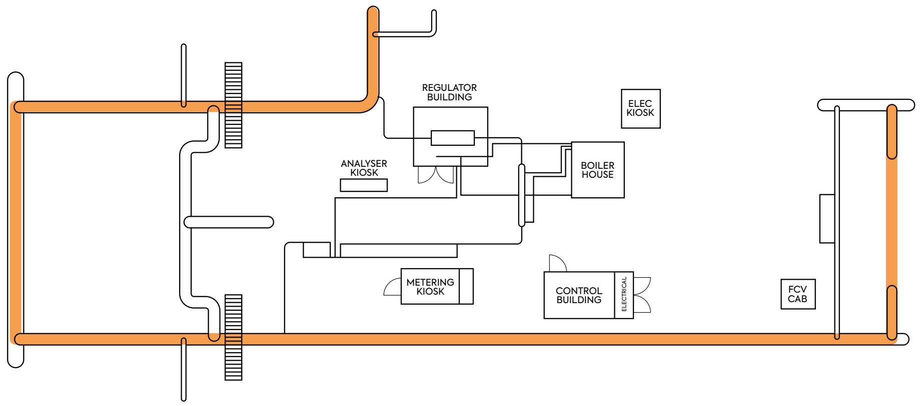
Low flow rate

Flow 1 – 0.12mSCm/day
Flow 2 – 0.24mSCm/day
Flow 3 – 0.36mSCm/day



High flow rate

Flow 4 – 0.36mSCm/day
Flow 5 – 0.82mSCm/day
Flow 6 – 1.28mSCm/day
Flow 7 – 1.74mSCm/day



Testing Summary

Testing was successfully completed on the FutureGrid Flow Loop in February 2024. All gas compositions were tested as per the test programme, as well as additional tests which had been identified as opportunities for additional data collection.

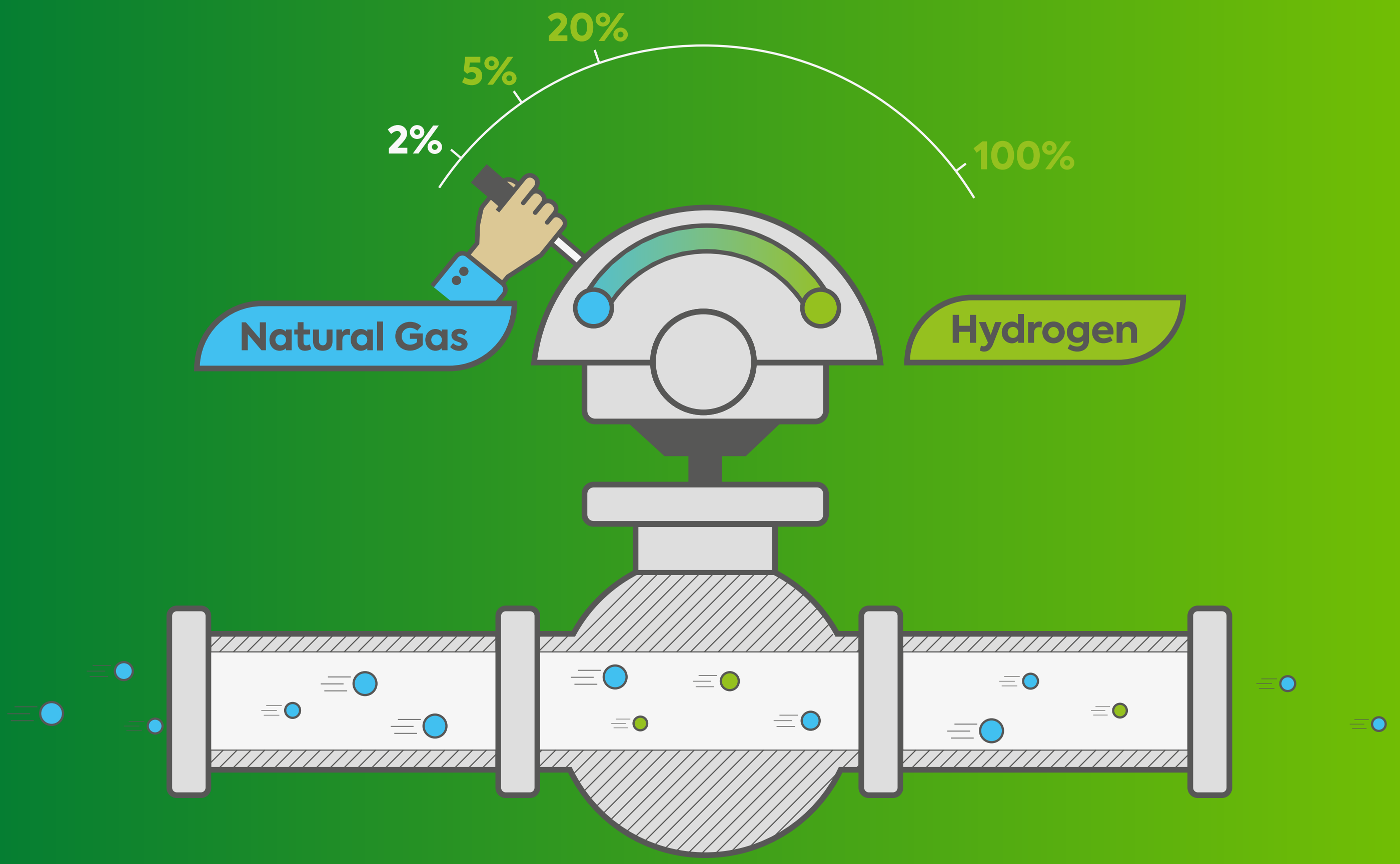
Performance testing considered the operation of ball valves, flow control valves, regulators, and filters. The performance of different types of flow meter was also investigated, and a gas chromatograph for gas quality. Venting operations have also been carried out, and a vibration survey of the facility has been undertaken.

Testing undertaken on the FutureGrid flow facility successfully demonstrated the capability of existing ex-service natural gas transmission infrastructure to safely transport hydrogen. Most of the assets performed broadly as expected, and testing was successfully completed across all gas compositions.

The following sections provide a summary of the findings, with more detail in the Deliverables Section 3.1, 3.2, 3.3 and 4.1.

Ofgem Deliverable 3.1

Testing 2% hydrogen



Ofgem Deliverable 3.1

Testing 2% hydrogen

Deliverable date:	**January 2024** (Original bid date: October 2022)
Evidence required:	• Completion of the 2% hydrogen flow test as detailed in the Master Test Plan, including launch and close-out events. **Completed** • Identification of future test requirements as a result of the findings. **Completed** • Results collated, documented and validated for impact on next phases of hydrogen development activities. **Completed**
Key summary:	• The FutureGrid flow facility achieved the original objective set by National Gas to test key ex-service assets that are representative of the gas transmission system, using a hydrogen gas blend of 2% under a range of different flow conditions. • The gas chromatograph operated well and provided consistent gas analysis data to support the overall field trials at 2% hydrogen blend. • There was no observable difference in flow rate measured between the FLEXIM ultrasonic clamp-on pipe meter, SICK (CloCC-A and CloCC-B) ultrasonic meters and Daniel orifice plate meter when tested using natural gas, or a 2% blend. • There was no noticeable difference in valve operation and associated noise for 2% blend compared to the natural gas baseline. • There was no noticeable difference in the opening and closing time of the flow control values when testing for 2% compared to the natural gas baseline. • At this stage of the test programme, significant changes in noise levels emitted by venting operations caused by the 2% blend have not been observed. This has been concluded on the basis that the changes in noise levels recorded so far are caused by changes in propagation conditions.

For repurposed electrical, instrumentation and mechanical assets, the main aim of the testing was to gain all evidence determining the relationship of the 2% hydrogen blend with repurposed assets that have already seen many years of natural gas service. The evidence required includes, researching:

- Any changes to the operations of the two flow control valves situated on the FutureGrid site, specifically open and close times of the valves and any changes in power gas control. The process contains one 18" Mokveld flow control valve from the ex-Enron Billingham ICI Above Ground Installation site and one 8" Neles control valve, from the ex-Sellafield site.
- How 2% hydrogen interacts with pressure reduction equipment, this was carried out using the ex-Hays Chemicals pressure reduction skid. The skid comprises of two Pietro Fiorentini pilot-controlled regulators with incorporated slam-shut overpressure protection devices, two further pilot-controlled pressure reducing regulators and two pressure relief valves to protect against overpressures.

For evidence, maintenance activities including inspections to be conducted as per policies and procedures carried out by trained and competent personnel as determined by DNV and the original equipment manufacturers' instructions. This includes testing of all equipment. Testing includes equipment response times, testing for gas leakage, ensuring consistent equipment control accuracy, and determining safety device pressure variations from predetermined set points. This was to ensure no changes occur to what is deemed as acceptably safe on the transmission network today.

- For evidence of boiler operation, maintenance, inspections and reviewing operating procedures as determined by National Gas and the original equipment manufacturer. This includes testing all equipment, ascertaining response times, checking for gas leakage, checking for increased levels of hydrocarbons, ensuring accurate and precise pressure control and checking to ensure safety device pressure variations are still within acceptable tolerances as found today on the natural gas transmission system. The aim of the evidence obtained will be used to closely analyse differences in gas consumption, thermal efficiency, and any concerns with any newly found or existing defects, through conditions such as existing internal corrosion and the effects that hydrogen may have. Standard service checks consisting of the pilot light, inspection of the boiler flue, checking for correct gas pressure and gas flow, ensuring all electrical controls remain unchanged between natural gas and operating with a 2% hydrogen blend.
- How effective mechanical isolation valves that are commonly found on our network are, at sealing 2% blends. This is done through a mixture of Cameron ball valves, Robert Cort ball valves, Audco plug valves and small bore Oliver valves that make up the main majority of the valves within the process. Evidence including to check the sealing capability of the valves seats with the additional 2% blend of hydrogen, as per National Gas' procedures and original equipment manufacturers' instructions. Noise assessments were undertaken to determine if there were any noticeable increases in decibels when venting sections of pipeline or ball valve cavities.
- Changes to behaviour of high-pressure vessels, filter strainer/elements which are used to protect downstream equipment from contaminants within the pipeline. Analysing for changes in differential pressures at different flows, and the effects of hydrogen on the filter housings and elements.

The FutureGrid flow facility successfully met National Gas' objective of testing critical service assets within the National Transmission System using a 2% hydrogen blend across varying operational conditions. Testing with a 2% hydrogen blend was carried out over 124 days between 6th September 2023 and 7th January 2024. During this period, the weather conditions were mixed; sun, cloud, rain, and the ambient air temperature ranged from 3°C (minimum) to 27°C (maximum). The full set of results for 2% testing is captured in DNV's technical report. Due to the 24/7 running, the re-compressor was not able to be vented for a noise check during the testing. This was moved to after the 5% testing. On completion of the high-flow tests, some issues were encountered with the compressor. These were addressed by the manufacturer but resulted in a 10-week delay to the schedule. Once corrected, the low-flow tests were completed without interruption. Only the outlet and inlet legs of the compressor, and the compressor itself were decommissioned and purged for the duration of the repair work.

2% testing showed that overall there was little deviation from the 100% natural gas baseline, with all meters and instrumentation still working as expected across the test facility. There was a slight decrease in hydrogen content in the gas mixture during the testing as outlined in DNV's report, due to the inability to achieve ideal mixing to form a homogeneous mixture at injection.

At the start of the 2% hydrogen blend testing period (6th September 2023) the gas comprised 2.29% hydrogen, 92.55% methane, 4.59% ethane and 0.36% propane. The hydrocarbon measurements are consistent with those from the natural gas test (recognising that the concentrations are lower due to the presence of hydrogen). At the end of the test (7th January 2024) the gas comprised 2.10% hydrogen, 91.48% methane, 5.62% ethane and 0.56% propane. The gas chromatograph was operational throughout the testing period. Management of the hydrogen concentration was undertaken by discrete quantity injection at selected times and then mixing with observation of the hydrogen concentration via the chromatograph throughout. This pulsed approach followed by time to mix the hydrogen and form a homogeneous mixture was undertaken several times to maintain the hydrogen content close to the target concentration. The trend in measured hydrogen content indicates that mixing occurs around the flow loop and that it can be controlled close to the target hydrogen content thus mitigating against any decrease in hydrogen concentration around the loop. Overall, the gas chromatograph operated well and provided consistent gas analysis data to support the overall field trials at 2% hydrogen content.

Mechanical Assets

Operation of the flow control valves did not significantly change when operated with a 2% hydrogen blend, and no changes were necessary to any of the equipment proving control, as the process gas to power the valve operated as it would for natural gas when using a 2% blend.

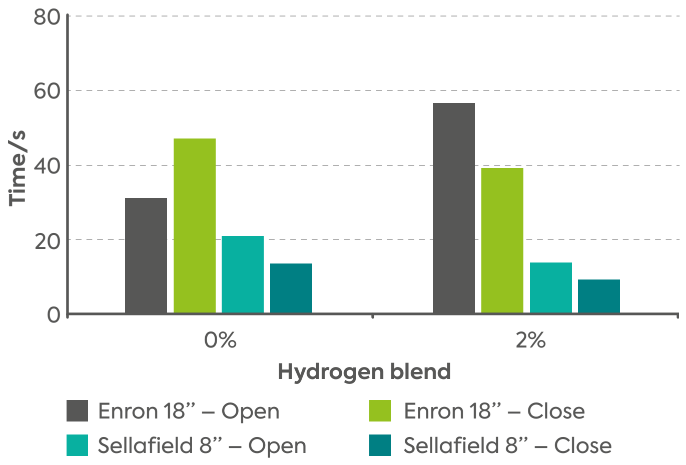


Figure 1: Flow control valves opening and closing times: comparison of natural gas and 2% hydrogen.

As part of the pressure reduction testing for the low-flow loop, where tests were conducted at flows of <0.36 mSCm/day (15000SCM/hour), this was conducted through the ex-Hays Chemicals pressure reduction skid. Upon testing, no changes from natural gas were observed, and this included carrying out full maintenance and inspection of both the working and standby streams, there were no deviations from the usual operating set points or new defects due to the 2% hydrogen blend.

Fuelling the three commercial boilers which form part of the FutureGrid Phase 1 process, the boilers are used to preheat natural gas providing mitigation for where decreased temperatures will be experienced downstream of natural gas pressure reducing equipment. No changes were noted in any of the assets with a 2% blend, as to what would be seen when operating with natural gas operation.

Regarding isolation ball valves where an acceptable gas-tight seal for isolation was achieved with natural gas, sealing integrity did not change with cavity blow down at a 2% blend of hydrogen and held a very similar gas-tight seal as to what was originally found for natural gas baseline testing. This was also the case for sealant injection points, valve stem seals, captive vented pipeline plugs and also body vent valves. Unfortunately, valve 006 (Robert Cort) did not seal with natural gas due to unknown defects, so testing was not commenced with any blends or 100% hydrogen for this particular valve.

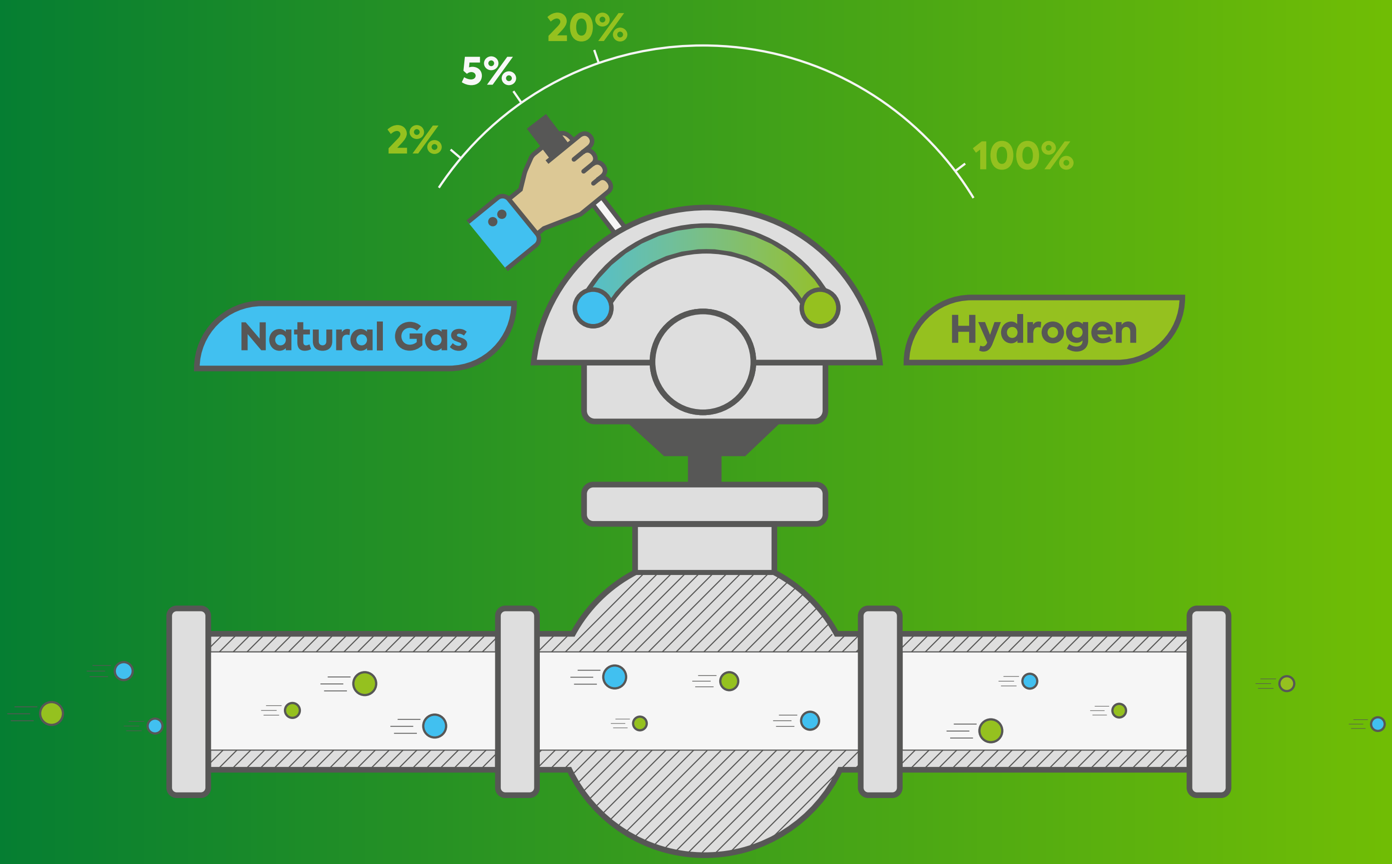
As part of testing, the process was protected by one 18" high-pressure filter, and two smaller quick release filters situated as part of the low-flow loop, no leakage was detected through the band lock or quick release sealing arrangement when using 2% hydrogen. Under high-flow testing, slightly elevated differential pressures were recorded with 2% hydrogen but were not a cause for concern.

Vibration surveys of the facility have been undertaken. The vibration studies carried out were not sufficient to conclude whether hydrogen addition will have an impact on pipework vibration on the transmission system. No discernible differences were noted in flow-induced vibration measurements between natural gas and 100% hydrogen operation, due to the dominance of the mechanical excitation associated with operation of the compressor. It was also noted that the flow rates on the facility were low, and not truly representative of the flow rates on the transmission system. Increased flow rates that are more representative of the transmission system will be achievable in the FutureGrid Phase 2 compression project, which is due to be operational during 2025. Consideration should be given to carrying out a detailed vibration study as part of that testing scope.

All pressure reduction components continued to function as previously. The regulators controlled pressure within typical operating limits, slamshuts fired at pressures consistent with their set pressures and the pressure reduction system saw no change in operation.

Ofgem Deliverable 3.2

Testing 5% hydrogen



Ofgem Deliverable 3.2

Testing 5% hydrogen

Deliverable date:	**11th-21st January 2024** (Original bid date: N/A)
Evidence required:	• Completion of the 5% hydrogen flow test as detailed in the Master Test Plan, including launch and close-out events. **Completed** • Identification of future test requirements as a result of the findings. **Completed** • Results collated, documented and validated for impact on next phases of hydrogen development activities. **Completed**
Key summary:	• The FutureGrid facility successfully maintained consistent operational performance across a range of conditions during the 5% hydrogen blend testing, meeting the evidence criteria set for the programme. • The gas chromatographs maintained accurate gas analysis throughout the test and valve operations during the testing did not show any deviations from the natural gas baseline, confirming reliability under hydrogen blends. • There was no noticeable difference in flow rates measure by the ultrasonic and orifice plate meters. • There was no noticeable difference in the opening closing time of the flow control values when testing for 5% compared to the natural gas baseline. • At this stage of the test programme, significant changes in noise levels emitted by venting operations caused by the 5% blend have not been observed. This has been concluded on the basis that the changes in noise levels recorded so far are caused by changes in propagation conditions.

For repurposed electrical, instrumentation and mechanical assets, the main aim of the testing was to gain all evidence determining the relationship of the 5% hydrogen blend with repurposed assets that have already seen many years of natural gas service. The evidence required includes researching:

- Any changes to the operations of the two flow control valves situated on the FutureGrid site, specifically open and close times of the valves and any changes in power gas control. The process contains one 18" Mokveld flow control valve from the ex-Enron Billingham ICI Above Ground Installation site and one 8" Neles control valve, from the ex-Sellafield site.
- How 5% hydrogen interacts with pressure reduction equipment, this was carried out using the ex-Hays Chemicals pressure reduction skid. The skid comprises of two Pietro Fiorentini pilot-controlled regulators with incorporated slam-shut overpressure protection devices, two further pilot-controlled pressure-reducing regulators and two pressure relief valves to protect against over-pressures.
- For evidence, maintenance activities including inspections to be conducted as per policies and procedures carried out by trained and competent personnel as determined by DNV and the original equipment manufacturers' instructions. This includes testing of all equipment. Testing includes equipment response times, testing for gas leakage, ensuring consistent equipment control accuracy, and determining safety device pressure variations from predetermined set points. This is to ensure no changes as to what is deemed as acceptably safe on the transmission network today.

- For evidence of boiler operation, maintenance, inspections and reviewing operating procedures as determined by National Gas and the original equipment manufacturer. This includes testing all equipment, ascertaining response times, checking for gas leakage, checking for increased levels of hydrocarbons, ensuring accurate and precise pressure control and checking to ensure safety device pressure variations are still within acceptable tolerances as found today on the natural gas transmission system. The aim of the evidence obtained will be used to closely analyse differences in gas consumption, thermal efficiency, and any concerns with any newly found or existing defects, through conditions such as existing internal corrosion and the effects that hydrogen may have. Standard service checks consist of inspecting the pilot light and the boiler flue, checking for correct gas pressure and gas flow, ensuring all electrical controls remain unchanged between natural gas and operating with a 5% hydrogen blend.
- How effective at sealing 5% blends the mechanical isolation valves are that are commonly found on our network. This is done through a mixture of Cameron ball valves, Robert Cort ball valves, Audco plug valves and small bore Oliver valves that make up the main majority of the valves within the process. Evidence including to check the sealing capability of the valves seats with the additional 5% blend of hydrogen, as per National Gas' procedures and original equipment manufacturers' instructions. Noise assessments are also to be undertaken to determine if there are any noticeable increases in decibels when venting sections of pipeline or ball valve cavities from the baseline data.
- Changes to behaviour of high-pressure vessels, filter strainer/elements which are used to protect downstream equipment from contaminants within the pipeline. Analysing changes in differential pressures at different flows, and the effects of hydrogen on the filter housings and elements.
- Vibration analysis to be undertaken for operating with natural gas and 100% hydrogen.

Through collaborations with European partners, the FutureGrid team kept a watchful eye on policy developments in Europe which could impact the use of hydrogen on the continent and, by extension, the UK through our two gas interconnectors. In a recent policy paper draft, the European Commission suggested that a readiness for the acceptance of 5% hydrogen by volume could be the first step for European transmission network operators in a transition to hydrogen. This would mean that gas entering the National Transmission System (NTS) through the interconnector could have up to 5% hydrogen blended with natural gas.

The FutureGrid team liaised with Ofgem in November 2022, and it was decided that the 5% project would be set up as a separate NIA project with its own deliverables and funding mechanisms. However, in order to take full advantage of cost and time savings, the 5% testing is incorporated within the FutureGrid test plan. The NIA project was sanctioned on November 2022. It is estimated that it will provide a consumer cost saving of £470,000, and will also save 1 month to the project. The project has been divided into the follow four deliverables:

NIA Deliverable 1 – Test plan review and sign-off – 12th December 2023 to 13th February 2024.

NIA Deliverable 2 – Asset preparation and 5% hydrogen 95% natural gas fill of high-pressure reservoir – 8th to 9th January 2024.

NIA Deliverable 3 (also known as NIC Deliverable 3.2) – 5% hydrogen blend test on the facility – 10th to 18th February. GO/NO GO decision point for the test facility to progress to 20% test 18th to 19th February 2024.

NIA Deliverable 4 – Data analysis and review for 2% and 5% hydrogen including report – 9th January 2024 to 28th February 2024.

Testing with a 5% hydrogen blend was carried out over 124 days between 6th September 2023 and 7th January 2024. During this period, the weather conditions were mixed; sun, cloud, rain, and the ambient air temperature ranged from 3°C (minimum) to 27°C (maximum).

The addition of hydrogen to achieve the target composition of 5% was performed after the tests on 2% hydrogen and the experience gathered through that process. The hydrogen concentration follows a similar pattern to the trends at 2% and the hydrogen measurements in natural gas appear to be repeatable. Overall, the gas chromatograph operated well and provided consistent gas analysis data to support the overall field trials at 5% hydrogen content. Management of the hydrogen content is achieved through repeated small injections, and these appear as spikes in the charts. The results highlight that the hydrogen is not fully mixed at the injection point but becomes more homogeneous as the flow continues around the loop. Consistency in performance was verified, with the gas chromatograph providing reliable gas analysis data throughout the testing programme.

Moreover, comparative studies compared to the natural gas baseline indicated no discernible differences in flow rates between FLEXIM ultrasonic clamp-on pipe meters, SICK ultrasonic meters, and Daniel orifice plate meters, irrespective of whether natural gas or 5% hydrogen blend was used.

Similarly, valve operations and the associated noise levels maintained a parity with the natural gas baseline, including response times of flow control valves. Lastly, no significant deviations in noise emissions during venting operations were attributed to the 5% hydrogen blend, suggesting that any changes observed were due to variations in propagation conditions rather than the blend itself.

Mechanical Assets

Operation of the flow control valves did not significantly change when operated with a 5% hydrogen blend, and no changes were necessary to any of the equipment proving control, as the process gas to power the valve operated as it would for natural gas when using a 5% blend.

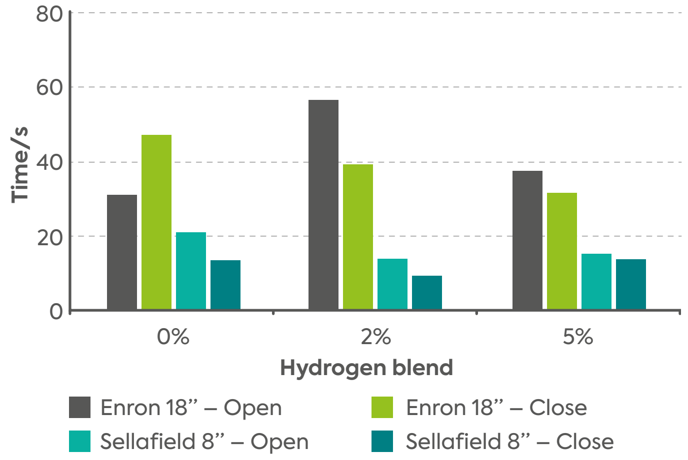


Figure 2: Flow control valves opening and closing times: comparison of natural gas and 2% and 5% hydrogen.

As part of the pressure reduction testing for the low-flow loop, where tests were conducted at flows of <0.36 mSCm/day (15000SCM/hour), this was conducted through the ex-Hays Chemicals pressure reduction skid, and upon testing, no changes from natural gas were observed. This included carrying out full maintenance and inspection of both the working and standby streams, and there were no deviations from usual operating set points or new defects due to the 5% hydrogen blend.

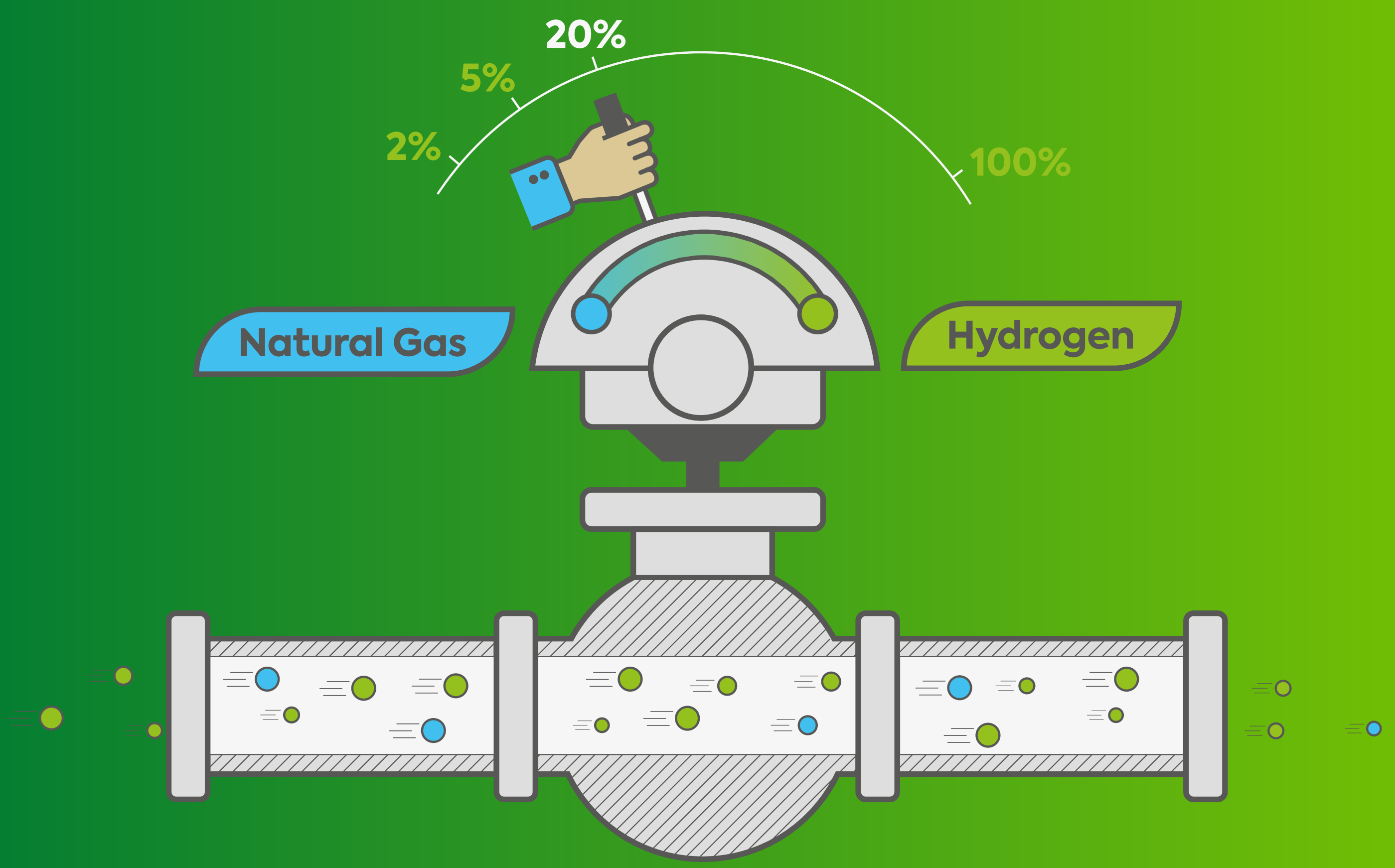
Fuelling the three commercial boilers which form part of the FutureGrid Phase 1 process, the boilers are used to preheat natural gas providing mitigation for where decreased temperatures will be experienced downstream of natural gas pressure reducing equipment. No changes were noted in any of the assets with a 5% blend, as to what would be seen when operating with natural gas operation.

Regarding isolation ball valves where an acceptable gas-tight seal for isolation was achieved with natural gas, sealing integrity did not change with cavity blowdown at a 5% blend of hydrogen and held a very similar gas-tight seal as to what was originally found for natural gas baseline testing. This was also the case for sealant injection points, valve stem seals, captive vented pipeline plugs and also body vent valves. Unfortunately, valve 006 (Robert Cort) did not seal with natural gas due to unknown defects, so testing was not commenced with any blends or 100% hydrogen for this particular valve.

All pressure reduction components continued to function as previously. The regulators controlled pressure within typical operating limits, slamshuts fired at pressures consistent with their set pressures and the pressure reduction system saw no change in operation.

Ofgem Deliverable 3.3

Testing 20% hydrogen



Ofgem Deliverable 3.3

Testing 20% hydrogen

Deliverable date:	**8th-16th February 2024** (Original bid date: October 2022)
Evidence required:	• Completion of the 20% hydrogen flow test as detailed in the Master Test Plan, including launch and close-out events. **Completed** • Identification of future test requirements as a result of the findings. **Completed** • Results collated, documented and validated for impact on next phases of hydrogen development activities. **Completed**
Key summary:	• The FutureGrid facility successfully maintained consistent operational performance across a range of conditions during the 20% hydrogen blend testing, meeting the evidence criteria set for the programme. • The gas chromatographs maintained accurate gas analysis throughout the test and valve operations during the testing did not show any deviations from the natural gas baseline, confirming reliability under hydrogen blends. • There was no noticeable difference in flow rates measure by the ultrasonic and orifice plate meters. • There was no noticeable difference in the opening closing time of the flow control values when testing for 20% compared to the natural gas baseline. • At this stage of the test programme, significant changes in noise levels emitted by venting operations caused by the 20% blend have not been observed. This has been concluded on the basis that the changes in noise levels recorded so far are caused by changes in propagation conditions.

This is the highest hydrogen blend we expect to see on the NTS and is expected to require little modification. This is due to most manufacturers rating their equipment to 20% and also the DSEAR regulations change the gas group from IIB to IIC, at this point a lot of electrical equipment would be required to be changed. To achieve net zero we believe this will be the highest blend the network will see and for the longest duration until we move to 100% hydrogen.

For repurposed electrical, instrumentation and mechanical assets, the main aim of the testing was to gain all evidence determining the relationship of the 20% hydrogen blend with repurposed assets, that have already seen many years of natural gas service. The evidence required includes, researching:

- Any changes to the operations of the two flow control valves situated on the FutureGrid site, specifically open and close times of the valves and any changes in power gas control. The process contains one 18" Mokveld flow control valve from the ex-Enron Billingham ICI Above Ground Installation site and one 8" Neles control valve, from the ex-Sellafield site.
- How 20% hydrogen interacts with pressure reduction equipment. This was carried out using the ex-Hays Chemicals pressure reduction skid. The skid comprises of two Pietro Fiorentini pilot-controlled natural gas pressure regulators with incorporated slam-shut overpressure protection devices, two further pilot controlled pressure reducing regulators and two pressure relief valves to protect against overpressures.

- For evidence, maintenance activities including inspections to be conducted as per policies and procedures carried out by trained and competent personnel as determined by DNV and the original equipment manufacturers instructions. This includes testing of all equipment. Testing includes equipment response times, testing for gas leakage, ensuring consistent equipment control accuracy, and determining safety device pressure variations from predetermined set points, this is to ensure no changes as to what is deemed as acceptably safe on the transmission network today.
- For evidence of boiler operation, maintenance, inspections and reviewing operating procedures as determined by National Gas and the original equipment manufacturer. This includes testing all equipment, ascertaining response times, checking for gas leakage, checking for increased levels of hydrocarbons, ensuring accurate and precise pressure control and checking to ensure safety device pressure variations are still within acceptable tolerances as found today on the National Gas Transmission System. The aim of the evidence obtained will be used to closely analyse differences in gas consumption, thermal efficiency, and any concerns with any newly found or existing defects, through conditions such as existing internal corrosion and the effects that hydrogen may have. Standard service checks consisting of the pilot light, inspection of the boiler flue, checking for correct gas pressure and gas flow, ensuring all electrical controls remain unchanged between natural gas and operating with a 20% hydrogen blend. In this test the operation of the boiler was completely unchanged with no increase in failed starts or breakdown faults. No intervention was needed to change the pilot flame or start sequence timing at the start of 20% blend. At 20% this is the maximum amount of hydrogen percentage these existing boilers would ever see due to the DSEAR restrictions and any blend above this boilers would need to be modified. However, at 100% Hydrogen the Joules Thompson effect would be opposite of natural gas and the boilers would not be required at any pressure reduction station.
- How effective mechanical isolation valves that are commonly found on our network are, at sealing 20% blends. This is done through a mixture of Cameron ball valves, Robert Cort ball valves, Audco plug valves and small bore Oliver valves that make up the main majority of the valves within the process. Evidence including to check the sealing capability of the valves seats with the additional 20% blend of hydrogen, as per National Gas' procedures and original equipment manufacturers instructions. Noise assessments also to be undertaken to determine if there are any noticeable increases in decibels when venting sections of pipeline or ball valve cavities.
- Changes to behaviour of high pressure vessels, filter strainer/elements which are used to protect downstream equipment from contaminants within the pipeline. Analysing for changes in differential pressures at different flows, and the effects of hydrogen on the filter housings and elements.

Testing with a 20% hydrogen blend was carried out over 9 days between 8th February and 16th February 2024. While testing during this period, the weather conditions were mixed; sun, cloud, rain and snow, and the ambient air temperature ranged from -1°C (minimum) to 12°C (maximum).

The gas chromatograph was operational throughout the testing period, and the overall performance was good with regular measurements providing quantification of the hydrogen content and supporting the approach to maintain the value close to 20%.

The average volume flow rate measurements specifically for the natural gas, 2%, 5% and 20% hydrogen blend tests there does not appear to be any significant difference in flow measurement from the three meter types utilised. The gas chromatograph was operational throughout the testing period, and the overall performance was good with regular measurements providing quantification of the hydrogen content and supporting the approach to maintain the value close to 20%. The measured hydrogen content for the high flow tests were more stable and consistent than the lower flow test results, perhaps related to the test loop venting that took place in between the high and low flow tests.

The metering in the loop at 20% was fully comparable due to having a new up to 30% hydrogen ready ultrasonic meter that could be compared to a standard natural gas ultrasonic meter and we could see the point the normal meter started to deviate, this did not occur in this test and both meters worked the same showing the same flow rate. This finding does not take into consideration of long term exposure to hydrogen on normal meters so further work may be required to consider long term permeation.

Mechanical Assets

Operation of the flow control valves did not change when operated with a 20% hydrogen blend, no changes were necessary to any of the equipment proving control, as the process gas to power the valve operated as it would for natural gas when using a 20% blend.

As part of the pressure reduction testing for the low-flow loop, where tests were conducted at flows of <0.36 mSCm/day (15000SCM/hour) this was conducted through the ex-Hays Chemicals pressure reduction skid. Upon testing no changes from natural gas were observed, this included carrying out full maintenance and inspection of both the working and standby streams, there were no deviations from usual operating set points or new defects due to the 20% hydrogen blend.

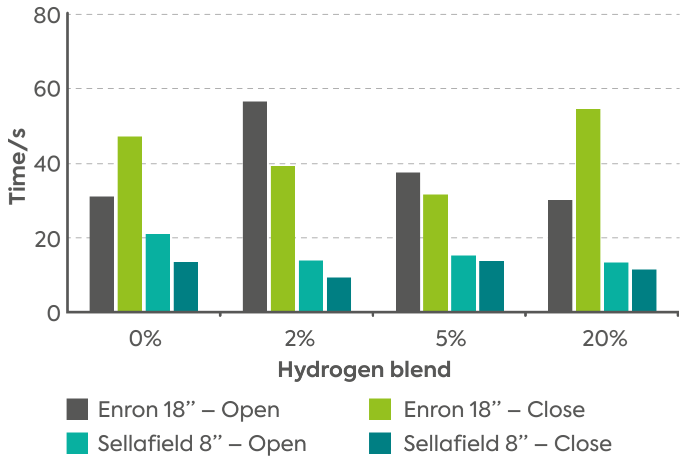


Figure 3: Flow control valves opening and closing times: comparison of natural gas and 2%, 5%, and 20% hydrogen.

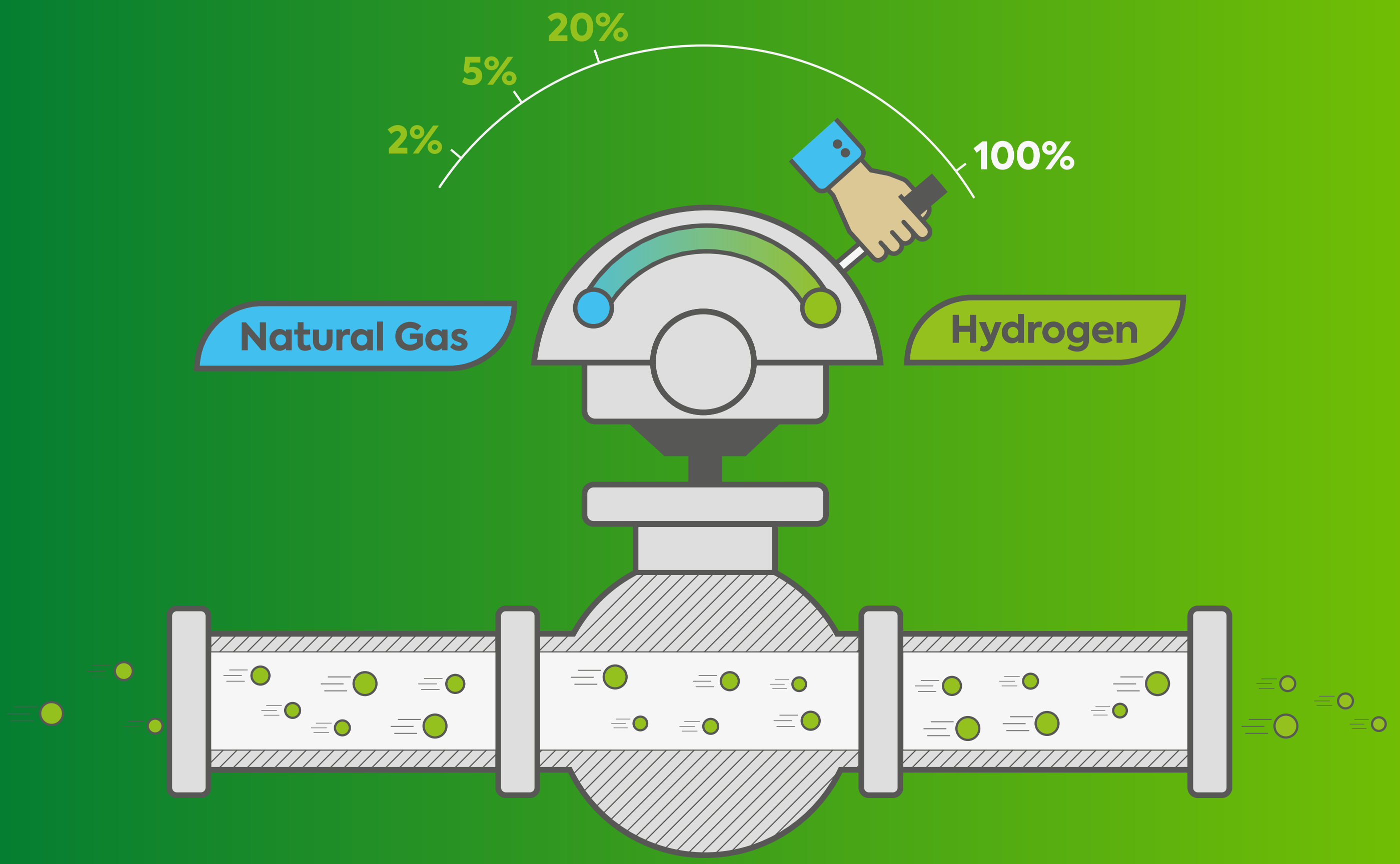
Fuelling the three commercial boilers which form part of the FutureGrid Phase 1 process, the boilers are used to preheat natural gas providing mitigation for where decreased temperatures will be experienced downstream of natural gas pressure reducing equipment. No changes were noted in any of the assets with a 20% blend, as to what would be seen when operating with natural gas operation. The heat load required was slightly reduced for 20% hydrogen.

Regarding isolation ball valves where an acceptable gas tight seal for isolation was achieved with natural gas, sealing integrity did not change with cavity blow down at a 20% blend of hydrogen and held a very similar gas tight seal as to what was originally found for natural gas baseline testing. This was also the case for sealant injection points, valve stem seals, captive vented pipeline plugs and also body vent valves. Unfortunately valve 006 (Robert Cort) did not seal with natural gas due to unknown defects, so testing was not commenced with any blends or 100% hydrogen for this particular valve. No real change in qualitative noise assessment using Dines Scale was noted from baseline data when using 20% hydrogen blend, as per T/PR/MAINT/5032 for measuring venting noise levels, it was similar to 5%.

All pressure reduction components continued to function as previously. The regulators controlled pressure within typical operating limits, slamshuts fired at pressures consistent with their set pressures and the pressure reduction system saw no change in operation.

Ofgem Deliverable 4.1

Testing 100% hydrogen



Ofgem Deliverable 4.1	
Testing 100% hydrogen	
Deliverable date:	**22nd-29th February 2024** (Original bid date: February 2023)
Status	Completed
Evidence required:	• Completion of the 100% hydrogen flow test as detailed in the Master Test Plan, including launch and close-out events. **Completed** • Identification of future test requirements as a result of the findings. **Completed** • Results collated, documented and validated for impact on next phases of hydrogen development activities. **Completed**
Key summary:	• Certain flow devices were not compatible with 100% hydrogen, so flow was only measured using the FLEXIM USM and the orifice plate. • During the testing period, shorter operation of the gas chromatograph provided measured hydrogen content over 99%; however, longer operation led to sample failures highlighting incompatibility with 100% hydrogen. • Assumptions made in respect to how hydrogen can affect cooling and influence pressure drop were validated and confirmed that pre-heat is not required for 100% hydrogen. • Hydrogen flux testing showed no detectable hydrogen permeation through the pipelines. • Noise levels increased during venting operations attributed to hydrogen handling, yet vibration impacts were deemed minimal and not a direct consequence of hydrogen properties. • Safety devices such as slam-shuts were shown to continue to operate as required.

For repurposed electrical, instrumentation and mechanical assets the main aim of the testing was to gain all evidence determining the relationship of the 100% hydrogen blend with repurposed assets that have already seen many years of natural gas service. The evidence required includes, researching:

- Any changes to the operations of the two flow control valves situated on the FutureGrid site, specifically open and close times of the valves and any changes in power gas control. The process contains one 18" Mokveld flow control valve from the ex-Enron Billingham ICI above ground installation site and one 8" Neles control valve, from the ex-Sellafield site.
- How 100% hydrogen interacts with pressure reduction equipment, this was carried out using the ex-Hays Chemicals pressure reduction skid. The skid comprises of two Pietro Fiorentini pilot controlled natural gas pressure regulators with incorporated slam-shut overpressure protection devices, two further pilot-controlled pressure-reducing regulators and two pressure relief valves to protect against overpressures.

For evidence, maintenance activities including inspections to be conducted as per policies and procedures carried out by trained and competent personnel as determined by DNV and the original equipment manufacturers' instructions. This includes testing of all equipment. Testing includes equipment response times, testing for gas leakage, ensuring consistent equipment control accuracy, and determining safety device pressure variations from predetermined set points. This is to ensure no changes as to what is deemed as acceptably safe on the transmission network today.

- Vibration assessments carried out to ensure increased levels are not observed when operating with natural gas, or 100% hydrogen, which may affect pipeline integrity.

Testing with 100% hydrogen was carried out over 8 days between 22nd February and 29th February 2024. While testing during this period, the weather conditions were mixed, with sun, cloud and rain, and the ambient air temperature ranged from -2°C (minimum) to 8°C (maximum). For these tests, the Eakring metering skid (CloCC-A and CLoCC-B flow meters) and the Hays boiler house were isolated from the facility as neither were compatible for 100% hydrogen. In addition a specific 100% hydrogen orifice plate was inserted in the same metering stream as used previously.

As mentioned above, the two CLoCC USMs were isolated from the facility as they are not compatible with 100% hydrogen. The flow rate was only measured using the FLEXIM USM and the orifice plate (note, for the 100% hydrogen tests the 32mm diameter orifice plate was used. For 100% hydrogen, the Daniel orifice plate meter and FLEXIM clamp-on meter continued to measure volume flow (the SICK meters were isolated as they were not compatible with 100% hydrogen), although the flow rate measured by the Daniel orifice plate meter was consistently higher than the FLEXIM meter (this is contrary to what was observed during the natural gas and hydrogen blend tests).

The gas chromatograph results for 100% hydrogen were hampered by a sample regulator failure; however, operating the gas chromatograph for short-term measurement during each flow test showed that in most tests, the measured hydrogen content was over 99%.

After 20% testing had completed, the boilers for pre-heat were switched off and isolated from the system as the co-efficient for cooling with pressure drop was assumed to be positive rather than negative, meaning the temperatures may increase when reducing pressure with 100% hydrogen. This was later confirmed through the data analysis.

At the end of the flow tests, hydrogen flux testing was carried out on the 4", 12" and 18" pipework. There was no evidence of hydrogen permeating through the steel and all measurements were 0 pl/cm^2/s at an ambient temperature of 5°C.

Although a trend of increasing noise levels emitted by venting operations caused by increasing hydrogen proportion in gas blends had not been observed, the 100% hydrogen blend did cause higher noise levels to be measured overall, particularly from the main process vent. Vibration measurements were undertaken when testing with 100% natural gas and 100% hydrogen, with no discernible differences in flow-induced vibration. The pressure pulsations from the compressor reduced during the 100% hydrogen testing due to operation at higher compressor running speeds. This reduction was considered to be due to an improved understanding of the operation of the compressor as a result of the observations during the baseline natural gas vibration survey.

There was no noticeable difference in ball valve operation and associated noise when tested using natural gas or hydrogen. The cavity leakage for each valve was quantified as either not audible (0) or just audible (1), according to the Dines Scale in T/PR/MAINT/5032. Attempts were made to measure noise from the faint leaks present, but the measurements were saturated by the surrounding ambient noise levels.

To avoid substantial venting, the GC sampling was active for only a short period of time at the start of each flow test, to confirm the initial hydrogen content, recognising that the hydrogen content should remain reasonably constant once the 100% target condition had been met. The flow test order was F4, F5, F6, F7, F3, F2, F1. The following measurements were made of hydrogen content,

- F4 sampled 22nd February at 09:15 99.09 H2%
- F5 sampled 23rd February at 09:27 99.65 H2%
- F6 sampled 24th February at 17:02 99.73 H2%
- F7 sampled 26th February at 07:54 93.98 H2%
- F3 sampled 27th February at 16:22 99.08 H2%
- F2 sampled 28th February at 06:02 98.89 H2%
- F1 sampled 29th February at 07:38 93.87 H2%

The flow rate measurements were close to target. The FLEXIM clamp-on meter was used as a reference meter. The Orifice plate consistently measured a higher flow rate than the FLEXIM, deviating from the FLEXIM between +1.2% and +4.5%, depending on flow rate. It should be noted that the FLEXIM meter is likely to be the least accurate of all the meters and would be unsuitable as a custody transfer meter at NTS entry or exit points.

Comparison with Natural Gas and 2%, 5% and 20% hydrogen Blend Performance

Vibration:

No changes in vibration characteristics were observed as a result of changing gas composition. However, vibration monitoring during testing was dominated by the excitation of the compressor and therefore further work is recommended to assess the possible effects on vibration. FutureGrid Phase 2 Compression provides a promising opportunity to gather more data in this area.

Compressor speed:

For the 100% hydrogen tests, the compressor was not able to achieve the target flow rate. The compressor was only able to achieve a flow rate of 60,685 SCM/hour [1.46 MSCM/day]. This is less than the maximums achieved for natural gas (68,208 SCM/hour), 2% hydrogen (67,750 SCM/hour), 5% hydrogen (68,500 SCM/hour) and 20% hydrogen (68,958 SCM/hour). However, this trend is consistent with the specification for the compressor; the maximum flow rate for 100% hydrogen would be less than that for natural gas.

Gas quality and composition:

No key observations for comparison with the natural gas and hydrogen blend tests due to the analysis approach being altered for the 100% hydrogen tests.

Ball valves tests:

No real change in qualitative noise assessment using Dines Scale, per T/PR/MAINT/5032

Flow control valve tests:

The opening and closing times for the 8" Sellafield FCV and the 18" Enron FCV were tested with 100% hydrogen. Compared to natural gas, the opening and closing times for the 8" Sellafield FCV reduce with the addition of hydrogen but remains a constant as the % hydrogen increases. The closing time is shorter than the opening time. It was not possible to test the Sellafield FCV with 100% hydrogen but this will be addressed as part of future facility operations. The opening and closing times for the 18" Enron FCV are longer than the Sellafield FCV. The opening time is longest for 2% hydrogen, reducing with increasing hydrogen to 100%. The opening time for natural gas is similar to that for 20% hydrogen. There is no clear trend of the effect of hydrogen on the closing time. For hydrogen blends up to 5% the closing time was seen to reduce with increasing hydrogen. However, the closing time at 20% hydrogen was approximately 7s longer than for natural gas. The closing time for 100% hydrogen was the shortest

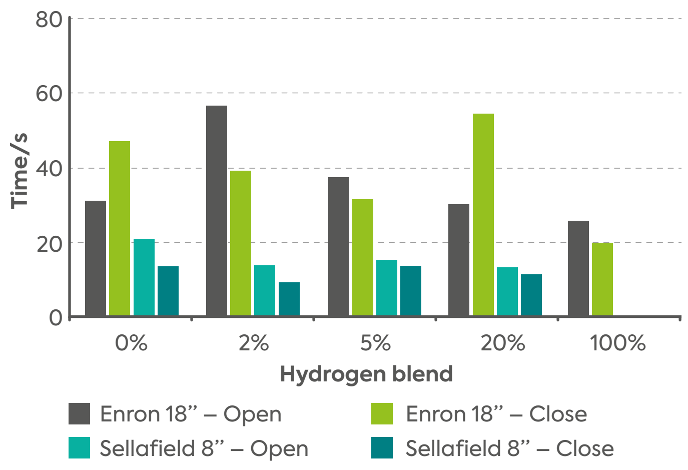


Figure 4: Flow control valves opening and closing times: comparison of natural gas and 2%, 5%, 20% and 100% hydrogen.

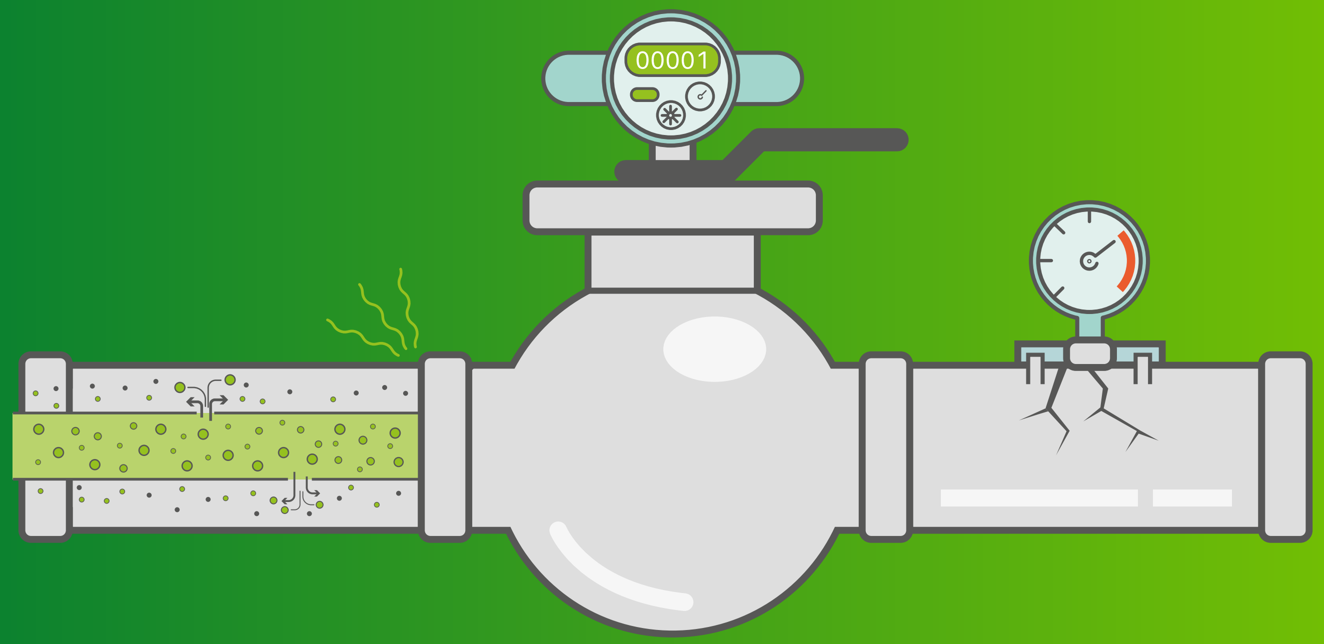
Flow rate measurement:

The average volume flow rate measurements were compared between natural gas, 2%, 5% and 20% hydrogen blend tests. There does not appear to be any significant difference in flow measurement from the three meter types. It is acknowledged that the average flow rate measured during flow 2 for the 2% hydrogen blend tests show a notable reduction from the two CLoCC USMs and the orifice plate, compared to the FLEXIM, but this is inconsistent with the other test results. In general, the lowest flow rate was measured by the Orifice plate. However, the opposite was observed for 100% hydrogen; the highest flow rate was measured by the Orifice plate for each flow rate. Unfortunately, due to the incompatibility of the CLoCC USMs with 100% hydrogen, they were isolated from the flow facility for the 100% hydrogen tests.

All pressure reduction components continued to function as previously. The regulators controlled pressure within typical operating limits, slamshuts fired at pressures consistent with their set pressures and the pressure reduction system saw no change in operation.

Ofgem Deliverable 4.2

100% hydrogen fatigue testing



Ofgem Deliverable 4.2	
100% hydrogen fatigue testing	
Deliverable date:	**February 2024** (Original bid date: April 2023)
Status	Ongoing
Evidence required:	• Completion of fabrication and hydrostatic pressure test of the standalone fatigue test module using a selection of pipeline welding procedures. **Completed** • Commence pressurising the test module with hydrogen and hold at pressure to enable permeation of the hydrogen into the pipe wall. Begin the pressure cycling of the test module. **Completed** • Completion of the required number of pressure cycles and completion of the test. **To be completed Q4 2024** • Results collated, documented and validated for impact on next phases of hydrogen development activities. **Completed for Interim Report** • Identification of future test requirements as a result of the findings. **To be completed following full pressure cycling**
Latest update summary:	• A test facility was fabricated to investigate the effects of hydrogen and fatigue on a selection of welds currently in use in the gas network. The test facility has completed 30,000 cycles as of 15th March 2024 which is twice the lifecycle of a 36" pipeline using a cycle stress of 125 N/mm2. • The current test plan estimates that the remaining cycles will be completed by November 2024 at 75,000 cycles. Due to the substantial quantity of data obtained, representative 1-hour sections of data have been analysed at 5,000-cycle milestones to ensure that the pipe is experiencing stress ranges in the region of 125 N/mm2 throughout the test. This has been shown at each milestone from 5,000 to 30,000 cycles by the conformity of measured hoop strain to theoretically predict strain corresponding to the desired stress range. • Although only representative sections of the data have been subject to in-depth analysis, all data from 0 to 30,000 cycles is present, with the cumulative cycle count from the recorded data matching that shown on the system display screen to within 3%. • One defect has been detected on a single weld which will require monitoring during the remaining test cycles and investigation after completion of the test programme to determine the cause of the defect and if hydrogen has had any detrimental effects. However, it has been determined to be a construction defect and not a result of hydrogen fatigue.

Test Arrangement

The fatigue testing was conducted on a specially designed 36" pipeline fatigue facility at DNV's Spadeadam Engineering Centre. The facility replicated the stress conditions seen in service by subjecting full-size pipeline specimens to pressure cycling with hydrogen. The test used a 125 N/mm² hoop stress range, adhering to IGEM/TD/1 Edition 5 standards. Various weld procedures from the last five decades were selected and inspected using radiography, ultrasonic, and magnetic particle inspections to meet BS4515 and National Gas P2 standards. The system was initially purged with nitrogen and then filled with hydrogen of 99.99% purity. To ensure the material was adequately saturated with hydrogen, a 10-day soak at 45 barg was implemented to achieve near-maximum hydrogen concentration at 1 mm depth.

Results

Over 30,000 pressure cycles have been completed to date, with the testing aimed at reaching 75,000 cycles by November. Throughout the initial 30,000 cycles, the data showed consistent stress ranges around 125 N/mm², aligning with theoretical predictions. Strain data, collected at 5,000-cycle milestones, confirmed that the pipe was experiencing the expected stress conditions. Despite one detected defect in a weld, which will require ongoing monitoring, the integrity of the pipeline materials, welds, and fittings was maintained. The defect, found on a fitting-to-fitting weld, may have resulted from misalignment rather than fatigue. Non-destructive testing (NDT) was conducted before and during the test programme, including radiography, magnetic particle inspection (MPI), and ultrasonic testing (UT). These inspections verified the welds' integrity, and subsequent inspections at 15,000 and 30,000 cycles showed no significant changes. Hydrogen flux measurements indicated that any hydrogen permeation through the pipe walls was below detectable levels, ensuring that hydrogen's effects were accurately captured within the designed test parameters.

So far during testing, the results confirm that the fatigue testing setup effectively replicates the stress conditions that pipelines would face in hydrogen service. Initial results up to 30,000 cycles demonstrate that the pipeline materials, welds, and fittings can endure the specified fatigue conditions without notable degradation. The defect found will be closely monitored, and further testing up to 75,000 cycles will provide more comprehensive data on the long-term effects of hydrogen on pipeline integrity. Overall, the test arrangement and results support the readiness of the GB's gas transmission system to safely transport hydrogen.

Ofgem Deliverable 5.0

QRA & Safety Case

Ofgem Deliverable 5.0

QRA & Safety Case

Deliverable date:	**April 2024** (Original bid date: March 2023)
Status	Completed
Evidence required:	• Overpressure testing on secondary offline NTS test facility. **Completed** • Validation of results into existing QRA model and any mitigations reviewed (updated QRA and mitigation log). **Completed** • High-level review of NGGT's policies and procedures documented **Completed** • Prepare a commented version of the safety case. **Completed** • Updated asset assessment and hydrogen risk review. **Completed**
Latest update summary:	The FutureGrid QRA report extensively evaluates the safety and risk scenarios of operating the National Transmission System (NTS) with hydrogen as compared to natural gas. A summarised overview of the findings are below: **QRA process review:** The NTS uses the HATS (Hazardous Assessment of the Transmission System) process to assess risks associated with transporting natural gas through high pressure pipelines. Using information gathered from the rupture tests, this process was replicated for hydrogen to understand any risks and potential mitigations. The assessment showed that hydrogen can be transported through NTS pipelines with risk remaining in the ALARP range. **Safety case review:** National Gas use a comprehensive Safety Case to manage risks on the system. This document was extensively reviewed with recommendations for any changes required with the introduction of hydrogen. 215 comments were made in total with 11 of these falling into the 'high' category suggesting significant impacts on the safety case. **Policies & Procedures review:** National gas' operational document suite is comprised of over 600 policies, procedures and standards which govern day to day operations. This suite was extensively reviewed with the impact of hydrogen and any recommendations clearly noted. It is anticipated that 48% of documents reviewed will require changes to accommodate hydrogen operation. **Hazardous area impact assessment:** Hazardous areas have been identified as an area of significant change when repurposing assets for hydrogen operation. This piece of work assessed the impact of the new SR/25 hydrogen supplement on hazardous areas at two National Gas sites for 20% and 100% hydrogen.

National Gas are taking a comprehensive approach to safely transition the National Transmission System from natural gas to hydrogen. The FutureGrid programme is generating much of the key technical evidence that will form the foundation of our safety management system.

This approach, illustrated through detailed procedural and safety output diagrams (see following pages), encompasses a variety of tests – from rupture and material tests to quantitative risk assessments (QRAs) – designed to validate the integrity and operational safety of the network under diverse conditions.

Key safety outputs are derived from testing different hydrogen concentrations and their impact on existing infrastructure. The safety process follows a structured path: starting with evidence gathering and risk assessments, moving through hazard identification, and culminating in the implementation of strategic mitigation measures and emergency response protocols.

This structured approach ensures that every aspect of network operation is accounted for, from the initial procedure reviews through to operational implementation, which includes updates to the NTS safety case to reflect findings from hydrogen blend testing. This proactive safety strategy not only supports the immediate goals of the FutureGrid project but also sets the stage for future repurposing initiatives, such as potential CCUS (Carbon Capture, Utilisation, and Storage) applications, ensuring that the facility continues to provide value and safety in a decarbonising energy landscape.

The FutureGrid QRA report provides a detailed assessment of the implications of introducing hydrogen into the National Transmission System (NTS), highlighting the similarities and differences in risk profiles compared to natural gas. The report maintains that, while the fundamental failure frequencies are expected to align closely with those observed for natural gas, specific attention must be given to hydrogen's unique properties, especially under high-pressure scenarios.

Hydrogen's potential to cause overpressures from delayed ignition is a significant factor in its overall risk profile. This necessitates the inclusion of both immediate and delayed ignition scenarios in the risk assessments until more conclusive evidence is obtained. The resultant analysis indicates that without mitigation, there could be an increase in risk when transitioning to hydrogen; however, these risks can be effectively managed through comprehensive mitigation strategies, such as operational adjustments, enhanced surveillance, and infrastructure reinforcement. Additional work is ongoing to assess whether delayed ignition is possible in real-world scenarios.

The sensitivity analysis included in the QRA report is particularly crucial, providing insights into how different variables affect the risk outcomes. The possibility of adapting the existing infrastructure to accommodate hydrogen, with adjustments in operational pressures and physical reinforcements, is explored as a viable pathway to maintaining safety within acceptable limits. The mitigation measures analysed – ranging from slabbing to using heavy wall pipes – underscore the feasibility of safely integrating hydrogen into the gas transmission network.

In conclusion, the transition to hydrogen, as detailed by the FutureGrid QRA report, requires rigorous planning and implementation of targeted safety measures. Although the introduction of hydrogen could present increased risks, the report provides a clear roadmap for managing these risks to ensure that the system remains within established safety thresholds. This careful approach ensures that the strategic integration of hydrogen into the NTS not only meets current safety standards but also supports the broader goal of transitioning to a low-carbon energy system.

FutureGrid safety outputs

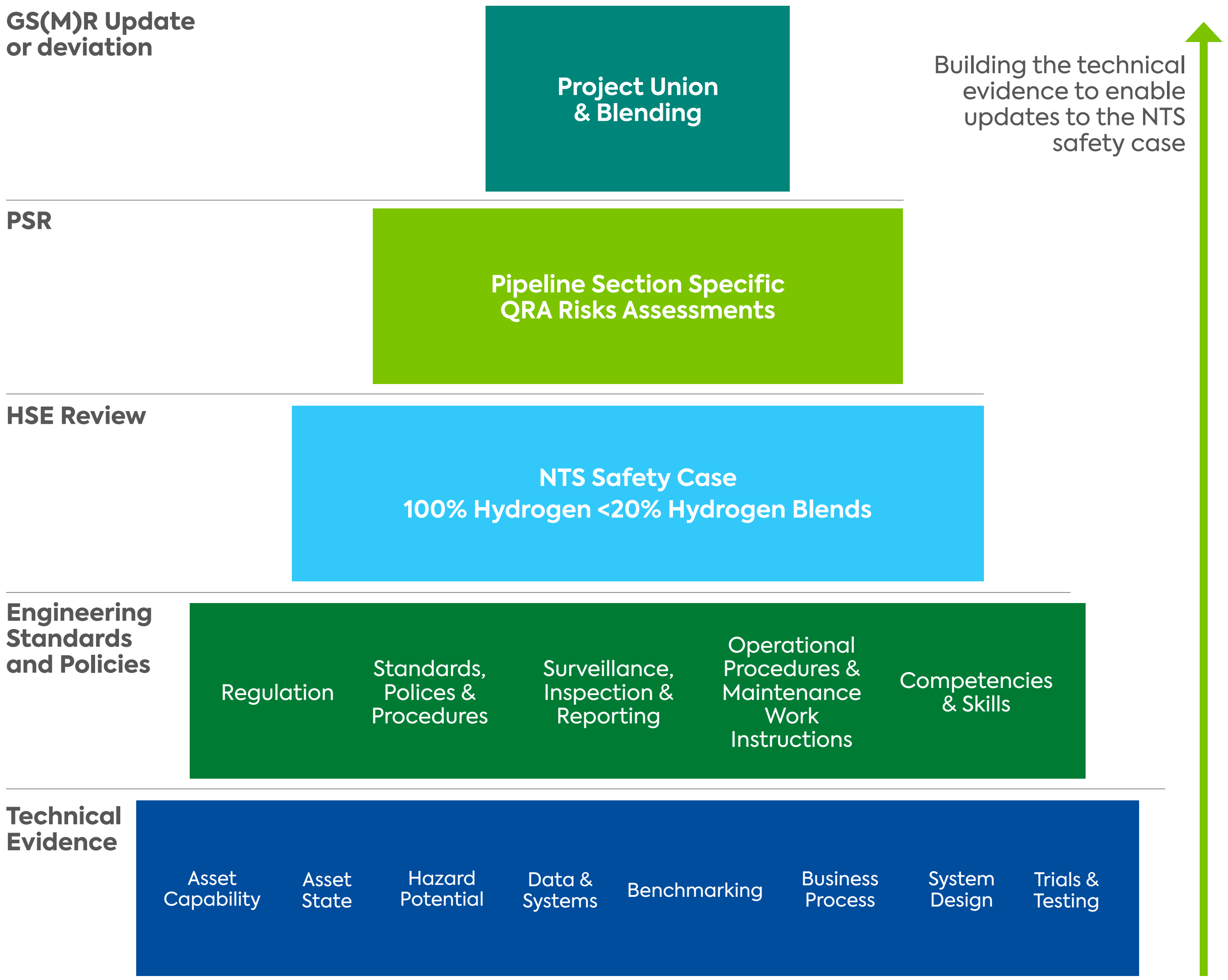
There are many similarities in how hydrogen behaves compared to natural gas, but there are also differences for some key safety parameters. We must be able to understand these in more detail and how the varying concentrations of hydrogen could have an impact. This will allow us to develop our safety standards. FutureGrid supports this with the key outputs from the Phase 1 testing:

Procedures review	Categorisation of NG procedures as high, medium, low impact with a report detailing the methodology findings and next steps for each.
Hazardous assessment of the transmission system (HATS)	Assess impact of hydrogen on (MAPD) Major Accident Prevention Document. Provide an updated HATS for the NTS pipelines, based on the network transporting hydrogen instead of natural gas.
Quantitative risk assessment (QRA)	Record and update the Hazard Assessment Methodology Manual (HAMM) where deviations are required for assets transporting hydrogen.
Hazardous area impact	Hazardous Area Drawings will be produced for each asset type at 20% & 100% hydrogen and compared to existing natural gas drawings. IGEM also working on SR/25 update for hydrogen.
Overpressure risk (OR)	Identify whether the existing methodology can be adapted for 100% hydrogen. If needed, develop an appropriate methodology for risk analysis and emergency planning purposes.
National Gas (NG) Safety case	Review the NG safety case (policies, procedures and work instructions) and provide recommendations for updates depending on the impact of hydrogen. Review will involve SMEs.

Building the hydrogen technical safety case

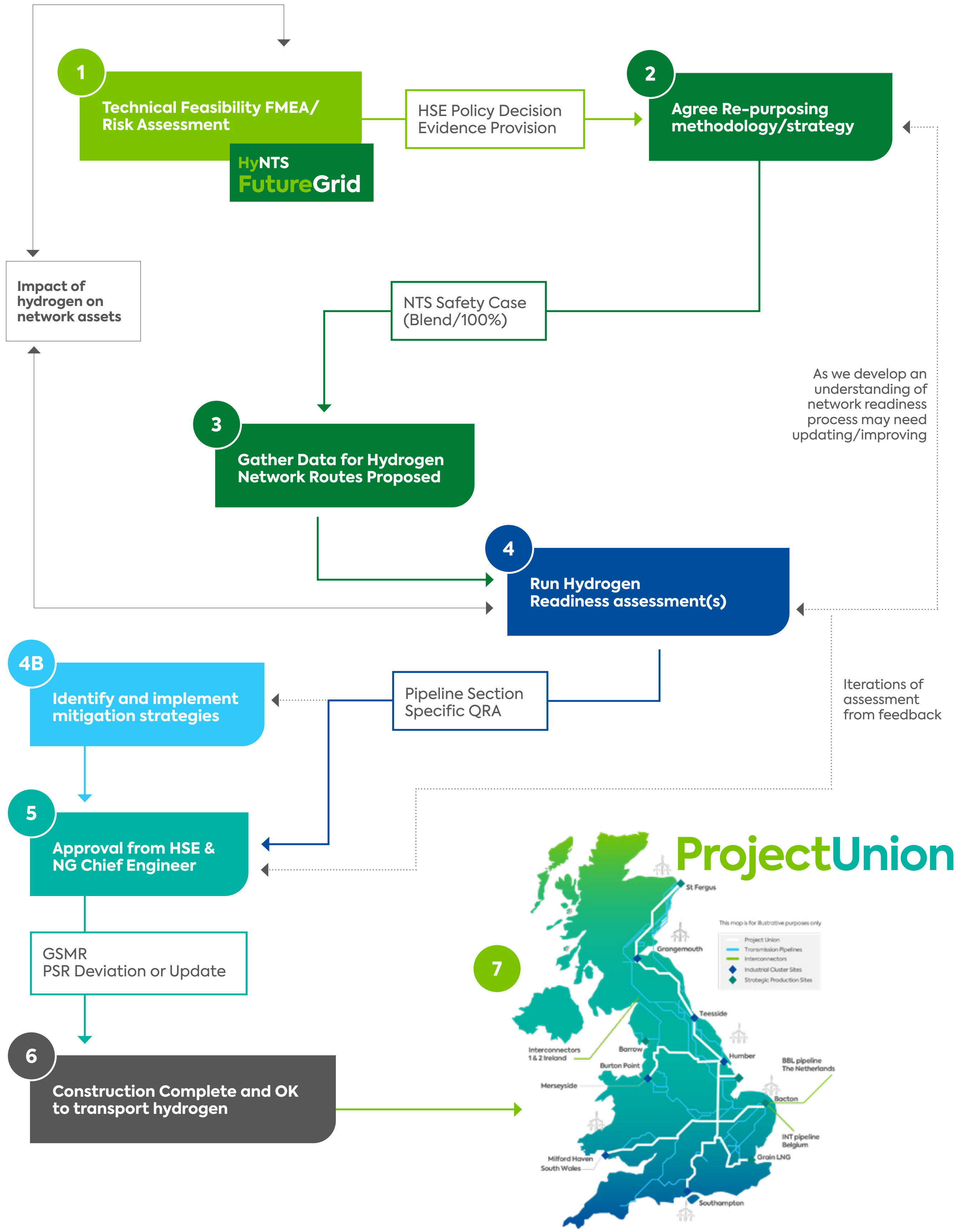
The FutureGrid project has greatly enhanced the understanding of how GB's NTS would operate with hydrogen blends and 100% hydrogen.

FutureGrid forms part of a wide range of innovation projects that play a key part to developing the technical evidence for the transition of the network to hydrogen. As illustrated in the diagram, the foundation of the work we do is building the technical evidence, which in turn drives out the engineering standards and policies that are required. This feeds into the HSE safety review which in turn requires the relevant policy changes to enable hydrogen blends and 100% hydrogen in Project Union across our network.



Our approach to delivering the NTS Safety case

From testing to implementation



Ofgem Deliverable 6.0

Knowledge dissemination

Ofgem Deliverable 6.0

Knowledge dissemination

Deliverable date:	**March 2024** (Original bid date: April 2023)
Status	Ongoing
Evidence required:	As per the dissemination section of this submission, the team will deliver a variety of dissemination activities throughout the project period. These will be completed at regular intervals during the project lifecycle and on closure.
Latest update summary:	This deliverable is in relation to the knowledge shared throughout the project and will be completed when the project is completed. Impacts on deliverable 4.2 have also caused an impact on this deliverable.

From the outset of FutureGrid, we have adopted a 'digital first' approach to engagement and dissemination. We want to be as open and inclusive as possible for stakeholders across the UK and provide collaborative opportunities internationally.

We have challenged ourselves to bring FutureGrid to life for as many people as we can, whether that's through virtual sessions, walkthroughs, digital models, or on-site visits. This approach does not eliminate the need for face-to-face engagement. Instead, it ensures that physical events are digitally supported, utilising live stream technology to allow stakeholders to participate and engage in ways that fit their personal circumstances. This includes presentations, panel discussions, and learning sessions.

This has proven very successful, even with the disruption caused by Covid-19 at the outset of the project. By maintaining our 'digital first' approach, we have ensured continued resilience for our engagement activities, knowledge dissemination, and collaboration.

A key tool for our in-person engagement at exhibitions has been the development of the FutureGrid digital model. It provides an opportunity to showcase the final facility plan using 3D modelling. This allows users to interact and learn more about the specific assets, including what the purpose of the asset is, what testing we will be doing on it and key statistics such as technical specifications, age of the asset and where it was sourced from. The model received excellent feedback, and we plan to continue to develop this to help bring the facility to life for those who can't visit in person.

Throughout the project, we have continually built on the strong foundation we established for engaging with our stakeholders and disseminating information about the project. The success of our mixed media approach on digital platforms has seen us build on our key pillars of engagement that allow us to be accessible to all stakeholders both nationally and internationally.

FutureGrid has become a cornerstone of National Gas' Hydrogen Transition Strategy to help achieve Net Zero 2050. This alongside Project Union and the wider portfolio of innovative projects and initiatives is vital to demonstrate that our network can transport hydrogen safely and to ultimately set out the transition plan for our network. Given the sheer scale and importance of FutureGrid providing a physical demonstration of hydrogen being transported within our high-pressure gas transmission assets, it features highly across our engagement as a business. From Senior Ministers, Government Officials, consumer groups, our customers and stakeholders and the wider general public – our engagement about who we are and what we do features heavily on how we are preparing to help the UK achieve net zero. As a result, in addition to the specific FutureGrid activities we've conducted throughout the project, it is firmly embedded within our engagement and has featured countless times throughout our comprehensive engagement programme.

FutureGrid Engagement

As part of our wider engagement ambitions, we remained focused on the use of a variety of media, allowing stakeholders on both a UK and global scale to engage and interact with the project. We established key pillars of engagement which allowed for our stakeholders to learn about FutureGrid and engage with the team.

FutureGrid Site Tours

Site visits and tours have been pivotal in communicating the importance of FutureGrid in building up evidence that we can safely transport hydrogen across our network. It's been vital to bring this story to life and demonstrate to our stakeholders, senior policy makers and ministers that we are ready to transition our network to hydrogen and are doing all the key things we need to do in order to make this a reality. The facility and the physical demonstration have been invaluable in telling that story and allowing people to understand the magnitude of the challenge that we face, but also to demonstrate that it is in hand.

We have hosted more than 1,000 people on site since the start of the project. This is a phenomenal number supported greatly by our project delivery partners DNV's excellent facilities that allow us to engage with a broad range of stakeholders to share our story. Not only has it been really important to share our story, but it's allowed us to bring the FutureGrid hydrogen programme to life and engage a wide range of experts both internally and externally to gain their expertise and support. The FutureGrid facility has developed thanks to the input of these technical experts, and we now have a facility that can continue to grow, educate, inform and demonstrate the capability of assets in a hydrogen environment. The facility has a significant role to continue playing in the education, demonstration and qualification of assets as we move forward, and is still highly in demand for visits to this day. Pairing the physical and virtual site visits alongside our broad range of digital engagement has generated very positive feedback from our stakeholders.

Over
1000
people have visited the site

FutureGrid Testing Guide

A key output in 2023 was the development of our FutureGrid testing guide. We were clear from the start that this was a vital tool we needed to create in order to allow us to effectively communicate how the testing would operate at the facility and allow our stakeholders to understand more about the FutureGrid project. Throughout our engagement in the earlier stages of FutureGrid, we were able to understand how our stakeholders wanted to digest the information around our testing approach and ultimately why the results and outputs of that were so key. The result was the FutureGrid testing guide, which was produced and published mid-2023 and timed to coincide with the start of the testing on the facility. Over 500 sustainably printed testing guides have been distributed to date, with several thousand additional downloads from our website.

To view the FutureGrid testing guide, please go to nationalgas.com/FutureGrid or **click here.**

FutureGrid In-Person Events

We have engaged across the UK regions as well as international platforms, maintaining our pivotal role in collaboration. We are part of the Hydrogen Gas Asset Readiness (H2 GAR) group with several of the European Transmission System Operators (TSOs). In this group we share a wealth of knowledge and research on the impacts of hydrogen on transmission assets with our international counterparts.

We have showcased this project at major industry events in order to share knowledge with stakeholders. We have also attended key conferences in order to gain knowledge from other networks and the wider industry.

Engagement at these events has been vital for us to be able to engage directly with customers, stakeholders and those interested parties who want to understand our journey to net zero. Given the size and scale of FutureGrid, it's very hard to bring everybody to it, however, utilising the digital model we've developed and the key engagement tools and information has been key for us to bring this project to life and allow those who cannot physically visit the site to be more engaged and involved. There are countless events in which the team has supported both internally and externally to promote the project and, most importantly, to build excitement around this world-leading project. The legacy of FutureGrid Phase 1 continues beyond its completion and with the start of Phase 2, the FutureGrid programme is setting a global example of how innovation and cutting-edge technology and development can help bring a clean energy future. As we continue with Phase 2, the successes of the FutureGrid Phase 1 project will continue to be celebrated and form a vital part of building our safety case for transitioning our network to hydrogen.

Note: all links on the page these can be accessed on the digital version of the report available at **nationalgas.com/FutureGrid**

Highlights of some of the key events where we have showcased FutureGrid:

- UK International Conference on Gas Decarbonisation, March 2021
- The Energy Networks Innovation Conference (ENIC), October 2021
- Pipeline Maintenance and Integrity Management Conference, October 2021
- UKOPA Annual Conference, May 2022
- IGEM North East & Yorkshire Innovation Day, June 2022
- YPPE Hydrogen Event, July 2022
- Energy Innovation Summit, Sep 2022
- 10th Pipeline Maintenance and Integrity Management, Oct 2022
- IGEM Awards December 2022
- Utility Week Live, May2023
- Innovation Zero, May 2023
- Energy Innovation Summit, Sep 2023
- Conservative and Labour Party Conferences, 2023
- Innovation Zero, April 2024





FutureGrid Explore

FutureGrid Explore are webinars and in-person events focused on key topics relating to the FutureGrid project. These interactive events allow stakeholders to learn more about the project and participate in relevant discussions. These have continued to receive very positive feedback, with several stakeholders joining live and catching up with the recordings after the event. Highlights from the project include:

Constructing the test facility – October 2021
This FutureGrid Explore webinar was conducted when we commenced construction of the facility. We provided information on what assets the facility would consist of and where they were sourced from. We also mentioned how they would be constructed.

Maintaining the National Transmission System (NTS) – March 2022
This FutureGrid Explore webinar looks at the ways that we currently maintain the National Transmission System (NTS) and how FutureGrid will help us understand what future maintenance may look like.
Click here to watch.

Our compression and deblending challenges – July 2022
This FutureGrid Explore webinar looked at the challenges associated with hydrogen compression and deblending. Dave Hardman (Strategic Innovation Specialist) and Lynsey Stevenson (Hydrogen Innovation Engineer) gave an overview of some of the innovation projects we're looking at to help us overcome these challenges.
Click here to watch.

FutureGrid Hydrogen Testing Guide launch
In this session, Tom Neal, Shaun Bosomworth, Lloyd Mitchell and Daniel Knowles introduced the testing approach being taken with the various hydrogen concentrations being tested at the FutureGrid facility over the coming months (2, 5, 20 and 100% hydrogen). They also shared some of the high-level results from the standalone hydrogen testing that's already been carried out on site.
Click here to watch.

Our compression and deblending challenges
In this FutureGrid Explore webinar, we looked at the challenges associated with hydrogen compression and deblending. Dave Hardman (Strategic Innovation Specialist) and Lynsey Stevenson (Hydrogen Innovation Engineer) gave an overview of some of the innovation projects we're looking at to help us overcome these challenges.
Click here to watch.

FutureGrid Feature

FutureGrid feature articles are focused on the key topics our stakeholders were interested in. They tackle some of the big questions around the Hydrogen Transition and provide more information on the fundamentals of what this could mean to us all. Some of the key feature articles we've shared over the course of the project were:

Decarbonisation and Net Zero policy – what does it mean? – January 2022
In 2021, the UK government published several critical documents that will heavily influence the delivery of a Net Zero energy system. In this feature article, we talk about what this means for us and how we are responding to deliver a Net Zero future.
Click here to read.

What is a GB hydrogen backbone? – August 2022
We're looking at repurposing existing pipelines within our network to create a hydrogen backbone for GB. But what exactly is a hydrogen backbone? In this feature article, we talk about what the backbone means and how it benefits the UK.
Click here to read.

FutureGrid InFocus

FutureGrid InFocus gives stakeholders the opportunity to hear from those working on the FutureGrid Project, whether that be the direct team or colleagues supporting the project. FutureGrid InFocus was a blog series providing insight and updates around the progress of the project as it happened. We provided a more personal perspective on the opportunities of hydrogen and how FutureGrid unlocked these. Some of our blogs included:

Reaching our hydrogen future – August 2021
Find out more about the opportunities that hydrogen presents in the future of the energy industry in the FutureGrid InFocus blog written by Tom Neal (FutureGrid Manager).
Click here to read.

Construction has started – October 2021
Find out more about the opportunities that hydrogen presents in the commencement of construction in the FutureGrid InFocus blog written by Shaun Bosomworth (FutureGrid Senior Delivery Engineer).
Click here to read.

The different phases of FutureGrid – May 2022
Find out more about how we plan to expand the FutureGrid programme to enhance our knowledge of transporting hydrogen across our network in the FutureGrid InFocus blog, written by Haroon Khan (FutureGrid Project Manager).
Click here to read

What are the opportunities of a hydrogen gas network? – July 2022
Find out more about the opportunities that hydrogen presents in the energy industry in the FutureGrid InFocus blog written by Tom Neal (FutureGrid Manager).
Click here to read.

FutureGrid Chat

FutureGrid Chat was a podcast series that brings together key experts across the project and wider industry to talk about the big questions in hydrogen and how FutureGrid supports this. With the rise in podcasts in the Net Zero space, we developed these to bring in a wider range of voices to cover the key topics our stakeholders informed us they wanted to hear more about. Some of the key podcasts in our series are featured below:

Our offline hydrogen test facility – May 2021
In this episode of FutureGrid Chat hosted by Jennifer Pemberton, Lloyd Mitchell (Hydrogen Engineering Lead for FutureGrid), Steve Johnstone (Senior Engineer Innovation Team) and Sarah Kimpton (DNV – Gas Quality Expert), the general offline hydrogen test facility and hydrogen were topics of discussion.
Click here to listen.

The decommissioning assets – November 2021

All about the NTS – April 2022
Kirsty McDermott (Senior Welding Engineer), Shaun Bosomworth (Senior Delivery Engineer) and Daniel Knowles (Hydrogen Engineer) discuss the characteristics of the National Transmission System (NTS), both now and in the future.
Click here to listen.

FutureGrid and other innovation projects – July 2022
In this episode of FutureGrid Chat hosted by Lloyd Mitchell (Hydrogen Engineering Lead for FutureGrid), Peter Martin and Robert Best (Hydrogen Innovation Engineers) discuss some of the innovation projects they are working on that support FutureGrid.
Click here to listen.

To see all the webinars, articles, blogs and podcasts, please visit our website **nationalgas.com/FutureGrid** and go to the 'Events and Resources' section.

Closure of FutureGrid Phase 1

As we move forward on closing FutureGrid Phase 1, our engagement does not stop. A key deliverable is this very report alongside a number of FutureGrid online webinars, both internal and external, which will focus on the key findings of the project and provide us the opportunity to ask more questions. In addition, a FutureGrid programme event later in 2024 will be held at the site to allow for key stakeholders to visit. See the progress on FutureGrid Phase 1 and learn more about FutureGrid Phase 2 as that progresses. In addition, a number of events, conferences and other engagement activities will continue to discuss FutureGrid Phase 1 and its outputs.

Note: all links on the page these can be accessed on the digital version of the report available at **nationalgas.com/FutureGrid**

Ofgem Deliverable 7.0

Comply with NIC Governance for knowledge transfer

Ofgem Deliverable 7.0

Comply with NIC Governance for knowledge transfer

Deliverable date:	**March 2024** (Original bid date: April 2022)
Status	Ongoing
Evidence required:	• Annual Project Progress Reports which comply with the requirements of the Governance Document – In progress. • Complete Close Down Report which complies with the requirements of the Governance Document – To be completed in 2023 reporting period. • Evidence of attendance and participation in the Annual conference as described in the Governance Document – In progress.
Latest update summary:	This deliverable is associated with the activities which will be conducted as part of the governance. There is an overall delay in the project and this deliverable will be completed once the project is completed.

Throughout the project we have engaged in the annual innovation conference previously known as the Energy Networks Innovation Conference (ENIC) and now known as the Energy Innovation Summit (EIS).

Digital event information was shared about FutureGrid with the development of the digital model as outlined in deliverable 6 above, featuring in the 2022 Energy Innovation Summit and also in the 2023 conference. FutureGrid will feature highly at EIS 2024 where the results of Phase 1 will be discussed and shared along with the progress and plans for Phase 2 on the FutureGrid Compression and FutureGrid Deblending projects.

As part of the knowledge dissemination, we have completed progress reports and closure reports which are available on our website. The aim of these reports was to share how the project was managed and the key challenges which were encountered. It also provided information of key outputs of the project. In addition to this, we have also completed detailed technical reports which have been shared with key stakeholders and can be made commercially available.

Links to the progress reports and key highlights are shared below.

FutureGrid Project Progress Report 2021

Click here for the full report

Key Highlights:

1. The governance groups for the project have been established. This means that different progress meetings and steering groups have been put in place.
2. Ground surveys and groundworks have been completed. The latter activity was crucial, and required before unfavourable weather for groundworks set in.
3. Several standalone tests that were detailed in the master test plan have been completed. The knowledge obtained from these tests will be applied to the full facility test. Key learning is also being shared with other interested parties as the tests are being completed.
4. The build stage of the project is being progressed as planned. The assets were initially inspected to determine their suitability for the build. Some of these assets required remediation work and some were rejected as the cost of remediating them would be significantly more than sourcing alternative assets.
5. The QRA has started and is planned to be completed over the full duration of the project. The full list of NGGT procedures are being reviewed and sites for QRA review have been selected.
6. A bilateral contract (DNV-NGGT) and multiparty contract (all project partners) have been signed: the bilateral contract was signed first, followed by the multiparty contract. The scope of works and the project plan was also reviewed as part of the contract reviews.
7. A communication plan was put in place so we could share learning with interested parties, together with the progress of the project. We also created events, podcasts and articles providing the latest updates in this reporting period.

FutureGrid Project Progress Report 2022

Click here for the full report

Key Highlights:

1. Asset integrity tests have been completed.
2. Assets have been remediated as required and made fit for service.
3. All assets are now installed, and construction is nearing completion.
4. The facility is being prepared for commissioning and testing.
5. A full triage of GT&M procedures has been completed as part of the QRA development.
6. Extensive range of engagement activities delivered.
7. The change control of programme delay and addition of the 5% blending test NIA project was also mentioned. This provided the latest updates of the project and the challenges being faced at the time of writing the progress report; it also mentioned how the challenges were being addressed.

FutureGrid Project Closure Report 2024

The decision was jointly made between National Gas and Ofgem that a 2023 project progress report was not required as this would be superseded by the FutureGrid project closure report due in 2024. In addition, the publication in mid-2023 of the FutureGrid testing guide provided key updates to our stakeholders that the construction and commission had completed and that we were undertaking the key testing, the results for which would not be available until the full testing had been completed.

This allowed the future closure report to fully encompass the results and observations made from the testing while reflecting back on progress across the whole project as featured in the 2021 and 2022 reports.

Note: all links on the page these can be accessed on the digital version of the report available at nationalgas.com/FutureGrid

Performance against budget

The project direction was issued at the end of 2020 and the NIC budget was defined along with each of its sub-categories. Although the project end date was extended, there have been no changes in the overall revised costs from the original NIC budget.

In November 2021, the budget was re-adjusted as the project has progressed to align project spend more accurately against project programme. It was then further re-adjusted in November 2022 and November 2023 to re-align with the project programme, and there were no overall changes in the project costs. The variance change in these years was reported in their retrospective project progress reports found at nationalgas.com/FutureGrid.

The table below provides an overview of the original NIC budget, with budget revisions and the final spend figures under each category. These figures are tracked via our SAP system and financial records for the project.

FutureGrid Phase 1 budget and spend to date

	Original NIC Budget	Revised Budget Nov 2021	Revised Budget Nov 2022	Revised Budget Nov 2023	Total spend	Variance of total spend to revised budget Nov 2023
Labour	£5,303,769	£5,201,157	£5,263,849	£5,287,997	£5,298,780	£10,783
Equipment	£4,229,006	£4,443,221	£4,356,642	£4,367,494	£4,356,642	-£10,852
Contractors	£65,020	£65,020	£65,020	£30,020	£30,089	£69
Travel & Expenses	£50,400	£50,400	£84,287	£84,287	£84,287	£0
Contingency	£420,159	£308,556	£308,556	£308,556	£308,556	£0
Other (Comms)	£160,000	£160,000	£150,000	£150,000	£150,000	£0
IT	£10,000	£10,000	£10,000	£10,000	£10,000	£0
Totals	**£10,238,354**	**£10,238,354**	**£10,238,354**	**£10,238,354**	**£10,238,354**	**£0**

Note: all links on the page these can be accessed on the digital version of the report available at nationalgas.com/FutureGrid

Commentary on budget line items:

Labour:
The actual spend on labour is 0.2% more than the total revised budget in November 2023. This is because DNV were able to do some of the subcontracted work in-house, which meant that less was spent on equipment.

Equipment:
The actual spend on equipment is 0.2% less than the total revised budget in November 2023. This is mainly due to work being done in-house by DNV.

Contractors:
The actual spend on contractors is 0.2% higher than the total revised budget in November 2023. This is only £69 more than the expected spend. It should be noted that in November 2023, part of the contractors' budget was moved to labour, and this was because during the project we realised we needed more labour time for an internal specialist's review to obtain initial comments. Once the comments on the document were addressed, the final version was provided to the HSE for peer review.

IT:
The IT budget was spent in 2021, as per the communication plan, and no further spend was allocated.

Travel & Expenses:
The travel and expenses are allocated based on our internal SAP system. The spend has been achieved.

Contingency:
National Gas anticipated requiring new equipment and remediation activities to avoid any impediment to testing. We were able to remediate the assets and a portion of that was covered under the contingency budget.

Other:
The communications budget was spent with no costs remaining. It should be noted that in November 2022, the communications budget was reduced by £10,000 and the costs were moved to labour. This is because we were efficient and managed to conduct in-house communications activities.

The variance reported in the closure report is a comparison of total spend with the revised budget in November 2023. Overall, the variance from November 2023 is £0; however, there have been movements of costs across categories.

It should be noted that overall the project costs are within budget despite challenges being faced on the project. The project duration did increase, but our financial management ensured that appropriate costs were set aside for this. This is a major success on the key principle of project management, and this has also been noted as a lesson learnt for future projects.

NG has contributed labour costs in some scenarios (e.g. review of documents by internal resources and virtual operational support) at no cost to the project. We have also sourced some items (e.g. upgrade of control cabin to include more space and facilities for onsite activities including welfare facilities) totalling £55k at no additional costs to the project itself. The furniture in the control cabin was re-used from National Gas's site in Solihull (estimated at £6k); this has been contributed by National Gas to the project at no cost.

As part of the NIC application process, the Full Submission NIC Cost Table set out the requirements to articulate all funding required broken down by spend category and partner. As part of the calculations for the funding requested from Ofgem, the amount was adjusted by the forecast interest rate based on Bank of England Base Rates. This reduced the funding awarded by £40,787.69, the amount of interest expected to be generated from the NIC funds held in the project bank account over the duration of the project. This was a funding risk to the project, with a strong possibility the funds would not be fully generated leaving a shortfall that National Gas would be required to cover.

At the end of the project, the amount of interest gained was £135,482.92 due to the increase in interest rates towards the end of 2023. When the £40,787.69 adjustment is deduced this leaves a positive of £94,695.23. National Gas has reinvested this interest into ringfenced contingency pot for the Phase 2 SIF Compression and Deblending for Transport projects ensuring the consumer value is still delivered.

Business case update

FutureGrid NIC Benefits Case

FutureGrid forms a key part of National Gas' hydrogen transition strategy and provides a range of key evidence required as part of our safety case development for the transportation of hydrogen within our network.

The FutureGrid Phase 1 NIC project submission was set out in the first half of 2020, in the earlier stages of National Gas' hydrogen programme development and business case. Ultimately, the benefits focused on unlocking the potential of hydrogen across the NTS, with 100% pipelines. At the time of developing the original bid in 2020, Project Union was an emerging concept and so the benefits case was not understood in as much detail. As such, the benefits relating to 100% pipeline have developed and the approach to capturing the opportunities has also developed.

Within this section, the original business case as per the original FutureGrid NIC submission is set out, and the wider business case in development for Project Union is outlined.

As per the FutureGrid Phase 1 NIC project submission, there are two key financial benefits set out:

- **Creation of a world leading net zero test facility as a focus for hydrogen testing:** In order to gather the required understanding and knowledge of how a hydrogen NTS would operate, a number of the different types of assets and tests we would need to carry out could either be completed separately or combined on a single test facility. This projected benefit would see £20.5m saved against the cost of conducting all eligible tests separately.
- **Avoiding valve replacement as part of work to connect industrial clusters:** Currently, the most likely scenario for hydrogen transition and adoption will be at industrial clusters. The NTS will be used to join several clusters together by 2040, for which plans are being developed in detail under Project Union. To facilitate this, safety critical assets such as valves would all need to be replaced for hydrogen operation if they are not proven to be compatible to operate safely with hydrogen blends up to 100%. FutureGrid unlocks the opportunity to prove this compatibility, with projected benefits of avoiding a proportion of valve replacement being at least £46.5m.

In addition, there were two key carbon emissions reduction benefit opportunities, with a total of 81m tonnes of carbon emissions expected to be avoided:

- **Unlocking the opportunity for the NTS to convert to 100% hydrogen by 2050:** We have assumed a linear reduction in demand towards 2050 as previously quoted in the ENA Pathways Report, reducing from 880 TWh in 2020 to 440 TWh in 2050. Assuming 440 TWh and a CO_2 emissions per energy demand of 0.0549 kg/ft3 by converting the NTS to 100% hydrogen by 2050, we will reduce carbon emissions by 81 million tonnes CO_2e.
- **Avoiding valve replacement as part of work to connect industrial clusters:** Removing the need for all valves to be replaced by proving their compatibility with hydrogen could see 100,000 tonnes of CO_2e being saved based on an initial part of the NTS transitioning to hydrogen.

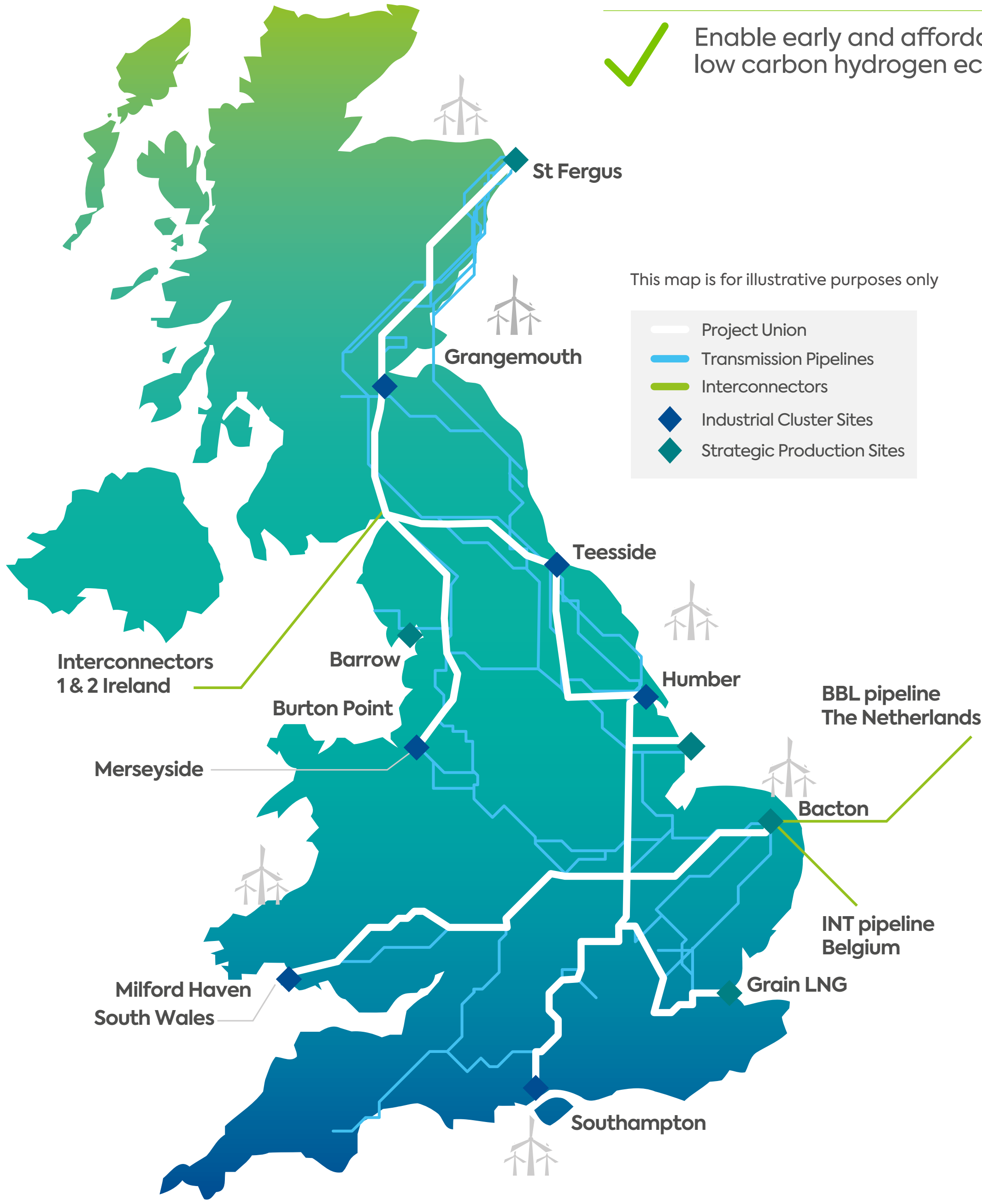
Project Union Development

Ultimately, the importance of FutureGrid within our Hydrogen programme has become greater with the project spearheading the technical demonstration and development of safety evidence for operating a network with hydrogen. This has increased FutureGrid and the wider innovation portfolio's criticality in the development of Project Union and the conversion of the NTS to hydrogen.

ProjectUnion

Project Union will connect, enable net zero and empower a UK hydrogen economy, repurposing existing transmission pipelines to create a hydrogen 'backbone' for GB by the early 2030s.

- ✓ Repurpose ~1500 miles of the NTS through a phased approach in line with Government's cluster prioritisation and green hydrogen development.
- ✓ Connect cross GB supply, demand and strategic storage sites, enabling growth of a UK hydrogen economy.
- ✓ Use existing infrastructure to deliver a low carbon future, reducing environmental impact of new construction.
- ✓ Enable early and affordable market growth of a low carbon hydrogen economy to achieve net zero.



ProjectUnion

Project Union will deliver a hydrogen transmission backbone, connecting industrial clusters and strategic hydrogen production sites with storage and users across Great Britain, by the early 2030s. Through the phased repurposing of existing assets alongside new infrastructure, a hydrogen backbone of up to 2,500km will be created.

The backbone will initially link strategic hydrogen production sites, including the industrial clusters, with storage and users across the UK by the mid-2030s and provide the option to expand beyond this initial hydrogen transmission network to connect additional consumers.

Through continued customer engagement, it is evident that many hydrogen producers are heavily dependent on connecting to a transmission system to allow for flexibility and resilience, and starting now will allow an operational hydrogen pipeline network to be present at the required timescale of customer network demand.

There are key benefits to Project Union, which include:

Decarbonisation of industry & power
Fair access to green and blue hydrogen enabling businesses to decarbonise. Access to transmission enables green hydrogen production to scale.

Energy storage and resilience
System resilience to move and store sufficient volumes across the country.

Connectivity and efficiency
Connect production and storage with demand, enabling system efficiency through shared infrastructure.

Market coupling
Connect isolated production sites enabling competition, reducing costs and improving security of supply.

Levelling up and job creation
Potential for >100,000 jobs by 2050, and contribution of £13billion to GVA.

Global leader in green innovation
Attract global investors by getting best value from national infrastructure and enabling rapid scale up.

Flexibility and optionality
Flexibility in power generation, storage and consumption. Optionality in future hydrogen decisions whilst maintaining gas networks' delivery.

Consumer-centric
Innovative, cost-effective consumer focused energy solutions, e.g. the pilot hydrogen town brings scalability & phasing.

FutureGrid Benefits Progress

The benefits case set out within the original NIC submission still stands. In certain cases, this has been outperformed, while in others, the benefit is still expected. This is due to the longer horizon for realisation which ultimately rests on transitioning the network to hydrogen in order to be achieved. The table below outlines the progress against these benefits.

Benefit Description	Type	Type	Comment
Creation of a world-leading Net Zero test facility as a focus for hydrogen testing	Financial	Outperformed	The core of this benefit focused on the significant efficiencies of integrating a number of our key representative assets from the National Transmission System in one hydrogen test loop. This allows for simultaneous testing as opposed to a number of separate tests which would be highly inefficient, especially from a cost perspective of assets, materials, hydrogen and associated costs for operating these tests. The £20.5 million has been achieved through the successful delivery of the FutureGrid Phase 1 project. In addition to this saving, the FutureGrid Phase 2 Deblending for Transport Strategic Innovation Fund (SIF) project has further contributed. The ability to utilise the Phase 1 facility and connect the hydrogen deblending and purification system for demonstration has saved over £5 million to date, as there is not a requirement to build assets in a separate test loop; instead the facility can be utilised in full. Further details of this benefit are captured under the Phase 2 project; however, the Phase 1 FutureGrid facility has been vital in unlocking this.
Avoiding valve replacement as part of work to connect industrial clusters	Financial	Expected	These three benefits are directly linked to the wider transition of the NTS to hydrogen and subsequently the cost that can be saved by being able to repurpose rather than replace specific valves, and the environmental benefit in being able to transport hydrogen a greener, cleaner fuel. Testing outputs from this project provide greater clarity on the suitability of the valves for repurposing and our wider asset base. This feeds directly into the work being carried out considering the Project Union routine as well as opportunities for introduction of hydrogen blends across other parts of the network, although this cannot be realised until hydrogen is introduced into the network. FutureGrid has delivered the key evidence that supports this as an enabler to unlocking this benefit.
Unlocking the opportunity for the NTS to convert to 100% hydrogen by 2050	Environmental	Expected	
Avoiding valve replacement as part of work to connect industrial clusters	Environmental	Expected	

FutureGrid Phase 2 is now underway, which consists of the FutureGrid Compression and FutureGrid Deblending for Transport projects. These have been funded under Ofgem's Strategic Innovation Fund (SIF). As part of these projects, there are a number of Special Conditions that are monitored by UKRI, who administer the SIF process. Several of these conditions are focused on the continued value generated for the consumer from the combined FutureGrid Programme, including both the Phase 1 Test Facility, the additions by the Deblending project and the Phase 2 Compression test loop.

This encapsulates a wider set of FutureGrid Programme benefits, including these outlined under Phase 1: the practical cost savings of a complete test facility for a wide range of assets versus individual test setups for each asset, and the benefits of enabling a hydrogen blend and 100% hydrogen backbone (Project Union).

FutureGrid Phase 1 has achieved its goal – it has provided key test data for a wide representative range of assets on our network and is an active test facility that can be further utilised. This has been demonstated by a number of current and future NIA projects being able to use the facility and the ability for the FutureGrid Deblending for Transport Project to utilise and modify the existing facility for a full-scale demonstration, saving over £5m in setup costs for a separate demonstration. As we progress with the development of FutureGrid Phase 2, we will further develop the commercial proposition for the FutureGrid programme in order to unlock maximum value for the consumer and ultimately enable the transition of our network to hydrogen.

Project learnings

Project learning is a key element to innovation and forms part of our overall innovation process at National Gas. We share project lessons, learnings, insights and opportunities in order to ensure continuous improvement of our project portfolio cycle.

At original inception, FutureGrid Phase 1 took on a plethora of lessons from previous innovation projects, NIC projects and various other pieces of work. It also quickly adapted to the fast-changing landscape developing under Covid to ensure no significant issues were overlooked.

As the project has continued, FutureGrid Phase 1 has produced a number of key lessons as captured below. Most notably, FutureGrid Phase 1 has fed directly into the development of both the FutureGrid Compression and Deblending projects as they've moved through the SIF project life cycle to beta projects. A number of the early successes at the start of these projects are directly attributable to lessons taken from Phase 1.

Capturing lessons is vital, as this knowledge gained can be implemented for future projects of a similar nature to deliver them more efficiently and effectively. We have held quarterly workshops between NG and DNV to discuss the lessons learnt in the project. These have been tracked throughout the project and are mentioned where relevant in the monthly governance meetings. The aim of this process is to benefit future phases of the project and other similar projects. These lessons are shared internally within NG and with DNV.

As the wider FutureGrid programme continues, we will continue to capture key lessons and knowledge to improve future projects and programmes, helping us to develop our knowledge and understanding and deliver the most effective projects that deliver value to UK consumers.

Key project governance learnings

Project Mobilisation and Ways of Working: The NIC FutureGrid project commenced after "Road Map to FutureGrid" NIA was completed. The project direction was provided in December 2020. National Gas swiftly created an internal organisational structure and a full organogram with DNV interactions. Based on this, National Gas recruited the full team instantly. The team were then able to get involved in the initial contract discussions and refine the contracts. One of the first tasks conducted was to establish ways of working. These were all set up at the start of the project and were further refined over the time period.

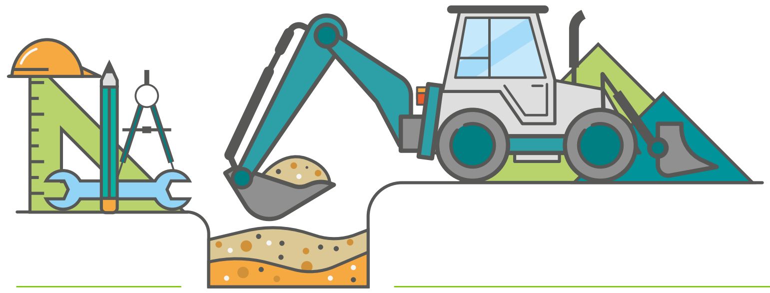
Project Management: At the start of the project, we set up all the governance activities that we anticipated would be required with different stakeholders (e.g. Weekly DNV Catch-up, Monthly Partner Steering Group and Quarterly Network Steering Group). In addition to this, we also set up SharePoint folders and Microsoft Teams to aid all partners in working collaboratively. We have pro-actively managed any issues by having ad hoc discussions and swiftly responding to any issues. Where there were critical path issues, e.g. an LMF recompressor unit, we have worked collaboratively with DNV to rectify the issue and have also mobilised internal resources to site to provide specialist support at the earliest opportunity.

Finances: We have pro-actively worked to develop a system to track project costs. This system was designed based on a combination of our internal finance system, Ofgem's reporting template and DNV's application of payment system. DNV would submit their application of payment on work completed monthly, and this would be reviewed against the milestones completed and approved. This method has been successful as we were able to challenge work completed vs payment request. It was also further refined over time to improve efficiency. In addition to this, our internal finances were also tracked monthly to keep a record of invoices and time sheeting being completed. This has been successful as we were able to complete the project on budget despite it being completed later.

Partner interaction and coordination: At the start of the project we mapped out governance activities and ways of working. The partner interaction and co-ordination was defined which was further refined for efficiency. DNV was the main project partner and we had weekly interactions and also ad hoc conversations where required. With the other partners we had a monthly steering group in which we provided the work completed in the past month. We also provided a forecast for work for the next months and areas where we would require support from the partners. This was useful as it allowed them to align their resources accordingly.

Communications Plan: Detailed plans into FutureGrid communication works were principally based on monthly themes. Following feedback received from various stakeholders, the detailed communications plan for FutureGrid is now developed as a three-month look ahead to reflect gathered interests and support received from both internal and external stakeholders.

Collaboration: To support the qualification of FutureGrid pipelines, there was reliance on information from materials related to innovation projects during the project design phase. This created new knowledge requirements. In a bid to address this limitation, the agreed remediation was to expand the knowledge pool, to have more engagements with innovation SMEs and similar projects completed in the past. This was to bridge the knowledge gap for projects done in future phases.



Key design / build learnings

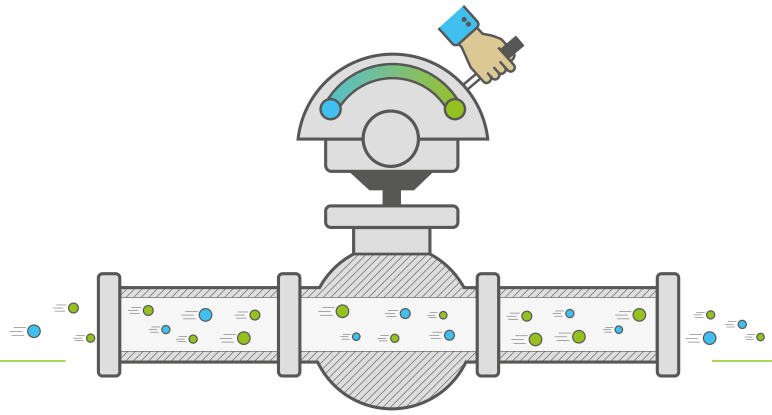
Design: A key challenge during the design of the facility was the collation of all the records required to ensure a suitably informed design. Key challenges in particular resulted in the need to carry out extensive sampling of material sections in order to have confidence in the material type and to understand its properties and characteristics. This is a challenge that we expect will be encountered in Project Union, and the sampling requirement is currently being incorporated into the project scope.

Asset maintenance: Maintenance has been carried out on some of the decommissioned assets to ensure safe operation within the FutureGrid test facility without compromising the project ethos of representing the NTS. NGS rectified defective Cameron isolation ball valves to ensure optimal safe operation. Other examples include planned preventative maintenance. This was due to early engagement with the relevant internal teams and meant that the assets were all serviced and ready for installation early.

Decommissioned assets: During the conceptual detailed design phase, it was identified that some of the decommissioned assets required some further maintenance. This posed a challenge in the redisposition of existing assets and arrangements to suit the project. Part of the agreed remediation going forward is the need for detailed assessments of assets during decommissioning planning and works.

Meters: During the FutureGrid build phase, the Instrumentation Engineer identified a way of adding an additional meter in the facility, which enhanced the testing by cross-referencing across the existing meters, meaning all flow rates can be measured on all tests.

Spares: Delays were experienced while ordering spares to support the build phase of the project mostly due to supply-chain issues. Going forward, following confirmation of required assets in the project's spares list, orders will be made to prevent the occurrence of long lead times in the future.



Key testing learnings

Test plan: The test plan was developed to maximise the use of the facility and replicate the maximum amount of transmission scenarios. This was achieved by creating two flow loop philosophies, high and low-flow loops. The high-flow loop had no pressure drop on it, allowing the recompression unit to run freely up to its maximum flow rate. This replicated the higher velocities we see on the NTS.

The low flow loop simulated a smaller customer offtake where National Gas would typically drop the pressure with pre heat and then meter the gas to a fiscal level to bill the end user. This loop had a maximum flow through its assets and the compressor matched that flow. Both flow loops had 6 flow rates going up in incremental stages again representing the different scenarios seen on the NTS. On the facility there were different technologies in metering and the flow loop layout with the test plan, meant that at all the flows there was comparable data between the relevant assets.

Testing: Testing was successfully completed with all hydrogen blends and 100% hydrogen, new methods included safer ways of working with hydrogen and this was implemented into the test procedures used. Revised methods of working included using nitrogen to purge vent stacks before any hydrogen venting was to take place, to ensure ignition risk was fully mitigated.

Technical challenges: The flow facility has achieved the original objective set by National Gas to test key ex-service assets that are representative of the gas transmission system, using hydrogen gas blends under a range of different flow conditions.

However, some teething issues were encountered after commissioning of the facility:

- When carrying out the natural gas valve operational checks, the 36" Cort ball valve (Lanark) was leaking, and despite multiple attempts, it was not possible to obtain a positive seal. Due to no availability of a replacement, and complexities with swapping out the valves, National Gas requested that the valve should remain open and be excluded from further testing, and testing should continue to be scheduled without this.
- There were some issues with the Hays filter skid which required a major overhaul. However, it later became apparent that there remained issues with the filter that could not be rectified. Following agreement with National Gas, the Hays filter DP transducer was replaced with the Enron filter DP transducer, following completion of the 2% hydrogen high-flow tests (note that a second issue was later found, affecting the differential pressure results for the 2% hydrogen low-flow tests, and the 5% hydrogen tests).
- The compressor is used to control the pressure and flow rate around the facility. This is achieved via three set points: inlet pressure, outlet pressure and flow rate. These are maintained by adjustment to the compressor speed and the bypass valve. On completion of the high-flow tests with 2% hydrogen, some issues were encountered with the compressor. These were addressed by the manufacturer but resulted in a 10-week delay to the schedule. Some parts needed to be replaced, but it was not confirmed if this was due to hydrogen exposure. It should be noted that when the compressor was working once again, the remaining tests using 2% hydrogen, and all of the testing using 5%, 20% and 100% hydrogen, were completed without issue. It should be noted that the ex-service flow control valves that are located around the facility are not electrically connected to the system, so do not form part of the flow control loop.
- Vibration measurements were undertaken when testing with 100% natural gas and 100% hydrogen, with no discernible differences in flow-induced vibration. The pressure pulsations from the compressor reduced during the 100% hydrogen testing due to operation at higher compressor running speeds. This reduction was considered to be due to an improved understanding of the operation of the compressor as a result of the observations during the baseline natural gas vibration survey. These surveys have not been sufficient to conclude whether hydrogen addition will have an impact on pipework vibration, as the results were dominated by the mechanical excitation of the compressor and are therefore not directly relevant to service assets on the transmission pipeline system. It is recommended that further studies are undertaken at more representative flow rates that will be in use on the transmission system. A discussion around the key elements of the test programme is provided in the following sub-sections.
- Challenges arose due to ATEX and DSEAR concerns when moving from a class 2A to 2C gas. For example, instrumentation, lighting and other electrical equipment had to be considered. The original Hays kiosk was identified as not compliant with hazardous area classification regulations, meaning the doors had to be removed, which caused some technical challenges with the winter weather conditions at Spadeadam and National Gas' assets. New methods of safe venting and purging were utilised to overcome any additional risks associated with venting hydrogen. Some issues were encountered with relief valves lifting early when operating with high-pressure hydrogen. It is yet to be ascertained whether it was equipment related or hydrogen related, and further research into this area will be carried out.
- Challenges were faced with obsolete components of various assets partway through testing, and new solutions had to be implemented to allow testing to proceed. Maintenance carried out between blend testing inadvertently caused some issues further downstream when carrying out normal maintenance such as inline y-strainers. A very low amount of new stem leaks from plug valves were encountered as we moved further up the range of hydrogen concentrations. Due to issues unreleated with hydrogen, the brand new LMF compression unit failed and caused considerable delays in identifying cause and effects. The compressor is designed specifically for operation with hydrogen and was associated with the defective parts identified within the system.

Key safety case & QRA learnings

Engaging SMEs early: SME knowledge and experience is critical in providing context and shaping the process for assessing the impact on our QRA and Safety case. Involvement from the National Gas Safety team from the very start ensured we were able to clearly articulate the NG safety management process and ensure that the outputs of the work package being carried out by DNV were directly applicable to our operations. This was key to the delivery throughout the project, ensuring that the work package remained on track and ultimately delivering a strong set of outputs.

Procedure review: Assessing National Gas' suite of policies and procedures at this stage in the innovation programme showed the resource requirement to deliver an updated document suite.

This highlighted the opportunity to collaborate between UK gas networks to reduce the overall workload, spawning an additional innovation project.

Hazardous area review: Good documentation is essential for making informed decisions around the effect of hydrogen on hazardous areas. Having all documentation organised in a consistent format will help conduct similar reviews across all sites.

Rupture tests: Considering real-life scenarios can help develop more robust methodologies for testing. During FutureGrid Phase 1, new testing techniques were developed for rupture testing hydrogen pipelines which will deployed on further tests as part of a Joint Industry Project in late 2024.

Key project learnings

The lessons we learnt in Phase 1 were adopted and then implemented into FutureGrid Phase 2. We have already started implementing them in this project. A few of the examples are as follows:

Project planning: We have conducted project planning by setting project milestones in advance of the project commencing. We have also used the RASIC register for each deliverable to define the roles of each project partner. In addition to this, the project plan with clear deliverables for each stage gate has also been defined prior to the project commencing.

Legal process: One of the lessons we learnt was to commence legal discussions as early as possible and also define clear deadlines. We implemented this lesson into the legal discussions at the start of Phase 2 and were able to complete it within a two-month time frame, which is a significant achievement for projects of that size.

Project management: We implemented all the positive project management learnings we had refined in Phase 1 into Phase 2. This meant the governance structure and the steering group setup are similar. In addition, we are also managing risks and financial management in a similar method as it was proven to be successful in Phase 1.

Intelligent management of onsite specialists and resource to maximise output: We learnt in Phase 1 that the site specialists and resource time need to be managed efficiently in order to maximum output. We worked in collaboration with DNV to shape resources profiles and level of escalation at both DNV and National Gas. As a result we were able to delegate duties and were able to deliver in the most efficient manner.

Decommissioned assets sourced earlier: We have sourced most of our assets as early as possible to avoid any dependencies on other de-commissioning projects. The assets were sourced and stored at one of our facilities in Cawood.

Inspection of assets prior to transport: In Phase 1, once the assets were transported to Spadeadam, we conducted inspections and remediation activities as we realised some of the assets were not in the condition we expected initially. As a lesson, we are conducting asset inspections prior to assets being delivered on site to avoid transporting assets which are unfit for purpose. Also we are conducting valve remediation activities at National Gas Service's depot which means that these activities are conducted in the most efficient and cost-effective manner.

Design: One of the key lessons learnt in Phase 1 was the management of the design process in the project. We have planned the design process at the very initial stage of the project by outlining key milestones and sub-tasks prior to the project commencing. We have also limited any construction activities without design approvals, which avoids any changes to the construction activities due to design changes. In addition to this, we have also future-proofed the design by adding PIG traps to the design.

Spares consideration: We found having as many spares as possible in Phase 1 to be a key lesson. We are conducting early surveys of the Huntingdon site before decommissioning to determine critical spares. Also, we are in the process of creating a spares management plan for assets.

QRA & Safety Case: The management of safety on a high-pressure transmission system is a deep highly specialist subject which requires a deep understanding of the risks and processes. We found that involving our Subject Matter Experts at each stage of the project helped ensure that the results were robust and reflected the realistic operation of the NTS.

Replication of FutureGrid

The FutureGrid project was designed to test and demonstrate a broad range of gas transmission operations and assets in a realistic environment.

The processes to construct, commission, operate and gather data for both the FutureGrid Test Facility and standalone tests have been well documented throughout the project and are included in the technical reports for their respective work packages.

The FutureGrid Test Facility will remain active at DNV Spadeadam with it serving as a test-bed for dedicated hydrogen research projects such as the 100% Hydrogen Metering project, which will be conducting testing in 2024. The instrumentation used to collect data throughout the FutureGrid project will remain in place, allowing additional data to be captured to further support the project's findings.

The learning attained through the design and construction of FutureGrid can be replicated, and opportunities may be available to exploit this. Any sharing of this knowledge would be dependent upon a commercial agreement being reached, as well as a level of confidence that the replication of the facility could be carried out in a safe manner. However, given the investment made into the FutureGrid facility, it should be ensured that it is utilised to its full extent, rather than duplicating effort elsewhere.

The FutureGrid facility was designed in accordance with the ASME B31.12 standard and any applicable IGEM standards with hydrogen supplements available (TD/1, TD/13, SR/25). The details included in these standards would give direction for any attempts to replicate the facility, including guidance on materials qualification, exercise and hazardous area classification. The learning attained throughout the design and construction of the facility will be invaluable as the scale and ambition of UK hydrogen projects continues to grow. This would not have been possible by carrying out all testing at a component-level scale.

Although there is no intention to duplicate the facility, the results from the testing will be used to replicate hydrogen blending on the NTS. The results provide a safety and technical demonstration that NTS assets can be repurposed for hydrogen operations, and this will underpin decisions made in preparing the network for operating with hydrogen blends and 100% hydrogen via Project Union. Further details about how the results from FutureGrid will be translated into next steps and implemented into NG's strategy are included in the implementation of FutureGrid section.

Phase 1 facility: FutureGrid Test Loop

- Exclusive use of the facility for testing – has to fit in during other planned work.
- Collective use / testing on the facility during operations – either the SIF or other uses.
- Inclusion of asset(s) to the facility to be tested over a longer duration while the facility is used for other testing.

Technical evidence from FG & wider innovation portfolio

- Key testing outputs and data from FutureGrid Phase 1 programme.
- NIA project outputs including test reports and data.
- Additional testing information and SME expertise of commercial value.

Opportunities are actively being pursued to generate the maximum value from the FutureGrid facility via alignment with NG's net zero strategy, including the addition of hydrogen-ready assets to the facility and the feasibility of using it to assess the potential of carbon transportation. External opportunities are also being pursued, including the use of the facility by other TSOs and the testing of prototype assets by OEMs. This would ensure that the facility continues to deliver value by enhancing the development of the asset capability knowledge, trialling innovative new equipment and providing an excellent training ground for operators.

Any testing data, analysis and outcomes attained through testing at FutureGrid will be available for other GB network licensees to access upon request.

Where there is interest from other operators or commercial parties from across the world, we will explore opportunities to create a paywall to protect the investment made in FutureGrid.

A key requirement to be able to replicate the FutureGrid facility is the assets that were available to NG. The facility was designed based upon the decommissioning programme and asset availability from the NTS; as such, any attempts to replicate the facility would be dependent on the assets being released from the network. This would make it difficult to replicate the facility in its exact configuration, with its layout (and also the operating parameters of the recompression unit) being dependent on what assets are available. As highlighted, the list of components is as follows:

Component	Description
High Pressure Reservoir	60m length of new 1200mm (48") diameter X65 grade carbon steel pipe and wall thickness 22.4 mm sourced directly from manufacturer in 2020.
Flow Control Valve	A 450mm (18") flow control valve manufactured in 1992 sourced from Billingham, Stockton on Tees.
Boiler House and Heat Exchanger	One boiler house with three boilers and one heat exchanger manufactured in 2010 sourced from Sandbach, Cheshire.
Low Pressure Reservoir	A 900mm (36") diameter pipe of 19.1mm wall thickness manufactured in 2007 sourced from Ambergate, Derbyshire.
Ball Valve	Two 450mm (18") diameter ball valves and 50mm (2") bypass pipework manufactured in 1992 sourced from Billingham, Stockton on Tees.
Non-Return Valve	A 450mm (18") non-return valve manufactured in 1998 sourced from Sandbach, Cheshire.
Regulator Skid	An 80 mm (3") regulator skid manufactured in 1998 sourced from Sandbach, Cheshire.
Metering & Gas Quality Kiosks	The data centre consisting of telemetry kiosks, metering and gas quality equipment sourced from Sandbach in Cheshire.
Filter	A 450mm (18") diameter filter manufactured in 1992 sourced from Billingham, Stockton on Tees.
Filter Skid	A filtering skid manufactured in 1998 consisting of two 3" filters sourced from Sandbach, Cheshire.
Pipeline Isolation Valve	A 900mm (36") diameter ball valve with 450mm (18") diameter bypass pipework and plug valves manufactured in 1975 sourced from Lanark, Scotland.
Recompression Unit	A recompression unit manufactured in 2022 with 8" inlet and 8" outlet sourced New.
Ultrasonic Meter	Two 3" ultrasonic meters which have been newly sourced to be suitable for a twin stream system.
Orifice Plate Metering Skid	A metering skid manufactured in 1998 consisting of 4" parallel streams with a single orifice plate in each sourced from Sandbach, Cheshire.
Flow Control Valve	A 200mm (8") flow control valve manufactured in 1992 sourced from Lake District, Cumbria.
FutureGrid Control Room	A 6m x 10m control room manufactured in 2022 sourced new.

Implementation of FutureGrid

Hydrogen Blending

National Gas is making preparations to accept 2% blended hydrogen onto the NTS from the end of 2025, when European gas networks plan to update the gas specifications that will be accepted onto their networks. Following on from this, we are also making plans to be able to accept blended hydrogen up to a 20% blend in anticipation of an update being made to G(S)MR to allow this from 2027. The deployment of hydrogen blends onto the network will provide a pathway for hydrogen production to start to enter UK energy networks until Project Union transitions pipelines to 100% hydrogen. This is being carried out in parallel to any work under Project Union.

FutureGrid Phase 1 has successfully demonstrated that our existing assets that were tested as part of Phase 1 can safely handle hydrogen blends up to 20%. This confirms the feasibility of integrating hydrogen into our current systems, ensuring safe deployment across our network as we advance towards greater decarbonised energy solutions.

Project Union

Project Union will enable net zero and empower a UK hydrogen economy by creating a hydrogen 'backbone' for GB by the early 2030s. This will be partly achieved through the repurposing of approximately 1,500 miles of NTS pipelines to carry 100% hydrogen, and the findings of FutureGrid are critical to the success of this challenge. The FutureGrid evidence will be used to develop and refine Project Union as it progresses through the Front End Detailed-Design (FEED) study.

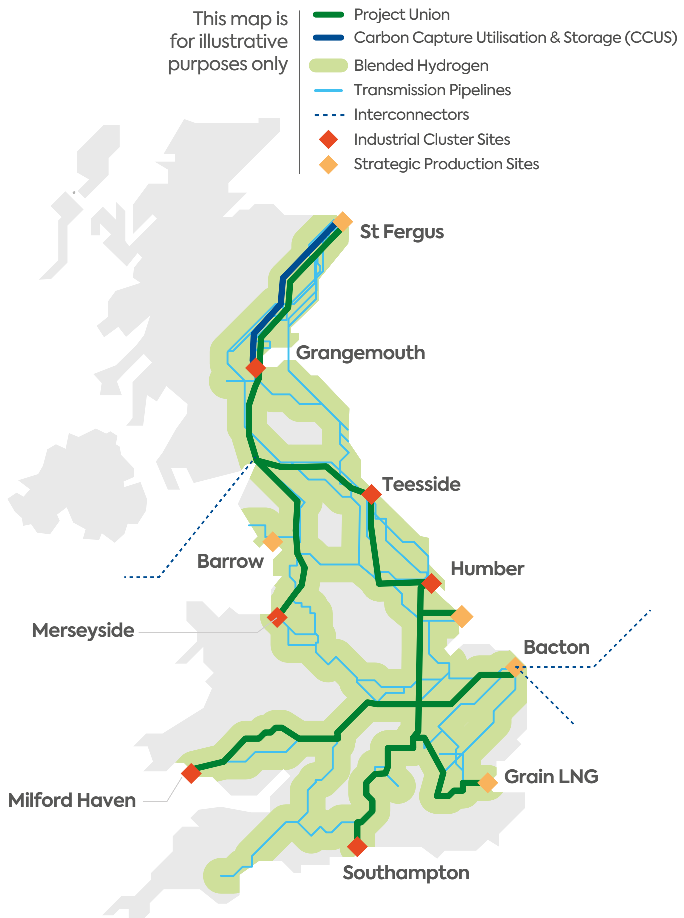
Through the safe demonstration of several assets, including our valves and pipelines, showing that hydrogen can be integrated with use of these assets tested for blends of up to 20%, FutureGrid is a key element to unlocking Project Union and its benefits, driving towards a clean transition to Net Zero by 2050. The results from FutureGrid will give us a critical steer and help us to evolve our policies and procedures to enable hydrogen deployment on the NTS. With the understanding of how our assets perform with Hydrogen, we can enhance our focus on more complicated assets such as compressors and progress our research into the new technologies we will need in a net zero world. Our knowledge from FutureGrid will ensure our day-to-day operations continue to be world class for safety and reliability.

Actions required from GDNs and NG

- To use these results in conjunction with the other evidence gathered from HyNTS to assess whether, and how, hydrogen can be used on the existing gas networks.
- To determine with this evidence what further modifications are required for the network to transport hydrogen.
- To use this evidence to continue to build the pathway to sustainable energy networks.

Actions required by non-gas parties

- The UK Government needs to decide in 2026 to support a hydrogen backbone and the safe and economically sound move to a cleaner NTS.
- The HSE will assess the outputs from the project and determine what evidence gaps remain for hydrogen to be operated safely in the network .
- DNV will continue running the facility for Phase 2 of FutureGrid – compression and deblending.



Safety Case Development

- The FutureGrid project has greatly enhanced the understanding of how GB's NTS would operate with hydrogen blends and 100% hydrogen, which is crucial to facilitate the transition of the network to hydrogen.
- There are assets that are not included in the FutureGrid facility which will require some understanding about how they operate – we will continue to close out these gaps through other projects in our hydrogen safety case portfolio (HyNTS).
- The FutureGrid facility is a unique test site sited in a remote area. The test site cannot be replicated due to its nature, but the results from the testing can be used to replicate the operations on the NTS and other gas networks now it has been safely demonstrated.
- There will continue to be a requirement for new innovative technology to be developed to support any differences in how a hydrogen NTS will operate. The FutureGrid facility will continue to provide a vital role in trialling this new technology with the 100% hydrogen metering project an example of this.

Project next steps

- NG will actively raise the profile of FutureGrid to attract interest from parties interested in testing.
- NG will seek opportunities to sell the data and understanding from FutureGrid to international parties.
- NG will continue to use FutureGrid to trial new technologies.
- Further research opportunities lie in the development of operational procedures and best practices with hydrogen which can be used to enhance our existing skills and competencies.
- NG will seek to utilise the FutureGrid facility to deliver training needs when they are further understood.
- NG will seek to use the FutureGrid data to develop standards that could potentially be commercialised if desired.
- NG will use the outputs from FutureGrid to support trialling hydrogen blends on the NTS and the consideration of the optimum location.
- The HSE will assess the findings from this project and determine whether hydrogen can be safely integrated onto the network.
- DNV will continue running the facility for Phase 2 of FutureGrid – compression and deblending.

The facility and learning generated from the project will continue to assist in unlocking hydrogen's potential on the NTS. Starting with the facility itself, this world-class test facility will be instrumental in providing further evidence for hydrogen usage. This, primarily for NG and DNV, will be the operation and demonstration of a hydrogen-natural gas deblending facility for FutureGrid Phase 2 Deblending. This will be explained later on, along with the expansion of the facility to further demonstrate NTS asset compatibility with hydrogen for FutureGrid Phase 2 – Compression.

In addition to the next steps of the project, the facility will be made available for interested parties to trial new technologies for hydrogen and hydrogen blends. There is also scope to run the facility with carbon dioxide passing through, proving the case for carbon capture, transmission and storage.

To raise the profile of the facility for this testing, FutureGrid will have an updated website page launched on the new National Gas website which will promote the use of the facility for third-party trials. This will be available at **nationalgas.com/futuregrid**

Training is essential for preparing the business and wider industry to be fit for a hydrogen future, and this facility can be a key part of this. When these needs are further understood, FutureGrid can provide this service.

The HSE as a project partner will now assess the data and conclusions generated from the project, assessing outputs including the Quantitative Risk Assessment, facility flow data and the standalone testing with a view to making recommendations on the safety case for hydrogen by the end of 2024.

The facility outputs have generated some further development opportunities, including the need to further develop operational procedures, which is currently being investigated by the 'Policies and Procedures' project led by NG.

Note: all links on the page these can be accessed on the digital version of the report available at **nationalgas.com/FutureGrid**

FutureGrid: Closure Report | National Gas

Learning dissemination

Including the project partners and the additional gas networks, the Network Steering Group was set up to meet quarterly. This was to share updates on the project and provide a platform to share learning with the networks.

Information shared by National Gas:

- Fatigue rig maximum operating stress, requested by Cadent.
- Test plan shared with all networks.
- Hydrogen Gas Asset Readiness (H2GAR) project report – requested by all networks.
- Details of FutureGrid shared with NSI – Interventions for Hydrogen by Asset Group.

This report was shared with fellow gas network operators who have provided peer reviews and comments on the contents and discussion around the results. Additionally, this report has been circulated among relevant subject matter experts within National Gas who have also fed back with their knowledge of the gas industry.

Additionally, DNV's flow facility technical report has been shared with the other gas network licensees, and this contains a more technical deep dive into the results of the flow tests and was used by the team in compiling this report. For third parties who require access to DNV's report, please email FutureGrid@nationalgas.com for more details.

For general public consumption, this report will be published on the National Gas website for interested parties to access. The team has published articles, recorded podcasts and held webinars to share learnings from the project and provoke discussions around the testing with key stakeholders.

5% blending:

As the 5% blend testing was formed from an NIA project pathway, the information gathered from testing was to be shared onto the ENA portal as per the Ofgem governance. The project page can be found here

Note: all links on the page these can be accessed on the digital version of the report available at nationalgas.com/FutureGrid

Project Milestones
Events to launch the project, showcase the build and update on the testing programme.

Creating Event Opportunities
Such as the UK / EU event and other collaborative opportunities to showcase FutureGrid & partners.

Industry Events
Energy Networks Innovation Conference, Utility Week and other key Hydrogen / Net Zero Events.

Site Tours
Tours for internal promotion and key external stakeholder engagement and promotion.

SME Development & Knowledge
Active programme of activities and workshop / events to engage and update the SMEs (Subject Matter Experts).

Public Perception & Education
Public facing events and opportunities to educate and promote hydrogen – supporting local events.

Key Project learning documents

For more information on our progress in previous years, the 2021 and 2022 FutureGrid progress reports can be found at nationalgas.com/futuregrid, in the Events and Resources section.

Key documents:

Here you will also find our FutureGrid testing guide, which introduces the decommissioned assets we have used on our facility, along with the testing they have undergone. Additionally, there are FutureGrid podcasts, articles, webinars and blogs to peruse, all of which take a deeper dive into topics such as Net Zero policy, our NTS and the different phases of FutureGrid.

Note: all links on the page these can be accessed on the digital version of the report available at nationalgas.com/FutureGrid

FutureGrid Project Progress Report 2021
Progress report summarising the work done up to the end of 2021.

FutureGrid Project Progress Report 2022
Progress report summarising the work done up to the end of 2021.

FutureGrid Testing Guide
Introduces the decommissioned assets we have used on our facility, along with the testing they have undergone. Also provides an overview of the standalone testing and safety outputs, along with a view to the future with Phase 2 and the implementation of FutureGrid.

FutureGrid Flyover
LinkedIn post showcasing an aerial view of the site.

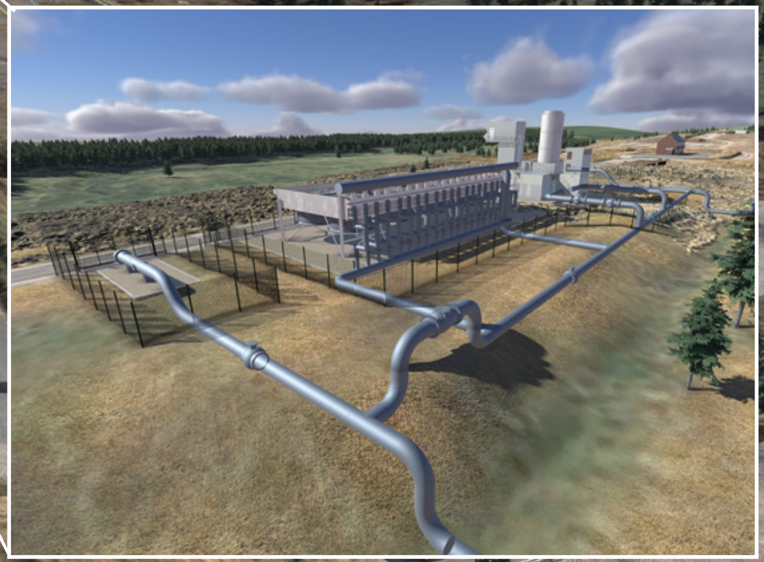
What are the opportunities of a hydrogen gas network?
Find out more about the opportunities that hydrogen presents in the energy industry in this FutureGrid InFocus blog written by Tom Neal (FutureGrid Manager).

Repurposing compression Equipment for hydrogen
FutureGrid Engineer Simon Avery takes us through an update for the project, along with what still needs to be done past Phase 1 for FutureGrid.

How deblending can unlock the power of hydrogen for transport
Phase 2 Deblending Manager Lloyd Mitchell describes the potential of adopting hydrogen for transport and how deblending can support the deployment of hydrogen vehicles across the UK.

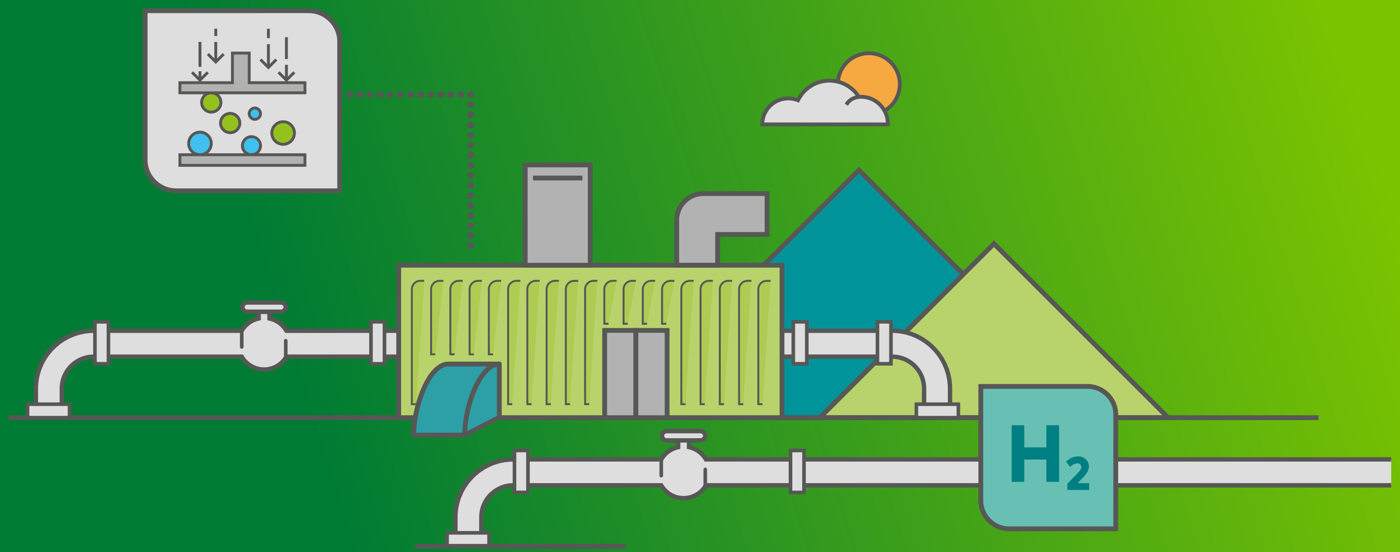
Phase 2 development

Now that Phase 1 testing has been completed there are additional phases planned to adapt the FutureGrid facility and allow for further development. These are essential for understanding how a hydrogen NTS would operate. Designs are well underway at the time of publishing for Phase 2 Compression and Deblending.



FutureGrid

Compression



FutureGrid Compression is a SIF Beta Project that investigates the key challenges associated with compression of hydrogen using existing National Transmission System (NTS) assets. This project has two key aims:

- Demonstrate the hydrogen blend the existing compression fleet can operate at with minimal modification.
- Identify the level of modification that needs to be made to an existing compressor system for it to operate with 100% hydrogen.

Advancing from the successful completion of the award-winning HyNTS FutureGrid Phase 1 project undertaken by National Gas and DNV, expansion of the test facility is vital to demonstrate that hydrogen can be transported safely and securely nationwide, just as it is today for natural gas. The project will develop evidence that our existing compressor fleet can be economically optimised for hydrogen use, by providing a technical demonstration at the Spadeadam facility. New compression systems cost £60m and there are roughly 70 compressor units on the NTS, so the opportunity to demonstrate the repurposing of these assets could significantly reduce the cost of the energy transition.

A decommissioned gas turbine representative of the current fleet will be fuelled by different blends of hydrogen up to 25%, then, following modifications, 100% hydrogen. This will provide technical and safety evidence for the repurposing of our current gas turbine fleet. Following this, the full compression system, including the power turbine, gas compressor and the cab and ancillary equipment, will operate at the Future Grid hydrogen test facility, to demonstrate that the assets can be repurposed for hydrogen blends and 100% hydrogen. A compression test loop will be constructed out of decommissioned NTS assets to test the compressor systems in a range of hydrogen scenarios.

The anticipated benefits of the project are considerable, as it promises to:

- Offer the potential to repurpose gas turbines for hydrogen use, thereby mitigating CO_2 emissions from compressor stations.
- Enhance the resilience of the hydrogen network through the use of existing compression units.
- There are approximately 70 compressor units on the NTS, which would cost £60m to replace.
- Repurpose the assets, which could significantly reduce the cost of the energy transition to the consumer.

This project will demonstrate the capability and adaptability of both the rotating machinery package and the full system, and it will give a comprehensive understanding of their performance within a hydrogen network. It's a strategic step towards formulating a broader strategy for the NTS compression system's transition to hydrogen.

This project will develop evidence that our existing compressor fleet can be modified for hydrogen use in a cost-effective manner.

A decommissioned gas turbine representative of the current fleet will be fuelled by different blends of hydrogen up to 25% then, following modifications, up to 100% hydrogen.

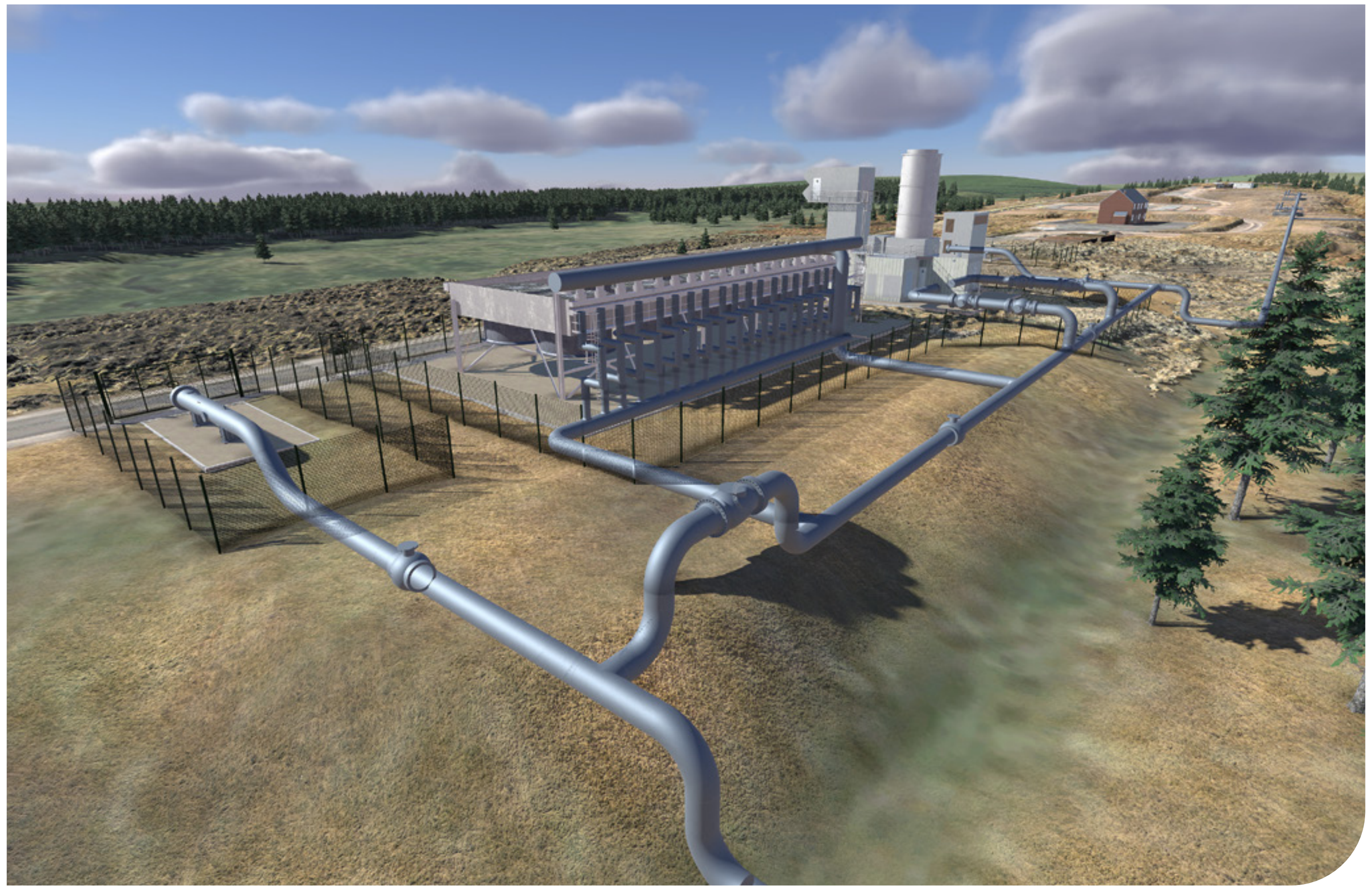
The full compression system including the power turbine, gas compressor, the cab and ancillary equipment will undergo comprehensive offline testing as part of the FutureGrid facility.

A 1km compression test loop will be constructed out of decommissioned NTS assets to test the compressor systems in a range of hydrogen scenarios.

This will demonstrate the capability of both the rotating machinery package and the full system. It will give an understanding of how these would operate on a hydrogen network.

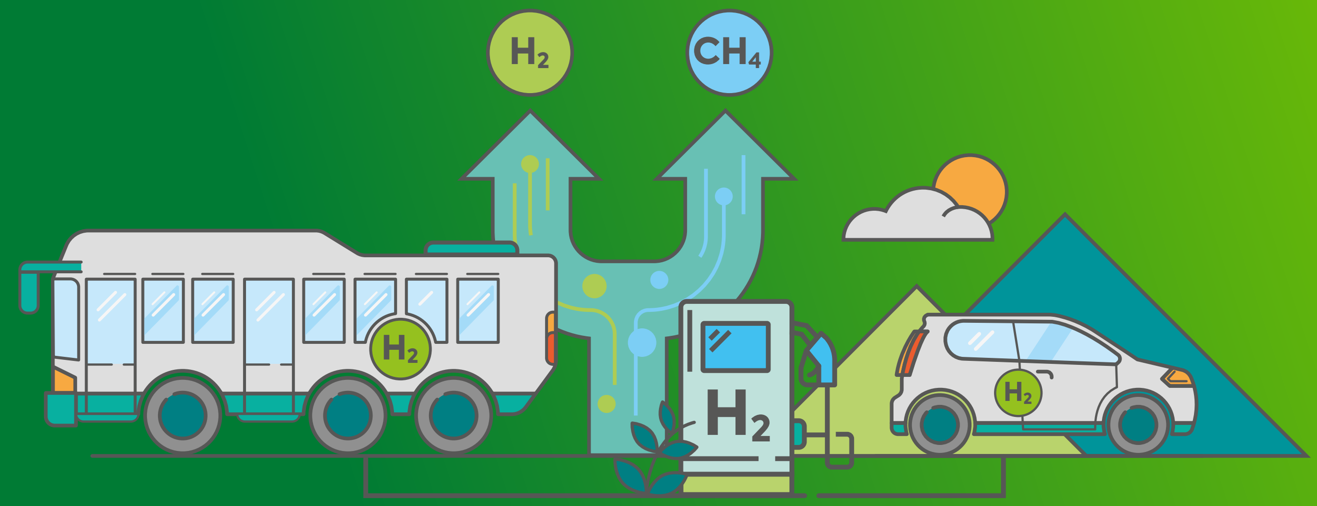
This testing is key to provide technical and safety evidence that demonstrates the compression assets can be repurposed for hydrogen blends up to 100% hydrogen.

The outputs of this project will ultimately help develop the business case for repurposing compression assets as part of Project Union, National Gas 100% hydrogen backbone across the UK.



FutureGrid

Deblending



FutureGrid Deblending for Transport Applications is a SIF Beta Project which will develop an offline test facility to demonstrate the separation, purification and compression of hydrogen to support transport applications. The project will also work with the transport industry to identify the potential routes to deployment of this technology, to support the decarbonisation of transport in the UK.

National Gas has adopted a 'dual pathway' approach to the deployment of hydrogen GB's Gas Transmission System. The first of these two pathways will focus on the conversion of certain pipelines to a dedicated 100% hydrogen supply through Project Union. The second will enable blending of hydrogen up to 20% across the rest of the NTS. This approach enables the rapid decarbonisation Britain's major industrial clusters while continuing to develop a robust hydrogen supply chain throughout the UK.

During this transition, there is expected to be a growing demand for high-purity hydrogen to support the deployment of hydrogen fuel-cell vehicles, particularly in market segments that are less appropriate for battery electrification. The HyNTS FutureGrid Deblending project seeks to enable low-cost hydrogen delivery to these applications through the NTS. The project uses two-stage deblending, a purification process which can be tailored based on the above pathway being considered, as well as the specific transport application being supplied.

The project will demonstrate the full end-to-end process, starting with hydrogen blended into the FutureGrid Test Facility up to concentrations of 20%. The blended gas will then pass through the deblending unit which will extract the gas from the blended gas stream at around 98% purity. This hydrogen stream will then be directed to the purification and compression system which will increase its purity to fuel-cell grade while simultaneously increasing the pressure to 500 bar. This purified and compressed hydrogen will be used to supply a variety of hydrogen vehicles on site ranging from small cars and vans to large plant machinery such as diggers.

Gas separation technology has historically only been used in specific chemical industrial processes and has never been trialled on a variable gas network. Therefore, it is important to demonstrate through the project that the technology can operate with fluctuations in the gas inlet of temperature, flow, pressure and composition. The modularity of this system will be highly valuable when considering potential applications across the UK.

Once the demonstration has been successfully completed, the data gathered will be used to develop a commercial demonstration with one of the many stakeholders engaged throughout the project. This could be the supply of hydrogen to a public refuelling station, bus depot, shipyard or any other location with a large source of difficult-to-decarbonise transport.

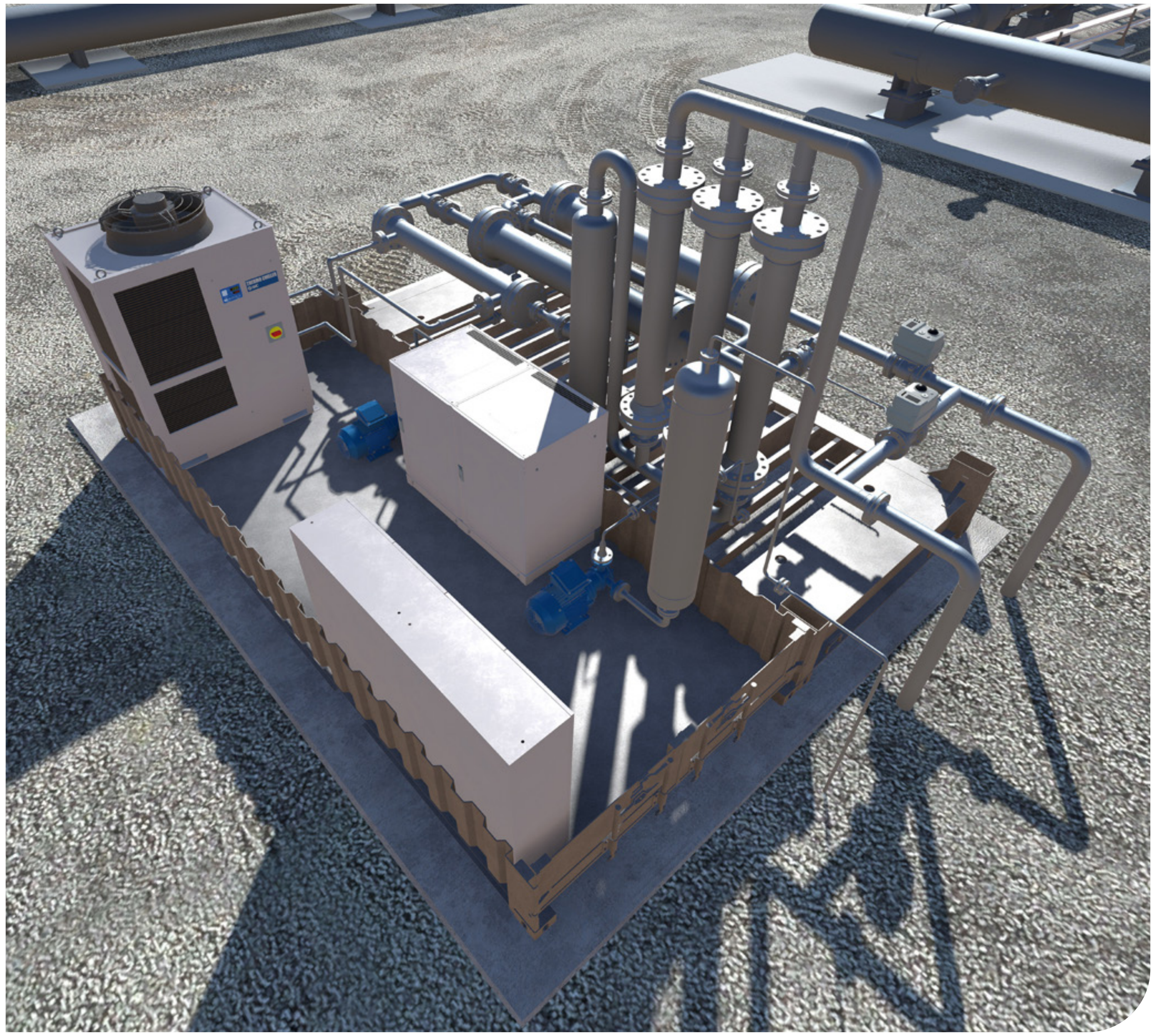
In summary, the Deblending project will provide comprehensive evidence for the use of the NTS to support hydrogen transport applications while working with the industry to identify opportunities to decarbonise UK transport.

This project focuses on the deblending of gases within the high-pressure National Transmission System (NTS) to enable delivery to transport applications.

Without this technology, refuelling of transportation assets will be limited to the use of locally produced hydrogen, until the gas networks can transport 100% hydrogen.

The project will showcase the full process, starting with taking blended transmission gas through the electrochemical separation system which purifies and compresses the gases, culminating in refuelling hydrogen vehicles of a variety of sizes.

The project will also develop low-cost mobile solutions for deblending and purification that can be migrated around the UK networks as we transition to 100% hydrogen.



FutureGrid Governance Checks

As part of the NIC Governance requirements 8.82 National Gas is required to engage a third party to review the project deliverables and assess whether they have been achieved.

To complete this we have engaged QEM Solutions Limited who have undertaken a full review and produced a report which is available upon request (subject to confidentiality requirements). This review was conducted throughout June 2024 across all project outputs. QEM have deemed the project to have successfully achieved all deliverables as highlighted below in the summary table:

Ofgem Deliverables

No.	Deliverable Title	Outputs	Completed	Summary
1.0	Groundworks & construction	As built drawings, written scheme of examination and DNV report of activity & lessons learnt.	Achieved	There is adequate evidence to demonstrate the successful construction of the FutureGrid Test Facility at the Spadeadam site, operated by DNV. The evidence has been provided in the form of several reports following the testing of the facility and its components. The results of testing have been used to evaluate and update QRA models and associated software, although it is recognised in most cases that further research and testing is required a complete and comprehensive pack of as built drawings were available and completed to a good standard. This also included Hazardous Area Drawings.
2.0	Standalone testing & commissioning	Successful completion of testing and commissioning processes with supporting documentation & Dissemination of facility design and layout to allow detailed development of Phase 2 & 3 interactions. The design will not be completed until the build has been completed.	Achieved	The test facility is made up of previously working assets that were removed from different sites around GB, by NG, as part of their decommissioning campaign. The assets are representative of GB's gas transmission system, from the entry point (e.g. onshore gas terminal) to the exit point (e.g. local distribution network). The standalone tests have been completed for permeation, testing pipe coating and cathodic protection, fatigue, asset leakage, as well as rupture testing and flange testing. There is evidence of a comprehensive testing plan being followed for each component.
3.1	Testing 2% hydrogen	Completion of 2% H2 tests identified by the master testing plan inc. launch and close out events. Identification of future test requirements as a result of the findings. Results collated, documented, and validated for impact on next phases of hydrogen development activities.	Achieved	Testing with a 2% hydrogen blend was carried out over 124 days between 6th September 2023 and 7th January 2024.). All tests have been undertaken in compliance with the testing plan.
3.2	Testing 5% hydrogen	Completion of 5% H2 tests identified by the master testing plan inc. launch and close out events. Identification of future test requirements as a result of the findings. Results collated, documented and validated for impact on next phases of hydrogen development activities.	Achieved	Testing with a 5% hydrogen blend was carried out over 11 days between 11th January and 21st January 2024.). All tests have been undertaken in compliance with the testing plan.
3.3	Testing 20% hydrogen	Completion of 20% H2 tests identified by the master testing plan inc. launch and close out events. Identification of future test requirements as a result of the findings. Results collated, documented, and validated for impact on next phases of hydrogen development activities.	Achieved	Testing with a 20% hydrogen blend was carried out over 9 days between 8th February and 16th February 2024. All tests have been undertaken in compliance with the testing plan.
4.1	Testing 100% hydrogen	Completion of 100% H2 tests identified by the master testing plan inc. launch and close out events. Identification of future test requirements as a result of the findings. Results collated, documented, and validated for impact on next phases of hydrogen development activities.	Achieved	Testing with 100% hydrogen was carried out over 8 days between 22nd February and 29th February 2024. All tests have been undertaken in compliance with the testing plan.
5.0	QRA & safety case	Overpressure testing on secondary offline NTS test facility. Validation of results into the existing QRA model and any mitigations reviewed (updated QRA and mitigation log). High-level review of NGGT's policies and procedures documented. Prepare a commented version of the safety case. Updated asset assessment and hydrogen risk review.	Achieved	There is evidence that overpressure testing has been carried out and reported to a good standard. Details of the experiments are well described in Hazard Assessment of the National Gas System for Operation with Hydrogen Report. The results and analysis of all release testing (Transient and Steady State) is also described and complimented by photographs and graphical representation. A similar comprehensive approach has been used for Overpressure analysis and Thermal Radiation.
6.0	Knowledge dissemination	Overpressure testing on secondary offline NTS test facility. Validation of results into existing QRA model and any mitigations reviewed (updated QRA and mitigation log). High-level review of NGGT's policies and procedures documented. Prepare a commented version of the safety case. Updated asset assessment and hydrogen risk review.	Achieved	To support this requirement NG have adopted a 'digital first' approach to engagement and dissemination which is consistent with the Network Innovation Competition. The approach has 4 key pillars: • FutureGrid Explore • FutureGrid InFocus • FutureGrid Feature • FutureGrid Chat There is sufficient evidence to demonstrate this Deliverable has been achieved, as intended, following a review of the evidence provided.
7.0	Comply with knowledge transfer of the Governance Document	Annual Project Progress Reports which comply with the requirements of the Governance Document. Complete Close Down Report, which complies with the requirements of the Governance Document. Evidence of attendance and participation in the Annual Conference as described in the Governance Document.	Achieved	Two Annual progress Reports have been provided and reviewed. These are comprehensive and compiled to meet the requirements of this Deliverable, namely, FutureGrid Project Progress Report December 2021 which is available of the ENA website and FutureGrid Project Progress Report November 2022. There is evidence that NG have attended many relevant conferences, of both Industry specific events and Innovation conferences which are recorded within the FutureGrid Project Action Tracker.

IPR

The results and outputs from testing on both the Standalone Hydrogen Test Modules and Offline Hydrogen Test Facility have generated IPR throughout the duration of the project in addition to outputs relating to the safety case.

This IPR is contained in the detailed technical reports compiled as part of the project. These are held by National Gas and, where relevant in accordance with NIC Governance Document v3.1, will be shared freely to facilitate and accelerate knowledge dissemination. Where there is commercial interest outside of the requirement to freely share and disseminate, a royalty will be sought in order to access this information and will be returned to the consumer. In addition, the FutureGrid Closure Report has been made in accordance with NIC Governance Document v3.1, which contains a key overview of the project and outcomes. This will be made available on our website **nationalgas.com/FutureGrid**.

Background IPR exists within the equipment used to construct the FutureGrid Test Facility and will remain the property of the supplier(s) as part of the commercial product. Knowledge and experience from the DNV and HSE-SD from other NIA and NIC funded projects will constitute background IPR. It will be fed into FutureGrid and, according to the respective governance arrangements, will be freely available to be accessed by the FutureGrid project. There is also background IPR in relation to the hydrogen research provided by Fluxys as part of their in-kind contribution to FutureGrid.

Material change

The overall project was completed on budget and there has not been an overall delay by more than 1 year. This means the overall project has not had a material change.

However, as highlighted in the FutureGrid 2022 Progress Report, there were several deliverables in the project which have had a delay due to those deliverables extending by more than 1 year than the dates stated in the initial project bid submission. They were on the risk register and were closely monitored and mitigated where necessary to minimise the likelihood and associated consequences of them occurring.

A major delay in the construction and commissioning phase of the project was due to Covid-19 causing global volatility to supply chains. Unfortunately, the risk to the construction of the outer container (shell) of the recompression unit materialised in September 2022. The manufacturer, LMF, had exhausted all mitigation options to reduce the impact to the programme and minimise the delay. Despite LMF's best efforts, the outer container caused a delay of more than 1 month to the recompression unit delivery.

During the commissioning stage of the project, the availability of specialist third parties required to complete critical activities and considerations for other scheduling issues, such as site closure for Christmas and weather impact for commissioning activities, had caused further delay. This had a knock-on impact to Ofgem deliverables 1.0 and 2.0, causing them to be delayed.

In the testing phase of the project, there were unforeseen issues on the recompressor unit. Testing had to be paused while the problem was analysed. It was discovered that certain parts of the recompressor unit had unexpected issues and would need to be replaced. This meant that the recompressor unit had to be isolated and depressurised, then the parts were received from LMF in Austria. Once the parts had been replaced, the recompressor had to run for a few hours before testing could resume. These issues had an impact on Ofgem deliverable 4.0, causing it to be delayed.

Data access details

Details on network or consumption data arising in the course of an NIC or NIA-funded project can be requested by interested parties, by emailing **.box.GT.innovation@nationalgas.com**.

National Gas already publishes much of the data arising from our NIC/NIA projects at **smarter.energynetworks.org**.

In addition to this, as part of the communication and engagement plan, NG has held webinars for the purpose of sharing knowledge throughout the duration of the project. We plan to continue these events as the project continues. There are also specific events planned for the completion of different blends of hydrogen. These webinars and events will be open to all interested parties.

We have also set up a shared email box in which any queries about the project can be addressed. The email is: **futuregrid@nationalgas.com**.

The website **nationalgas.com/futuregrid** also contains presentations, videos, files and images relevant to the project which can be accessed by interested parties.

Accuracy Assurance Statement

This report has been prepared in accordance with the Network Innovation Competition (NIC) Governance Document v3.1 published by Ofgem. The report has undergone a review and challenge from the FutureGrid Steering Group. This has also been reviewed and signed off by Gary Tomlin, the Project Sponsor for DNV.

I can confirm that the process followed to compile and review this report is compliant with the control requirements outlined above and the report is robust, accurate and complete.

Corinna Jones
Head of Innovation

Date: July 2024

Contact Details

For further information about the project and to request a copy of the full technical report (please note restrictions apply to free access), please get in touch with the team:

FutureGrid@nationalgas.com

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Note: all links on the page these can be accessed on the digital version of the report available at **nationalgas.com/FutureGrid**

Appendix 1

Acronym Key

Acronym	Definition	Acronym	Definition
AGI	Above Ground Installation	NDT	Non-destructive Testing
ALARP	As Low As Reasonably Practicable	NGN	Northern Gas Networks
ASME	American Society of Mechanical Engineers	NGS	National Gas Services
CO_2	Carbon dioxide	NG	National Gas
DNV	Det Norske Veritas	NIA	Network Innovation Allowance
ENA	Energy Networks Association	NIC	Network Innovation Competition
EU	European Union	NTS	National Transmission System
FAT	Factory Acceptance Test	OFGEM	Office of Gas and Electricity Markets
GB	Great Britain	PIG	Pipeline Inspection Gauge
GDN	Gas Distribution Network	PMC	Pipeline Maintenance Centre
GSMR	Gas Safety Management Regulations	PPR	Project Progress Report
H2 GAR	Hydrogen Gas Asset Readiness	PSI	Pound per Square Inch
HAMM	Hazard Assessment Methodology Manual	PSR	Pipeline Safety Regulations
HATS	Hazardous Assessment of the Transmission System	PSSR	Pressure Systems Safety Regulations
HSE	Health and Safety Executive	QRA	Quantitative Risk Assessment
HSE-SD	Health and Safety Executive – Science Division	R&D	Research and Development
HyNTS	Hydrogen in the National Transmission System	RF	Raised Face
ILI	In Line Inspection	RTJ	Ring Type Joint
IPR	Intellectual Property Rights	SAT	Site Acceptance Test
IPRM	Internal Project Review Meeting	SCADA	Supervisory Control and Data Acquisition
IT	Information Technology	SIF	Strategic Innovation Fund
LMF	Leobersdorfer Maschinenfabrik	SME	Subject Matter Expert
LSAW	Longitudinal Submerged Arc-Welding Pipe	TSOs	Transmission System Operators
MAPD	Major Accident Prevention Document	TWh	Terawatt hour
MOP	Maximum Operating Pressure	UK	United Kingdom
MPI	Magnetic Particle Inspections	UT	Ultrasonic Testing

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