Gas
Transmission

Hydrogen Blends in the NTS
A theoretical exploration

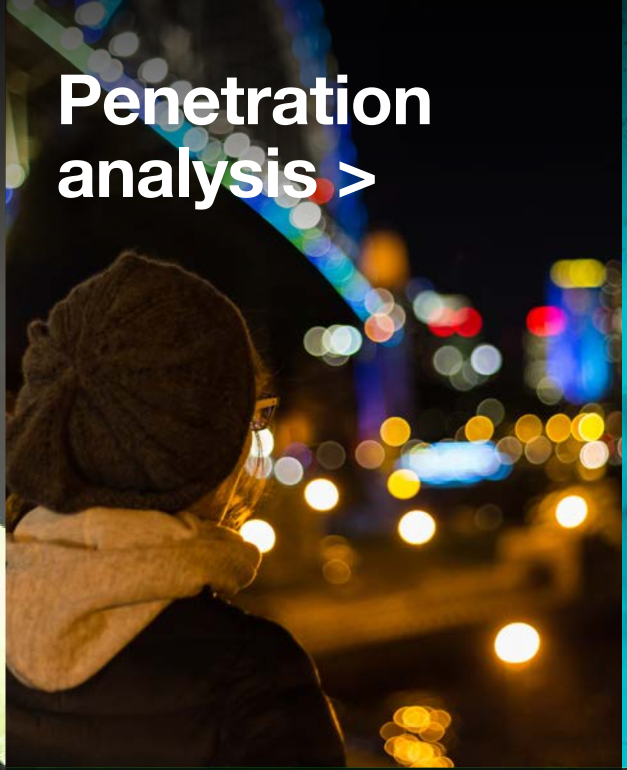
Gas Future Operability Planning

October 2021

nationalgrid

GFoP Report
September 2021

Welcome and introduction >



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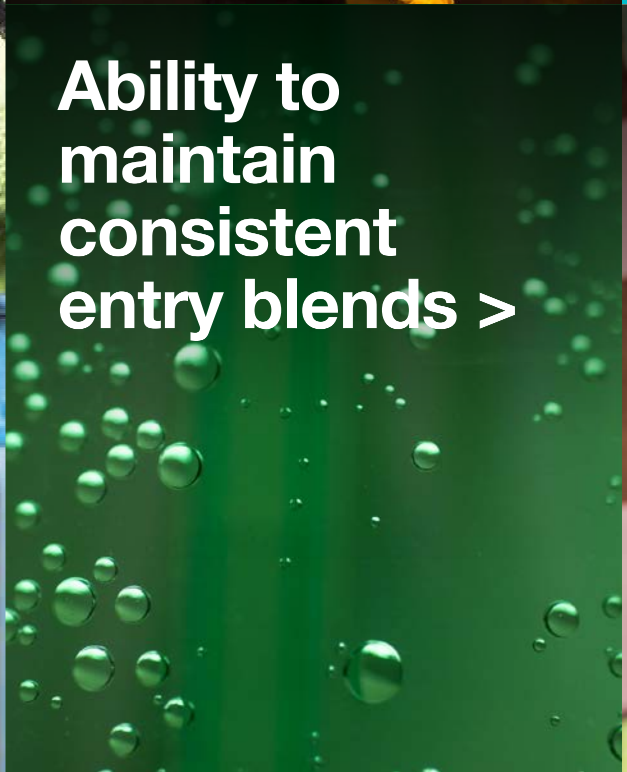

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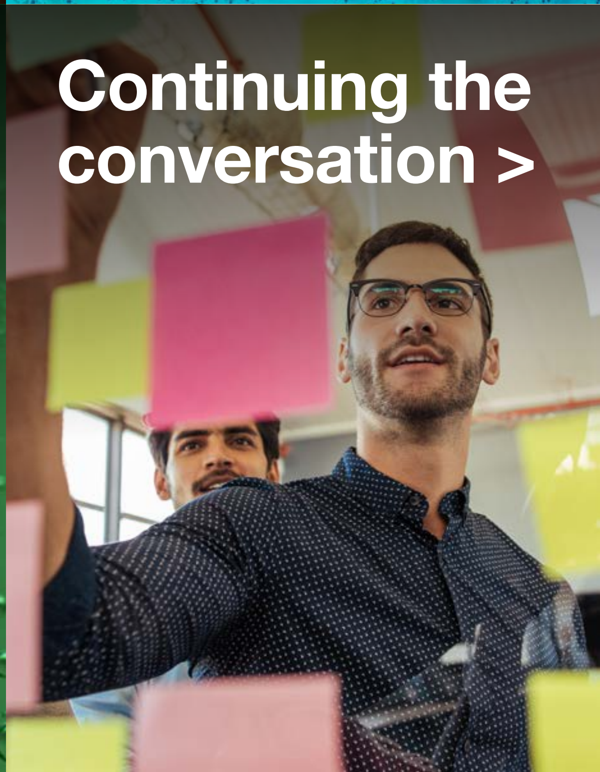

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How to use this document

We have published the *Gas Future Operability Planning (GFoP)* publication as an interactive document.

Home

This will take you to the home page.

Arrows

Click on the arrows to move backwards or forwards a page.

Enlarge/reduce

Hover over the magnifying icon to make charts bigger or smaller.

Glossary

Defined words and additional information (indicated by) can be viewed by clicking the yellow book symbol in the left-hand navigation bar.

'Linked' content

Words in light blue and underlined have links to other pages in this document, or are URLs.

Welcome

Welcome to our *Gas Future Operability Planning (GFoP)* publication

The Gas Future Operability Planning (GFoP) is a periodical publication delivered by the National Grid Gas System Operator. GFoP aims to shape the debate on how the changing energy landscape could impact the operability of the gas National Transmission System (NTS).

The Government's Hydrogen Strategy highlights the significant role blending could play in the development of the hydrogen economy. The purpose of this publication is to share insights that will help inform the debate on hydrogen blends in the NTS. We will explore the impact of potential hydrogen blends in terms of the penetration into the network for different scenarios. This publication is designed to inform the energy industry, and engage with customers and stakeholders.

I hope you find this publication both interesting and informative. Throughout this document we ask for your thoughts to help shape a net zero future and I encourage you to share your views with us.

You can find details of how to do this at the end of this document in Continuing the Conversation. Please also contact us directly via .box.OperationalLiaison@nationalgrid.com.

Other Gas System Operations publications in this suite include:

- ***Annual Network Capability Assessment Review (ANCAR)***, with the first report published in June 2021.
- ***Winter Outlook***, published annually, with the next due in October 2021.
- ***Gas Ten Year Statement (GTYS)***, with the next due in November 2021.
- ***Network Capability Annex***, published alongside GTYS, with the next due in November 2021.
- ***Summer Outlook***, published annually, with the next due in March 2022.

Ian Radley
Systems Operations Director

Contribution to debate

Figure 1

The last edition of the *Gas Future Operability Program (GFoP)* titled Enabling Net Zero explored how increasing low carbon gases in the gas networks could enable net zero carbon emissions. The publication in particular focussed on two potential roles the National Transmission System (NTS) could play in a net zero future:

1. A natural gas NTS or

2. A hydrogen NTS.

In this edition we have conducted a theoretical exploration of the impact of hydrogen supplies on the NTS in terms of the penetration into the network for different scenarios.

- We investigate the impact on the NTS from theoretical hydrogen supplies at Bacton and St Fergus.
- We explore a terminal injection blend percentage of 2%, 5% and 20% between the two terminals.
- We assess the impact of users that engage in deblending activity on the blend percentages in the NTS.

This topic has high interest among National Grid's stakeholders and customers. The Government has set a blending target for 2023 in its Ten Point Plan. A target to work with industry to complete the testing necessary to allow up to 20% blends of hydrogen into the gas distribution networks. You can find it here.

The Government's Hydrogen Strategy highlights the significant role blending could play in the development of the hydrogen economy. How can the NTS aid this exploration and does the NTS have a role to play in hydrogen blends? You can find it here.

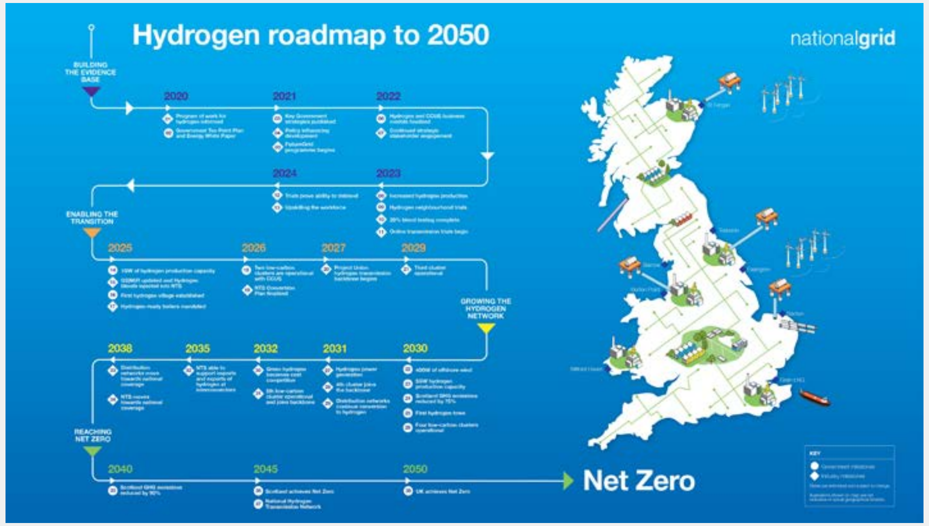
The aim of the publication is to share insights that will help inform debate, particularly in the following areas:

- Are we going to see a consistent blend?
- Do we need to maintain a consistent blend?
- What blends and how much fluctuation can different customers expect?
- What blend percentages in the NTS would be appropriate?

It is important to note that this publication only focusses on the operation of the network. It does not look into markets or regulatory arrangements neither does it consider asset requirements for operating a blended network. A much broader programme of works is currently ongoing within National Grid which encompasses asset requirements, markets and the commercial arrangements for blending in the context of the NTS. This will unlock the potential of hydrogen to deliver on the pathway to the UK's 2050 net zero targets.

This publication is an exploratory piece of work and should be considered as an exercise to highlight the operational impact on the NTS from blending.

Figure 1
Hydrogen roadmap to 2050



Some ongoing work:

FutureGrid: HyNTS
Hydrogen in the NTS

Hydrogen GMaP
Hydrogen Gas Market Plan

Three themes

For the purpose of this document we will explore the impact of hydrogen blends on the NTS along three themes.

Theme 1: Penetration analysis

Blend scenario: Hydrogen blends injected at selected terminals at certain percentages. In this scenario:

- Hydrogen supplies are blended at St Fergus and Bacton.
- Other entry points on the NTS supply only natural gas.
- Bacton Interconnectors receive the blend available when exporting.
- Terminal injection blend percentages of 2%, 5% and 20% by volume.

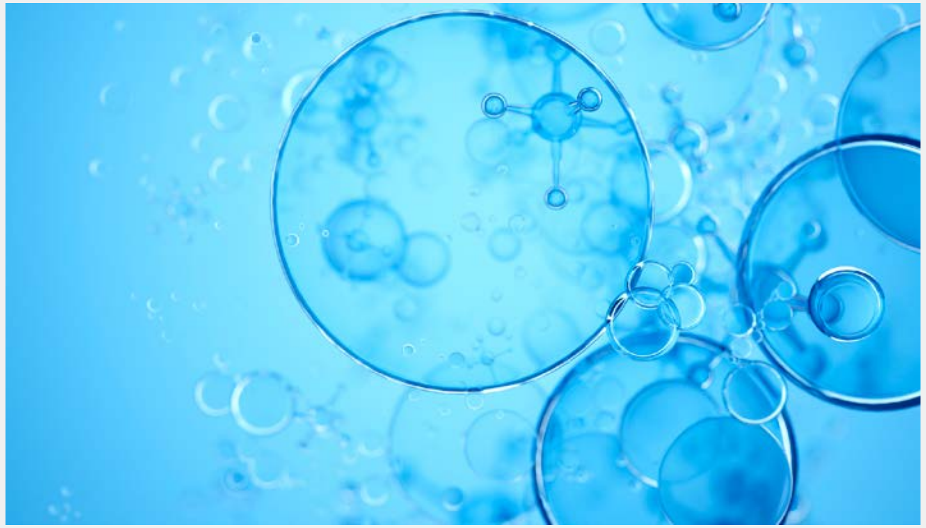
Theme 2: Impacts of deblending

Deblend scenario: Certain customers only take natural gas and re-inject hydrogen into the NTS. In this scenario:

- Deblending is done at the Irish Interconnector in the North West and at Peters Green Distribution Network (DN) offtake in the South East.
- The Irish interconnector receives only natural gas.
- Hydrogen supplies are injected at St Fergus and Bacton.
- Other entry points on the NTS supply only natural gas.
- Bacton Interconnectors receive the blend available when exporting.
- Terminal injection blend percentages of 2%, 5% and 20% by volume.

Theme 3: Ability to maintain consistent entry blends

In this section, we have used recent historic data to understand the challenges of maintaining a consistent hydrogen blend at an entry terminal. This section looks to draw out the challenges this may present for hydrogen producers and terminal operators.



Note: Hydrogen has a higher energy content than natural gas but is less dense, meaning that roughly three times the volume of hydrogen is needed to generate the same amount of energy as natural gas.

	Hydrogen	Natural Gas
Chemical formula	H_2	70-90% CH_4
Density (kg/m³)	0.0838	0.716
Molecular weight (g/mol)	2.02	16.043
Energy per mass (KWH/Kg)	109	13.8
Methods of production	• Steam Methane Reforming (SMR) • Autothermal Reforming (ATR) • Electrolysis • Gasification	• Hydrogenation of CO_2 • Anaerobic Digestion • Gasification

Penetration analysis

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Blend scenario: Penetration behaviour is consistent across the different blends

Figure 2

Key observation

- Distance of penetration is consistent regardless of the start percentage.
- Changes in the blend levels are dependent on the operating strategy and flow levels from terminals without a hydrogen blend.

In this scenario, the blended gas is injected into the NTS at St Fergus and Bacton while other entry points have only natural gas.

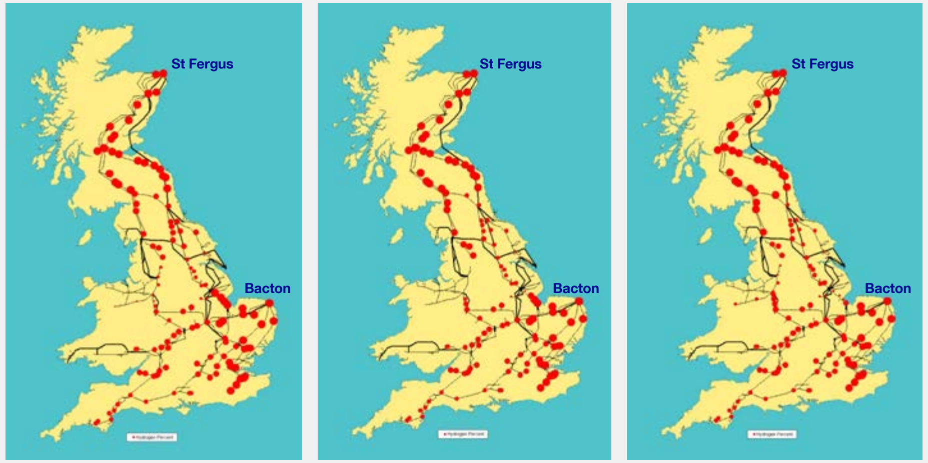
The first point to notice in figure 2 is that we see the same penetration throughout the network regardless of blend percentage. The scale on each of the diagrams has been set to be the same. This is to show, that regardless of the blend percentage, the penetration behaviour is the same.

The scenario demonstrates that irrespective of concentration, once hydrogen is blended into a supply it can be expected that some hydrogen will penetrate a long way into the network, although the concentration will decrease with distance as it blends with gas from other terminals.

In addition the configuration of the network in terms of compressor usage and regulator settings will also influence where the gas from a particular supply terminal will be directed, with the NTS generally being pre-disposed particularly towards the south and south east.

Figure 2
Different hydrogen blends injected into the NTS

20% Hydrogen Blend	5% Hydrogen Blend	2% Hydrogen Blend



The diagrams above show the NTS and the various blend percentages injected into the network at St Fergus and Bacton.

The bubbles in the diagram are offtake points and the bubble size is proportional to the percentage hydrogen at the offtake.

Point to note: the scale on each of the diagrams has been set the same.

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Blend scenario: Average winter day findings

Figure 3 and 4

We have considered an average winter day to understand the behaviour of hydrogen blend in the NTS. The bubbles in figures 3 and 4 depict the concentration of hydrogen.

The analysis shows the following:

1. Looking at the flow of gas from St Fergus and Bacton, we see a consistent hydrogen blend, depicted by the similarly sized bubbles. However the blends percentage decreases as it gets to the Midlands.
2. The reduced levels of hydrogen in the Midlands are due to the levels being diluted by natural gas entering the system at Teesside, Easington and Barrow. A hydrogen blend entering the network at these points would impact the blend levels shown in the Midlands.
3. The more natural gas that enters the network without hydrogen, the more diluted the blend will become. For example if there is an aim to achieve a 20% blend in the network, then most offtakes will not get 20% if there are limited points of blended supply.
4. We have to be mindful that, supply and demand patterns can change dramatically depending on the day, and we would see a different set of results for different supply and demand patterns.

Figure 3
20% hydrogen blend at St Fergus and Bacton on a winter day

20%
Hydrogen Blend

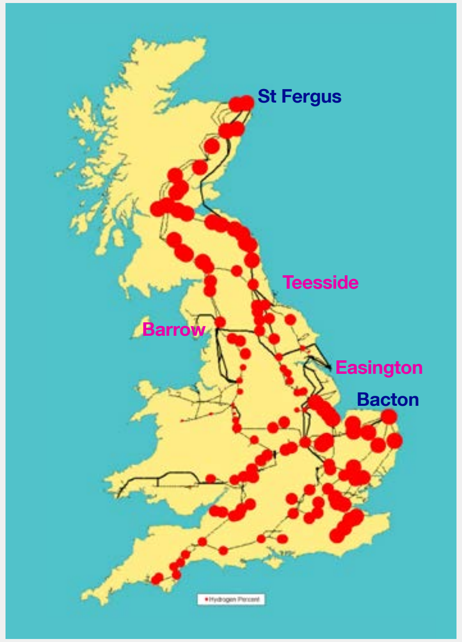


Figure 4
5% hydrogen blend at St Fergus and Bacton on a winter day

5%
Hydrogen Blend

Blend scenario: Average summer day findings

Figure 5 and 6

In the summer, blended gas from St Fergus permeates more significantly into the NTS. Figure 5 shows how gas from St Fergus is seen to travel further into the network in the summer when compared to the winter with higher percentages of hydrogen seen in the North West and North East.

The reason for greater penetration into the network in summer is mainly due to low demands not taking the supply away, so the blended gas at high concentration penetrates further into the network.

However, the percentage of gas supply coming from St Fergus is also higher in this scenario, and this will also have affected the extent of penetration of blended gas from St Fergus into the NTS.

It is also seen that this behaviour is not replicated by the blends coming from Bacton. The percentage supply from Bacton is also greater than other supply points, but there is a large interconnector export element in the summer scenario which therefore limits the penetration of blended gas from Bacton into the NTS.

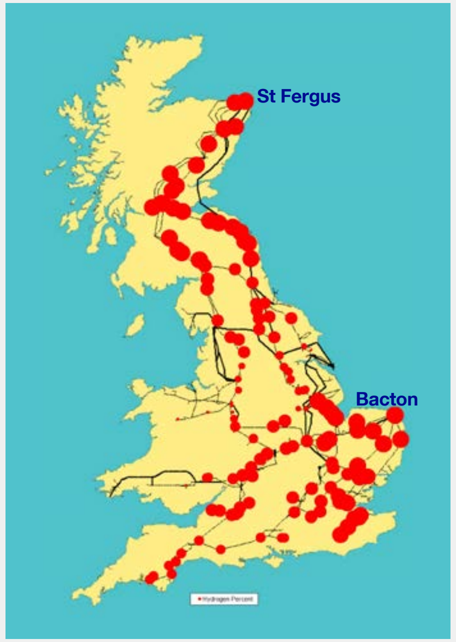
Point to note: the bubbles only appear on offtakes with a demand, and for the summer there are several offtakes with zero demand.

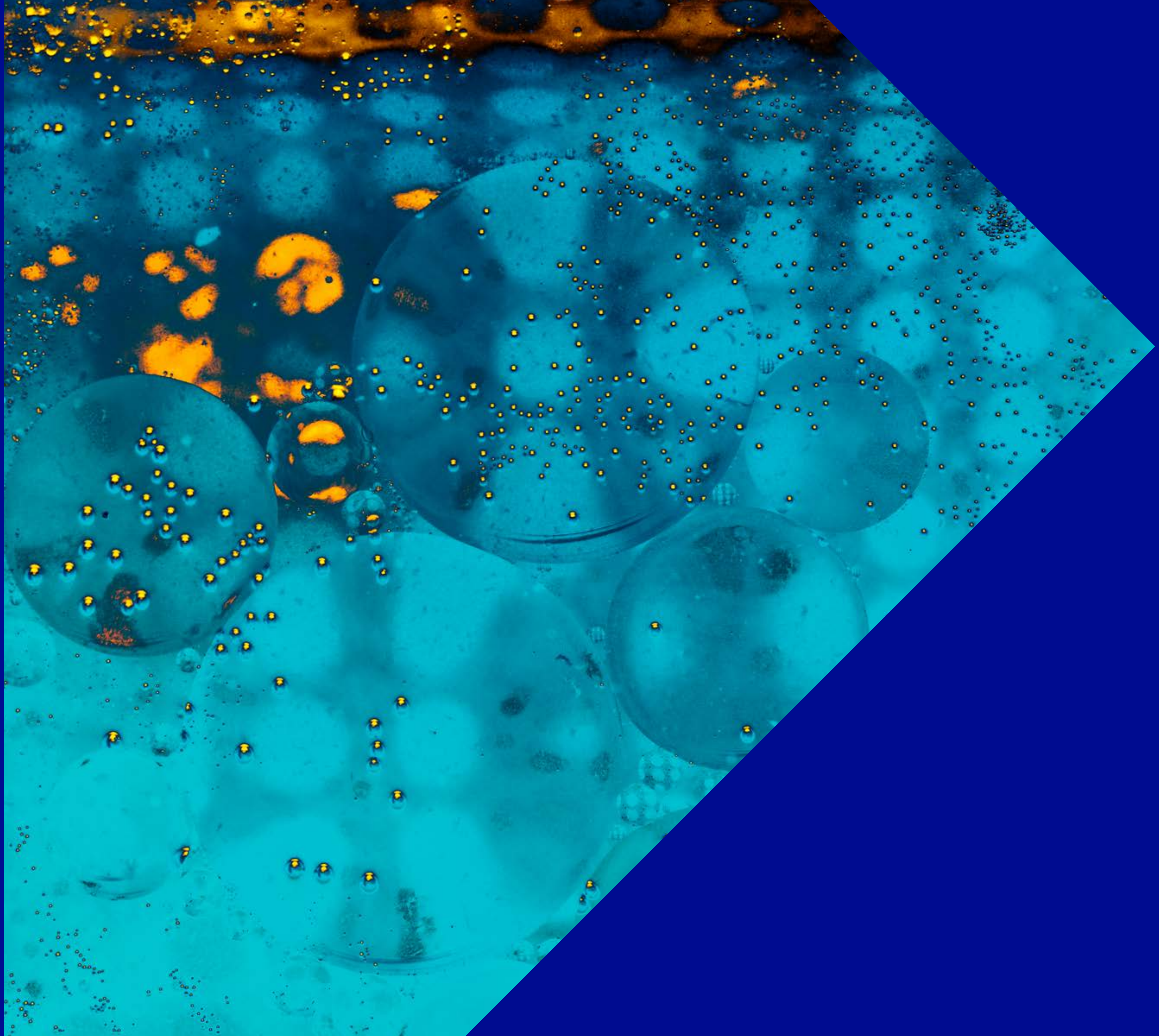
Figure 5
20% hydrogen blend in the NTS on a summer day

20%
Summer

Figure 6
20% hydrogen blend in the NTS on a winter day

20%
Winter





Impacts of deblending

Deblending

Deblending technology

There is growing industry momentum that deblending technology could be installed on the gas networks to enable a wider rollout of hydrogen blending on the gas networks in a hydrogen transition.

Deblending technology could play a pivotal role in the rollout of hydrogen blending by:

- Protecting customers from receiving a hydrogen blend. Customers who are sensitive to gas quality fluctuations or require methane feedstock could be shielded from receiving a hydrogen blend through the installation of deblending technology. By protecting specific customers from receiving a hydrogen blend, this technology could in turn enable a wider rollout of hydrogen blending on the gas networks.
- Deblending technology could enable customers (who may be sensitive to gas quality fluctuations) to receive a consistent hydrogen blend (for example a consistent 2% hydrogen blend).
- Providing customers with 100% hydrogen. Some customers, such as hydrogen transport refuelling stations, could benefit from using deblending technology to extract from blended gas networks pure hydrogen at the required gas quality specifications for fuel cell vehicles.

The FutureGrid project aims to incorporate a physical trial of deblending technology as part of the second stage of the project.

Deblend scenario considered

We have gone further to understand the penetration behaviour in the case of deblending. In this scenario certain customers only take natural gas from the NTS and reinject the hydrogen back into the network.

- The deblend was done at the Irish Interconnector Moffat in the North West and at Peters Green in the South East.
- The Irish interconnector received only natural gas.
- Hydrogen supplies were injected at St Fergus and Bacton at 20%.
- Other entry points on the NTS supplied only natural gas.
- Bacton Interconnector received the blend available.

These offtakes were chosen due to:

- The size of the offtakes.
- The Irish interconnector receives an undiluted percentage from St Fergus.
- Peters Green receives a diluted percentage from Bacton.
- Peters Green is at the end of a pipeline.

These offtakes therefore allow us to test multiple scenarios from just two offtakes.

Deblend scenario: Sensitive to gas interactivity

Figure 7

Key observation

- Re-injection of deblended hydrogen could lead to localised higher concentrations.

The deblend at the Irish interconnector took only natural gas, and the offtakes local to the interconnector all took the blend available from the connecting pipeline.

Figure 7 shows that what we find is a localised higher concentration of hydrogen in the area where deblending occurred (pipes shown in green). In this scenario the blend goes as high as 30% in that localised area of the network. This can be attributed to the fact that most of the 20% blend from St Fergus penetrates down to the Irish Interconnector and because St Fergus is a single point of supply with little gas flowing north. When deblending takes place and hydrogen is reinjected, there is a localised higher concentration of hydrogen.

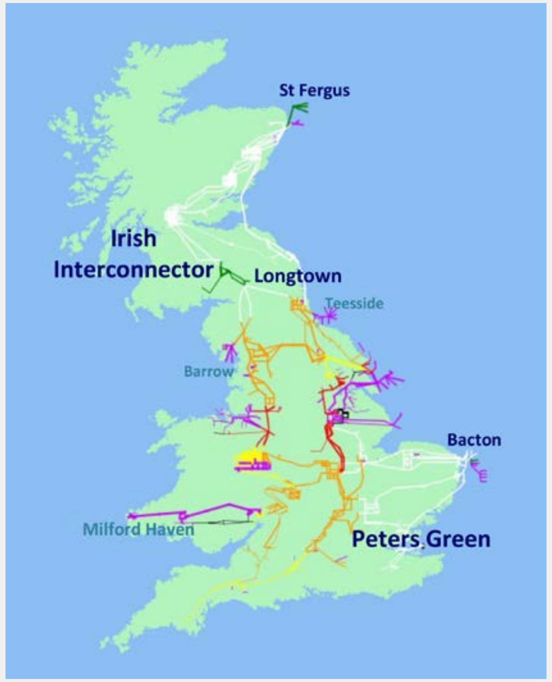
This 30% blend may not be acceptable and may need to be controlled. This might result in lower concentrations being required in other areas or at the entry terminals in order to ensure a limit is not breached.

The re-injected concentration at the Irish Interconnector continues until Longtown. It is at this point gas from the Teesside and Barrow supply terminals begins to reduce the blend concentration back towards 20%. This highlights the possibility that some areas on the NTS could be more sensitive to gas interactivity. For example, gas coming from Milford Haven will stay consistent until it interacts with gases from other parts of the network, which at the earliest could be at Wormington or Churchover.

In this theoretical study we have shown that reinjecting deblended hydrogen could be a challenge. However, it is unlikely that deblended hydrogen will be reinjected into the network because of the likely requirement for re-pressurising the hydrogen. There are many pathway options for hydrogen deblended from the gas network which are later discussed in this study. Furthermore, there is an on-going industry deblending study considering this.

Figure 7
The NTS depicting the various blends

20%
Hydrogen blend was injected into the network at St Fergus and Bacton.



The diagram above shows the NTS and the various blends in the network.

- The green pipes are areas of the NTS between **21–30%**
- The white pipes are areas between **15–20%**
- The orange pipes are areas between **10–15%**
- The yellow pipes are areas between **5–10%**
- The red pipes are areas between **1–5%**
- The black pipes are areas between **0.1–1%**
- The purple pipes are areas between **0–0.1%**

Deblend scenario: Peters Green

Figure 8

The deblend behaviour that occurs at Peters Green varies from the findings at the Irish Interconnector. In this scenario the percentage of hydrogen at Peters Green has been reduced due to it mixing with gas from other terminals, like Easington.

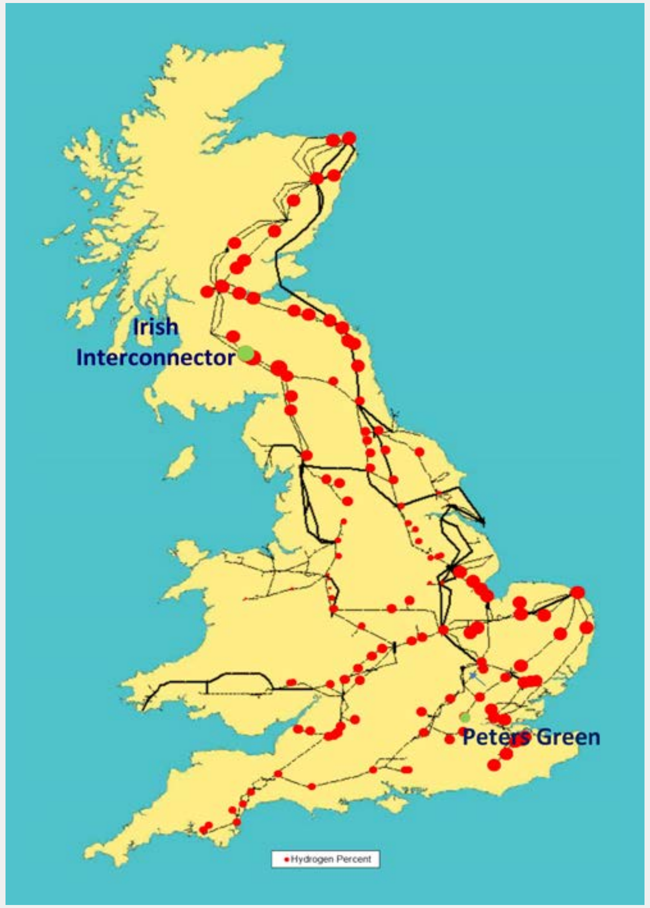
The blend that gets to Peters Green from Bacton, dropped to 11% from a 20% blend at the supply point. However, when deblending is done, we get the same effect of an increase in localised concentration but because the gas going to Peters Green is less concentrated, the blend in the area stays within the required 20%.

A point to note is Peters Green is at the end of a pipeline. A question this raises is: "If off-takes at the end of the pipeline do not want hydrogen, how will this be handled?"

As mentioned earlier, it is unlikely that deblended hydrogen will be reinjected into the network. However, in this theoretical study we have considered it and discuss possible solutions on the next page.

Figure 8
20% hydrogen blend in the NTS. Deblend at Irish Connector and Peters Green

20%
Deblend



Deblend scenario: Localised concentration

It is important to note that, the localised higher concentration we find is based on the assumption that when there is deblending at an offtake, the hydrogen is reinjected back into the network.

There could be alternative commercial arrangements, where:

- both natural gas and hydrogen can be taken.
- the hydrogen remaining after deblend may go into the distribution network, or it could be used in a different way like being sold to a transport or industrial customer or where 100 per cent hydrogen is required such as Project Union.
- another option could be to re-inject at another convenient part of the NTS. This may mean having to lay new pipes.

The analysis has shown that if we assume a consistent blend in the network, and we then deblend, there could be localised concentration spikes at re-injection points.

Ability to maintain consistent entry blends

Entry blends: St Fergus

Figure 9 Figure 10

Key observation

Achieving a consistent entry blend may require:

- Adapting the production profile
- The use of hydrogen storage

In this section, we use recent historic data to understand the challenges of maintaining a consistent hydrogen blend at an entry terminal. This is necessary as National Grid does not control the level of natural gas supply at a terminal, which is determined by the market. Supply fluctuates over the year with higher supplies normally seen in the winter and lower supplies in the summer, together with significant day to day variation. This section looks to draw out the challenges this may present to maintain a consistent blend level. A 2% hydrogen blend is considered in this example.

In 2019/20 the average winter flow at St Fergus was 57.8mcm/d. A 2% hydrogen blend at this level would amount to 1.2mcm/d flow of hydrogen, assuming hydrogen production remains static throughout the year.

From the diagrams, we can see in the summer months the blends are slightly more than 2% but rarely go above 3%. In the winter they remain steady at 2% and slightly lower. Although, we had a two week period in the summer of 2020 (August) when the blend at the entry point would have doubled and peaked at a high of 9%, later on in the winter the blend would have dropped well below 2%.

Questions

1. How then do we maintain a consistent 2% at St Fergus?
2. Does it matter that it is not a consistent blend?

We believe a consistent blend would be helpful for the gas industry – over the next few pages we suggest how we could achieve this.

Figure 9
1.2mcm hydrogen in the NTS at 2% blend (April 2019 – July 2021)

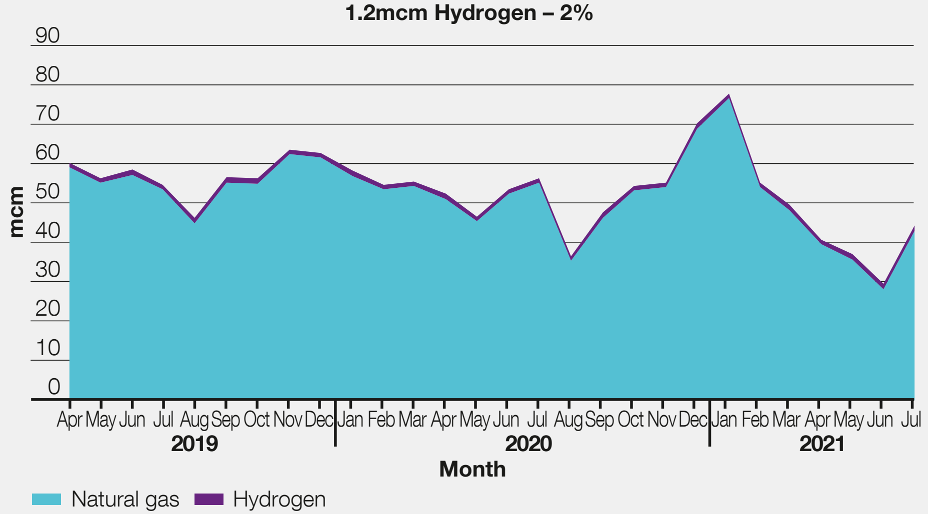
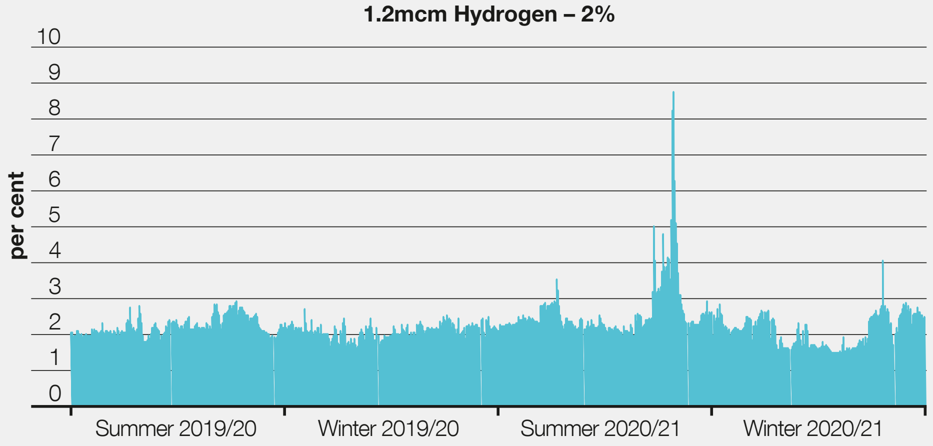


Figure 10
Daily Hydrogen per cent at consistent 1.2 mcm/d injection (April 2019–March 2021)

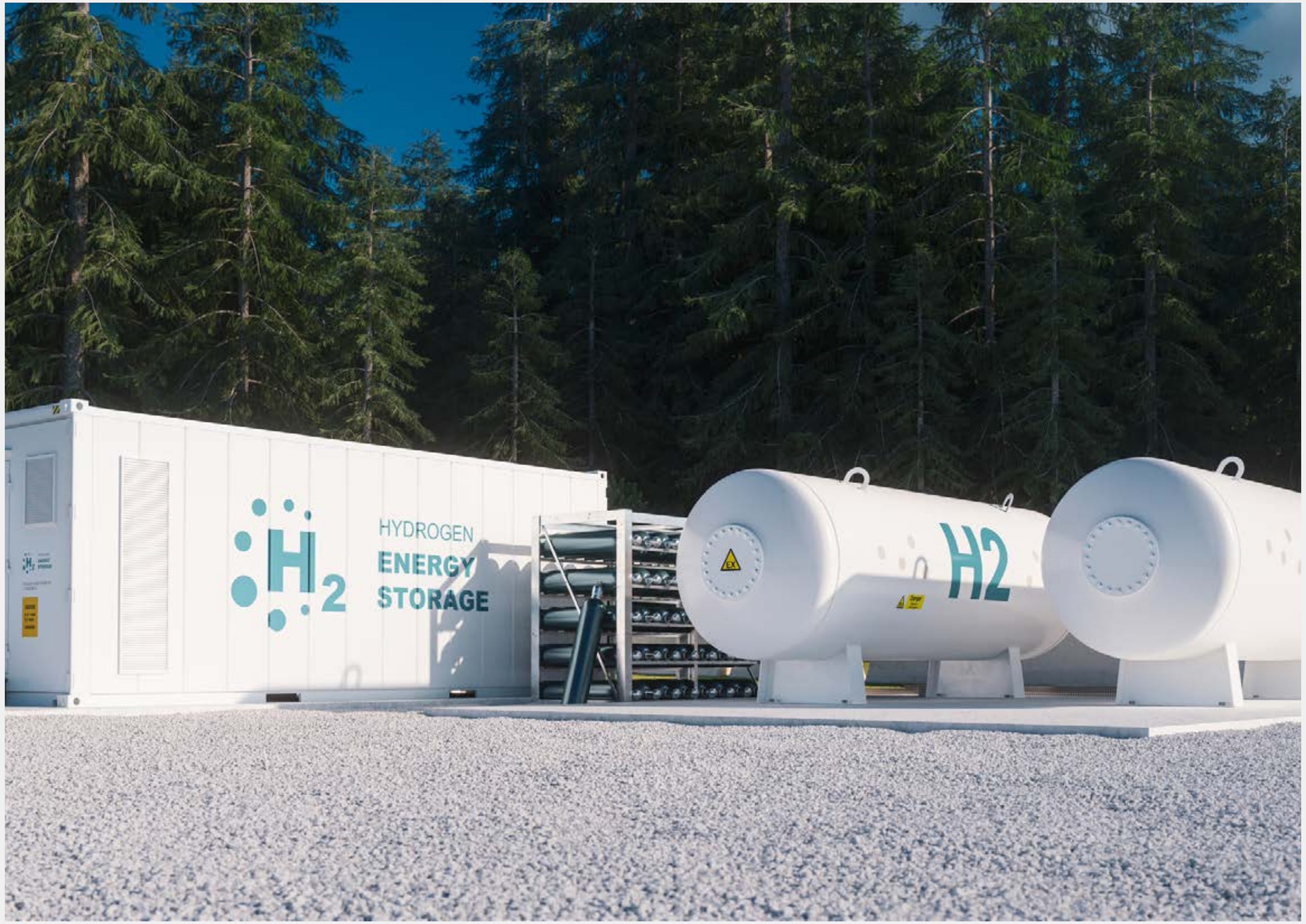


Achieving a consistent blend at entry

To achieve a consistent blend a few options could be considered:

1. Blend the hydrogen with natural gas from other terminals that do not have hydrogen injection.
2. Hydrogen storage – In this case any hydrogen that cannot be injected onto the NTS would be stored, and then used to supplement hydrogen production levels at times of high natural gas supplies.

The options above are based on the assumption hydrogen production is static throughout the year. There are indications that the hydrogen production plants could be in modular forms. In which case there is the possibility that during the summer months, fewer production trains could be turned on, reducing hydrogen production. Options 1 and 2 above could be used to further flatten the curve.



Adapting production profile

Figure 11

On this page we consider the option of blending the hydrogen with Natural Gas from other terminals to see the impact this would have. Using the historic data referred to in the preceding pages, and assuming 1.2mcm/d hydrogen flow, the red line on figure 11 shows how much additional natural gas would be needed to achieve a 2% hydrogen blend at St Fergus.

This could be done at St Fergus by moving gas from Teeside north up feeder 13 to supplement the St Fergus flows when required. This would require detailed analysis that is out of the scope of this study.

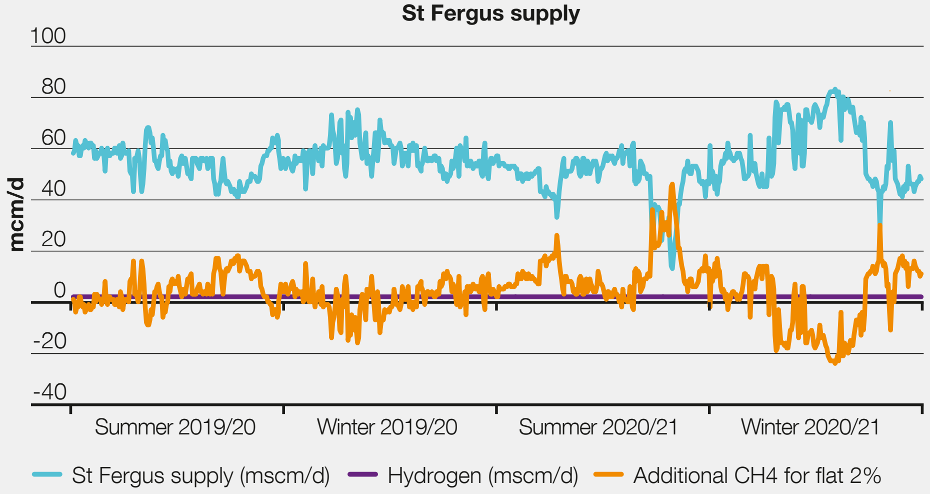
The summer months are when significant low supplies are seen on the NTS.
In this particular case, we see a 40 day period in the summer where an average of 12.8mcm/d additional natural gas would be required daily to achieve the desired blend (Highlighted in the orange – **hover here to view**).

In another instance we have a period of 30 days where an average of 27mcm/d additional natural gas would be required daily to achieve the desired blend (Highlighted in the orange – **hover here to view**).

The diagram also shows this is not confined to just the summer months; there are times in the winter where the addition of more natural gas would be required to achieve the desired blend.

These points provide a good indication of areas to explore further. A much broader range of research and analysis on blending in the context of the NTS is currently ongoing within National Grid looking into this in more detail.

Figure 11
St Fergus supply (April 2019 – March 2021)



Hydrogen storage

Figure 12 Figure 13

Figure 12 shows the movement of hydrogen in and out of storage to maintain the required 2%. Figure 13 depicts the cumulative volume of hydrogen in storage over the period covered.

The diagrams model potential use of storage to balance the requirement for hydrogen where a constant 2% hydrogen blend percentage is maintained in the supply at St Fergus. This shows balancing of hydrogen flows would occur throughout the year and it can be envisaged that a wide range of balancing needs will occur (with daily, inter-day and inter-seasonal balancing needs).

In this scenario hydrogen flows are assumed to be a flat 1.2mcm/d all year and it shows the difficulty of reducing the storage requirement.

Figure 12
Hydrogen storage flow to maintain 2%

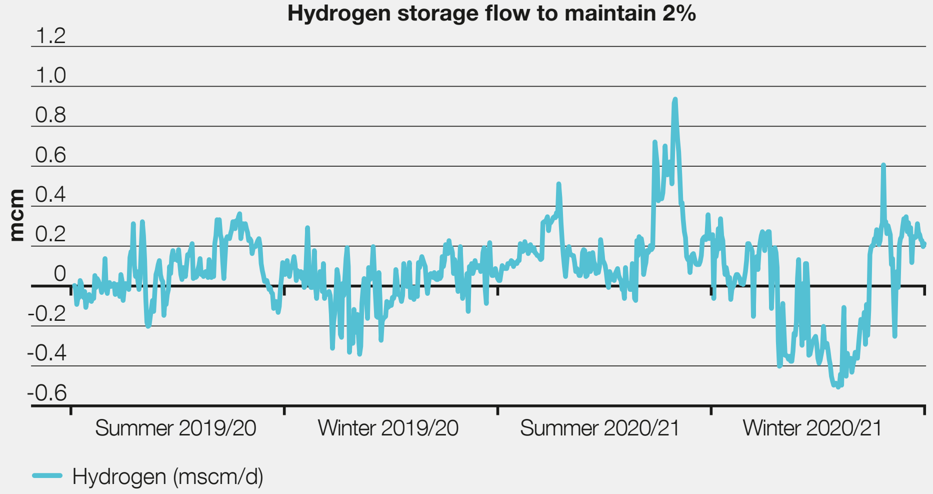
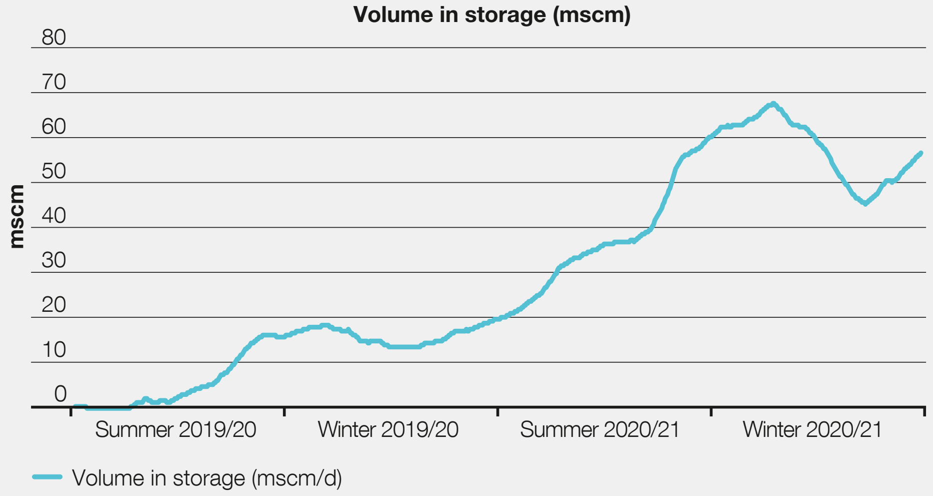


Figure 13
Cumulative volume of hydrogen in storage



Continuing the conversation

There is a lot more work to do to prepare for a potential hydrogen economy in Great Britain and blending could play a big part.

Considering the Government's Hydrogen Strategy and the growing momentum behind the role hydrogen could play in a net zero Great Britain, it is important that we find a blending pathway.

We would like you to share yours thoughts on our findings and further discuss with you.

We have shown that reinjecting deblended hydrogen could be a challenge. However, we believe there are many pathway options for hydrogen deblended from the gas network such as:

- It could be reinjected back into the gas networks at a more suitable blending location.
- It could go into the distribution network.
- It could be used in a different way like being sold to a transport or industrial customer or where 100 per cent hydrogen is required.

We have shown that maintaining a consistent blend could be a challenge if hydrogen production is static throughout the year. However, we believe hydrogen storage and adapting production profiles are options that could be considered.

Please contact the GFoP team here to tell us your thoughts on the questions we have posed in this document.

Please contact the Gas Markets Plan team here to tell us your thoughts on commercial solutions for hydrogen blending on the NTS that could enable net zero. Your feedback will support the development of the Hydrogen Gas Market Plan.

Please contact the FutureGrid team here to tell us your thoughts on the assets as pertaining to blending in the context of the NTS.

A much broader programme of works is currently ongoing within National Grid which encompasses asset requirements, markets and the commercial arrangements on blending in the context of the NTS. This will unlock the potential of hydrogen to deliver on the pathway to the UK's 2050 net zero targets.

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