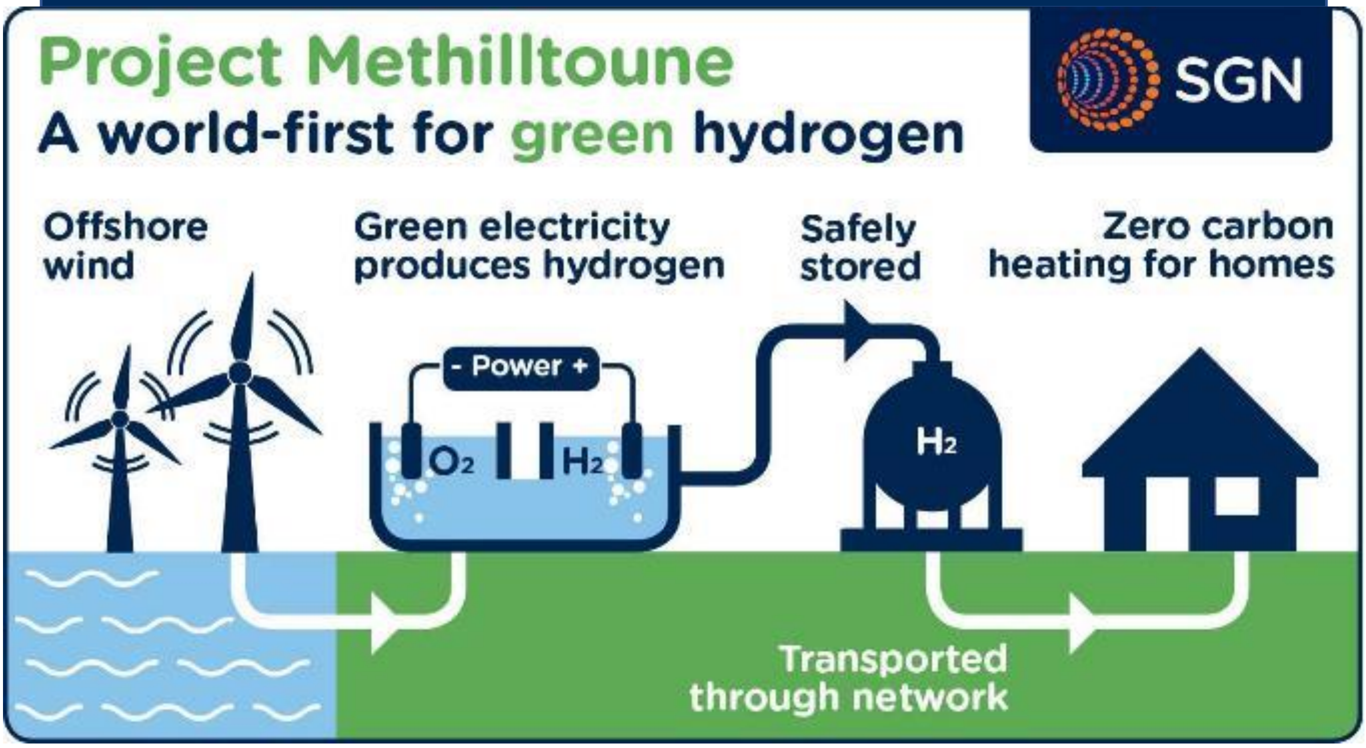
RIIO GD2 Business Plan Appendix

Energy Futures – Energy Systems Transition

December 2019



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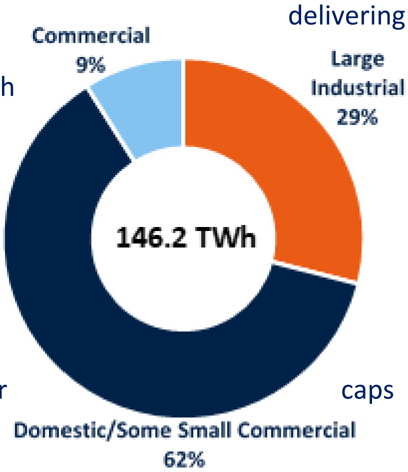
1 Introduction

The energy system is seeing unprecedented change and the often-competing tenets that form the renowned energy trilemma require continuous balancing and careful navigation in pursuit of a decarbonised energy system.

We understand the importance and the need for decarbonisation towards net zero emissions. We also recognise that climate change is a primary concern for customers and stakeholders and something they wish us to address.

Building on the world leading research we have completed in during RIIO GD1, we have set out an ambitious plan to deliver a net zero solution for the UK. The foundation for this is the gas quality decarbonisation pathway, which sets out the key steps we need to take to evidence, demonstrate and establish Hydrogen as a critical energy vector. Our proposal for GD2 is to play a key role in the delivery of the necessary evidence to underpin customer, market and government decisions on the future of their energy supply. We are also proposing a means of delivering outcomes for proven technologies and solutions.

Figure 1: Energy Delivered By Customer Type



Fundamentally, natural gas is the bedrock of the UK whole energy system, delivering in 2018 878 TWh[1] of energy (37.7% of primary energy). Of this, 509 TWh was directly required for heat. Up to 150 TWh of energy is delivered through our network and over 60% of this energy is to domestic customers who use it to heat their homes. The pie chart[2] shown in Figure 1 shows a breakdown of gas delivered by SGN based on figures from 2017/2018.

The UK Government has passed legislation committing the UK to a legally binding target of net zero by 2050. The UK's 2050 net zero target, one of the most ambitious in the world, was recommended by the Committee on Climate Change (CCC), the UK's independent climate advisory body. The pathway to this reduction is through a series of five-year caps on GHG emissions termed 'Carbon Budgets'. The CCC has proposed an earlier target of net zero by 2045 in Scotland, reflecting its potential to decarbonise faster than the rest of the UK.In 2016 the UK CO2 emissions were estimated to be 378.9 Mt CO2e. Of this, emissions associated with use of gas represented 163.6 Mt CO2e. Since some forms of carbon emissions are not amenable to decarbonisation usage these targets imply the need for low carbon heat by 2050.

[1] Digest of United Kingdom Energy Statistics 2019 – BEIS

[2] SGN Long Term Development Statement https://www.sgn.co.uk/uploadedFiles/Marketing/Pages/Publications/Docs-Long-Term-Development-Statements/SGN-LTDS-2018.pdf SGN Long Term Development Statement https://www.sgn.co.uk/uploadedFiles/Marketing/Pages/Publications/Docs-Long-Term-Development-Statements/SGN-LTDS-2018.pdf

Figure 2: The Energy Trilemma

The continued use of and reliance on natural gas for the nation's heat energy does not deliver net zero. As a major distributor of the nation's energy, we as a network have a social responsibility to find a way to deliver this energy to meet demand now and in the future in a way compliant with the energy trilemma.

There is not a one-size-fits-all solution to the decarbonisation of any aspect of the whole energy system, especially heat. Biomethane, renewable energy delivered by electricity and hydrogen will all play a major role in the energy system as it transitions to a greener future.

Our proposal for GD2 outlines how we plan to evidence the suitability of the gas network to safely transport energy through hydrogen and continue to facilitate more biomethane, a no/low regret action, that could also be aligned with Carbon Capture and Storage (CCS). By unlocking the potential of hydrogen as an energy vector, we believe that the challenge of decarbonising the whole energy system and particularly the challenge of decarbonising heat, can be tackled in the most affordable and practical way, offering the best customer value proposition.

1.1 RIIO-GD1 Summary

In RIIO-GD1 we have seen a seismic shift in engagement with customers and stakeholders. This is now a far more significant aspect of our business, in part due to the regulatory incentives to encourage the networks to engage, but more significantly reflecting the level of change in stakeholder expectation and emerging technologies in energy. Our stakeholders are asking us to do more and at a faster pace, which will require the provision of the means to facilitate the exploration of solutions that they want both now and, in the future, to solve the challenge of decarbonisation whilst protecting our customers.

Within the GD1 timeframe, SGN, the wider gas industry, and the UK energy whole system has seen unprecedented change. Biomethane has been introduced into the gas blend, and its quantity has increased year on year. Coal power generation has been almost completely phased out of our energy blend and gas generation now represents the foundation of GB's electricity supply. Renewable power generation, particularly wind generation, has seen significant growth in capacity. We have completed ground breaking projects such as:

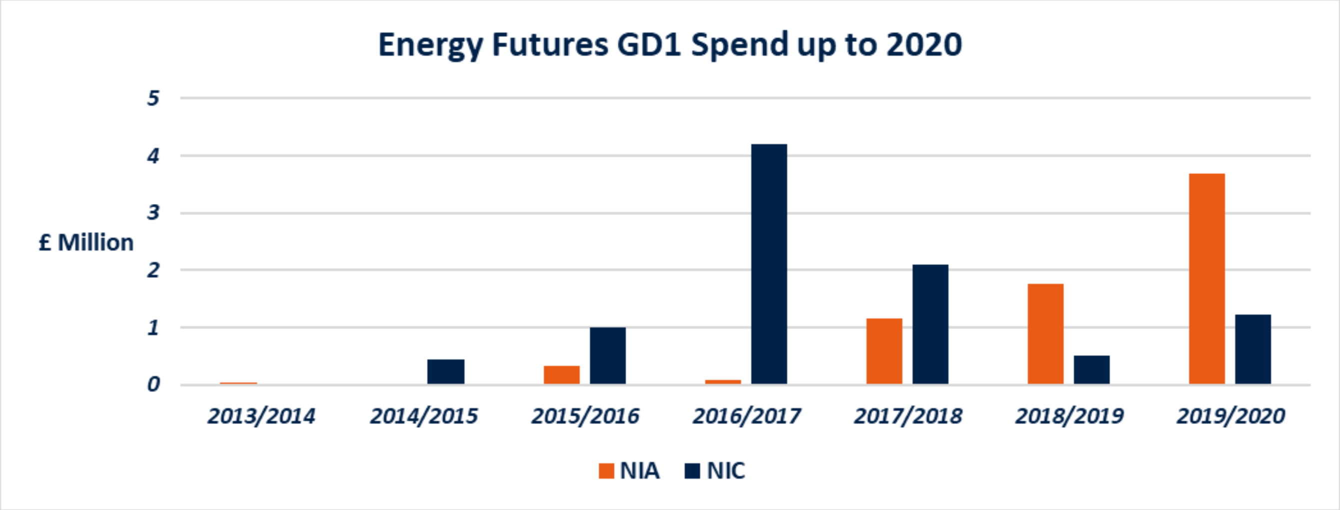
- Opening up the Gas Market, which proved that widening the envelope of gases allowed under the Gas Safety (Management) Regulations (GS(M)R) has no impact on the safe operation of appliances.
- Real-Time Networks', which aims to develop a first of a kind energy model capable of simulating the gas network in real time through the collection of real-time gas data at the consumer and network level, is nearing completion and will be finalised by early 2020, providing critical evidence to change industry standards.
- Our H100 project has advanced the safety case for the transportation of hydrogen gas in the network. We are now working towards the construction and operation of the UK's first 100% hydrogen network by 2023.

Other networks too have demonstrated key evidential projects towards the decarbonisation of the network, including Northern Gas Networks 'H21' and Cadent's 'HyDeploy', blending 20% hydrogen with natural gas.

By the end of GD1, SGN's carbon emissions will have reduced by over one million tonnes. This is due to the introduction of biomethane into the gas network and the reduction in pre-combustion emissions from reduced leakage as a result of our Iron Mains Risk Reduction Programme. Further carbon reductions can be realised from the removal of the need to add nitrogen gas in the processing of LNG as a result of proposed GS(M)R changes stemming from our Opening up the Gas Market project.

Our overall NIA and NIC spend up to this is shown in Figure 3.

Figure 3: GD1 Spend



As we move from GD1 into the new RIIO2 period there are lessons that were learnt through the innovation projects undertaken in GD1 that will provide essential input in GD2. Specifically, as we transition from natural gas to blended hydrogen and 100% hydrogen networks some of the unique opportunities in stakeholder and consumer engagement that were provided through the Opening up the Gas Market project in Oban can be replicated. Stakeholder engagement will be key in our GD2 transformational projects where local communities will play a critical role in the deployment of new technologies, requiring the knowledge and confidence in the ability of our network to deliver energy safely and securely.

1.2 Our Objectives for GD2

Our primary objective during the GD2 period is to demonstrate that our network can safely, technically and economically, facilitate the distribution of low carbon gases as a viable alternative in the decarbonisation of the whole energy system.

To do this we are proposing a set of high-level targets and objectives for GD2, these are:

- Collaboratively provide evidence for the gas quality decarbonisation pathway.
- Build and operate a 300 home, 100% H_2 network by 2022/23.
- Support the conversion of an existing network to 100% H_2 by 2024/25.
- Remove or reduce the need for processing with manufactured gas, such as propane, for 10% of system entry gases.
- Provide 10% capacity improvement for embedded entry injection.
- An aspiration to reduce modelled 1:20 peak demand within <7bar distribution system by 15-20%, subject to successful completion of new network modelling methodology under Real Time Networks.
- Develop whole systems charter with DNO/DSOs.

Our objectives for GD2 are highly ambitious but necessary if we as an industry are to achieve the decarbonisation targets. We have set out how we propose to achieve these objectives, the required projects to do so, how we believe these projects should be funded and what the expected benefits are as a result of achieving our objectives for GD2 and beyond. Within our GD2 proposal a variety of funding mechanisms set out how we will facilitate responsiveness, deliver decarbonisation outcomes and support emerging needs across energy vectors. In terms of customer acceptance of our proposal, our stakeholder engagement has indicated that our NIA Energy System Transition bid is within the value that consumers would be willing to pay.

A summary of the funding is shown in Table 1.

Table 1: Proposed Funding Mechanisms

Mechanism	2021 - 2022	2022 - 2023	2023 - 2024	2024 - 2025	2025 - 2026	Total Spend (£ Million)
NIA Energy System Transition	14.50	13.63	10.39	5.79	7.09	*51.40*
NIC Energy System Transition	26.5	41.0	18.67	22.42	41.92	*150.50*
Use it or Lose it - Biomethane and Whole System Technology Rollout	0.00	0.00	2.00	3.00	5.00	*10.00*
Energy System Transition (EST) Reopener	0.00	7.00	100.00	64.60	51.60	*223.20*

Over the GD2 period this equates to:

- An estimated 69 projects completed. If fully deployed, approximately 14/year
- A total investment across the Energy System Transition and Whole Systems of £435.1m, approximately £87m/year
- A potential CO_2 saving, if fully deployed of 3,430,000 tCO_2e, or 686,000 tCO_2e/year.

2 Our Proposal for GD2

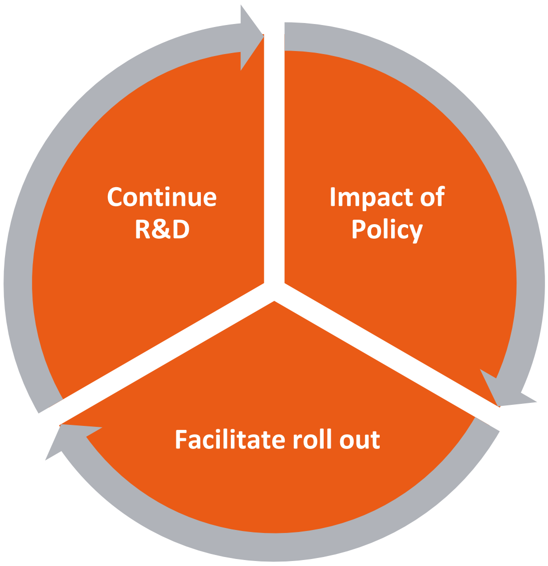
We have set out how we propose to achieve our objectives, the projects that we will undertake, how we believe these projects should be funded and the expected benefits for GD2 and beyond.

2.1 Our GD2 Proposed Funding Mechanisms

To address the priorities of decarbonisation and the whole systems concept as set out by stakeholders and customers, we are proposing four funding mechanisms to ensure we can be responsive to emerging needs, evidence, support and facilitate decarbonisation and whole system solutions during RIIO-GD2.

The proposed tiered funding mechanism will:

- Provide continued discretionary investment in research and development for projects that support the decarbonisation pathway and whole systems;
- Ensure that a discretionary "use it or lose it" mechanism is in place for the rollout of biomethane technology projects, based on examples and governance; and
- Ensure that where there is a significant material impact on the networks from policy decisions, a re-opener mechanism is available for larger decarbonisation projects to provide delivery options.



A tiered mechanism, as proposed and shown in Table 2

Table 1 will bring benefits to consumers beyond network efficiency and reflect the uncertainties surrounding decarbonisation. The "use it or lose it" funding pot would incur no costs to consumers if it were not utilised. Whilst any changes in policy can be accommodated using the reopener mechanism, under pinning our proposals for a whole-systems approach for networks.

Table 2: Proposed Funding Mechanisms

Mechanism	Purpose	Estimated Spend
NIA Energy System Transition	Mirroring NIA for decarbonisation and whole-systems related R&D.	£51.4 million
NIC Energy System Transition	Mirroring NIC for decarbonisation and whole-systems related demonstrations and implementations.	£150.5 million
Use it or Lose it – Biomethane and Whole System Technology Rollout	Discretionary Project and technology roll-out to facilitate system solutions for biomethane and whole systems.	£10 million
Energy System Transition (EST)Reopener	Large scale decarbonisation projects to support implementation of Policy decisions.	£223.2 million

Energy System Transition

We have identified four themes for research, development and demonstration in GD2:

- Whole Systems – research and demonstration is carried out considering the whole system to evidence cross vector benefits.
- Emerging Technologies – research and demonstration of new technologies with potential to facilitate greater levels of decarbonisation and/or security of supply.
- Demand Forecasting – research into dynamic changes in demand forecasting due to rapidly evolving energy system.
- Pathways Project – research, development and demonstration projects that evidence the pathway to decarbonisation of the gas network.

For each theme, there are a number of key areas for research development and demonstration. A full breakdown of these projects is detailed in the project annex and categorised as either NIA Energy System Transition or NIC Energy System Transition.

To support the portfolio, we propose to adopt both a proactive and reactive approach to project initiation and partnership. We propose that all our projects will be undertaken with third party partners. This has proven very successful in GD1 and we seek to replicate this into GD2.

Proactive towards project partnership

For the challenge areas identified where the problem is well defined, we will issue invitations to partner with third parties through a competitive process, in accordance with procurement regulations. These proposals will be evaluated based on their value proposition to determine project awards, where upon we will form a partnership, providing industry expertise, network access and up to 100% funding for third parties in accordance with the innovation governance.

We are also proactive in seeking new innovations and project partners, through our industry watch; our external memberships; and through challenging our ever-increasing array of project partners to come up with solutions to our industry issues.

Reactive towards project partnership

As we progress through the period we need to be open to great ideas and opportunities, being flexible and responsive to new proposals and emerging technologies. Many of these may be region specific. It is important to treat commercial proposals sensitively and to ensure protection of origin where demonstrably unique. For emerging technology, we can protect third party ideas by progressing under our Utility Contract Regulations exemption for research and development where there is a demonstrable value proposition.

We will continually prioritise the ideas and develop projects for both the NIA and NIC, or GD2 stimulus, based on their scale, feasibility, potential to add value to the UK energy consumer and support the energy system transition.

All project proposals are subject to a challenge and review at our Energy Futures executive team, which reports directly to our Board.

Use it or lose it – Biomethane and Whole System technology rollout

We are actively working with our existing biomethane producers who are clear that we need a mechanism for the rollout of solutions evidenced from R&D in GD1 and as they emerge at the start of GD2, to increase the volume of green gas entering our network. There is a concern that there is no mechanism to deliver outcomes within the regulatory period. Following a year-long trial at three existing biomethane sites at the start of GD2, we are proposing a "use it or lose it" mechanism to install the technology developed at other biomethane sites across our network.

Recognition that where developments in the decarbonisation pathway and whole systems strategy require network investment to facilitate and implement would have previously been funded under the Innovation Roll-out Mechanism (IRM). This funded the rollout of proven innovations which contributed to the development in GB of a low carbon energy sector or other broader environmental benefits.

This fund is necessary to help grow and encourage an increase in the volume of biomethane on the network, breaking down the barriers for biomethane production and progressing the pathway to a decarbonised gas network. Regulations and capacity barriers exist through no fault of the biomethane producer, and we believe that it is in the interest of the wider consumer community to assist in the investment for biomethane production, reducing the cost of energy realised through less processing activities, and also in terms of the benefits to society through the use of low carbon green gas.

The proposal for a “use it or lose it” funding mechanism can also apply to other technologies that may be proven during the GD2 period. Elements of the research and development we are carrying out in the whole systems sphere may reach a technology readiness level where they can be successfully implemented across the network. These would bring benefits not only to the gas network but across other sectors as well, such as the electricity network operators.

Energy System Transition (EST) Reopener

In order to execute the significant rollout of projects evidenced that support heat decisions by the UK & Scottish government in the early 2020s, we are proposing an uncertainty mechanism for projects that we believe to be likely to deliver maximum decarbonisation per pound invested.

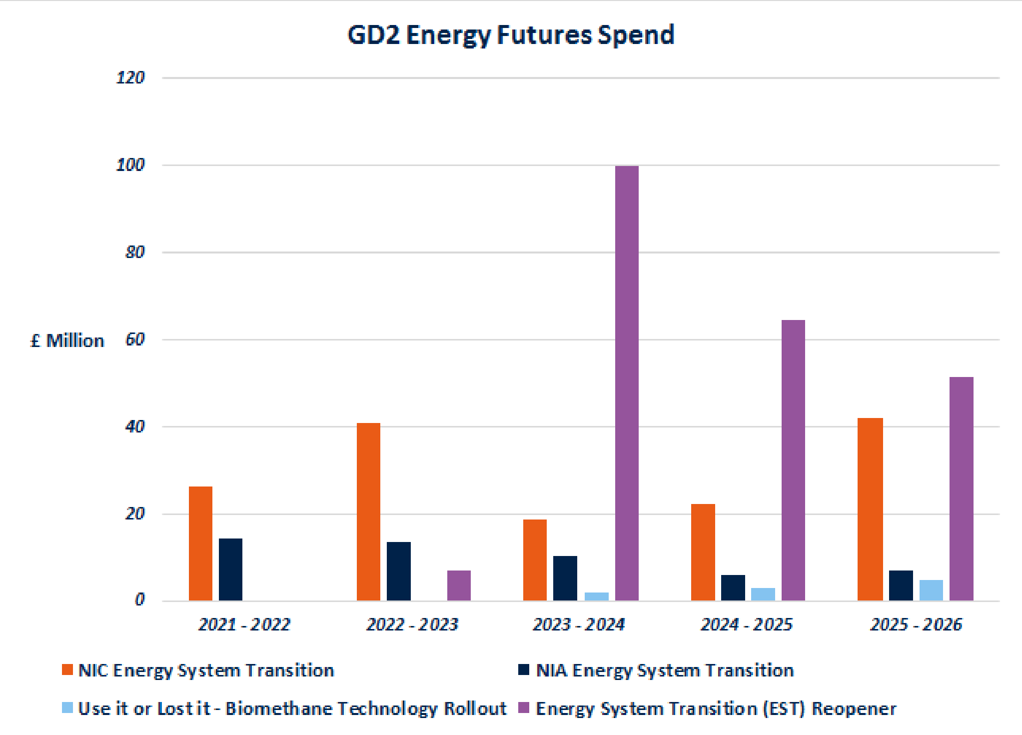
Whilst the previous mechanisms under the Energy System Transition and Biomethane technology rollout can fund lower value R&D and network investment, the rollout of larger pilot projects, on the back of government policy decisions will require a different funding mechanism. To support these policy decisions during the price control period it may be better to recover the costs of larger decarbonisation projects over the RAV rather than have a direct impact on consumer bills. Having an uncertainty re-opener would be one way of doing this. An important element of the re-opener would be the inclusion of key technology, process and operational training to provide the skills required across industry for decarbonisation of the sector to be progressed.

Reopener windows would allow companies or Ofgem to propose adjustments to expenditure allowances for certain cost categories related to the decarbonisation agenda that were deemed to be too uncertain to provide ex ante allowances at the time of our Final Proposals. Following appropriate consultation this would provide a transparent method for additional funding to be made available.

Summary

Our investment in projects over the GD2 period to advance the energy system transition is shown in the graph below. The early years of the price control period are predominantly R&D utilising funding under the Energy System Transition, whilst the roll out of biomethane or whole systems technology under the “use it or lose it” mechanism in the mid to later years of the period follows the successful demonstration of the technology. As the energy landscape changes during the mid-point of the price control period, on the back of policy decisions around heat, there will be a need for additional funding through the EST Reopener.

Figure 4: GD2 Energy Futures Spend



The following graphics highlight our key projects and initiatives both now and moving into RIIO- GD2. A breakdown of all the projects proposed, with explanation and justification are in the project annex.

Figure 5: Scotland Projects

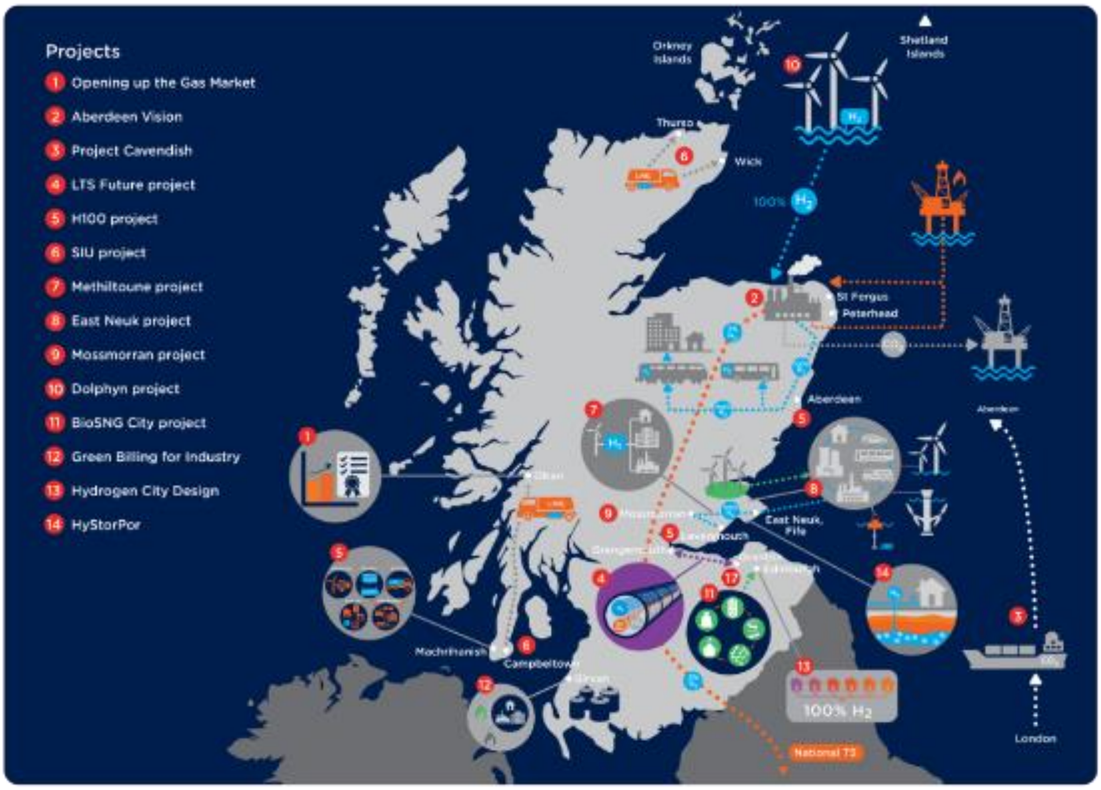
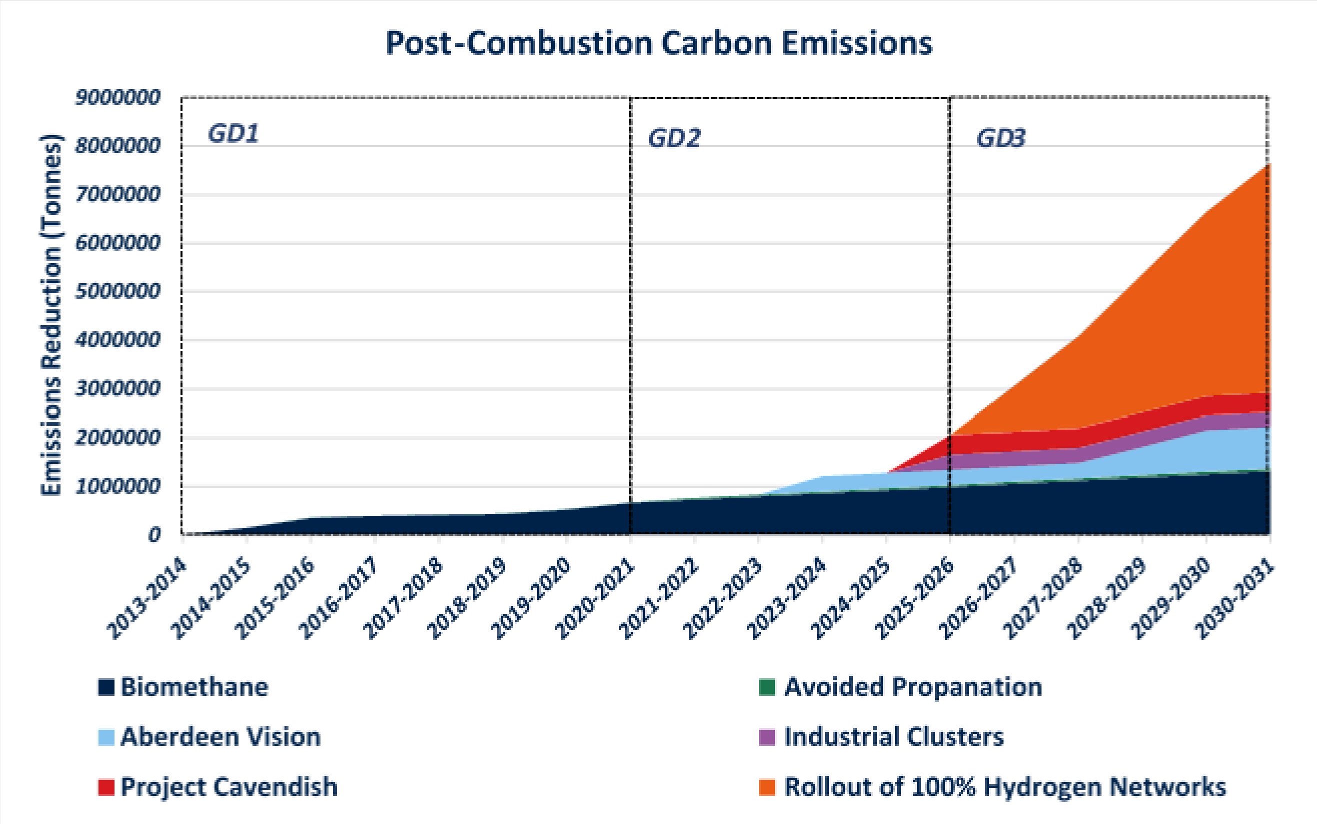


Figure 6: Southern Projects

2.2 Carbon Emissions Reduction Potential

All calculations described here have been assured by DNV GL third line assurance process[3].

Figure 7: Post Combustion Emissions Reduction



Provided all remaining relevant objectives are achieved in GD1 with regards to decarbonisation, we project that by the start of GD2, the energy we deliver will contain 97.17% natural gas and 2.83% biomethane (hydrogen is not present in the network at this stage). Net-zero legislation requires 100% of the energy we deliver to be low carbon; biomethane and hydrogen must replace all natural gas in our network.

Biomethane has the potential to deliver deep decarbonisation, but the feedstock does not exist at present to realistically supply 100% of current gas demand and it is unlikely to exist in the future; our network can only be fully decarbonised if hydrogen is transported in the future. As such, the GD2 period is critical for building out the evidence base to enable the safe transportation of hydrogen through our network, and by extension, enable the decarbonisation of the gas network. The acceleration of research, development and demonstration of hydrogen as an energy vector is required in GD2.

The decarbonisation of the gas networks will increase in GD1 and by the end of GD2, we can deliver over 2 million tonnes of emissions reductions (compared to the start of GD1) from the energy we deliver, provided:

- We successfully deliver our suite of research and development to prove the safe transportation of 100% hydrogen in our network.
- Subject to the success of the research and development into hydrogen, we propose to use the EST Reopener mechanism to commence the rollout of hydrogen in our network, through the utilisation of

industrial by-products and blends of hydrogen through project Cavendish and Aberdeen Vision.

- The equivalent of 450,000 customers are supplied by biomethane (assuming an annual demand of 12,000 kWh per customer per year4) by the end of GD2.
- Due to work set out in our Real-Time Networks Project and Cadent's Future Billing Methodology project, changes in gas quality standards remove the need to propanate biomethane to enrich its energy content.

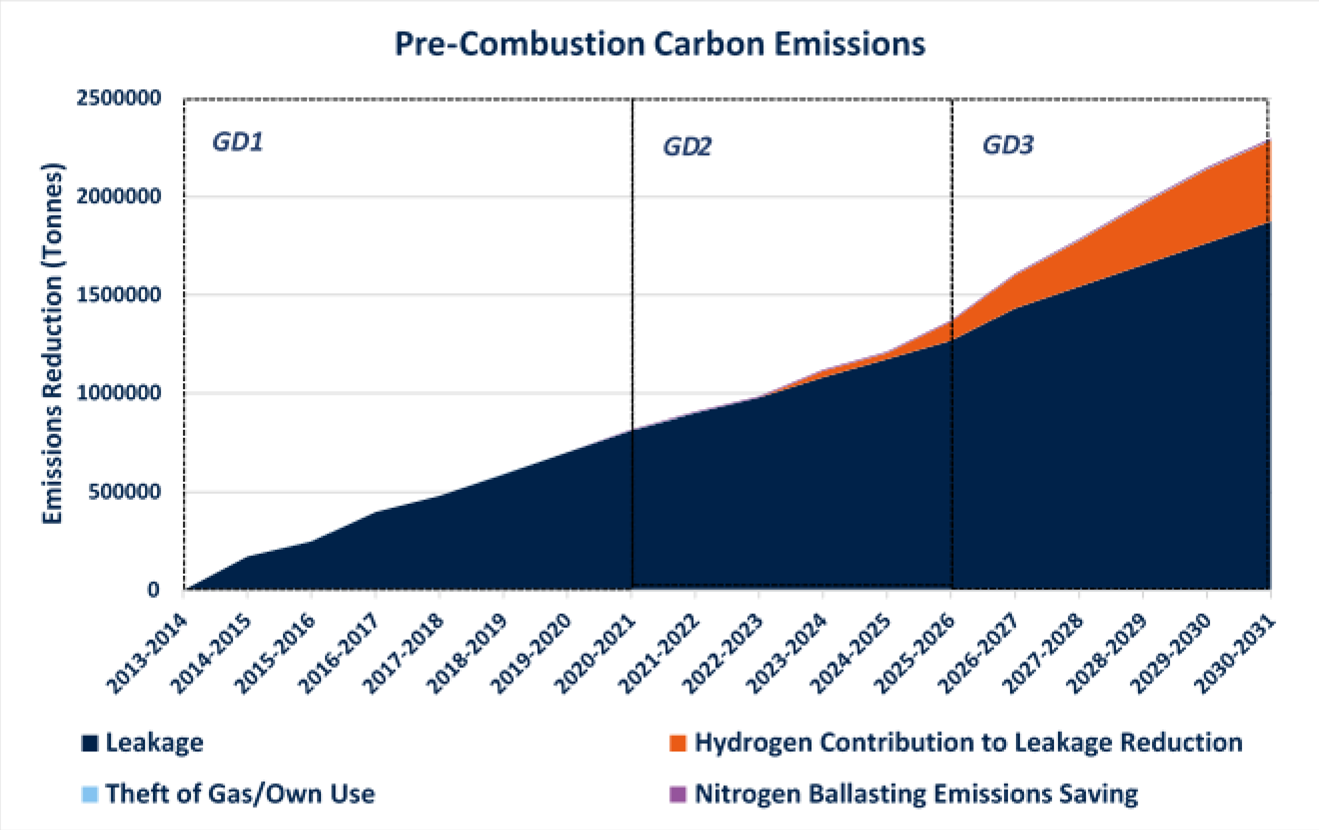
Subject to policy decisions surrounding the decarbonisation of heat and the success of our innovation programme, GD3 could deliver the significant rollout of 100% hydrogen networks across a number of cities and towns (1.1 million-meter points supplying customers across 10 cities in Scotland and the South). By the end of GD3, we forecast a 7.66 million tonne reduction in the emissions of the energy we deliver, compared to the emissions of the energy at the start of GD1. We aim to provide the evidence base for hydrogen such that in GD3 and beyond, the network is in a state where the conversion of further customers to hydrogen will be largely routine and business as usual, paving the way to achieve decarbonisation targets in line with government targets.

Provided all objectives are achieved and all projections are realised, in terms of decarbonising the energy we deliver, by the end of GD2, we project 8.38% of the gas delivered to be green, and by the end of GD3, 33% to be Hydrogen. This progress will enable us to drive deep decarbonisation beyond GD3 to one day achieve a network where 100% of energy is hydrogen or biomethane, achieve decarbonisation targets.

As well as the decarbonisation of the energy we transport, we must also decarbonise all emissions associated with shrinkage and the embedded carbon involved in ensuring the gas we accept is within specification. Leakage accounts for the vast majority of our emissions; at the start of GD1, 780.67 GWh of energy was lost through network leakage.

[4] https://www.ofgem.gov.uk/gas/retail-market/monitoring-data-and-statistics/typical-domestic-consumption-values

Figure 8: Pre-Combusted and Company Associated Emissions



Leaking natural gas is significantly more effective as a greenhouse gas than the emission of its combustion, reducing leakage through mains replacement, as well as preparing the network for the energy transition to hydrogen, can significantly reduce the emissions associated with leakage.

We project that, compared to the start of GD1, the emissions from shrinkage and embedded carbon will reduced by 820,000 tonnes by the end of GD2 and 2.3 million tonnes by the end of GD3. Provided:

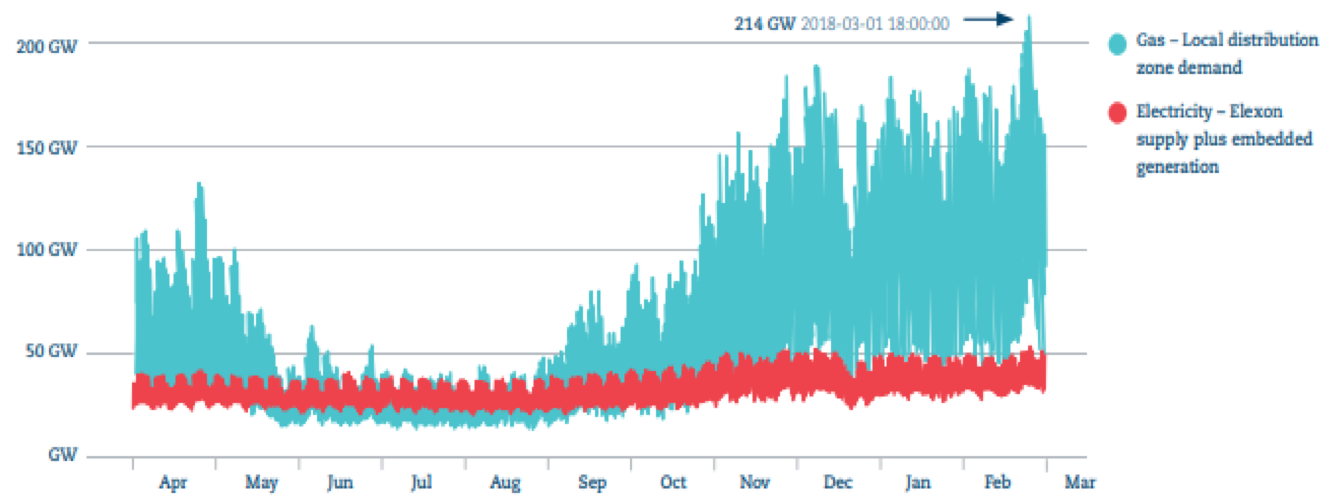
- Leakage reduces at the expected rate in line with the accelerated mains replacement programme.
- The volume of green gas transported changes at the projected rate, resulting in less natural gas leaking.
- Theft of gas and our own use gas reduce at the projected rate.
- Nitrogen ballasting is not required for LNG injected to our network at Grain by the start of GD2 as a result of changes to gas quality standards as a result of our Opening up the Gas Market project and changes to GSMR.

3 Policy Environment

Decarbonisation of our energy industry is critical and is one of the greatest challenges we have ever faced. The decarbonisation of heat is particularly challenging, but no one wholesale solution is currently available or yet fully developed and evidenced. Heat load is the largest duty on the gas network and is highly variable. **Figure 9**[5] shows the GB gas demand at an LDZ level (heat demand) and electricity demand between April 2017 and March 2018. This dataset included the demand during the 'beast from the east' cold front, conditions nearing the 1:20 peak demand. Heat demand (which is the LDZ gas demand), is significant compared to electricity demand, it has a very high rate of ramp and by nature is mismatched intra-seasonally.

Supplying this demand presents several major barriers to the wholescale decarbonisation of heat using energy delivered by electricity and particularly renewable energy delivered by electricity.

Figure 9: Gas and Electricity Demand April 2017 - March 2018 Including the Beast from the East



3.1 Net Zero

The UK Government has passed legislation committing the UK to a legally binding emissions target of net zero by 2050. The UK's 2050 net zero target — one of the most ambitious in the world — was recommended by the Committee on Climate Change (CCC), the UK's independent climate advisory body. The pathway to this reduction is through a series of five-year caps on GHG emissions termed 'Carbon Budgets'. The CCC has proposed an earlier target of net zero by 2045 in Scotland, reflecting its potential to decarbonise faster than the rest of the UK. In September 2019 the Scottish government set an ambitious interim target of 75% emissions reduction by 2030.

In 2016 the UK CO_2 emissions were estimated to be 378.9 Mt CO_2e[6]. Of this, emissions associated with use of gas represented 163.6 Mt CO_2e. Since some forms of carbon emissions are not amenable to decarbonisation usage these targets imply the need for low carbon heat by 2050.

Major UK Government policy decisions on heat are not expected until around 2023/24 and therefore heat policy implementation is likely to be limited prior to this and during most of GD2.

[5] Taken from Wilson et al. 'Challenges for the decarbonisation of heat: local gas demand vs electricity supply Winter 2017/2018' UKERC Briefing Note, 2018.

[6] BEIS 'Final UK Greenhouse Gas Emissions National Statistics 1990-2016'

In October 2017, the UK Government unveiled its Clean Growth Strategy[7]. This document outlined the policies by which the government plans to deliver the fourth and fifth carbon budgets (covering the periods 2023-2027 and 2028-2032). These budgets call for a significant acceleration in the pace of decarbonisation.

The Scottish Government published its Energy Strategy in December 2017[8], setting a target for the equivalent of 50% of the energy for Scotland's heat, transport and electricity consumption to be supplied from renewable sources by 2030. It voiced strong support for our H100 project to demonstrate a 100% hydrogen network in Scotland, for the safe transportation of hydrogen in the gas network.

Based on the Energy Strategy, the Scottish governments document 'Scotland's electricity and gas networks: vision to 2030' looks at the ways in which Scotland's electricity and gas network infrastructure will continue to support the energy system transition.

> *Gas Networks*
>
> *'By 2030... gas networks remain a vital and flexible component of Scotland's national infrastructure, delivering affordable energy for heating our homes and businesses. The energy carried by the networks will be lower carbon than it is today. The policy, regulatory and technical developments will have been put in place to allow natural and low carbon gas to be blended in the networks, including some contribution from hydrogen. We will also understand clearly the feasibility and costs of repurposing the gas networks to carry 100% hydrogen and will have made strategic decisions about the long-term role of the networks and decarbonisation of heat.'*

3.2 Implications for the Gas industry

There are no major decisions to reduce uncertainty in terms of heat policy direction going into GD2. Our intention is to work with the other GB gas networks to evidence the pathway for the decarbonisation of the gas grid. We will also work closely with BEIS as the UK Government develops its thinking on the decarbonisation of heat, which is central if we are to achieve the Industrial Strategy and Clean Growth objectives that have been set.

The Government's approach to heat decarbonisation encompasses a range of programmes and initiatives, underpinned by innovation and "learning by doing". This aligns with our proposals for the funding mechanisms we have defined, where demonstration, evidence gathering and enabling change are key outputs during GD2.

Linked to this is the consideration of how low carbon heat can be supported. In the Government's March 2019 Spring Statement, there was a clear indication in the announcement for the need to:

> *'accelerate the decarbonisation of gas supplies by increasing the proportion of green gas in the grid, helping to reduce dependence on burning natural gas in homes and businesses and meet climate targets'*

The support for biomethane injection into the gas network is currently through the Renewable Heat Incentive (RHI) which is due to close in 2021. The next Spending Review needs to consider how best to further grow the market in green gas within the network.

A full roadmap for heating will be published in mid-2020 taking into account the outcomes of the next spending review. SGN will work with the other GB gas networks to evidence their pathway for decarbonisation of the gas networks[9].

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[7] BEIS 'The Clean Growth Strategy Leading the way to a low carbon future' October 2017

[8] Scottish Government 'Scottish Energy Strategy: The future of Energy in Scotland' December 2017

[9] Pathways to Net-Zero: Decarbonising the Gas Networks in Great Britain, October 2019

3.3 Least Cost Decarbonisation Studies

A number of reports have been recently commissioned and published investigating the role of hydrogen as an energy vector in delivering renewable energy in a decarbonised energy system.

National Infrastructure Commission

Element Energy and E4tech were commissioned by the National Infrastructure Commission (NIC)[10] to undertake an analysis of the cost of decarbonising the UK's heat infrastructure, specifically space heating and hot water. A comparison of the main pathway options finds that re-purposing the gas grid to deliver low carbon hydrogen, if this option can be delivered safely and at scale, is the lowest cost option under most scenarios studied.

'Given that the cost of this pathway could be more than £100 bn lower in discounted system cost than, for example, the heat pump electrification pathway, there is a strong case to invest in research and trials of the associated supply chain technologies, including hydrogen appliances, building and network level repurposing, hydrogen storage and CCS. This is crucial to gain a better understanding of the true cost of the pathway, its risks and regulatory requirements.'

Committee on Climate Change

Imperial College London was commissioned by the Committee on Climate Change (CCC)[11] to evaluate the technical feasibility and overall system costs of alternative heat decarbonisation pathways. One of the key conclusions from the studies carried out is that none of the heat decarbonisation pathways can be excluded from large scale deployment, due to the proximity of overall system costs across the pathways within a significant level of uncertainty.

This points to the need for the rollout of pilot trials which will develop the knowledge and experience required address uncertainties about the different heat decarbonisation pathways.

The CCC's recent net zero technical report[12] identifies hydrogen as a *key enabler* to reach net zero. Key policy recommendations put forward include:

- Continued support and innovation funding for large-scale demonstrations of hydrogen production.
- Support for development of carbon capture and storage (CCS) as a key enabler of large-scale production of low carbon hydrogen ('blue' hydrogen).
- Support for development of 'HyReady' boilers, capable of running on natural gas and hydrogen (with minor modifications).

Navigant

Gas for Climate, a consortium of EU gas transport companies, commissioned Navigant to assess the future role of renewable gas in the EU energy system. The study[13] found that it was possible to scale up renewable and low carbon gas production within the EU to 270bcm by 2050. This includes both renewable methane and hydrogen.

This can achieve a net zero carbon EU energy system by 2050 while saving €217bn annually across the EU,

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[10] Element Energy, E4Tech (on behalf of the National Infrastructure Commission) *Cost analysis of future heat infrastructure options*, March 2018

[11] Imperial College London, (on behalf of the committee on Climate Change), *Analysis of Alternative UK Heat Decarbonisation Pathways* August 2018

[12] Committee on Climate Change, *Net Zero Technical report*, May 2019

[13] Navigant (on behalf of Gas for Climate), *The optimal role for gas in a net-zero emissions energy system*, March 2019

compared to a scenario with a limited amount of gas.

KPMG Study

A recent study[14] undertaken by KPMG for the Energy Networks Association, looked at four approaches to decarbonisation of Britain's heat requirements and found that maintaining use of the gas system with extensive use of biogas and hydrogen – the 'Evolution of Gas' option - to be the lowest cost and most easily achieved route.

Table 3: KPMG Decarbonisation Study

	Evolution of Gas	Prosumer	Diversified Energy	Electric Future
Practical obstacles	Low/Medium	Very high	Medium/high	High
Incremental costs	£104 – 122bn	£251 – 289bn	£156 – 188bn	£274 – 318bn
Incremental cost per consumer	£4,500 – 5,000	£11,00 – 12,500	£6,800 – 8,000	£12,000 – 14,000

A further issue is the impact of transport electrification. Whilst Compressed Natural Gas (CNG) and hydrogen fuel cell trucks envisaged to play a significant role in the transportation of heavy goods, many scenarios predict that electric vehicles (EV) will dominate the domestic market. The typical peak domestic electrical load is 3kW so use of even a slow charger will potentially double the peak power supply to an individual house. Aside from the potential costs of reinforcing local grids to carry this additional power, large numbers of EV charging stations could have a significant effect on the patterns of electricity usage.

Changes in the electricity system are already starting to impact the gas system, coupling what have been, up until now, largely separate systems. To manage short term supply and demand matching and provide other ancillary services, a market has been put in place which has incentivised the construction of 'peaking plant'; that is power generation assets that are used intermittently and at short notice. The lowest cost assets in this class are gas-fired generators, usually reciprocating engines, connected to the gas distribution networks, therefore translating peak electricity demand into additional gas demand. While some of the market arrangements that incentivise the construction of these assets have recently been scaled-back or suspended, the underlying system requirement will continue to grow.

ENA – Pathways to Net-Zero: Decarbonising the Gas Networks in Great Britain

Following our development of the Pathway to decarbonisation, the Energy Networks Association (ENA) commissioned Navigant to independently review and validate the pathway. This aims to provide policy makers and networks a set of deliverables and recommendations as to the optimal approach in the decarbonisation of the gas networks and the nation's heat. The report will be the first output of the project, which will give an independent assessment of the role of our gas infrastructure moving forwards.

The detailed report compared a balanced and electrified pathway to net zero. Where the balanced scenario optimises the use of low carbon gases (hydrogen and biomethane) with electricity and the electrified scenario achieving net zero through mainly the use of the electricity sector, with the gas networks utilised in a limited capacity. Overall, in terms of the decarbonisation of the nation's heat, the report found the balanced scenario (in which the majority of heat is decarbonised through the nation's gas supply through the use and rollout of biomethane and hydrogen) to be the most affordable, deliverable and of least disruption to customers compared to the electrification scenario. Furthermore, the report estimated a larger role for biomethane than

[14] KPMG for the ENA '2050 Energy Scenarios – The UK Gas Networks role in a 20550 whole energy system' July 2016

either we or the CCC have estimated. However, the identified steps to delivering a net zero network are consistent with repex in GD2. This report concludes that the gas networks can make a significant and telling contribution to decarbonising our energy system in an affordable and deliverable way, which is of least disruption to consumers, but to achieve this by 2050, significant action is needed during the GD2 period.

We believe that the ambition we have shown in our business plan to facilitate and work towards the decarbonisation of the nation's gas supply and heat in GD2 is consistent with the ambitious requirements, messages and necessary timelines outlined in the ENA report.

3.4 Customers

Customers are concerned about the environment but at the same time expect a safe, reliable and convenient supply of energy at an affordable cost[15]. Getting it right for customers is a key challenge. Many solutions cause significant disruption or require concessions in how energy is used. There is a need to evidence the impact of potential decarbonisation solutions for customers. We need to be responsive to emerging technologies and provide options and explanation in a meaningful way. Finally, we need a means of facilitating customer wants and needs, both now and in the future.

We embarked upon a programme of research with a representative group of our customers to understand what they consider to be the priorities we should focus on, and the relative importance of each of these. The first phase of this research was undertaken in early 2018, where we held a series of deliberative workshops with 147 customers representing the following groups: urban customers, rural customers, millennials (future bill-payers) and SME businesses. These workshops identified seven key customer priorities:

- Acting safely
- Keeping the gas flowing
- Keeping costs down
- Future energy solutions
- Minimising environmental impact
- Providing excellent service
- Supporting those vulnerable in the community

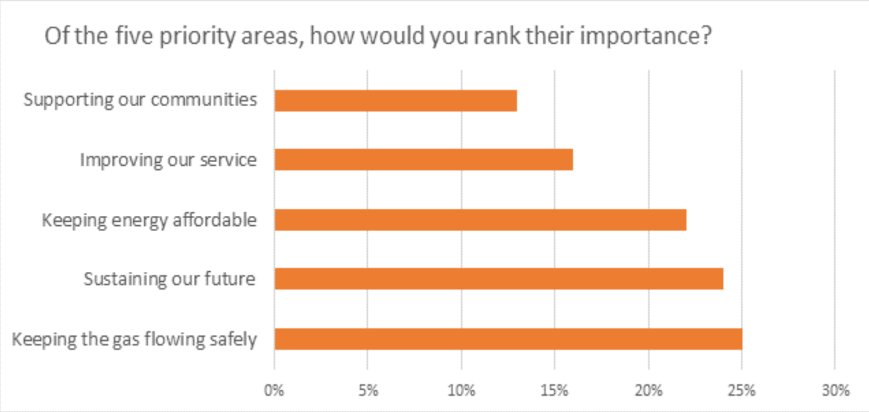
Customers told us that all these areas were important. Having been informed about what we currently do in each area, customers were asked to indicate where they would like us to increase our investment. The results are shown in the plot adjacent. Customers view investment in future energy solutions as one of our top priorities, behind keeping costs down. It was assumed that SGN would continue to keep the gas flowing and to act safely. In subsequent phases of research, including quantitative willingness to pay and acceptability testing, customers have consistently prioritised investment in future energy solutions[16].

We have undertaken an extensive programme of engagement throughout the development of our GD2 business plan to better understand our customers' and stakeholders' priorities and reflect their views as we develop our proposals. This is described in more detail in chapter 4 of our business plan and the Enhanced Engagement appendix (022). Prior to undertaking research with customers, we asked our stakeholders at our 2017 Moving Forward Together workshops which of five key priority areas they felt were most important. The

[15] Explorative Qualitative Workshops and interviews (Exploratory Phase) (Ref 002)

[16] Conjoint & WtP summary report (valuation phase) (ref: 005), Business Plan Acceptability Testing phase 2 (ref 079)

results were as follows[17]:



We are also helping both Scottish and UK Governments to build the evidence base around options for decarbonisation. To set challenges and test our emerging thinking for decarbonisation and energy futures, we established a Future of Heat Specialist Panel. This panel comprises individuals and organisations engaged in the future of heat and ranged from those involved in gas systems to those with alternative views, such as electrification of heat or conversion of gas grids to hydrogen.[18,19]

3.5 Future of Heat Specialist Panel 1

At the first session, we asked stakeholders to identify what the near-term certainties and uncertainties were.

You Said – Near-term Uncertainties	***You said – near-term certainties***
• **Gas network can provide a pathway to decarbonisation** • **Level of political support** • **Impact of energy efficiency measures** • **Levels of public environmental awareness** • **Can technology meet policy objectives?** • **Impact of smart technology**	• **Decarbonisation targets equivalent or higher** • **People will still need heat and gas** • **SGN mains replacement will continue** • **Renewable generation will increase** • **The energy system will be more complex** • **Fuel poverty still a concern** • **Consistent high safety standards** • **Gas quality will change within safe limits**
Criteria for future choices developed at the last meeting	***You said – what should SGN do?***
• **Equality of access for consumers** • **Ability to manage disruption** • **Ability to keep options open** • **Socialisation of cost** • **Safety – at least as safe as today** • **Consumer/social acceptability** • **Local context and relevance**	• **Consider the pathway in context of reducing carbon intensity** • **Work out different generation points for low-carbon gas** • **Do not underestimate generation resource available in Scotland** • **Work jointly with other industry players** • **Be part of a common voice on technical aspects** • **Look at international experience** • **Concentrate on where will make the biggest impact**

[17] Data source: MFT workshops 2017 from 59 stakeholders

[18] Future of Heat specialist panel Aug 2018 (ref 023)

[19] Future of Heat specialist panel Dec 2018 (ref 024)

3.6 Future of Heat Specialist Panel 2

At the second Future of Heat Specialist Panel, we set out our approach to addressing these uncertainties. We presented our pathway for decarbonisation and how we intend to generate low-carbon hydrogen from off-shore renewable wind energy in Scotland. To achieve this, we will work jointly with other industry players, such as Scottish Power Energy Networks, to develop a whole-systems charter to enable SGN to operate a fully responsive network. We are also learning from international experience and we will concentrate our build up of knowledge from around the world, where SGN will make the biggest impact.

The engagement was in the form of 'You said" and then 'We did, or we propose to do.' The feedback from these specialist panels and our stakeholder workshops has shaped our proposal for funding mechanisms in RIIO GD2.[20]

Based on stakeholder feedback, we are proposing:

- Continued research and development for projects that support the decarbonisation pathway.
- Discretionary rollout of decarbonisation projects, based on examples, subject to governance.
- Re-opener for larger projects.
- Frontier areas, towns & cities
- Whole systems – Blueprint, micro and macro and charter.
- Biomethane – centralised injection points, similar to Portsdown Hill; Avoided propanation for embedded entry; Smart controls for increased capacity.
- Off gas grid – options, Highlands & Islands.
- Local planning – Councils, LEPs – communication and developing local solutions.

Building on the success of the specialist panels, in August 2019 we held Shared Future workshops to share and discuss our GD2 proposals with expert, informed stakeholders. Stakeholders were supportive of ambitious decarbonisation proposals[21].

[20] Shared Net Zero Future workshop - Scotland (ref: 090)

[21] Shared Net Zero Future workshop - Scotland (ref: 090)

3.7 Engagement with the CEG/Stakeholders influence on this plan

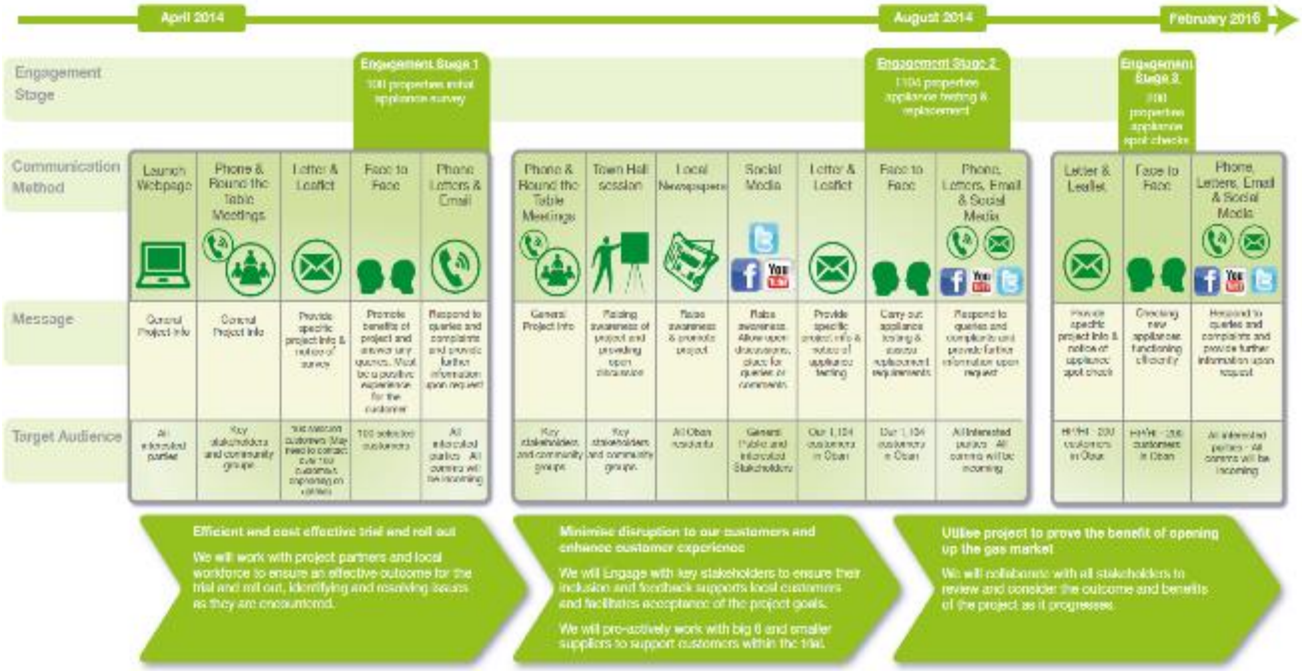
Throughout the development of the Energy Systems Transition section of the Business Plan we have been grateful for the comments and challenges received from our CEG and the wider group of stakeholders we have engaged with. Specifically, the comments received on the draft chapter have made us refine the content of this section, adding clarity and relevance where necessary.

The importance of working together to develop and provide understanding for this chapter of the plan was highlighted through the engagement that took place at our Future of Heat panel sessions, CEG deep dives into specific aspects and at our Shared Future event. The discussions that took place at these sessions have allowed the development of the plan, aligning our outputs and with stakeholder expectations.

Engagement in GD2

We recognise the importance of engaging fully with customers and stakeholders through our projects. In GD1, we identified the benefits of having a fully developed engagement plan in place, an example of this is our Opening up the Gas Markets' project[22]; an overview of our customer engagement strategy is seen in Figure 10. We aim to replicate a similar approach to this for our GD2 projects where appropriate.

Figure 10: Opening up the Gas Markets Customer Engagement Graphic



3.8 Hydrogen

During our engagement activities, it was clear that both customers and stakeholders were excited by the opportunity to replace the natural gas supply with hydrogen or hydrogen/natural gas blends. However, feedback suggested that it was unclear how the gas networks would accommodate this change and how this could be communicated in a way to support UK and Scottish Government policy. Hydrogen has the potential to significantly decarbonise the nation's heat, whilst minimising disruption and cost to customers. Figure 11

[22] Opening up the Gas Markets Customer Engagement Plan, 2014

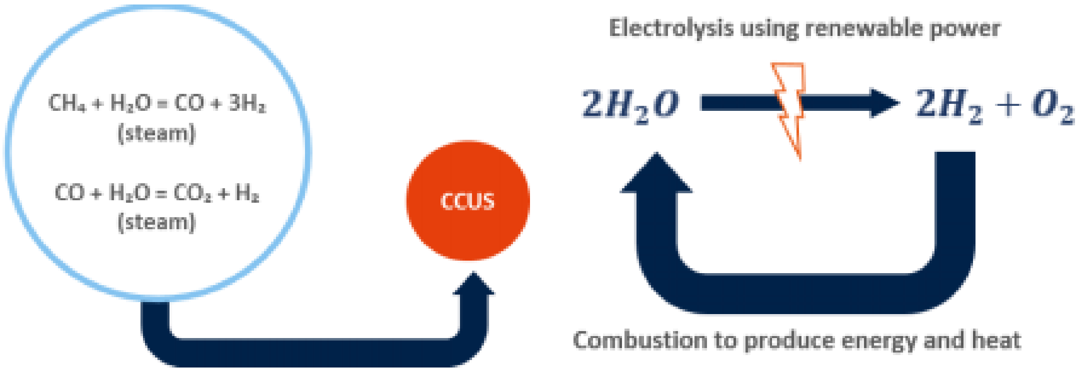
shows a hydrogen boiler from Worcester Bosch.

Figure 11: Hydrogen boiler

Hydrogen is both the simplest chemical element and the most abundant in the universe. On Earth, hydrogen is found in the greatest quantities in the form of either water or hydrocarbons such as methane. It can be generated from water using electrolysis or from hydrocarbons using a steam reforming process. It is a versatile compound and is widely used as a feedstock and intermediate in the chemical industry. When hydrogen is combusted, it only produces water as a byproduct to heat energy. When generated through the electrolysis of water using renewable electrcity, it is known as green hydrogen. Studies such as our HyGen study and Dolphyn project suggest that Green Hydrogen can be cost comparable with Natural gas at GW/h scale.

If generated from natural gas through steam methane reformation, so long as the carbon dioxide is captured, it offers a carbon-free at point of use, high intensity energy vector with the potential to decarbonise the gas grid – this is known as blue hydrogen. By generating blue hydrogen centrally, we have the potential to capture emissions from over 23 million GB gas consumers with further benefits such as decarbonisation of transport (via refuelling stations for fuel cell electric vehicles) and a route to market for curtailed or dedicated renewable electricity generation (via electrolysis). Methods to produce hydrogen are shown in Figure 12.

Figure 12: SMR and Electrolysis Hydrogen Production



4 Biomethane and Embedded Entry

Distributed gas from a range of sources is meeting a growing share of UK demand. Following the introduction of Renewable Heat Incentive (RHI) tariffs for biomethane injection, the market for biomethane to grid has grown rapidly in the past five years. While commercial production of unconventional indigenous gas sources is yet to be proven in the UK, the current government has a clear appetite to move towards a more diverse and secure gas portfolio and envisages a ramp up of unconventional indigenous gas production over the coming decades.

Based on industry estimates of reserves[23], potential production rates and policy targets, by 2030 between 5% and 34% of UK gas demand could be provided from the distributed gas sources. Most scenarios predict production rates in the region of 7.5 Mscm/day and 29 Mscm/day from biomethane and indigenous gas sources respectively. Note there is a moratorium on development of shale gas in Scotland currently[24]. Due to their low production pressures, it is likely that biomethane and Coal Bed Methane (CBM) will be injected mainly at the Intermediate Pressure (IP) and Medium Pressure (MP) tiers of distribution networks, with some injection at the Local Transmission System (LTS), whereas the predicted pressure and volumes of commercially produced shale gas mean that it is likely to be suitable for NTS injection, or LTS.

The growth of distributed gas injection fundamentally relies on there being a positive business case for gas producers. A range of factors affect the business case, including policy (such as the RHI, which currently brings significant revenues to biomethane producers injecting their gas to the grid), technical requirements for injection, and the capacity available for injection on the network. If a local network has very low demand, a gas producer will either only be able to inject a small amount of gas (which may not be enough to make a worthwhile business case for production) or will have to consider more costly methods to inject their gas (e.g. installing a pipeline to a location with greater downstream demand).

Due to the diminishing number of cost-effective injection opportunities on some networks, (which is compounded by the tendency for biomethane plants to be geographically clustered around various feedstock sources), more innovative methods of managing supply and demand across networks will need to be implemented to make capacity available and unlock the full potential supply of distributed gas sources. In addition, if the costs associated with distributed gas injection (including connection costs and various operating costs) could be reduced for future projects, this would help to make more projects viable in the future, ensuring that the benefits to the grid are maximised. This is a key focus for us in our GD2 business plan. Our "Use it or lose it – Biomethane technology rollout" funding mechanism is designed to remove barriers and facilitate higher injection volumes of green gas.

The primary barriers for future injection of distributed gases, were identified through consultation with industry stakeholders involved in the process of injecting distributed gas to the grid. There is a focus on the barriers relating to distribution network requirements and conditions (commercial and regulatory aspects were considered in terms of the opportunities for distributed gas that potential changes could bring). The barriers can be summarised in order of estimated relative impact:

- Minimum CV requirements for injection to the distribution network, leading to high propanation costs.
- Capacity constraints on the distribution network, leading to high connection costs in order to connect at a point with sufficient capacity.
- Connection costs remain high, in part due to the lack of standardisation of GDN connection design specifications.

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[23] Distributed Gas Sources report by Element Energy for NGGD, SGN and WWU January 2017

[24] Reference Scottish Government moratorium

These barriers were highlighted and discussed with the biomethane industry through our participation in the Energy Networks Association Biomethane Workgroup. This group brings together the GDNs, biogas/biomethane trade associations such as ADBA[25] and REA[26], along with representation from biomethane producers. Our proposals have also been shared at the UK AD Expo[27].

The maximum injection capacity offered by GDNs to biomethane producers for injection is limited to the minimum demand downstream of the potential gas entry point. This varies a great deal at different points in the network, meaning that depending on the location of a distributed gas production facility, the closest network segment may not have enough capacity to allow injection.

Pipelines can be installed to carry the gas from the point of production, either to a higher-pressure tier which has more downstream demand, or to a location where the network has sufficient capacity at that tier. However, pipeline costs (which are typically covered by the gas producer) can be very high and can adversely affect the business case for connection and injection to the grid. In areas of low gas demand, with multiple projects seeking to inject gas to the grid, injection may become increasingly costly as a result of this. Without cost-effective solutions to capacity constraints, the growth of distributed gas is likely to be limited.

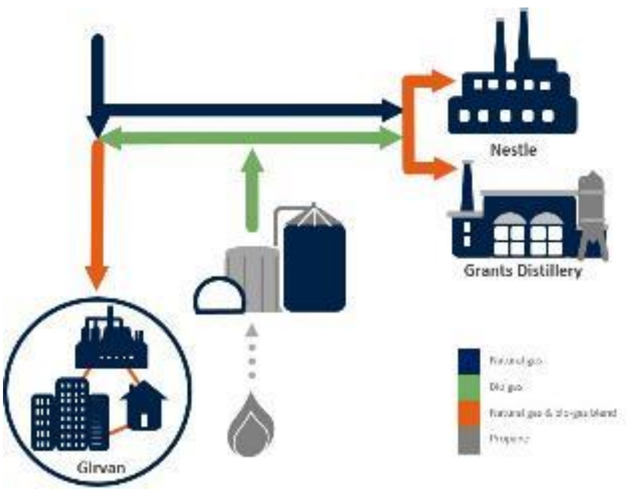
Various network management options, which optimise capacity by storing gas temporarily or by providing access to demand from other parts of the network, have been explored and in some cases implemented to address real constraints in the UK and elsewhere in Europe.

Developments of methodologies for increasing capacity of the gas network to accommodate embedded entries will apply to new sources of gas too, such as hydrogen and thus are a low regret solution.

4.1 Examples of Proposed Work in GD2

Green Billing for Industry Example

Grants of Girvan is one of the largest biomethane entry points into the SGN Network supplying 3,500 scm/h of green gas. We can reduce or eliminate the volume of propane requiring injection to enrich the gas to the prevailing gas quality for billing purposes. The vast majority of the biomethane flow is supplying two downstream supply points (Nestle & Grants). By deploying some of the innovative sensor installations developed under the Real-time Networks project (such as bidirectional flow metering we hope to offer a significant reduction in propane enrichment, greening the gas even further. The billing arrangements currently restrict our ability to deliver these solutions by enforcing a Calorific Value cap, forcing networks to maintain a 1 MJ/m^3 range of CV within the network. We will be carrying out a small NIA project to evidence this methodology, billing and sensor solution.



[25] www.adbioresources.org

[26] www.r-e-a.net

[27] www.biogastradeshow.com

Since commissioning, approximately 3 Mscm of propane has been injected at the Girvan biomethane plant which has cost approximately £2.3 million. This is a net cost to the operator of over £1.3 million and, unlike the biomethane, it is not renewable and, has resulted in over 16,500 tonnes of CO2 emissions.

Figure 13: Ebbsfleet example for smart control of biomethane in the network

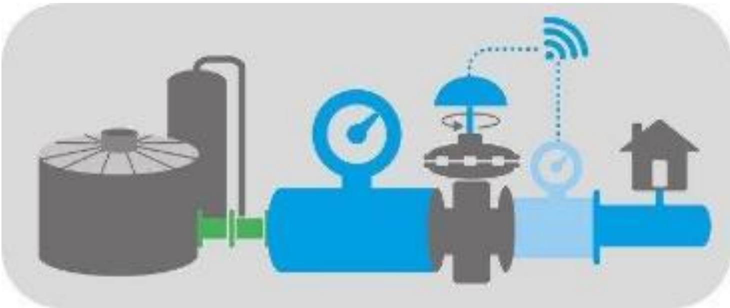


Figure 2: Utonomy/SGN Solution

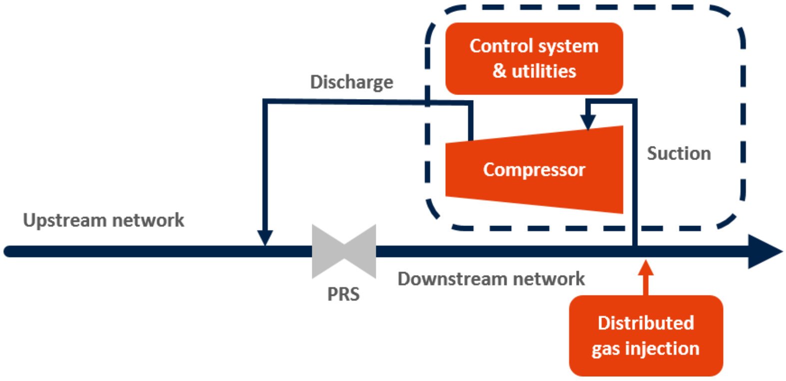
At Ebbsfleet biomethane facility in Kent we are in discussion with the producer to trial the new pressure management and control technology we have developed in RIIO-GD1[28]. This smart Utonomy/SGN solution allows automated set-point control of the injection facility, which works in conjunction with the district governors (the pressure control systems supplying the local network). This would prioritise the injected flow rate from the biomethane entry points by line packing our network with biomethane.

[28] Pressure management and control project, SGN

Gore Basin - Isle of Wight example of Reverse Compression Optimised Capacity

The constraint issues identified for distributed gas producers where there is insufficient demand on the network to accommodate the constant volume of gas they can inject could be solved using other methods.

There are various theoretical solutions to this issue, as 'line-packing' of the immediately accessible system will only accommodate a slight increase in injection capacity for a limited period before injection can no longer be achieved.



One possible solution to the issue of insufficient demand would be to install compressor equipment at an existing PRS(s) and compress gas to the higher-pressure tier upstream. This is essentially expanding the accessible mains network in which the distributed gas can be temporarily stored (i.e. 'line-packing' on the network upstream of the injection facility).

Gore Basin biomethane facility is an existing embedded entry point injecting into the Isle of Wight Medium Pressure grid, the injection rate for this facility is currently 600 scm/h. This site can experience issues with the entry of gas during low demand periods, especially overnight during the summer months.

The project will look at the various elements in compressor design, installation and control, including dynamic simulation of the compressor operation in a stable manner with optimal compressor capacity, electrical demand and connection and site location.

4.2 GD2 Rollout

The general deployment of new biomethane sites in GD2 will be dependent on the renewal of RHI in GD2. Existing sites connected to our network, of which there are 26, may all benefit from one or more of our GD2 initiatives following a year-long trial of the three technologies detailed above at the start of the period.

We are actively working with our existing Delivery Facility Operators (DFO) who have requested an increase to the volume of green gas entering the network. Many of these customers have already increased their delivery capacity, with several DFO's requesting further capacity studies. We want to ensure we support and provide technical solutions to ensure the increased flows from these sources are accommodated, greening the gas in our network even further. A snapshot of sites under study is shown in Table 4.

Table 4: Strategy to Increase Biomethane Capacity Site-by-Site

Site	Status	Comment
Peacehill Farm	Ongoing	Request to increase flow
Poundbury	Design	Request to increase flow
Helmdon, Black Pitts	Ongoing	Request to increase flow
Mitchum	Scope	Request to increase flow
St Nicholas Court Farm	Scope/Design	Request to increase flow

We are also detailing plans associated with network entry capacity mapping to provide an indicative view of available capacity on the network to re-shape the connections' process into a more informed and efficient process. The investment timeline and confidence level of successful deployment in GD2 in each of the projects in shown in Table 5 below.

Table 5: Biomethane Projects Investment Timelines and Confidence Levels

Project	Investment Timeline	Confidence Level of Successful Deployment
Green Billing for Industry	Investment planned in 2023 with benefits from 2026	Medium (Feasibility underway)
Reverse Compression Optimised Capacity	Investment planned in 2023 with benefits from 2026	Medium (Feasibility pending GD1)
Smart Control of Biomethane in the Network	Investment planned in 2023 with benefits from 2026	Medium (Feasibility pending GD1)

Our proposal for GD2 represents potentially significant value to customers, producers and other stakeholders alike. Increased biomethane capacity in the system will increase the proportion of green gas in the network, reducing reliance on fossil fuels and reducing the carbon intensity of the energy we deliver. The projection of carbon savings in GD2 and GD3 illustrates the significant carbon savings as a result of increased biomethane injection.

The proposed "use it or lose it" mechanism will be used in part to install the technology developed across our network, which is necessary to help grow and encourage an increase in the volume of biomethane on the network, breaking down the barriers for biomethane production and progressing the pathway to a decarbonised gas network. Regulations and capacity barriers exist through no fault of the biomethane producer, and we believe that it is in the interest of the wider consumer community to fund the investment for biomethane production, reducing the cost of energy realised through less processing activities for the biomethane producer, and in terms of the benefits to society using low carbon green gas.

The expected funding profile for this rollout is indicated Table 6 below:

Table 6: Use it or Lose it Mechanism

	2021 - 2022	2022 - 2023	2023 - 2024	2024 - 2025	2025 - 2026	Total Spend (£ Million)
Use it or Lost it – Biomethane and Whole System Technology Rollout	0	0	2	3	5	10

Maximising the volume of biomethane to the network allows the optimised usage of existing network assets, assets which customers have already paid for. In addition to this, biomethane producers will benefit from projects that have a more positive business case and are therefore more likely to finance further projects thus increasing the overall availability of low carbon energy in the gas network in the future.

Biomethane is a resource the gas sector must fully maximise the use of. The feedstocks used to produce biomethane such as agricultural and food waste will be produced in any case. Utilising a waste resource which would otherwise naturally decompose encourages a circular economy. Biomethane allows us as a network to progress with the decarbonisation of the energy we deliver whilst the road to social proof of hydrogen and the evidence base as set out in the Gas Quality Decarbonisation Pathway is proven. Reducing the processing requirements of biomethane for network injection because of changes to legislation is a key step in our pathway to decarbonisation. Reducing our dependency on fossil fuels also enables the production of native gas within our whole energy system, which brings with it multiple macroeconomic benefits and unlocks and enables the market for biomethane injection.

5 Demand Forecasting

5.1 Current Demand Forecasting Methodology

It is essential that we forecast demand accurately to ensure security of supply for our customers. There is a clear relationship between low ambient temperature, health implications and fatality from hypothermia, with the most vulnerable in society, particularly those in fuel poverty, being the most exposed[29].

We currently use an econometric "top down" process for forecasting demands to be supplied from our transmission network (>7 bar) to meet the 1 in 20 peak day demand requirement. To date, this has provided an accurate correlation between forecast and actual demand. Table 7 below[30] compares the actual and forecast annual and peak day demands in each of our LDZs.

Table 7: Regional Gas Demand Forecast vs. Actual

LDZ		Actual	Forecast	%
Scotland	Annual Demand (TWh)	49.37	48.69	98.6
	Peak day demand (mscmd), 28th Feb 2018	27.66	32.15	86.03
South East	Annual demand (TWh)	55.31	54.60	98.7
	Peak day demand (mscmd), 1st March 2018	38.32	43.34	88.42
South	Annual Demand (TWh)	39.13	39.25	100.3
	Peak day demand (mscmd), 1st March 2018	27.11	31.21	88.98

The current method allows for gradual changes to be forecast (such as general uptake of thermal efficiency measures in the domestic sector or changes to the economy) but the approach is not conducive to major shocks or changes in behaviour where there is no prior experience and therefore confidence in forecasts to 2030 and beyond cannot be accurately qualified. For our below 7 bar distribution system, demand forecasting is more complex and requires detailed analysis of the likely diversity of demand from customers.

We apply these demands within a sophisticated network modelling software tool, Synergi[31]. This allows us to determine the size of pipe and associated equipment for any capital investment activity. This modelling system is a 'steady state' network analysis tool, one that simulates the network's operation in a 1:20 scenario.

5.2 Expected Changes to Demand Forecasting Methodology

Changes in the energy system mean that the forecasting of gas demand will become more complex and not follow traditional relationships. A review carried out by Delta-ee of gas demand forecast drivers[32] has identified a wide range of factors which are expected to impact on gas demand between now and 2030. Most drivers show a decreasing annual demand, but with variable changes in peak demand. Based on Delta-ee's assumptions, the scenarios for biomethane injection that were identified as low (2 new biomethane entry sites

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[29] Findings on the determinants of indoor temperatures in English dwellings during cold conditions, Hamilton et al 2017

[30] From SGN Long Term Development Statement, 2018 https://www.sgn.co.uk/uploadedFiles/Marketing/Pages/Publications/Docs-Long-Term-Development-Statements/SGN-LTDS-2018.pdf

[31] https://www.dnvgl.com/services/pipeline-integrity-management-software-synergi-pipeline-1363

[32] 18105 SGN Gas Demand Forecasting, Delta-ee, 2018

per year based on current growth rates) and high (based on National Grid's FES scenarios) would give an estimated 11.4 GWh/year – 27.4 GWh/year input of gas to the grid. Delta-ee's estimated outcome is that biomethane injection would reduce SGN's total demand for natural gas by <0.1% of the total 143 TWh demand in 2016.

Table 8: Future Demand Scenarios

	Low scenario	High scenario
Scenario description	61 biomethane sites connected to SGN's network by 2030 (2 new sites per year)	587 biomethane sites connected across UK by 2030 (from FES 2015)
Gas demand change (approx.)	11.4 GWh on SGN's network Decrease	110 GWh across UK network 27.4 GWh on SGN's network Decrease
% of SGN 2016 annual gas demand	<0.1%	0.1%
Effect on peak	None expected, as input to the gas grid is not likely to coincide with peak.	

However, our own analysis indicates that the volume of biomethane will be in the region of <3-4%. These values were derived from the contracted volume of biomethane that can be injected into the network and our annual demand forecasting figures taken from our long-term development statement.

Another factor affecting demand is the increasing reliance on peak power generation, fuelled by gas, to balance the levels of variable renewable generation being introduced into the power system. Indeed, as renewable electricity installations increase, decentralised gas-fired peaking plant is replacing centralised base-load power plant[33]. Increasing uptake of electric vehicles will potentially impose significant new loads and variability to the electricity network which, in turn, appear likely to transfer to an unknown extent to the gas network in the form of peaking plant.

In parallel with the changes driven by the power sector, the below 7bar network is becoming increasingly complex due to embedded entry of biomethane and changing demand patterns, modelling requires to be more sophisticated to allow transient analysis of network impacts. Our Real-Time Networks[34] project will look to improve our ability to model and manage this energy.

There is now the opportunity for energy networks to consider how best to deliver maximum decarbonisation and system interoperability in the most efficient possible manner, reflecting the uncertainties that variable changes in demand from both interactivity between the networks and beyond the meter. The research into dynamic changes in demand forecasting due to rapidly evolving energy system will need to be carried out during GD2. We have identified a number of research and development projects that will be carried out over the period under the NIA Energy System Transition funding mechanism, see Annex 3.

6 Gas Quality Decarbonisation Pathway

The pathway illustrates the key technical, commercial and policy steps to achieving 100% decarbonisation together with the research and development that will provide evidence underpinning each step change. The first three steps are concerned with securing the gas supply, removing barriers and enabling change. The next three steps will stimulate the hydrogen economy by developing and implementing strategic projects to blend hydrogen. The need for increasing quantities of green hydrogen will, in turn, stimulate the renewable power

[33] Capacity Market Behaviour in the Aurora report

[34] https://www.sgn.co.uk/real-time-networks/

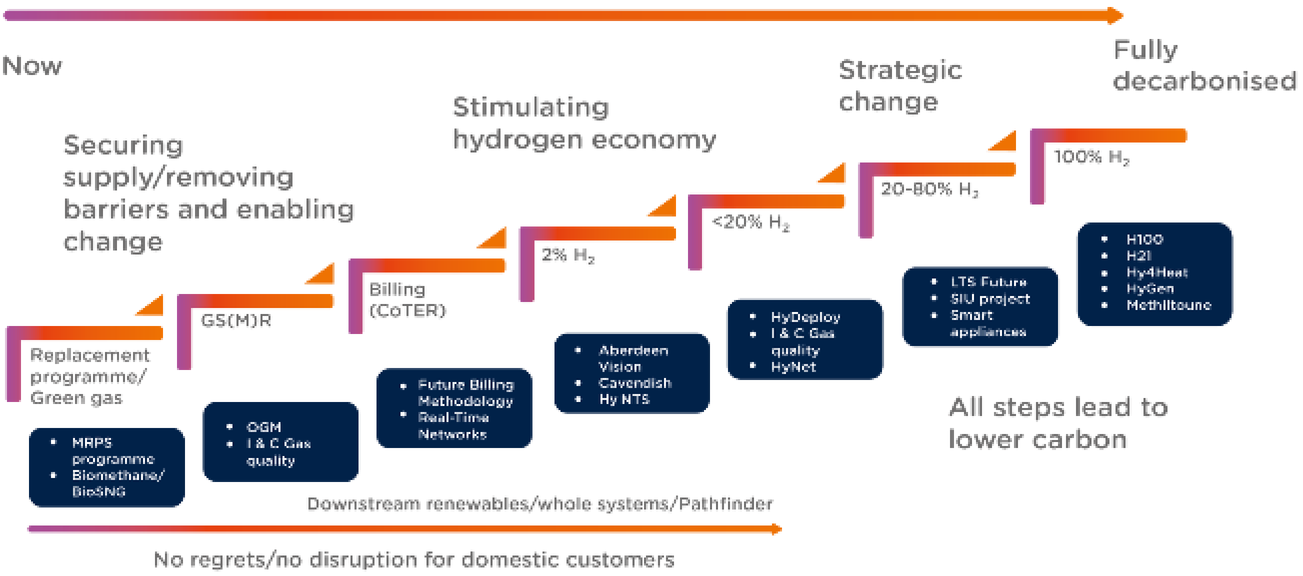
generation sector. The final step is a mandated conversion from natural gas to 100% hydrogen.

The pathway was developed by the gas transporters in collaboration with key industry stakeholders, Scottish Government and UK Parliamentarians. The steps are now collectively recognised by policy-makers and the gas networks as necessary for moving towards decarbonisation.

The pathway is based on a philosophy of evidenced steps which prepare the gas infrastructure for transition before carefully introducing hydrogen. As the evidence base is built, and the hydrogen chain becomes established, the transition can be accelerated or slowed as appropriate. At the beginning of the pathway, there is very little extra expense, but midway through the pathway, when we need to stimulate the hydrogen economy there will be additional costs. This is a least regrets route – it avoids stranding gas network assets and does not preclude other solutions. The pathway is not time-limited, but research and development is time constrained as BEIS requires the evidence for the decarbonisation of heat and energy to be ready by 2023.

Now that the pathway is agreed in principle, an academic review is being carried out. A professional publishing firm will present the pathway in a way that will engage and inform all stakeholders. This is being co-ordinated by the Energy Networks Association and with funding from the Network Innovation Allowance (NIA); the work will be delivered by Navigant[35].

Figure 14: Gas Quality Decarbonisation Pathway

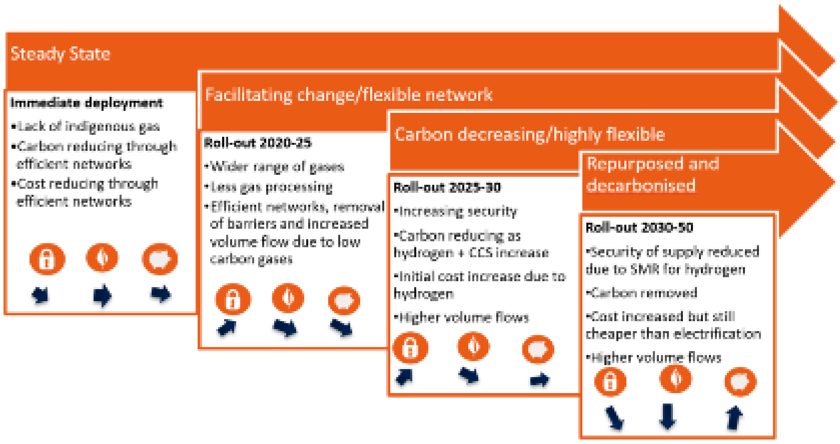


[35] Pathways to Net-Zero: Decarbonising the Gas Networks in Great Britain, October 2019

SGN has defined four market states on the pathway which will need approval and support from investors, stakeholders and Ofgem. The market states, in the order of increasing decarbonisation, are:

- Steady state
- Flexible network and facilitating change
- Highly flexible network and carbon reducing
- Repurposed and decarbonised

Figure 15: Network States



If hydrogen is to replace natural gas in the longer term, investment in the gas networks needs to be maintained prior to stimulating the hydrogen economy. The gas networks are complex, and one solution may not fit them all. One plausible outcome is for some networks, or parts of them, to become flexible and not progress further. Other networks could progress to become highly flexible and achieve greater decarbonisation. There will also be many networks that become fully decarbonised and repurposed to transport 100% hydrogen. For each step on the pathway, SGN will establish the scale of investment, the carbon saving and the impact on security of supply.

The updating of two sets of industry standards by IGEM is critical for successful delivery of the decarbonisation pathway:

- Gas Safety (Management) Regulations - the IGEM Gas Quality Group aims to transfer GS(M)R from statute to become an IGEM standard and to increase the upper Wobbe Index to enable >90% of the world's LNG supply to be used without additional nitrogen ballasting at UK LNG terminals. Critically the new standard will provide the framework for change and investment.
- Development of hydrogen standards - the IGEM Hydrogen Standards group is already working with industry and Government. For example, the BEIS Hy4Heat program and the Hydrogen Program Development Group are working on standards for hydrogen downstream of consumer meters.
- Gas (Calculation of Thermal Energy) Regulations – new industry codes and practices are required to eliminate unnecessary processing and ensure Hydrogen blending can occur.

The safe and reliable increase in hydrogen concentration on the pathway needs to be underpinned by research and development and investment in strategic projects. Government policy makers are also awaiting the outcome of industry research and development to provide options for the decarbonisation of heat as outlined in the BEIS[36] Clean Growth report and the Scottish Government Energy strategy. SGN is working collectively with the other gas networks and industry to deliver the R&D needed by 2023/4.

[36] BEIS clean growth – transforming heating report December 2018

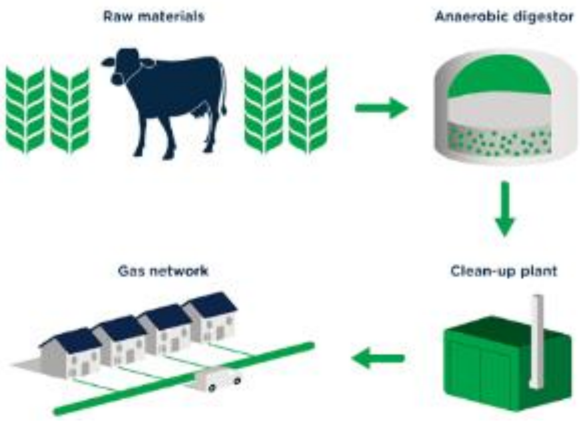
6.1 Mains Replacement Programme and Green Gas

Replacement Programme

The ongoing renewal of the gas infrastructure, through programmes such as the Iron Mains Risk Reduction Programme (IMRRP) ensures its ongoing availability and enhances its capability for the distribution of low carbon alternatives to natural gas. It is important that these programmes take account of the possible future roles of the gas network.

Green gas

Distributed gas from a range of sources is meeting a growing share of UK demand. However, biomethane producers face a range of challenges, including changes to the RHI, technical requirements for injection, and the availability of capacity for injection into the network.



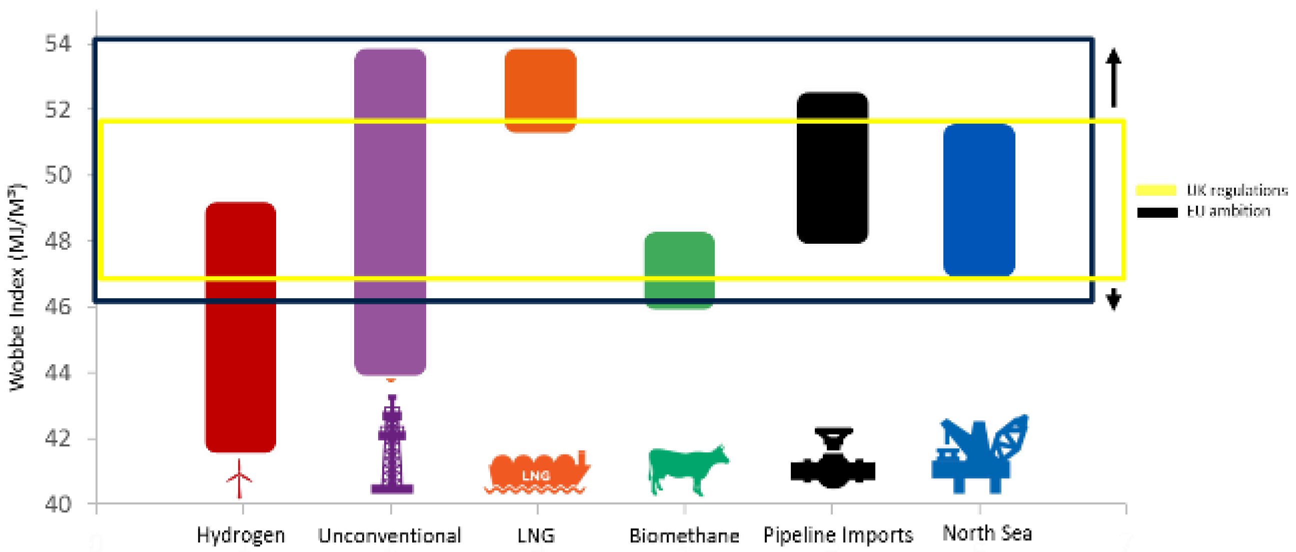
Throughout GD1, we have worked with stakeholders to identify the key barriers that will allow an increase in the volume of distributed gases injected into the network.

Building on the knowledge developed through Real-Time Networks, a number of projects will be demonstrated in GD2 that will investigate new pressure management and control technologies to alleviate CV and capacity constraint issues.

For a full description of progress made under GD1, and the projects that will be demonstrated in GD2, please refer to section 4.0.

6.2 The Gas Safety (Management) Regulations

The Gas Safety (Management) Regulations (GS(M)R) govern the characteristics of gas that can currently be introduced and supplied into the GB gas grid. The gas quality requirements in GS(M)R are restrictive compared to those of other European countries and limit the capability of the gas network to make use of new sources of gas such as unconventional gases, biomethane or the potential for hydrogen blending.



European Union member states are working towards a harmonised and wider gas specification called the European Association for the Streamlining of Energy Exchange – gas (EASEE-gas). Changing GS(M)R to align with EASEE-gas would widen the market and accommodate the introduction and use of abundantly available alternative sources of gas without the need for expensive processing, the Wobbe Index being one example.

Opening Up the Gas Market Project

To provide evidence for the widening of GB gas limits, SGN initiated the Opening up the Gas Market (OGM) NIC project in Oban. OGM was a three-stage project which sought to demonstrate whether gas, which meets the EASEE-gas specification but sits outside of the characteristics specified within GS(M)R, could be safely distributed and utilised safely and efficiently to domestic customers in GB.

The results from the project showed a definitive need for GS(M)R changes to reflect current gas quality in the UK, reduce unnecessary costs and carbon associated with the addition of manufactured gases and proposed opening the UK to a wider range of sources of gas on the global market. This seminal work created the base evidence for change now and in the future.

6.3 Gas (Calculation of Thermal Energy) Regulations

Many unconventional gas sources are low in calorific value, but compliant with GS(M)R for Wobbe Index – examples are green gases such as biomethane and shale gas. Early indications are that shale gas in England is almost pure methane and therefore similar in chemical content to biomethane. However, the current implementation of the Gas (Calculation of Thermal Energy) Regulations requires these low calorific value gases to be enriched with propane to increase the calorific value for commercial, rather than safety reasons increasing the carbon footprint.

The Regulations require calorific values within a charging area to be similar so that no customers are disadvantaged. The current billing system is based on 13 local distribution zones (LDZs) across the whole of GB and this worked well for North Sea gas when the calorific value was relatively uniform. However, the increased diversity of gas quality and embedded injection of biomethane has resulted in a wider range of calorific values.

Each LDZ has several inputs and the gases do not mix within the network. Customers living close to an input of high CV gas consistently receive gas with a CV greater than the Flow Weighted Average Calorific Value (FWACV). Conversely, customers living near a low CV input consistently receive gas with a CV lower than the FWACV. Under the Gas (Calculation of Thermal Energy) Regulations and, as a consumer protection measure, the FWACV used for customer billing cannot be more than 1 MJ/m^3 above the lowest CV entering the charging area – this is known as the CV cap. Even when the CV cap is invoked, the same group of customers are disadvantaged and provided a cross subsidy. The unbilled energy in a CV-capped LDZ is made up by National Grid Gas and the cost for the shrinkage is ultimately funded by gas consumers as part of increased transportation charges.

Future Billing Methodology

Cadent are addressing the billing issue with their Future Billing Methodology NIC[37] project which will permit all GS(M)R compliant gases to be admitted into the network without additional, and expensive, processing. The Future Billing Methodology project is investigating the zone of influence of each source of gas entering the network.

Real-Time Networks

SGN's Real-Time Networks (RTN) NIC project is being delivered in parallel with the Future Billing Methodology project. Real-Time Networks will provide a better understanding of energy flow into and out of the network that will enable a step-change in network management. The enhanced network modelling capabilities

[37] Future Billing Methodology NIC project – more information is available at https://futurebillingmethodology.com/

developed from Real-Time Networks project should be applicable and available for improving the determination of the zones of influence for customer billing.

6.4 2% Hydrogen

Adding hydrogen is an effective way to decarbonise heat and energy. The injection of 2 mol% hydrogen does not sound significant, but it is the first step to much deeper decarbonisation. The gas networks jointly have an industry roadmap for increasing the amount of hydrogen:

It is anticipated that 2 mol% hydrogen will be able to be accommodated across the whole gas network, including the National Transmission System. A blend of up to 20 mol% hydrogen is safe for domestic consumers without any changes to their appliances. 100 mol% hydrogen will require customer appliances to be converted although the PE pipes in the distribution networks are safe for transporting hydrogen.

Not all gas networks or users will be able to convert to 100% hydrogen and there will inevitably be a mix and match of local solutions. For industrial gas consumers using natural gas as a feedstock, conversion to hydrogen is clearly not possible. Energy intensive users are likely to prefer to continue to use gas, in the form of hydrogen or hydrogen blend, rather than convert to electricity.

There are several reasons for starting with 2 mol% hydrogen:

- It burns like natural gas and domestic consumers will not notice the difference.
- Only minor, if any, changes to combustion systems for most industrial and commercial users will be required.
- CNG vehicles are unaffected by this percentage.
- Critically 2% provides key stimulus for both Hydrogen and CCS at strategic hubs.

Introducing low levels of hydrogen into the grid will be enabled by changes to GS(M)R and the experience gained from projects such as Opening Up the Gas Market (OGM). The Aberdeen Vision and Cavendish projects aim to stimulate the hydrogen economy whilst lowering carbon emissions. Both these projects are based around blending 2% of hydrogen into a section of the high-pressure gas transmission system. Whilst 2% is a low concentration, the natural gas volumes are high, so the hydrogen supply for each of these projects is expected to be 150 - 250 MW, approximately 30% of the gas demand for medium sized city. This is a commercial scale hydrogen plant[38] which means that hydrogen produced will be on a comparable cost basis to that generated for industry worldwide.

St Fergus is a major UK gas terminal, typically supplying around 35% of mainland GB gas needs. During January 2018, average flow was 95 mcm/day of natural gas. Our Aberdeen Vision project which proposes blending 2% of hydrogen into this stream would allow the introduction of 270 MW of decarbonised gas into the National Transmission System in the first phase, avoiding emissions of up to 357,000 tonnes/yr of CO_2

[38] The BOC operated reformer on Teesside supplies 32,000 tonnes/yr of H_2 equivalent to 140 MW

6.5 Up to 20% Hydrogen

As the evidence base grows (through technical research projects such as Aberdeen Vision, Project Cavendish, HyDeploy and I&C Gas Quality) and the network is further readied (by deploying the knowledge from earlier projects), higher levels of hydrogen can be introduced. This will increase the level of decarbonisation with continued use of existing infrastructure, industrial equipment and domestic appliances.

Aberdeen Vision

Our Aberdeen Vision project, in partnership with National Grid, is one of the projects which, using GD1 NIA funding, is intended to demonstrate the commercial and technical viability of:

- Injecting 2% hydrogen into the NTS.
- A 100% hydrogen pipeline to Aberdeen.
- A 20% blend into the Aberdeen distribution network

St Fergus gas terminal, located 40 miles north of Aberdeen, is well suited as a hydrogen development location. Central to Aberdeen Vision would be a reformation plant producing hydrogen from natural gas landed at St Fergus. CO_2 released from the gas during this process would be captured and exported to the proposed Acorn CCS project. Product hydrogen would be injected to the NTS and transported to Aberdeen, whilst captured CO_2 would be exported offshore for sequestration.

The hydrogen would transported as a 2% blend in the NTS and a dedicated 100% hydrogen pipeline to Aberdeen. Hydrogen is already in use for transport in Aberdeen where a fleet of hydrogen powered buses and refuelling stations are currently in operation and proposals are in progress to increase the capacity. Hydrogen supplied to a hub at Aberdeen could supply these refuelling stations, be blended into the local natural gas network as a 20% blend and would offer further opportunities for 100% hydrogen use in shipping and other markets. The cost of hydrogen production at the transport hubs using electrolysis from grid electricity at present is around £10/kg of hydrogen. The projected cost of hydrogen produced from reformation and carbon capture is £1.39/kg[39].

Project Cavendish

Cavendish is the second key project for 2% hydrogen injection into the NTS and 20% into the distribution network. National Grid are leading with SGN, Cadent and ARUP as partners. Project Cavendish is based in the South-East of England and will involve hydrogen production from reformation technology at the existing liquified natural gas terminal at Grain LNG. This project aims to:

- Produce hydrogen at Grain LNG terminal through reformation technologies.
- Construct a dedicated hydrogen transmission line from Grain LNG to East London.
- Feed local distribution systems with hydrogen for use at hubs for transport (buses, taxis and private vehicles in East London.
- Supply hydrogen to Uniper for use in Greenwich power station to provide power for Transport for London.
- Facilitate up to 20% hydrogen blends into local distribution zones in the South-East

HyDeploy

HyDeploy is an NIC project which was developed from the earlier HyStart NIA project. It is sponsored by a consortium including NGN and Cadent. The project aims to demonstrate that a blend of hydrogen and natural gas, beyond that permitted in the current GS(M)R specification, can be distributed and utilised safely and

[39] WP6 Aberdeen Vision Project Final Report, October 2019

efficiently in the UK distribution network without disruptive changes for consumers. It will be the first UK trial of blended hydrogen and natural gas.

Keele University has a closed, private gas network, which it is utilising as a 'living laboratory' under its Smart Energy Network Demonstrator (SEND). It comprises a network and appliances typical of the GB gas distribution systems, domestic and commercial users including a CHP, but under the control of the University as a local, licenced supplier. It is an ideal host for the first national step towards hydrogen deployment as, much like the Opening up the Gas Market project, it manages the risk and enables a more ambitious trial than would otherwise be achievable.

HyDeploy 2

Further NIC funding has now been awarded for a second phase of larger scale trials. HyDeploy2 is a four-year programme of work starting in 2019, led by gas distribution network Cadent working in partnership with Northern Gas Networks, Progressive Energy, scientific consultants at the Health and Safety Laboratory, and with other members of the same consortium who are behind the initial HyDeploy trial project at Keele University.

£14.9m of RIIO GD1 NIC funding will cover two trials in the north of England, each of 750 homes One trial will be in the Cadent network in the NW of England and the second in the NGN region of the NE/Yorkshire. Identifying suitable locations, and consulting customers and authorities in those areas, will be the next steps.

Following the success of the HyDeploy2 project, there will be a requirement for a wider roll out of hydrogen blending facilities on the network. Success of HyDeploy2 will be a further stimulus towards introducing a market for hydrogen and the need to include hydrogen in any government incentive scheme for green gas. The learning from this project will be crucial to all distribution networks in the deployment of blending facilities.

6.6 20% – 80% Hydrogen

20-80% hydrogen is arguably the most challenging step on the pathway for appliances. Natural gas appliances will need replacement or modifications to safely use concentrations of hydrogen over 20% whilst hydrogen boilers will only work at H_2 concentrations greater than 80%. The reason for the need to change appliances over the transition between natural gas and pure hydrogen can be shown by comparing some of the properties of the two unblended gases. The calorific value of hydrogen is about one third of that of natural gas but the Wobbe Indices of the two are similar – this could lead to the assumption that hydrogen and natural gas were interchangeable on the same burner. Unfortunately, due to the difference in flame speed and density, this is not the case and natural gas appliances will need to be converted to hydrogen appliances.

For appliances to operate safely over a wide range of hydrogen content, control systems need to be developed that could adapt fuel-air ratio rapidly, perhaps through intelligent and smart control systems or installation of gas conditioning equipment. There will also be a need at this stage for an extensive programme of R&D into smart appliances and industrial heat technologies to allow some users to bridge this change in gas compositions.

Operating gas systems in this range of gas mixes may not be necessary on the route to 100% hydrogen – conversion could be carried out on a regional basis but the option to run the whole spectrum of gas blends through the gas grid should not be dismissed as it may allow unrestricted re-purposing of the transmission system to deliver hydrogen or natural gas across the whole of the GB system. This will provide greater flexibility on the route to decarbonisation.

It may be possible to operate a transmission system with different hydrogen blends; however, this is not yet proven technology. Increasing the concentration of hydrogen in the Local Transmission System needs to be investigated carefully as transporting gas blends rich in hydrogen would be very different from transporting natural gas. The higher the pressure, the greater the difference from natural gas.

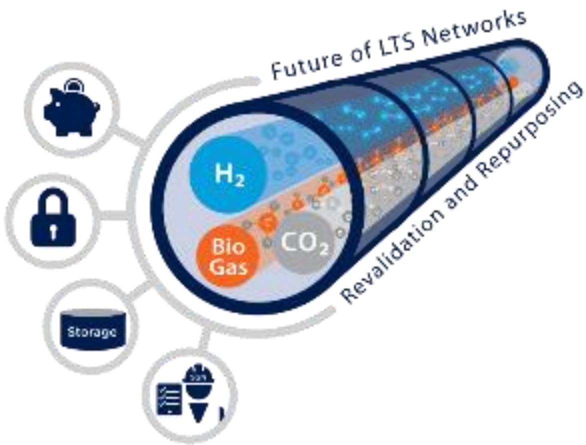
A possible solution identified to address the transportation of hydrogen/methane blends within the existing

UK gas system is to “de-blend” the mixed gas streams at scale on a regional basis. If proved to be technically and economically feasible the concept could provide a credible pathway to achieving the transition from <20% hydrogen/methane blends to a fully decarbonised gas network.

This method of distributing low carbon hydrogen could allow certain sensitive consumers, such as a combined cycle gas turbine (CCGT) power stations, to continue to receive a steady supply of natural gas without disruption to the transition of the gas network. Other consumers, such as early adopters of low carbon hydrogen, will conversely be able to receive a hydrogen gas stream. Therefore, this technology maintains optionality for consumers during the transition to a low carbon gas network.

LTS Futures

An area that has had less attention to date has been the assessment of potential hydrogen storage, up to 100% hydrogen, and transportation options within the Local Transmission System (LTS). The pathway to decarbonisation of the LTS requires a robust and scientific review to ensure that all critical technical, operational and safety challenges and risks have been considered. The development of the LTS as a storage and transportation solution as an output of this study will help to inform the ongoing research activities within the distribution and transmission system. Specifically:



- There will be a clear prospect for the role of the LTS within a future hydrogen and CO_2 transport and storage system and a well-defined pathway of the steps required to reach confidence for this conclusion.
- The project could also identify opportunities for future hydrogen and carbon capture innovations and be a critical milestone on the pathway to decarbonisation.
- The repurposing and future use of existing pipelines would deliver significant savings in cost, time and disruption associated with the construction of LTS pipelines.

Phase 1 of this project is a combination of a desktop study and consultation with regulators. This will evaluate existing technical information, guidance and standards and engaging with industry. The outputs will be:

- An assessment of the capability of the LTS to store and transport pure and H_2 blends and CO_2. A Case Study produced on an existing decommissioned pipeline between Grangemouth and Granton.
- Identification of potential challenges that would prevent the storage and distribution of pure and H_2 blends and CO_2 in the LTS and recommendations for mitigation.
- Identification of considerations deemed critical in order to provide a clear Go/No Go decision to move on to the next phases of physical trials.

The conclusion of Phase 1 will lead to further GD2 phases of the project.

6.7 100% Hydrogen

A gas grid flowing 100% hydrogen is the ultimate and necessary goal if the Scottish and UK decarbonisation targets are to be met whilst continuing to make full use of the extensive GB gas grid assets.

H100

Our Hydrogen 100 project (H100) has been designed to demonstrate the safe, secure and reliable distribution of 100% hydrogen in our gas network. The project is built-up of a series of smaller packages that specialise in each aspect of hydrogen research under the following workstreams:

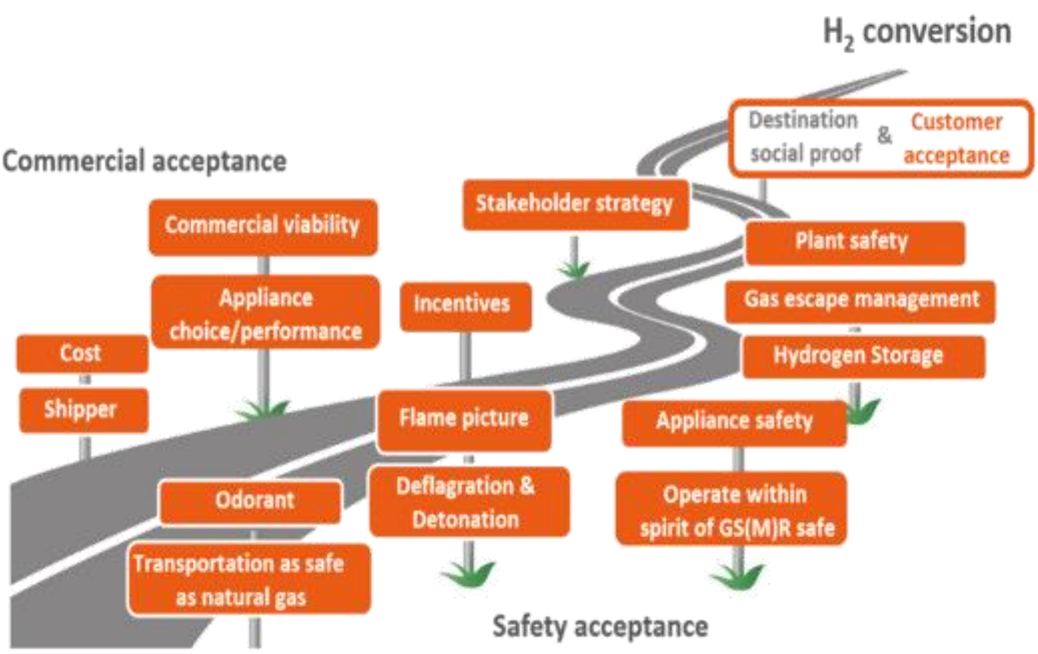
- **Workstream A** is a suite of projects that support the Workstream B Feasibility Study. These have been designed to identify, evidence and mitigate the risk associated with the move from distributed natural gas to hydrogen and to build the evidence base required to construct our safety case. In support of the feasibility study there is a further series of evidence building projects – each devised as part of the 'road to social proof roadmap'.
- **Workstream B** is the Feasibility and Front-End Engineering Design (FEED) studies to identify, resolve and evidence known local network features and issues in preparation for construction and operation of a hydrogen network. The identified project demonstrator will result in the construction and distribution of the first 100% hydrogen network.

The project's aim is to develop quantitative evidence that will advise government policy, HSE and regulation and ultimately allow the construction and operation of the first 100% hydrogen network in Scotland.

The 'road to social proof roadmap' seeks to identify socio-economic and technical issues associated with our hydrogen feasibility study. It supports the development and building of the evidence base required to satisfy our customers and stakeholders. It consists of the elements that cover all aspects of gas distribution that may be affected by the switch from natural gas to hydrogen, including the blueprint for training for the conversion.

This is a large and complex project with the feasibility and FEED studies pulling together all elements. The feasibility studies will enable eventual selection of the site that delivers the best UK scalable demonstration model.

Figure 16: Hydrogen Road to Social Proof

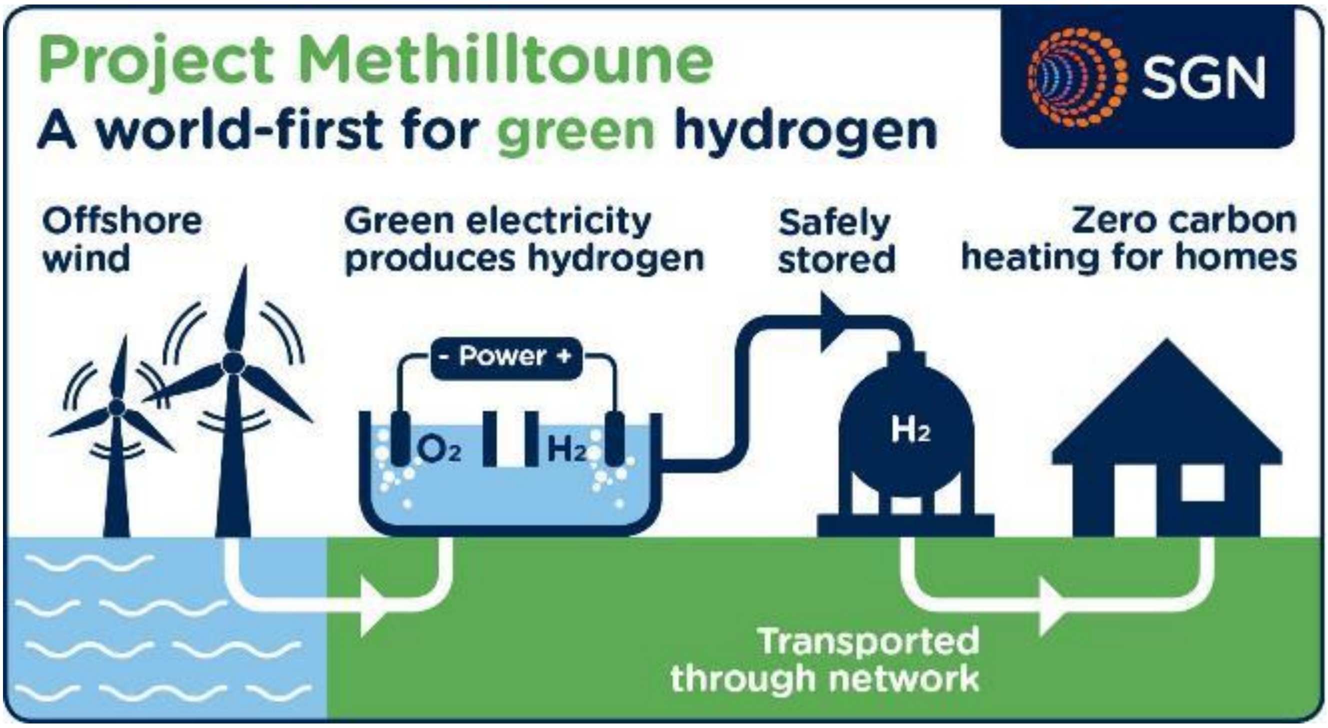


Methilltoune

Methilltoune is a proposal for the resilient supply of zero carbon hydrogen to support the demonstration of a scalable 100% Hydrogen distribution network. The project was awarded £500k funding by BEIS under the Hydrogen Supply Programme to carry out the conceptual and detailed design of a hydrogen generation and storage system.

The next phase of construction and operation of a 'first of a kind' energy system demonstrator is included under our proposed NIC Energy System Transition funding mechanism, marrying this hydrogen supply solution with the H100 project to construct the entire end to end supply, distribution and end use system.

Figure 17: Methilltoune Project Image



HyGen (Low Carbon Infrastructure Transition Programme (LCITP))

The purpose of this study was to identify the best options for hydrogen generation and storage at each of the sites selected for the H100 feasibility study. Each of these sites offers a different opportunity and range of options in terms of the best technical and economic solution.

The study also determined the long term scale up and viability of each scheme taking account of possible synergies with other sectors (e.g. industrial by-products, changes to electrical systems, etc). An important aspect will be the enabling of wider hydrogen usage (for extended heat or transport application) in the future. The output from the work will be a preferred solution or 'scheme' for each site which will be a starting point for the next phase of the project.

Hy4Heat

Hy4Heat is a £25m innovation programme, commissioned by BEIS, to determine whether it is technically possible, safe, and convenient to replace natural gas (methane) with hydrogen in residential and commercial buildings and gas appliances.

Hy4Heat

The programme comprises nine work packages and is dedicated to developing the evidence needed to confirm that Hydrogen can safely be used downstream of the meter – i.e. in the appliances in customers' homes and businesses.

SGN sit on the Hydrogen Coordination group for this project, along with other gas distribution networks, National Grid, IGEM and Ofgem

H21 – Testing of Network Features with Hydrogen

This NIC project, in which SGN is a funding partner, will undertake an experimental testing programme which will provide the necessary data to quantify the comparative risk between a 100% hydrogen network and the natural gas network. It builds on the existing H21 Leeds City Gate NIA, has been strategically designed to complement the BEIS £25m Hy4Heat programme and will work closely with the HyDeploy project sharing customer liaison and social science best practice.

H21 – Network Operations

The objective of H21 – Network Operations is to provide quantified safety-based evidence to confirm gas distribution networks are suitable to transport 100% hydrogen. Experimental testing carried out in phase 1 is providing necessary data to quantify comparative risk between a 100% hydrogen network and the existing natural gas network.

Phase 2 will contribute further to this evidence base, by investigating the impact of 100% hydrogen distribution from LTS offtake to the consumer's meter on current operational and maintenance activities, regulations and procedures. The project will provide a range of procedures on the below 7 bar networks which is applicable to all network operators and supportive of other relevant hydrogen programmes, such as Hy4Heat, H100 and HyNet.

6.8 Next Steps

The GD1 projects described above have and will provide crucial research and evidence towards each step of the gas quality decarbonisation pathway. We have an extensive range of projects in development for GD2 that will provide UK government with the evidence required to make key policy decisions in 2023 regarding the decarbonisation of heat and energy.

Table 9 below summarises our key strategic projects to be carried out into GD2. For more comprehensive details of these GD2 pathway projects, see Annex A.

Table 9: Pathway Projects

Project	Description	Step	Funding mechanism	Amount (£ Million)
R&D	Various (see Annex A, B and C)	Pathway	NIA Energy System Transition	14.6
		Emerging Technologies		3
		Demand Forecasting		0.9
Methilltoune Phase 2	Prove the resilient bulk supply of zero-carbon hydrogen to support the demonstration of a scalable 100% hydrogen gas network.	100% H_2	NIC Energy System Transition	7.5
H100 Levenmouth	The H100 Levenmouth project will evidence how hydrogen can be safely and securely delivered through a piped network to homes.	100% H2	NIC Energy System Transition	15.0

Hydrogen Entry Units for the Distribution Network	R&D into optimised and simplified hydrogen injection points and configurations.	2% H_2	NIA Energy System Transition	2.5
Industrial Clusters	Major industrial by-product study and potential rollout through uncertainty mechanism circa 50,000 tonnes of hydrogen and potential hub development.	<20% H_2	NIA Energy System Transition	2
			EST Reopener	34.2
Project Cavendish - Demonstration Phase	Injection of 20% hydrogen into the gas network in the Medway region of south east England, providing decarbonisation and air quality benefits.	2% H_2	NIA Energy System Transition	3.5
			EST Reopener	80
Aberdeen Vision - Demonstration Phase	Partnership with National Grid demonstrating the commercial viability of: • Injecting 2% hydrogen into the NTS. • A 100% hydrogen pipeline to Aberdeen. • A 20% blend into the Aberdeen distribution network	2% H_2	NIA Energy System Transition	0.5
			EST Reopener	94
Future LTS	Significant program to evaluate the potential role of the LTS for energy transformation.	20-80% H_2	NIA Energy System Transition	5.6
			NIC Energy System Transition	18
100% Hydrogen Conversion Demonstration - Community Trial	Facilitation of 100% conversion demonstrations in conjunction with Hy4Heat.	100% H_2	NIA Energy System Transition	4
			EST Reopener	15

Hydrogen Transformation – Identified gaps	Facilitate the demonstration and provide evidential outputs for any gaps identified through the Hydrogen Transformation Group following completion of the current GD1 work and proposed GD2 projects.	100% H_2	NIC Energy System Transition	10
Gas Control of the Future	This project will undertake a feasibility study and demonstrate new needs for control, methods of communication, alarms, security of supply and safe control of operations within our Gas Control environment.	100% H_2	NIA Energy System Transition	0.5
			NIC Energy System Transition	6
Multi-Occupancy Buildings (MOB)	Understanding the safety requirements for hydrogen in MOBs will be a key step on the gas decarbonisation pathway.	100% H_2	NIA Energy System Transition	1.3
			NIC Energy System Transition	34
Deblending	This project will help stimulate a hydrogen economy by improving the means of delivering variable concentrations of hydrogen.	100% H_2	NIA Energy System Transition	0.5
			NIC Energy System Transition	15.5
Custody Transfer Metering for Hydrogen	Metering will be an essential step on the gas decarbonisation pathway. Technology developed through this study could be rolled out to other GDNs, providing value for money to energy customers.	100% H_2	NIA Energy System Transition	0.1
			NIC Energy System Transition	1.0
Robotic Below Ground Mapping	Pre-hydrogen conversion survey of the network using robotic hardware.	100% H_2	NIA Energy System Transition	0.5
			NIC Energy System Transition	5
Local Transmission System – New Materials	This project would build upon the knowledge developed through the LTS Futures project and form part of a technical investigation into the safe use of RTP technology for hydrogen conveyance in the UK.	100% H_2	NIA Energy System Transition	0.2
			NIC Energy System Transition	10
Pressure Reduction	This project will investigate the safest and most cost-effective way of delivering 100% hydrogen through our network, with the aim of reducing cost to customers and allowing the network to operate efficiently.	100% H_2	NIA Energy System Transition	0.5
			NIC Energy System Transition	4

7 Assurance

Our Business Plan, including Appendices, has been subject to a rigorous assurance process which is detailed in Chapter 3 of the Plan and the Board Assurance Statement.

Our Chief Executive Officer was appointed as the Sponsor for the Energy System Transition Appendix which has been through the following levels of review and assurance:

First Line

This was undertaken at project level by the team producing the document, as a regular self-check or peer review.

Second Line

This was undertaken independently within the organisation to review and feedback on product development, including a workshop on decarbonisation. Both Senior Manager and Director sign-off was obtained.

Our RIIO-GD2 Executive Committee: (1) considered the appropriateness of assurance activity for the Appendix and (2) provided assurance to SGN's Board that the Business Plan meets Ofgem's assurance requirements.

Third Line

This was undertaken by external advisors and groups providing critical challenge during the development of products within the Business Plan. In addition to the feedback and challenge provided by the Customer Engagement Group (CEG) and Customer Challenge Group (CCG) this Appendix was developed after consultation with and advice from:

Advisor / Group	Contribution
Stakeholders	Specialist Heat Panel stakeholder sessions and Shared Future stakeholder event.
DNVGL	Calculations checks and final review of Appendix.

Fourth Line

This was undertaken by independent and impartial external providers, who provided a detailed and comprehensive report to both the Executive Committee and Board of Directors:

Advisor / Group	Contribution
Ove Arup and Partners	Review of Energy Futures Appendix against Ofgem's assurance requirements.

8 Annex Contents

1. GD2 Pathway Projects

Research and Development Projects

Underpinning the execution of the decarbonisation pathway are a number of important research and development and feasibility studies we have identified in building the evidence base necessary to mandate a change to a 100% hydrogen network. All costings are estimates.

Project	Description and Relevance	NIA Energy System Transition Funding (£M)
Membrane Soft Parts Assessment for Hydrogen Suitability following H21	Testing of elastomeric polymer soft parts, nylon, and their suitability for hydrogen	0.4
Stornoway propane network conversion feasibility	Technical study to consider conversion potential of SGN's propane network to hydrogen	0.5
100% Hydrogen Conversion Strategies and Solutions (Regional Level)	Technical studies to determine the optimal sectorisation and conversion methodology for 100% hydrogen	0.8
Forcing Gas Solutions for Avoided Mixing and Agitation	Development of simplified techniques for mixing of gases at entry points	0.5
Biomethane / Hydrogen Interactive Network Solutions	Both control and mixing and reverse compression applications between distribution and transmission	0.2
Pipeline Linepack optimisation for blended hydrogen and 100% hydrogen and biomethane	Feasibility study into linepack optimisation within LTS	0.8
Hydrogen Carrier and Storage Solutions (Ammonia and LOHC's)	Feasibility study of methods to carry and store hydrogen	0.5
COMAH for Hydrogen	Feasibility study into implications of the introduction of hydrogen in relation to COMAH	0.2
Biomethane Optimised Entry	Simplification/standardisation of the PS5/PS6 process to speed up connection process	0.1
Hydrogen Safety Devices	Development of new safety devices following H100/H21 for retrofit	1.4
Material Analysis (Distribution)	Assessment of new and existing material compatibility with alternative distributed energy sources (both liquid and gas)	4

High Pressure Storage Repurposing	Feasibility study to determine the suitability of existing high-pressure storage assets and sites for alternative energy storage	1
Real-Time Networks - Phase 2	Testing of Hydrogen sensors and variation in gas quality utilising Real-Time Networks	2
Impact of Contaminants of Green Gas Sources in Gas Network	Multiple projects subject to gaps identified by gas quality standard working group UK	0.2
Centralised entry for green gas	Feasibility study into optimised location for centralised green gas entry system	1.5
Thrust and Anchorage	Anchoring hydrogen pipelines in order to mitigate thrust concerns due to transport of hydrogen	0.3
Velocity and Saltation	Assessment of velocity constraints and saltation constraints involved in the transportation of hydrogen through our pipeline system	0.2
Total		**14.6**

Methilltoune Phase 2

Project Methilltoune Phase 2 seeks to prove the resilient bulk supply of zero-carbon hydrogen to support the demonstration of a scalable 100% hydrogen gas network. The Phase 2 funding will allow for the construction and demonstration of hydrogen production and storage from offshore wind, which will generate critical knowledge and infrastructure to support an end to end demonstration. The combined Methilltoune and H100 system will evidence how bulk hydrogen production can be produced in a scalable manner through electrolysis of renewable sources to meet the demands of domestic heating. The system will also identify and demonstrate the associated cost reduction pathways while maintaining a resilient and secure supply of energy.

The Methilltoune and H100 projects form key evidentiary projects in the pathway to decarbonisation, removing barriers, securing supplies, stimulating the hydrogen economy and delivering a zero-carbon option. We believe that the consumer value proposition that hydrogen appliances afford, which has been widely recognised as relatively lower cost and lower disruption than other decarbonisation solutions, needs to be tested to inform key decisions on the future of energy in the GB. This is the first of a kind demonstration that requires end to end process co-ordination.

We are proposing a two-stage approach for Phase 2 starting in 2021, which is in keeping with most construction projects;

- Phase 2A- Front End Engineering and Design (FEED) and then
- Phase 2B - Construction.

Benefits

The deliverables at the end of Phase 2A are outline planning consent, a land agreement, completed qualitative safety risk assessment reviewed by the HSE, agreed commercial model, funding commitment for the H100 gas network and appliances and tender prices from the supply chain. These deliverables themselves have value in confirming arrangements for hydrogen for heating community trials, an essential evidence gathering step in the heat decarbonisation policy work. They will also support future work on cost reductions for bulk hydrogen production, based on real tender prices.

At the end of Phase 2 we expect to have moved the TRL level of integrated hydrogen production facilities from 2 to 7 and as a result:

- Demonstrated that intermittent renewables can be used to generate gas grid reliable hydrogen, providing confidence that this is a technically achievable solution.
- Developed the necessary control systems required to manage the hydrogen production and supply.
- Produced a design methodology and repeatable detailed design for a hydrogen production facility from renewables.
- De-risked future commercial investments and at scale demonstrations by proving a regulatory model and integrated supply chain that can be repeated and optimised in subsequent projects.
- Enabled a whole system solution which is essential to determining consumer response to hydrogen and build wider confidence in 100% hydrogen for heating as a large-scale solution to decarbonising heat.
- Provided real data on the costs of bulk hydrogen production both in facility construction and maintenance and operation that can be used to help value engineer future solutions to optimise the proposed cost reduction pathway.
- Demonstrated the best of British engineering, supporting export potential of consulting, design, manufacturing and construction expertise.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Detailed Design & Permitting	2021 – 2022	NIC Energy System Transition	1.0
Construction and Commissioning	2021 – 2026	NIC Energy System Transition	6.5

It should be noted that the current GD1 H100 NIC bid will include the hydrogen supply element as described above. Should this GD1 NIC bid be successful there will not be a requirement for this GD2 NIA Energy System Transition funding for Project Methilltoune Phase 2.

H100 Levenmouth

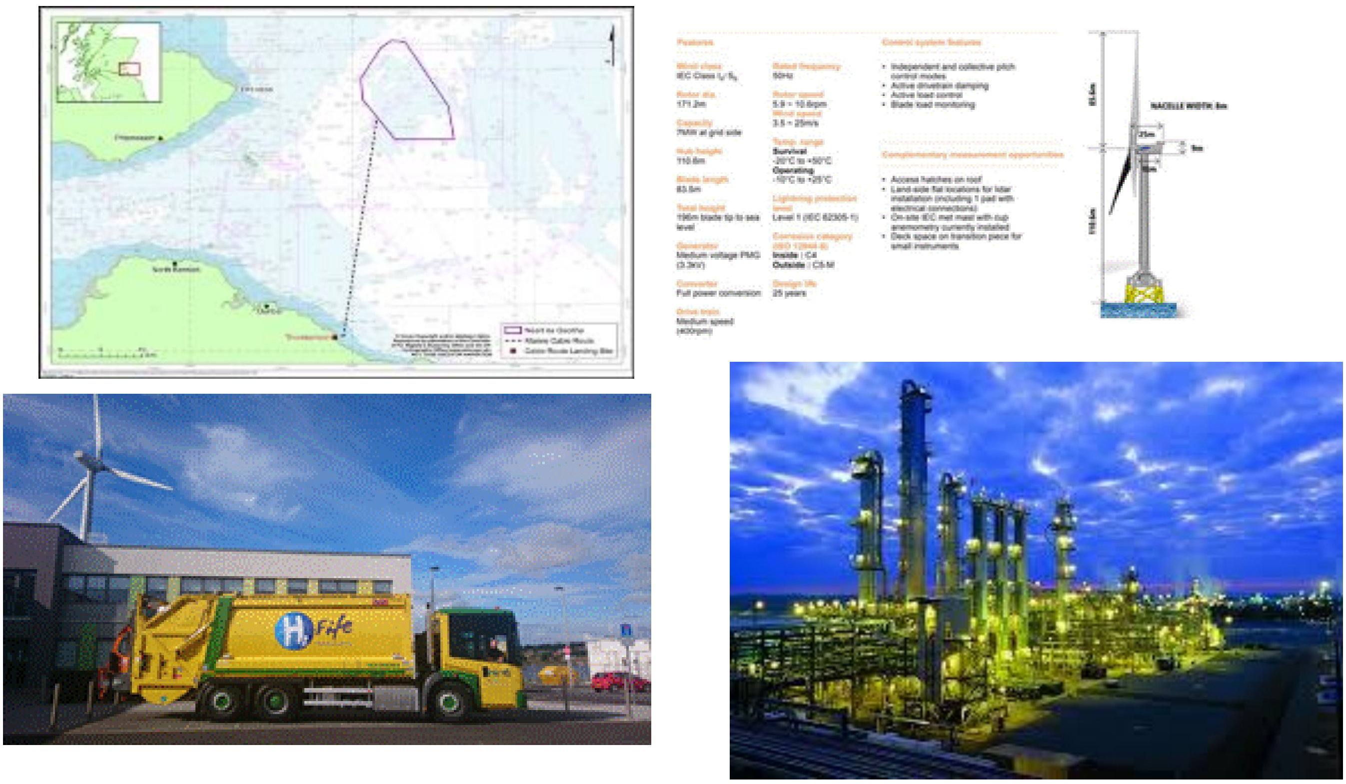
Levenmouth is on the South coast of Fife and includes the three coastal towns of Leven, Methil and Buckhaven. In 2014 Bright Green Hydrogen, Fife Council and Toshiba collaborated to develop the Levenmouth Community Energy Project winning funding from the Scottish Governments Local Energy Scotland Challenge Fund.

The 7MW offshore wind turbine at Levenmouth was acquired by ORE Catapult from Samsung Heavy Industries in December 2015. The turbine is located 50m from the shore, neighbouring Energy Park Fife and has a pedestrian access walkway to the turbine platform. ORE Catapult are the current owners of the 7MW offshore wind turbine located at Energy Park Fife and on Thursday 30 August 2018, ORE Catapult was awarded a Section 36 consent variation by the Scottish Government to operate the Levenmouth turbine until 2029. A commercial arrangement is required between SGN and ORE Catapult to dedicate the primary function of the turbine to providing electricity for the hydrogen production system at Levenmouth.

The H100 Levenmouth project, starting in 2021, will build on this infrastructure by installing additional electrolysis plant and the construction of a hydrogen network serving 300 domestic sized properties. Location of the H100 project in Levenmouth provides favourable options for further expansion:

- The proposed Neart Na Gaoithe (NNG) wind farm array expansion off the Fife coast which is currently electricity grid constrained could be developed to provide additional power for local hydrogen production.
- There is also scope to expand hydrogen production using industrial by-product H_2 from the nearby Fife Ethylene Plant (FEP) at Mossmoran.

Figure 18: Proposed NNG Wind Farm, Fife Council Hydrogen Vehicles and Fife Ethylene Plant



Phase	Timing	Funding Mechanism	Amount (£ Million)
Detailed Design	2021 – 2022	NIC Energy System Transition	1.0
Construction and Commissioning	2021 – 2026	NIC Energy System Transition	14.0

Benefits

The H100 Levenmouth project has the potential to set the agenda for greenhouse gas reduction by evidencing how hydrogen can be safely and securely delivered through a piped network to homes. The site will be at the forefront of developing business models that support the future commercial viability of hydrogen production and distribution.

Hydrogen Entry Units for the Distribution Network

Following the anticipated success of the $HyDeploy_2$ project by Cadent and Northern Gas Networks with a public trial of 20% hydrogen blending with natural gas, there will be a requirement for a wider rollout of hydrogen blending facilities on the network. Success of $HyDeploy_2$ will be a further stimulus towards introducing a market for hydrogen and the need to include hydrogen in any government incentive scheme for green gas. The learning from this project will be crucial to all distribution networks in the deployment of blending facilities.

The $HyDeploy_2$ project states that *'on a per annum basis at a GB level, the 20% carbon saving equates to around 6 million tonnes saving per annum, or around 200kg CO_2eq per householder per annum. In carbon terms, it is equivalent of removing 2.5 million vehicles from the road.'*

The $HyDeploy_2$ project will develop a roadmap for the deployment of hydrogen blending facilities in collaboration with all the GDNs. This will look at:

- **Network models**. System techno-economic assessment, including cost optimal network injection points and pressure tiers, linked to network capacity, scale of hydrogen sources and types, and existing/expected network control strategies.
- **Regulatory basis.** Engagement with shippers and suppliers and building on the outputs from the Future Billing Methodology project, practical recommendations will be made relating to billing regimes for the future from a hydrogen perspective. Recommendations regarding the transition from case by case Exemptions to Regulation changes will be made.
- **Commercial basis.** Refinement of ownership models and provision of techno-economic data to enable development by HMG of appropriate support structures.
- **Skills and Training.** Establish the optimal approach for developing the skills required not only within the GDNs, but also amongst the wider gas fitter community. Together these four components will form a Comprehensive Roadmap for full deployment.

Similar to the distributed entry points for biomethane there will be a mixture of ownership for the equipment located at these sites, with a clear demarcation between the facility operator (producer of the hydrogen) and the network. These facilities are likely to be located where injection into the higher-pressure tiers is possible, providing the most effective economy of scale for hydrogen production and distribution. This is not to exclude the possibility of blending into the lower pressure tiers in certain areas.

These facilities will need to communicate with our Gas Control Centre to ensure blending is managed under monitored, controlled and safe procedures.

With each of these new entry points for hydrogen there will be a requirement to engage with the local communities, this would form part of the enabling activities for the introduction of hydrogen. From this a clear understanding of consumer requirements can be gained, along with engagement with key supply chain stakeholders.

Benefits

Improving the process by which hydrogen producers connect to the network, allowing for a greater uptake of hydrogen blending across the UK. A collaborative approach, building upon the knowledge gained through HyDeploy and $HyDeploy_2$ will enable the cost-effective roll-out of hydrogen blending sites. The blending of hydrogen up to 20% can improve carbon reduction and local air quality with minimal disruption to customers.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Enabling Activities	2022 – 2026	NIA Energy System Transition	0.5
Construction and Commissioning	2023 – 2026	NIA Energy System Transition	2

Industrial Clusters

Throughout GB there are industrial clusters that, because of the processes they carry out, produce hydrogen as a by-product. One of these is in the production of ethylene an example of which is the Fife Ethylene plant at Mossmorran in Fife.

The Fife Ethylene Plant uses natural gas liquids as a feedstock, producing over 830,000 tonnes[40] of ethylene each year. The plant uses a process of steam cracking to produce ethylene, which involves heating ethane until it breaks down (or "cracks") to form a mixture of ethylene and other gases, including hydrogen. This by-product hydrogen could be used to supply local industry or homes, where the gas network has been converted to transport hydrogen, either as a blend or 100% hydrogen use.

We are currently engaging with the operators on the possible access to this resource for decarbonisation projects in Fife and the wider region. In order to utilise the hydrogen produced at the plant new infrastructure will be required to connect the ethylene plant to the gas network. Our proposal for RIIO-GD2 will be to work with the plant operator to understand the technical and operational needs, as well as the infrastructure required to make a physical connection to the network. This will be undertaken by the development of the FEED and onto detailed design, construction and operation using funding under the re-opener mechanism.

The use of by-product hydrogen could be replicated in other parts of GB, we will look to work with other industries and networks where this is possible to increase the amount of hydrogen in the network that would have previously been considered a waste product. Other potential sites could be around the Grangemouth area in Scotland or the Fawley refinery, near Southampton.

Benefits

This project makes the most efficient use of existing infrastructure and resources, whilst stimulating the hydrogen economy in Fife. Whether used as a blend or 100% hydrogen, these uses have the potential to improve carbon reduction and local air quality.

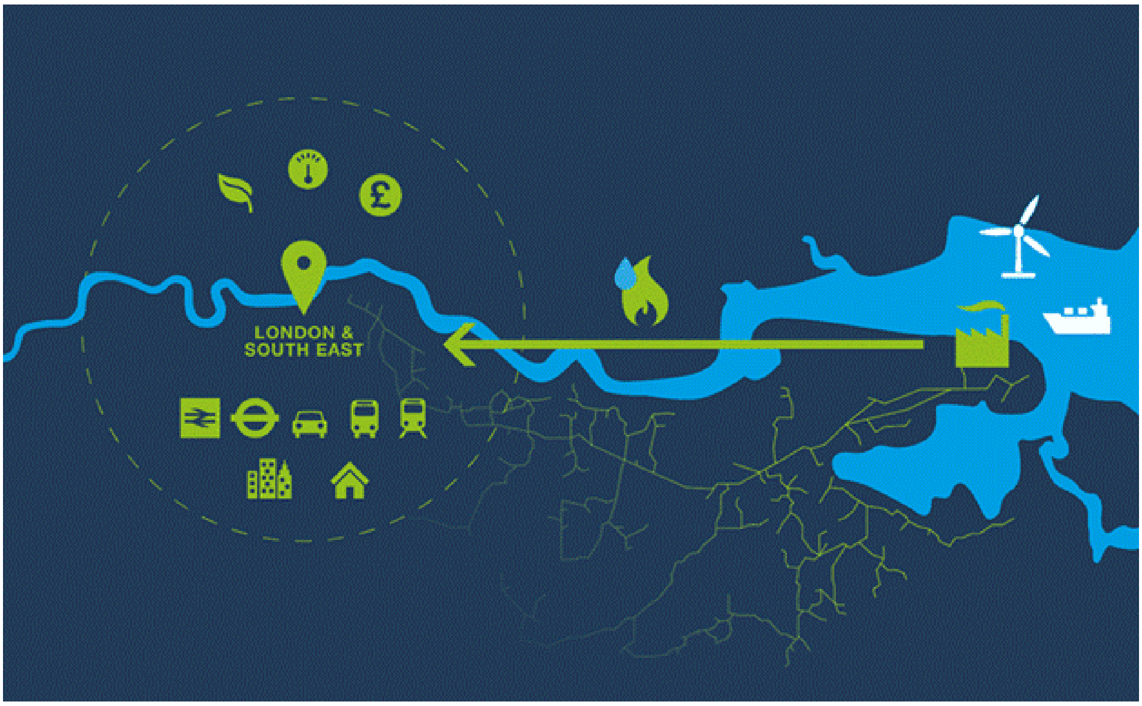
[40] https://mossmorran.org.uk/wp-content/uploads/2017/07/FEP_brochure.pdf

Phase	Timing	Funding Mechanism	Amount (£ Million)
FEED	2021 – 2023	NIA Energy System Transition	2
Pipeline Construction (Plant to Network)	2023 – 2025	EST Reopener	15
3/4 Local Blending Facilities	2024 – 2026	EST Reopener	4
10 km LP H_2 Distribution Pipeline	2024 – 2026	EST Reopener	8
4/5 PRU's	2024 – 2026	EST Reopener	4.2
H_2 Connection Facilities	2024 – 2026	EST Reopener	3

Project Cavendish – Demonstration Phase

As described in the decarbonisation Pathway above, Project Cavendish is our project looking at injecting 20% hydrogen into the gas network in the Medway region of south east England, to give decarbonisation and air quality benefits. During GD2 SGN will seek to take Project Cavendish though the FEED stage and onto detailed design, construction and operation using funding under the re-opener mechanism.

Figure 19: Project Cavendish



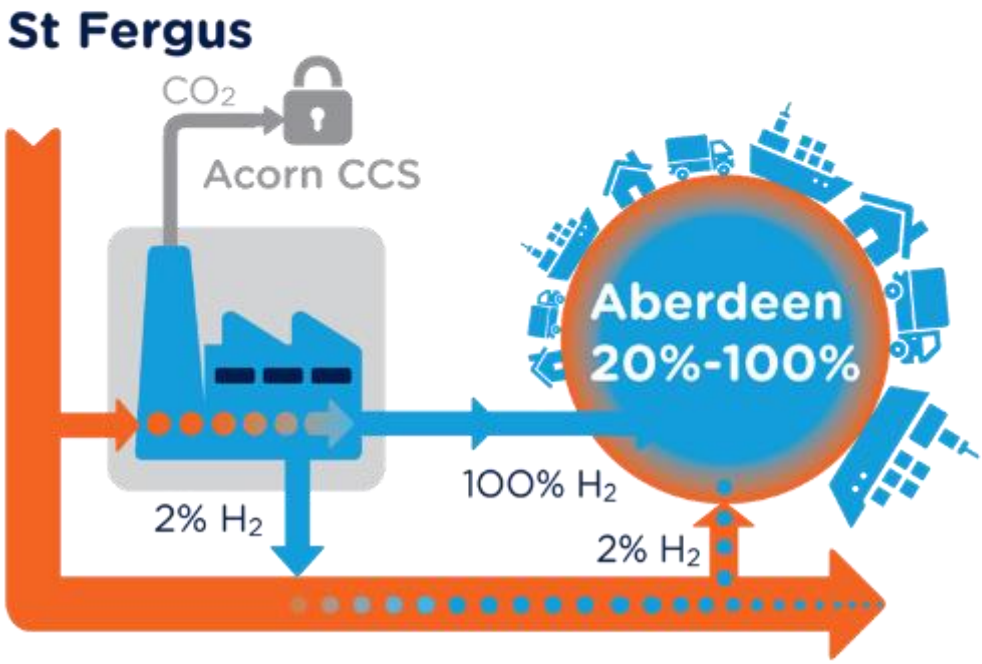
There are some elements of this project that lie out with the ability for SGN to fund through the proposed mechanisms and it may not be possible for SGN to lead on some of these areas, such as the installation of the hydrogen production through SMR. Alternative sources of funding will be required, through the project partners, to ensure that a structured demonstration of the technology can be achieved.

Phase	Timing	Funding Mechanism	Amount (£ Million)
FEED	2021 – 2022	NIA Energy System Transition	1
Detailed Design and Permitting	2021 – 2023	NIA Energy System Transition	2.5
Network Preparation	2024 – 2026	EST Reopener	5
40 km Hydrogen Pipeline to London	2024 – 2026	EST Reopener	65
3/4 Local Blending Facilities	2024 – 2026	EST Reopener	10

Benefits

Preparedness for deep decarbonisation of Medway and Transport for London, bringing about carbon reduction benefits and air quality improvements. Stimulation of hydrogen economy will bring widespread macroeconomic benefits in the region.

Figure 20: Aberdeen Vision



Our Aberdeen Vision project in partnership with National Grid is one of the projects which, in GD2 and beyond, is intended to demonstrate the commercial viability of:

- Injecting 2% hydrogen into the NTS.
- A 100% hydrogen pipeline to Aberdeen.
- A 20% blend into the Aberdeen distribution network

St Fergus gas terminal, located 40 miles north of Aberdeen, is well suited as a hydrogen development location. Central to Aberdeen Vision would be an SMR plant producing hydrogen from natural gas landed at St Fergus. CO2 released from the gas during this process would be captured and exported to the proposed Acorn CCS project.

Product hydrogen would be exported to Aberdeen and captured CO2 exported offshore for sequestration. Hydrogen would be exported down to Aberdeen both as a 2% blend into the NTS and in a dedicated 100% hydrogen pipeline. Hydrogen is already in use for transport in Aberdeen, where a fleet of hydrogen fuel cell buses and two refuelling stations are currently in operation and proposals are in progress to double the capacity. Hydrogen supplied to a hub at Aberdeen could supply these refuelling systems, be blended into the local natural gas network at 20% and would offer further opportunities for 100% hydrogen use in shipping and other markets.

Benefits

Preparedness for deep decarbonisation of Aberdeen region, bringing about carbon reduction benefits and air quality improvements. Stimulation of hydrogen economy will bring widespread macroeconomic benefits in the region.

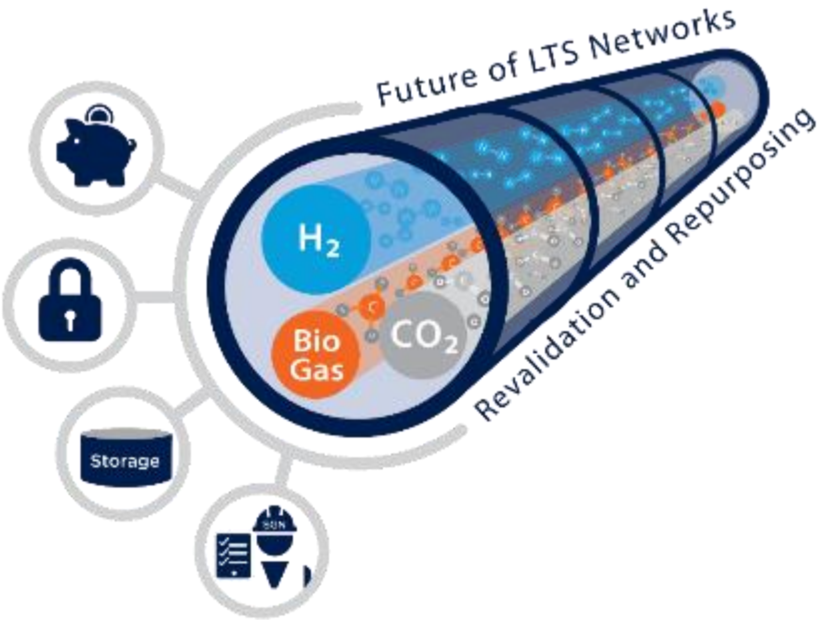
Phase	Timing	Funding Mechanism	Amount (£ Million)
Second Stage Feasibility	2021 – 2022	NIA Energy System Transition	0.5
Detailed Design and Permitting	2022 – 2023	EST Reopener	7
65 km Hydrogen Pipeline to Aberdeen	2023 – 2024	EST Reopener	70
Aberdeen Hydrogen Network (10 km LP H_2 Distribution Pipeline and 4/5 PRU's	2023 – 2024	EST Reopener	15
End User Conversion at Aberdeen (300 Domestic Users)	2025 – 2026	EST Reopener	2

Future LTS

An area that has had less attention to date has been the assessment of potential hydrogen storage and transportation options. The pathway to decarbonisation of the Local Transmission System (LTS) requires a robust and scientific review to ensure that all critical technical, operational and safety challenges and risks have been considered. The development of the LTS as a storage and transportation solution as an output of this study will help to inform the ongoing research activities within the distribution and transmission system. Specifically:

- There will be a clear role for the LTS within a future hydrogen and CO_2 transport and storage system. A well-defined pathway of the steps will be required to establish confidence in the future of the LTS for hydrogen.
- The project could also identify opportunities for future hydrogen and carbon capture innovations and be a critical milestone on the pathway to decarbonisation.
- The repurposing and future use of existing pipelines would deliver significant savings in cost, time and disruption associated with the construction of LTS pipelines.

Figure 21: Future LTS



The Phase 1 scope for this project is currently under development with Health & Safety Laboratory (HSL) and will be a combination of desktop study and consultation with regulators. This will evaluate existing technical information, guidance and standards and engaging with industry. The outputs will be:

- An assessment of the capability of the LTS to store and transport pure and H_2 blends and CO_2. A Case Study produced on an existing decommissioned pipeline between Grangemouth and Granton.
- Identification of potential challenges that would prevent the storage and distribution of pure and H_2 blends and CO_2 in the LTS and recommendations for mitigation.
- Identification of considerations deemed critical in order to provide a clear Go/No Go decision to move on to the next phases of physical trials.

The conclusion of Phase 1 will be a 'Go, no go' decision on whether further GD2 phases of the project will be relevant and will depend on the outcome of the assessment and Grangemouth-Granton case study.

After completion of Phase 1 during GD1, we hope to progress further phases of this project during RIIO GD2. Phase 2 will be laboratory and offline testing the exact scope of which is one of the outputs of the Phase 1 studies.

Further phases will include integrity testing of the Grangemouth to Granton pipeline which would include hydraulic testing, online integrity inspection of the pipe wall and assessment of the condition of pipeline coating via cathodic protection inspection analysis and assessments. This work, confirming the pipeline state, is a necessary precursor to subsequent phases which will culminate in testing and operation of the pipeline with hydrogen/CO_2.

Benefits

The Future LTS project enhances the evidence for the safety case which proves the safe transportation of H_2 and CO_2 through the gas network. This project contributes to the development of key hydrogen storage and carbon capture innovations on the pathway to decarbonisation. Furthermore, the ability to use existing infrastructure to transport H_2 and CO_2 can result in reduced cost and disruption to consumers.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Laboratory and Offline Testing	2021 – 2022	NIA Energy System Transition	0.2
LOHC Feasibility Study	2021 – 2022	NIA Energy System Transition	0.3
Insertion/Lining Feasibility Study	2023 – 2024	NIA Energy System Transition	0.3
Pipeline Hydraulic Testing and Integrity Inspection and Assessment	2021 – 2022	NIA Energy System Transition	1.5
Experimental Design and Risk Assessment	2021 – 2022	NIA Energy System Transition	1.5
Engineering Design and HAZID	2022 – 2023	NIA Energy System Transition	1.5
QRA to Assess all Known and New Risks and Assign Frequency	2022 – 2023	NIA Energy System Transition	0.3
Full Scale Field Trial	2021 – 2024	NIC Energy System Transition	18

100% Hydrogen Conversion Demonstration – Community Trial

To support and align with the BEIS Hy4heat project a community demonstration of 100% hydrogen will be required. The timing of this will fit in with the next phase of our H100 project, following the demonstration of the 100% hydrogen network from Phase 1. The location of the H100 demonstration is yet to be decided, as the feasibility and FEED studies are currently on-going and the results of which won't be known until the end of 2019.

SGN will take the H100 concept further with the conversion of an existing section of the network, supplying approximately 300 properties with 100% hydrogen. It may be possible to utilise an adjoining section of the grid from the Phase 1 of the H100 demonstration site.

If hydrogen can be successfully demonstrated as a means of decarbonisation, significant costs to the consumer could be avoided. The 2050 energy scenarios report by KPMG suggests the conversion of the gas network to hydrogen compared to electrification could generate savings in the region of £7000 to £9500 per customer, or £152bn to £214bn.

This project and the demonstration stages that follow will play a key role in proving the potential of a hydrogen network adoption and conversion.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Feasibility Study	2022 – 2023	NIA Energy System Transition	2
Demonstration	2023 – 2025	EST Reopener	15
Feasibility Studies for Future Phases	2025 – 2026	NIA Energy System Transition	2

The locations being assessed for the H100 demonstration network are at Levenmouth in Fife or Machrihanish in Argyll and Bute. One of these sites will be selected for the Phase 1 H100 demonstration project. This selection process is currently underway as part of the GD1 NIA study. The other site will remain under consideration for H100 Phase 2.

Benefits

The H100 conversion project has the potential to set the agenda for greenhouse gas reduction by evidencing how hydrogen can be safely and securely delivered through a piped network to homes. The site chosen will be at the forefront of developing business models that support the future commercial viability of hydrogen production and distribution.

Hydrogen Transformation – Identified gaps

This project will facilitate the demonstration and provide evidential outputs for any gaps identified through the Hydrogen Transformation Group and the Hydrogen Program Development Group following completion of the current GD1 work and proposed GD2 projects.

This could consist of multiple demonstration studies subject to the conclusion of projects such as H21, H100, Hy4Heat.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Demonstration	2021 – 2026	NIC Energy System Transition	10

Benefits

Conversion from natural gas to hydrogen has the potential to set the agenda for greenhouse gas reduction by evidencing how hydrogen can be safely and securely delivered through a piped network to people's homes.

Gas Control of the Future

This project will undertake a feasibility study and demonstrate new needs for control, methods of communication, alarms, security of supply and safe control of operations within our Gas Control environment. This will reflect the changing use of our network through the introduction of more distributed gas sources, the connection of peaking plants to the distribution network, increased complexity of billing, smart automated pressure control systems and energy management.

There will also be an opportunity to incorporate system changes that look towards a more integrated whole systems approach with power networks, specifically data sharing that leads to the efficient operation of both systems.

Benefits

Building on our work towards a whole energy system solution we will require improved controls and coordination for the introduction of more low carbon gases to our network. These solutions will result in more efficient gas and electricity networks, reducing carbon emissions, improving system security and reducing cost to customers.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Feasibility Study	2021 – 2022	NIA Energy System Transition	0.5
Demonstration	2022 – 2026	NIC Energy System Transition	6

Multi-Occupancy Buildings (MOB)

The tightness of the gas infrastructure within MOBs with regards to 20% hydrogen blend has been tested as part of the HyDeploy project. Our proposal for GD2 will build upon that knowledge to test the safe performance of risers and laterals in MOBs for the transportation of 100% hydrogen.

This will include the full testing of infrastructure of MOB's to assess the technical and safety requirements necessary for the introduction of 100% hydrogen gas, with feasibility studies split into above and below 6 storey buildings.

Benefits

Understanding the safety requirements for hydrogen in MOBs will be a key step on the gas decarbonisation pathway. This project will provide Ofgem and customers with a more complete understanding of the technical and safety requirements for heating in MOBs and help inform future decisions in this area.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Feasibility Study	2021 – 2023	NIA Energy System Transition	1.3
Physical Testing – Above 6 Storeys	2025 – 2026	NIC Energy System Transition	23
Physical Testing – Below 6 Storeys	2023 – 2026	NIC Energy System Transition	11

Deblending

Blending hydrogen into the existing natural gas pipeline network has been proposed as a means of increasing the output of renewable energy systems. Subject to the results from HyDeploy, below 20 mol% hydrogen can be blended into the gas network safely with minimal impact on customers and household appliances.

Blending hydrogen into natural gas pipeline networks could also provide a means of delivering pure hydrogen to markets, using separation and purification technologies downstream to extract hydrogen from the natural gas blend close to the point of end use, avoiding the cost of building dedicated hydrogen pipelines or other costly delivery infrastructure during the early market development phase.

During GD2 we intend to carry out a feasibility study into the implementation of hydrogen blending and point-of-use separation (‘deblending’). This project will establish possible demand for hydrogen geographically against a range of end usage technologies, assess the optimum configuration of deblending technologies to match developed demand side scenarios and undertake a techno economic assessment of the implementation of deblending. This will provide a blue print for regional deblending, leading to the development of network, conversion process and commercial arrangements models for deblending.

Our proposal for GD2 also sees the rollout of this technology with project demonstration taking place during the period.

Benefits

This project will help stimulate a hydrogen economy by improving the means of delivering variable concentrations of hydrogen. By demonstrating a safe means of extracting hydrogen from a gas blend at close to the point of end use, we would remove the need to build dedicated hydrogen pipelines during the early market phase. This could result in reduced cost and disruption to consumers.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Feasibility	2021 – 2022	NIA Energy System Transition	0.5
Rollout	2022 – 2023	NIC Energy System Transition	15.5

Custody Transfer Metering for Hydrogen

Metering systems perform a critical role for gas flow measurement into the distribution network. This allows us to determine the quantity and financial value of the gas flowing through our network. The selection of a specific meter type depends on its application, and the move to a 100% hydrogen gas within the network will require a change to the metering instrumentation currently in place.

This study will investigate the viability of different metering options (including ultrasonic flow meters and differential pressure meters) to determine the optimal solution for a 100% hydrogen network.

Benefits

The development of custody transfer metering will be an essential step on the gas decarbonisation pathway. Technology developed through this study could be rolled out to other GDNs, providing value for money to energy customers.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Feasibility Study	2021 – 2022	NIA Energy System Transition	0.1
Demonstration	2021 – 2026	NIC Energy System Transition	1

Robotic Below Ground Mapping

Our network is a complex structure and pinpointing the exact location of our infrastructure will be vital when we undertake the planning and physical conversion of the network to 100% hydrogen. Mapping and topographical surveys will provide a comprehensive understanding of our network, where 3D surveying can give an accurate picture of the below ground environment.

Benefits

This project will provide an accurate physically mapped survey of our built assets to aid in the planning and conversion of the network 100% hydrogen.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Feasibility Study	2021 – 2022	NIA Energy System Transition	0.5
Demonstration	2021 – 2026	NIC Energy System Transition	5

2. Emerging Technologies Projects

Emerging Technologies R&D Projects

We have identified several areas where the research and demonstration of new technologies with the potential to facilitate greater levels of decarbonisation and/or security of supply require to be undertaken. All costs are Estimates

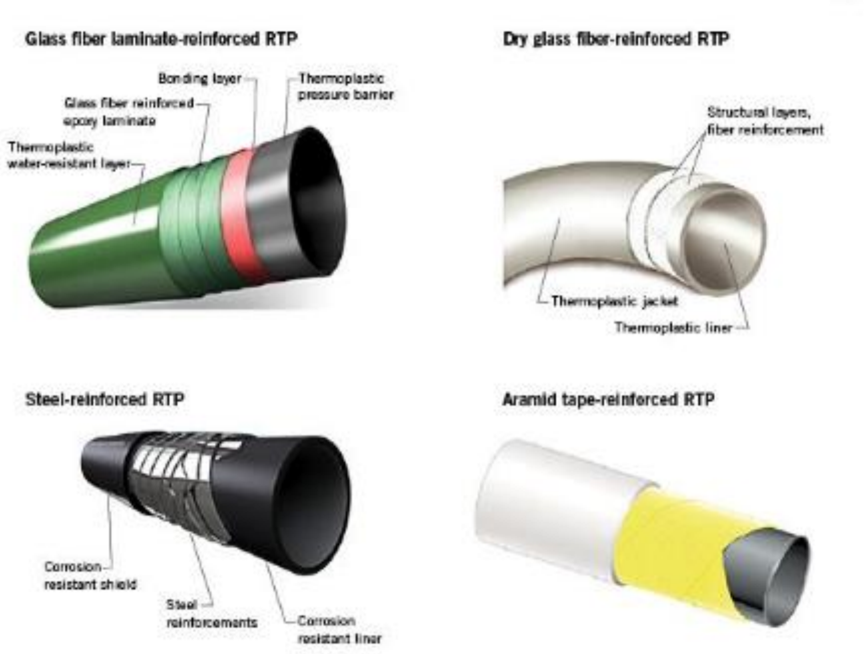
Project	Description and Relevance	NIA Energy System Transition Funding (£M)
Compressors	Consideration of compression and storage as alternative to linepack	0.2
Odorant	Assessment of new odorants which are fuel cell compatible	0.3
Gas Quality Data Provision	Study to identify how to provide large industrial users with gas quality forecasts	0.4
Reverse Compression	Assessment of developments in reverse compression technologies both for hydrogen and green gases	0.5
Energy Intensive Users	Site specific technoeconomic studies to support large industrial users' options for decarbonisation	1
CH_4 to Atmosphere Reduction R&D	R&D of leakage from above ground installations	0.2
NOx Reduction R&D	R&D into medium combustion plant within our network	0.1
Methanation Site Evaluation	Technoeconomic study to determine likely methanation sites within SGN's footprint and evaluation of how to configure the network to accommodate	0.3
Total		**3.0**

Local Transmission System – New Materials

Pipelines could be a feasible long-term solution for delivering large quantities of gaseous hydrogen over long distances and distributing it in urban and rural settings. However, there could be hydrogen compatibility issues in the steel pipelines typically used in the Local Transmission System (LTS).

Reinforced Thermoplastic Pipelines (RTPs) are a promising alternative to low-alloy high-strength steel from both performance and cost considerations. RTP is a proven technology in oil and gas conveyance and the recent drive for a hydrogen economy has driven rapid innovation to qualify RTP for hydrogen conveyance. In Delfzijl, Netherlands, an RTP pipeline is being developed that will transport green hydrogen produced from windfarms in the North Sea to companies in the chemical and industrial sectors in the Groningen region[41].

Figure 22: LTS New Materials



This project would build upon the knowledge developed through the LTS Futures project and form part of a technical investigation into the safe use of RTP technology for hydrogen conveyance in the UK.

Benefits

RTP technologies could make a significant contribution to the economic feasibility of hydrogen transportation, reducing cost and disruption to consumers. RTP technologies are also capable of driving us further along the gas decarbonisation pathway.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Feasibility Study	2024 – 2025	NIA Energy System Transition	0.2
Construction	2025 – 2026	NIC Energy System	10

[41] https://www.soluforce.com/soluforce/news/5842-soluforce-to-be-used-to-transport-green-hydrogen.php

		Transition	

Pressure Reduction

This project will investigate developments in pressure reduction for 100% hydrogen networks, carrying out R&D for alternative means of pressure reduction and associated ancillary equipment in field trials. This will include energy recovery through exothermic expansion during pressure reduction.

Figure 23: Oxford Flow gas regulator

Benefits

This project will investigate the safest and most cost-effective way of delivering 100% hydrogen through our network, with the aim of reducing cost to customers and allowing the network to operate efficiently.

Phase	Timing	Funding Mechanism	Amount (£ Million)
Feasibility Study	2022 – 2023	NIA Energy System Transition	0.5
Demonstration	2024 – 2025	NIC Energy System Transition	4

3. GD2 Demand Forecasting Projects

Demand Forecasting R&D Projects

The research into dynamic changes in demand forecasting due to rapidly evolving energy system will need to be carried out during GD2. We have identified the following research and development projects that will be carried out over the period. All costs detailed below are estimates

Project	Description and Relevance	NIA Energy System Transition Funding (£M)
Domestic Fuel Cells	Technoeconomic study into viability of co-generation fuel cells and their impact on the network	0.1
Heat Networks - Connections and Management	Technoeconomic study to determine the optimal network configuration for heat networks/CHP	0.1
UK Energy Flow Intensity Mapping	Identification of emerging trends in energy needs across vectors	0.3
Smart Meter Data	Evaluation of smart meter data with particular regard to EV connected and heat pump connected application	0.1
LTS Power Stations	Evaluation of the potential for energy recovery from pressure reduction	0.1
Wave / Tidal for Hydrogen	Technoeconomic study to evaluate how we can accommodate/configure the network to provide route to market	0.1
Peaking Plant Phase 2	Expansion of novel capacity market modelling to consider potential changes in demand on the network for hydrogen	0.1
Total		**0.9**